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Determination of Fast Neutron Spectrum Using Zero Crossing Techniques

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ABSTRACT. The neutron fluxes from an Am/Be source and from a graphite slab bombared with 14.1 MeV neutrons have been measured by an NE-213 organic scintillator using a zero cross-over technique and compared with that measured by a charge comparison method. The accuracy of the measured Am/Be spectrum was examined using the standard spectrum and other measurements. Measured spectra from the graphite assembly were tested using the calculated results of the one dimensional discrete ordinate code ANISN using the ZZFEWG 1/31-1F neutron library. The experimental technique, in this work, is shown to be useful in measuring the neutrons in the range 14.1 MeV to 1.8 MeV for D-T fusion reactor neutronics.

The pulse shape discrimination (P.S.D.) technique has been the subject of current interest for many authors (Roush *et al.* 1964, Miller 1968, Taylor and Kalyna 1970, Blalkowski and Szczepantkowski 1978, and Adams and White 1978). Two methods are applied. One method is to compare the charge of the wholly integrated pulse with that of the partially integrated one. This method which is known as charge comparison was originally developed by Brooks (1959) for scintillators pulses. The second one is to integrate the pulse and then by the zero crossing method to differentiate between the different rise times obtained by Alexander and Goulding (1961). The first method is superior for high dynamic range and low energy operation, and the second for short processing times of pulse shape information (Sabbah and Suhami 1968).

In the present work, the neutron spectrum from a graphite slab bombared with 14.1 MeV neutrons and the neutron spectrum of Am/Be source have been measured using the two methods of discrimination. In both cases the measurements were carried out under the same conditions. The spectra emitted from graphite were compared with the spectrum calculated with the one dimensional discrete ordinate code ANISN using the ZZFEWG 1/31-1F cross section library.

Experimental

The neutron detector was a cylinder of NE-213 liquid scintillator of dimensions 4 cm by 4 cm in a BA1 cell supplied by Nuclear Enterprises Ltd coupled to a 14 stage photomultiplier tube type 56 AVP. The modified dynode chain used is shown in Fig. 1. The use of zener diodes enables the gain to be changed without running into space charge saturation and high count rates can be accommodated. If only resistors are used, when the dynode voltage is adjusted to obtain the desire gain, the top dynodes may have insufficient voltage across them during the pulse to remove the electrons rapidly, thus causing saturation.

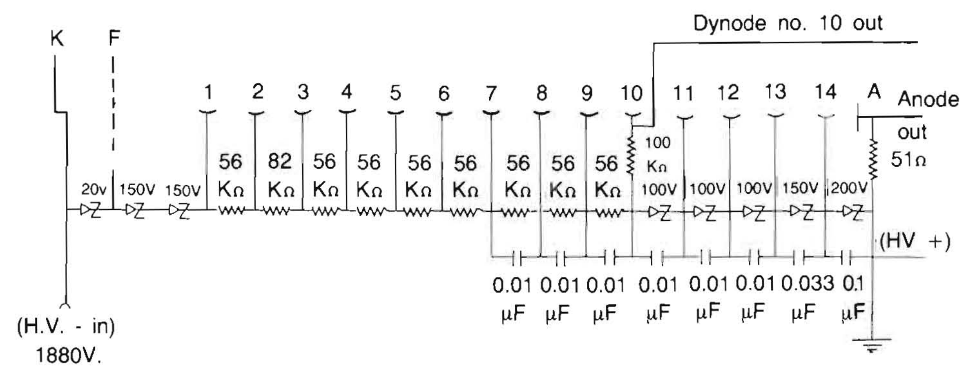

Fig. 1. Dynode chain of the photomultiplier tube type 56 AVP

The zero cross-over system, used in the present work, is shown in Fig. 2. The pulse shape from the photomultiplier tube output (dynode 10) depends on the kind of incident radiation. The neutron pulse contains a slow component which decays more slowly than the gamma pulse. Accordingly, the zero cross-over point of a bipolar pulse produced by an integration and two successive differentiations is different for neutrons and γ- rays. On the other hand, the starting point of the fast component of the pulse does not differ appreciably for neutrons and γ- rays. Consequently, the time interval between the leading edge of the bipolar pulse and the zero cross-over point is different for these two radiations (Fig. 3 at E). This time interval is converted to pulse height by a time-to-pulse height converter (TPHC), whose start signal is taken from the anode through a fast discriminator.

The spectrum of the output pulses from the TPHC shows two peaks corresponding to neutrons and γ-rays (Fig. 3 at F). The peak corresponding to neutrons is selected by a single channel analyser, whose output pulse increased in length by a pulse-strecher is used to gate a 512 channels multichannel analyser (MCA). The linear pulses coming from the main amplifier are delayed by a linear delay amplifier to coincide with the gate pulse and are then passed to the input of the MCA. Figure 3 shows diagrammatically the time selection output pulses at various points in the system.

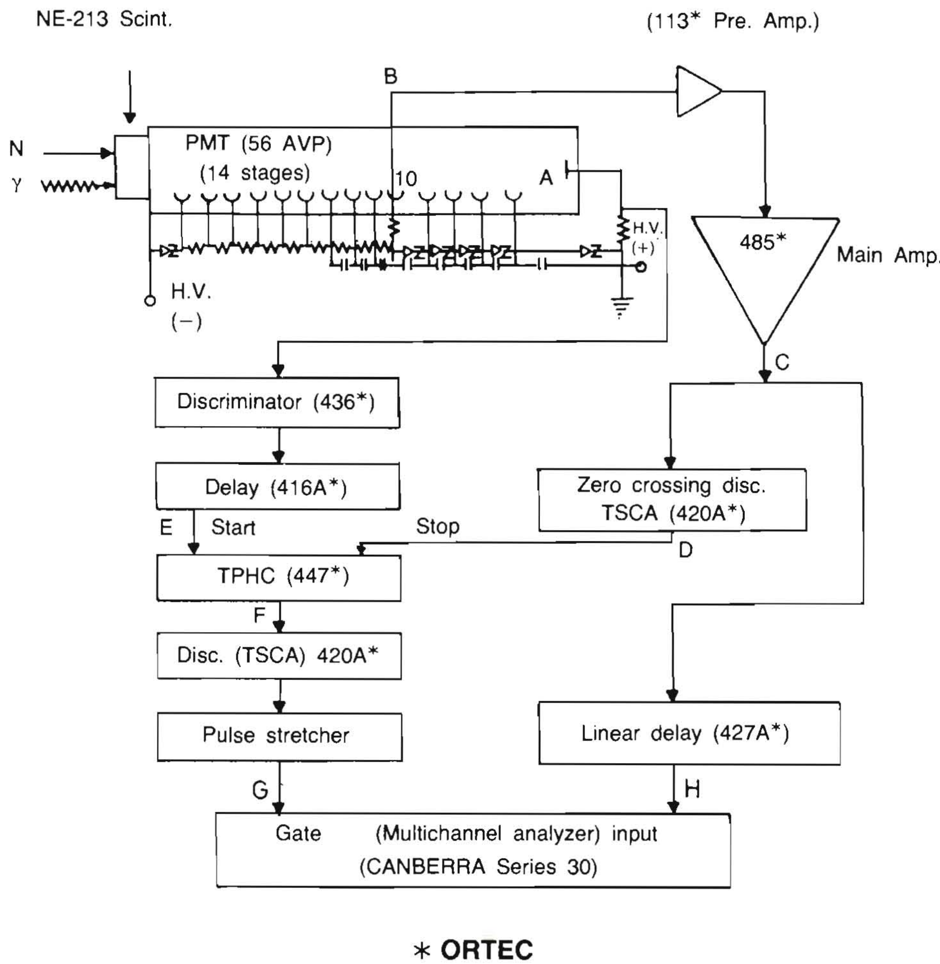

Fig. 2. The block diagram of the circuit used for neutron detection

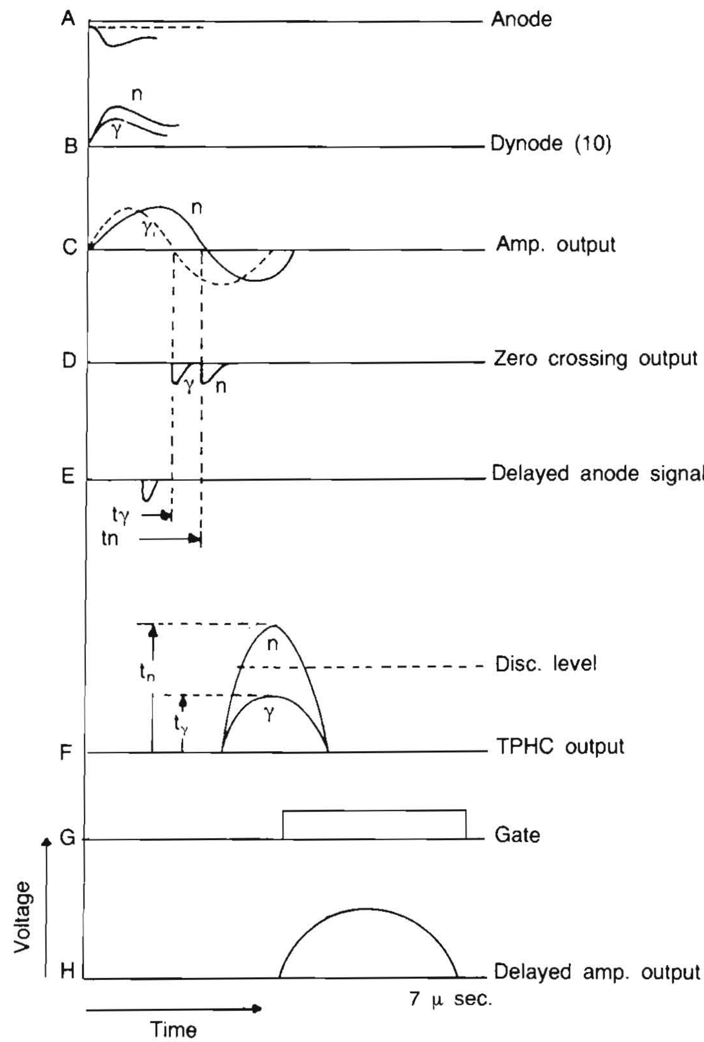

Fig. 3. The time selection output pulses at various point in the P.S.D. system

A computer programme NSPEC was used to analyse the data and obtain a neutron spectrum. This programme uses the differentiation method based on the method of Toms (1971) and the proton pulse height and energy data from Maier and Nitschke (1968). The statistical uncertainty has been carried out using the NSPEC programme and it was found in order of ± 12%.

Results and Discussion

The spectrometer linearity was tested by means of γ-ray sources ^{22}Na, ^{137}Cs, ^{54}Mn and ^{60}Co which the half height channel number of the measured Compton distribution is plotted as a function of the electron energy assigned to that half height assuming that the half height corresponding to the Compton edge that is given by Knox and Miller (1972)

$$E_c = E_\gamma / [1 + (0.51 / 2E_\gamma)]$$

whese E_γ is the energy of γ- quanta in MeV.

Since high energy γ-rays are not available for calibrating the system, the position of the experimental 14.1 MeV peak in Fig. 4 is identified from the half height of the 14.1 MeV edge of the integrated pulse height distribution and equated to an electron energy 7.7355 MeV (Bashter 1985). This sets the energy scale and forces the 14.1 MeV peak to the correct energy.

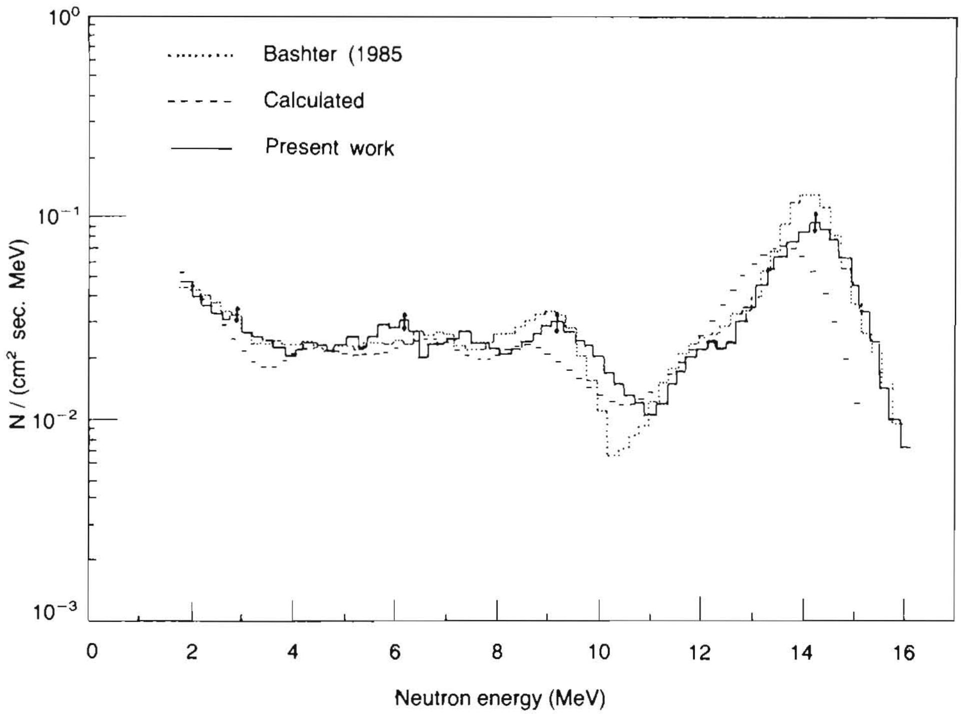

Fig. 4. Neutron flux at the surface of 26.7 cm thick graphite slab

The detection efficiency of the scintillator as a function of energy was calculated using the hydrogen cross sections from Wasson (1963) and carbon cross sections from Garber and Kinsey (1976). The shape correction factor as defined by Broek and Anderson (1960) was also applied.

To check the proper functioning of the liquid scintillation spectrometer as well as the computer programme NSPEC for unfolding of the proton energy spectrum, a neutron spectrum of an Am/Be neutron source of neutron emission 2.5×10^6 n/sec (obtained from the Radiochemical Centre, Amersham, U.K.) was taken using the spectrometer. Fig. 5. presents the present Am/Be spectrum with the measured by the charge comparison method (Bashter 1985) and another recent one measured by zero crossing method with the FORIST code for unfolding the spectrum (Tsechanski *et al.* 1983). The spectra were compared with the standard spectrum given by the source manufacturer (Radiochemical Centre Catalogue

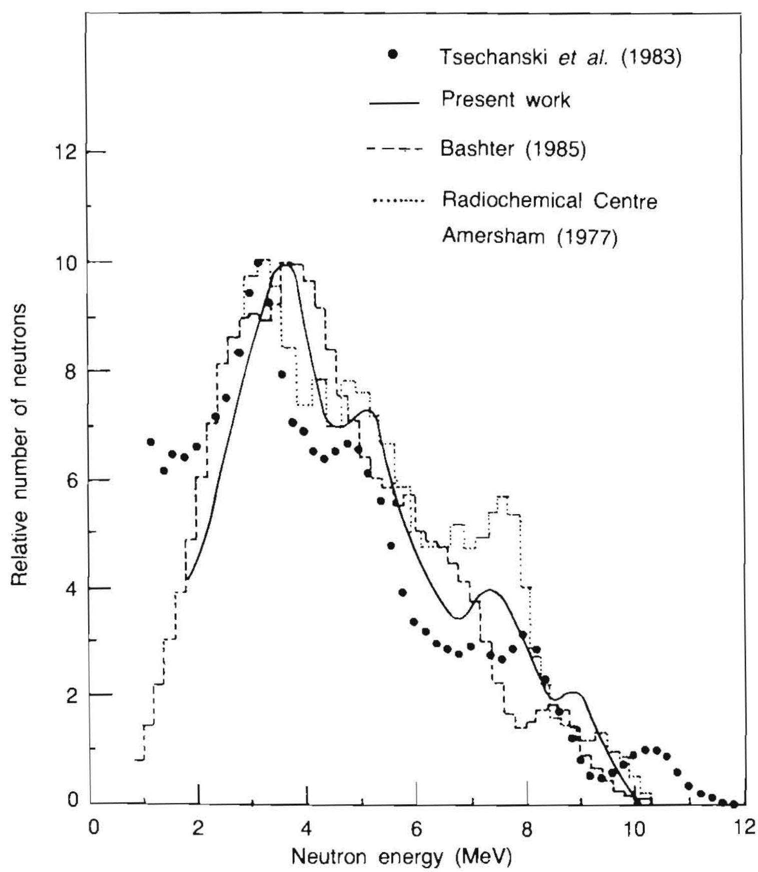

Fig. 5. Am - Be neutron spectrum

1977). From the figure, it can be seen that our measured spectrum agrees with the others especially the standard one. The slight differences in the intensities at the observed peaks can be attributed to the different compositions of the sources in the given cases. As seen also, the coincidence in the position of maxima and minima shows the absence of non-linear distribution in the electronics of the present spectrometer for the neutron energy of interest.

Figure 4 shows the neutron spectrum emitted from a graphite slab of thickness 26.7 cm bombarded with 14.1 MeV neutrons and compared with that measured and calculated spectra from Bashter (1985). Both measurements and calculations have been normalised to a flux of 1n cm^{-2} sec^{-1} at the detector in the absence of any shield. It will be noticed from the figure that the theoretical and experimental 14.1 MeV peaks are not quite in the same position and the experimentally observed bump on the low energy side of the spectrum (which is caused by elastic scattering) is less prominent in the calculated spectrum. This is a consequence of the smoothing process applied to the calculated spectrum to present it in a form similar to the measured spectrum and the cross section data set group structure since the top group is 0.4 MeV wide with limits 14.2 and 13.8 MeV, and the second group is 1 MeV wide from 13.8 MeV to 12.8 MeV. Also, the width of the top group makes the calculated full energy peak somewhat wider than the experimental peak. In general satisfactory agreement between measurements and calculations obtained although the comparatively coarse group structure does produce a smoothed spectrum with smaller variations in flux than the measured values. The peak indicated by error bars around 9,6 and 3 MeV are due to the secondary neutrons emitted by the inelastic scattering which results from the excitation of carbon-12 nucleus to the discrete energy levels, *i.e.* 4.47, 7.66 and 9.64 MeV levels respectively.

Conclusion

The results presented above demonstrate the versatility of the zero crossing technique of pulse shape discrimination in the range 14.1 MeV to 1.8 MeV neutrons. This energy range is important to study for test nuclear data and calculation methods for D-T fusion reactor neutronics. The NE-213 scintillation spectrometer system has proved to be an effective tool for checking the accuracy of the neutron cross section libraries and the neutron transport codes.

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قياس طيف النترونات السريعة
بطريقة العبور الصغرى

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تم قياس فيوض النترونات المنبعثة من المصدر أمير سيوم ـ بيريليوم، ومن شريحة جرافيت عرضت لمصدر نترونات مقداره ١٤,١ مليون الكترون فولت وذلك بإستخدام الكاشف العضوى (NE-213) مستخدماً طريقة العبور الصغرى، ثم قورنت النتائج بطريقة مقارنة الشحنة.

ولإختبار دقة النتائج في حالة المصدر أمير سيوم ـ بيريليوم تمت مقارنة الطيف الناتج مع الطيف القياسي وقياسات أخرى أجريت من قبل. أما النتائج التي حصل عليها من شريحة الجرافيت فتم إختبارها بالحسابات النظرية لبرنامج أنيسن مستعينين بمجموعة الحسابات ZZFEWG 1/31-1F.

وقد ثبت أن الطريقة المستخدمة في هذا البحث صالحة لإجراء قياس النترونات الناتجة من التفاعل ديترون ـ تريتيوم المستخدم في مفاعل الاندماج النووي، وذلك في المدى من ١٤,١ إلى ١,٨ مليون الكترون فولت.