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ИССЛЕДОВАНИЕ ФОНОВЫХ ХАРАКТЕРИСТИК ДЕТЕКТОРОВ КЭУ, МКП И ФЭУ ПРИ ОБЛУЧЕНИИ НЕЙТРОНАМИ И ГАММА-КВАНТАМИ

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Аннотация

В работе представлены результаты измерения чувствительности регистрирующих элементов детекторов частиц, применяемых для диагностики плазмы, – канальных электронных умножителей (КЭУ), микроканальных пластин (МКП) и фотоумножителей (ФЭУ)-к фоновому нейтронному и гамма излучению, и приведена оценка предельного потока фонового излучения, при котором детекторы теряют работоспособность.

Abstract

This paper presents the results of measurements of sensitivity of the registering elements of particle detectors for plasma diagnostics, the Channel Electron Multipliers (CEM), the Microchannel Plates (MCP) and Photomultipliers (PMT) to neutron and gamma radiation and estimates of intensity level which can cease their operability.

The scintillation detectors of particles responding to emission of hydrogen and helium isotopes are widely used for diagnostics of plasma. These detectors consist of a converter or scintillator and a registering element, which is either a Channel Electron Multiplier (CEM), Microchannel Plate (MCP) or a Photomultiplier (PMT). The modern thermonuclear installations, especially those with tritium cycle, work at high level of gamma and neutron radiation. The intensity of background n- and gamma radiation depends on power of the plasma discharge and on location of detectors, and may be in the range from 10^6 to 10^{11} $s^{-1}\cdot cm^{-2}$. A series of investigations of properties of such detectors was carried out recently [1].

The aim of this work was to measure the sensitivity of the registering elements of detectors: CEM, MCP and PMT, apart from the scintillating elements, to neutron and gamma radiation, and to find the limits which their sensitivity imposes on possible level of this radiation, where the operability of detectors will cease.

To imitate the typical working conditions, we have maintained an experimental setup with interchangeable sources of radiation and with the investigated detecting elements inside of 20 mm thick vacuum chamber of stainless steel. The experimental setup and the specifications of used detecting elements CEM, MCP and PMT were described in [1] . The radiation of plasma was imitated by the ^{252}Cf source with the following properties [2]:

- The continuous spectrum of fission neutrons with energies from 0.025 eV to 10 MeV, with average energy **$\langle E_n \rangle$=2.41 MeV,**

- The continuous spectrum of gamma quanta with energy up to 10 MeV, average **$\langle E_\gamma \rangle$= 850 keV.**

Besides that, to measure the contribution of gammas to the amplitude spectrum of the detector signals, we used the source of ^{60}Co (**$E_{\gamma 1}$ = 1173 keV** , **$E_{\gamma 2}$ = 1332 keV**).

The following modules have been used for measurement of amplitude spectra of signals from the detectors: the charge-sensitive preamplifier with gaussian shaping of pulses, with time constant of 1 mks, the spectrometric amplifier FK4222, the multichannel analyzer EG&G ORTEC TRUMP and a personal computer with software for analysis of spectra.

The amplitude spectra of signals were of usual shape for the nose-like background and had no special structure (counts decreasing exponentially with the amplitude), the obtained amplitude distributions were presented in the form of plots of integral sensitivities (counts above the threshold value) versus the threshold of registration. The integral sensitivity $S(U_n)$ was defined as:

$$S(U_{\Pi}) = \int_{U_{\Pi}}^{\infty} \frac{dS}{dU} dU$$

where $\frac{dS}{dU}$ is the differential sensitivity to the background radiation.

It is equal to

$$\frac{dS}{dU} = \frac{1}{I_{\Pi} \cdot t} \cdot \frac{dn}{dU}$$

where $\frac{dn}{dU}$ is the amplitude distribution of the detector signals,

I_{Π} is the total intensity of incoming neutrons and/or gamma quanta on the sensitive surface of the detector, and t is the duration of measurement.

The total intensity I_{Π} was calculated in every given geometry with the formula:

$$I_{\Pi} = I_0 \cdot \frac{d\Omega}{4\pi}$$

where I_0 is the intensity of particle emission into the solid angle 4π, i.e. the source activity.

The relative solid angle $\frac{d\Omega}{4\pi}$ was calculated as

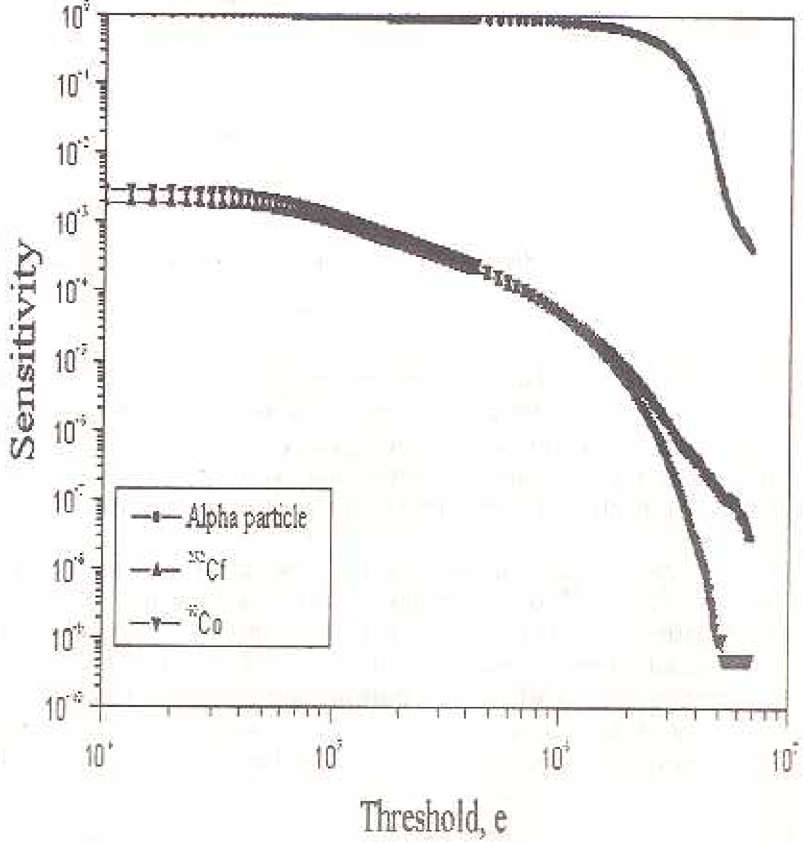
$$\frac{d\Omega}{4\pi} = \frac{1}{2}\left(1 - \frac{h}{\sqrt{h^2 + r^2}}\right)$$

where h is the distance from the source to the sensitive surface of the detector, r is the radius of the surface.

The results of measurements of integral sensitivities of the detectors with CEM, MCP and PMT to the background n-γ radiation versus the registration threshold are presented on the Figure. The value of registration threshold was set in units of the pulse charge, after amplification by the CEM and MCP respectively, and in the number of photoelectrons for PMT.

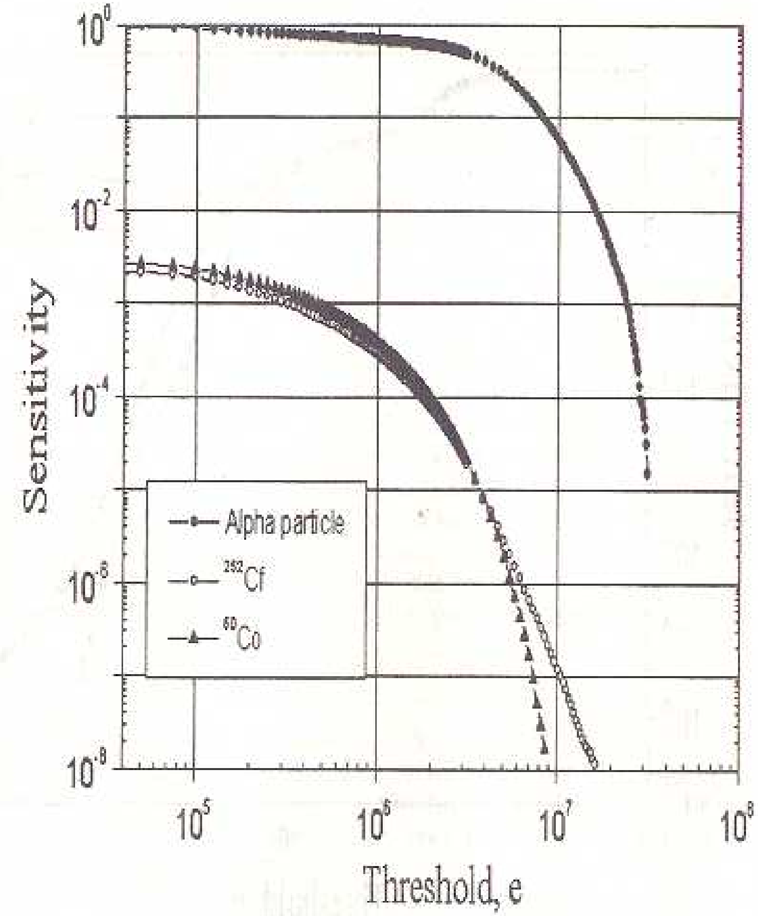
One can see from this data that these curves are similar with both sources, ^{252}Cf and ^{60}Co. The sensitivity falls in the same manner. Moreover, the detectors with CEM and MCP are less sensitive to the background at low-threshold limit than PMT are, actually $3.2 \cdot 10^{-3}$ vs $5.6 \cdot 10^{-2}$ for PMT. We have to note, that for all detectors the amplitude spectra are much wider with the source ^{252}Cf than with ^{60}Co. This is due to much wider energy spectrum of gamma-quanta from ^{252}Cf both emitted by the source itself and also those produced in the chamber walls due to the processes (n,n') and (n,γ).

We can estimate the limitation on the maximal level of background which the registering elements CEM, MCP and PMT impose on the operability of particle detectors from the experimental data on the total sensitivity of these elements to n-γ radiation. The effect of background manifests itself in increased background current from the detector, above which we have to select the pulses of required particles by proper setting of the threshold. The detected particles have the energy spectra of shape similar to Gaussian. The detectors are known to operate in linear mode only when $\langle I_n \rangle \ll I_{\Pi}$, where $\langle I_n \rangle$ is the average current, and I_{Π} is the maximal current of the detector.

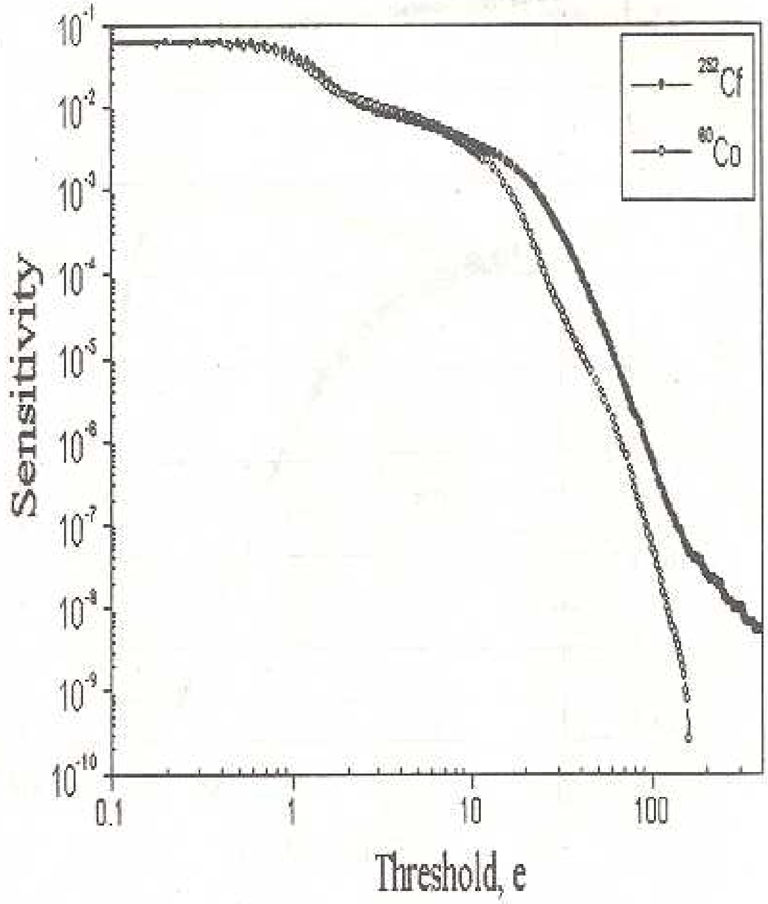


a)

Figure. The measured dependencies of integral sensitivities of three types of detectors to the background radiation vs registration threshold, a – for CEM, b – for MCP and c – for PMT



b)



c)

Our measurements prove that this condidion is true for CEM and MCP detectors only up to background level of ~ 10^6 s^{-1}. At the typical flux of n-γ radiation between 10^6 and 10^{11} $s^{-1}\cdot cm^{-2}$, we have from 10^3 to 10^8 s^{-1} background signals in a detector, and the MCP and CEM detectors can be inoperable . The situation is different with PMTs, because their output current is about 2 orders of magnitude higher, than that of CEM and MCP. So we expect their rate limit be much higher, and the estimates show that PMTs can still operate at background rates of ~ 10^{11} s^{-1}.

Conclusions

The obtained experimental data proves that CEM and MCP are less sensitive to neutron and gamma radiation than PMT. This is because the most of sensitivity of CEM and MCP to n and gamma radiation is due to fast electrons produced in the material of chamber that contains the detector. The emission rate of these electrons from Fe is $6 \cdot 10^{-3}$. For PMT the situation is different, because the largest contribution to the sensitivity is from the interaction of gamma quanta with the entrance window of PMT, hence the sensitivity depends linearly on its thickness. But in spite of this, in general the detectors with PMTs may be used at higher rates of background.

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