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Development of deuteron-recoil spectrometer for fast neutron spectrum measurements

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1. Introduction

While NE-213 proton-recoil spectroscopy has beeen a standard method in fast neutron physics for some time now, it suffers from two disadvantages in the framework of our neutronic fusion-reactor blanket studies. Firstly, the size of the cell containing NE-213 cannot be reduced beyond 12 mm x 12 mm without badly damaging the energy resolution. This limits the in-situ spectrum measurements within a blanket configuration and tolerance to high neutron intensities. Secondly, the unfolding of NE-213 spectra with "FORIST" [1] code often results in oscillations and negative solutions. As an improvement towards minimising these two drawbacks, we have looked at the possibility of performing deuteron-recoil spectroscopy using the deuterated liquid scintillator NE-230.

2. Advantages of NE-230 with respect to NE-213

The NE-213 liquid scintillator is composed to a great extend of C_6H_6. The most important recoil-particules are, therefore, protons. For an incident neutron energy of 14 MeV, the range of such particules is about 2.5 mm. In the NE-230 liquid scintillator, hydrogen has been replaced by deuteron to 99%. The great advantage is that the deuteron range in the scintillator is twice shorter than that of proton. Therefore, for the same incident neutron energy, the deuteron range is about 1.2 mm; we can reduce further the size of the NE-230 cell compared to the NE-213, without damaging too much the energy resolution of the detector. That implies a better tolerance to high neutron intensities; and more realistic in-situ spectrum measurements are possible. Moreover, the response function of the NE-230, with respect to NE-213, has a peak, instead of a plateau, because of the non-isotropic diffusion of the D(n,n)D reaction. This property makes the unfolding, with "FORIST" code, of NE-230 spectra easier.

3. Unfolding of neutron spectrum

The unfolding method of neutron spectrum is based on the measured or caculated response functions of the detector. The NE-213 (and NE-230) spectrometer gives only the recoil-particules distribution. So to come back to the neutron spectrum, we must know as precise as possible, the response functions of the scintillator. For the NE-213, the "O5S" code [2] exists already. It calculates, with a Monte Carlo method, the response functions of this scintillator. For the NE-230 response functions, we have modified this code to include the (n,D) nuclear reactions.
The procedure of calculation of the response functions is the following: (1) evaluation of all significant neutron-scintillator components interactions; (2) treatement of the significant nuclear rections: choice of the nuclear reaction model, determination of the emission angle of the products of these reactions and the energy they have kept; (3) calculation of the energy lost by the ions in the scintillator; and (4) determination of the light output as a function of the energy lost by the ions in the scintillator. The comparison of the calculated data (the proton range and the light output table for each recoil particules) and those tabulated in "O5S" for the NE-213 scintillator

has showed a good agreement. Therefore, the NE-230 response function matrix was built with this modified code.

4. Experimental procedure and results

At this stage of our investigation, cylindrical NE-230 [2" x 2"] cell has been coupled to the same photomultiplier tube and base, used for the standard NE-213, and tested in various neutron fields using standard sources: PuBe and ^{252}Cf. The validation of the NE-230 calculated response matrix has been done, by unfolding spectra of these standard neutron sources using "FORIST" code.

The unfolded spectra of PuBe and ^{252}Cf sources are shown in fig.1 and fig.2. There is a good agreement in the shape of the expected and the measured spectra. Meanwhile, in fig.1, the energy correspondence between the reference [3] and the measured spectra is not satisfying enough for low energies (up to 6 MeV). The reason of this divergence is perhaps in : the non-linearity of the output signal (a check up of the PMT base is necessary), the light output table (a nuclear reaction has been badly estimated for heavier recoil-particules) or the isotopic deterioration of the reference source (20 years old). In fig.2 we found the same energy problem with the right peak (~ 2.5 MeV instead of ~ 1.8 MeV). Moreover, the left peak indicates a gamma contamination of the neutron spectrum. With the zero-crossing method, the time difference of the pulse shape between the gamma peak and the neutron peak is about 9 ns for the NE-230, and about 30 ns for the NE-213. It is, therefore, more difficult to do gamma discrimination with NE-230, in comparison with the NE-213, when there is too much gamma.

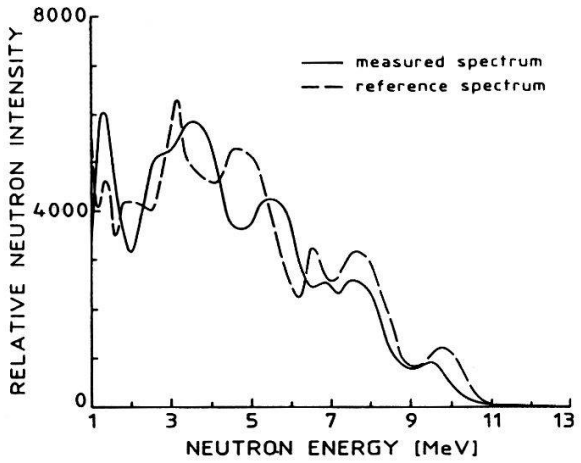

Fig.1: unfolded spectrum PuBe source with NE-230 spectrometer

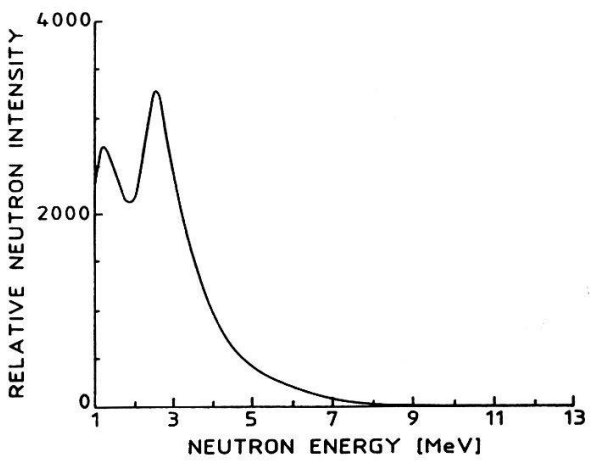

Fig.2: unfolded spectrum ^{252}Cf source with NE-230 spectrometer

5. Conclusion

The technical feasibility of this new deuteron-recoil spectrometer has been shown. The discrimination of neutron and gamma signals is more difficult to realize in NE-230 with respect to the NE-213, especially when there are more gammas than neutrons. The validation of this new method, by the unfolding of standard neutron sources, has given good results. The shape of reference source spectra is acceptable. At present, there is still an energy problem with the unfolded spectrum.

In a futher stage, the size of this NE-230 spectrometer will be reduced.

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