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Total fluence influence on the detected magnitude of neutron burst using proportional detectors

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ABSTRACT

The measurement of very short neutron bursts, when individual neutrons cannot be counted in the usual manner, is possible with proportional detectors (such as ^{3}He) taking the integration of the total electric charge due to many overlapped interactions, as the measure of the amount of the neutron signal. This method requires a correction related to the total amount of neutrons that interacted with the detector. This correction originates in the well-known build-up of positive electric charge too slow to be dislodged from the detection volume during the neutron burst. This causes self-shielding of the applied electric field with the ensuing reduction of the charge multiplication process in the gas, described in the literature.

Short neutron bursts from a plasma focus device and a conventional isotopic neutron source were employed in the experimental phase and the known theory was applied in the analysis, which justifies assigning the observed effects to the space-charge shielding of the externally applied electric field.

This work introduces a correction to the neutron yield derived from the registered electric charge, through a model of collected charge reduction as a function of total neutrons measured.

1. Introduction

It is possible to produce steady state efficiency calibration of a detection system based upon proportional detectors, such as the ^{3}He counter, to be later applied to the measurement of a burst of neutrons closely overlapping in time (Tarifeño-Saldivia et al., 2009). The usual situation is that the burst consists of fast neutrons and the detectors are sensitive to slow neutrons, for which reason the detectors will be embedded in a neutron moderator of appropriate shape, probably polyethylene or paraffin. The moderator will spread out the original fast neutron spectrum to a partially "thermalised" spectrum and it will also spread out the time distribution of the neutrons due to the multiple scattering processes inside the moderator. The total efficiency calibration may then be carried out with an isotopic neutron source of mean energy not too far from that to be later detected.

This very common detection system is usually employed in situations where the signals from individual neutrons can be distinguished from each other, filtered through a single channel analyzer and counted. But when individual neutrons cannot be distinguished from each other due to their high time overlap (even in presence of the time spread effect of the neutron moderator), the ensuing output signal may be a charge pulse comprising the rapid pile up of many individual detected neutrons (Moreno et al., 2008). This is the case as more frequently these detection systems are applied to the neutron production measurement of pulsed devices, such as low energy plasma focus apparatus (PF). The latter generate short bursts (10–50 ns) of fusion (some may be beam target interaction) neutrons (2.45 MeV with D_2 gas) with a yield that may be less than 10^7 neutrons per shot. This low neutron field restricts the usefulness of nuclear activation methods, especially when the need exists to characterize the neutron yield shot by shot in order to advance the models which describe the dynamics of the processes which originate the nuclear fusion in such devices.

Within this scenario, the current status is to define the expected electric charge mean value of an individual neutron "η", measure the total electric charge through the oscilloscope area of the piled up signal from a neutron burst "X", and calculate the number of detected events "G"

$$G = \frac{X}{\eta} \tag{1}$$

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Later, through a calibration factor "j" obtained with a steady state isotopic neutron source of known yield, operated in the usual "one pulse-one neutron" mode, the neutron yield "Y" of the above neutron burst is obtained as

$$Y = j \cdot G \tag{2}$$

In what follows, the shape of individual pulses from ^{3}He tubes detecting weak neutron bursts from a PF have been identified. This was accomplished recording the output charge signal for each burst in a digital oscilloscope and studying their shape frame by frame. By such process the signals corresponding to individual neutrons can be observed in the tail of the time distribution, after the high initial pile-up has died away. Finally, with such information, the pulse height spectrum (PHA) of these neutrons arisen from short bursts was reconstructed and compared with that produced with a low yield ^{252}Cf neutron source.

The aim of the work here described is to provide a correction to the number of neutrons deduced from the total electric charge collected after a neutron burst, which will be underestimating that total number due to the diminished electron multiplication inside each detector tube, caused by positive charge accumulation in the active volume. Thus, the correction must be a function of the initial neutron number deduced. It will be related to the lowering of pulse amplitude as a function of number of detected neutrons in a burst. The theory of electron gas multiplication in proportional counters from the literature will be reviewed and employed to this purpose.

2. Pulse height distribution spectrum (PHA)

The electric charge of individual pulses originated in the detection of each neutron is usually integrated in a charge sensitive preamplifier and is thus turned into a voltage signal, whose value is often called its pulse height. The circumstances that govern the variations of pulse height in a proportional counter are very well known, but for the sake of the present analysis it will be convenient to review them here.

For the particular case of the ^{3}He proportional counter employed here, the pulse height distribution exhibits a peak corresponding to the total energy of the exothermal reaction, deposited by the reaction products in the gas through ionization.

$$^3\mathrm{He} + \mathrm{n} \Rightarrow \ \mathrm{p} + {}^3\mathrm{H} + 764\ \mathrm{keV} \tag{3}$$

In this well-known ^{3}He(n,p)T reaction, the absorption of a slow neutron produces a proton and a tritium nucleus with kinetic energies 573 and 191 keV respectively, emitted in opposite directions due to momentum conservation. These charged particles ionize the gas losing a mean energy per interaction W. This value as given by different authors (Jesse and Sadauskis, 1953; Bortner and Hurst, 1954) ranges from 40 to 46 eV/ion pair for ultrapure Helium and is reduced to 30 eV/ion pair with small traces of impurities (Jesse and Sadauskis, 1952; Bortner and Hurst, 1954). For our detector we determined experimentally a value of 39.9 ± 1 eV, through ec. 6 and a calibrated amplifier. This value will be used throughout this paper.

Whenever any of these particles collides with the detector wall, part of the kinetic energy is not delivered to the ionization process in the gas, thus producing a charge pulse of diminished value. This is known as "the wall effect" (Shalev et al., 1969) and it induces the appearance of a plateau in the PHA spectrum to the left of the full energy peak, as depicted in Fig. 1.

The full energy pulses in Fig. 1 exhibit a voltage which is a function of the electric charge generated by a neutron through the described mechanism. This charge may be estimated as

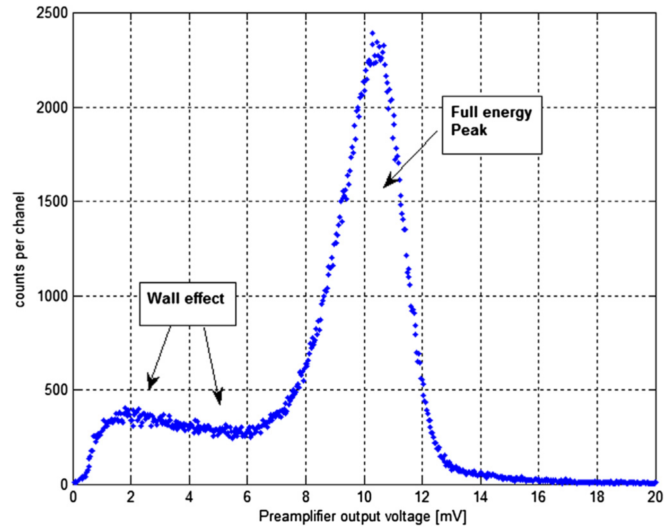

Fig. 1. ^{3}He PHA polarized at 1400 V with ^{252}Cf neutron source.

$$Q = n_o e M \tag{4}$$

where n_o: is the number of electron–ion pairs generated through primary (original) ionization by the ^{3}He(n,p)T reaction particles (573 keV proton, 191 KeV el triton), e: electron charge, M: gas multiplication factor of the following ionizations.

The number of electron–ion pairs can be estimated as

$$n_o = \frac{E}{W} \tag{5}$$

where E is the energy (in eV) of the ionizating particles liberated in the reaction (764 keV) and W is the mean energy necessary to ionize the gas (Fig. 2).

When the amplification system is "charge sensitive" as the one employed in this work, the ensuing pulse amplitude is directly proportional to the electric charge delivered by the detector

$$Vp = G \cdot Q = G \cdot \frac{E}{W} \cdot e \cdot M \tag{6}$$

3. Gas multiplication and its relation with detector polarization

The process of charge multiplication in the proportional detector takes place when an electron gains enough energy in the applied electric field as to ionize the neutral gas. The incremental fraction of the number of electrons (dn/n) per unit length (dr) can be written as the Townsend equation

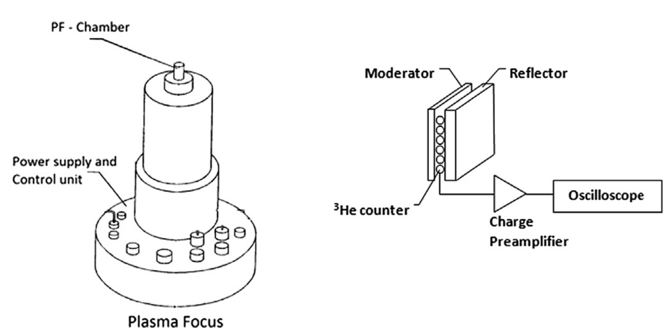

Fig. 2. Experimental setup.