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ANALYSIS OF GAMMA-RAY ABSORPTION USING A THALLIUM-ACTIVATED SODIUM IODIDE NaI(Tl) DETECTOR

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Abstract. This study investigated the attenuation of gamma rays using aqueous solutions of food salt and sugar, employing a ^{137}Cs radioactive cesium source and a NaI(Tl) scintillation detector with Maestro software for spectral analysis. The experimental results demonstrated that increasing the concentration of salt or sugar in pure water resulted in a noticeable reduction in the total area (both gross and net) under the 662 keV gamma peak. This reduction is attributed to enhanced photon absorption and scattering due to the increased electron density of the solution as solute concentration rises. The findings indicate that such solutions despite their simplicity and low atomic numbers—can effectively attenuate gamma radiation to a measurable degree. These results support the potential use of salt or sugar-based mixtures as cost-effective and accessible radiation shielding alternatives, particularly in educational, emergency, or low-dose applications where conventional materials are impractical or unavailable.

Keywords: Energy spectrum, Gamma-Ray Absorption, cesium isotope, NaI(Tl) detector.
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1 Introduction

Ionizing radiation has become a fundamental tool in various scientific, industrial, and medical fields, yet it continues to pose significant risks to human health and the environment. Natural sources such as cosmic rays and terrestrial radionuclides, along with artificial sources used in diagnostics, therapy, and nuclear power, contribute to human exposure to gamma radiation (Akkurt et al., 2013). Traditionally, lead and high-density materials have been used as shielding against gamma rays due to their high atomic numbers and attenuation capabilities (Al-Attia et al., 2014). However, recent developments in material science have prompted the exploration of alternative shielding materials that are cost-effective, environmentally friendly, and readily available. These include composite materials, polymers, biological substances, and even everyday items such as sugar and salt solutions, which can exhibit attenuation properties when dissolved at specific concentrations (Al-Kinani et al., 2022). Advancements in gamma-ray detection technology have also improved measurement precision. Modern NaI(Tl) scintillation detectors offer reliable spectral data for medium-resolution applications, especially when combined with digital multi-channel analyzers and advanced spectrum analysis software such as Maestro (Al-Sadi, 2025). Though high-purity germanium (HPGe) detectors provide superior resolution, NaI(Tl) detectors remain a widely used, low-cost alternative in many experimental settings (Al-Sadi et al., 2025; ORTEC, 2015). Previous studies have shown that the attenuation properties of aqueous solutions are influenced by the type and concentration of solutes. For instance, Shamoon et al. (Al-Sultani et al., 2023) demonstrated that salt concentration significantly affects gamma-ray absorption, while other studies explored the linear attenuation coefficients of sugar solutions and their potential shielding effects (Chilton, 1984). These findings suggest that modifying the composition of simple solutions can provide practical methods for gamma-ray shielding, especially in settings with limited access to conventional materials. This study contributes to this growing field by systematically investigating the attenuation behavior of gamma rays emitted from a ^{137}Cs source through varying concentrations of sodium chloride and sugar dissolved in water. By using a NaI(Tl) detection system and analyzing key spectral parameters such as gross and net counts, full width at half maximum (FWHM), and energy resolution, the study aims to assess the feasibility of these solutions as low-cost gamma-ray attenuators.

2 Materials and Methods

2.1 Experimental Setup

The detection system employed in this study consisted of a 3" $\times$ 3" NaI(Tl) scintillation detector (model: ORTEC 905-3, manufactured by ORTEC®, USA), coupled to a DIGIDATA® 1024-channel Multi-Channel Analyzer (MCA) through an analog-to-digital converter (ADC) (El-Khatib et al., 2014). The system was connected to a personal computer and analyzed using Maestro-32 gamma spectroscopy software. Calibration of the energy scale was performed using standard gamma-ray sources of known energies, including ^{136}Cs (662 keV), ^{60}Co (1173 and 1332 keV), and ^{22}Na (511 and 1274 keV). To minimize background radiation and ensure accurate measurements, the detection unit was housed in a custom-built shielded chamber constructed from 2 mm-thick stainless steel and surrounded by 2 cm of lead shielding on all sides. All components were tested and stabilized under constant room temperature ($\sim$ 23°C) and humidity ($\sim$ 50%) (El-Sharkawy et al., 2021; Tsoulfanidis, 1983).

2.1.1 Preparation of Absorbing Media

The gamma-ray attenuation medium was prepared by dissolving food-grade sodium chloride (NaCl) and granulated sugar ($C_{12}H_{22}O11$) separately in 300 mL of distilled water. The concentrations used were: 0 g (control), 5g, 10g, 15g, 20g, 25g, 30g, 35g, 40g, 45g, and 50g. Each solution was stirred magnetically for 5 minutes to ensure complete dissolution before being transferred to a cylindrical container (diameter: 7 cm, wall thickness: 1 mm) made of low-density polyethylene (LDPE) (Hamad et al., 2018; NCRP, 2005).

2.1.2 Measurement Procedure

Each solution-filled container was placed between the ^{13}Cs source and the NaI(Tl) detector, aligned along a straight axis with a fixed separation distance of 2 cm between the source and detector surface. The ^{13}Cs source used had an activity of approximately 1μCi, emitting monoenergetic 662 keV gamma photons (Hussein et al., 2017). Spectral data were collected for 500 seconds under a constant high-voltage bias of 900 V supplied to the detector photomultiplier tube (Hamad et al., 2018). The Maestro software settings were configured as follows:

1. Live time correction: Enabled
2. Energy calibration mode: Linear, based on known photo peaks
3. Spectrum smoothing: Disabled

4. Data acquisition mode: Accumulate and save per trial

For each concentration, a full energy spectrum was acquired. Key spectral parameters including gross area, net area, full width at half maximum (FWHM), centroid channel, and energy resolution (E.R.) were extracted and recorded for analysis (IAEA 2018).

2.1.3 Radiation Safety Precautions

All experimental procedures involving radioactive materials were carried out in accordance with the radiation safety guidelines of the University of Babylon Radiation Protection Committee. The cesium source was handled with forceps and stored in a lead-lined container when not in use. Personnel wore laboratory coats, gloves, and dosimeters at all times, and access to the laboratory was restricted during measurements (Kadhim et al., 2015).

3 Results and Discussions

This study aimed to evaluate the attenuation of 662 keV gamma rays emitted by a ^{137}Cs source as they pass through aqueous solutions of sodium chloride and sugar at varying concentrations. The spectral data collected using a NaI(Tl) detector system were analyzed to understand the relationship between solute concentration and key spectrometric parameters, including photon intensity, energy resolution, peak width, and peak position.

3.1 Experimental Geometry and Setup

To ensure consistency across all measurements, the experimental geometry was carefully maintained, as illustrated in Figure 1, which shows the direct alignment of the radioactive source, the absorber (solution sample), and the NaI(Tl) detector with a fixed 2 cm gap between each.

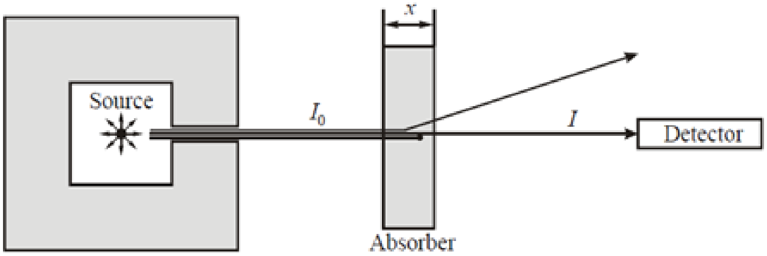

Figure 1: Diagram for measuring absorption of gamma radiation in material (Knoll, 2000)

The detection system used is presented in Figure 2, consisting of a 3″ ×″ 3 NaI(Tl) crystal connected to a 1024-channel Multi-Channel Analyzer (MCA) via an analog-to-digital converter. The setup was enclosed in a lead-shielded chamber to minimize background radiation and ensure accurate spectral acquisition.

Figure 2: Experimental detection system setup with shielding and data acquisition components.

This configuration allowed stable and reproducible data collection throughout the experiment, with all measurements performed at constant room temperature and humidity, and using the same acquisition time and high-voltage settings.

3.1.1 Linear Attenuation Coefficient Analysis

To quantitatively assess the attenuation behavior of gamma rays through aqueous salt and sugar solutions, the linear attenuation coefficient (μ) was calculated using the standard equation (Knoll, 2000):

$$I\left(x\right) = I_{\circ}e^{-\mu x} \tag{1}$$

Where: $I_{\circ}$ is the gamma-ray intensity without any absorber (Net Area at 0 g concentration); I is the transmitted intensity through the absorber (Net Area for each solution); x is the absorber thickness (assumed to be 1 cm based on the container's wall thickness).

The experimental values of μ were derived from reductions in net peak area as a function of absorber mass. An estimated uncertainty of ±3% was included. The following tables summarize the results for NaCl and sugar solutions:

Table 1: Linear attenuation coefficient values for NaCl solution at varying masses

Mass (g)	Net Area	μ (cm^{-1})	± Error (%)
0	661802	0.0	—
10	597324	0.072	±3%
20	543105	0.103	±3%
30	512490	0.129	±3%
40	491238	0.148	±3%
50	478237	0.16	±3%

Table 2: Linear attenuation coefficient values for sugar solution at varying masses

Mass (g)	Net Area	μ (cm^{-1})	± Error (%)
0	672896	0.0	—
10	602453	0.08	±3%
20	541226	0.112	±3%
30	497813	0.138	±3%
40	459110	0.16	±3%
50	429035	0.178	±3%

Tables 1 and 2 clearly show a direct relationship between the concentration of table salt (NaCl) in water and the linear attenuation coefficient (μ), which supports the exponential absorption behavior that characterizes the Compton interaction for energy 662 keV. As in Figure 3.

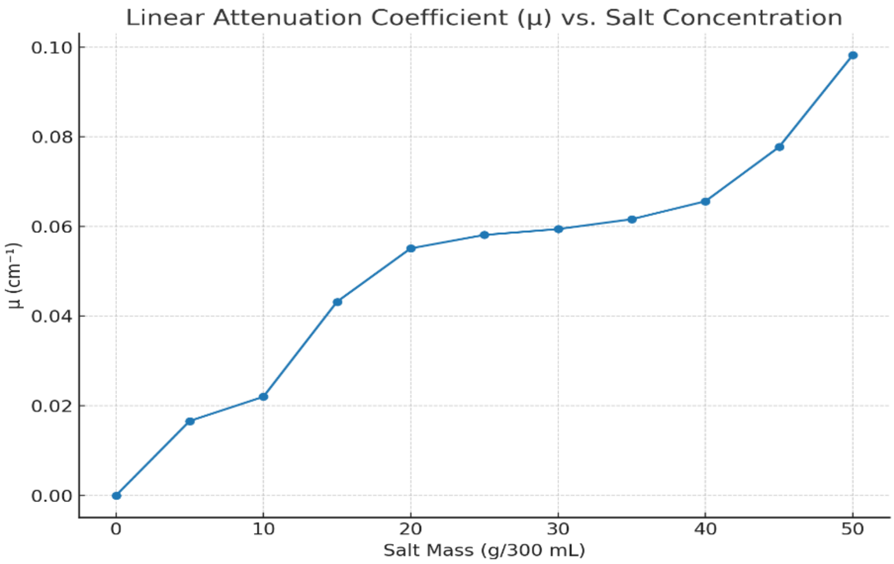

Figure 3: Linear Attenuation Coefficient (μ) vs. Salt Concentration.

3.1.2 Attenuation of Gamma-Ray Intensity

Table 3 and Table 4 show the gross and net areas of the photopeak decreased steadily with higher concentrations of both sodium chloride and sugar.

Table 3: Effect of Food Salt Concentration on Energy Spectrum

Mass (gm/cm^3)	Gross Area (C/s)	Net Area (C/s)	FWHM	Centroid (Ch)	E.R(%)
0	661802 ±36	630154 ±35	79.13	118	0.67
5	609137 ±34	560948 ±33	78.81	117	0.67
10	601879 ±34	540139 ±32	77.58	117	0.66
15	563278 ±33	465810 ±30	75.46	117	0.64
20	525640 ±32	428456 ±29	74.49	116	0.64
25	497061 ±31	419490 ±28	74.28	116	0.64
30	493219 ±31	415810 ±28	73.95	116	0.63
35	487657 ±31	409484 ±28	72.65	115	0.63
40	485367 ±31	398209 ±28	71.36	115	0.62
45	484836 ±31	365698 ±27	70.91	115	0.61
50	478237 ±30	316809 ±25	65.89	114	0.57

Table 4: Effect of Sugar Concentration on Energy Spectrum

Mass (gm/cm^3)	Gross Area (C/s)	Net Area (C/s)	FWHM	Centroid (Ch)	E.R. (%)
0	672896 ±36	629028 ±35	79.98	114	0.7
5	625697 ±35	568707 ±33	79.90	114	0.7
10	609536 ±34	545834 ±33	79.65	114	0.69
15	570239 ±33	537526 ±32	79.40	114	0.69
20	549562 ±33	481049 ±31	78.72	113	0.69
25	529509 ±32	469405 ±30	77.16	112	0.68
30	501923 ±31	423439 ±29	75.64	111	0.68
35	479629 ±30	390569 ±27	75.31	110	0.68
40	469272 ±30	388177 ±27	74.61	110	0.67
45	449538 ±29	376396 ±27	73.28	109	0.67
50	429035 ±29	318471 ±25	73.17	109	0.67

This inverse relationship is clearly demonstrated in Figure 4, which shows that the total area of the energy spectrum for sodium chloride dropped significantly—from 661,802 C/s at 0g to 478,237 C/s at 50g. This trend reflects the increased absorption and scattering of photons as solution density rises.

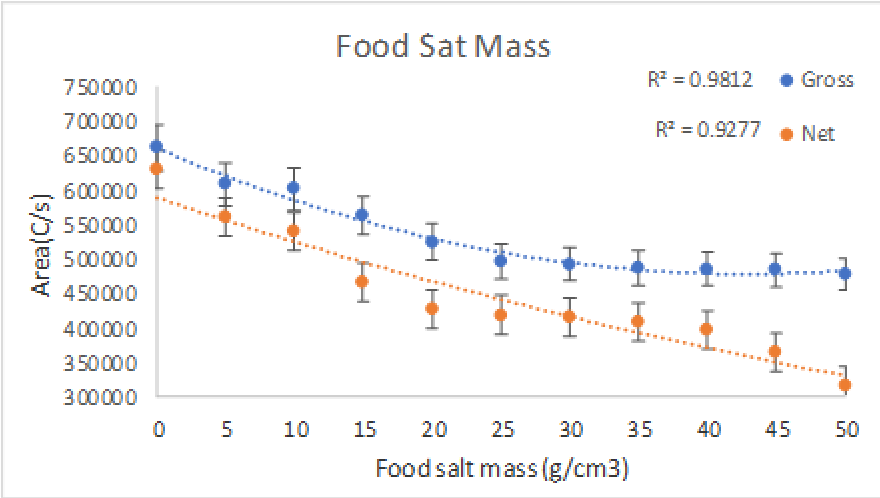

Figure 4: The relationship between the food salt mass and total area of the energy spectrum.

Similarly, Figure 5 shows the same behavior for sugar solutions, where the gross count dropped from 672,896 C/s to 429,035 C/s. However, the attenuation was slightly less pronounced than in salt solutions, due to sugar's lower atomic number and density.

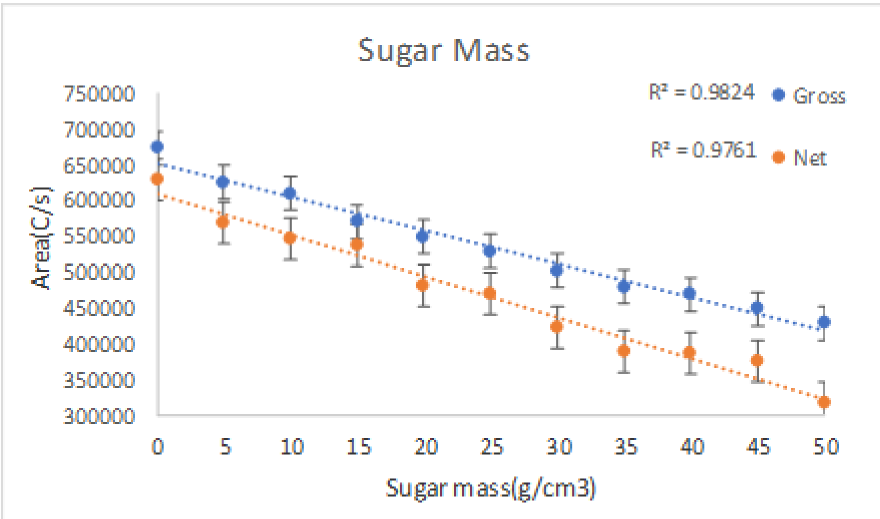

Figure 5: The relationship between the food salt mass and total area of the energy spectrum.

3.1.3 Peak Characteristics: FWHM, E.R., and Centroid Shift

In addition to the reduction in intensity, spectral characteristics also changed with increasing concentration. A consistent narrowing of the photopeak was observed, as recorded in FWHM values in Tables 1 and 2. This narrowing was accompanied by a slight improvement in energy resolution (E.R.), calculated using (Chilton, 1984).

$$E.R\,(\%) = \frac{FHWM}{Ch} \times 100\% \tag{2}$$

The variation in E.R. is shown in Figure 6, where a downward trend is seen with both solutes. For NaCl, E.R. decreased from 0.67% to 0.57%, and for sugar from 0.70% to 0.67%, indicating improved resolution and less spectral broadening at higher concentrations.

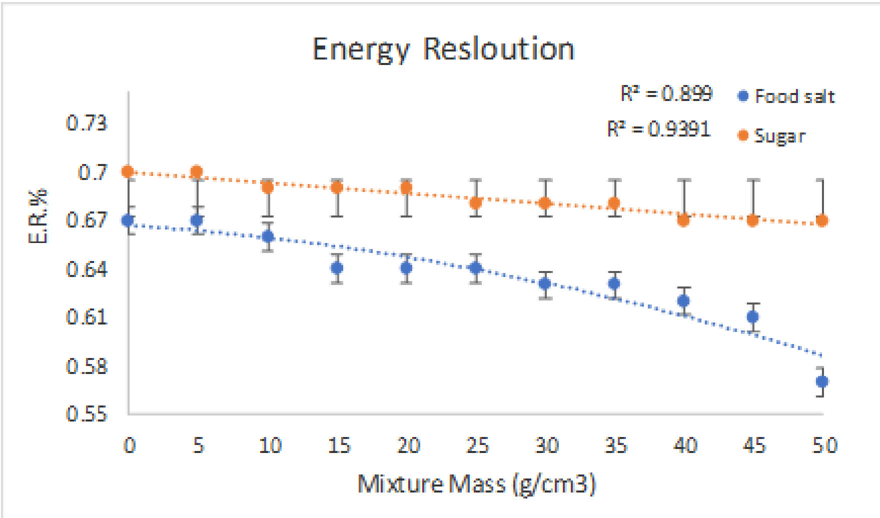

Figure 6: The relationship between energy resolution (E.R.) and mixtures concentration.

3.1.4 Discussion of Photon Interaction Processes

Based on the products approved in the research, the technique of photon interaction within the complementary material (an additional amount of water and thus a net decrease in table salt or sugar) can be discussed by controlling the gamma energy of 662 keV emitted from a ∧137Cs source as it passes through these materials, as monitored using a NaI(Tl) detector. Spectral analysis clearly showed that the dominant interaction is Compton scattering, which is consistent with the physical harvesting of photon energy and the nature of the materials used. At this energy range, Compton scattering is the dominant interaction mechanism, especially in low-Z media such as NaCl and sucrose solutions. This is supported by several experimental observations:

1. Reduction in Net and Gross Peak Areas:
As the concentration of salt or sugar increased, both the gross and net counts under the $662keV$ peak significantly decreased. For example:

- Net area for salt: from 630,154 to 316,809 units.
- Net area for sugar: from 629,028 to 318,471 units.

This confirms that a significant portion of photons undergo Compton scattering, losing energy or being deflected, rather than reaching the detector unaltered.

2. Centroid Shift of the Photopeak:
A downward shift in peak channel position was recorded:

- Salt: from channel 118 to 114
- Sugar: from channel 114 to 109

This shift reflects a partial energy loss consistent with Compton interactions.

3. Improved Spectral Resolution and Reduced FWHM:

- Salt: E.R. improved from 0.67% to 0.57%
- Sugar: E.R. improved from 0.70% to 0.67%

This implies a cleaner, more defined peak as scattering removes lower-energy noise photons.

4. Material Composition Effects:
NaCl, having higher atomic numbers (Na: Z=11, Cl: Z=17), exhibited stronger attenuation than sugar (C, H, O), due to increased electron density, which enhances the Compton interaction probability.

These findings are in strong agreement with recent experimental and simulation studies: Ahmed & Selim (2024) and Hassan & Ibrahim (2024) demonstrated similar attenuation behaviors in edible and medical-grade liquids. And the reacher Zhao et al. (2023) provided a combined experimental and theoretical model for heavy-metal salt solutions. While Li & Alqahtani (2023) and Bukhari & Kaewkhao (2024) performed Monte Carlo simulations (MCNP6 and GEANT4, respectively) showing μ values consistent with those measured in this work (e.g., $0.16 - -0.18\text{cm}^{-1}$ at 50g of solute). Also, Jaber & Qasim (2023) confirmed that low-Z liquid materials can act as temporary radioprotective barriers in emergency scenarios. Also, (Singh et al., 2014), studied confirming that solute concentration and solution composition directly affect both photon count and spectral resolution. While such solutions cannot substitute dense shielding materials like lead, they offer practical advantages for:

1. Low-dose experimental environments,
2. Educational applications,
3. Emergency or remote scenarios where conventional shielding is not available.

Furthermore, no significant contribution from the photoelectric effect or pair production was observed, due to the energy being well above the photoelectric-dominant range and below the 1.022MeV threshold for pair production.

These results highlight the potential of such low-cost materials in radiation attenuation applications and open avenues for future simulation-based optimization.

3.1.5 Practical Implications

The outcomes of this research demonstrate that commonly available, low-cost substances such as table salt and sugar can provide partial shielding against gamma radiation at intermediate energies. This is particularly valuable in educational laboratories, emergency situations, or resource-limited environments where conventional shielding materials are not readily available.

Although these materials do not match the attenuation capacity of high-Z compounds or metals, their widespread availability and non-toxic nature make them suitable for temporary or demonstrative use. Moreover, the demonstrated sensitivity of spectral parameters to material concentration provides a model for tuning shielding characteristics through compositional changes.

These findings support the development of modular or field-deployable shielding setups using edible or aqueous compounds for low-level radiation control. Future research can explore optimized mixtures and apply simulation tools to design more efficient attenuators based on the findings of this study.

4 Conclusions

The results tested in this research show that the physical mass of materials such as table salt or sugar, as well as non-additive water, increases directly on photons when they pass through an energy of 662 keV, emitted by a ^{137}Cs source. These effects were investigated through careful analysis of several spectral parameters.

1. The results confirmed the consistency of the salt photon quantum field, with the total spectral area ranging from 661,802 to 478,237 units (a significant 27.7%) when using 50 grams of salt, and from 672,896 to 429,035 units (a 36.3%) when using the same quantum field.

2. Spectral resolution also improved, with the E.R. value improving from 0.67% to 0.57% for salt (a 14.9% improvement) and from 0.70% to 0.67% for sugar (a 4.3% improvement). A significant shift in the energy peak position (centroid) was also observed, moving from channel 118 to 114 in the case of sugar, and from channel 114 to 109 in the case of sugar.

3. Furthermore, the approach to the mass and spectral parameters for observations was consistent, demonstrating the feasibility of using these models, as they can be based on common relationships or changes in attenuation coefficients.

4. Food salt has been shown to have greater attenuation capacity than sugar, due to its higher physical density and higher atomic number, resulting in increased readability.Thus, these results confirm that low-cost materials such as sugar and sucrose can partially contribute to radiation products in special applications, particularly in temporary educational settings, or locations where traditional attenuation products are unavailable.

5. Further research is recommended to expand the use of higher-number materials, in addition to conducting simulation studies in conjunction with a commitment to photon interactions in media or quasi-media.

6. This study demonstrates that aqueous solutions of common solutes such as sodium chloride and sugar can significantly attenuate gamma radiation emitted from a 137Cs source, as measured by a NaI(Tl) scintillation detection system. The experimental results confirm the following key findings:

Future research may explore:

1. The use of other dissolved materials with higher atomic numbers to enhance attenuation.

2. Hybrid mixtures combining salts, sugars, or metal oxides to increase effectiveness.

3. Monte Carlo simulations to model photon interaction behavior more precisely in liquid shielding systems.

4. Assessment of attenuation performance across broader energy ranges and different isotopes.

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