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Research Article

Calibration of handheld gamma spectrometers to measure radioactive materials in lungs

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ABSTRACT

After a Radiological Dispersal Device (RDD), although Whole Body Counter (WBC) is a special device to measure whole body radiation, there is not enough time to transfer injured party to the centers equipped with the devices. This project investigated possibility of measurement of radioactivity entered to body as a result of breathing during the accident using a handheld spectrometer. The experiments and measurements are performed using a gamma spectrometer, a slab phantom and source combined of Co-60 and Cs-137. Moreover, a RMC Π phantom used for calibration of the Whole Body Counter (WBC) in Iran is also used as a reference for comparison. It should be mentioned that in all steps of experiments and measurements, background radiation has played key role in obtaining final results and its effects are analyzed separately. Finally, according to extraction of effective parameters in efficiency and minimum detectable activity (MDA), an instruction is prepared for calibration of handheld gamma spectrometers its arrangements are also codified to present and deploy it in Nuclear Disaster Management Centers of Iran.

Key words: calibration, handheld gamma spectrometers, measurement of materials, radioactive

INTRODUCTION

A nuclear and radiological accident is practical an accident, during which some radionuclides are distributed in the air. The accidents are usually results of natural disasters (earthquake, tsunami, etc.) and unnatural events (malicious attacks, war, etc.). According to the reports from October of 1996 to 2001, about 1495 radioactive sources are in the U.S are stolen or lost and each of them can cause a nuclear disaster [1].

The project has the ability to use a handheld detector to measure radioactive pollutants inside the tissue in a nuclear accident. The detector used in this study is a gamma-ray detector. As a result, only a gamma-ray emission source in discussed in this study; although the pollutions can happen in form of alpha, beta and gamma radiation. According to common report of Department of Energy (DOE) and Nuclear Regulatory Commission (NRC), the most important radioisotopes in this field include Cs-137, Co- 60, Am- 241, Ir- 192 [3, 9].

Moreover, two sources of Sr-90 and Y-90 that emit electron in their beta decay are so important and the electrons may cause Bremsstrahlung.

The radionuclides are applicable in cases of medical diagnosis; for example, Am-241 is available in smoke detectors and Cs-137 and Ir-192 in radiation medicine and treatment of cancer and I-131 is available in centers for disease control and prevention, along with cases of diagnosis of thyroid cancer [7]. After a nuclear and radiation accident, many people may be infected with external or internal contamination and be transferred to hospitals or other centers. The hospitals are not usually able to prescribe medicine for all of infected people, since the methods of expression of external contamination are defined more completely; although ways of expressing internal contamination are not completely defined, especially in cases that the radioactive materials are inhaled and entered to the body [7]. Hence, it is necessary to design a method for careful evaluation of injured people to separate people needing medicine from others, so that they can receive the medicines with no waste of time and immediately after influence of radioactive material to body. Whole Body Counter (WBC) is a device, designed to measure and determine accumulation of radioactive materials in human body. The device is equipped with a very sensitive detector inside the cab of the lead shielding to reduce background radiation [4].

Although the device is the best device to measure the radioactivity entered to body in a nuclear accident, most of the times the accidents happen far from the device and on the other hand, number of labs quipped with the device is limited and they can't count activity for large number of people during short time. As a result, in nuclear and radiation accidents, any kind of device with capability of estimating radioisotopes in the environment should be used to monitor contamination of radioactive in the environment and inside the body.

It should be mentioned that now monitoring infection of people has gained attention of many centers under supervision of International Atomic Energy Agency (IAEA) according to increasing use of radioactive materials in medicine and industry in work affairs or accidents. Using portable detectors with ability of gamma-ray spectrometry as available equipment at the accident site can help a lot to measure internal infection of victims [6].

The detectors are less sensitive than WBC devices, but they can be used for fast measurement of radioactivity in lung of injured person. For example, sodium iodide detector is available in most universities and nuclear labs in big cities. The detectors are spectrometers that can detect Photopeaks Characteristics of a radionuclide in the resulting spectrum. The devices can be purchased in lower price compared to semiconductor counterparts. One example of the portable detector equipment is GR-135 mini SPECT handheld spectrometer including Nal (TL) detector. To determine usefulness of the handheld detector, efficiency of detection for desired sources of Co-60 and Cs-137 should be estimated [8].

To specify application of the detectors in special cases, a slab phantom can be used, along with a standard gamma source. After performing required measurements by Exploranium GR-135 mini SPECT, calibration of handheld gamma spectrometers is done sue to calculations related to minimum detectable activity (MDA). Use of gamma spectrometers available in Iran to determine internal contamination of gamma elements of Co-60 and Cs-137 in lung and creation of a secondary calibration lab in Nuclear Research Center in this field can clear importance and requirement of conducting tis study simply. Availability of a portable and fast detection system to determine internal contamination in lung and designing a fast detection system to control internal infection of radiation staff can be considered as one of the main objectives of this study. It is expected that finally it could be assumed that the GR-135 mini SPECT and GR-130 gamma spectrometer could be available in radiation centers in Iran [2].

Gamma-ray spectrometry in the above experiments is done using Identi View software as operational software of GR-135 mini SPECT detector. It means that the spectrometer can determine Photopeaks Cs-137 and Co-60 and can also provide all required information in field of analysis of gamma-ray spectrum.

This is because; to estimate minimum detectable activity needs information such as photopeak count, background radiation count and so on.

Literature review

An academic group (J. D. Hutchinson et. Al, 2005) conducted a study in a handheld gamma spectrometer with brand "GR-130 mini SPECT" to estimate radioactive contamination in lungs of injured people. In this detector device, Nal was used in dimensions of $38*38*51mm^3$, along with an internal photomultiplier tube (PMT) and included256 channels for gamma-ray spectrometry [2].

Operational software to transfer the information on the GR-130 mini SPECT device to computer for further analysis is named Spect View that has not the ability of exact photopeak count on the spectrum. Hence, Hutchinson Group had to use Mont Carlo simulation to display the counts. The procedure of experiments and findings of this group are used as a good reference in this study. Another academic group named Shaheen Azim Dewji have conducted experiments on a sodium iodide detector with a crystal with dimensions of 51*51*51mm3 with brand "Canberra" to estimated body internal contamination. The device included a pre amplifier and an internal magnet covered by an aluminum layer [7].

In this study, contamination expression needs a computerized simulation, since distribution of radionuclides can't be calculated easily in lab [7]. In this group, first the response of Nal (TL) 802-2*2 detector us simulated using the code MCNP-5 and then, validity of the model is measured in response to measurements in experiments by a slab phantom [7]. Thickness of Plexiglas sheets used in the experiments was in range 0-9cm and they were also simulated using MCNP-5 code. It should be mentioned that response of the detector is estimated for 6 different radionuclides to prove validity of the simulation for different range of gamma-ray energy. In this method, the results of empirical calculations in lab are compared to the results obtained in MCNP simulation and the result was to gain a scaling factor for each radionuclide separately. The aim of this simulation for different thicknesses is to show that the factor makes no change for each radionuclide depending on different thicknesses of lining of lung in terms of response of the detector. In addition to the above mentioned experiments, this group conducted a series of investigations on 6 anthropomorphic phantoms (female, male and kid) and finally, the threshold range of effective dose was determined using Dose and Risk Calculation (DCAL) software for all cases.

Through collecting and training method of measurement of background radiation and collection of information of patients and determining rate of counts, the group announced that with the presence of 802-2*2 Nal (TL) detector, skilled technicians are needed for calibration of the detection equipment, since the investigations in this field have been limited. As it was mentioned, there are a few studies in this field even in developed countries. Hence, as no practical evaluation is conducted in this field in Iran, the present study can be considered as a novel work in field of spectrometry. In regard with conducting the project, it should be noted that the technology of measurement of gamma-ray elements is highly depended on their energy and the density of desired organ. The density of lung tissue varies in range 0.22-0.45kg/lit because of existence of air in it and the variations in thickness of chest wall is in range 5-20mm. in lower energies than 100keV, the interaction of photoelectric adsorption is dominant and atomic number z values can affect weakening gamma ray with low energy. Hence, this study has investigated gamma emission elements with higher energy than 100keV like Co-60 and Cs-137 as the most important internal contaminators in nuclear accidents. As similar phantom of human body is needed to perform the experiments and preparing desired phantom of lung (like chest phantom Humanoid Torso Phantom loaded with an Am/Eu source) is too difficult and it is impossible to make it due to the available facilities [5, 3 and 4], a slab phantom from Polymethyl-methacrylate (PMMA) with formulation of $(C_5O_2H_8)_n$ and density of ($1.19gr/m^3$) can be used as human body phantom in the experiments.

Methodology

Assessment of hardware and software information of GR-135 handheld gamma spectrometers [8]

GR-135 gamma-ray portable spectrometer is composed of Nal (TL) crystal detector with volume of 73741mm3 and with 2.75kg in weight. The detector can be used to measure counting rhythm or for spectral analysis of radiation source. GR-135 detector with the navigation used in this study is illustrated in figure 1. The most efficiency is in front part of the detector and hence, its front panel is used to measure radiation source. In addition to spectral analysis, appropriate uses of the detector include surveying the contaminated soil and determination of its risk. In this detector, survey mode and dose rate mode and nuclide identification mode are used. Before any measurement, the detector should be calibrated using Cs-137 source with activity of 0.25 μCi. This source is supplied by the company with the spectrometer device.

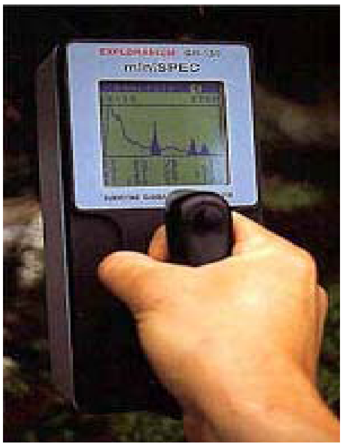

Figure 1: GR-135 detector from front view

System Support Software:

System support software is called Identi View and it can be prepared using relevant CD-ROM. The software is on basis of Windows program and under NT and Windows 98 and 2000.

Figure 2 illustrates Identi View software and an example of a spectrometry by the software.

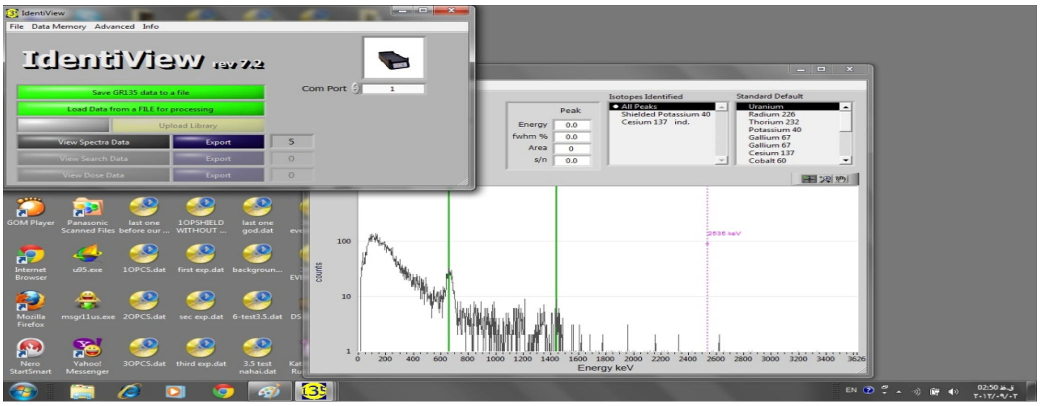

Figure 2: Identi View operational software

Standard Mixed Gamma Source

The measurements are performed using a standard source containing radionuclide solution and by a calibrated germanium gamma spectroscopy system.

Isotopes existed in this source include Cd-109, Co-57, Ce-139, Cs-137, Co-60 and Y-88.

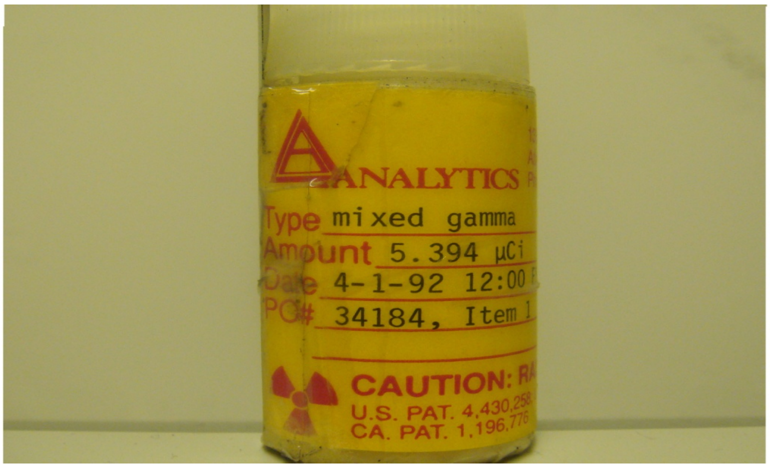

Figure 3: standard source

Slab phantom

Slab phantom is made of thin Plexiglas sheets and can provide different weakening thicknesses between the detector and source. Each sheet has cross section of 30*30cm^2 and thickness of 0.5-1cm. When all sheets are placed beside each other, a thickness equal to maximum thickness of tissue to 4.5cm is created. Through calculating wall thickness of Plexiglas box used in the experiments, the thickness reaches 5.5cm. The material of this phantom is Polymethyl-methacrylate (PMMA) with formulation of $(C5O2H8)_n$ and density of (1.19gr/m3).

RMC II phantom

RMC II phantom is a phantom used for calibration of a WBC device in Iran. The phantom has three parts including neck, upper and lower parts with different thicknesses in mentioned areas. The manner of designing the phantom is in such manner that in each area, an empty area right to size of standard source is existed and the source can be placed in it.

Experiments

Slab phantom experiments

After performing several series of experiments, which were different in terms of distance of detector from source and thickness of Plexiglas sheets, the optimal mode to make phantom and distance of detector from source was designed in such manner that the best results could be obtained in terms of activity. As Nal (sodium iodide) existed in GR-135 mini SPECT detector is located in front core part of the detector, the output of the detector in this area reaches optimal level. Hence, design of the arrangement of detector and source should be in such manner that the two can be in line with each other. Hence, a base was designed for the source from Plexiglas sheets with thickness of 0.5cm. Moreover, a box was also prepared from Plexiglas sheets to use thickness of one of its walls to increase accuracy of experiments through doing experiment in different thicknesses.

RMC II reference phantom

The aim by performing these experiments is finally estimation of efficiency and minimum detectable activity of the phantom in vitro and comparison of the results with calibration experiment is done on July 21-25 on 1992.

It should be mentioned that the vitro situations designed here are in some cases different from standard calibration conditions and the most important one if type of used detector. The detector used in vitro in this study is GR-135 mini SPECT with crystal Nal 38*38*51mm^3. However, the detector used in standard calibration is germanium detector with a Nal crystal with dimensions of 76*127*406mm^3 placed in a lead shield cab to reduce amount of radiation to minimum level.

Results

According to measurement methods mentioned before, the measured data by GR-135 can be entered to computer using Identi View software.

Analysis of the obtained spectrum by this software is due to counting per second.

Photopeak area counting

Slab phantom

For two radioisotopes of Cs-137 and Co-60 of standard source, photopeak area counting is done for 5 different thicknesses of slab phantom during 60, 600sec and the results are respectively presented for the two radioisotopes in tables 1 and 2.

a) **Result obtained for Cs-137 source**

Table 1: photopeack area counting of slab phantom for Cs-137 source

photopeak area counting (count/sec)		thickness (cm)
600sec	60-sec	
373±6	335±18	1.5
344±6	325±18	2.5
310±5	313±17	3.5
266±5	267±16	4.5
253±5	252±15	5.5

b) Results obtained from Co-60 source

Table 2: photopeack area counting of slab phantom for Co-60 source

photopeak area counting (count/sec)		thickness (cm)
600sec	60-sec	
72±3	-	1.5
57±2	-	2.5
57±2	-	3.5
56±2	-	4.5
49±2	-	5.5

It should be mentioned that activity of Co-60 is about 1 time lower than activity of Cs-137 and on the other hand, NaI (TL) detector is reduced with increase in energy of gamma photons. Hence, Co-60 radioisotope was not detected in 60sec measurement.

The above counts are obtained from analysis of the spectrums obtained from Identi View software and the spectrums can be observed based on arrangement of timing for different thicknesses in next pages.

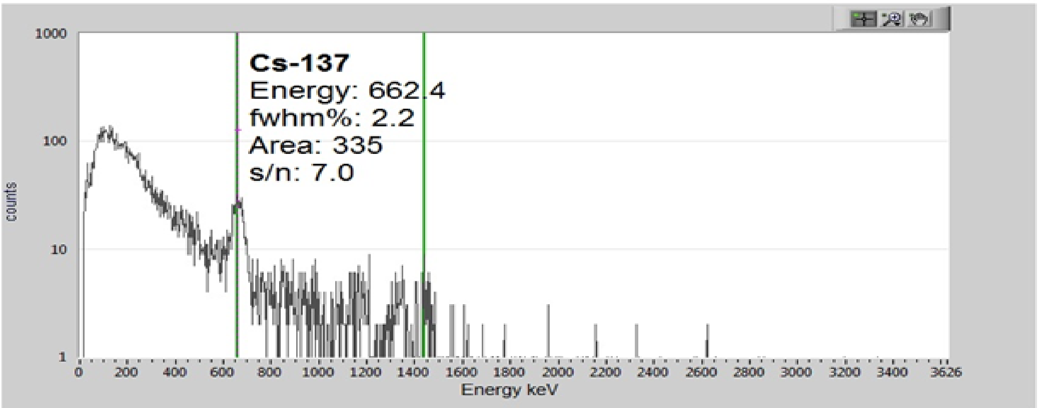

Figure 4: gamma-ray spectrometer spectrum in 60sec detection for thickness of 1.5cm

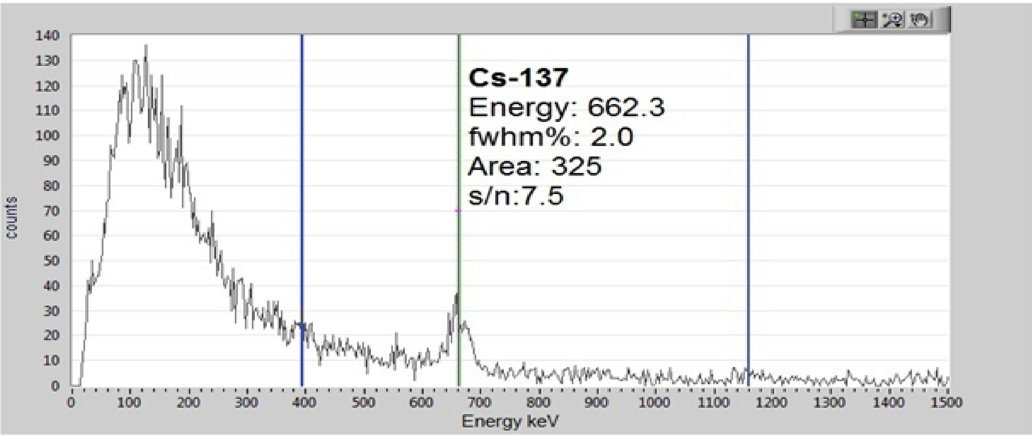

Figure 5: gamma-ray spectrometer spectrum in 60sec detection for thickness of 2.5cm

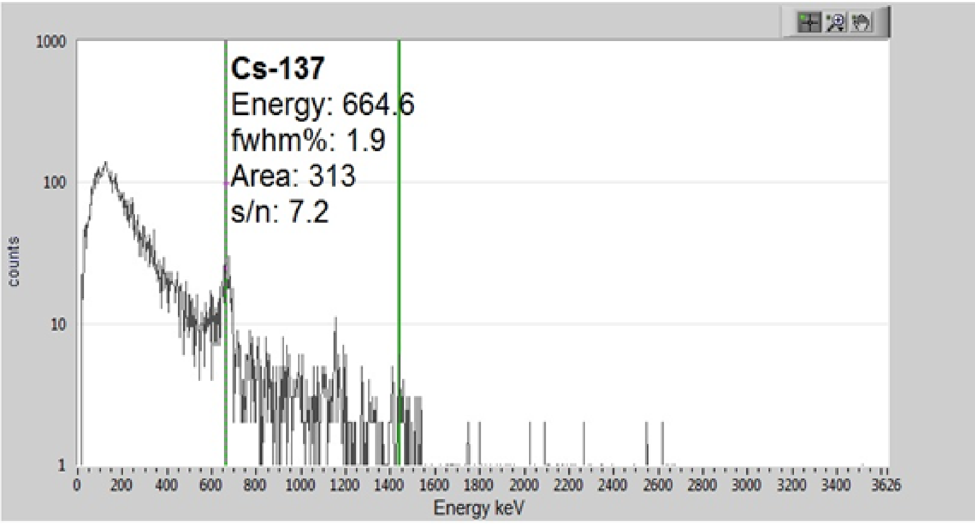

Figure 6: gamma-ray spectrometer spectrum in 60sec detection for thickness of 3.5cm

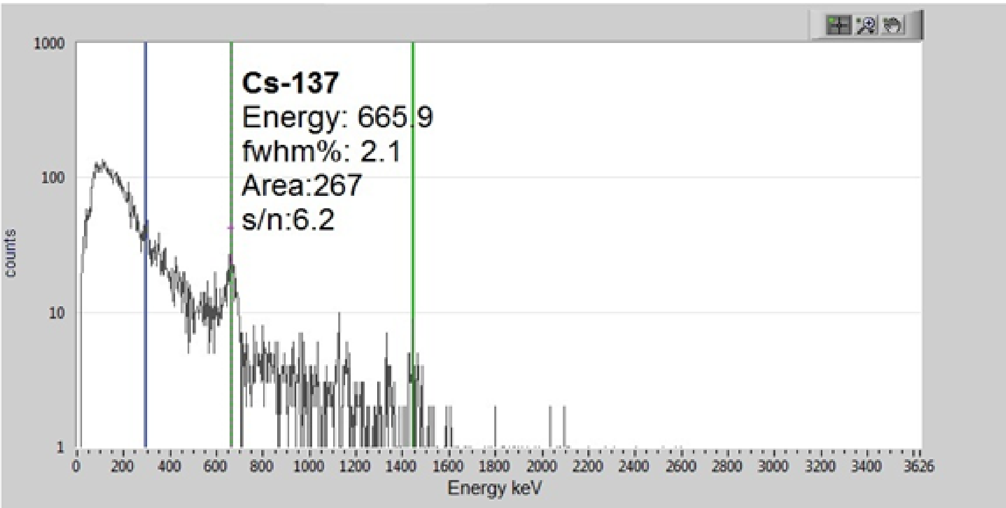

Figure 7: gamma-ray spectrometer spectrum in 60sec detection for thickness of 4.5cm

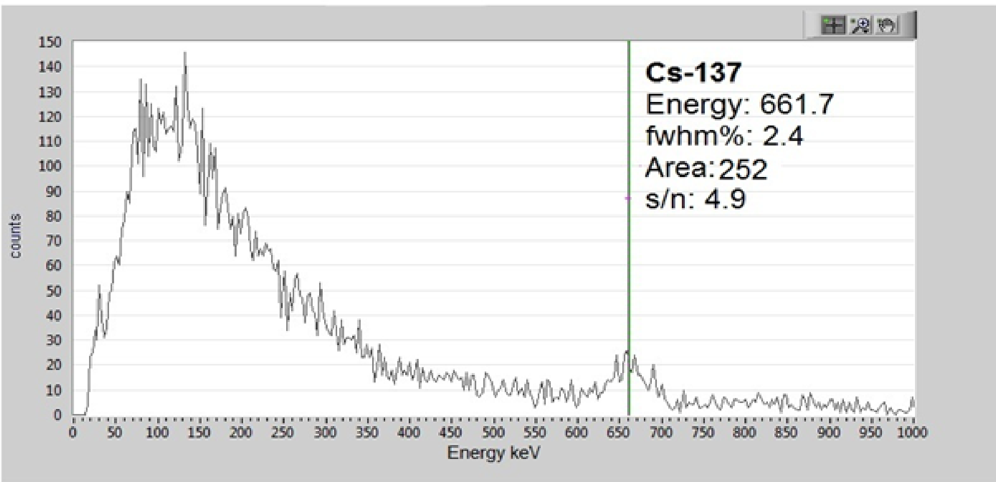

Figure 8: gamma-ray spectrometer spectrum in 60sec detection for thickness of 5.5cm

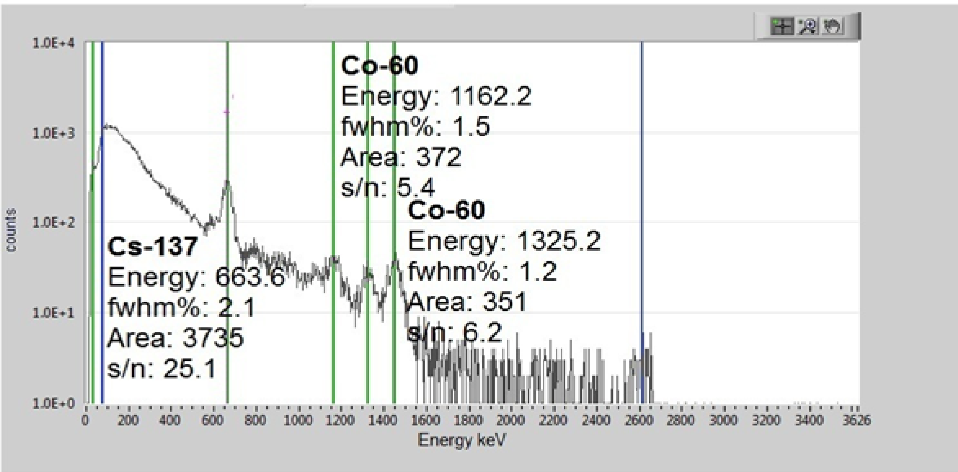

Figure 9: gamma-ray spectrometer spectrum in 600sec detection for thickness of 1.5cm

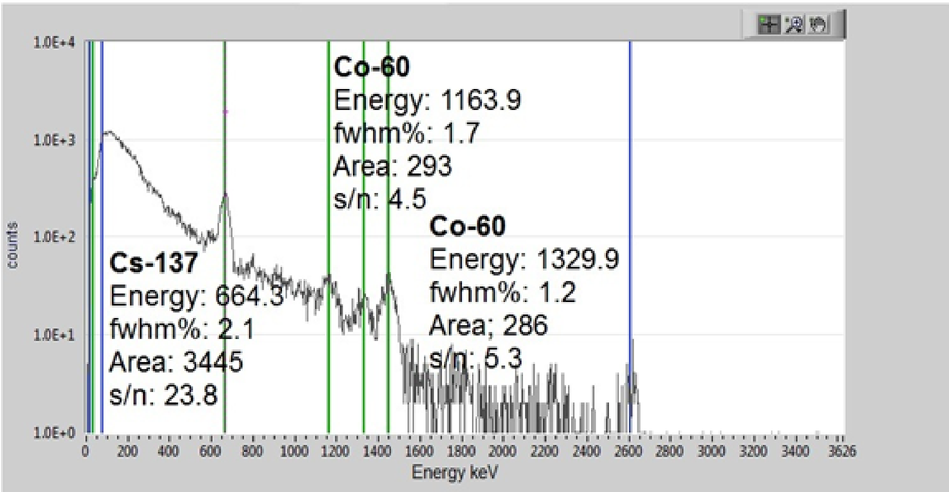

Figure 10: gamma-ray spectrometer spectrum in 600sec detection for thickness of 2.5cm

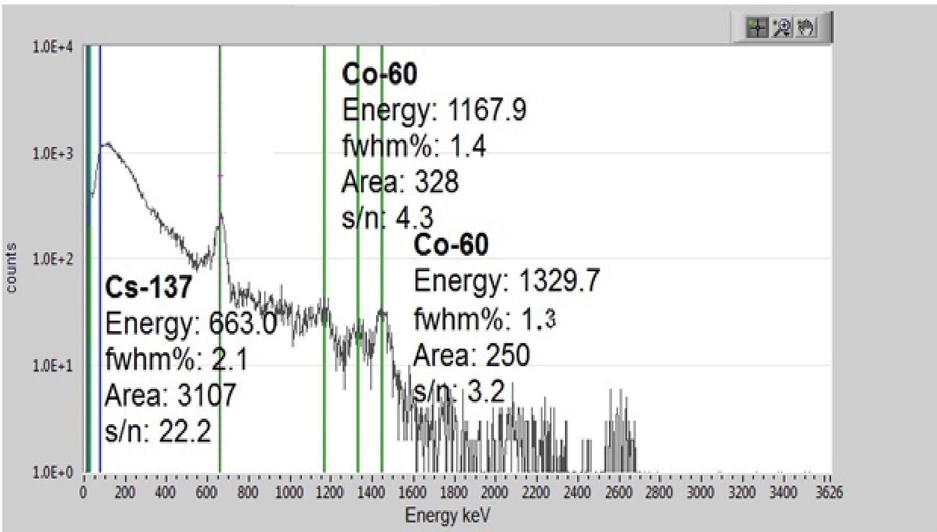

Figure 11: gamma-ray spectrometer spectrum in 600sec detection for thickness of 3.5cm

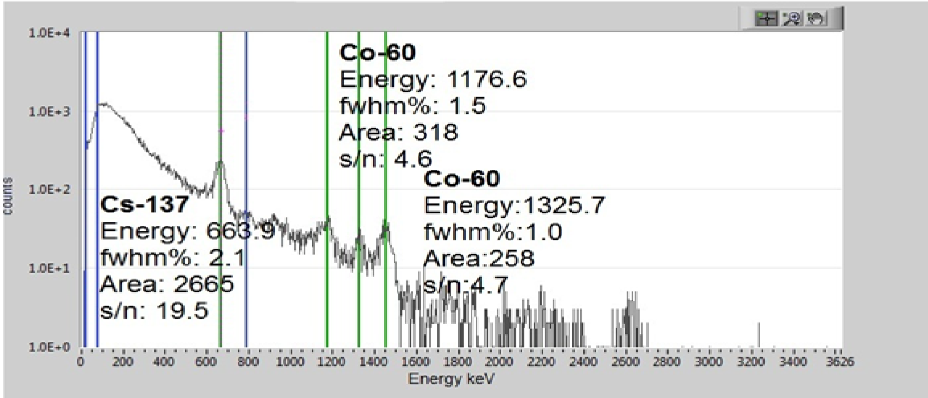

Figure 12: gamma-ray spectrometer spectrum in 600sec detection for thickness of 4.5cm

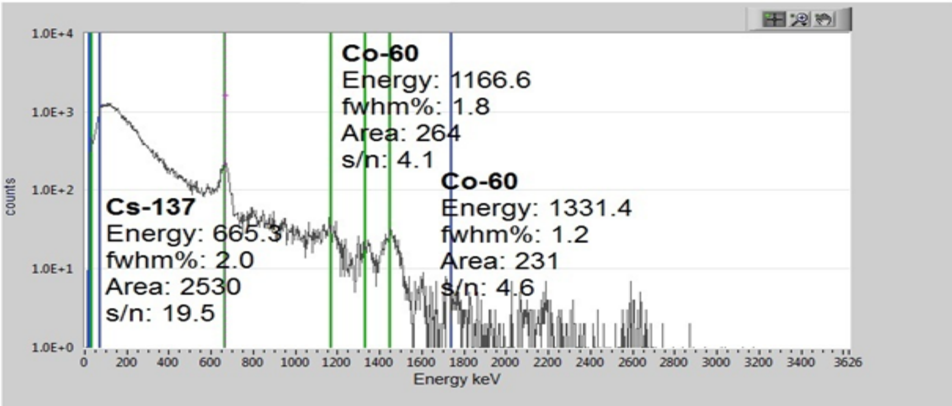

Figure 13: gamma-ray spectrometer spectrum in 600sec detection for thickness of 5.5cm

RMC II reference phantom

The results obtained from photopeak area count for upper part of RMC II for two radioisotopes of Co-60 and Cs-137 during 300sec are presented in table 3.

Table 3: photpeak area counting of upper part of RMC II phantom during 300sec for two radioisotopes of Co-60 and Cs-137

photopeak area counting (count/sec)		thickness (cm)
Co-60	Cs-137	
61±3	240±7	upper part (5.446cm)

The spectrum obtained from measurement of GR-135 device resulting in above counts for upper part is presented in next page.

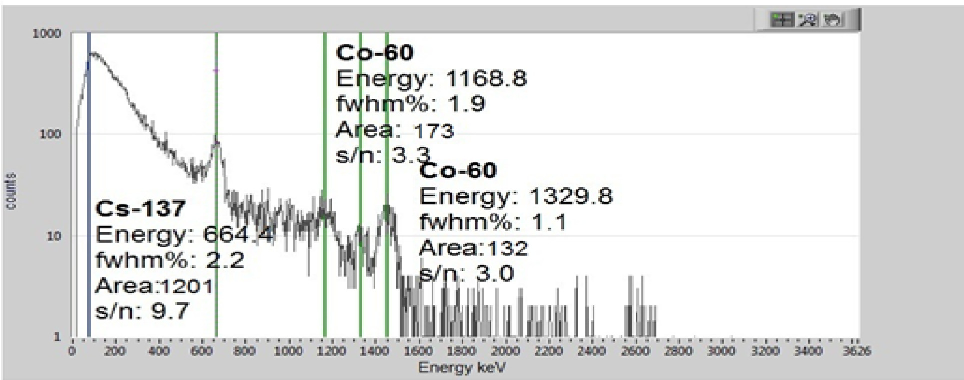

Figure 14: gamma spectrometer spectrum in 300sec detection for upper part of RMC II phantom

Background radiation

As it was mentioned, the experiments of this project are performed in Novin Medical Institute in Tehran. As a result, it is clear that the spectrum of background radiation in this place could be absolutely different from background radiation spectrum while a nuclear accident. Total count rate of background radiation in Novin Medical Institute during 600sec was about 94000count/sec. The counting rate in different Regions of Interest (ROI) is obtained respectively for slab phantom and RMC II in tables 4 and 5.

Table 4: background radiation count of slab phantom during measurement time of 660sec

radionuclide	POI No	energy (keV)	background radiation counting (count/sec)				
			1.5cm	2.5cm	3.5cm	4.5cm	5.5cm
-	0	-	80417±284	80131±283	80154±283	79957±283	80131±283
-	1	39-83	10398±102	10618±103	10688±103	11062±105	11409±107
Cs-137	2	630-693	911±30	883±30	861±29	871±29	830±29
Co-60	3	985-1495	2603±51	2525±50	2585±51	2510±50	2513±50

Table 5: background radiation counting of RMC II phantom during measurement time of 600sec

background radiation counting (count/sec)	energy (keV)	ROI No	radionuclide
upper part			
80977±284	-	0	-
12353±111	39-83	1	-
858±29	630-693	2	Cs-137
2760±52	985-1495	3	Co-60

Where the background radiation affects minimum detectable activity clearly, different background radiation spectrums are studied that the obtained spectrums are presented in next pages. As it was observed in tables above, the background radiation count for each isotope of Co-60 and Cs-137 varies in different thicknesses in range of 3-10%. However, as Co-60 radioisotope in standard source has lower activity rate than Cs-137, it can't be detected in short times of measurement because of high rate of background radiation of Cobalt Source. However, this problem can be solved with the increase in measurement time. Hence, in cases that background radiation is lower than its normal level for any reason, measurement time can be increased for careful detection of each existing radionuclide. In addition to place of background radiation counting, shielding is also another factor affecting reduction of background radiation. In appendix c, the gamma-ray spectrometers for the mode of arrangement of experiments without equipped to lead shield are observable. Background count rate in different regions of interest (ROI) in this arrangement are presented in table (c-1) and the effects of shield compared to final arrangement can be observed easily.

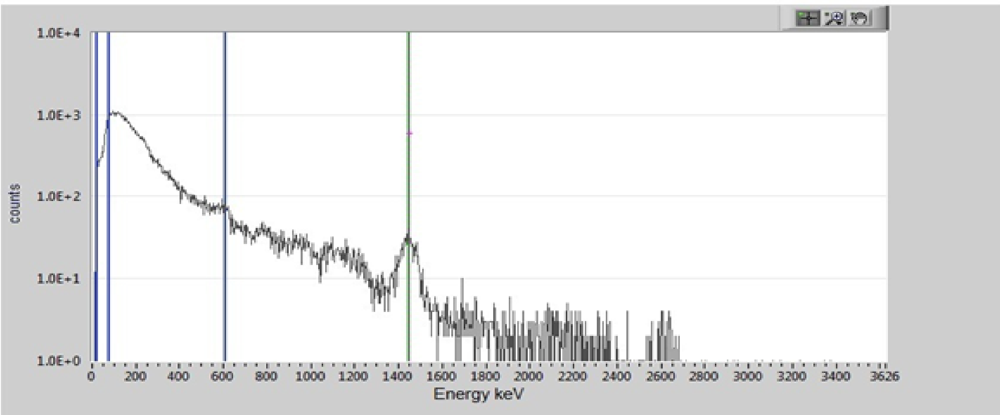

Figure 15: background radiation spectrum for thickness of 1.5cm of slab phantom during 600sec

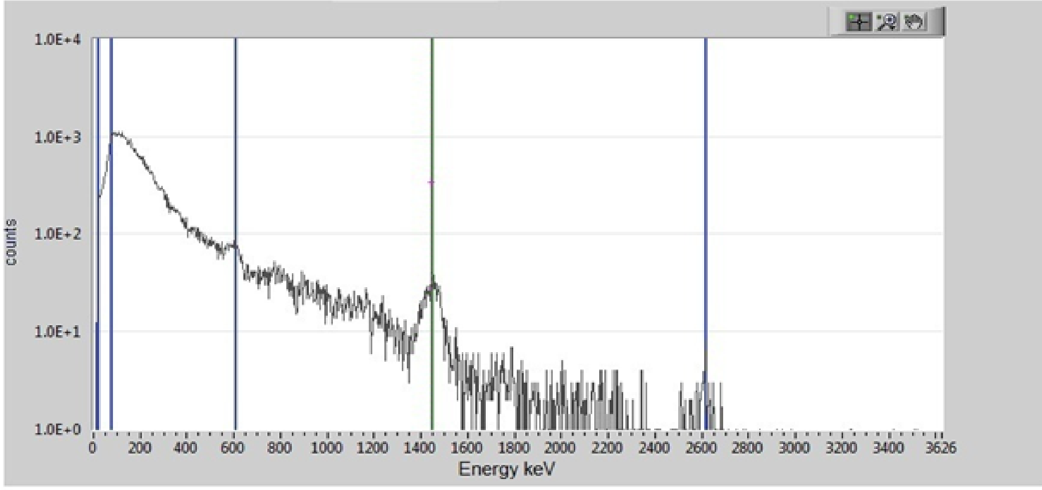

Figure 16: background radiation spectrum for thickness of 2.5cm of slab phantom during 600sec

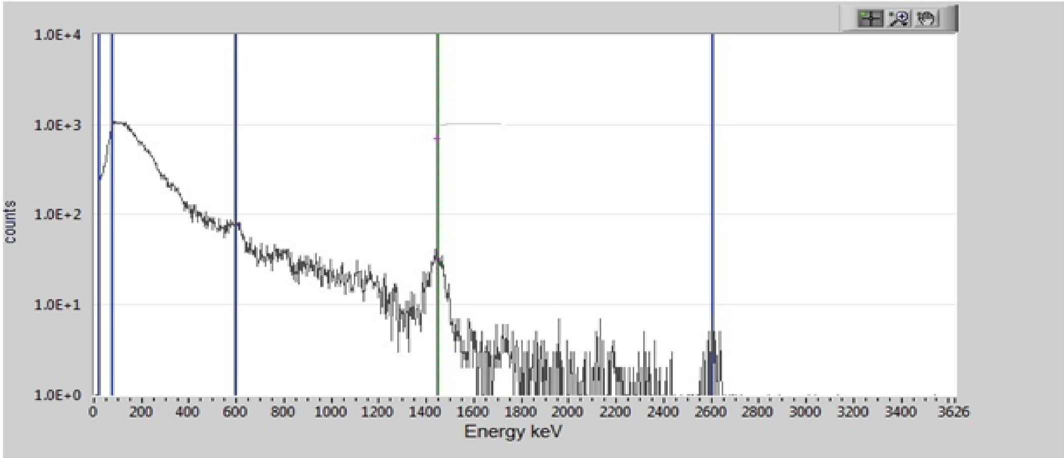

Figure 17: background radiation spectrum for thickness of 3.5cm of slab phantom during 600sec

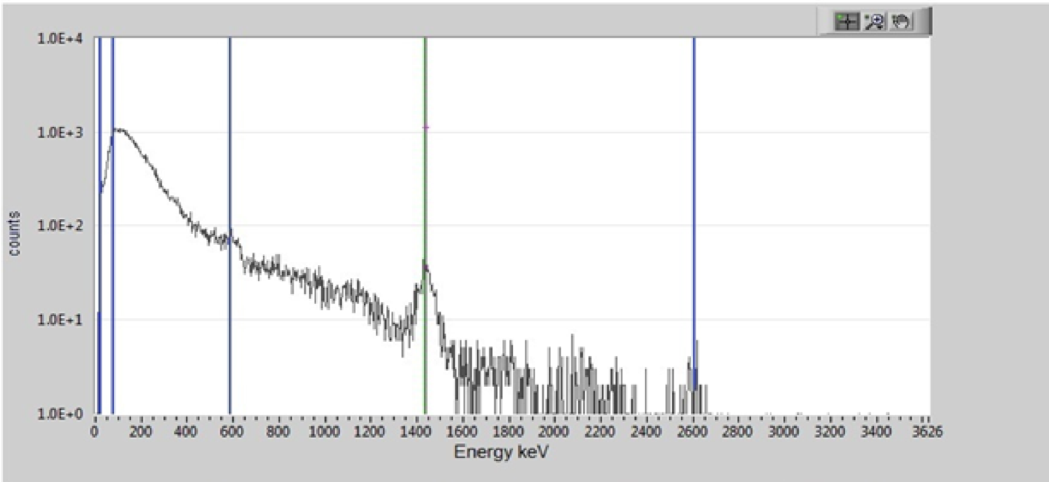

Figure 18: background radiation spectrum for thickness of 4.5cm of slab phantom during 600sec

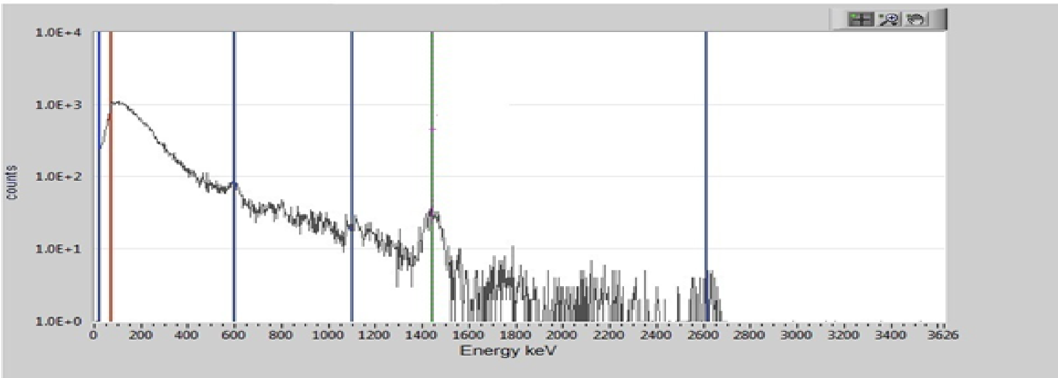

Figure 19: background radiation spectrum for thickness of 5.5cm of slab phantom during 600sec

MDA calculations

Slab phantom

Minimum detectable activity (MDA) calculations of slab phantom for two radioisotopes of Cs-137 and Co-60 during times of 60 and 600sec per Bq are presented in table 6.

Table 6: MDA calculations for slab phantom

MDA (Bq)		thickness (cm)	time (sec)
Co-60	Cs-137		
-	1382.55	1.5	60
-	1403.39	2.5	
-	14.39.91	3.5	
-	1699.125	4.5	
-	1756.61	5.5	
1249.96	576.88	1.5	600
1536.89	585.38	2.5	
1555	600.45	3.5	
1583.7	708.64	4.5	
1793.23	732.22	5.5	

As it was expected, increase in thickness of phantom has led to increase in MDA. In other words, the more the lower the thickness of phantom is, the lower level of MDA is measurable. With the increase in time of counting, fewer MDA could be achieved and the process is observed in table 6 easily.

RMC II phantom

The results obtained from MDA during 300 seconds for RMC II phantom for both radioisotopes of Co-60 and Cs-137 per Bq are presented in table 7.

Table 7: calculations of MDA for MRC II phantom

MDA (Bq)		thickness (cm)
Co-60	Cs-137	
1859.26	975.93	upper part (5.446cm)

In calibration examination, the Whole Body Counter (WBC) device is used in Iran using RMC II phantom in presence of Co-60 radioisotope and minimum detectable activity (MDA) lowers than 200Bq. However, the amount was measured 9 times higher than this in vitro and using GR-135 device. The first and the most important cause for such difference, if the background radiation varies in different places, can be the lead shield used in calibration of WBC that can reduce the radiation to high extent. Different detections with different yields can be also another reason for the difference.

CONCLUSION

As it was mentioned, the aim by conducting this study was to investigate possibility of measurement of radioactive material level in lung of an injured person in a nuclear accident using a handheld and portable detector. To specify this issue, a GR-135 mini SPECT gamma-ray spectrometer and slab phantom composed of Plexiglas sheets are used. The operational software used for GR-135 detector was called Identi View software and provided conditions to investigate the number of counts and energy and resolution for each detected photopeak by the detector. The software is more perfect software compared to operational software of GR-130 detector called "Spect View". Because; in addition to display the spectrum resulted from detection, it has provided conditions to conduct the mentioned investigations through moving the pointer on the spectrum. Moreover, using the detectors, the amount of background count could be obtained from the monitor of the device through moving the pointer in different regions of interest (ROI). However, the said detector has also some disadvantages. In spectrum mode, is height of pulse in each channel is more than 66000 counts (or Kcps of 66000 is recorded in counting mode), the device is saturated and sends saturation message if the death time exceeds 70%, the system will overloaded. These factors can cause limitation in measured activity and counting time. Moreover, after a radiologic or nuclear accident, the air of the temperature of the place is considered as a background in addition to natural background and such background count in the place should be subtracted from activity counting. Moreover, if a patient has external infection, the amount of the infection may be seemed more than infection in lung and hence, in measurement of external infection of a patient, the counting would be corrected before counting the lung [4]. The estimations of efficiency in different thicknesses of slab phantom showed that the efficiency is decreased with the increased thickness of phantom, since as it is expected, increase in thickness of phantom can cause adsorption of more initial gammas emitted. The efficiency of GR-135 mini SPECT detector in photopeak regions of energy for two radioisotopes of Co-60 and Cs-137 is estimated to 0.04-0.07 for the mentioned thicknesses. In general, according to estimated efficiency, the results of counting by the handheld detector show that internal contamination in type of Co-60 and Cs-137 for a person can be detected about 500-2000Bq and use of this handheld detector can be useful for fast screening of infected people in nuclear accidents. The WBC device is able to detect minimum detectable activity to 200Bq for lung of an adult during 5min; although GR-135 detector can measure this amount for mean thickness of 3.5-4.5cm of slab phantom that is relatively equal to thickness of lung of an adult person during 5min to 1850Bq. Based on the detector used in WBC device and good shielding of the device to reduce background radiation, such difference can't decline capability of GR-135 detector for fast screening of infection level of people in nuclear accidents. This because; RG-135 is cost-effective compared to WBC device and is also easily portable and is available. As effect of background radiation on counting low level samples is considerable, using lead shield can be useful to reduce background radiation and detection of samples with low radiation; because appropriate shielding can reduce background radiation and MDA of system considerably and this can lead to detection of peak of the energy related to radioisotope in sources with low activity by the detector.

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