CHAPTER 3 – Experimental Methods

3.1 Pre-Experiment

At the beginning of the experiment, an open geometry count reading was taken for 30 seconds. This reading serves as an indicator of the fluctuation in the background radiation count at the area surrounding the experiment at set-up. Using the NIM system (WINDOW Fully Open), background count was recorded at an average of 39000counts per 30seconds. With the NIM system set at INTEGRAL MODE, the average background count was about 800counts per 30seconds for all measurements at 356keV, and 662keV.

A simple procedure was performed to determine the operating voltage range of the scintillation detector as shown in Fig 3. Operating voltage used for this experiment is 1200V and system stability was determined using Chi Square test[21].

3.2 Measurement Sequence

Counting procedure for mass attenuation coefficient measurements was done in the sequence described below.

1. Without source (A1)
2. With source (B1)
3. With source + Sample (repeated 3 times)
4. With source (B2)
5. Without source (A2)

Counting time was set at 30seconds per measurement. It is reported that percentage difference between Count Data Without Source (A1) and Without Source (A2) is less

than 1.5% and percentage difference between Count Data With Source (B1) and With Source (B2) is less than 1%. Thus, it can be said that the experiment is performed under the same equipment condition and with good reliability.

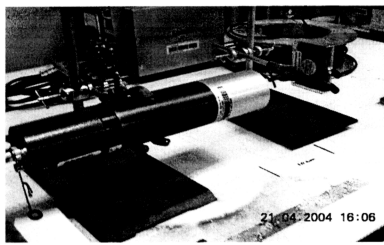

Fig. 3. Determining the detector Operating Voltage using 1μCi Cs-137

3.3 Attenuation measurements at 356keV for short distances

3.3.1 Determination of μ/ρ for Distilled Water, Toluene and Ethanol

The objective of this experiment is to obtain gamma ray mass attenuation coefficient for distilled water, toluene and ethanol at short distances by varying the source to sample and sample to detector positions. In this set-up, a 2mm x 25mm source collimator and a 15mm detector collimator was used. Gamma rays of 356keV were obtained from a 1.04mCi of Ba-133 radioactive isotope. The transmission configuration was set-up and measurements were recorded by the NIM system. A narrow beam is passed through the centre of liquid and the transmitted radiation intensity is recorded as count rate. In this aspect of the experiment, four different Detector-Sample-Source distances were explored. It is expected that the measurements will produce the μ/ρ (experiment) values that are close to the μ/ρ value (theory). In other words, experimental errors should be at

the minimum for some positions. Different separation combination for source to sample and sample to detector were explored and are described below.

Table 2. Experimental set-up configurations of Source to Sample and Sample to Detector

Position	Source (Ba-133)	Sample	Detector	Note
1	5cm	10cm	5cm	Distance at half sample size
2	10cm	10cm	10cm	Equidistant
3	10cm	10cm	5cm	Sample nearer to source
4	5cm	10cm	10cm	Sample nearer to detector

Some measurements were also taken with various mass thickness ($1.8 g/cm^2$ to $22.0 g/cm^2$) of the water sample.

3.4 Attenuation measurements at 356keV and 662keV

3.4.1 Determination of μ/ρ for Selected Solids and Liquids

The objective of this experiment is to obtain gamma ray mass attenuation coefficient for the selected solid and liquid samples. This set-up has used a 3mm source collimator and a 15mm detector collimator. For liquid samples, gamma ray energy of 356keV and 662keV with activities of 1.04mCi and 0.37mCi respectively were used. However, for solid samples activities of 1.04mCi and 2.01mCi at the respective energies were used. The transmission configuration was set-up and measurements were recorded by the NIM system according to the measurement sequence. The Detector-to-Source distance was fixed at 1 metre. A narrow and parallel beam was maintained throughout the second experiment. The incident beam is passed through the centre of liquid and mid point length of the solids. The source, detector and their housing were placed on a rigid PVC frame and alignment was performed with the aid of a low-energy laser.

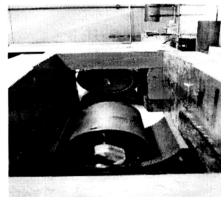

Fig. 4. Detector and Source (with pen source holder) in lead shielding placed opposite each other in a straight line

3.4 Calculations

Calculation of the expected coefficient values for compounds were made based on mixture rule that is by addition of mass attenuation coefficient values for elements from the Hubbell[3] database multiplied by their respective weight fractions. For calculation of mass attenuation coefficients for compounds, fraction by weight of each type of element in a compound is given in Table 2. Element weight fraction is calculated using the chemical composition of compounds, atomic and molecular weights.

1. n-pentane, Molecular Formula = C_5H_{12}

Atomic Weight of H=1.008a.m.u and atomic weight of C=12.011a.m.u

Total Atomic Weight of C_5H_{12} = (5 x 12.011) + (12 x1.008) = 72.151a.m.u

Weight fraction of C in C_5H_{12} = (5 x 12.011)/ 72.151 = 0.832351

Weight fraction of H in C_5H_{12} = (12 x 1.008)/72.151 = 0.167648

2. Water, Molecular Formula = H_2O

Atomic Weight of H=1.008a.m.u and atomic weight of O =15.595a.m.u

Total Atomic Weight of H_2O = (2 x1.008) + (1 x 15.595) = 17.611a.m.u

Weight fraction of H in H_2O = (2 x1.008)/ 17.611= 0.114474

Weight fraction of O in H_2O = (1 x 15.595)/ 17.611= 0.885526

3. Ethanol, Molecular Formula = C_2H_5OH

Atomic Weight of C=12.011a.m.u, atomic weight of H=1.008a.m.u and atomic weight of O =15.595a.m.u

Total Atomic Weight of C_2H_5OH = (2 x 12.011) + (6 x1.008) + (1 x 15.595) = 45.665a.m.u

Weight fraction of C in C_2H_5OH = (2 x 12.011)/ 45.665= 0.526048

Weight fraction of H in C_2H_5OH = (6 x1.008)/ 45.665= 0.132442

Weight fraction of O in C_2H_5OH = (1 x 15.595)/ 45.665= 0.341508

4. Toluene, Molecular Formula = C_7H_8

Atomic Weight of C=12.011a.m.u, atomic weight of H=1.008a.m.u

Total Atomic Weight of C_7H_8 = (7 x 12.011) + (8 x1.008) = 92.141a.m.u

Weight fraction of C in C_7H_8 = (7 x 12.011)/ 92.141= 0.087518

Weight fraction of H in C_7H_8 = (8 x1.008)/ 92.141= 0.912481

5. Palmitic Acid, Molecular Formula = $C_{16}H_{32}O_2$

Atomic Weight of C=12.011a.m.u, atomic weight of H=1.008a.m.u and atomic weight of O =15.595a.m.u

Total Atomic Weight of $C_{16}H_{32}O_2$ = (16 x12.011) + (32 x1.008) + (2 x 15.595) = 255.622a.m.u

Weight fraction of C in $C_{16}H_{32}O_2$ = (16 x12.011)/ 255.622= 0.751797

Weight fraction of H in $C_{16}H_{32}O_2$ = (32 x1.008)/ 255.622=0.126186

Weight fraction of O in $C_{16}H_{32}O_2$ = (2 x 15.595)/ 255.622= 0.122016

6. Oleic Acid, Molecular Formula = $C_{18}H_{34}O_2$

Atomic Weight of C=12.011a.m.u, atomic weight of H=1.008a.m.u and atomic weight of O =15.595a.m.u

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Total Atomic Weight of $C_{18}H_{34}O_2$ = (18 x12.011) + (34 x1.008) +

(2 x 15.595) = 281.66a.m.u

Weight fraction of C in $C_{18}H_{34}O_2$ = (18 x12.011)/ 281.66= 0.767585

Weight fraction of H in $C_{18}H_{34}O_2$ = (34 x1.008)/ 281.66= 0.121678

Weight fraction of O in $C_{18}H_{34}O_2$ = (2 x15.595)/ 281.66= 0.1107363

7. Linoleic Acid, Molecular Formula = $C_{18}H_{32}O_2$

Atomic Weight of C=12.011a.m.u, atomic weight of H=1.008a.m.u and

atomic weight of O =15.595a.m.u

Total Atomic Weight of $C_{18}H_{32}O_2$ = (18 x12.011) + (34 x1.008) +

(2 x 15.595) = 279.644a.m.u

Weight fraction of C in $C_{18}H_{32}O_2$ = (18 x12.011)/ 279.644= 0.767585

Weight fraction of H in $C_{18}H_{32}O_2$ = (32 x1.008)/ 279.644= 0.115346

Weight fraction of O in $C_{18}H_{32}O_2$ = (2 x 15.595)/ 279.644= 0.1107363

8. Paraffinic Hydrocarbon, Molecular Formula = C_6H_{32}

Atomic Weight of C=12.011a.m.u, atomic weight of H=1.008a.m.u and

Total Atomic Weight of C_6H_{32} = (6 x12.011) + (32 x1.008) = 104.322a.m.u

Weight fraction of C in $C_{18}H_{32}O_2$ = (6 x12.011)/ 104.322= 0.690803

Weight fraction of H in $C_{18}H_{32}O_2$ = (32 x1.008)/ 104.322= 0.309196

9. Asphaltic Hydrocarbon, Molecular Formula = $C_{60}H_{122}$

Atomic Weight of C=12.011a.m.u, atomic weight of H=1.008a.m.u and

Total Atomic Weight of C_6H_{32} = (60 x12.011) + (122 x1.008) = 843.636 a.m.u

Weight fraction of C in $C_{18}H_{32}O_2$ = (60 x12.011)/ 843.636 = 0.856277

Weight fraction of H in $C_{18}H_{32}O_2$ = (122 x1.008)/ 843.636 = 0.143722

From the information in the Table 3, an expected value of the mass attenuation coefficient for a sample can be calculated using the published data in Hubbell[3]. For cement and brick, the expected values are derived from the published results of M.N. Alam[17].

Table 3. Chemical composition of compounds and composite materials

Material	**Chemical Composition (Fraction by weight)**
Water	H=0.114474 O=0.885526
n-pentane	H=0.167648 C=0.832351
Ethanol	H=0.132442 C=0.526048 O=0.341508
Toluene	H=0.087518 C=0.912481
Palmitic Acid	H=0.126186 C=0.751797 O=0.122016
Oleic Acid	H=0.121678 C=0.767585 O=0.1107363
Linoleic Acid	H=0.115346 C=0.773118 O=0.111534
Paraffinic Hydrocarbon	H=0.309196 C=0.690803
Asphaltic Hydrocarbon	H=0.145769 C=0.854231
Polyethylene	H=0.143722 C=0.856277
Cement[32]	H=0.01 C=0.001 Mg=0.002 O=0.529 K=0.013 Na=0.016 Si=0.337 Fe=0.014 Al=0.034 Ca=0.044
Concrete[30]	H=0.022100 C=0.002484 O=0.574930 Na=0.015208 Mg=0.001266

	Al=0.019953 Si=0.304627 K=0.010045 Ca=0.042951 Fe=0.006435

3.4.1 Error Calculation

The errors in $(\mu/\rho)_{exp}$ values are calculated from the errors in the intensities I_o (without sample), I (with sample), and densities using the following relation, also used by A. Kurtoğlu and A.Beril Tuğrul [13].

$$\delta (\mu/\rho)_{exp} = (-1/ x\rho) \{ [(I\delta I_o - I_o\delta I / I I_o) + x\delta\rho \ln I/ I_o] \}$$

3.4.2 Experiment Optimisation

In transmission method, the absorption law in equation (3) also describes the equation adapted to study the design of experiment for nuclear measurements. The response of a nuclear instrument operating in transmission mode depends on three variables. If two of them remain constant the output will be a function of the third one, which can be determined in condition that a suitable calibration was performed before. For example, with attenuation coefficient, μ and mass thickness, x as constants and density, ρ a variable, the maximum sensitivity is 1. The acceptable interval is between 0.50 and 1.80. Sensitivity is one of the most important evaluation and design parameters. It relates variation in the system output produced as consequence of variations in the input signal. Relative sensitivity is the ratio between a variation in the system output and the relative variation in the input signal that produces the said modification. The system output is the count rate and the signal input is the magnitude to be measured symbolized by thickness or density.