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THE POTENTIAL OF THE LONDON UNDERGROUND FOR LIQUID SCINTILLATION COUNTING

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ABSTRACT. A portable gamma spectrometer has been used to survey three locations that are part of the London Underground Transport System (the "tube"). Up to an order of magnitude reduction in the cosmic ray flux was observed relative to the laboratory level. The likely reduction in background count rate achievable by underground siting of currently used Packard and LKB liquid scintillation counters is considered. It is noted that in the present, surface usage for radiocarbon dating, the background count rate of low-potassium glass vials in the LKB is not substanially higher than that of PTFE vials.

INTRODUCTION

It is well known that in low-level liquid scintillation counting a substantial proportion of the overall background count rate is induced by cosmic rays. The cross-talk component of this contribution can be reduced by pulse height comparison (Laney, 1971; Soini, 1975) as illustrated below. For further reduction either physical shielding or electronic anti-coincidence shielding is required. The latter tends to be expensive and the former is usually not a practical proposition for the majority of laboratories. Two laboratories have however reported the advantages of locating scintillation counters in deep sites (Schotterer & Oeschger, 1980; Calf & Airey, 1982). The work presented in this paper is primarily a survey of three locations that are part of the London Underground Transport System (the "tube"). Backgrounds for low potassium glass and PTFE vials are also discussed briefly.

THE GAMMA SPECTROMETER

In the survey, a portable gamma spectrometer was used. This was Harwell type 3086 2-channel battery-operated device with a 44.5mm diameter by 50.8mm long sodium iodide crystal. This detection system has the obvious advantage of portability, and it provides data not only on the relative cosmic ray flux but also on relative natural radioactivity levels in the given locations. The pulse height spectrum for each gamma ray detected consists of a photopeak and below this a Compton continuum. For detection of natural radioactivity (*ie,* uranium, thorium, and potassium-40) in the surroundings pulse height windows can be set to detect the photopeaks of gamma rays specific to each series. If the probe is placed in the center of a series of homogeneous, gamma-infinite matrices, each doped with one of the natural radioactivities, spectrum stripping factors can be determined to enable elimination of both the Compton continua from higher energy gamma rays and any counts from overlap of photopeaks (as discussed in Aitken, 1985). There are no gamma rays from natural radioactivity that have energies as high as 3MeV; hence, any counts above a threshold corresponding to this energy should be attributable to cosmic rays.

The three sites in the London Underground were the disused King William St Station near Monument, a part of Holborn Station already in use for cosmic-ray experiments, and a so-called "deep shelter" near

Goodge St Station. These will be referred to as A, B, and C, respectively. Measurements were also made in the laboratory currently housing the liquid scintillation counters.

RESULTS AND DISCUSSION

The results of the survey are given in Table 1. The precise depth of the underground sites is not necessarily known due to the complex geometry of the tunnels; the table gives the nominal depth of London clay. The ^{14}C laboratory is in a basement beneath one load-bearing floor and a glass roof (together corresponding roughly to 800kg m^{-2}).

The data for uranium, thorium and potassium in each location are for the most likely positions in which a counter might be sited. The errors on these count rates are between 3 and 8%. Spectrum stripping would not be appropriate due to the inhomogeneous nature of the measurement positions. What is relevant is the relative count rates in each of the locations given that the relative concentrations of uranium, thorium, and potassium does not vary widely from site to site.

The natural radioactivity levels of the various locations can be seen to vary by roughly a factor of two, with site C being approximately comparable with the present counter position and the other underground sites having higher levels. None of the sites has excessive levels, however.

Before discussing the count rate above the threshold equivalent to 3MeV, it should be noted that this may not be all cosmic induced. Sodium iodide crystals can have a small uranium and thorium content, the alpha particle emissions of which give a broad peak in the spectrum between 3 and 5MeV that is noticeable in underground measurements. For crystals 76mm in diameter and 76mm long the correction can be 10% at site B (J Barton, 1984, pers commun). Clearly this is a volume effect, but it can also be batch dependent. For the purposes of this survey, however, only gross count-rate changes are of interest and such corrections can be ignored.

TABLE 1
Gamma spectrometer measurements in the three underground locations and in the radiocarbon laboratory at the British Museum

Location	Nominal depth of London clay	Count rate			
	(m)	U (s^{-1})	Th (s^{-1})	K (s^{-1})	Cosmic (s^{-1})
Radiocarbon lab 1*	—	0.26	0.22	0.89	0.483 ± 0.006
2*	—	0.03	0.02	0.03	0.365 ± 0.014
A. King William St	20	0.58	0.50	1.89	0.081 ± 0.005
B. Holborn	30**	0.43	0.35	1.16	0.038 ± 0.003
C. Goodge St	36	0.26	0.20	1.24	0.041 ± 0.005

* Two measurements were made in the ^{14}C laboratory: one in the normal counter position and the second in a shield that was previously used for gas counting. This shield is constructed of ca 0.3m of low-activity steel and incorporates 0.2m of boron-loaded paraffin wax.

** The depth at Holborn is normally quoted as 60m water equivalent (J Barton, 1984, pers commun).

On the basis of the nominal depth of sites A, B and C, the last would clearly be expected to give the lowest cosmic-induced count rate, but from the rates measured it appears in fact to be of comparable depth to site B. The count rates in A and B are consistent with their nominal depths (d) since at such depths there is approximately a $1/d^2$ relationship.

Relative to the cosmic-induced count rate in the laboratory, both sites B and C show an order of magnitude lower rate. Clearly this does not directly relate to the decrease in background that would be achieved in a liquid scintillation counter since only part of that background is cosmic induced. Unfortunately, it has not yet been possible to site a counter in the Underground. The likely effect can be partially assessed by looking at the components of the background in as far as these can be separated from each other. These are summarized in Table 2. The standard error on these count rates is typically between 1 and 4%, but it should be noted that the measurements were not all done during the same time interval. The two counters are a Packard Tricarb model 3003 and an LKB (Wallac) "Kangaroo," *ie*, a model 1217 with additional features. Both counters are operated at low voltage and high gain. The LKB has a so-called "carbon background compensation" (CBC) feature. This discriminates against cross talk by comparison of the heights of the pulses in the two photomultipliers; coincidences where this ratio is > 2:1 are rejected (Soini, 1975; Laney, 1971). The figures in Table 2 were taken with the CBC in. The effect on efficiency is a decrease of only ca 2%, whereas the empty chamber ("cross-talk") count rate is reduced by more than an order of magnitude.

TABLE 2

Count rates for glass and/or PTFE vials in two counters

	LKB count rate (cpm)		PAC 1 count rate (cpm)
	w1*	w2*	
Noise (blackened vial)	0.06	0.02	1.19
Empty chamber**	0.42	0.21	5.85
Empty glass vial (20ml)	1.05	—	6.65
Empty glass vial (15ml)†	0.56	—	5.91
Empty PTFE vial (15ml)‡	—	1.54	—
Glass vial (20ml) + background (15ml)§	3.53	—	8.34
PTFE vial (15ml) + background (15ml)	—	3.20	—
Efficiency	56%	59%	58%

* w1 and w2 are the windows set in the LKB counter for low-potassium glass and copper-capped PTFE vials, respectively; they are the same width, but w2 starts at lower pulse height than w1: CBC and low bias were used (see text). The Packard (PAC 1) counter was set only for glass.

** The count rates are as measured; hence, the "empty chamber" rate includes that attributable to noise.

† This was a normal Packard 20ml low-potassium glass vial with the top blackened to leave a clear section with nominal volume of 15ml.

‡ The copper-capped PTFE vials were supplied by Wallac to a design similar to that of the aluminium-capped vials of Calf and Polach (1974).

§ The background samples comprised 5.5ml of benzene synthesized from anthracite plus 9.5ml of PPO in toluene at a concentration of $4g\ l^{-1}$.

The components largely attributable to cosmic ray events are cross talk and an additional effect due to the empty vial. There will also be an effect due to the presence of a sample though this is difficult to separate from effects due to vial radioactivity and gamma rays in the surroundings. Additional shielding has not yet been used to assess the latter. Nevertheless, taking only those cosmic components that are separable, it can be seen that even for the LKB, about a 25% decrease in the background might be achieved for 20ml low-potassium glass vials. For the Packard, where there is no CBC, the effect on background of counting in the Underground could be a reduction of some 65%.

It is interesting to note the relatively small apparent difference in the LKB of the backgrounds of the 20ml low-potassium glass and 15ml PTFE vials. The LKB has a selectable high bias that is intended to discriminate against the pulses induced by the gamma emission of potassium-40. In fact the measurements of Table 2 were made with low bias, but the windows had been set to discriminate against tritium and thus high bias was not expected to significantly reduce the background count rate. When the effect of high bias was investigated, however, there was a statistically significant *increase* of ca 12% in the count rate for a background sample relative to that with low bias for the same window (w1 in Table 2). This is apparently due to a small increase in gain that accompanies the bias change. Approximately half of the PTFE vial background appears to be attributable to the empty vial; this contrasts with the lower rate for the empty glass vial. This difference is apparently due to light being scattered from the surface of the PTFE (Polach, pers commun). Given that masking of the upper part of the glass vial would further reduce its background count rate, in the LKB there seems to be little advantage in using PTFE over low-potassium glass.

SUMMARY AND FUTURE WORK

A gamma spectrometer survey of three Underground locations has shown:

1) normal natural radioactivity levels

2) more than an order of magnitude reduction in cosmic ray flux at two of the locations relative to that in the present laboratory.

Negotiations are in progress to site at least one liquid scintillation counter at location C (Goodge St, chosen in part due to ease of access). It is intended that additional shielding against natural radioactivity will be applied probably using some of the low-activity steel from the shield previously used for gas counting (see Table 1). The presumed advantage of using PTFE vials rather than glass are in fact not obvious in the current LKB counting system, but in percentage terms may be more marked when other components of the background are reduced. A hidden advantage is the possibility of lower vial-to-vial background variability. This has been shown to be a potential source of systematic error in age determination when glass vials are used (Ambers, Leese & Bowman, 1986). Clearly this needs to be checked for PTFE vials.

It is also intended that a 7ml PTFE vial be used. The volume decrease will be achieved using butyl-PBD as scintillant dissolved directly in the sample benzene. Apart from reducing the background, it will then also be possible to correct if necessary for sample evaporation.

It is hoped by these various measures that background count rates comparable with those of Calf and Airey (1982) of ca 0.6cpm may be achieved.

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