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Cosmic veto gamma-spectrometry for Comprehensive Nuclear-Test-Ban Treaty samples

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ABSTRACT

The Comprehensive Nuclear-Test-Ban Treaty (CTBT) is supported by a global network of monitoring stations that perform high-resolution gamma-spectrometry on air filter samples for the identification of 85 radionuclides. At the UK CTBT Radionuclide Laboratory (GBL15), a novel cosmic veto gamma-spectrometer has been developed to improve the sensitivity of station measurements, providing a mean background reduction of 80.8% with mean MDA improvements of 45.6%. The CTBT laboratory requirement for a ^{140}Ba MDA is achievable after 1.5 days counting compared to 5–7 days using conventional systems. The system consists of plastic scintillation plates that detect coincident cosmic-ray interactions within an HPGe gamma-spectrometer using the Canberra Lynx^{TM} multi-channel analyser. The detector is remotely configurable using a TCP/IP interface and requires no dedicated coincidence electronics. It would be especially useful in preventing false-positives at remote station locations (e.g. Halley, Antarctica) where sample transfer to certified laboratories is logistically difficult. The improved sensitivity has been demonstrated for a CTBT air filter sample collected after the Fukushima incident.

1. Introduction

The Comprehensive Nuclear-Test-Ban Treaty (CTBT) bans any nuclear explosions, for military or civil purposes [1]. Until treaty ratification, a verification process is being undertaken for the establishment of a robust International Monitoring System (IMS) for treaty compliance. This consists of a network of radionuclide monitoring stations that perform high-resolution gamma-spectrometry on air filter samples at 80 global locations. Measurement is undertaken for 85 radionuclides indicative of nuclear weapons tests and reactor incidents including ^{140}Ba, ^{95}Zr, ^{99}Mo, ^{141}Ce, ^{147}Nd, ^{131}I, ^{134}Cs and ^{137}Cs [2]. If the sample is found to contain multiple occurrences of these anthropogenic radionuclides at anomalously high concentrations, and at least one is a fission product, then the sample is sent to a certified laboratory for more sensitive gamma-spectrometry analysis [3]. This sample transfer may be logistically difficult for monitoring stations situated at remote locations (e.g. Halley, Antarctica) and it is desirable to increase station sensitivity to avoid unnecessary laboratory analysis. Such stations often have an auxiliary detector suitable for modification to improve detection sensitivity without interruption to routine measurements. This is being investigated by the UK CTBT Radionuclide Laboratory (GBL15) based at the Atomic Weapons Establishment (AWE, Reading, UK) where advanced gamma-spectrometry systems have been developed to improve the sensitivity of CTBT measurements [4–7]. This includes a novel cosmic veto device to detect coincident muon interactions within an HPGe gamma-spectrometer [4,5].

The cosmic veto gamma-spectrometer utilises a widely available Canberra Lynx^{TM} multi-channel analyser (MCA) to eliminate the requirement for an individual MCA, high-voltage power supply (HVPS) and dedicated coincidence electronics (e.g. coincidence analyser and delay gate generator). Unlike most existing cosmic veto devices this functionality is provided by a single unit [8–15]. The Lynx provides an easily configurable system accessible using a JAVA interface over the Internet Protocol Suite (TCP/IP). This optimises the MCA for installation at remote monitoring stations, where onsite technical assistance is not readily available, but TCP/IP connectivity is continuously available as part of the CTBT Global Communications Infrastructure (GCI). Initial research by GBL15 utilised the time-stamp functionality of the Lynx to provide comprehensive logging of all events with 100–200 ns time resolution [4,5]. Post-processing was then applied to eliminate coincident events and provide typical background reductions of 70–80% and Minimum Detectable Activity (MDA) improvements of 40–50%. This indicated potential to significantly increase station sensitivity where only a 1 day measurement is performed.

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However, the acquisition and processing of large time-stamp data files (> 2 GB) was computationally intensive and made the system unsuitable for implementation within the IMS. Working closely with Canberra Industries Inc. (Meriden, USA), a solution has been developed that upgrades the Lynx firmware allowing real-time cosmic-ray background suppression without the requirement for post-processing.

2. Methodology

2.1. Instrumentation

The cosmic veto system included a Canberra (90% relative efficiency) extended p-type HPGe detector (model GX8021) with Canberra Lynx MCA. High voltage was set at +4500 V with a rise time of 8 μs and flat top of 1 μs. The detector was situated within a low-background graded shield of lead (125 mm), aged lead (< 25 Bq/kg ^{210}Pb, 25 mm), tin (1 mm) and copper (1.6 mm). Surrounding the shield were five 55 cm × 55 cm Bicron BC408 plastic scintillation plates controlled by a single Canberra Lynx MCA. Rise time was set at 1.2 μs and flat top at 0.6 μs. The Lynx was used to power all five plates using a Scionix 5-way power supply splitter with integrated pre-amplifier (model AM100(5–1)–E2-X) with each plate set at +700 V. Each Lynx was connected to a computer using an Ethernet (10/100 T) connection. For initial time-stamp configuration of the coincidence window a synchronisation cable was run from unit-to-unit (Fig. 1). After configuration, this was replaced with a TTL-pulse gating cable connected to the ICR output of the scintillation plate Lynx and gate input of the HPGe Lynx. Basic setup and calibration of the detectors was performed using the Lynx JAVA interface (Firmware Version 1.1.1.78).

2.2. Coincidence configuration

Determination of the coincidence gating window was performed using the time-stamp functionality of the Lynx, with post-processing enabling the rejection of coincident detector-scintillator events. It required the use of custom (C++) acquisition software and the designation of a master MCA (HPGe) and slave MCA (plates). When acquisition was started, an initialisation signal was sent from the master to slave unit using the synchronisation cable, exactly synchronising the start times for each MCA. All events interacting with the HPGe and plates were then logged to a comma-separated text file for data analysis after acquisition. Measurement was performed for 30 min duration to demonstrate configuration on a time-scale more suitable for an IMS station, compared to previous research that utilised a 7 day acquisition [4,5]. The time-stamped data was analysed using custom Microsoft Access 2003 software controlled using the Visual Basic for Applications language. The database was programmed to determine the time distribution of coincident events in the comma-separated text files produced using the MCA control software. Once this information was obtained, the synchronisation cable was replaced with the gating cable, and the HPGe operated using the Lynx JAVA interface. Using this software and the information derived from the time-stamp distribution, the Gate Delay, External Gate Delay and Pulse Width parameters were set in coincidence mode and refined using the digital oscilloscope functionality of the Lynx (Fig. 2). After satisfactory alignment of the Store and External Gate Delay, the Lynx was set to anticoincidence mode for routine acquisition (rejecting coincident cosmic-ray events).

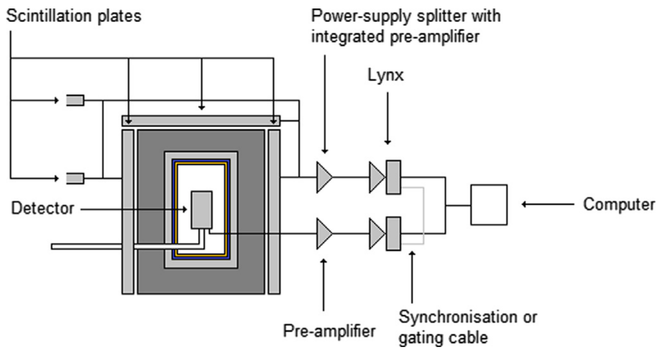

Fig. 1. Schematic of the experimental setup for cosmic veto system. Only three scintillation plates are shown.

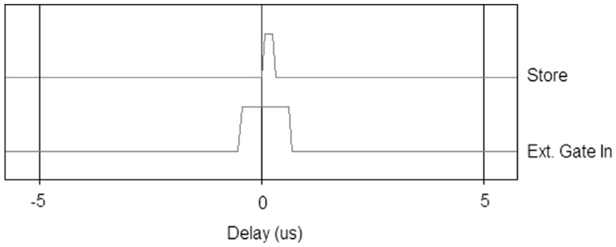

Fig. 2. Alignment of the store and external gate delay using the Lynx digital oscilloscope.

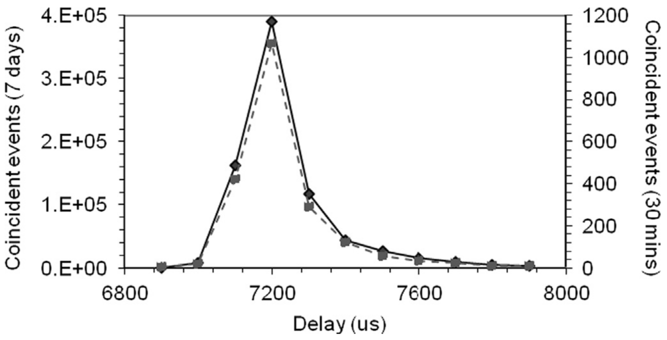

Fig. 3. The time distribution of coincidence events between the HPGe and plates for 30 min (dashed line) and 7 day (solid line) measurements.

2.3. Samples

The system was tested using empty shield measurements and a CTBT sample collected on 18 April 2013 from radionuclide monitoring station JPP38 (Japan). This sample was contaminated with radionuclides from the Fukushima incident (11 March 2011).

3. Results and discussion

3.1. Coincidence configuration

The time distribution of coincidence events between the HPGe and plates was examined within the range of ±100,000 ns. During a 30 min background measurement there were 5849 coincident events recorded, of which 35.2% occurred 7000–8000 ns in the HPGe after an initial plate event. These results followed those obtained during a 7 day acquisition, resulting in significant reduction of the HPGe spectrum [4,5], and occurring as a prominent Gaussian peak in the timing distribution (Fig. 3). Their occurrence at 7000–8000 ns was a function of the HPGe rise time (8 μs) and flat top (1 μs) as the measured event time is taken at the signal pulse maxima (use of the leading-edge would remove the