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Research Article

Calibration of a conventional hand-held gamma spectrometer for measuring inner internal contamination in the thyroid

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ABSTRACT
After a radiological radiation despite the fact that whole-body counter is a special apparatus especially to measure total body radiation, there is not enough time to transfer injured people to the centers equipped with this device. This project discusses about the possibility of measuring radioactivity caused by the breathing of individuals at the time of incident by hand-held spectrograph. Experiments and measurements have been carried out by a gamma-ray spectrograph and a thyroid phantom and a 131I hotbed. It should be noted that background radiation plays an important role in the outcome of the final result in all stages of testing and measurements which its effects will be examined separately. In the end, an instruction will be prepared for calibration of handheld gamma spectrometers with regard to extracting parameters affecting the efficiency and minimum detectable activity and its measures will be developed for provision and deployment in nuclear disaster management centers in the country. The absolute return of detector was measured for Phantom thyroid containing 131I in the range between 0.1 and 0.03 in terms of distances up to 15 cm. in this research the amount of LLD was obtained to be equal to Bq128 which was in line with the results of Sumber group (equal to 142 Bq). We also practically showed that this device is capable of identification and estimation of 131I- activity inside thyroid phantom in values near Bq250. This device has the required practical capability to classify internal contamination of patients and it is very useful in this respect for programs of internal contamination estimation in radiological accidents which may occur in nuclear medicine centers and the nuclear industry.

Keywords: calibration, handheld gamma spectrometer, thyroid

1. INTRODUCTION
A nuclear and radiological accident is actually an accident during which radionuclides will be distributed in the environment. These accidents can usually be the result of natural disasters such as earthquakes or floods or acute problems and technical defects or terrorist activities and sabotages. According to reports, about 1495 radioactive sources have been stolen or lost in the US from October 1996 to September 2001 and each of them can cause a nuclear accident [1]. This project discusses about the possibility of measuring radioactivity caused by the breathing of individuals at the time of incident by hand-held spectrograph. The detector used in this study is a gamma-ray detector, thus only sources of gamma-ray emission have been examined in this project while these infections can occur in form of alpha and beta and gamma radiation. A joint report from energy department and nuclear commission introduces radioisotopes which have the greatest attention in this regard in pairwise form which are: 137-Cs ,192- ,Ir241Am- ,60-Co [2.3]. In the same

way, two 90-Y and 90-Sr sources which emit electrons in their beta decay are also important, these electrons may cause Bremsstrahlung. These radionuclides are industrially used for medical diagnosis. For example, 241Am- is industrially used in smoke detectors and 137-Cs and 192-Ir are used in cancer treatment. In addition to these 6 radionuclides 131I- is used in Disease Control and Prevention centers and in diagnosis of thyroid cancer [4]. After a nuclear and radiation accident, many individuals may suffer from external contamination or internal contamination by breathing radioactive materials and refer to hospitals or other centers. Hospitals usually will not be able to prescribe proper drug for all of these individuals because external contamination methods have been defined much more completely while methods for expressing internal contamination especially in cases where a fraction of radioactive material have been inhaled into the body are yet to be fully defined [4]. Hence, designing a method to accurately evaluate injured individuals to separate people in need of medication from others is necessary so that meditation is done in cases where the drug is needed without delay after the entry of radioactive material to the body. Whole-body counter is a device designed to measure and determine the concentration of radioactive substances in the human body. This device is equipped with a highly sensitive detector in a chamber of lead shielding to reduce background radiation [5]. Despite the fact that this device is the best way to measure radioactivity in the body in a nuclear accident, it is usually located far away from the city center and it is also not capable of counting activity for a large number of people in a short time. Thus, any device which has the ability to estimate radio isotopes in the environment must be used to monitor radioactive contamination in the environment and inside of the body in in nuclear and radiological accidents. It should be noted that currently the monitoring of contamination of people is focused on by many responsible centers including IAEA with respect to growing use of radioactive materials in industry and medicine. The use of Portable detectors which are capable of gamma spectroscopy help a lot in evaluation of internal contamination of patients as available equipment at the scene [6]. These detectors are less sensitive compared with whole-body counters but can be used in quick measurement of radioactivity in thyroid of injured person. For example, Sodium iodide detector is available in most universities and nuclear laboratories in large cities. These detectors are spectrographs which identify peaks of a radionuclide in the resulting spectrum. These devices can even be purchased with a lower price compared to semiconductor counters. An example of these portable detection equipment is GR-135 mini SPEC handheld spectrometer which has NaI (Tl) detector. The detection efficiency for intended source of 131 I- must be measured and estimated for determination of efficacy of this handheld detector [7]. In special cases a thyroid phantom with a standard gamma source has been used to determine the use of these detectors in which calibration of handheld gamma spectrometers is done after carrying out the necessary measurements by Exploranium GR-135 mini SPEC detector with respect to calculations related to minimum detectable activity. In the end, the output of the device will be the activity and the sensitivity of device will be examined more closely during the project. Use of gamma spectrometers in the country to determine the internal contamination of 131 I- gamma elements in thyroid and formation of a secondary calibration laboratory in the Institute of Nuclear Sciences in this regard can easily make the importance and necessity of this study clear. Access to a portable and quick detection device to determine the internal contamination in thyroid and forming a system for fast detection in control of internal contamination of radiation personnel can be considered as one of the main objectives of this study. Gamma-ray spectrograph, thyroid phantom and minimum detectable activity are terms which will be studied during the project.

Gamma-ray spectroscopy in above mentioned tests is done by IdentiView software which is the operating software of mini SPEC GR-135 detector which means that this spectrograph determines the number of photopeak and all of the information necessary for the analysis of gamma-ray spectrum can be collected in this way because we need the minimum detectable activity such as the number of photopeak, counting of background radiation and etc.

2. Research background and literature

Adverse effects of radiation on human health have been discovered after years of discovery of X-rays and radioactive materials and increasing use of radiation in different aspects of life and the entry of unwanted radiation has become inevitable to life cycle in a way that conclusion of 400 atmospheric nuclear tests in the atmosphere only in 1950 to 1960 led to production and fall of hundreds of radioactive elements to the environment. Scintillation detectors (sodium iodide) and semiconductors (germanium) are usually used for gamma spectroscopy in laboratories to assess and control radiation of environmental samples. In this case, given the low level of radioactivity in environmental samples and t the fact that this measurement is a low-level measurement, Scintillation detectors of sodium iodide are evaluated as detectors with high efficiency and easy access [8]. Almost all methods of detection with the exception of Cherenkov detector use absorption of all or part of the energy of nuclear particles resulting from ionization or excitement caused by detector environment. In case of charged particles, ionization and excitation occurs by the interaction of electromagnetic field of particles with electrons of detector environment and in the end we will observe other ionizations and excitations in the line of movement of primary particles. Uncharged particles such as gamma rays and X must transfer all or some of their energy to electron to create ionization or excitation under several processes including Compton or photoelectric interactions. In a similar way, neutrons create particles which play an important role in ionization or excitation under the effect of interaction with a nucleus [9]. As it was expressed, the gamma rays can store energy in the detector through three mechanisms (photoelectric- Compton scattering - ion pair production). In figure (2-2), an input photon to the detector can save all of its energy in the detector by photoelectric interaction (A) or save its energy again in the detector through photoelectric interaction of its energy after one or several Compton scattering (B) A photon entering through Compton scattering and escaping of scattered light from the detector, only a fraction of its energy is stored in the detector (C) If the photoelectric interaction occurs near the wall of detector, there is the possibility of escape for formed X-ray (due to movement of upper-layer electrons to lower layer) and this results in not being able to store all incoming photon energy in the detector (D) Most detectors have guards to reduce background radiation. Gamma rays or X-rays can stored their energy in the detector after interaction between photon and the guarding material.

The entering photon may cause Compton interaction in the guard and the scattered photons may enter the detector (E) or the X-ray generated by guard may have interaction with the detector (F) or the photon created due to collapse of ions may enter the detector due to generation of a pair in the guard (G) most of the X-ray and gamma interactions are with atoms of iodine (I) in sodium iodide detector (NaI(Tl)) and this is due to high atomic number of sodium compared to iodide. However, thallium also has a high atomic number but it is only used as an impurity with a very low amount in the crystal of sodium iodide [11].

2.1. Theoretical Foundations of Research

Among all conventional scintillations, NaI crystal which has been activated with thallium has the most application for detecting gamma rays. Scintillation counters of NaI (Tl) are used when energy resolution power is not the most important factor in intended measurement. Nowadays, NaI (Tl) detectors are provided either in form of crystals with desired size or in form of a complete set mounted on a suitable photon multiplier. In this set, the front surface of the crystal has been covered by a flat window and its other sides have been aluminum to prevent moisture and destruction as well as magnesium oxide as restorer. Optical Amplifier is in contact with crystal and a clean silicone oil has been used to ensure the transmission of light. Optical amplifier is connected to the main base. Pins of base key are connected to high voltage power supply in a series. There is usually a pulse amplifier behind the optical amplifier and as a result pulses can be transferred without electrical noise by cable. The set of crystal, optical amplifier, resistor string and amplifier can be placed in a sturdy and light box. Some of these boxes are sealed by the manufacturer and some are separable and provide the ability to be replaced. All of these components must be used carefully. If the crystal is hit, some undesirable levels may form inside of it which leads to appearance of high reflection and refraction of light which reduces the he resolution of Crystal [10].

3. MATERIALS AND METHODS

3.1. Evaluation of hardware and software characterization of GR-135 handheld gamma spectrometers GR-135 handheld gamma spectrometers are a major transformation in the field of radiation monitoring. This device not only allows the user to search and find radioactive materials but it also automatically identifies radionuclides. GR-135 handheld gamma spectrometer has been made of Nal (TI) crystal detector with the volume of 4.5 in^3 which its weight is 5.5 lbs. this detector can be used to measure the count rate or for spectral analysis of light source. GR-135 detector and its navigation used in this article have been shown in figure (4-1). The highest efficiency is in front of the detector that is why the front panel is used to measure the light source. Appropriate applications of this detector in addition to spectral analysis are surveying contaminated soil and determination of its risk level. Survey mode, Dose rate mode and Nuclide identification mode are used in this detector. The detector must be calibrated with 137-Cs source with the activity of 0.25 Ciµ before carrying out any measurement. The manufacturer company provides this source along with the spectrometer.

3.1.1. Describing the system and hardware and software specification [7]

3.1.2. Available modes in the system:

GR-135 can work with two methods of radiation monitoring:

A) Search + Dose mode:

In this mode, the GR-135 acts as a searcher which shows the count rate at any time in terms of (counts / sec). The light intensity can be determined by changing the level of sound if an automatic sound level meter is used or the user sets the level of alarm. A Chart-record is shown from the last 100 points on the screen during the search. This mode particularly searches for radioactive materials or performs network inspection and surveillance activities for counting. This mode also shows the current dose rate in terms of unit and optional quantity along with cumulative dose with the time at its disposal. A dosimeter is used to determine the relative level of risk and assess the condition for movement of radioactive materials. The surface dose is searched in this mode.

B) Identify mode (core identification):

In this mode GR-135 find the spectral data in terms of level of emitted energy and accumulates the share of net counting from the sample and spectrum analysis. Cores which create spectra are identified by comparison with core library and related tabular form. These essential information can be used to determine the evaluation of risk of radioactive materials.

C) Uses:

131I- is used in nuclear medicine and tracking industry. 131I- is widely used in nuclear medicine due to short half-life and distribution of living particles and it is used for medical diagnosis and treatment of thyroid cancer (131I- capsules containing tiny particles of NaI sodium iodide for medical purposes have been designed to be ingested by patients. Fluid sodium iodide is used for diagnosis and treatment of thyroid disorders).

3.2. Thyroid Phantom

Thyroid Phantom has been made from plexiglas panels attached together. The height of each of these panels is 3 cm and 5 of these panels are attached to each other to each the desired height of 15 cm. two holes have been created in this Phantom as lobes of the thyroid. As it can be seen in the map of phantom, the diameter of each of these holes is 2 cm and the distance between the center and the center of these two holes is 3.3. cm. Also the cross-sectional diameter of phantom is 13 cm. the created phantom can be observed in figure 1. Thyroid phantom has been used in these experiments to simulate the human body in internal contamination.

Figure 1: thyroid phantom made of Plexiglas with vials containing 131l- source

3.3. Arrangement of experiments

As it was expressed in the first section, the purpose of these series of experiments is ultimately the calculation of efficiency and minimum detectable activity to achieve a proper procedure for the use of a gamma-ray spectrograph in emergency contamination.

3.3.1. Phantom thyroid experiments

In the first step, calibration and phantom sources are placed on a flat table free of contaminants. Then detector is placed in phantom containing source at regular intervals. Each experiment is repeated at least three times in order to achieve an appropriate standard deviation. The ability to transfer spectrum to PC will be provided by the respective interface after recording it in the device. The efficiency will be estimated for each above mentioned experiment after spectrum analysis and extraction of data of each photopeak. In the end, the above mentioned values will be quantitatively obtained by estimation of background counting in the same window with determined efficacy value and with the use of formula related to calculation of MDA and LLD.

4. RESULTS

According to what was said in section 4, data measured by GR-135 can be transferred into the computer using IdentiView software. The analysis of spectrum obtained by this program is in terms of counts per second.

4.1. Counting photopeak zone

4.1.1. Thyroid Phantom

Counting of thyroid phantom for standard 131I-source in different distances of thyroid phantom for f 55 seconds and for different activities of source have been shown in table 1 and 2.

Table 1: counting photopeak zone (counts / second) of thyroid phantom at intervals of 55 seconds at different intervals of detector of Phantom for 129.5 kBq activity level of source in one lobe

Counting photopeak 131 keV I-729		Counting photopeak 131 keV I-638		Counting photopeak 131 **keV** I-**364**		Counting photopeak 131 keV I-**77**		Distance Cm
s/n	Area	s/n	Area	**s/n**	**Area**	s/n	Area	
5.9	188	10.6	694	**65.8**	**17024**	9.1	1124	0
5.5	155	10.8	588	**52**	**11698**	7.6	818	5
5.5	155	10.8	588	**52**	**11698**	7.6	818	7
3.3	80	8.3	384	**45.2**	**8323**	5.6	527	10
-	**-**	5.3	186	**32.8**	**4525**	**-**	**-**	15

Table 2: counting photopeak zone (counts / second) of thyroid phantom at intervals of 55 seconds at different intervals of detector of Phantom for 129.5 kBq activity level of source in two lobes

Counting photopeak 131 keV I-729		Counting photopeak 131 keV I-638		Counting photopeak 131 **keV** I-**364**		Counting photopeak 131 keV I-**77**		Distance Cm
s/n	Area	s/n	Area	**s/n**	**Area**	s/n	Area	
10.5	782	28.7	4168	**152.5**	**96585**	24	6892	0
7.7	358	17.8	1630	**100**	**40345**	15.7	3023	5
6.1	208	11.1	740	**71.6**	**20839**	10.1	1461	10
3.3	91	11.7	629	**55.6**	**12533**	7.8	922	15

It should be noted that the values of fwhm% related to keV360 photopeak is 2.9% and is 1.6% for photopeak with 729 keV energy and is 2.2% for photopeak with 638 keV energy. Above counts are obtained from analysis of spectra obtained from the IdentiView program and these spectra can be observed in the next pages in order of mentioned distances.

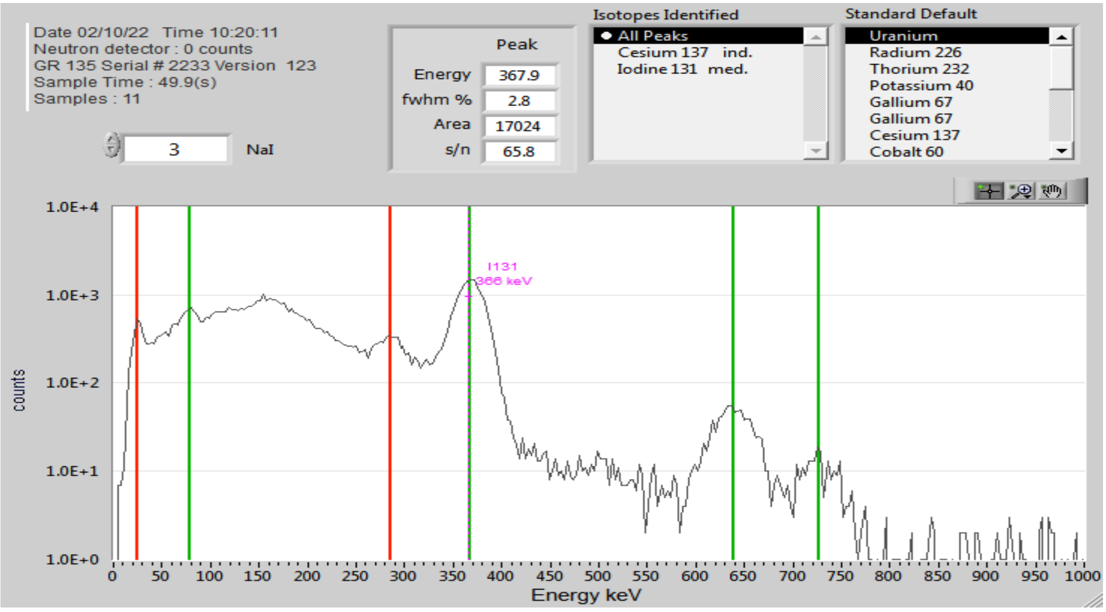

Figure 2: spectrum of gamma spectrometer in 55 seconds detection for distance of 0 cm and in presence of 129.5 kilo Becquerel source in one lobe of thyroid phantom

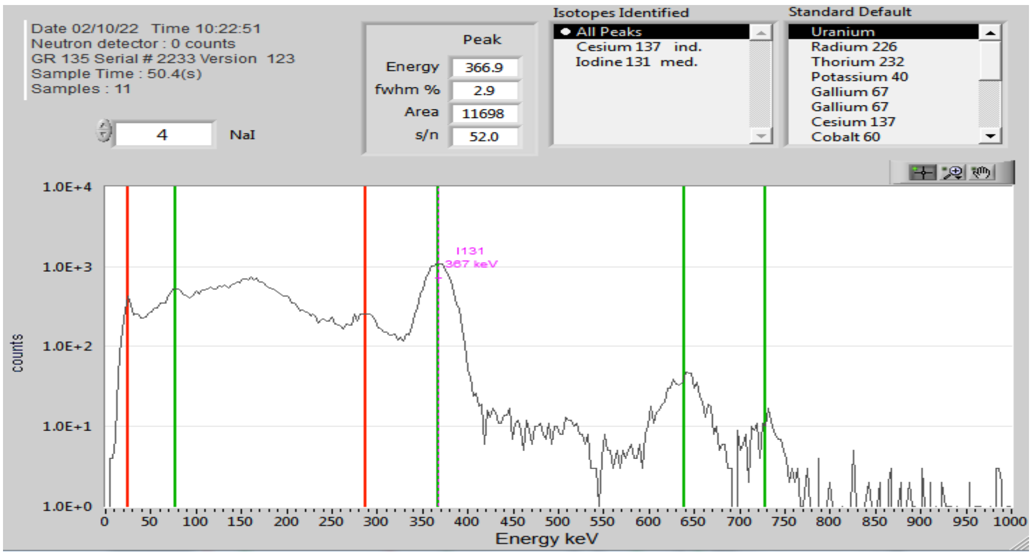

Figure 3: spectrum of gamma spectrometer in 55 seconds detection for distance of 5 cm and in presence of 129.5 kilo Becquerel source in one lobe of thyroid phantom

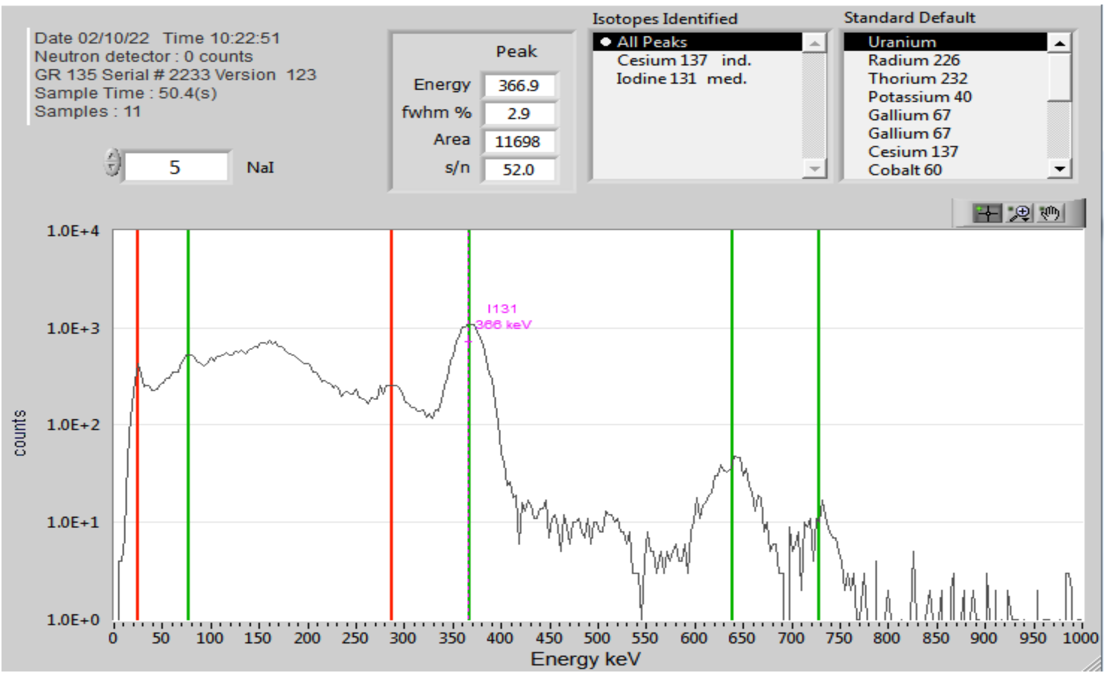

Figure 3 (عدد شکل در متن فارسی تکراری است، لطفا بررسی شود): spectrum of gamma spectrometer in 55 seconds detection for distance of 7 cm and in presence of 129.5 kilo Becquerel source in one lobe of thyroid phantom

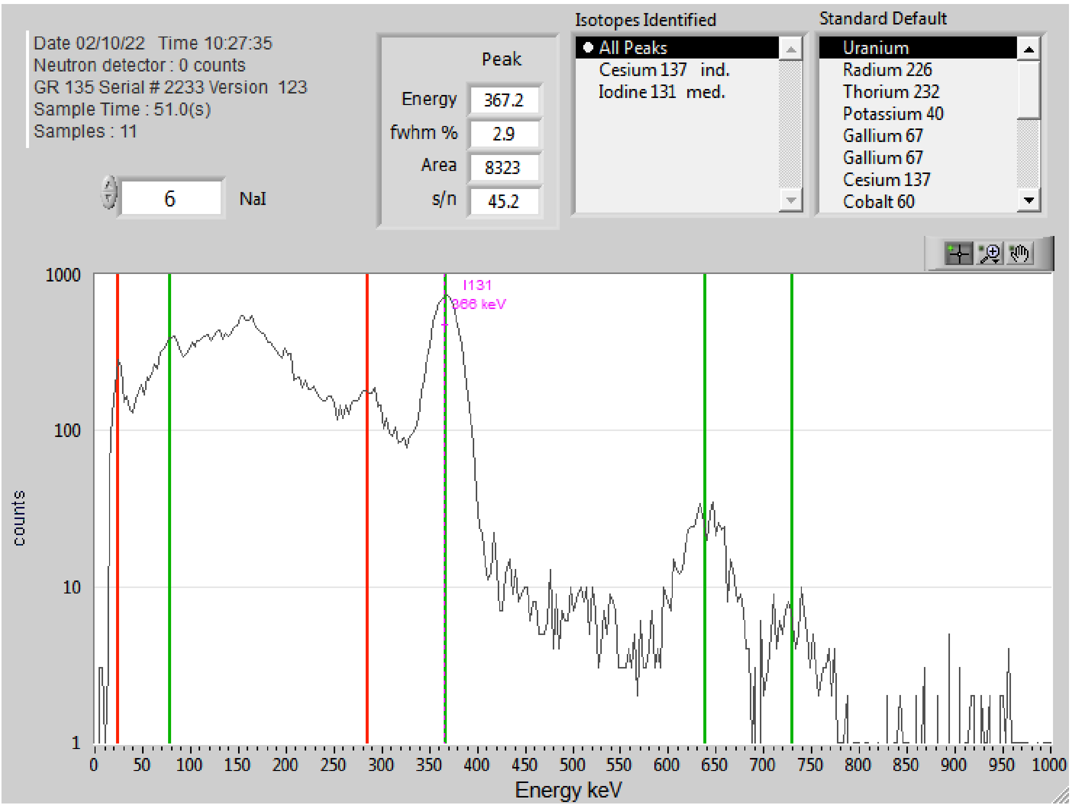

Figure 4: spectrum of gamma spectrometer in 55 seconds detection for distance of 10 cm and in presence of 129.5 kilo Becquerel source in one lobe of thyroid phantom

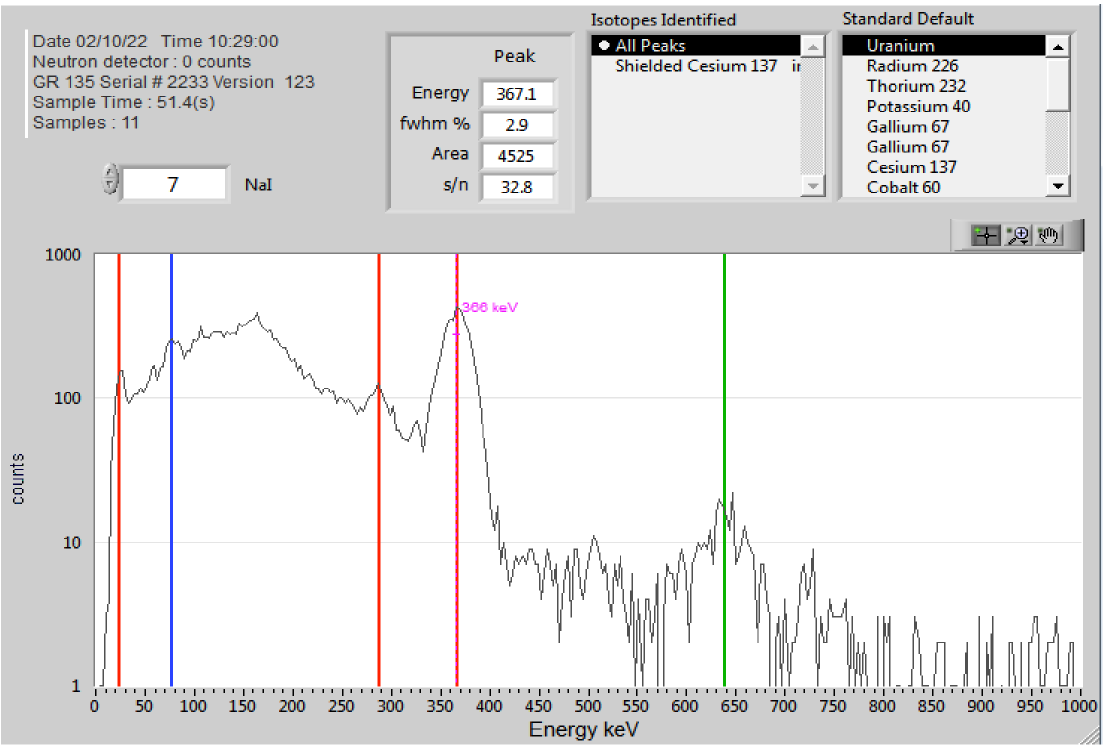

Figure 5**:** spectrum of gamma spectrometer in 55 seconds detection for distance of 15 cm and in presence of 129.5 kilo Becquerel source in one lobe of thyroid phantom

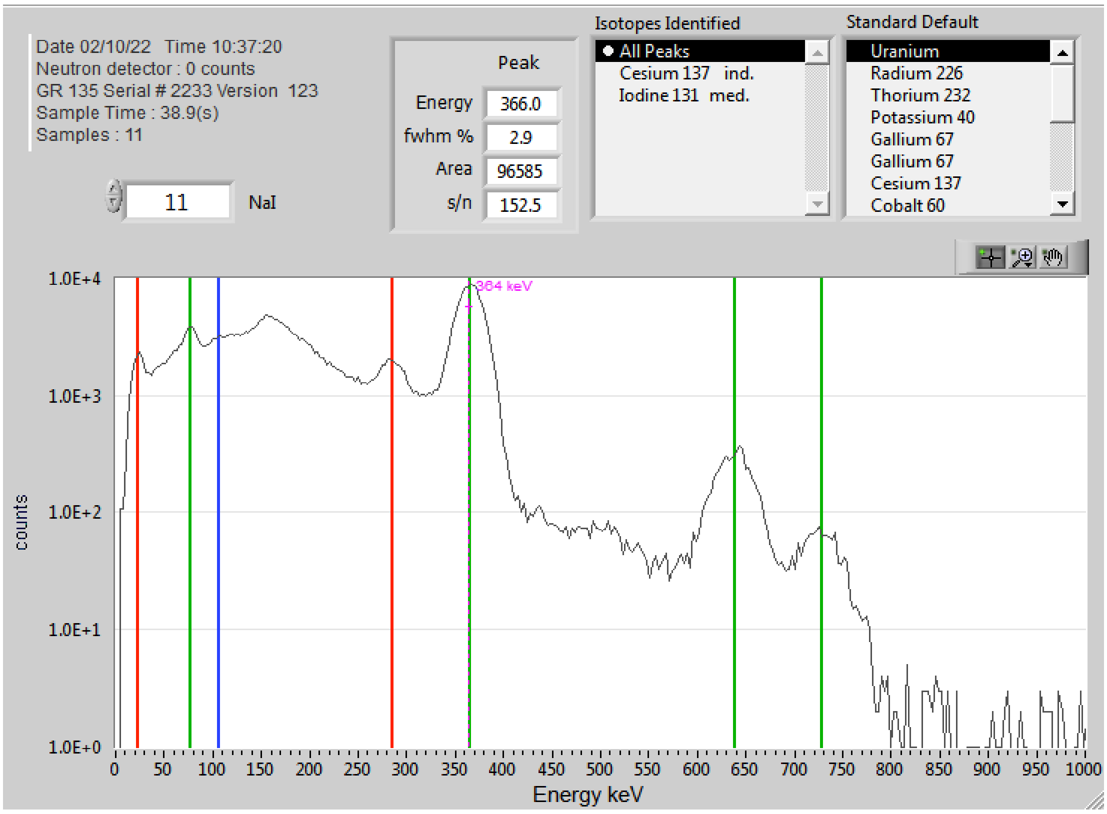

Figure 6**:** spectrum of gamma spectrometer in 55 seconds detection for distance of 0 cm and in presence of 351.5 kilo Becquerel source in two lobes of thyroid phantom

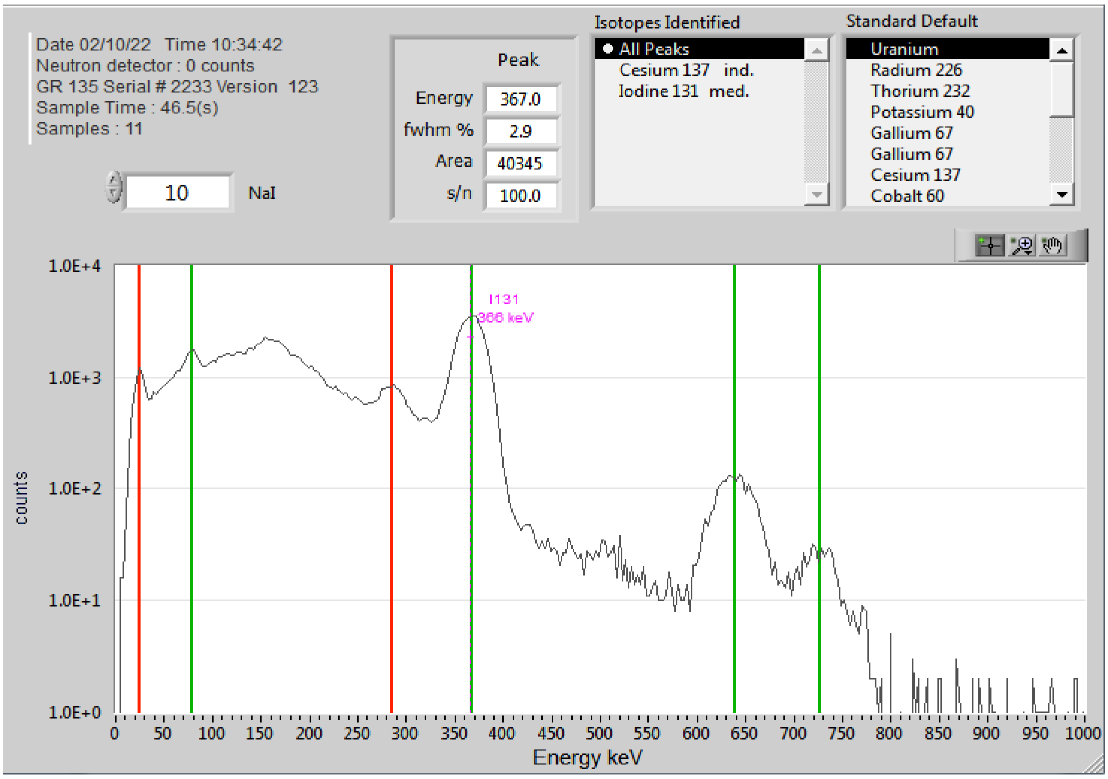

Figure 7: spectrum of gamma spectrometer in 55 seconds detection for distance of 5 cm and in presence of 351.5 kilo Becquerel source in two lobes of thyroid phantom

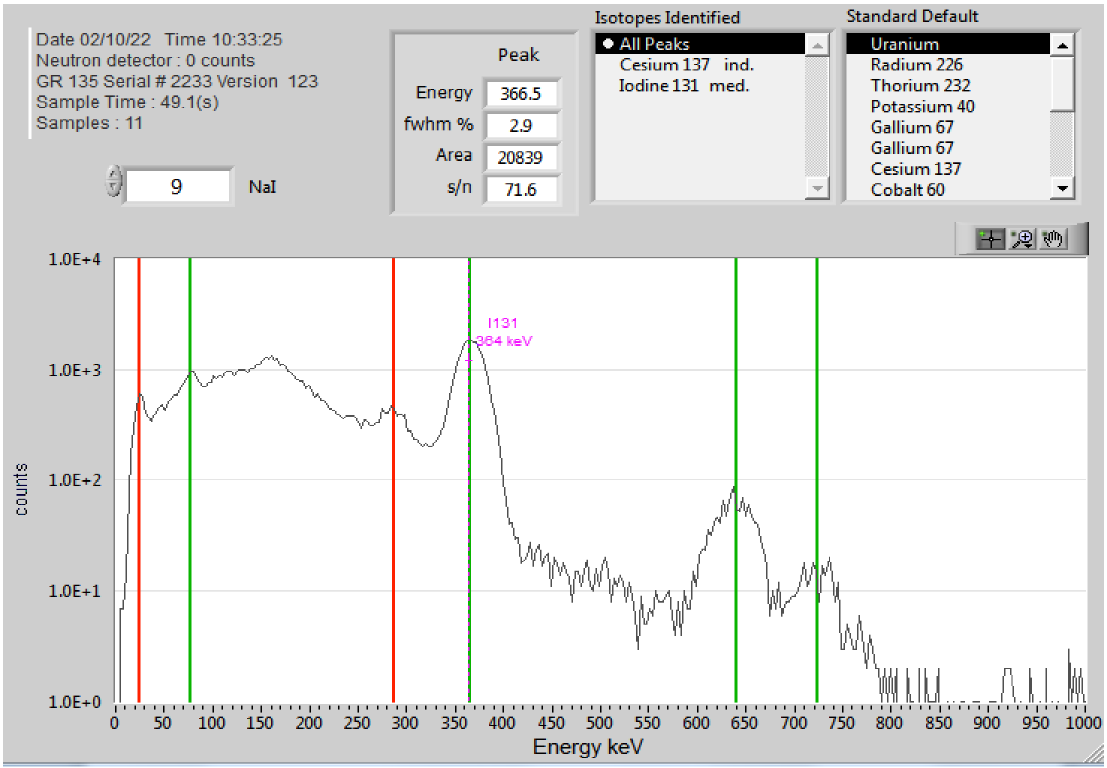

Figure 8: spectrum of gamma spectrometer in 55 seconds detection for distance of 10 cm and in presence of 351.5 kilo Becquerel source in two lobes of thyroid phantom

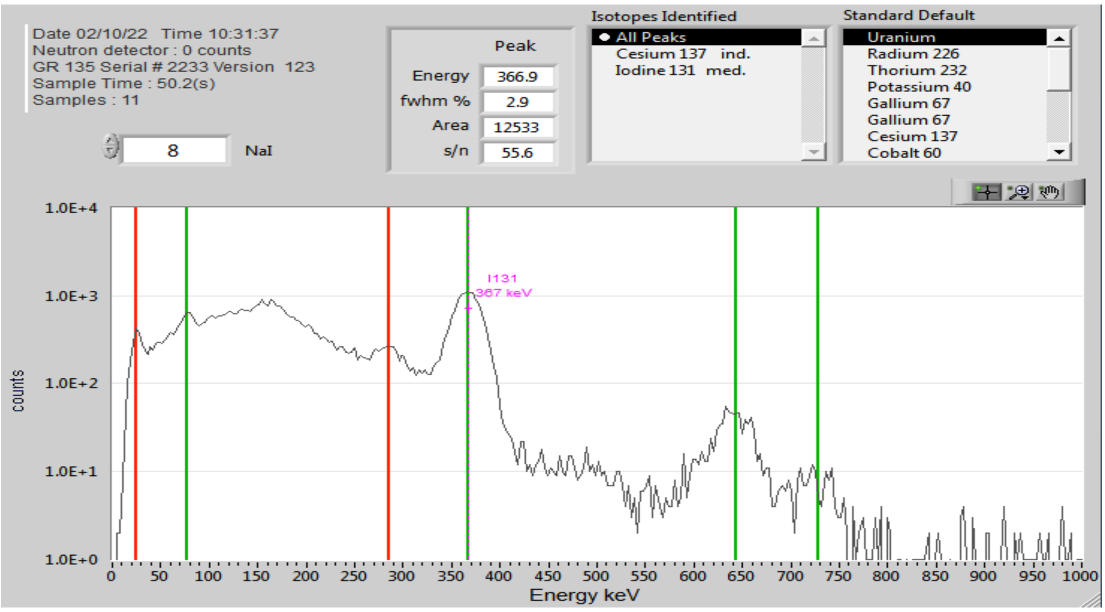

Figure 9: spectrum of gamma spectrometer in 55 seconds detection for distance of 15 cm and in presence of 351.5 kilo Becquerel source in two lobes of thyroid phantom

4.2.1. Computing absolute returns

4.2.1. Thyroid Phantom

The absolute return of GR-135 detector for various distances for the period of 55 seconds with respect to activity calculated for 131-I source to the value of 129.5 kBq and 351.5 kBq was calculated in the same way mentioned in section (4-5) and its results can be observed respectively in Tables (3) and (4)

Table 3: The absolute return of thyroid phantom at intervals of 55 seconds at different intervals of detector of Phantom for 129.5 kBq activity level of source in one lobe

I-131 Absolute return	Distance Cm
0.1314	0
0.0903	5
0.0903	7
0.0642	10
0.0349	15

Table 4: The absolute return of thyroid phantom at intervals of 55 seconds at different intervals of detector of Phantom for 129.5 kBq activity level of source in two lobes

I-131 Absolute return	Distance Cm
0.2747	0
0.1147	5
0.0592	10
0.0356	15

As it was expected, increasing distance from thyroid phantom reduced the absolute return for primary gamma photon because less photons reach the detector by increasing the distance of photons

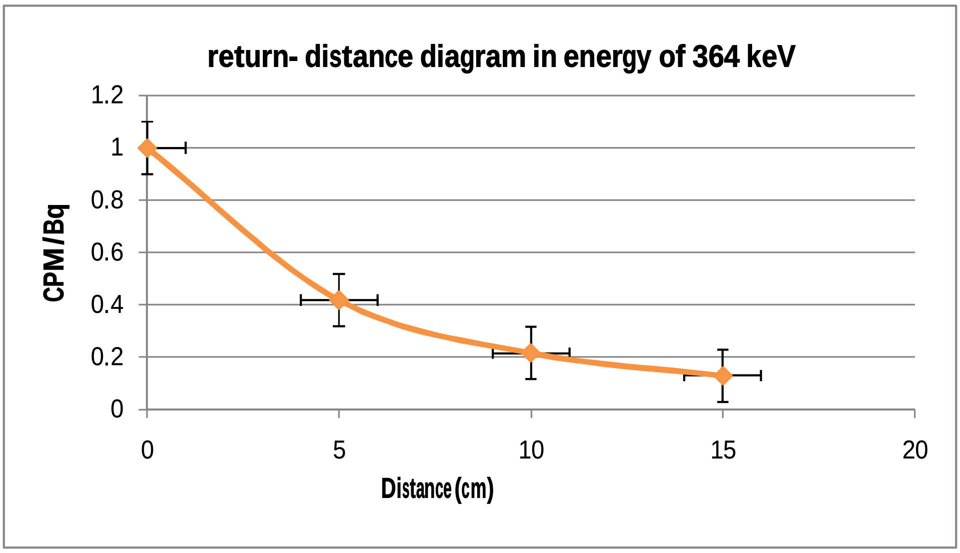

Figure 10: the dependency of normalized values of MDA in relation to the distance

4.3. Background radiation

As it was mentioned before, the experiments of this project were carried out in Novin Nuclear Medicine Institute in Tehran, thus it is obvious that the background radiation spectrum in this place can be quite different from background radiation spectrum in the place of measurement at the time of a radiological incident. Spectra related to background radiation for 55 and 300 seconds can be observed in the following section.

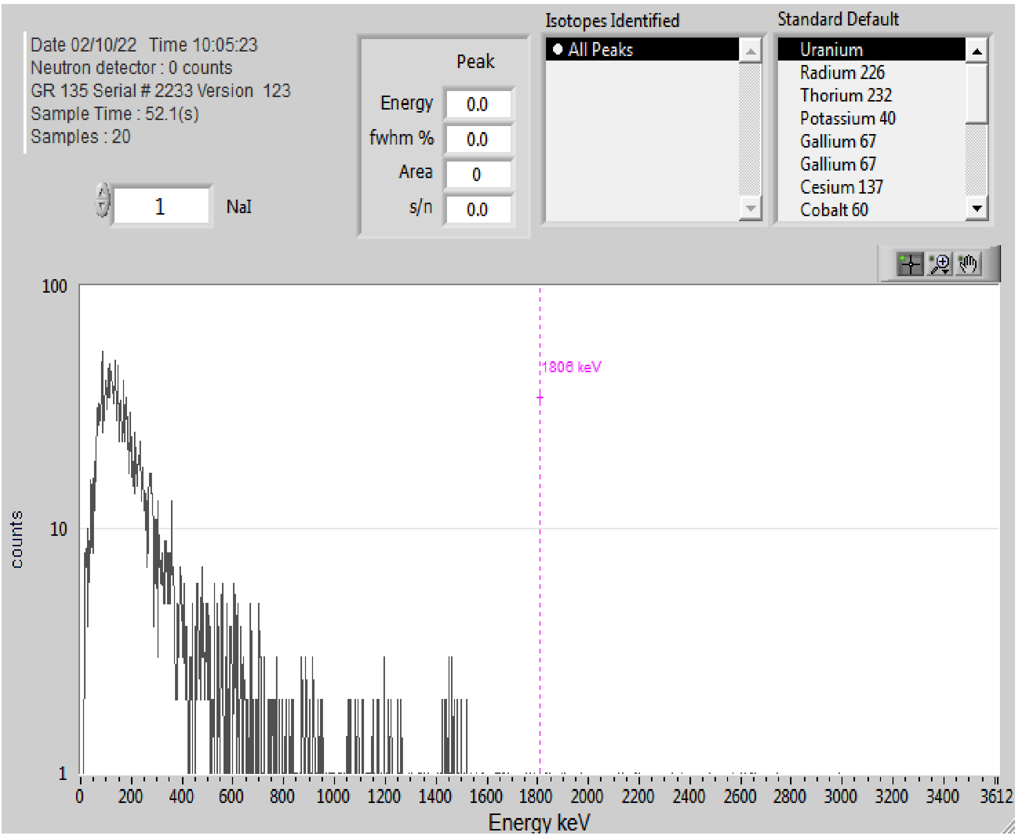

Figure 11: background radiation spectrum for 55 seconds of measurement

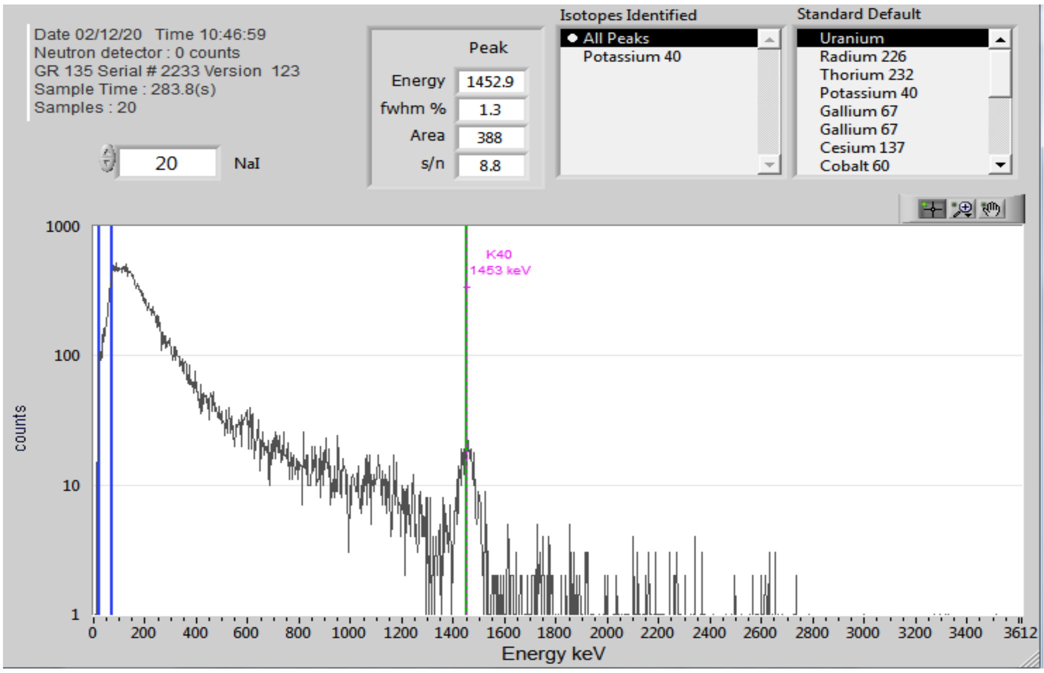

Figure 12: background radiation spectrum for 300 seconds of measurement

4.4. MDA calculations

4.4.1. Thyroid Phantom

Calculations of minimum detectable activity for 55 seconds and 300 seconds of counting in terms of Bq have been shown in tables below.

Table 5: MDA calculations of thyroid phantom at intervals of 55 seconds at different intervals of detector of Phantom for 129.5 kBq activity level of source in one lobe

The minimum detectable activity (Bq)	Distance (cm)
1306	0
1900	5
1900	7
2673	10
4918	15

Table 6: MDA calculations of thyroid phantom at intervals of 55 seconds at different intervals of detector of Phantom for 129.5 kBq activity level of source in two lobes

The minimum detectable activity (Bq)	Distance (cm)
624	0
1496	5
2899	10
4821	15

As it was expected, increasing the distance of Phantom increases the level of detectable MDA. In other words lower levels of MDA are measurable with lower distance from Phantom to the detector. Quantitative amounts of MDA can be obtained using above mentioned tables. MDA values indicate that individuals can be classified with exposure from 630 Bq in cases of contamination.

5.5. LLD calculations

We have calculated the amount of LLD which is the lowest level of detection in the system according to equation (1) which has been mentioned here again which was obtained to be equal to 128 Bq while the amount of LLD in the work of sumber group was equal to 142 Bq.

$$LLD = 3.29\sqrt{r_b t_g\left(1+\frac{t_g}{t_b}\right)} + 3$$

$$LLD = 3.29\sqrt{22.09 * 55\left(1+\frac{55}{300}\right)} + 3 = 128\ Bq$$

Thus, the results indicate that the error obtained from these two values is 10%. So the amount obtained in this research is equal to the amount obtained by Sumber group. Since we want to obtain amounts to be practically counted, we waited for the activity of source to be reduced to 250 Bq which was on 02/02/92 (Monday, April 22, 2013). Measurements were repeated after this period, the results of which can be observed in spectra of figures (13) and (14).

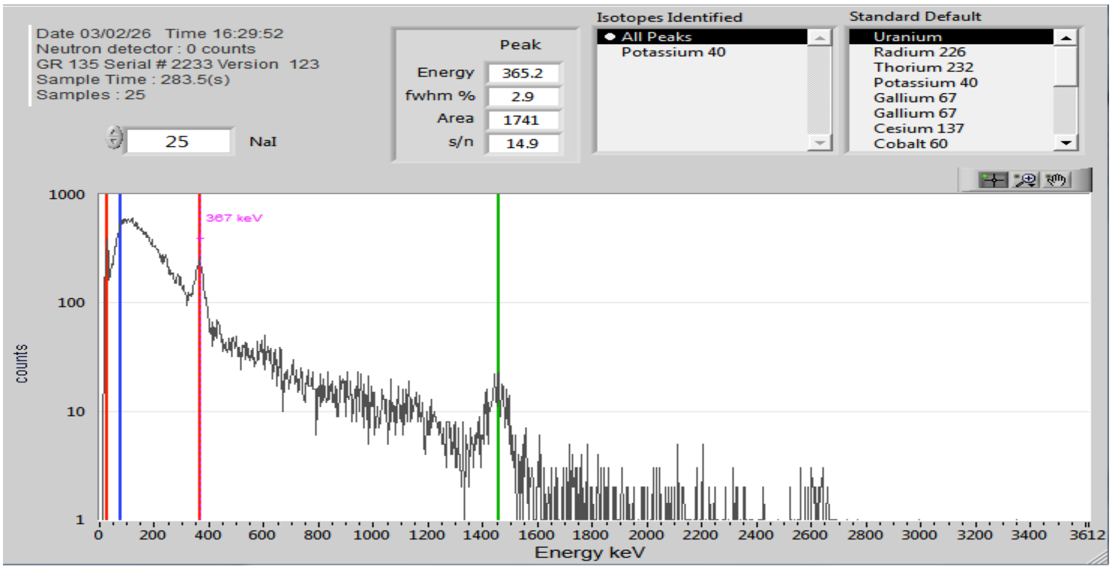

Figure 13: gamma spectrometer spectrum in detection for 300 seconds in the presence of 250 becquerel source in one thyroid lobe

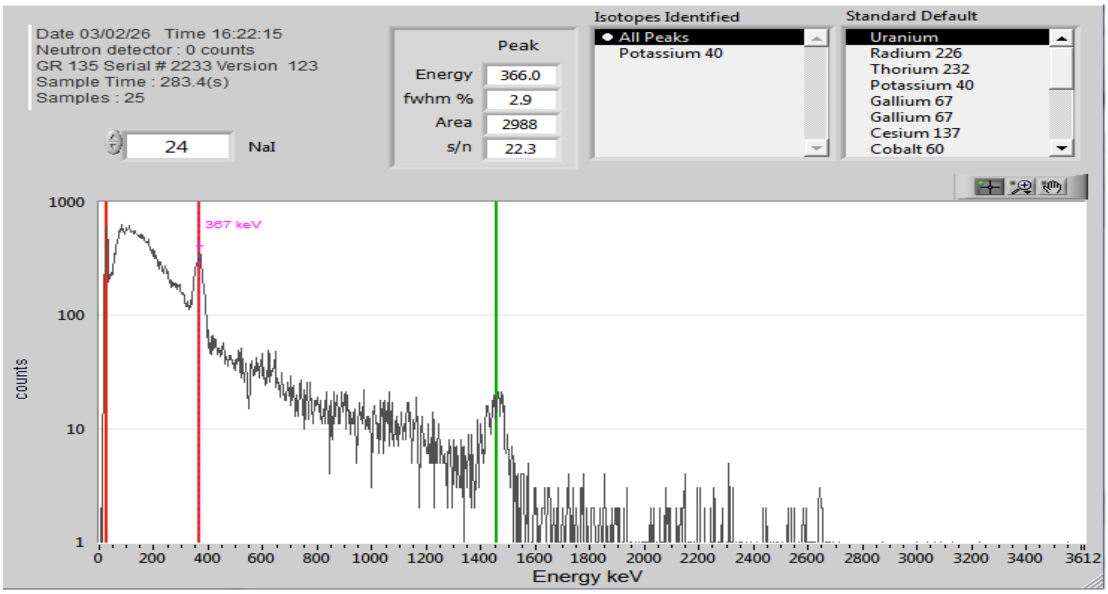

Figure 14: gamma spectrometer spectrum in detection for 300 seconds in the presence of 250 becquerel source out of the Thyroid phantom at the distance of 1 cm from the detector

5. CONCLUSION AND RECOMMENDATION

5.1. Conclusion

The aim of this project is evaluation of the possibility of measuring 131-I internal contamination using a handheld and portable detector for personnel and persons involved in the production of radioactive material and its application in nuclear medicine.

To clarify this issue, a GR-135 mini SPEC gamma spectrometer and thyroid phantom with standard source of 131-I were used. The application of this detector which is named IdentiView made the possibility of counting and energy and resolution possible for each of the photopeaks identified by the detector which is a complete software and displays spectrum of detection and has the ability to carry out mentioned evaluations by moving pointer on the spectrum. In addition, the number of background counting can be obtained from the LCD of the device by moving the pointer in different frequencies of energy. Efficiency calculations at different distances from the surface to up to a distance of 15 cm from thyroid phantom showed that the efficiency decreases with increasing distance from the Phantom and the range of 0.1 to 0.03 is in terms of CPM / Bq. As we expected, the highest efficiency was for detection was obtained in the Phantom level. In general, according to the calculated efficiency, the detector has the ability to detect the minimum detectable amount which is approximately 128 Bq. MDA values indicate that in case of internal contamination with thyroid, individuals with internal 131-I contamination higher than 630 Bq can be classified. With respect to detector used in topical thyroid counter device which is larger as well as the proper guard for this device which has been used to reduce amount of background radiation, the level of above mentioned detection for GR-135 along with its rapid mobility and lower prices have made this device to be very suitable for the estimation of 131-I contamination

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5.2. Recommendation

- Carrying out simulation calculations for GR-135 mini SPEC detector and thyroid phantom and designing appropriate guard to improve MDA
- Feasibility study for use of sodium iodide detectors for 125-I

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