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Development of nuclear emulsion for fast neutron measurement

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Abstract

Nuclear emulsion is high sensitive photographic film used for detection of three-dimensional trajectory of charged particles. Energy resolution of nuclear emulsion is 21% (12%) FWHM against neutron energy of 2.8 MeV (4.9 MeV). Nuclear emulsion has high gamma ray rejection power. For now, at least 2×10^4 gamma rays/cm^2, no increase of as a background for neutron measurement when scan using automatic nuclear emulsion read out system HTS. This value suggests that it is applicable even under high gamma ray environment, such as nuclear fusion reactor.

1. Introduction

Nuclear emulsion is high sensitive photographic film used for detection of three-dimensional trajectory of charged particles. The principle of the measurement of fast neutron with nuclear emulsion is the detection of proton recoiled by neutron. The whole image of 3D track is recorded with the spatial resolution of about 1 µm, which is the silver grain size. The detector size is very flexible and no need of power supply. From these features, nuclear emulsion can be very powerful detector applied to the dosimetry, spectrometry and imaging in various fields (fusion plasma diagnostics, medical application, space radiation measurement, fundamental physics, radiography, etc.) by analyzing statistically 3D tracks. We are developing the nuclear emulsion itself in our laboratory by using nuclear emulsion gel production machine, so we can control the sensitivity for various purposes. By using this machine, we developed new nuclear emulsion gel (crystal size is 220 nm) optimized for the detection of recoil protons by fast neutrons. So we will introduce performance of nuclear emulsion for fast neutron measurement.

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2. Emulsion performance evaluation

2.1. Energy resolution

If we know incidence direction of neutron, we can estimate neutron energy from recoil proton track length and angle. For measuring energy resolution, we irradiated with monochromatic energy neutron at Japan Atomic Energy Agency Fusion Nuclear Source (FNS) and National Institute of Advanced Industrial Science and Technology (AIST). In both facilities, neutrons generate by D-D nuclear fusion reaction. By changing the acceleration energy of deuterium and angle of location of the detector from the beam axis, it can be irradiated with neutrons of different energies. This time, by using neutrons which kinetic energy is 2.8 MeV (FNS) and 4.8 MeV (AIST), we evaluated energy resolution of emulsion.

By using SRIM, we can convert track length into recoil proton energy. From recoil energy and angle of track from the incident direction of neutron, neutron energy is determined. So we measured track length and angle using optical microscope. 2.8 MeV proton track length is about 70 m and that of 4.8 MeV is about 160 μm in nuclear emulsion. So only use over 35 (80) μm tracks in 2.8 (4.8) MeV in energy resolution estimates, because short tracks are sensitive to measurement error and contamination rate of scattered neutron from around structures events are higher. Figure 1 is measurement results of neutron energy distribution. Against 2.8 MeV and 4.9 MeV neutron, energy resolution is 21% and 12% FWHM. Compared with Geant4 simulation, these are almost consistent, but measurement result is lower. In the actual environment has uncertainly, such as measurement errors and scattered neutron events. And the actual neutron energy is not monochromatic energy, have several % energy fluctuation (Kondo et al., 2008). It can be thought measurement results became lower compared with simulation.
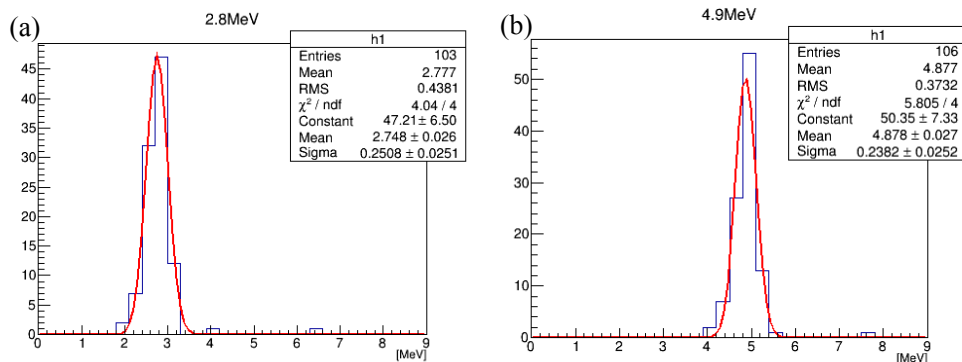

Fig. 1. (a)measurement result of neutron energy distribution (2.8MeV). ; (b) (4.9MeV).

2.2. Gamma ray rejection

Gamma rays generate electrons by photoelectric effect and Compton scattering. Electrons are developed only several μm from stop point. Because energy loss of electrons is lower than that of protons (Fig.2). Simulated by SRIM and ESTAR (Berger et al., 2005). So we can distinguish proton track and electron track easily. But in high gamma ray environment, such as fusion nuclear reactor, emulsion will become black by a lot of electron tracks and cannot recognize proton tracks. So using difference of energy loss, we developed new nuclear emulsion and developing method only high energy loss particles are developed.

When lowering development ability of developer, namely oxidation-reduction potential (ORP) of developer is raised, silver crystals become difficult to be developed. Moreover, we doped Rhodium in AgBr crystals. Rhodium will capture ionization electron, so electrons with small energy loss become hard to be developed, but high energy loss particles like proton will still have high development probability. In combining these two methods, we developed emulsion with high gamma ray rejection power.
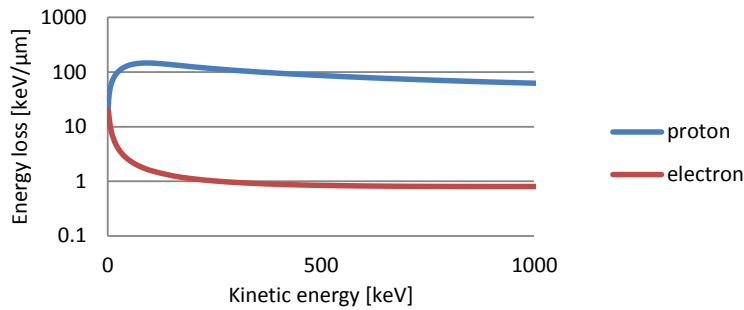
Fig. 2. Energy loss of proton and electron in AgBr.

Using 241-Am gamma ray source, we evaluated gamma ray rejection power of emulsion. Figure 3 shows the number of developed silver crystal per one electron. The probability that gamma ray will generate electron in emulsion is simulated by Geant4. By increasing the amount of Rhodium, electron tracks will be difficult to be developed. But proton tracks still can be recognized by doping Rhodium 10 μmol/molAg. For now, at least 2×10^4 gamma rays/cm^2, no increase of as a background for neutron measurement when scan using automatic nuclear emulsion read out system. This value suggests that it is applicable even under high gamma ray environment, such as nuclear fusion reactor.
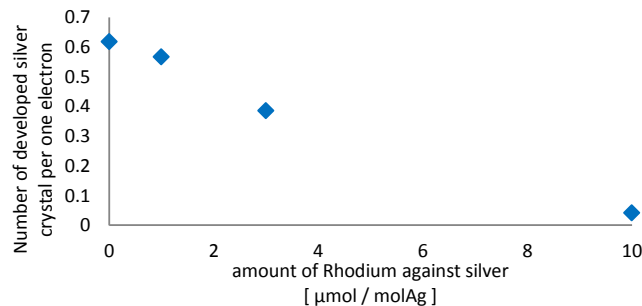

Fig. 3. Number of developed silver crystal per one electron.

3. Conclusion

Nuclear emulsion with such a performance is going to apply in various situations. Now, it is planning measuring the spectrum and directional distribution of environmental neutrons from the sub-MeV to several GeV using the automatic nuclear emulsion read out system (Morishima et al., 2010). For measurement of the high-energy neutron of several 10 or more MeV, proton track length is more than centimeter. But using not recoil protons but recoil carbon, oxygen, silver, etc., these track length is less than 1mm until at least 1 GeV, so we can measure enough with small detector.

References

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