Neutron response functions of a EJ-200 plastic scintillator

J. Paepen¹, L. Maran², P. Mästelin³, E. Munaron⁴, B. Pedersen⁵, P. Schillebeeckx⁶, F. Schulte⁶, G. Varasano⁷.

¹ European Commission, Joint Research Centre, Geel, Belgium. ² Dipartimento di Fisica dell’Università di Padova, Padova, Italy. ³ INFN, Laboratori Nazionali di Legnaro, Legnaro Italy. ⁴ European Commission, Joint Research Centre, Ispra, Italy. ⁵ FH Aachen, University of Applied Sciences, Aachen, Germany

INTRODUCTION

Non-destructive methods to characterize α-active nuclear waste strongly rely on the detection of neutrons. Neutron emission by alpha-active waste is caused by spontaneous fission, \((α, n)\) reactions mainly on oxygen and multiplication of neutrons by neutron induced fission reactions. When nuclear fission occurs a group of prompt fission neutrons is emitted simultaneously. These neutrons have an energy distribution, which in first approximation follows a Maxwellian distribution with an average energy in the order of 2 MeV. The number of emitted prompt fission neutrons, often referred to as multiplicity, is characterized by a statistical distribution. In an \((α, n)\) reaction only one neutron is emitted. The difference between the neutron multiplicity of neutrons resulting from fission and an \((α, n)\) reaction can be used to distinguish between them.

Waste characterisation systems consist mostly of a moderator surrounding a neutron detector that is sensitive to low energy neutrons, in most cases a proportional counter filled with \(^3\)He gas. The detection system is connected to a signal processor that allows a multiplicity analysis of neutrons that are correlated in time. The pioneering work of such an analysis has been carried out by Hage and Cifarelli [1-4] at the JRC Ispra (I). They developed analytical expressions to link the total spontaneous fission rate, the ratio of \((α, n)\) neutrons to spontaneous fission neutrons, the multiplication and detection efficiency to the experimental observables. The result of such a multiplicity or neutron correlation analysis can be used to determine the amount of Pu in the drum.

The data analysis can strongly be hampered, when spallation reactions are induced in the waste and/or materials surrounding the detection system. Such spallation reactions can be induced by high-energetic atmospheric muons. They are followed by the emission of neutrons with a relatively high multiplicity. Hence, it is difficult to separate them from prompt fission neutrons. Since an increase of the amount of material around the detector would increase this contribution, passive shielding is not recommended. Therefore, an active shield is proposed that consists of an array of plastic scintillators surrounding the measurement setup. The idea is to inhibit the treatment of a signal observed in the neutron detector, once a muon or neutron is entering the system from outside and is detected in the plastic scintillators.

The main objective of the measurements at the CN 7MV accelerator of the INFN Legnaro (Italy) was to study the neutron response of a EJ-200 plastic scintillator to be used as veto. Neutron response functions were obtained from time-of-flight (TOF) measurements. The results of these measurements were combined with results of measurements at mono-energetic neutrons beam carried out at the 7 MV Van de Graaff accelerator of the JRC Geel (Belgium).

EXPERIMENTAL DETAILS

The 7 MV Van de Graaff accelerator at INFN Laboratori Nazionali di Legnaro (I) was operated in pulsed mode, enabling neutron time-of-flight measurements. Protons were accelerated towards a 250 µm thick metallic Li target. The beam was operated at proton energy of 4.65 MeV at a frequency of 600 kHz.

Experimental neutron response functions of a rectangular EJ-200 plastic scintillator with dimensions (30 cm x 40 cm x 2.5 cm) were obtained. The scintillator was coupled to a PMT produced by ET Enterprises. Data were acquired with a CAEN DT5730B digitizer. The data throughput rate at INFN for full digital time-of-flight measurements was too high for the DPP-PDS control software. Therefore, a dedicated software was developed at JRC Geel (B). Fig. 1 shows the experimental set-up.

To convert the light output of the scintillator into an energy scale measurements with a Cs and AmBe radionuclide source were carried out.

Fig. 1. Experimental setup for the neutron time-of-flight measurements at the INFN LNL (I).

RESULTS

An example of a TOF spectrum obtained with a 4.65 MeV pulsed proton beam is shown in Fig. 2. The figure
shows a sharp gamma flash peak at the beginning, followed by a neutron peak. The steep neutron peak is followed by a tail, which is caused by slower neutrons with a lower energy.

Fig. 2. A time-of-flight spectrum emitted by a 4.65 MeV proton beam on a 250 μm thick solid Li-target. A collimator was placed between the target and the neutron detector in the direction of the proton beam.

TOF cuts were applied to extract the light output response functions at a given neutron energy. The cuts were made with 1 ns TOF windows. The corresponding neutron energy spread is much less than the energy resolution of the light output. An example of such a response function for a 3 MeV neutron is shown in Fig. 3.

Fig. 3. Light output spectrum produced by the detection of a 3 MeV neutron in a 25-mm thick plastic scintillator.

From the response functions to mono-energetic neutron the specific light output and resolution was derived for different proton energies applying a procedure that is described by Tomanin et al. [5]. The specific light output as a function of proton energy for the 25 mm thick detector is shown in Fig. 4. The results of measurements at mono-energetic neutron beams produced at the VdG accelerator of the JRC Geel are also included. This figure shows that the specific light output for protons is about a factor 3 less than the one for electrons. The light output function was fitted using the analytical expression;

\[
L(E) = E \left( b_0 + \frac{b_1 E}{1 + b_2 E} \right) .
\]  

(1)

This expression, taken from Tomanin et al. [5], is a modified version of the one used by Kornilov et al. [6].

Fig. 4. Specific light output function for protons for a 25 mm thick plastic scintillator. The data derived from the VdG data at the JRC Geel (B) by ■ and for the neutrons from the time-of-flight data at the INFN Legnaro (I) by ●. The full is the result of a fit using Eq. 1.