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Characterization of ^{226}Ra Point Source and Analysis Its Daughter Radionuclides

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Abstract: The 'Gamma Spectroscopy Setup' calibration is essential for comparatively better gamma energy detection and analysis. Standard calibration sources are available as small deposits on thin backing materials so that they may closely approximate non-absorbing point source. However, radioactive samples to be measured often have non-negligible volume and mass, gamma rays can be attenuated by self-absorption within the sample material itself. In such cases, correction must be made for this attenuation if an accurate determination of gamma ray emission rate from the entire sample is needed. Accordingly, separate spectra for each source provides results that are simple to interact, but the calibration process is the time consuming and tedious. The substitution of a single source that emits many different gamma-ray energies is a tempting alternative because only a single calibration spectrum need be recorded and analyzed. The problem of interference between multiple responses become much more severe, however, and if precise results are to be obtained, more sophisticate methods of determining peak area must be used that take into account those interference effects. The point source ^{226}Ra has been taken under experiment for its characterization assessment. The daughter radionuclides obtained mainly ^{214}Pb, ^{214}Bi, ^{222}Rn, ^{218}Po, ^{218}At, ^{218}Rn, ^{218}Po, ^{210}Tl, ^{210}Pb, ^{210}Bi, etc. Efficiency calibration has been also done. The spectrum taken several times may be compared with each other to assess those changes of spectra for the time being.

Keywords: HPGe, MCA, Radiation, Shielding, Gamma, ^{226} Ra, Efficiency, Calibration.

1 Introduction

^{226}Ra is produced from ^{230}Th decay in the Uranium decay series. Most of the significant gamma radiation from ^{226}Ra decay comes from the radioactive Progeny ^{214}Pb and its daughter, ^{214} Bi which are produced following the decay of ^{226}Ra to ^{222}Rn, and then decays to ^{214}Pb. Since^{222}Rn is a gas it will escape to varying degrees, from unsealed sources, and the gamma radiation from ^{214}Pb and ^{214}Bi may not be significant in such cases. The daughter radionuclides ^{222}Rn, ^{214}Pb, and ^{214}Bi, each reach at the same activity as that of the ^{226}Ra within a few weeks of preparation, if the shielding is perfectly leakage prevented. A number of different gamma energies and yields are produced by the decay of ^{226}Ra and its Progeny. The produced energy ranges are from less than 50 KeV upto 2.5 MeV. The gamma rays that are from ^{226}Ra depend on its fabrication particular the type of material used and its thickness. Generally, escaped photons with energies less than about 50 KeV are not very important from a dose perspective. If, the photons with yields greater than 1% then effective gamma energy would be about 740 KeV [1, 2, 3].

Normally, the living being is being continuously exposed to radiation throughout the life on earth. Radiation comprises charged and uncharged particles as well as gamma radiation and X-rays those are from natural sources or artificial sources. As these are ionizing radiation, excessive exposure to them may pose a harmful threat to the human body (Tanha 2017). Globally, 85% of the ionizing radiation comes from natural sources in the environment and rest of 15% is from artificial sources. A survey shows that more than 85% of radiation workers have insufficient knowledge

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of radiation safety and protection rules & regulations while more than 80% of the public just heard about radiation from one source to another [10]. Reality is the medical personnel who takes the medical images of a patient using a radiation sources, does not provide any instruction about the radiation hazards to the patient. Virtually, all materials and environments on pur planet are naturally exposed to ionizing radiation. ^{226}Ra is often used for calibration of high resolution Gamma detectors (HPGe) and the spectrum data acquisition setup. ^{226}Ra are present in environmental and building material samples. The study shows, an evaluation of gamma energies emission from the point source ^{226}Ra. Due to the importance, extensive measurement of gamma-ray emission intensities have been carried out over three times, once a week. A lead shielded chamber has been used for this experiment.

2 Experimental Setup

A gamma Spectroscopy Setup has been developed in accelerator laboratory of Atomic Energy Centre Dhaka. This Gamma spectra acquisition setup is being used to detect radionuclides accumulated or present in any type of specimens. The major units of the system are shown in the following block diagram and explained briefly;

2.1 Data Acquisition

Data acquisition setup comprises mainly lead shielded chamber, gamma detector, bias supply unit, spectroscopy amplifier, MCA, PC with software (Genie-2000). The setup is being activated by providing required powers to all the units. All the units of the setup are compatible for NIM Bin power modules. The NIM Bin module is well regulated power Bin having the power options ± 6, ± 12 and ± 24 volts dc.

2.2 Lead Shielded Chamber

The experiment chamber is designed and fabricated to shield the entrance of background radiation into the chamber and also protect the emitted radiation from sample to outside the chamber wall except the detector path. The head of the gamma detector has been entered into the lead shielded chamber and set tightly with chamber wall. LN_2 pouring apparatus is also set with the detector and chamber base. The thickness of the 'lead-wall' is about 76 mm. The top cover of the chamber has been made of lead with same thickness and is being played by thread mechanism. A sample holder has been incorporated inside the chamber vertically on the detector head. The sample movement is being done through the top side of the chamber [7, 8].

2.3 HPGe Detector

A high purity germanium solid state detector has been installed at the bottom side of the chamber. The CANBERRA detector (Model: GC 12175) with 30 liters Dewar has been set perpendicular to the sample-holder. To activate the detector, the bias supply is being provided gradually up to 3.5 KV. An oscilloscope is also set to observe the status of bias fluctuation and output of the preamplifier and spectroscopy amplifier also.

2.4 Spectroscopy Amplifier

The NIM bin standard spectroscopy amplifier (Model: 671, ORTEC) has been installed to amplify the detected signals. The spectroscopy amplifier is being used for noise signals removing and also providing the bias supply to the preamplifier.

2.5 Multi-Channel Analyzer

The MCA/MCB, the most important unit of the data acquisition setup and installed at the next of the spectroscopy amplifier. Microprocessor and memory space of an MCA unit supports the data acquisition and I/O functions. This is the digital signal processing unit in which ADC is the main part that converts a continuous physical quantity (voltage pulses) into digital number (binary). ADC measures and sorts out the pulses according to their amplitudes. Digital signals propagate more efficiently than analog signals, largely because digital impulses, which are well-defined and orderly; are easier for electronic circuits to distinguish from noise.

3 Setup Calibrations

The detector is being supplied by 3.5 kV dc from NIM Bin standard bias unit. The spectroscopy amplifier, Ethernet MCA are set and powered from the NIM Bin module. For setup calibration, the point source ^{137}Cs, and ^{60}Co are being set inside the lead shielded chamber and near upside the detector head. By starting data acquisition, 661.7 KeV, 1172.5 KeV and 1332.6 KeV gamma energy photons are detected by HPGe detector those are the gamma energy lines of point sources ^{137}Cs and ^{60}Co respectively. These gamma energy photons are converted into voltage pulses and can be viewed the signals in oscilloscope and fitted to the input gate of the spectroscopy amplifier. The amplified output is then being fitted to the input gate of the MCA. The main function of the data processing is done in MCA. An ADC circuitry has been incorporated within the MCA that converted the incoming analog signals into digital pulses and processed the spectrum data and fitted to the computer through data cable and operated by the software Genie-2000 [7-12].

Gamma energy 661.7 KeV of !37Cs and upper energy line 1332.5 KeV of 60Co have been selected for setup calibration, the calibrated spectrums are projected in figure 3.

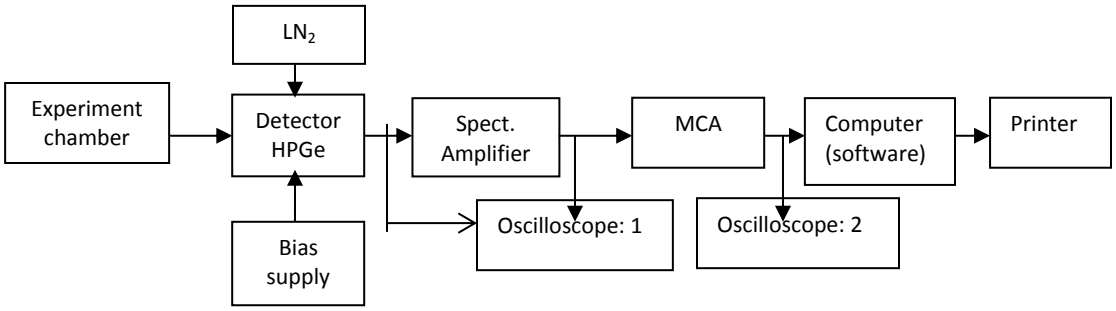

Fig. 1: Different units of 'Gamma Spectrometry System' of Accelerator Laboratory.

Fig.2: Photograph of 'Lead Shielded Chamber with detector.

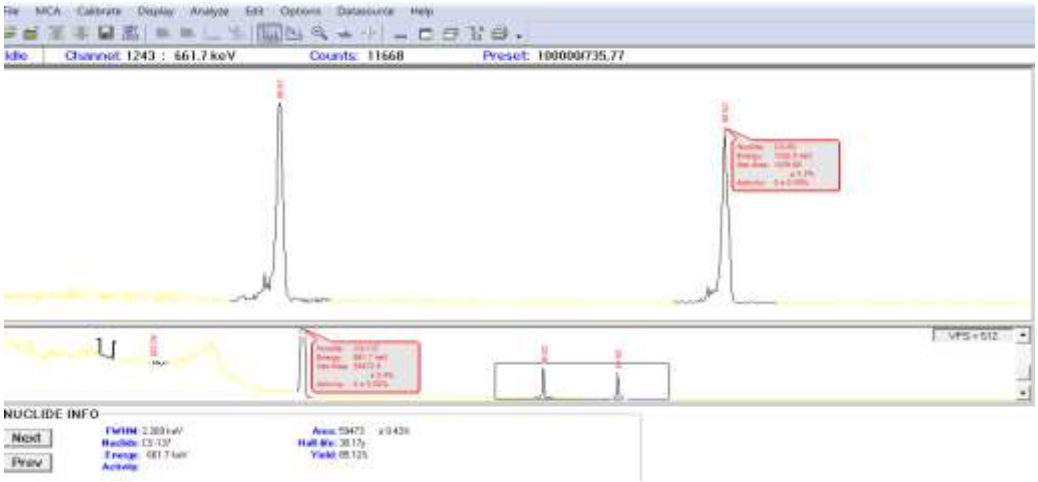

Fig. 3: Spectra of 'Gamma Spectrometry Setup' calibration using ^{137}Cs and ^{60}Co.

5 Activity of ^{226}Ra

The activity of ^{226}Ra point source at experiment time is calculated and defined as-

$A = A_0\, e^{-\lambda t}$ where, A_0 = Initial activity of ^{226}Ra = 370kBq ,

t = time passed from manufactured,
A = Present activity = ?

Half-life ($T_{½}$) of ^{226}Ra = 1610 years
$T_{½} = 0.693/\lambda$

So, $\lambda = 0.693/T_{½} = 0.693/1610 = 43.04\times10^{-5}$

$$A = 370\text{kBq} \times e^{-.000430434783\times12.67}$$
$$= 370\text{kBq} \times e^{-.00545364731}$$
$$= 370\text{kBq} \times 0.994559506$$
$$= 367.987017\text{kBq}$$

And total decreased activity = (370 - 367.987017) kBq = 2.012983 kBq.

6 Efficiency Calibrations:

The efficiency calibration has been done using obtained gamma energy values and the certified efficiency data file provided for this detector. The obtained efficiency curve and apart of calculated efficiencies have been shown below (figure 4);

Fig. 4: Efficiency curve obtained for ^{226}Ra characterization.

Table 1: Calculated efficiencies of the detector for different energy lines of a spectrum data file.

Pk/Index	Gamma Energy line (keV)	Calculated Efficiency	Measured Efficiency	Measured Error (%)	Deviation (%)
1	75.36	0.03467	0.03381	10.00	2.54
2	86.34	0.03261	0.03417	10.00	-4.58
3	151.89	0.03233	0.03056	10.00	5.79
4	185.94	0.03107	0.03056	10.00	1.66
5	196.03	0.03049	0.03056	10.00	-0.23
6	241.81	0.02746	0.02649	8.00	3.65
7	258.72	0.02628	0.02649	8.00	-0.79
8	274.47	0.02520	0.02649	8.00	-4.88
9	295.10	0.02387	0.02649	8.00	-9.90
10	351.87	0.02065	0.02036	8.00	1.45
11	388.34	0.01900	0.02036	8.00	-6.69
12	406.02	0.01829	0.01654	8.00	10.59
13	422.72	0.01768	0.01654	8.00	6.89
14	609.63	0.01343	0.01260	6.00	6.58
15	665.86	0.01275	0.01260	6.00	1.19
17	703.71	0.01237	0.01260	6.00	-1.85
18	720.20	0.01222	0.01260	6.00	-3.01

21	768.99	0.01186	0.01260	6.00	-5.91
22	786.64	0.01174	0.01260	6.00	-6.82
25	839.84	0.01142	0.01049	6.00	8.91
43	1378.80	0.00908	0.00910	4.00	-0.21
52	1691.79	0.00724	0.00699	4.00	3.52
54	176076	0.00678	0.00699	4.00	-3.02

7 ^{226}Ra Characterization

Experiment has been done for the characterization of ^{226}Ra point source using gamma spectroscopy setup at Van de Graaff Accelerator laboratory of AECD. All the NIM Bin standard units of data acquisition setup are activated providing appropriate power supplies [13-15]. The radioactive source ^{226}Ra was set inside the lead shielded chamber and started data acquisition. During 4506 seconds, the spectrum data has been collected and stored in a file. The data file is analyzed and the obtained spectra with partial results have been projected in figure 5.

The energies emitted from ^{226}Ra and its daughter radionuclides are α, β and γ radiations. The α and β radiations are not detected due to the absence of required detectors. Only High Purity Germanium (gamma) detector has been used for the detection of gamma photons emitted by ^{226}Ra and analyzed data has been shown in table 2.

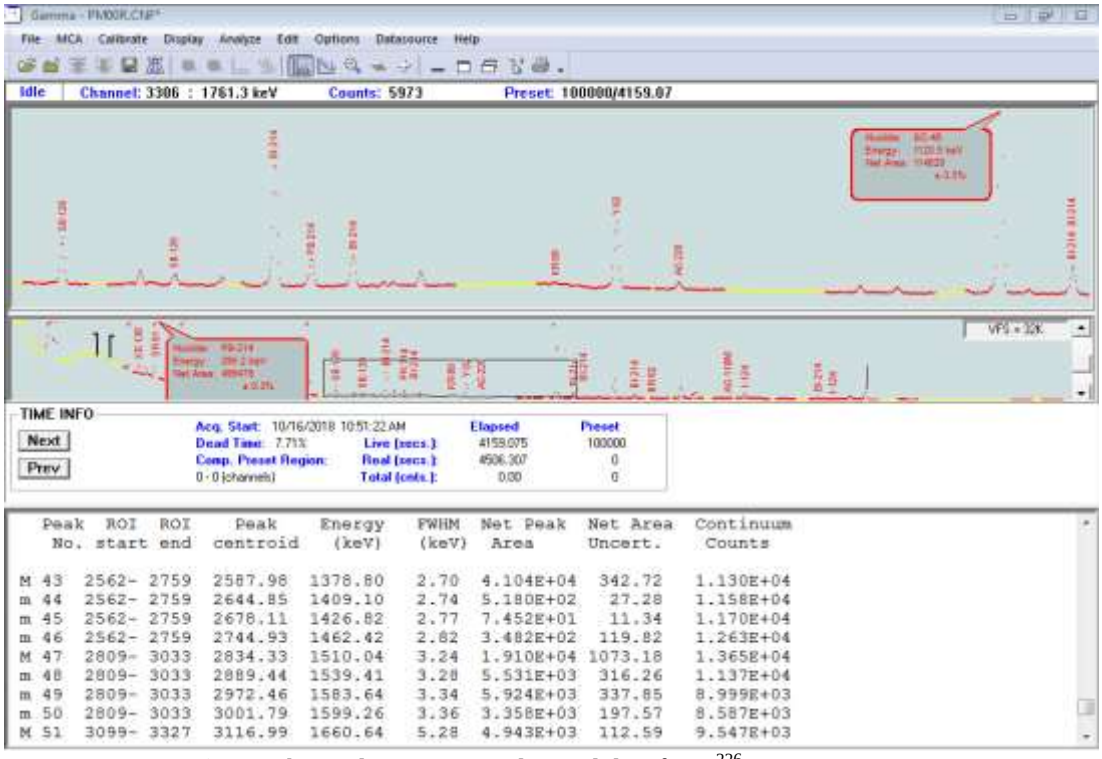

Fig. 5: Obtained spectrums and partial data from ^{226}Ra point source.

Table 2: Recommended energy lines, half-life & AE/decay, daughter nuclides of ^{226}Ra.

Energy Lines (keV)	Daughter Nuclides	Half-life	Absolute Emission/decay
75.36	^{212}Pb	10.64 hrs.	0.1077
185.94	^{222}Rn	3.82 days	0.0328
186.21	^{226}Ra	1600 yrs.	0.0351
241.81	^{214}Pb	26.8 min	0.0900
258.72	^{214}Pb	26.8 “	0.0055
274.47	^{214}Pb	26.8 “	0.0033
295.10	^{214}Pb	26.8 “	0.1970

351.87	^{214}Pb	26.8 “	0.3890
388.34	^{214}Bi	20.0 min	0.0041
406.02	^{214}Bi	20.0 “	0.0017
609.63	^{214}Bi	20.0 “	0.4330
665.86	^{214}Bi	20.0 “	0.0125
703.71	^{214}Bi	20.0 “	0.0047
720.50	^{126}Sb	12.4 days	0.5380
768.99	^{214}Bi	20.0 min	0.0504
786.64	^{214}Bi	20.0 “	0.0032
839.84	^{214}Pb	26.8 min	0.0059
1691.79	^{124}Sb	60.208 days	0.4730
1760.76	^{214}Bi	20.0 min	0.1700

Table 3: Main γ-energies of ^{226}Ra decay chain in radioactive equilibrium with its daughters.

Z / A	82	83	84	85	86	87	88
226							^{226}Ra ($T_{½}$=1620 yrs.)
225							
224							α, γ
223							
222					^{222}Rn ($T_{½}$= 3.82 days)		
221							
220					α		
219							
218			^{218}Po ($T_{½}$=3.05 min)				
217							
216			α				
215							
214	^{214}Pb ($T_{½}$=26.8min)	^{214}Bi ($T_{½}$= 19.7 min)	^{214}Po ($T_{½}$= 16.4 μs)				
213	β, γ	β, γ					
212		α					
211							
210	^{210}Pb ($T_{½}$=22.3yrs.)	^{210}Bi ($T_{½}$=5.01 days)	^{210}Po ($T_{½}$=138 days)				
209	β	β					
208							
207		α emission					
206	^{206}Pb (stable)						

8 Conclusions

‘Gamma spectroscopy’ data acquisition set-up has been utilized for the evaluation of ^{226}Ra point source and its decay series. A complex decay scheme is a difficult experience, requiring careful examination of all available data to ensure consistency throughout the assessment.

One of the major problems in quantitative gamma-ray spectroscopy is the determination of detection efficiency, for different gamma energy lines, detector geometries, compositions of samples or sources. Detector efficiency calibration for different gamma energies is a way of solution. Genie-2000 software provides certified data files

as reference values those are applied for efficiency calibration. Obtaining the unknown efficiencies for different gamma energies is being applied for activity calculation. Energy calibration of the data acquisition setup is done using known point sources ^{137}Cs and ^{60}Co. The steps from preparation to spectra analysis should be balanced and all the gamma-rays need to be included with their uncertainties and all other relevant information that needed to make best use of data. However, ^{226}Ra decay scheme consists of alpha & beta emissions those are not detected and analyzed in this study. Direct measurements are required for better study on all emission probabilities.

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