Analysis of ^{137}Cs Presence in Human Scalp Hair Samples Using High Purity Germanium Detector

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Abstract
Human hairs are one of the most important bio-indicators that be used for environmental and workplace exposure to toxic elements. The analysis of hair for its radionuclide content would reflect the intake of the nuclides into the human body over several preceding months. In this study investigation the presence of radioactive isotope (^{137}Cs) in hair of radiation worker at Al-Tuwaitha site by using gamma spectroscopy. We chose 50 people to study the scalp hair samples. Divided into two groups (25 radiation workers, 25 control groups). The specific activity of radio-cesuim ^{137}Cs in hair samples was measured by high purity germanium detector. No statistically significant difference was seen in ^{137}Cs between hair sample of radiation worker and control group (P-value: 0.4563, $P \leq 0.05$). In conclusion, worker and control groups were founded equally exposed with the same level ^{137}Cs within normal limit under Minimal Detection Activity (MDA).

Keywords: Radioactivity; Cesium nuclide; Highly-pure germanium; Scalp hair
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1. Introduction

Human beings are continuously exposed to ionizing radiation from the world around them, whether it comes from the earth, the atmosphere, or medical treatment. This is a normal occurrence and has always been the case. According to the International Atomic Energy Agency (IAEA), the radiation dose to the public is not more than 1 mSv per year. The international standard is to enable people working in and around radioactive material (researchers, workers at the nuclear power plant, X-ray technicians) to have exposures of no more than 20 mSv per year [1,2].

The ionizing radiation enters the body depends on the source of the ionizing radiation. X-rays and gamma rays may penetrate the body directly when exposed to an irradiating source. Alpha and beta particles do not penetrate the body very far but radioactive materials, which emit alpha, beta, or gamma radiation can be taken into the body alone or with other contaminated materials [3,4].

The main entry pathways for materials contaminated with radioactive isotopes include the nose and mouth, around the eyes and cuts in the skin. Materials contaminated with radioactive isotopes may also become trapped under the fingernails, in hair follicles and folds and creases in the skin. If the contaminated material enters the body by either ingesting or inhaling, the risks become greater depending on the quantity and type of radioactive isotope absorbed [5,6].

Various types of body tissue can be used as biological bio-monitoring. Human hairs are one of the most important bio-indicators that be used for environmental and workplace exposure to toxic elements [7,8]. The World Health Organization (WHO), Environmental Protection Agency (EPA), and IAEA have recommended the use of hair for worldwide environmental monitoring [9].

Trace elements incorporated into hair from the body (endogenous) must be differentiated from contamination by external (exogenous) source. To assess the suitability of hair as an indicator of trace elements and radionuclides exposure, we focused on the mechanism of contamination by exogenous matter [10,11]. The analysis of hair for its radionuclide content would reflect the intake of the nuclides into the human body over several preceding months [12]. Many radiometric methods for the determination of radionuclides for exact measurements, detecting radiation energy [13,14].

In this study investigation of the presence of radioactive isotope such as cesium, in hair of radiation worker at Al-Tuwaitha site by using gamma spectroscopy.

2. Materials and Methods

2.1 Calibration Gamma Spectroscopy

To obtain accurate results such as isotope detection, qualitative and quantitative analysis, the gamma spectroscopy system has to be calibrated both in terms of energy and efficiency. The High Purity Germanium (HPGe) Detector energy and efficiency calibration is as follows:

2.1.1 Calibration Energy

The calibration energy consists in the experimental determination of a function, usually a first degree polynomial, describing the energy of the incident photon dependence of the channel number in the spectrum. To find the relationship between the channel numbers and energy of photon, the standard sources of multi-peaked and/or multi-nuclide radioactive emitting gamma must be used. The multi-nuclide radioactive with different energy type (CBSS2) has certification no. 050219-1746026 used for energy calibration. This mix of radionuclide placed in petri dish with the same geometry as that of petri dish used to measure the scalp hair samples. This procedure can be reducing the error in the determination of the peak energy.

Table (1) shows the information of multi-nuclide radioactive has been used for calibration of energy.

Table (1) The radioactive isotopes data of standard source has been used for calibration

Radionuclide	Half-Life (days)	Activity (kBq)
Am-241	158004	4.317
Cd -109	461.9	15.34
Ce-139	137.64	1.671
Co-57	271.81	1.100
Co-60	1925.2	2.512
Cs-137	10976	2.073
Sn-113	115.09	2.413
Sr-85	64.850	5.102
Y-88	106.63	5.219
Cr-51	27.704	26.00
Pb-210	8119.3	17.46

The measurements of calibration carried out by putting the petri dish, which contained of standard source in the gamma spectrometry for 3600 seconds. The channel number and associated peaks were recorded and the graph between channel number and the energy was plotted. Figure (1) shows the spectrum of gamma ray of mixed radionuclides calibration source. While the relationship between energy of gamma lines and channel numbers is illustrated in Fig. (2), one can easy notice the linear relationship between the channel numbers and gamma-ray energies and mathematically represented by the following equation:

$$E\gamma = A + B \cdot Ch \quad (1)$$

where Eγ is gamma-ray energy, Ch is the spectral channel number for the center of the peak corresponding to Eγ (usually the channel with the maximum number of counts), A and B are constants to be determined for calibration.

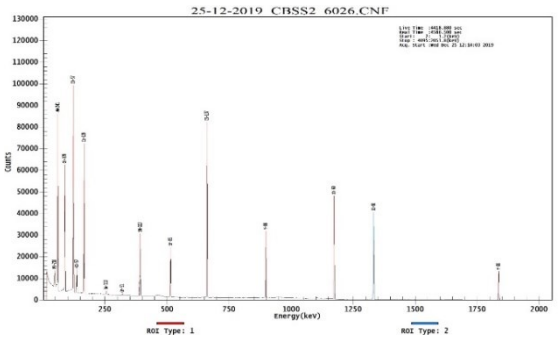

Fig. (1) The spectrum of gamma ray of mixed radionuclides calibration source

2.2 Calibration Efficiency

The calibration efficiency carried out using mixed standard source with different ranges of energy, which is the same standard source of multi-nuclide radioactive emitting gamma used in the calibration energy. This calibration allows the establishment of the detection efficiency of the detector as a function of the energy of the radiation, as well as allows finding the efficiency for those energy gamma rays, which does not present in the standard source has been used. The value for efficiency is dependent on the geometry of the sample size, density, and distance from detector. As shown in Fig. (3), the detection efficiency curve increase very rapidly with energy up to maximum value and then decreases in much smother manner after the turning point, and throughout the high-energy region.

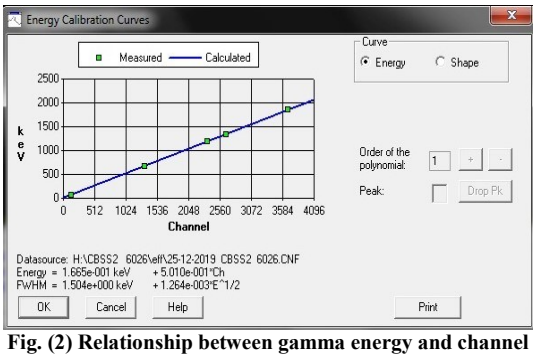

Fig. (2) Relationship between gamma energy and channel numbers

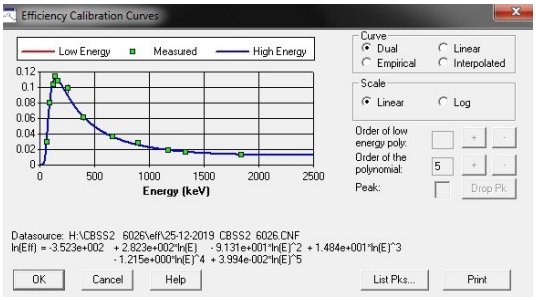

Fig. (3) The efficiency calibration curve of (HPGe) detector using mixed standard source

The detection efficiency of a nuclide for specific energy can be calculated from the formula:

$$\epsilon_\gamma = \frac{N}{I_\gamma \times T \times A_c} \times 100\% \quad (2)$$

where ϵ_γ and I_γ are detector efficiency and intensity at the energy E_γ, T is the counting time (3600 s) and A_c is the activity in Bq of standard source at the measured time, N is the net peak area under the specific peak corrected for the background at energy E_γ

2.3 Subjects of Study

We have chosen 50 people to study the scalp hair samples. Divided into two groups (25 radiation workers. This group who have daily work in radiation field (13 from Radioactive Waste Treatment and Management Directorate, 9 from the Radiation Safety Directorate, and 3 from Directorate of radiation filtering, 25 control groups). We take the highest values of TLD for radiation worker to select scalp hair as sample in our study Physical dosimeter records indicated that the total accumulated radiation doses in these individuals varied from 0.47973 to 2.28802 mSv for scalp hair sample groups as revealed in table (1). All subjects completed a standardized questionnaire that included information regarding personal data (age), time of employment (involving occupational exposure to IR up to the sampling time), non-occupational exposure to potential mutagenic hazards, smoking consumption.

2.4 Hair Samples Collection

The human hair without dying was collected from the scalp of the occipital region of male radiation worker and control only, using a pair of stainless steel scissor, the length of hair samples 3-4 cm was cut from the head, while the weight of a hair sample ranged between 7-9 g. Each hair

samples were filled into secure polyethylene bag with sealable tops to prevent cross contamination and store. The hair sample is contained label recorded in it the information about the sample such as code, date of collected, from any directorate. Samples collected from radiation workers were labeled from R1 to R25, while samples collected from control group was labeled from C1 to C25.

Table (2) Characterization of the samples (control and radiation worker populations)

Sample characteristics		Control	Radiation worker
Number of individuals		25	25
Exposure time (years) (X*± SE*)		0	18.84±7.79
Gender [n (%)]	Male	25 (100%)	25 (100%)
	Female	0	0
Age (years) (Range)		32-58	30-61
Smoking status (n%)	Smokers	0	0
	Non-smokers	25 (100 %)	25 (100%)
Duration of employment (yr) (Range)		0	4-35
Radiation burden over the last 2 years (Range mSv/years)		-	0.479-2.288

2.5 Washing of Hair Samples

After collection the hair, it was wash to remove only the exogenous contaminants. Endogenous contamination results from long-term exposure to substances that enter the organism and are incorporated into the hair structure during its growth, while exogenous contamination is due to contact of hair with smoke, cosmetics, sweat, handling during collection and storage, etc. The IAEA has recommended a standardized washing procedure [15]. The recommended procedure consist of 5-10 min washings under mechanical shaking using ultrasonic cleaner (QUIGG company, Germany) successively with acetone (Chem.-Lab, Belgium), three times deionized water (DDW), and acetone, and decanting off the wash liquid after each 5-10 min wash and then dried at room temperature for 24 hr. before use.

2.6 Digestion and measurement Samples

An accurately weighed portion (1g) of the hair sample placed in a clean reagent bottle with 25 mL capacity. 12 mL concentration 1M 70% HNO_3 (Sigma, USA) and 6 mL 50% H_2O_2 (Himedia Co., India) was added to reagent bottle and placed on hot plate (MEDILAB Co., Korea) for period between 25-60 min and heated at 90°C until the hair is completely digested, finally solution becomes clear in Fig. (4). After cooling to room temperature inside the fume hood. We put the sample in a petri dish with a diameter of 10 cm and a height of 1 cm and weigh it, Fig. (5).

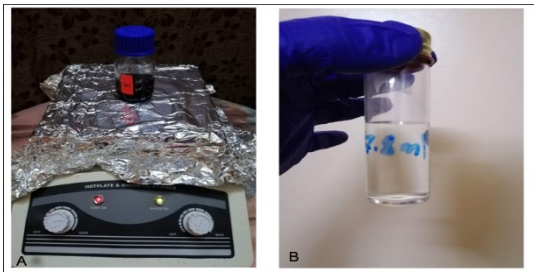

Fig. (4) (A) Digestion, (B) Result of digestion, for analysis by gamma spectroscopy

After then for measured the radio ^{137}Cs, sample was analyzed for a time four hours by high purity germanium detector (CANBERRA Company, USA) in laboratory of gamma spectroscopy in Central Laboratories Directorate, Ministry of Science and Technology with relative efficiency ≥40 and 1.8 keV energy resolution. HPGe crystal that has a diameter of 62 mm, a length of 60 mm and a distance from window 4.67 mm.

A cylindrical shield, surrounds the detector consisting of lead, copper, and cadmium with thickness of 11.5 cm, which provides an efficient isolation from other radiation sources used in nearby surroundings present at the laboratory site linked to a multi-channel analyzer made by Canberra instrument, and used the (Genie 2000) analysis program to analyze the spectra resulting from sample measurement.

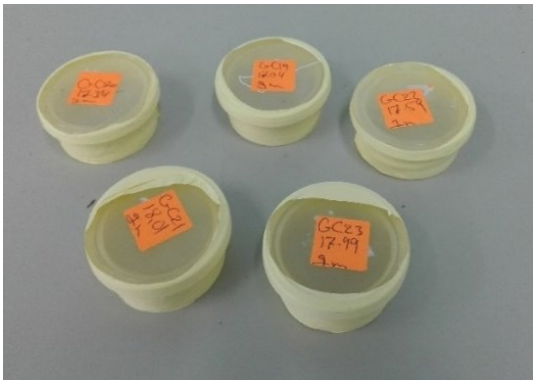

Fig. (5) Petri dish used for analysis by gamma spectroscopy

The specific activity of radionuclide in the sample can be calculated using the following equation:

$$A = \frac{N}{t \times I_\gamma \times \epsilon_\gamma \times M} \quad (3)$$

where A is the specific activity, $N=N_S-N_B$, where N is the corrected net peak area of the corresponding full energy peak, N_S is the net peak in the sample, N_B is the net peak in the background. t is the counting live-time of the sample spectrum collection (3600 s), I_γ is the emitting intensity of gamma ray, ϵ_γ is the detection efficiency and M is the weight of the sample (g)

4. Results and Discussion

The main purpose of the gamma-ray spectrometry with HPGe detector is the determination of quantification of the activity concentration for radio-cesium isotope in human hair sample. The activities of gamma-emitting ^{137}Cs were measured using gamma spectrometry system based on the analysis of the energies and peak areas of the gamma lines.

Table (3) Descriptive statistics, p-value for ^{137}Cs in hair of radiation workers and control group by gamma analysis

Descriptive statistics of ^{137}Cs activity (Bq/kg)		
	Control	Radiation Worker
Mean	0.0042	0.0066
Standard Error	0.0003	0.0032
Median	0.0013	0.00414
Standard Deviation	0.0016	0.0162
Minimum	0.000000159	0.000000232
Maximum	0.0083	0.0819
Count	25	25
P- value	0.4563	

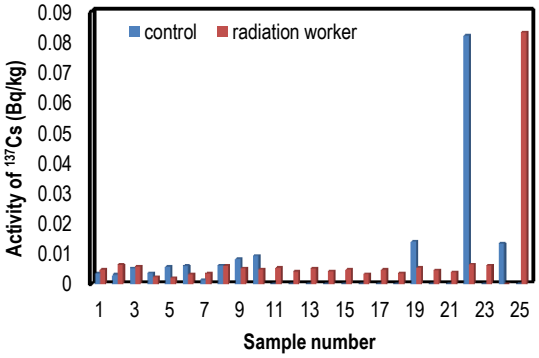

Fig. (6) The activity of (Bg/kg) for ^{137}Cs of control and radiation worker groups

Table (3) shows the descriptive statistics, p-value of radio-cesium isotope (^{137}Cs) (Bq/kg) in hair of radiation worker and control group. The average ±SD of ^{137}Cs (0.0066±0.0162), (0.0042±0.0016) in radiation worker higher than control group, however, no statistically significant difference was seen in ^{137}Cs between hair sample of radiation worker and control group (t-Test: p-value: 0.4563, P≤0.05). Figure (6) shows the activity of (Bg/kg) for ^{137}Cs of control and radiation worker groups, and figures (7) and (8), show the spectrum of gamma ray for maximum value of ^{137}Cs in some samples. Hair from male radiation worker and control show about the same level for ^{137}Cs. The activities were between 0.000000159 Bq/kg for control and 0.0819Bq/Kg for radiation workers. Kramer *et al.* (2018) found that the activity of ^{137}Cs in hair samples of Swiss men was 0.07±0.04 Bq/g although, the activity of ^{137}Cs in hair samples from Japanese men collected at Minamisoma-city, which is situated in 30km-exclusion zone around the NPPof Fukushima Dai-ichi was 2.3±0.2 Bq/g [16]. The activity of ^{134,137}Cs that found in hair samples were taken from inhibitants of cities Minsk and Kiev who did not visit Chernoble area were in the range 0.012-0.047 Bq/g. The activities of ^{134,137}Cs for post-accident workers were 0.04 and 0.024 Bq/g, respectively [17].

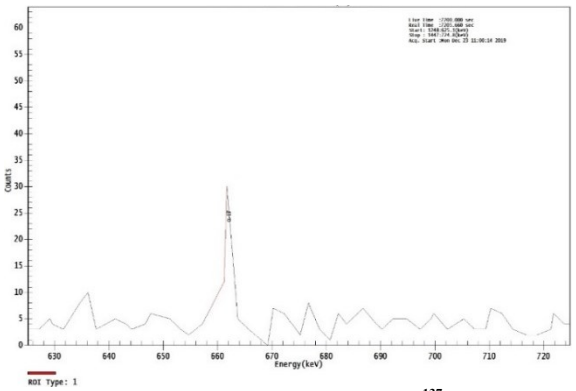

Fig. (7) Gamma ray spectrum for maximum ^{137}Cs in sample

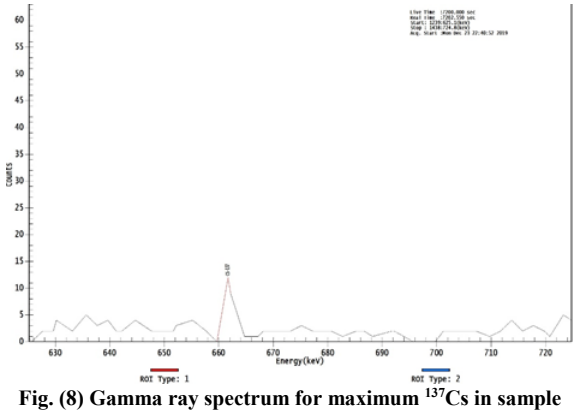

Fig. (8) Gamma ray spectrum for maximum ^{137}Cs in sample

5. Conclusion

In conclusion, worker and control groups were founded equally exposed with the same level 137Cs within normal limit under Minimal Detection Activity (MDA), after analyzed by gamma spectroscopy.

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