LOW LEVEL GAS MULTICOUNTER FOR ^{14}C DATING OF SMALL SAMPLES: ELECTRONIC, NUMERICAL AND SHIELDING OPTIMIZATION

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Abstract

Up to 14 methane samples can be dated simultaneously in our compact gas multicounter. Sample detectors are 10 ml (NTP) in volume each. They are made of copper and linked to form two 7 detector rigid assemblies which are filled *in situ*. Monitoring of the counting conditions is enabled through multichannel analysis of the cosmic pulse height spectrum, which shows the changes in gas amplification due to impurities or leakage. HV is set (and adjusted) automatically using the cosmic peak. All individual events are stored on disc, including pulse height (PH), risetime (RT) (both 256 Ch), time of arrival (TA), detector identification, anticoincidence status and elapsed and live time. Software programs analyse and validate data. Numerical discrimination and manipulations of counting parameters can be performed without destroying the original data set. Statistical quality control is based on chi-square and Poisson distribution of count rates around their mean in user defined energy regions as well as time of arrival of pulses mode. TA analysis offers the user an early means for recognizing some types of system malfunction that otherwise might remain undetected for long periods of time. RT analysis is used to discriminate sample beta pulses from environmental radiation pulses, resulting in a low background with compact and relatively inexpensive shielding. The automatic high voltage setting, PH, RT and TA electronics as well as the liquid scintillation anticoincidence systems are applicable to all existing gas counting systems.

Delivery of the gas multicounter to the Australian National University is to take place at the end of the year 1984.

Introduction

The gas multicounter shielding necessary to achieve a low background is of both passive and active type. The passive shield is of a graded, asymmetric design, maximizing radiation attenuation and consists of layers of lead and copper (Kaihola et al., 1983). The active shield, originally a plastic scintillator (NE-102), was replaced with a liquid scintillation guard.

The electronics is designed to enable multichannel analyses (256 channel energy resolution) of sample and guard ionizing events in a pulse height and pulse shape MCA mode coupled to time of arrival analysis (Currie et al., 1983; Kaihola et al., 1984a). The HV is set automatically by using the cosmic spectrum peak to select the appropriate HV from a microprocessor controlled 14 channel HV unit. Data acquisition is under personal computer control with data stored on hard disc. Software programs enable rigorous data evaluation and validation which is particularly important when only some 200 counts are dealt with per day.

The 10 ml copper sample counters have nylon insulators and single gas inlet/outlets with electromagnetically controlled miniature valves.

Methane was selected as the sample counting gas for radiocarbon dating (^{14}C detection at environmental levels) because it offered some advantages over carbon dioxide: (i) CH_4 is less sensitive to electronegative impurities, therefore higher filling pressures can be contemplated and (ii) the gas proportional counting region, the counting plateau, is reached at a significantly lower high voltage. These factors enabled us to consider counter designs which in spite of their small size would reach the required precision of ^{14}C age determinations (Polach et al., 1982).

Passive and Active Shield Characteristics

The passive shield contains only 700 kg of low residual activity lead (Boliden, Sweden). It is cast with a maximum thickness of 20 cm, located above the sample counters and 12 cm below them, and it features 7 cm side walls. The central area of the shield (where the sample counters are located) attenuates gamma radiation below 1.46 MeV by at least a factor of 150, at the $_{40}K$ emission line by 75 and above the $_{40}K$ energy by 32. These figures correspond to 7, 6 and 5 effective half-thicknesses of lead respectively, for the above energy ranges. The sample counter count rate, at 4 bars of CH_4, inside the passive shield is ca 8 cpm whilst 35 cpm are registered outside it. The former figure agrees well with the mean cosmic meson count rate of 0.8 cpm/cm^2 found in gas proportional counters (Mook, 1983). From the results it is clear that secondary x-rays produced in the lead are effectively absorbed by the inner layer of 1 cm thick copper.

The anticoincidence liquid scintillation guard dimensions are: length 55 cm, diameter 16 cm, with an off-centre cylindrical cavity 6 cm in diameter. This guard totally encloses the sample detectors.

The photons generated by ionizing events within the liquid scintillator are detected by four 3.8 cm phototubes located at each end and operate in summed coincidence between any of 2, 3 or 4 phototubes. The liquid guard count rate within the shield is 150 cps.

Coincidence time for guard pulses can be adjusted to be longer than 100 ns and the resulting inhibit pulse length can be defined independently. The sample pulse is delayed by 5 μs. The leading edge of the pulse is used for checking the anticoincidence status together with the inhibit pulse.

The count rate of a 10 ml (NTP) copper detector, filled to 4 bar pressure with CH_4, and operating in anticoincidence with the liquid guard, was 0.14 cpm (200 cpday) in a laboratory where no precautions were taken with respect to selection of construction materials or additional shielding. All pulses above the lower level of discrimination are accepted as counts. The Modern Reference Standard count rate (0.95 NBS Oxalic) is 0.255 cpm (360 cpday) giving a relatively unfavourable signal to noise ratio of 1.8:1. Because such a low signal to noise ratio would not give a useful radiocarbon dating precision (Polach et al., 1982), further electronic optimization of signal to noise is required.

Electronic and Numerical Noise and Background Reduction

To detect electromagnetic interference, the signal from a broad band RF amplifier is added to the anticoincidence gate of the guards. Provisions for an optional flat multiwire gas proportional counter, located above the shield also exist. The effectiveness of this 'cosmic umbrella' remains to be tested.

Among the identified noise generating areas are the high voltage holding capacitors and lead connections to the detectors (Sayre et al., 1981). We have opted for small size ceramic capacitors of LCC GHX015 12.5 kW type and shielded connecting leads triple insulated with Teflon. The capacitor assembly and HV wiring are encased in epoxy resin to form a unit with the preamplifier rigidly connected to the detectors, which remain *in situ* during sample changes. This results in zero noise on application of HV and makes the unit non-susceptible to HV discharge under high humidity conditions.

In order to improve the signal to noise ratio, pulse shape discrimination techniques have been applied to the sample detector pulses (Oeschger et al., 1976; Currie and Klouda, 1979). Sample pulses are divided into pulse height and rise time channels. RT related information is generated with the double differentiation and integration method in RC-stages, it is available as the amplitude of the differentiated pulse (ADP) (Currie and Klouda, 1979). The resulting DC signal values are channelled through an analogue multiplexer into analogue to digital converters. The data collected is displayed on a screen as a two dimensional plot with PH on the vertical and RT related amplitude of the differentiated pulse on the horizontal axis (Fig. 1). Colour acts as an indicator of the amount of sample signal or cosmic pulses present per pixel and provides a third dimension in this plot.

The numerical application of two dimensional PH/RT discrimination at 6 bars resulted in 50 % reduction in sample background whilst 85 % of the undiscriminated sample counts were collected. Numerical pulse height discrimination is applied to the data which is originally discriminated with a low hardware bias. Double pulses can be detected with a time of arrival resolution of 10 ms. Mutual coincidences between sample counters are also detected within the given time resolution. Maximum random coincidence count rate for sample pulses at 0.5 cpm modern rate in one counter, with all the others at the same count rate, is 1.5 counts per month (out of 20,000 counts in total). Random coincidences with the anticoincidence shield at 150 cps are 1 to 17 counts for 100 ns to 2.5 μs inhibit pulse duration, respectively.

Environmental interference is gated separately using a long (100 μs) inhibit pulse. The pulses are stored in the same way as guard gated pulses.

Discussion and Conclusions

The rigorous approach to data analysis (Currie et al., 1983) and flexibility of electronic parameter selection as described in this paper lead to a very acceptable signal to noise ratio of 4 : 1. This places this compact multicounter system in the average performance category of gas proportional counters (Mook, 1983). It is true that when using massive lead shielding in underground installations under optimal conditions, state of the art gas counters achieve a signal to noise ratio of 8 : 1 (Schotterer and Oeschger, 1980; Calf and Airey, 1982). This has also been achieved by some mini-gas counting systems using NaI (T1) anticoincidence shielding. Such a shield would also double the signal to noise ratio of our system; but at an additional cost of some US $ 50,000. We did not consider that in view of the progress in accelerator dating, such an investment is warranted (Kaihola et al., 1984b). Also the best of liquid scintillation counters using the anticoincidence principle achieve today a signal to noise, albeit for larger samples, of 100 : 1 (Polach et al., 1984; Kojola et al., 1984). We have therefore opted for a unit which is within the financial range of the user yet uses high technology with maximum electronic optimization in which the recently introduced concept of pulse time of a)

b)

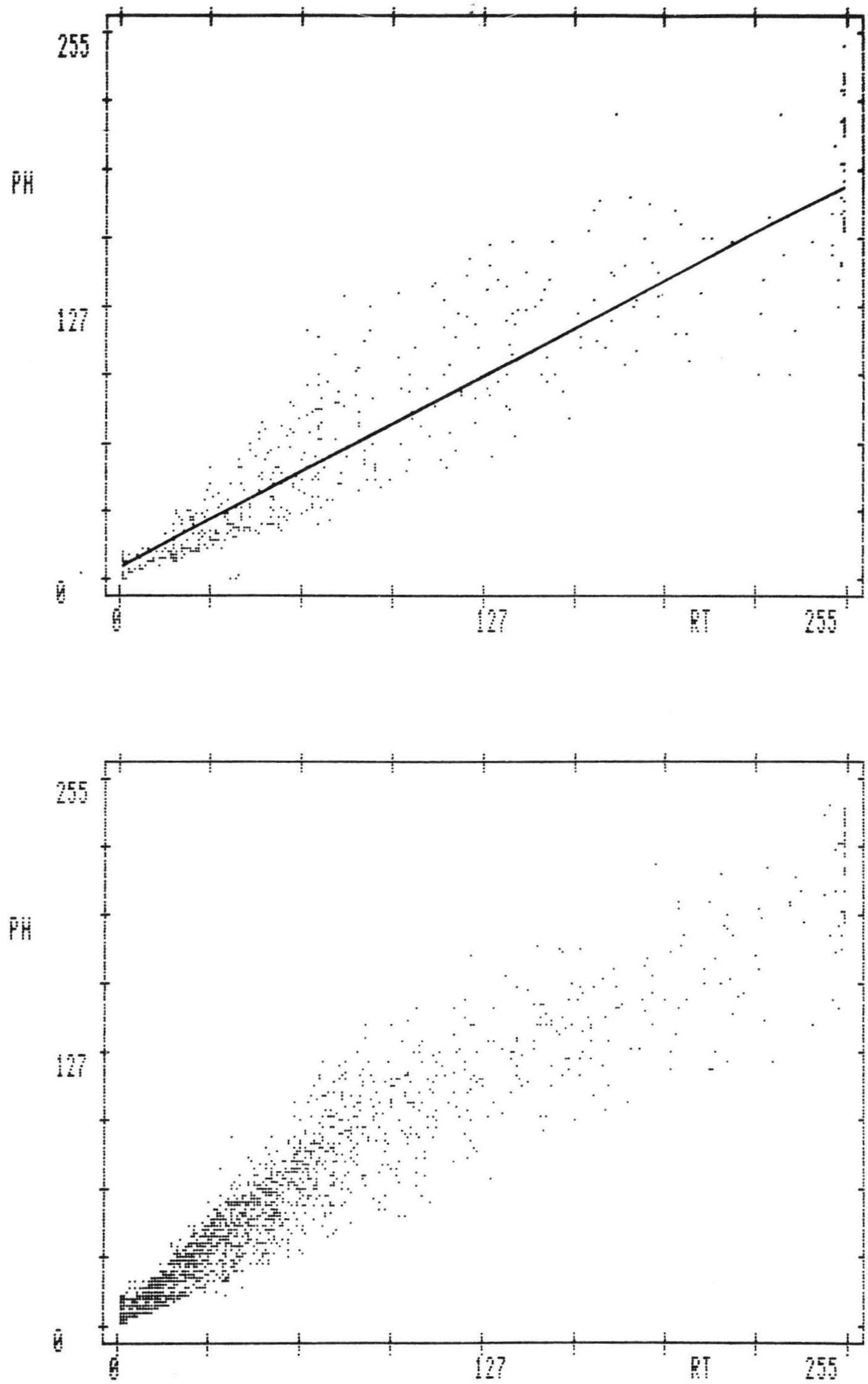

Fig. 1. a) Linear dual plot of ^{14}C sample and background counts. 85 % of sample counts are below the dividing line while only 50 % of background counts are there. b) Linear dual plot of coincidence, or mainly cosmic counts.

arrival analysis plays a significant role in data validation (Kaihola et al., 1984). It is worth noting that the electronics, liquid anticoincidence shield, and software developed for the mini-counters are equally applicable to the existing systems, whose performance thus can be readily enhanced. We are testing this concept in collaboration with the Geological Survey of Finland (Kaihola and Kankainen).

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