Nuclear Instruments and Methods in Physics Research A 836 (2016) 83–90

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

Modular total absorption spectrometer

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ARTICLE INFO

Article history:
Received 23 April 2016
Received in revised form
16 August 2016
Accepted 22 August 2016
Available online 24 August 2016

Keywords:
Beta decay
Total absorption spectrometry
NaI(Tl)
Simulation

ABSTRACT

The design and performance of the Modular Total Absorption Spectrometer built and commissioned at the Oak Ridge National Laboratory is presented. The active volume of the detector is approximately one ton of NaI(Tl), which results in very high full γ energy peak efficiency of 71% at 6 MeV and nearly flat efficiency of around 81.5% for low energy γ-rays between 300 keV and 1 MeV. In addition to the high peak efficiency, the modular construction of the detector permits the use of a γ-coincidence technique in data analysis as well as β-delayed neutron observation.

1. Introduction

A need for total absorption spectrometry in the studies of complex β-decays has been recognised since the 1970s [1]. Since then, several versions of high-efficiency total absorption spectrometers (TAS) have been built and utilised in $\beta-\gamma$ spectroscopy complementing the measurements using high energy resolution, but low efficiency Ge detectors. In particular, TAS measurements are mandatory for establishing the true β-decay pattern in fission products. One of the key phenomenon determining the decay properties of these neutron rich nuclei is the competition of allowed Gamow–Teller and first forbidden β transitions. Large decay energy (Q_β) values result in many relatively weak β transitions distributed over many final states in regions with high level energy and density. These β transitions may be followed by many γ transitions cascading to the ground or low energy isomeric state in the final nucleus. This is also known as Pandemonium effect [1]. To establish a true distribution of β feeding through the measurement of β and γ radiation, very high detection efficiency is essential even at the expense of energy resolution. It was demonstrated in several cases that the β-feeding pattern derived from measurements using high-resolution, low-efficiency germanium detectors was incorrect, compare, e.g. [2,3]. In experiments using low efficiency ($<10\%$) Ge arrays, the β-feeding is obtained as a difference between intensity of apparent γ-rays feeding and deexciting a given level in a daughter nucleus. Since many weak γ-transitions remain undetected, this results in erroneous reconstruction of β feeding pattern. Also, in some cases there are weak, but high energy γ-transitions emitted after β-decay, which were beyond the detection range of low efficiency Ge setup. Typically, a decay scheme studied with relatively low efficiency detectors has an overestimated β-population of low energy levels and missing β-strength at high excitation energies [2–4].

In the past 20 years experiments with different total absorption spectrometers have been performed at INEL [5], GSI-Darmstadt [6], ISOLDE facility [7] and Jyväskylä [8]. New TAS devices, like the Summing NaI(Tl) (SuN) detector [9] at the National Superconducting Cyclotron Laboratory and the DTAS detector designed for the future Facility for Antiproton and Ion Research (FAIR) [10], have been commissioned more recently and started data taking.

Here, we present the newly constructed Modular Total Absorption Spectrometer (MTAS) built and commissioned at the Holifield Radioactive Ion Beam Facility at the Oak Ridge National Laboratory. MTAS was constructed to study the β-strength distribution in fission products relevant to reactor decay heat analysis [11] and properties of antineutrinos produced by the decay of fission products in nuclear reactors.

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http://dx.doi.org/10.1016/j.nima.2016.08.046
0168-9002/

This article is structured as follows: Section 2 describes the detector array, Section 3 discusses GEANT4 simulations of the response functions and overall efficiency of MTAS, and a discussion of the new MTAS capabilities facilitated by its novel modular design is given in Section 4.

2. MTAS description

2.1. Geometry and control electronics

The Modular Total Absorption Spectrometer, produced by Saint Gobain Crystals (Hiram, OH), consists of 18 NaI(Tl) hexagonal modules. Each of the 18 modules is 21 inch long and 6.93 inch wide (side-to-side). There is also one central module of the same length and cross section, but with a 2.5 inch hole drilled through, as shown in Fig. 1. The total active NaI(Tl) mass is approximately one ton, making MTAS the largest and most efficient detector of this type currently in use. The crystals are arranged in a honeycomb like structure and the various modules are referred to as the Central (C) detector, the Inner ring (I) detectors, the Middle ring (M) detectors and the Outer ring (O) detectors. These assignments reflect the distance of each module to the central axis of the detector (see Fig. 1). Each NaI(Tl) crystal is enclosed in a carbon fiber housing (0.81 mm), with the stainless steel (0.04 mm), teflon (0.5 mm) and silicon putty (2.025 mm) layers. The through-hole of the Central detector has a similar housing with the exception of the silicon putty being only 0.68 mm thick. The Central detector is viewed by twelve 1.5 inch diameter ETI9102 Photo-Multipliers (PMTs) produced by ET-Enterprises (Uxbridge, UK), six on each end, while the other 18 detectors are viewed by 5 inch diameter ETI9390 PMTs, one on each end of the crystal. It results in a total of 48 PMT signals. Signals are fed to the *Pixie16, rev. D* digital electronics developed by XIA LLC (Mountain View, Ca) [12] using 12 bit digitisation at 100 MSPS. Digital Data Acquisition system allows for the trigger mode of operation, very low signal threshold, and capability to work with high rates. The high voltage for the photomultiplier tubes is supplied by remotely controlled ISEQ EDS F130P 16 channels modules capable of supplying up to 3 kV and 500 μ A per channel. The HV modules are housed in a Wiener mini-MPOD crate.

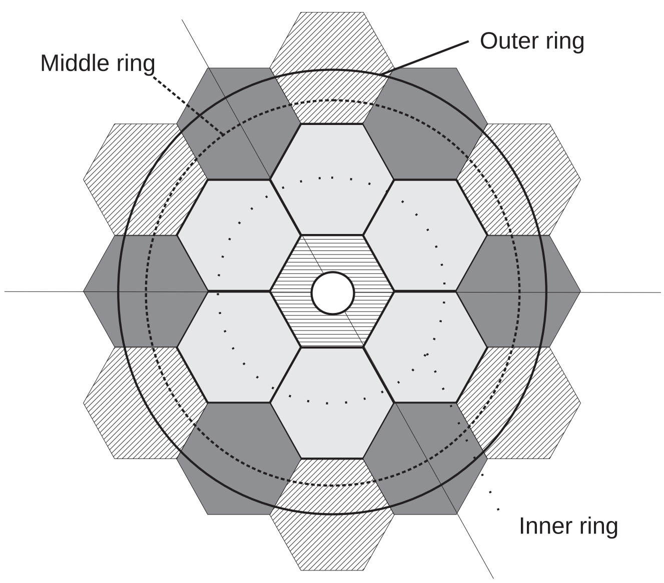

Fig. 1. The honeycomb arrangements of the NaI modules in MTAS. The Inner-ring modules are filled with light grey. The Middle-ring modules with dark grey, while the Outer-ring modules are hatched a 45°, while the Central detector is hatched horizontally.

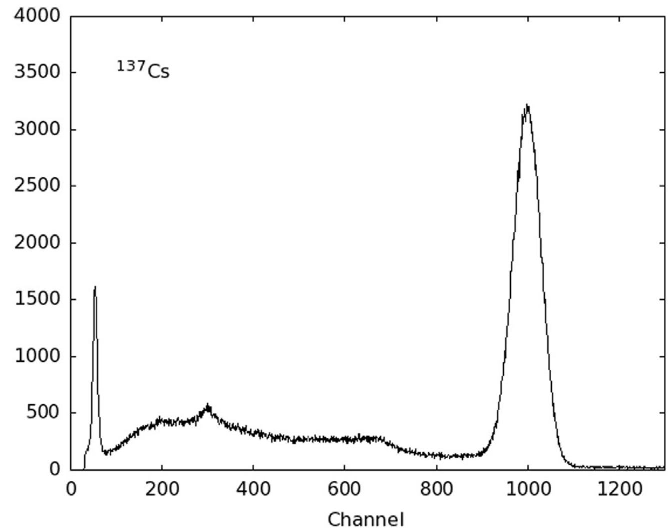

Fig. 2. A typical ^{137}Cs source spectrum measured with a single MTAS module. The source was placed at the middle of the crystal and 20 inch away from the surface of the module (broad beam). Note the presence of ≈ 33 keV barium X-rays to demonstrate the low energy threshold.

The performance of each individual crystal was verified with measurements using a ^{137}Cs source placed either at the centre of the crystal and 20 inch away from the module surface (broad beam) or just on the housing of the crystal in 20 different positions along the crystal, 1 inch apart.

Fig. 2 shows a typical response of one of the crystals to a broad beam γ-rays from ^{137}Cs. Due to the minimal amount of material used to encapsulate the crystals the ≈ 33 keV X-ray in daughter barium isotope can be detected. The full-width-at-half-maximum (FWHM) energy resolution at 662 keV for all crystals excluding the Central one is between 6.4% and 7.9%. Quoted values are for the summed spectra i.e., photomultiplier signals from both ends of the crystals were added in software. Fig. 3 shows the position (in channels) of 662 keV line vs. ^{137}Cs source position along the side of the crystal. The position of the peak remains constant within 1% along the entire crystal while in the central part (starting 2–3 inch from the each side) uniformity is better than 0.2%.

Because MTAS has such a large volume and high efficiency it is very important to shield it from background radiation. The count

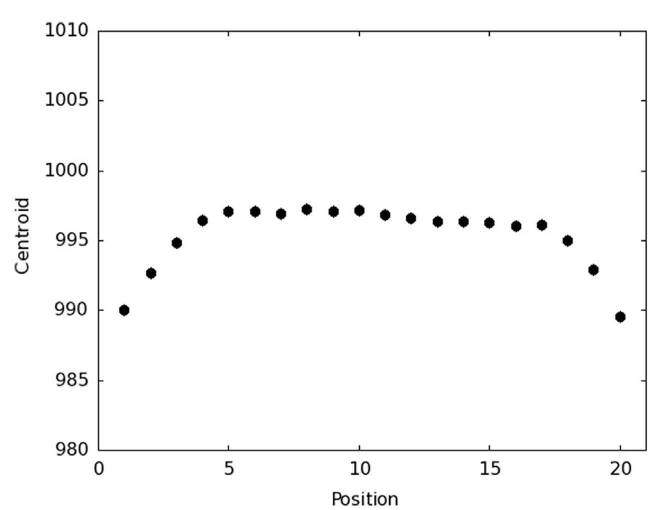

Fig. 3. Amplitude of the 662 keV peak (in channels) vs. the source position along the detector's main axis (in inches). The source was placed on one of the outside module's housing (i.e. not the Central detector).