Journal of Environmental Radioactivity 183 (2018) 54–58

Contents lists available at ScienceDirect

Journal of Environmental Radioactivity

journal homepage: www.elsevier.com/locate/jenvrad

On the gamma spectrometry efficiency of reference materials and soil samples

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ARTICLE INFO

Keywords:
Gamma spectrometry efficiency
Reference material
Soil sample
Self-attenuation

ABSTRACT

The relative discrepancies between the gamma spectrometry efficiency of RGU, RGTh, RGK reference materials and some soil samples have been studied using a MCNP model of a real HPGe detector. It has been shown that, in a specified geometry, efficiencies differences depend on the sample elemental composition. The elemental compositions of RGU-1, RGTh-1 reference materials and a soil sample have been evaluated using X-Ray fluorescence (XRF) method and used in the MCNP simulation along with RGK-1 and six other soil samples with different elemental compositions to calculate their efficiencies in different gamma ray energies. To estimate the maximum relative efficiencies differences between soil samples and reference materials, five soil samples with higher attenuation properties were selected from a large data set of soils elemental compositions. The results show that the efficiency differences between soil samples and reference materials are almost ignorable for more than 100 KeV gamma energies. It strongly depends on the sample attenuation factor in the lower energies, so use of a self-attenuation correction is essential for radionuclide counting in low energies gamma rays. Results show about 8 percent discrepancy between RGU and two soil samples efficiencies in 63.2 KeV energy.

1. Introduction

Gamma spectrometry is a widely used technique for determination of radioactive materials in the environmental samples. It is essential to know the detector efficiency for specifying the activity of the radioactive contents of the samples with the gamma spectrometry technique. The detector efficiency for a radionuclide counting in a sample depends on the geometry, material content and density of the sample (self-attenuation) in addition to the radionuclide incident gamma ray energy. For determining the activity contents of different radioactive materials with different gamma ray energies, an efficiency-energy calibration curve for a specified detector-sample configuration should be used. This calibration curve can be evaluated by the experimental count of the known activity radionuclide in the specified detector-sample configuration with the exactly same material as the main sample. This technique is time consuming, costly and sometimes impossible. Therefore the environmental analysis laboratories usually use the reference materials such as the IAEA reference materials to evaluate the efficiency curve for a specified sample in a given geometry such as Marinelli beaker. One of the common environmental samples for gamma spectrometry is the soil sample which is important for geoscience research and the radiological hazards analysis in the environment. Many researchers and laboratories use the IAEA-RGU-1, IAEA-RGTh-1 and IAEA-RGK-1 (IAEA reference materials) or analytical purity of KCl salt, Instead of RGK, to obtain the efficiency calibration curve for different soil sample measurement (Canbazoglu et al., 2013; Psichoudaki and Papaefthymiou, 2008; Mustapha et al., 2004; Turhan et al., 2012; Iurian and Cosma, 2014; Arnedo et al., 2017). The material composition of the RGU-1 and RGTh-1 had been made similar to the typical soil composition with the adding silica powder to the Uranium and thorium ore respectively (IAEA/RL/148, 1987). This technique was used to compensate the effect of reference materials and soil samples material compositions on the efficiency, but soils have a wide range of different chemical elements. The material composition of the samples and their gamma ray attenuation affects the spectroscopy efficiency. This effect is more significant in the lower energy gamma rays, therefore adding the silica powder to the RGK-1 with the 1461 KeV gamma energy of K-41 was not essential.

Many researchers have studied the influence of the sample self-absorption on the gamma spectrometry efficiency. They work on the effect of elemental composition and density as the main characteristics of the samples for self-absorption (Miller and Voutchkov, 2014; Li et al., 2011; Carrazana González et al., 2010; Landsberger et al., 2013; Kaminski et al., 2014). In this work the efficiencies of the different gamma ray energies in the IAEAE-RGU-1, IAEA-RGTh-1 and IAEA-RGK-1 have been compared with the different soil samples efficiencies with same density

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https://doi.org/10.1016/j.jenvrad.2017.12.012
Received 12 July 2017; Received in revised form 22 October 2017; Accepted 19 December 2017
0265-931X/

Table 1
Chemical composition of the RGU-1, RGTh-1 and SOIL1 (a soil sample from center of Iran) using XRF analyses.

	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	K_2O	CaO	TiO_2	Cr_2O_3	MnO	Fe_2O_3	ZrO_2	BaO	ThO_2	UO_2	La_2O_3	Ce_2O_3
RGU-1	0.70	0.45	N.D.	97.74	0.79	N.D.	N.D.	0.10	N.D.	N.D.	N.D.	0.10	N.D.	N.D.	N.D.	0.016	N.D.	N.D.
RGTh-1	0.68	0.44	N.D.	96.84	0.67	0.17	N.D.	0.39	N.D.	N.D.	N.D.	0.14	N.D.	N.D.	0.004	N.D.	0.1	0.28
SOIL1	N.D.	1.10	9.28	67.87	0.77	N.D.	2.99	5.16	1.21	0.20	0.12	10.20	0.10	0.06	N.D.	N.D.	N.D.	N.D.

N.D. = Not Detected, N.M. = Not Measured.

Table 2
Elemental compositions of the RGU-1, RGTh-1 and SOIL1 derived from XRF data, RGK-1 (100% K_2SO_4), SOIL2 from (Miller and Voutchkov, 2014) and SOIL3 and SOIL4 from (Smith et al., 2013).

	Na	Mg	Al	Si	P	S	K	Ca	Ti	Cr	Mn	Fe	Zr	Ba	Th	U	La	Ce	O
RGU-1	0.52	0.27	N.D.	45.69	0.34	N.D.	N.D.	0.07	N.D.	N.D.	N.D.	0.07	N.D.	N.D.	N.D.	0.01	N.D.	N.D.	52.92
RGTh-1	0.50	0.27	N.D.	45.27	0.29	0.07	N.D.	0.28	N.D.	N.D.	N.D.	0.10	N.D.	N.D.	0.004	N.D.	0.04	0.12	52.62
RGK	–	–	–	–	–	18.4	44.87	–	–	–	–	–	–	–	–	–	–	–	36.73
SOIL1	N.D.	0.66	4.91	31.73	0.34	N.D.	2.48	3.69	0.73	0.14	0.09	7.13	0.07	0.05	N.D.	N.D.	N.D.	N.D.	47.04
SOIL2	0.245	0.088	1.096	43.76	0.013	N.D.	0.225	0.118	0.123	0.003	0.015	0.724	0.055	0.054	0.004	N.D.	N.D.	N.D.	53.02
SOIL3	1.28	1.76	7.78	25.66	0.186	0.02	0.95	2.59	1.91	0.005	0.201	12.6	N.M.	0.058	0	0	0.003	0.005	45
SOIL4	0.99	1.5	4.31	23.68	0.15	0.02	0.02	20.7	1.67	0.001	0.097	5.94	N.M.	0.032	0	0	0	0.004	40
SOIL5	0.05	0.62	4.69	28.69	0.07	0.03	0.99	0.66	0.21	0.01	0.14	13.9	N.M.	0.03	0	0	0	0.03	50
SOIL6	0.33	0.62	3.76	26.68	0.08	0.03	0.82	8.73	0.13	0.002	0.66	13	N.M.	0.04	0	0	0	0.003	45

N.D. = Not Detected, N.M. = Not Measured.

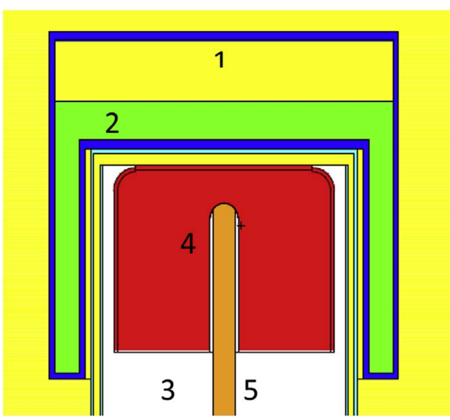

Fig. 1. Vertical section of the HPGe detector and Marinelli beaker MCNP model: 1- Marinelli beaker, 2- Soil sample, 3- Detector housing, 4- Detector Crystal (diameter = 7.97 Cm & height = 6.32 Cm), 5-Cupper cooling rod (diameter = 0.8 Cm).

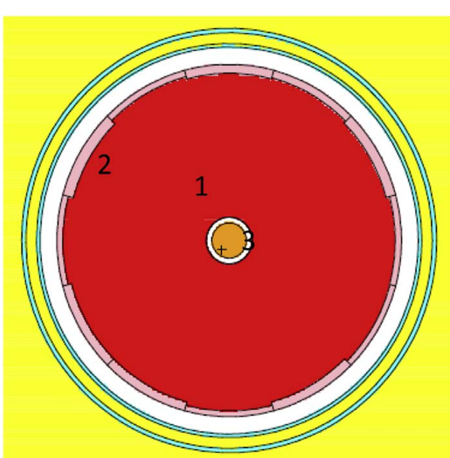

Fig. 2. Cross section view of the detector MCNP model: 1- Detector crystal main body 2- Dead layer with various thicknesses 3- Cupper cooling rod.

Table 3
Gamma ray energies and related radionuclides for efficiency simulations.

	Gamma ray Energy (KeV)	Radionuclide	Parent Radionuclide
RGU-1	63.3	Th-234	U-238
	92.78	Th-234	U-238
	143.76	U-235	–
RGTh-1	238.6	Pb-212	Th-232
	583.2	Tl-208	Th-232
	911.2	Ac-228	Th-232
RGK	1460.8	K-40	–

and distinct material composition using a MCNP X detector model which was described and validated in the reference (Modarresi et al., 2017). The effect of elemental compositions of soil samples on the efficiency variation in different energies has been studied. To estimate the maximum effect of elemental composition on the efficiency differences a large data of the different soils elemental composition has been used to investigate the higher absorber soils from a lot of samples. The resultant discrepancies between soil sample and reference material efficiencies are the experimental errors which are originated from reference materials use for the calibration curve evaluation.

2. Material and methods

The differences between various soil samples and reference material elemental compositions can lead to different gamma ray counting efficiencies in such samples. In order to determine the effect of this differences the material composition of the RGU-1, RGTh-1, RGK-1, an analyzed soil sample from center of Iran and some other soil samples with the reported elemental compositions in different researches have been used in an efficiency calculation MCNP model which is described and validated in reference (Modarresi et al., 2017). Since the soil compositions can be different based on the condition of their development, a large data set of soil compositions have been used in simulations in order to investigate the high attenuation soils effects on the gamma ray spectrometry efficiency.

The Marinelli beaker is considered as the soil samples counting geometry. The simulated detector is a coaxial P-type HPGe detector model GEM80P4-95 made by ORTEC Company (with 88 percent