Comparison and Analysis of Tritium Measurement Using a Liquid Scintillation Counter : Quantulus GCT 6220 and HIDEX 300SL-SLL

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1. Introduction

Tritium undergoes beta decay, emitting radiation with a half-life of approximately 12.3 years. As a radioactive isotope, it plays a crucial role in various fields, including medical tracers, nuclear fusion research, and radioactive waste management. In particular, Wolsong Nuclear Power Plant (NPP), which utilizes heavy water as a moderator, requires rigorous tritium management and monitoring. The analysis of tritium concentrations in the environment surrounding Wolsong NPP is a critical task for ensuring environmental safety and regulatory compliance.

A Liquid Scintillation Counters (LSC) is commonly used for tritium analysis. The LSC detects beta particles emitted from tritium as they interact with a scintillation liquid, producing light signals. These light signals are then captured by a Photomultiplier Tube (PMT), which converts them into electrical signals and amplifies them to quantify the radioactivity in the sample.

The Quantulus GCT 6220 (Revvity) and 300SL-SLL (Super Low Level, HIDEX) are widely employed in tritium analysis due to their high sensitivity and accuracy. With the recent discontinuation of the widely used Quantulus 1220, Numerous radiological analysis laboratories in South Korea have adopted the Quantulus GCT 6220 and 300SL-SLL for the measurement of low-level tritium. This study aims to evaluate the suitability of these newly introduced instruments for environmental radioactivity analysis. Additionally, through the analysis of proficiency test samples, we aim to establish a validated dataset for low-level tritium concentration measurements in environmental samples.

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2. Methods and Results

2.1 Quantulus GCT 6220 & 300SL

The Quantulus GCT 6220 (Revvity) is equipped with The BGO (Bismuth Germanate Oxide) detector guard system. This system is positioned between the sample and the PMT, preventing signal distortion. Additionally, enabling the Guard Compensation Technology (GCT) function significantly reduces background counts. However, in this experiment, the GCT function was disabled to simplify the measurement of low-energy beta emitters such as tritium, avoiding unnecessary corrections and minimizing potential errors. The final measurement conditions were as follows: coincidence time of 18 ns, an energy measurement range of 0–18.6 keV, and GCT Off Mode.

The 300SL-SLL is equipped with three PMTs (Photomultiplier Tubes). Since count rates vary significantly depending on the Region of Interest (ROI) and coincidence time, A Certified Reference Material (CRM) obtained from the Korea Research Institute of Standards and Science (KRISS) was used to determine appropriate settings. The final measurement conditions were set to a coincidence time of 25 ns and an ROI range of 5−180. Additionally, for comparison purposes, the default tritium ROI range provided by the software was also measured.

A major difference between the two LSCs is the type of detector, the number of PMTs, and the method of spectral representation. The GCT 6220 displays spectra based on energy (x-axis), whereas the 300SL-SLL represents spectra using channels. This distinction is a crucial factor in the interpretation and application of data obtained from each instrument. The specifications of the liquid scintillation counters used in this experiment are summarized in Table I.

Table I: Specification Comparison of GCT 6220 and 300SL-SLL

Model	Quantulus GCT 6220	300SL-SLL
Manufacturer	Revvity	HIDEX
Dimensions (cm)	103×81×47 (W)×(D)×(H)	52×63×68 (W)×(D)×(H)
Weight (kg)	217	180
Software	QuantaSmart	MikroWin300SL
Effiency (Unquenched) (%)	58	70
Detector	PMT 2	PMT 3
Spectrum	Energy-based	channel-based

2.2 Measurement and Analysis Methods

The GCT 6220 and 300SL-SLL conducted ten repeated measurements, each lasting 60 minutes per sample, including background samples. Prior to measurement, calibration was performed using a Certified Reference Material (CRM). In this study, proficiency test samples provided by the Korea Institute of Nuclear Safety (KINS) as part of their annual interlaboratory proficiency testing program were used. The sample type was seawater, spiked with tritium. The sample pretreatment was conducted using a distillation method with a distillation apparatus, and the samples were mixed with a scintillation cocktail at a ratio of 8:12 in a 20 mL plastic vial, followed by pre-conditioning inside the LSC at a controlled temperature for 24 hours before measurement. The measurement conditions are summarized in Table II before measurement.

Table II: Measurement Conditions of GCT 6220 and 300SL-SLL

Model	Quantulus GCT 6220	300SL-SLL
Calibration Source	^{3}H Ultima Gold Low Level Quenched Standard Set	
Coincidence Time	18 ns	25 ns
ROI	0-18.6 keV	5-180 5-300 5-350 (channel)
Cocktail	Ultima Gold LLT	
Vial Type	Plastic Vial	
Number of Measurements	10 times	
Measurement Duration	60 min/measurement	

The radioactivity concentration and Minimum Detectable Activity (MDA) were calculated using Equation 1 and Equation 2, respectively. Additionally, a chi-square test was performed to verify the statistical consistency and reliability of the measurement results for each instrument.

$$(1)\ A\ (Bq/L) = \frac{(CPM_{Sample} - CPM_{BKG})}{60} \times \frac{100}{E} \times \frac{1}{W}$$

A : Tritium radioactivity concentration
CPM_{Sample} : Count rate of the sample (counts/min)
CPM_{BKG} : Count rate of the background sample (counts/min)
E : Detection efficiency (%)
W : Sample volume (L)

Equation 1. Calculation of Radioactivity Concentration

$$(2)\ MDA\ \left(\frac{Bq}{L}\right) = \frac{(2.71 + 4.65\sqrt{N})}{E \times T \times S \times Y}$$

N : Background count
E : Detection efficiency (%)
T : Measurement time
S : Sample volume (L)
Y : Recovery factor (%)

Equation 2. Minimum Detectable Activity (MDA) Calculation

2.3 Results and Discussion

The concentration of the tritium proficiency test sample provided by the Korea Institute of Nuclear Safety (KINS) in 2024 was 52.6 ± 3.0 Bq/L. The measurement error was approximately 7 % for the GCT 6220 and 1.1 % for the 300SL-SLL, both of which met the proficiency evaluation criteria and received an A-grade rating. The measurement results are summarized in Table III.

Table III: Measurement Results and Proficiency Test Reference Value

Model	Quantulus GCT 6220	300SL-SLL		
ROI	Energy	Channel		
	0-18.6 keV	5-180	5-300	5-350
Activity (Bq/L)	56.3 ±3.09	52.5 ±3.54	53.2 ±3.66	52.4 ±3.78
Reference (Bq/L)	52.6±3.0			
Error (%)	7	0.19	1.1	0.38

By achieving an A-grade rating, the GCT 6220 and 300SL-SLL have demonstrated their suitability for low-energy tritium sample analysis. This data will serve as a highly valuable reference when designing and conducting similar studies utilizing such measurement systems.

3. Conclusions

This study evaluated the feasibility of the GCT 6220 and 300SL-SLL liquid scintillation counters as alternative instruments for analyzing low-level environmental samples.

Both the GCT 6220 and 300SL-SLL demonstrated excellent performance in measuring proficiency test samples. However, their verification for detecting low-level tritium concentrations in environmental samples remains insufficient. To ensure a higher level of accuracy, further research will be conducted to assess the precise measurement capability of these instruments in detecting environmental tritium at levels meeting the MDA threshold of 5 Bq/L.

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