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Development of pyroelectric neutron source for calibration of neutrino and dark matter detectors

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Abstract. The laboratory experimental setup for development of pyroelectric neutron generator for calibration of neutrino and dark matter detectors for direct search of Weakly Interacting Massive Particles (WIMP) has been developed. The setup allows providing and controlling the neutrons generation process realized during d-d nuclear fusion. It is shown that the neutrons with energy 2.45 MeV can be generated starting from a level of electric potential generated by pyroelectric crystal about 30 kV, in contrast to the typical neutron tubes which need the applied outer high voltage level about 100 kV.

1. Operational principals

Energy calibrations of dark matter and neutrino detectors are required for a correct interpretation of the collected data. Also neutron calibrations are necessary because an elastic scattering of neutrons by nuclei of detector's target leads to nuclei recoil which perfectly simulate the signal from WIMP or a coherently scattered neutrino. Several variants of the neutron calibration systems for low-background detectors are proposed [1,2] including use of the system, based on pyroelectric neutron source [2,3].

The few cm gap between the charged surface of pyroelectric crystal and deuterated target is enough to accelerate D-ions to initiate D-D reaction and produce fast neutrons with energy 2.45 MeV. Neutrons generation in D-D reaction with tantalate lithium ($LiTaO_3$) pyroelectric crystal was confirmed experimentally [3–5]. The neutrons generation requires forevacuum conditions with a residual gas about 1 mTorr of deuterium, in order the molecules could be ionized in the strong electric field. The field with magnitude about of 10^5 kV/cm appears close to the crystal surface during the crystal temperature changing. The tungsten tip with pin's diameter of several hundred nanometers is mounted on the pyroelectric crystal surface to generate such high electric potential. The principle of the pyroelectric neutron sources operation is shown schematically in figure 1.
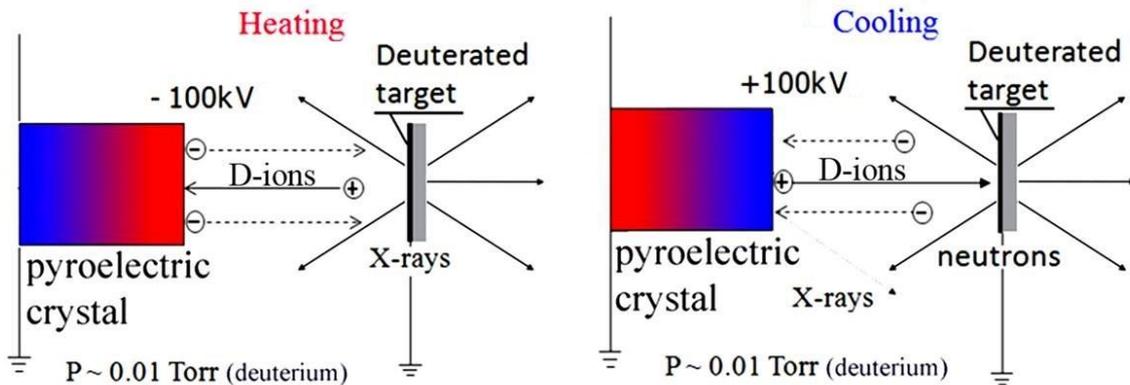
Figure 1. Operating principle of pyroelectric neutron source. When pyroelectric crystal generates negative high electric potential (left), electrons are accelerated away from the crystal and produce X-rays from the target. Positive D-ions are attracted to the crystal surface. When pyroelectric crystal generates positive high electric potential (right), electrons are attracted to the crystal surface and produce X-rays from the crystal. Positive D-ions are accelerated away from the crystal to the target and initiate D-D reaction with fast neutrons output.

Pyroelectric mono-energy (2.45 MeV) neutron source is considered as a useful tool for the neutron calibrations. Such sources have to be of several tens of cubic centimeters size and should have as low as possible consumption power. It is important that it could be constructed without any radioactive materials and do not require an external high voltage power supply. By the way, some of the features of the pyroelectric neutron source should be taken into consideration for application in low-background experiments. There is a significant X-ray background with the energy up to 100 keV and an intense heat exchange with the surrounding environment. The optimal way to minimize their contribution is a reduction of temperature range variation applied to the pyroelectric crystal but, as a result, a reduction of electric potential obtained by the pyroelectric crystal will happen.

2. The experimental setup
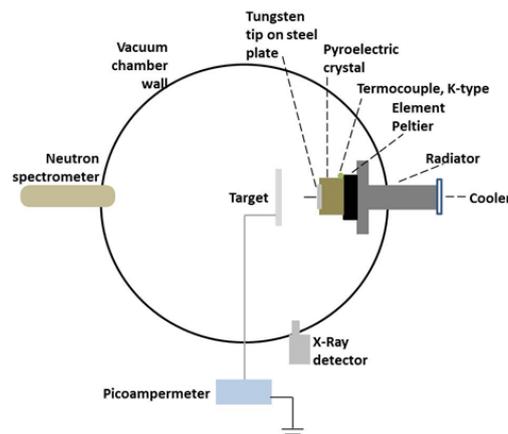The experimental setup for a pyroelectric source development was assembled as shown in figure 2.

Figure 2. The scheme of the experimental setup.

The pyroelectric high potential source contains cylindrical pyroelectric crystal $LiTaO_3$ with 20 mm diameter and 10 mm height, Peltier element, duralumin thermal conductor with the cooler fan at the end in the air. All elements of the assembly are glued by vacuum epoxy. The stainless steel disk with a tungsten tip is mounted on the crystal surface. The tip has 8 mm length and 400 nm diameter.

The deuterated target is prepared from stainless steel coated by deuterated plastic. The target is electrically isolated from the chamber wall and grounded through picoampermeter measuring the ion current from the target. The temperature of the crystal is monitored by a K-type thermocouple.

The deuterium pressure level in the chamber is fixed in the range of $1 \cdot 10^{-3}$–$3 \cdot 10^{-3}$ Torr.

Pyroelectric crystal temperature was cyclically varied by the Peltier element in the range of 25–80 °C, the X-ray spectrum, neutron spectrum and ion current from a target have been monitored synchronously. The neutrons have been observed during the cooling phase when crystal surface has positive potential.

The instruments used in the setup allow to measure X-rays spectra in 3–100 keV range and fast neutrons spectra in 0.1–11 MeV range. The detection efficiency of 2.45 MeV neutron is about 40%. The fiducial volume is about 12 cm^3 with 2.5 cm aperture.

Figure 3 shows the total neutron spectrum collected during the cooling phases within ten thermal cycles (total time 1500 s). 138 counts in area 0–4.5 MeV have been registered during the measurement. The background measurements show 64 neutrons in the same energy region. Taking the detector efficiency for 2.45 MeV neutrons and registration solid angle $3.2 \cdot 10^{-4}$ sr, the average neutrons intensity is about 22 neutrons per second. It is important to point out that the electric potential produced by a pyroelectric crystal does not exceed 50 kV, while in the other known works the potential used for neutron generation was about 100 kV [3–5]. It is also important to point out that the pyroelectric crystals allow to generate electric potential with value up to 350 kV in vacuum conditions [6].
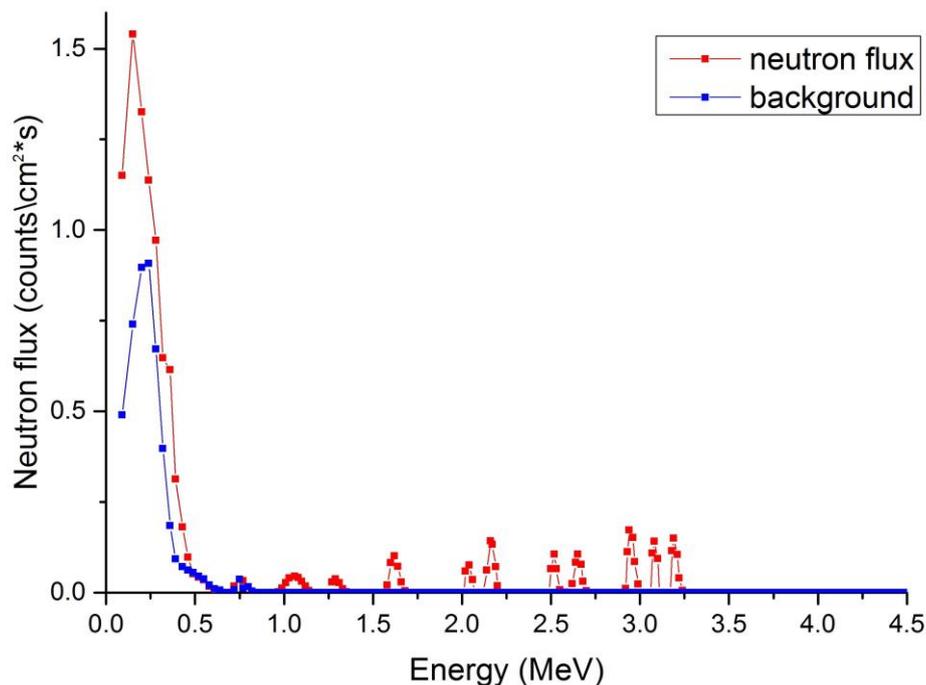

Figure 3. The total neutron flux related to energy during the cooling phase within ten thermal cycles (1500 s of total measurement time) vs background neutron flux (1700 s of total measurement time).

To confirm that the observed process is based on ion interaction, the ion current from a target was measured (figure 4). The measurements are done during the cooling part of the thermal cycles. This is a positive current of deuterium ions, which accelerated by the electric field from the crystal toward the grounded target. If the X-ray spectrum allows to estimate an upper limit of ion energy, the ion current allows to estimate the number of ions and thus to evaluate expected neutron yield from D-D reaction. The achieved maximum of ion current in the measurements was about 16 nA. Generally, the ion

current curves during the cooling phase were similar for each thermal cycle. During the first 50 seconds from the start of cooling it is observed slow increase of the ion current with several peaks up to 5 nA. Then during the 60-80 seconds interval the current increases above to 10 nA and hold on that level. Then the current fall sharply and grew slowly in the remaining cycle time. In our opinion, a sharp change of the ion current and the characteristic peaks indicate the presence of electrical breakdown between the tungsten tip and the target. The result of this effect is a reduction of the electric field strength generated by the crystal and a sharp decrease of the current.
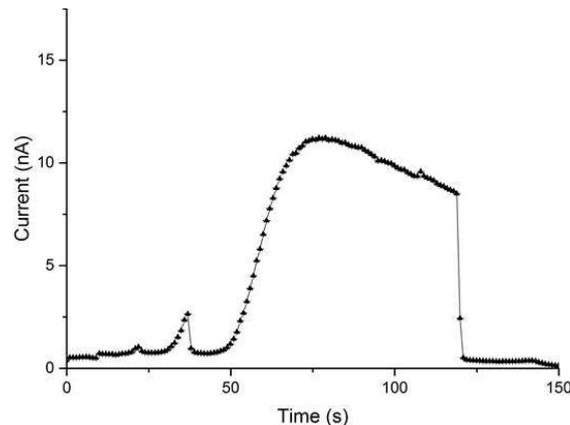

Figure 4. The ion current curve during the cooling phase of the temperature.

3. Conclusion

The possibility to develop pyroelectric neutron source for the calibration of low- background detectors with intensity about of a few tens of neutrons per second was confirmed on more time within the original experimental setup. The neutrons were observed under conditions when the potential generated by crystal does not exceed 50 kV that is substantially lower of the typical potential for the neutron tubes and previously reported pyroelectric sources [3-5]. The main obstruction for further development of pyroelectric neutron source is the possibility of electric breakdown which can be realized between the tip and the grounded source parts. The breakdown induces the degradation of the tip and the neutron yield decreasing. Currently, different ways to resolve this problem are investigated.

References
[1]   Bondar A E *et al.* 2013 (in Russian) Proposal for neutron scattering systems for calibration of dark matter search and low-energy neutrino detectors *NSU Bulletin. Series: Physics* **8** 27 (original Russian title: Proekt sistem rasseyaniya nejjtronov dlya kalibrovki detektorov temnojj materii i nizkoehnergeticheskikh nejjtrino. *Vestnik NGU. Seriya: Fizika*)
[2]   Chepurnov A S *et al.* 2015 *J. Phys.: Conf. Ser.* **675** 032031
[3]   Friske E *et al.* 2015 *Eur. Phys. J.* A **51** 42
[4]   Naranjo B *et al.* 2005 *Nature* **434** 1115
[5]   Geuther J *et al.* 2006 *Phys. Rev. Lett.* **96** 054803
[6]   Tornow W *et al.* 2010 *J. Appl. Phys.* **107** 063302