Evaluation of Interferences on Measurements of ^{90}Sr/^{90}Y by the TDCR Čerenkov Counting Technique

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A Master's Level Submission

Summary

Over the last few decades many techniques have been developed for determination of ^{90}Sr/^{90}Y in the environment. Čerenkov counting technique (developed in the 1960s) is widely used, but can be further developed by the application of emerging technologies. For example, it is believed that the application of the triple-to-double coincidence ratio (TDCR) liquid scintillation counting method can be used to simplify the measurement of ^{90}Sr/^{90}Y in aqueous solutions. The objective of this study is to discuss the ongoing research to optimize the conditions for determination of ^{90}Sr/^{90}Y activities by the TDCR Čerenkov counting technique.

1. Introduction

Strontium-90 (^{90}Sr) is an important anthropogenic source of radiological contamination. Strontium-90 has a relatively long half-life (28.78 years), high fission yield (6 %) [1] and high mobility in the environment compared to many other radionuclides [2]. Also, because of its chemical similarity to calcium, ^{90}Sr can enter human food chain and incorporate into bone tissues [1]. Thus, ^{90}Sr is one of the most hazardous radionuclides present in the environment. Strontium-90 decays to yttrium-90 (^{90}Y) with a maximum beta energy of 0.546 MeV. Yttrium-90 has a short half-life (64 hours) and decays to zirconium-90 with a maximum beta energy of 2.280 MeV. Due to its short half-life, ^{90}Y is often in secular equilibrium with its parent, ^{90}Sr. The secular equilibrium between ^{90}Sr and ^{90}Y forms the basis for the determination of ^{90}Sr by Čerenkov counting technique.

In the Čerenkov counting technique, fast electrons (from beta decay) moving in a dielectric and transparent medium (e.g., water) cause local electronic polarization of molecules, which rapidly return to the ground state releasing electromagnetic radiation known as the Čerenkov radiation [3], named after the discoverer of this phenomenon. The Čerenkov radiation emitted by the passage of a fast electron consists of a continuous spectrum of wavelengths extending from the ultraviolet into the visible part of the spectrum. Thus, the radiation is within the detection range (with a wavelength of maximum sensitivity at ~ 420 nm) of the photomultiplier tubes of a liquid scintillation counter (LSC) [4]. The technique for measurement of Čerenkov radiation by a LSC is called the Čerenkov counting technique. The energy threshold of a radionuclide for Čerenkov counting in water is 0.263 MeV [5]. Thus, ^{90}Sr and ^{90}Y, with maximum beta energies of 0.546 MeV and 2.280 MeV, respectively, are above the threshold energy; therefore, making the Čerenkov counting technique a suitable radionuclide testing method.

Čerenkov counting method has several advantages over conventional LSC counting. For example:

- Alpha emitters and low energy beta emitters (e.g. ^{3}H with maximum beta energy of 0.019 MeV and ^{14}C with maximum beta energy of 0.156 MeV) are discriminated.
- Low energy gamma emissions of less than 0.43 MeV will not interfere, as they do not produce a Compton electron with an energy above 0.263 MeV (threshold energy for Čerenkov counting) [3].
- There is no need for sample treatment or mixing of samples with cocktail; thus, waste generation is minimized.
- It is a non-destructive technique; thus, sample can be used for other purposes.
- Chemical quenching is eliminated as there is no need for scintillation cocktail.

Although the Čerenkov counting technique has been widely used, the method can be further developed by the application of emerging technologies. One powerful method, which can further simplify the measurement of $^{90}Sr/^{90}Y$ in aqueous solutions, is the triple-to-double coincidence ratio (TDCR) Čerenkov counting technique. Unlike the conventional double coincidence counting techniques, the TDCR technique uses a triple coincidence counting method, which has been made commercially available by recent improvements in technology. The TDCR Čerenkov counting method uses the ratio of counts registered by the triple photomultiplier tubes by the ratio of the counts registered by the double photomultiplier tubes of the LSC counter. The application of the triple-to-double coincidence counts allows for the rapid evaluation of interference with the activity measurements whereby the resultant ratios of the triple-to-double coincidence counts are expected to significantly reduce in the presence of interference such as sample colour; a phenomenon referred to as the colour quenching effect. This phenomenon exists when the sample colour attenuates the light that is produced; whereby the photons produced are absorbed by the colour in the solution, thus, resulting in reduced light output available for measurement by the photomultiplier tubes of the detector [6]. Generally, in the conventional LSC counting the colour quench is dealt with by preparing a series of external quenched standards and constructing a quench correction curve in order to determine the true decay rate of unknown samples. In contrast, the TDCR counting technique utilizes the measured ratio of double and triple coincidence counting rates for calculation of the detection efficiency with an automatic quench correction without the need for external calibration. The objective of this research is to find optimal conditions for TDCR Čerenkov counting of $^{90}Sr/^{90}Y$ using a Hidex 300 SL LSC. The effects of interfering factors on counting efficiency will be investigated. General interfering factors, including sample geometry (e.g., sample volume and counting vial) and colour quenching, will be evaluated and discussed in this study.

2. Project Plan

2.1 Instrumental

A Hidex 300 SL LSC (Hidex Oy, Finland) [7] is used for Čerenkov counting of $^{90}Sr/^{90}Y$. Hidex 300 SL LSC is a compact and multitask unit for quantitative detection of alpha and beta radiation. The detector assembly consists of three photomultiplier tubes (PMTs) with highly reflective measurement chamber design. The three PMTs are placed at 120^{o} apart to provide optimal measurement geometry and to facilitate TDCR counting. The detector chamber is equipped with an automatic adapter from 20-mL to 7-mL vial capacity, which allows for additional counting geometries. The shielding assembly consists of a measurement chamber with highly reflective opaque paint, which maximizes light collection, and a ~7 cm lead shielding in all directions, which provides reduction of background effects. The detector assembly of Hidex 300 SL LSC is shown in Figure 1.

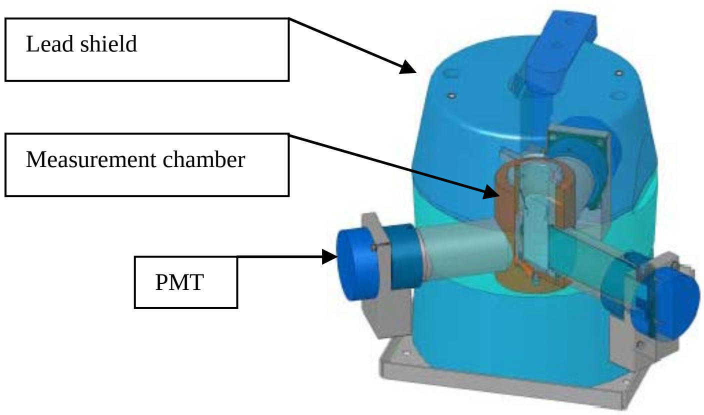

Figure 1. Detector assembly of Hidex 300 SL LSC [7].

2.2 Experimental

The scope of this project is to analyze the ratio of triple- to- double counts, obtained from Čerenkov counting of ^{90}Sr/^{90}Y standard solution, under different experimental conditions. First, the influence of geometry on counting efficiency will be tested by preparing two sets of samples in polyethylene plastic scintillation counting vials. Vials of 7-mL and 20-mL capacity will be used. For each of these plastic vials, varying liquid solution volumes will be tested. The active volume for these experiments will be 0.1 M HCl liquid solutions spiked with a known amount of ^{90}Sr/^{90}Y radioactive solution standard. For each of the 7-mL and 20-mL vials, an optimal volume, based on the computed counting efficiency, will be obtained. Once an optimal volume is obtained, the effect of counting vial type on TDCR Čerenkov counting efficiency of ^{90}Sr/^{90}Y will be evaluated by comparing glass and polyethelene plastic vials. Finally, to investigate the effect on the colour quenching phenomenon on the TDCR Čerenkov counting technique, varying amounts of a yellow food-grade colouring agent will be added to the active volume. A yellow dye will be used as this colour is effective at absorbing blue/ ultraviolet light [6] and is most often found in environmental liquid effluents. Other colour dyes (i.e., green) will be tested in subsequent experiments to evaluate the quenching effectiveness of the yellow dye used in this experiment.

3. Expected Outcome

It is anticipated that this study will demonstrate the optimization of sample geometry for TDCR Čerenkov counting technique of $^{90}Sr/^{90}Y$. Also, by using the ratio of the triple-to-double coincidence counts, the influence of colour on measurement of the activity of $^{90}Sr/^{90}Y$ will be determined. Once the counting conditions for $^{90}Sr/^{90}Y$ TDCR Čerenkov counting technique are optimized, further investigations will be performed to evaluate the effectiveness of the TDCR Čerenkov counting with other beta-emitting radionuclides that can be found in the environment (e.g., ^{40}K, ^{210}Bi, ^{60}Co, ^{137}Cs, ^{32}P, ^{147}Pm, and ^{14}C), which could potentially interfere with the determination $^{90}Sr/^{90}Y$ activities.

4. References

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