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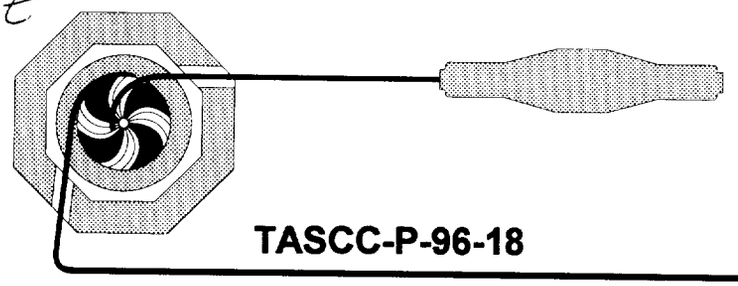

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THE CHALK RIVER AMS TIME-OF-FLIGHT DETECTION SYSTEM

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Abstract

At Chalk River, the final step in the identification of ^{129}I is a time-of-flight (TOF) measurement over a 2.5 m path. The *start/stop* signals are derived from microchannel plates that detect accelerated secondary electrons emitted from thin carbon films. This system provides a resolution of 400 ps (FWHM) for the 50 MeV iodine ions and the TOF peaks are closely gaussian. Resolution is limited by the uniformity of the start-detector foil. Masses 128 and 130 are separated from ^{129}I by about 2 ns. To improve transmission and to reduce energy straggling, the start detector has been constructed so that the beam is unobstructed by grids. In addition to TOF, the total energy (E) of the ions is measured with a passivated implanted planar silicon (PIPS) detector. Although ^{129}I standards and NaI blanks require only TOF for unambiguous identification of ^{129}I, many environmental samples are characterized by a plethora of peaks where both TOF and E are essential for unambiguous identification of ^{129}I.

1. INTRODUCTION

The isotope ^{129}I is of interest as an environmental and hydrological tracer and has significance to long-term nuclear waste management. The Chalk River AMS group has constructed a time-of-flight (TOF) detection system for the identification of ^{129}I.

After acceleration to 50 MeV $^{129}I^{5+}$ ions are mass filtered by the beam-transport system and by a crossed-field velocity filter and finally identified by measuring the particle TOF and total energy.

2. DESCRIPTION

2.1 Overview

A TOF "start" signal is produced when a micro-channel plate (MCP) assembly detects the secondary electrons created as an energetic ion traverses a thin (usually carbon) foil. A second similar detector, located 2.5 m further along the beam line provides a "stop" signal. Finally, the ion stops in a passivated implanted planar silicon (PIPS) detector that provides an energy signal. Neighboring isobars, masses 128 and 130, which are passed by the beam line and crossed-field filters are separated in time from mass 129 by 2.25 ns.

2.2 The Start Detector

The TOF "start" detector (see Fig. 1) incorporates a novel design that avoids the use of grids to accelerate secondary electrons. This increases ion transmission and eliminates energy degradation and scattering. To minimize variations in ion-path lengths, the start (and stop) foils

are perpendicular to the beam axis. The start foil, usually consisting of vacuum-evaporated C several $\mu g/cm^2$ thick, is mounted on a frame with a 1.5 to 2 cm diameter hole. Up to two frames may be mounted on an electrically-insulated target ladder that permits foils to be easily exchanged through a vacuum lock. This facilitates tests of timing resolution as a function of foil type or thickness.

Secondary electrons are accelerated anti-parallel to the beam direction across a 6 kV gap and deflected 20° by an electrostatic deflector as shown in Fig. 1. The accelerated electrons are then reflected onto a microchannel plate assembly (Galileo FTD-2003) that features high gain, low noise, fast response and a 50-Ω impedance-matched anode with a 20-mm active anode diameter. The magnification of this electro-optic system is about unity and the accelerating gradient can be adjusted to slightly focus the electrons at the expense of timing resolution. The mean transit time of electrons is approximately 6.5 ns and variations due to differing flight paths were calculated with SIMION[1] to be less than ±200 ps.

2.3 The Stop Detector

The "stop" detector (see Fig. 1) is of conventional design[2,3] with an expected timing resolution between 100 and 200 ps. Secondary electrons from a 30 $\mu g/cm^2$ carbon foil are accelerated across a 2200V gap formed by the foil and a grounded grid and then reflected onto a large microchannel plate assembly. The carbon foil is mounted on a 3 cm diameter frame to allow for the possibility of an enlarged beam-spot, and due to the unit magnification, a 3 cm diameter image is produced on the Galileo FTD 4000 MCP assembly. The MCP assembly is equipped with

a 40-mm diameter, 50-Ω impedance-matched anode. A 100 μm thick 900 mm^2 PIPS detector (Canberra) is mounted behind the electron reflector to stop the ions and measure their energy.

2.4 Electronics

All potentials, with the exception of the Si detector bias, are supplied by CAEN Model N471 dual high-voltage power supplies. The MCP anode signals are amplified by Ortec 9306 1 GHz preamplifiers and then discriminated with Ortec 9307 pico-timing discriminators. The discriminated start pulse is delayed by 250 ns, a value approximately equal to the flight time for 50 MeV ^{129}I. The delayed start and stop signals are input to an Ortec 467 time to amplitude (TAC) converter set to the 50 ns scale. The 8V analog-to-digital converter (ADC) is adjusted to have a gain setting of four times its range in order to increase the time dispersion to about 10 ns into 256 channels.

The energy signal, which is coincident with the TOF signal, but present about 70% of the time due to the effect of the grids, is amplified and digitized by commonly available nuclear spectroscopy electronics. The TOF and energy data are tagged with time relative to the beginning of each run and recorded on magnetic tape event-by-event for additional subsequent analysis, if necessary. A two-dimensional spectrum of energy versus TOF is shown in Fig. 2.

3.0 Operating Experience

The timing resolution of this system is dominated by energy losses in the start foil (see Fig. 3). The best resolution to-date, 370 ps FWHM, was obtained with two types of foils: vacuum evaporated C foils, 5 $\mu g/cm^2$ thick, mounted on a 1.5 cm diameter frame and a diamond-like

carbon foil, 1 $\mu g/cm^2$ thick, mounted on a 97% transmission grid (see Fig. 4). Estimates with TRIM[4] indicate that energy straggling contributes a negligible amount to the timing resolution (see Fig. 3) leaving target uniformity as the most likely cause.

The intrinsic timing resolution of the start/stop detectors has been measured in several ways (see Table 1). First, an r.f. bunched beam of 111 MeV ^{127}I was attenuated and directed through the start detector; a timing resolution of 260 ps FWHM was observed against the r.f. clock (see Fig. 3). This sets an upper limit of ~200 ps FWHM on this detection system since the beam-pulse width at half maximum is expected to be about 250 ps.

Secondly, the flight path between detectors was reduced by a factor of 4, consequently reducing to a negligible degree the contribution of straggling in the "start" foil. A TOF resolution of 220 ps FWHM was measured, indicating that each detection system contributed about 150 ps FWHM to the TOF resolution. Lastly, a 100 MeV ^{36}Cl beam was directed onto the TOF measurement system. The effects of energy loss variations or straggling should be a factor of two less than with a 50 MeV ^{129}I beam and, indeed, a TOF resolution of 380 ps FWHM was observed for ^{36}Cl under conditions that had earlier resulted in a 1 ns FWHM for an ^{129}I beam (see Fig. 4).

Another important figure of merit for TOF systems in AMS applications is the degree to which the tails from neighboring isobars underlie the peak of interest, as this can limit the sensitivity. The line shape for ^{129}I is gaussian at 10^{-3} of peak height (see Fig. 3). Although the results of the TRIM calculation for a 20 $\mu g/cm^2$ C foil, convoluted with a 250 ps FWHM Gaussian to conservatively reflect the intrinsic detector resolution, is grossly inadequate in accounting for the observed full-width half-maximum of a much thinner C foil, the similarities in

the profile of the tail suggest it may be straggling-related. Regardless of origin, this tail has never compromised our AMS measurements since the mass 128 background is very weak.

The effect of drifts in beam position has been measured by deliberately steering the ^{129}I beam vertically and horizontally. These tests corroborate the SIMION calculations. The centroids of the TOF signals shift a few hundred picoseconds but the FWHM remains unchanged.

The efficiency of the start detector relative to the Si energy detector for ^{129}I is 100% but it is less for such light ions as C that have less stopping power.

At Chalk River, a combination of both TOF and total energy detection has been essential in identifying ^{129}I. Although the standards and the simple chemical blanks, such as NaI, are characterized by simple TOF versus energy spectra, the environmental samples and process blanks often show additional peaks of velocity (TOF) similar to ^{129}I (but with lower energy) that could significantly alter the outcome of an isotopic ratio determination in the absence of the energy measurement. This is illustrated in Figs. 2 and 5. In Fig. 2 unidentified peaks are marked with a "?". Since their velocities are similar to ions of mass 129 or 130, their mass is proportional to energy. Due to the m/q constraint provided by the beam-line magnets and crossed-field velocity filter, the unidentified peaks can only occur at 10, 20, 30 or 40 MeV.

The machine background for ^{129}I, as established with a Si blank, is equivalent to a limiting isotopic-ratio of about 5×10^{-15}. This assumes that an iodine blank provides about 1 μA of analyzed beam current. Typical NaI blanks, produced with a minimal amount of handling, result in isotopic ratios of 10^{-14}. Blanks prepared by many chemical steps (see Fig. 5) sometimes contain amounts of ^{129}I that are significantly larger.

The time-dependence of ^{129}I memory (see an accompanying paper) is similar to that of ^{36}Cl and is likely due to residual iodine deposited on surfaces adjacent to the sample and insight of the halo of the Cs^+ beam.

4.0 CONCLUSIONS

The Chalk River TOF detection system offers excellent mass discrimination and 70% detection efficiency for ^{129}I. The TOF spectra are characterized by peaks with a 400 ps FWHM and are Gaussian at the 0.001 level. Neighbouring mass peaks are separated by 2.25 ns. The width of the TOF peaks are limited by thickness non-uniformities in the "start" foil. To date, vacuum-evaporated C foils, 5 $\mu g/cm^2$ thick, and a diamond-like carbon foil, 1 $\mu g/cm^2$ thick, have provided the best results.

ACKNOWLEDGMENTS

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TABLE 1

TOF Measurements to Determine the Intrinsic Resolution of the Start and Stop Detectors

Ion	Energy (MeV)	Detector Separation (m)	Foil Type‡	Foil Thickness ($\mu g/cm^2$)	Timing Resolution (ps FWHM)
^{129}I	50	2.5	a	20	700-800
^{129}I	50	2.5	a	10	630
^{129}I	50	2.5	a	5	370
^{129}I	65	0.57	a	20	220
^{129}I	65	2.5	b	10 + 20	1030
^{36}Cl	100	2.5	b	10 + 20	380

‡
a - vacuum evaporated C

b - Aluminized (10 $\mu g/cm^2$) polypropylene (20 $\mu g/cm^2$)

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FIGURE CAPTIONS

Figure 1: The time-of-flight detection system. The gridless "start" detector is shown on the left and the "stop" detector on the right. They are separated by a 2.5 m drift space and 50 MeV ^{129}I ions take about 280 ns to traverse this gap. In both detectors, timing signals are derived from secondary electrons created as the energetic ion traverses a thin carbon foil. The electrons are accelerated and deflected onto microchannel plate detectors. The "start" foil is 2 cm in diameter and biased at -6 kV. The "stop" foil is 3 cm in diameter and biased at -2.2 kV. The total ion energy is measured by a passivated Si detector. Detection efficiency in the Si detector is about 70% as a result of attenuation by three forward grids.

Figure 2: An energy versus time-of-flight spectrum obtained with the Chalk River TOF detection system. ^{127}I and ^{129}I are separated by about 4.5 ns. In addition to these, unidentified peaks are present at lower energies. These are labeled with a "?". Energy-degraded events due to the "stop" detector grids can be seen below the iodine peaks. A few $^{128,130}Te$ events are also visible at 50 MeV energy.

Figure 3: The left panel shows three lineshapes. Lineshape (a) provides an upper limit to the intrinsic resolution of the "start" detector and was obtained by measuring the response of the "start" detector against an r.f. bunched beam. Its FWHM is 260 ps with the bunch width contributing about 250 ps to this value. Lineshape (b) is an ^{129}I TOF peak obtained with a 5-μg/cm2 C "start" foil. Its FWHM is about 450 ps. Lineshape (c) is a simulation that combines an estimate of energy straggling[4] in a 20 μg/cm^2 C foil with an intrinsic detection

resolution of 250 ps FWHM. The striking difference between lineshapes (b) and (c) suggests that foil non-uniformities account for the observed widths.

The right panel compares 2 lineshapes that have been obtained with a 5-μg/cm^2 C foil (d) and a 1-μg/cm^2 thick diamond-like carbon foil (e) supported on a 97% transmission grid. The FWHM is 370 ps. Foil non-uniformities or thickness inaccuracies must account for the similar appearance of these lineshapes.

Figure 4: Timing resolution (FWHM) versus estimated energy loss in the "start" foil for various foil types. Two data points shown as triangles reflect operation under unrealistic conditions in order to ascertain the intrinsic timing resolution of the detectors. In one of the cases the flight path was reduced by a factor of four, and in the other, a light-ion beam with less stopping power was employed. Vacuum-evaporated C foils 5 μg/cm^2 thick and a 1-μg/cm^2 diamond-like carbon (DCC) foil have given the best resolution (370 ps (FWHM)) for 50 MeV iodine ions. Data points marked (a) were obtained with stretched and aluminized polypropylene foils; type (b) are aluminized polycast foils; type (d) are aluminized VYNS foils; and type (e) are 5-μg/cm^2 C coated with an unknown quantity of collodian.

C, CEF and DLC refer to vacuum-evaporated, cracked-ethylene and diamond-like carbon foils respectively. The number that follows this identifier indicates the nominal foil thickness in μg/cm^2.

Figure 5: Energy spectra for five types of samples, gated by a TOF between 288 and 290 ns (see Fig. 2). Note that the $^{129}I/I$ standard is free of the unidentified peak at 40 MeV that is present in many other environmental samples.

Time-of-Flight System

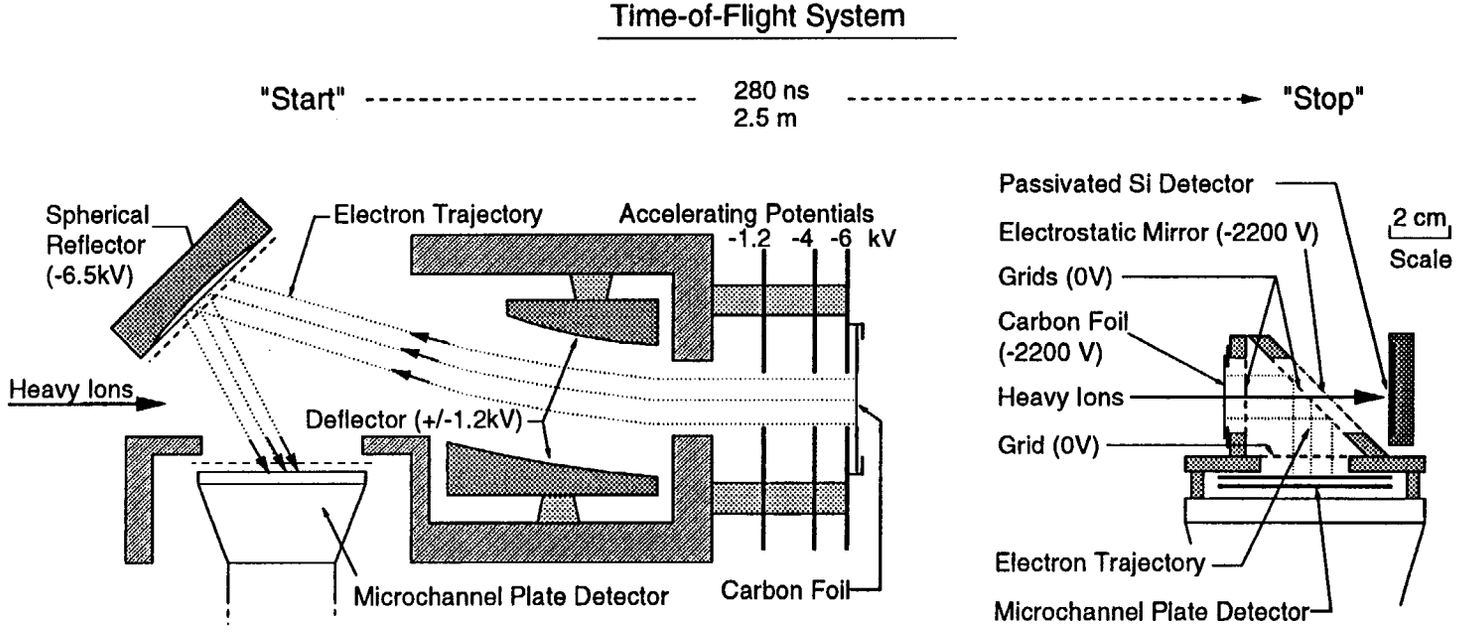

FIG 1

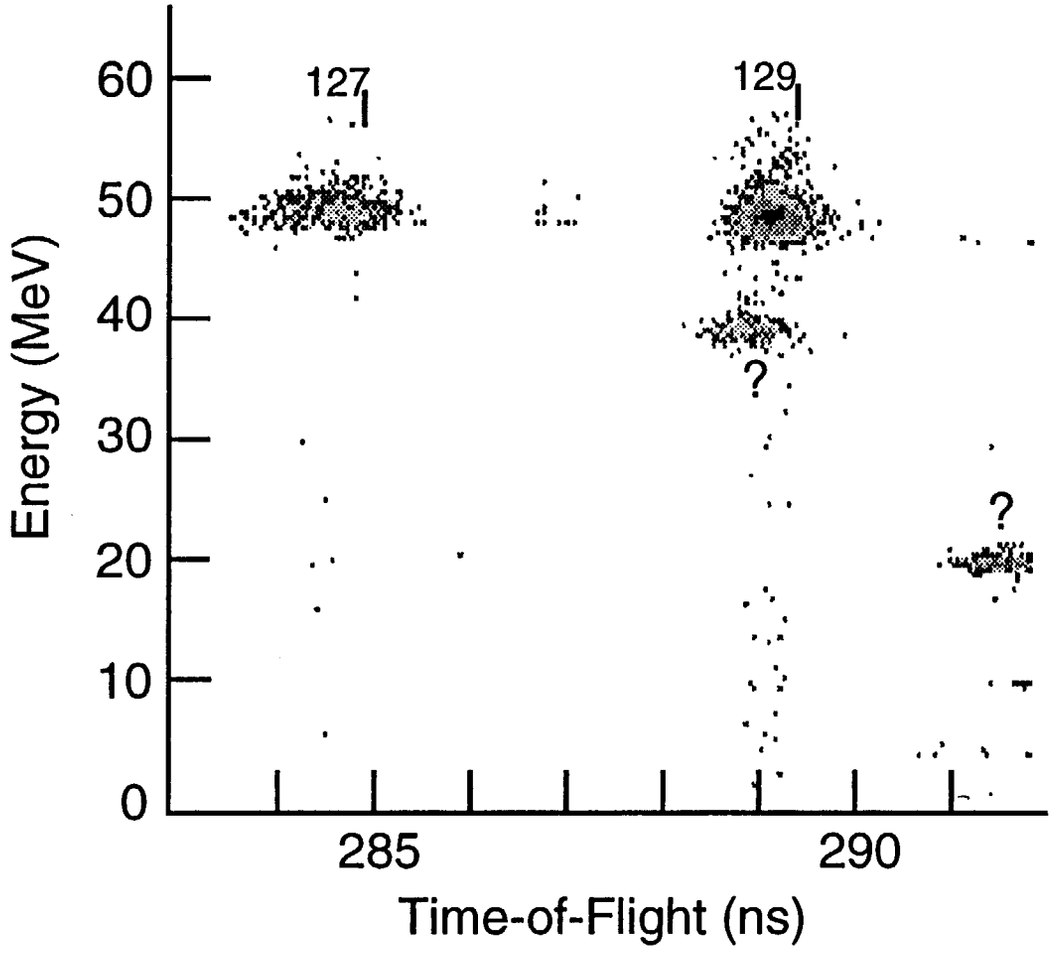

Fig 2

Time-of-Flight Lineshape

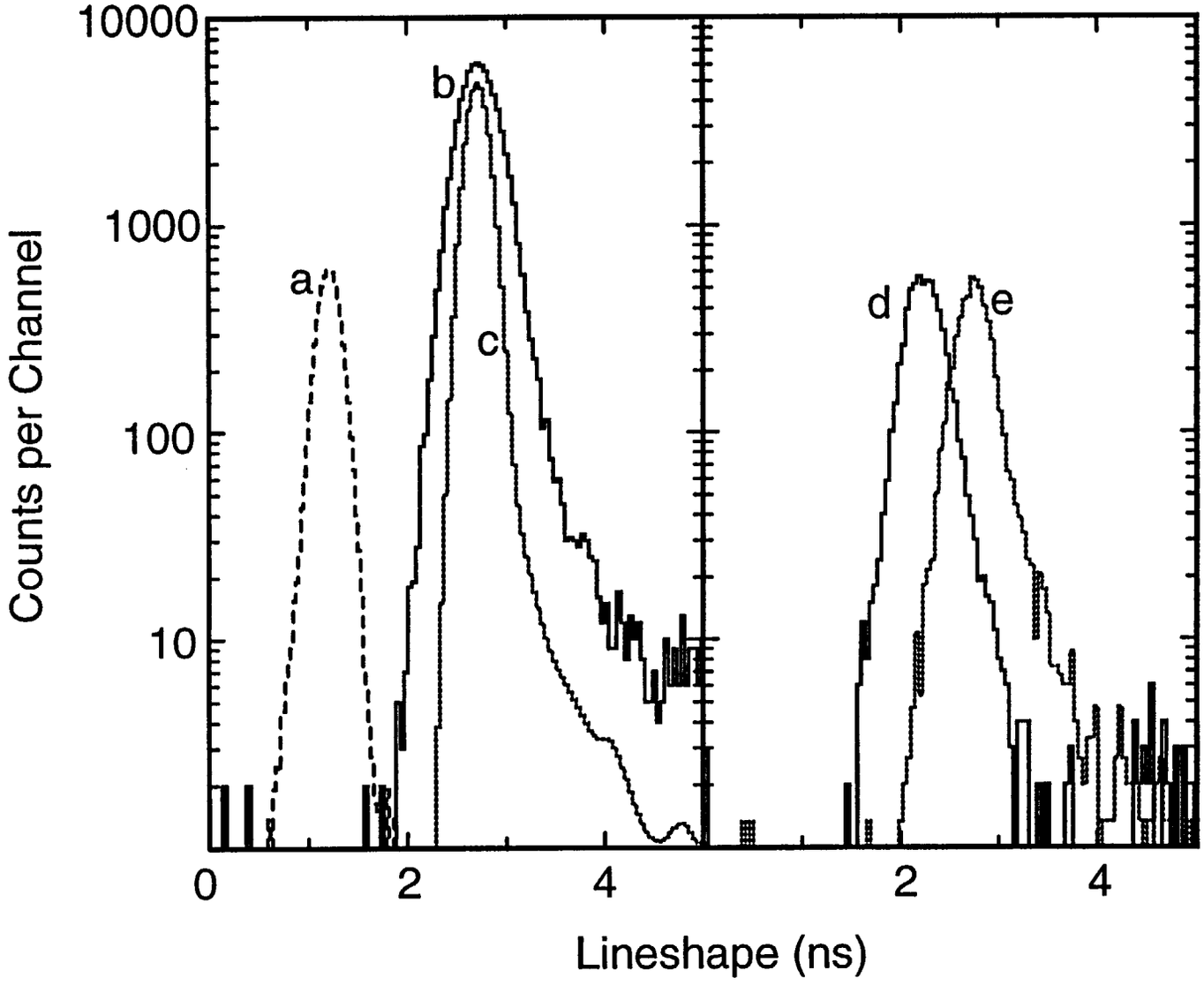

Fig 3

Time-of-Flight Resolution .vs. Foil Type

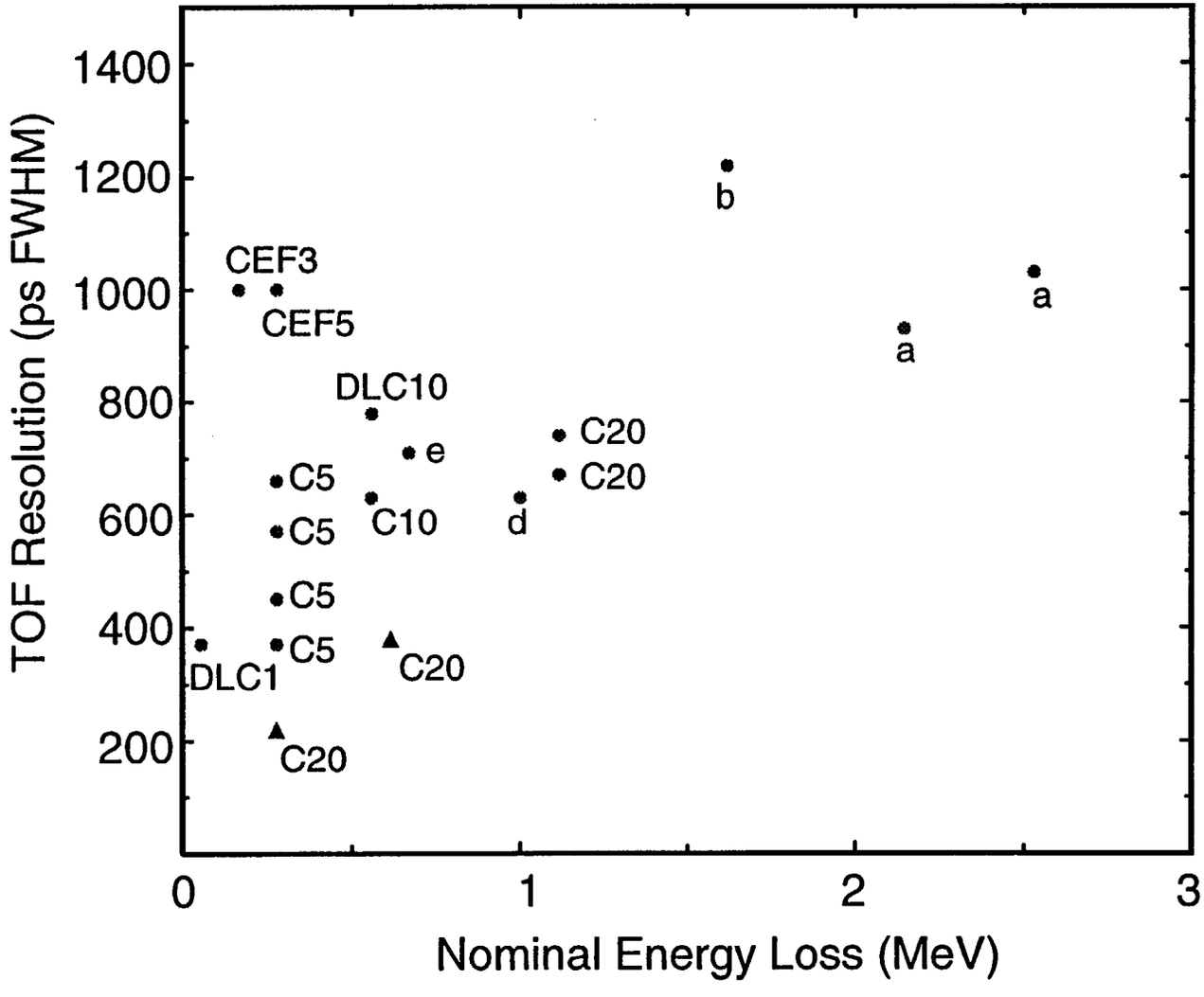

Fig 4

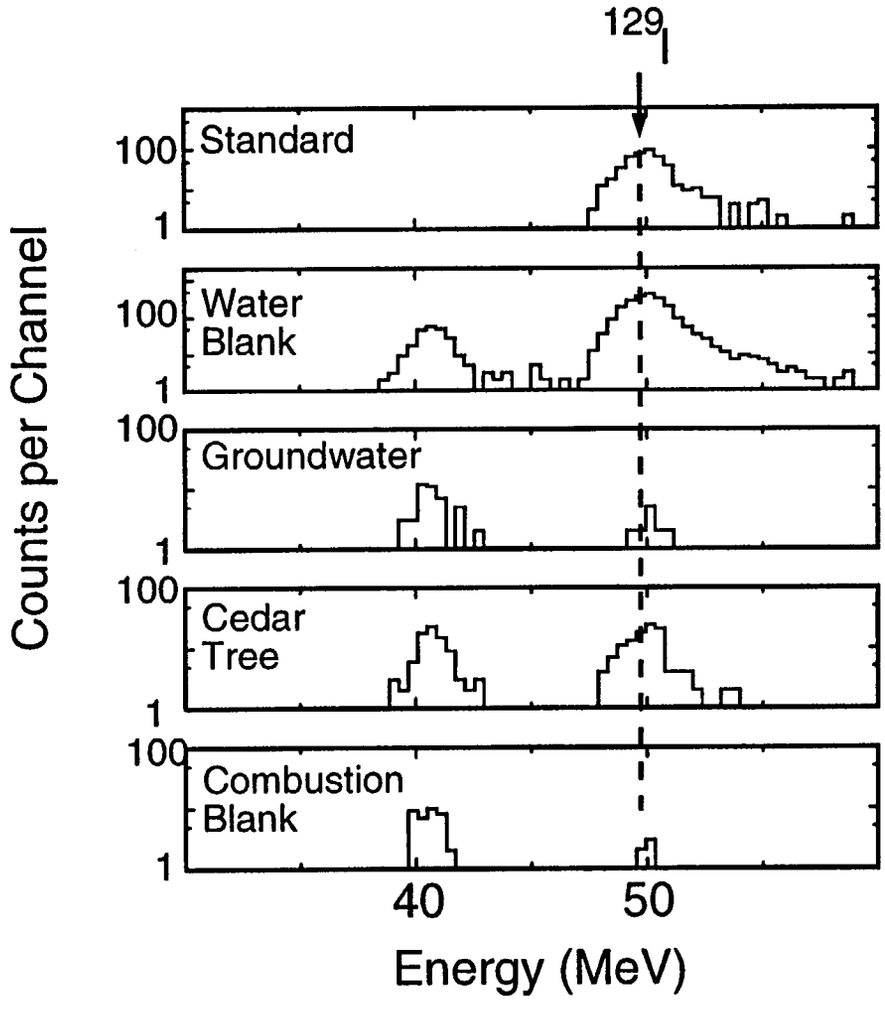
129I
Standard
Water Blank
Groundwater
Cedar Tree
Combustion Blank
100
1
Counts per Channel
40
50
Energy (MeV)

Fig 5