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SIGNAL FROM THE NATURAL RADIOACTIVITY OF DEPLETED URANIUM IN LIQUID ARGON*

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Abstract

The signal produced in a 2-mm liquid argon gap by the radioactive decays in depleted uranium is measured. Counting rates as a function of absorber thickness and for both positive and negative electric field polarities are also presented.

1. Introduction

At present, several groups are planning to build uranium - liquid argon calorimeters. Depleted uranium is used as a converter because of its high density and because of the near equal response to both electromagnetic and hadronic showers.[1,2] Liquid argon (LAr) is attractive as a sampling medium because of its ease of calibration and because it allows construction of instruments with virtually no gaps where particles can escape undetected. Thus the resultant calorimeter is compact and has improved energy resolution for hadrons.

One problem with uranium as a converter is its natural radioactivity. The fluctuations of the signals produced by this radioactivity cause a broadening of the pedestals and result in a deterioration of the energy resolution, especially at low energies.

The goals of our measurements are to understand the signals produced by the uranium radioactivity in the LAr, and to explore ways of reducing the sensitivity to this radioactivity.

2. Experiment Setup

The sample of depleted uranium used in our test consisted of primarily ^{238}U with about 0.3% ^{235}U. Its dimensions were 50 mm x 75 mm and 3 mm thick. When mounted in the test cell, 29 cm^2 were exposed to a 2-mm thick LAr gap. As shown in Fig. 1 the high voltage was applied to the uranium plate, with the signal taken from an electrode forming the other side of the LAr gap. A 25-nF capacitor was connected between the uranium plate and ground. This greatly reduced the electronic noise of the system.

The preamp used was a calibrated charge-sensitive amplifier (ORTEC 142 PC) with a fast response and a 50 μsec decay time. The signal was then shaped by an Ortec 450 research amplifier with a 250 ns shaping time, and analyzed with a LeCroy 3001 multichannel analyzer (qVt). The qVt was operated in the voltage mode with an internal trigger threshold equivalent to 1.5 channels. The overall calibration accuracy of the determination of the charge deposited in the LAr is believed to be $\pm$ 2%.

The electronic system was bipolar, allowing us to operate with the uranium plate at either positive or negative polarity while maintaining the sense electrode at ground potential. Since the positive ions have such a low mobility in LAr, only the induced signal from the electron drift is measured. The contribution to the signal made by any electron is proportional to the fractional distance it drifts across the LAr gap[3]. Thus, the difference in response to positive and negative polarities gives an indication of the charge distribution in the LAr. If the charged uranium decay products do not, for example, travel through the whole LAr gap, we should expect a smaller signal with positive than with negative polarity.

3. Experimental Results

The Uranium-238 decay chain is:[4]

$$ {}_{92}U^{238} \xrightarrow[1.4\times10^{17}\,s]{\text{alpha}} {}_{90}Th^{234} \xrightarrow[2.1\times10^{6}\,s]{\text{beta}} {}_{91}Pa^{234} \xrightarrow[70s\ \&\ 2.4\times10^{4}\,s]{\text{beta}} {}_{92}U^{234} \xrightarrow[7.8\times10^{12}\,s]{\text{alpha}} {}_{90}Th^{230} \longrightarrow \cdots $$

We expected that the dominant contribution to the signal from the ^{238}U decay chain would be from beta particles. The range of alpha particles in uranium is far too short for them to contribute. The end point-energies for the major beta particle emitters are 0.1 and 0.2 MeV for ^{234}Th, and 2.3 MeV for ^{234}Pa. Since the energy lost by a minimum ionizing electron in the 2-mm LAr gap is about 0.42 MeV, a substantial fraction of the beta particles from the uranium will not make it all the way across the LAr gap. Thus, we expected to see a difference for positive and negative bias on the uranium plate.

The pulse-height spectra taken without absorber are shown in Fig. 2. Figure 2a was taken with a potential of -2.5 kV on the uranium plate. The pulse-height spectrum taken with no high voltage, and the expected position of the signal produced by a minimum ionizing particle transversing perpendicularly the 2-mm LAr gap are also shown. Figure 2b shows the pulse-height spectrum for a potential of +2.5 kV. The pedestal for these measurements is in channel 9.

As expected, the pulse height spectrum measured with the positive potential is both lower in average pulse height, and has fewer events over the counting threshold, than for the spectrum taken with the negative collection potential. This reflects the many particles that do not cross the LAr gap.

The counting rates as a function of absorber thickness are given in Table I. These rates represent the intergrals of the areas above channel 20 in Fig. 2. The channel of the spectrum peak, after pedestal subtraction, and the full width at half maximum (FWHM) are also given. The overall error in the rates is estimated to be about $\pm$ 7%.

Our pulse-height spectra are similar to those reported by Ellison et al.,[5] who used a silicon detector instead of LAr. However, our rate with no absorber is only about one fourth of theirs. We do not understand the reason for this discrepancy.

The counting rates normalized to the measurement with no absorber, and with a −2.5 kV potential are given in Table II and plotted in Fig. 3. The absorbers used were brass sheets (ρ = 8.4 g/cm^3). We see that by using a positive potential and by using about 0.4-mm brass absorber, we can reduce the counting rate by 97%. The pedestal width, due to fluctuations of this signal, would then be reduced by almost a factor of 6. Of course, careful tests should be done to check the effect of such absorbers on the equalization of the responses to the electromagnetic and hardonic showers.

4. Conclusions

We have obtained the energy spectrum and the counting rates of the signal produced by depleted uranium radioactive decays in LAr for both polarities of high voltage on the uranium plate and with several absorbers. The observed signal is due to beta particles, a good fraction of which do not make it across the 2-mm LAr gap. The counting rate, with negative potential on the uranium plate and with no absorber, is approxiamtely 360 counts/cm^2/s and drops by about 40% when a positive potential is applied. If one also uses a 0.4-mm brass absorber the counting rate falls to about 3% this level.

Acknowledgements

We would like to thank Alex Elwyn of the Fermilab Safety Section for providing us with the depleted uranium plate.

Table I

Counting Rates

	H.V. = -2.5 kV			H.V. = +2.5 kV		
Absorber Thickness (g/cm^2)	Counting Rate ($counts/cm^2/s$)	Spectrum Peak** (channels)	Spectrum FWHM (channel)	Counting Rate ($counts/cm^2/s$)	Spectrum Peak (channel)	Spectrum FWHM (channel)
0	362	40	38	220	34	40
0.11	189	39	35	108	33	37
0.17	134	40	34	70	32	35
0.42	20	39	29	11	34	28
0.87	7	33	26	5	33	24

** A minimum ionizing particle would fall in channel 50.

Table II

Normalized Counting Rates for Various

Absorber Thicknesses and Field Polarities

Absorber (g/cm^2)	Normalized Rate H.V. = −2.5 kV	Normalized Rate H.V. = +2.5 kV
0	1	0.61
0.11	0.52	0.30
0.17	0.37	0.19
0.42	0.06	0.03
0.87	0.02	0.014

References

1. C.W. Fabjan et al., Nucl. Instr. and Meth. 141 (1977) 61.

2. B. Cox, "Uranium-Liquid Argon Calorimetry: Preliminary Results from the DØ Tests", Proceedings of the American Physical Society Meeting, Eugene Oregon, September 1985.

3. W.J. Willis and V. Radeka, Nucl. Instr. and Meth. 120 (1974) 221.

4. D. Strominger, J.M. Hollander and G.T. Seaborg, Rev. Mod. Phys. 30 (1958) 585.

5. J.A. Ellison et al., Nucl. Instr. and Meth. A235 (1985) 244.

Figure Captions

1. Schematic of the detector and electronics.

2. Pulse-height spectra obtained with no absorber. Spectra with the uranium potential of a) -2.5 kV, 0 kV, and b) +2.5 kV. The pedestal is Channel 9.

3. Relative counting rates as a function of absorber thickness for -2.5 kV and + 2.5 kV potentials. The solid lines have been drawn to guide the eye.

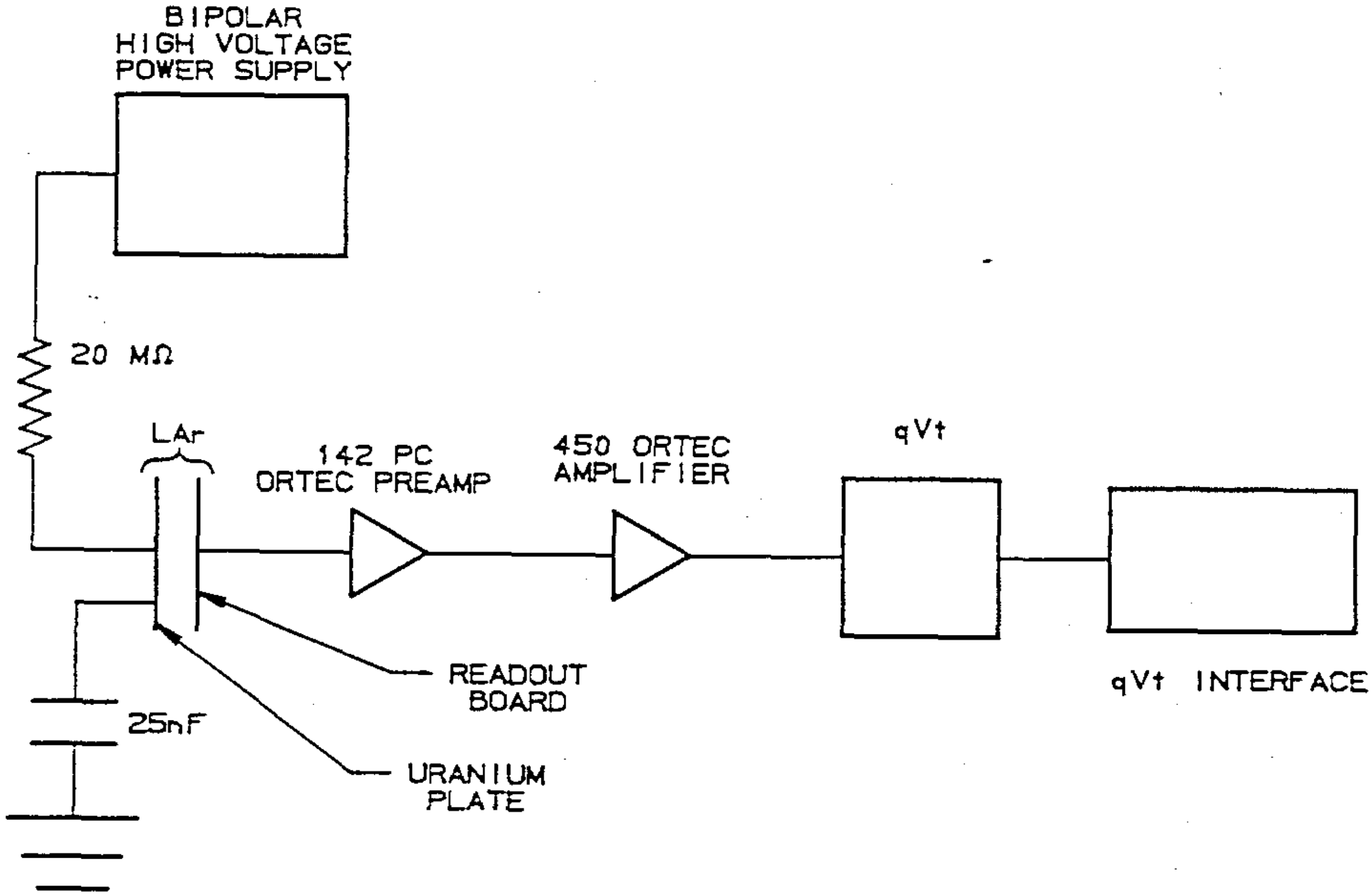
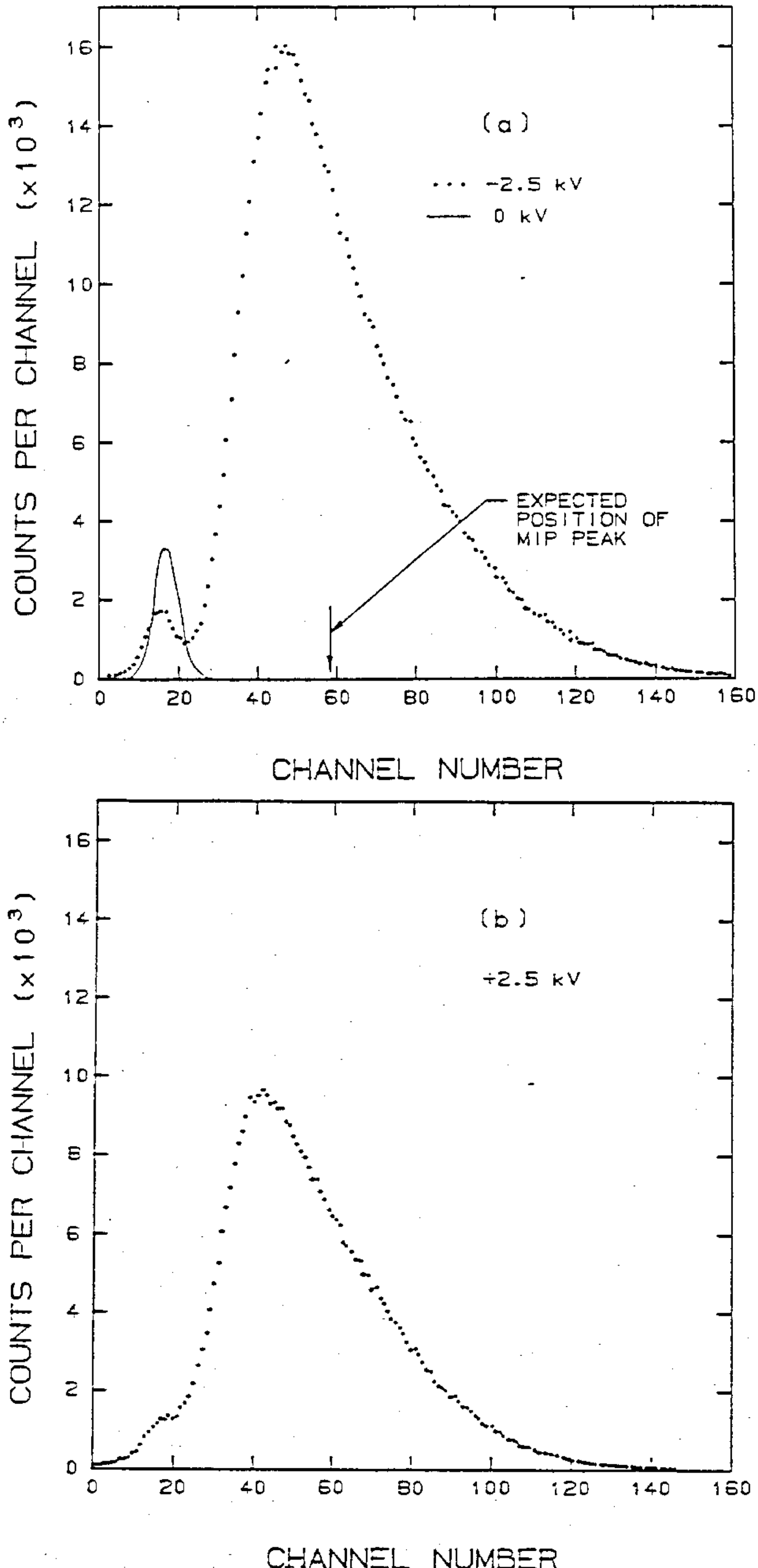
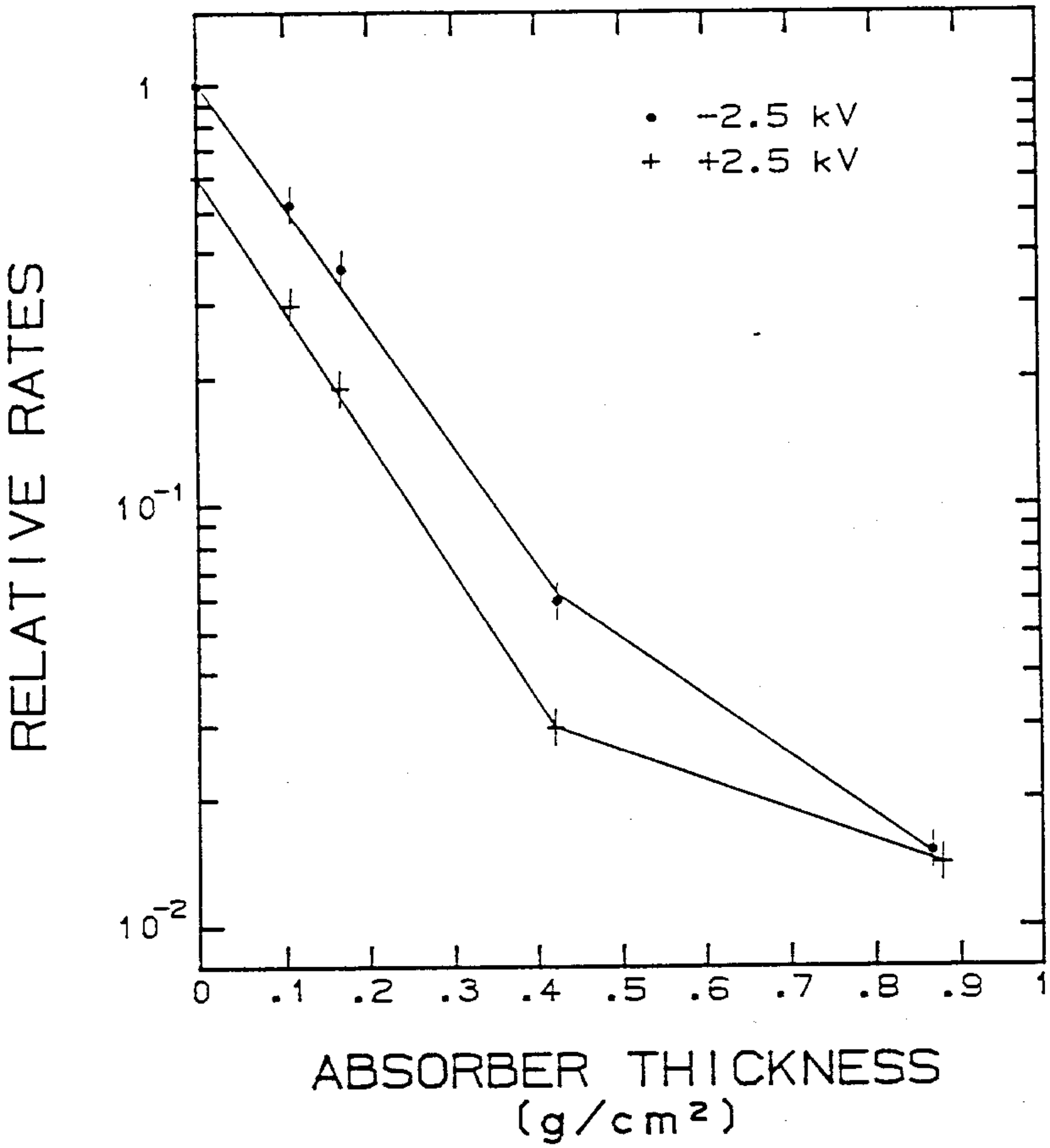

BIPOLAR
HIGH VOLTAGE
POWER SUPPLY
20 MΩ
LAr
142 PC
ORTEC PREAMP
450 ORTEC
AMPLIFIER
qVt
qVt INTERFACE
READOUT
BOARD
25nF
URANIUM
PLATE

Figure 1



COUNTS PER CHANNEL (x10³)
(a)
-2.5 kV
0 kV
EXPECTED POSITION OF MIP PEAK
CHANNEL NUMBER
COUNTS PER CHANNEL (x10³)
(b)
+2.5 kV
CHANNEL NUMBER

Figure 2



RELATIVE RATES
1
10⁻¹
10⁻²
• −2.5 kV
+ +2.5 kV
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1
ABSORBER THICKNESS
(g/cm²)

Figure 3