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Real-time gain shift correction for on-line alpha-liquid scintillation spectroscopy

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Abstract

A method for real-time correction of α-particle energy calibration in the SISAK detection system has been developed. The scintillation light yield is continuously monitored by measuring the inflection point of the Compton electron spectrum from a ^{137}Cs source. The energy of any registered α-particle in the SISAK liquid scintillation detection cells is corrected using the scintillation light yield, resulting in an energy resolution of ~300 keV. An experiment with the transactinide ^{257}Rf is described which demonstrates that this energy correction method works well under actual experimental conditions.

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Keywords: SISAK; Real-time energy calibration; Continuous α-liquid scintillation detection; Transactinides; Compton edge

1. Introduction

Liquid scintillation is a versatile detection method, offering almost 4π detection efficiency. By means of pulse-shape discrimination, liquid scintillation is used to selectively detect α-particles [1] in the presence of electrons and β-particles. The method is used successfully in a continuous manner with the on-line liquid–liquid extraction system SISAK[1] [2] for rapid detection of α-particles. The SISAK system with α-liquid scintillation is capable of detecting α-emitting nuclides with half-lives less than 1 s [3]. Recently, the system also proved to handle low count-rates: the transactinide ^{257}Rf (4.7 s) was positively identified at a count-rate of 1–2 atoms per hour [4,5].

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[1] Short-lived Isotopes Studied by the AKUFVE technique. AKUFVE is a Swedish acronym for Arrangement for Continuous Investigations of Distribution Ratios in Liquid Extraction.

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The SISAK system, which can be used for multistage solvent extraction, was developed for on-line studies of short-lived radionuclides and has been utilized in investigations of nuclear as well as chemical properties of numerous nuclides [6–8]. In the early 1990s, the system was adapted for transactinide ($Z \geqslant 104$) research [9–12]. For these nuclear and chemical investigations, the radionuclide is transported from the production site via a gas-jet (usually seeded with aerosols of KCl) to the chemistry apparatus. The challenges inherent in the studies of transactinide elements are the low production rates and the relatively short half-lives. Studies of transactinide nuclides involve detection of single atoms. A general review of the production and experimental techniques employed to investigate the chemical properties of the transactinide elements are given in Ref. [13].

In a SISAK liquid extraction experiment, the organic output phase containing the transactinide nuclide is combined with a scintillation solution and mixed with an inert gas (He or Ar) before flowing (typically at 1.0–2.0 ml/s) through a degasser centrifuge and into the detection cells. The detection cell is referred to as the meander cell because the detection volume has a meander-like shape. Analog electronics for pulse-shape discrimination along with an acquisition PC manage and record the data. Positive identification of a single transactinide atom can often be made by detection of the time-correlated α-decays of the transactinide parent and the resulting daughter. The data acquisition is event-mode triggered, and after detection of a transactinide α-decay, the solution can be retained in the detector cell for a longer time interval in order to record the decay of the typically longer-lived daughter nuclide.

The light production per keV of energy in most common liquid-scintillation mixtures is about ten times higher for β-particles and electrons than for α-particles, due to the large difference in the linear energy transfer (LET) values. Liquid-scintillation detection has relatively poor energy resolution compared with that of solid state detectors. However, with careful selection of the liquid-scintillation cocktail, energy resolution of about 300 keV full-width at half-maximum (FWHM) for 6.5–7.5 MeV α-particles is achieved.

When α-particles are slowed down and stopped in a liquid-scintillation solution the kinetic energy is converted into light. The light produced is proven proportional to the α-particle energy in the range 4–7.7 MeV [14,15]. Substances that lower the light yield in a scintillation solution are commonly referred to as quenchers. Either the quenching compound prevents the migration of the excitation energy in the solution (chemical quenching), or it absorbs the fluorescence light emitted by the scintillating molecule (color quenching). Water and oxygen are chemical quenchers, and examples of compounds present in SISAK extraction procedures. Good pulse-shape discrimination requires the removal of air-equilibrated oxygen from the liquid-scintillation solution, and this is done by sparging the solution with an inert gas as explained above. Nitric acid, a compound used in a SISAK extraction scheme to study element 104 is another chemical quencher, but also results in color quenching at high concentrations by coloring the liquid-scintillation solution yellow. SISAK transactinide experiments usually run continuously for many days. Under such conditions, phase separation and mixing of the scintillator ingredients with the organic output phase will vary and, thereby, cause changes in the light yield per keV of particle energy.

This paper describes a method that monitors the scintillation light yield, and automatically adjusts for yield variations in the liquid-scintillation detection system used during SISAK experiments. With a ^{137}Cs source attached to a monitoring cell, the Compton-edge inflection point of the scattered electrons gives a measure of the scintillation light yield. All events recorded during a transactinide experiment are automatically adjusted according to the Compton inflection point.

2. Experimental

An illustration of the meander detection cell is shown in the top of Fig. 1. The cell is made of a 70-mm-wide Teflon piece. A 1 mm disk of Kel-F and an 80-mm-long cylindrical light guide is mounted on top of the Teflon piece to conduct and spread the scintillation light evenly over the window of a