Iranian Journal of Medical Physics
Vol. 13, No. 4, December 2016, 269-275
Received: July 13, 2016; Accepted: August 28, 2016

**Original Article**

# Radiological Assessment of the Artificial and Natural Radionuclide Concentrations of Some Species of Wild Fungi and Nourished Mushrooms

Reza Pourimani[1*], Sana Rahimi[1]

## Abstract

**Introduction**
Artificial and natural radionuclides are found in diverse environmental compartments, such as water, soil, rocks, vegetables, animals, and human body tissues. As such, humans and environments are at constant exposure of these radiation types. In this research investigated specific activities of radionuclide and dose assessment of some species of mushrooms.

**Materials and Methods**
In this study, natural and artificial radioactivity concentrations were determined in *Agaricus bispora* (nourished mushrooms), *Cantharellus cibarius*, *Coprinus micaceus* (wild fungi species) and their composts through gamma-ray spectrometry using a high-purity germanium (HPGe) detector with 30% relative efficiency.

**Results**
Radioactivity concentrations of $^{238}$U and $^{232}$Th in edible mushroom samples were lower than the minimum detectable activity (MDA). For $^{40}$K and $^{137}$Cs, these concentrations were within the ranges of 1895.24-1920.24and <0.45-0.72Bq/kg, respectively. Moreover, specific activities of $^{238}$U, $^{232}$Th, $^{40}$K, and $^{137}$Cs in the composts varied within the ranges of < 0.47 - 3.40, 6.59-7.82, 1166.12-1428.27, and 0.75-1.97±Bq/kg, respectively. Excess lifetime cancer risk due to the ingestion of nourished mushrooms was calculated as $1.28\times10^{-4}$, which is lower than the maximum acceptable value.

**Conclusion**
Results of this study showed that the radioactivity concentrations of edible mushrooms are close to or lower than MDA. In addition, radioactivity concentrations of the composts were indicative of the low pollution of the studied regions by radiocesium. Annual consumption rate threshold was calculated as 26.7 kg in dry weight (fresh weight: 267 kg). Therefore, it could be concluded that consumption of these mushrooms is associated with no health consequences for consumers.

**Keywords:** Cancer risk, Foodstuff, Mushroom, Radionuclide



*1- Department of Physics, Faculty of Science, Arak University, Iran*
*Corresponding author: Tel: 0918161224; Fax: +98 086-34173406; E-mail: r-pourimani@araku.ac.ir

# 1. Introduction

Natural and artificial radionuclides are the main sources of radiation exposure for humans. Uranium ($^{238}$U, $^{235}$U), thorium ($^{232}$Th), and potassium ($^{40}$K) are among the main elements contributing to natural terrestrial radioactivity [1]. Average $^{238}$U content of the Earth's crust has been estimated at2.7 mg/kg, while this concentration may reach 120 mg/kg in phosphate rocks [2]. As for $^{232}$Th, the average content of this compound in the Earth's crust is approximately 9.6 mg/kg[3].Therefore, humans and their environment are at constant exposure to these radiation types, 81% of which accounts for natural radiation and 19% is attributed to artificial sources [4].

Environmental pollution induced by radioactive isotopes is caused by nuclear weapon tests and incidents in nuclear power plants [5]. Furthermore, release of radioactive materials (e.g., $^{137}$Cs and $^{90}$Sr) from different nuclear industries is likely to increase the radioactivity level of the environment. High environmental radioactivity has been shown to increase the radiation dose in general populations.

Food is a major source of various elements and radionuclides for humans. As such, measurement of radioactivity in the environment and foodstuff is of paramount importance to assess the direct or indirect exposure of humans to different radiation levels. Radio cesium pollution is considered a major health hazard for humans as these radioactive elements could be transferred through food chains [6].

After the Chernobyl disaster, mushrooms absorbed substantial amounts of radioactive elements [7].This study aimed to determine radionuclide activity concentrations in nourished mushrooms (*Agaricusbispora*) and two species of wild fungi (*Cantharelluscibarius* and *Coprinellusmicaceus*) and their composts in two regions of Iran. Radioactivity concentrations were measured through gamma-ray spectrometry using high-purity germanium (HPGe) detectors. In addition, we determined the radiological hazards associated with the ingestion of edible mushrooms and their maximum consumption threshold.

# 2. Materials and Methods

## *2.1. Fungi and Compost Sampling*

Nourished mushroom samples were collected from Sahneh region (Iran), and two types of wild fungi species were obtained from Songhor Koliai township gardens located in Kermanshah province, Iran. Using random integration and experimental sampling, samples were collected through a combined operation. Edible mushroom samples were obtained during various stages from Gharch Baran Company (Iran) (average weight: 10 kg of fresh mushrooms).

Samples were washed with distilled water twice (10 min) in order to remove soil and other materials. Afterwards, edible mushrooms were cut into small pieces with a plastic knife and spread for preliminary drying in the oven at 200ºC (2h).In the next stage, The samples were ground into powder and passed trough mesh number 50 and then packed in standard Marinelli beaker containers with a net weight of 330 g. In addition, compost samples were randomly collected from media before and after the first mushroom cultivation and following the second cultivation.

## *2.2. Fungi Identification*

After transferring the cultivated and wild mushrooms to the systematic plant laboratory of Arak University, morphological features (e.g., cap, stipe, shape of gills, and position) were assessed. Moreover, sample spores were evaluated using lacto phenol cotton blue and light microscopy. Afterwards, fungi were identified based on the available data and keys [8]. Morphological characteristics of mushroom samples and their scientific labels are depicted in Figure 1.

## *2.3. Determining radionuclide activity*

Measurements were performed using a gamma-ray spectrometer, P-type coaxial HPGe detector with 30% relative efficiency (model: GCD30195BSI; Baltic Scientific Instrument LTD (LV-005 Latvia) Energy resolution of the detector was 1.95 keV for a 1332.52 keV energy gamma ray produced by $^{60}$Co.Operating voltage was 3000 V, and standard Marinelli beakers were used in all the measurements.

In this study, graded shield detector in the chamber was composed of two lead and copper layers (thickness: 10 cm and 3 mm, respectively); this shield was applied to reduce background radiation. Soft components of the cosmic ray (consisting of photons and electrons) were decreased to a very low level using100 mm of the lead shield. Moreover, the X-ray (73.9 keV) emitted from the lead through interaction with external radiation was suppressed by the copper layer [9].

To minimize the effect of scattering radiation from the shield, the detector was located in the center of the chamber. Following that, samples were placed over the detector in a face-to-face geometry for 86,400 sec. Features of the Marinelli beakers employed in this study were as follows: 800 cc volume, 14 cm outer diameter, 11 cm height, 10 cm inner diameter, and 7.5 cm internal height.

All the measurements were conducted in the nuclear laboratory of Arak University, and the system was calibrated in terms of energy and efficiency. Energy calibration was carried out using a standard radioactive source. For efficiency calibration, we applied the Marinelli beaker standard source, consisting of radioisotopes with exact activities of $^{241}$Am, $^{152}$Eu, and $^{137}$Cs.

Absolute efficiency of the detector configuration was calculated based on the registered gamma ray spectrum, using the following equation (1):

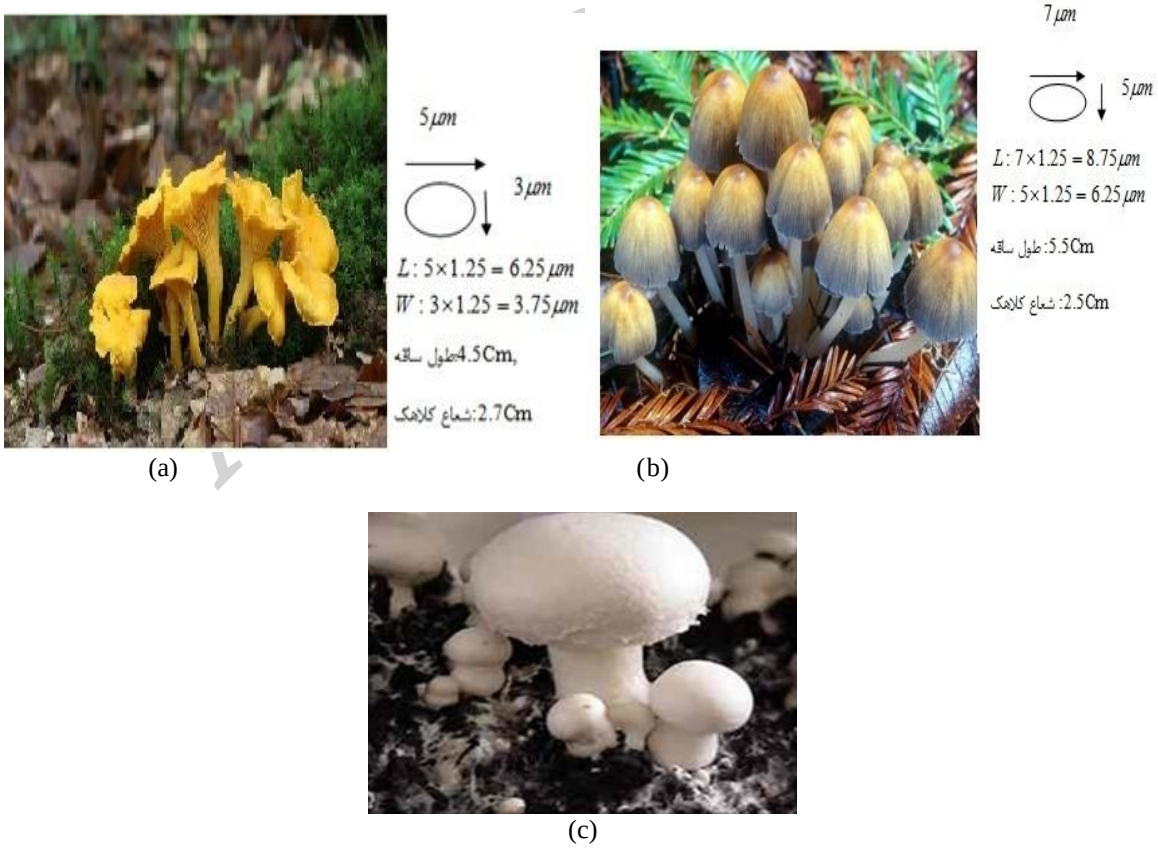
$$\varepsilon=\frac{N_i}{Act\times P_n(E_i)\times T}\times 100 \quad (1)$$

Where *Ni* represents the net count under the full-energy peak corresponding to Ei energy, *Act* is the radioisotope activity, *Pn(Ei)* signifies the probability of Ei photon emission, and *T* denotes the counting time [10].

The fitting function to the experimental data by the polynomial curve was as follows:

y=a+blnx+c/lnx+d(lnx)2+e(lnx)2+f(lnx)3+g/(lnx)3+h(lnx)4(2)

where *y* represents efficiency, *x* is the gamma ray energy (keV), and *a, b, c, d, e, g,* and *h* signify constants.




(a) (b)

(c)

Fig. 1. Mushrooms under consideration, a) Coprinus micaceuc (wild mushroom) ,(b) Cantharellus cibarius (wild mushroom), and (c) Agaricus bispora (cultivated mushroom).

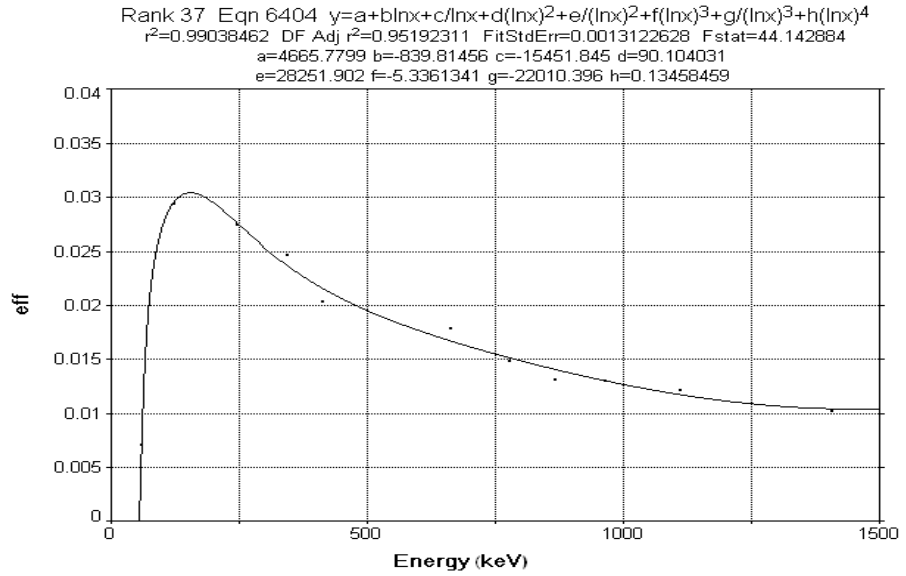



Figure2. Detector efficiency curve for standard Marinelli Beaker source

Plot of efficiency versus gamma ray energy is depicted in Figure 2 (constant coefficients shown on the top).

The specific activity of $^{238}$U was determined considering the intensity of 92,35 and 92.78 keV of $^{234}$Th with sum intensity 5.41 %. To measure the 232Th activity, we used 911.21 keV gamma line of $^{228}$Ac with intensity of 26.6% and 968.97 keV of $^{228}$Ac and an emission percentage of 17.4%. In order to determine $^{235}$U activity concentration, 143.78 and 205.03 keV gamma lines were employed. Moreover, 40K and $^{137}$Cs were obtained at1460.75 and 661.66 keV gamma ray lines, respectively [10].

After the analysis of all the registered gamma ray spectra (n=15), specific activities were calculated using EG&G Ortec Maestro II GammaVision32 software (Tennessee 37831, USA). Additionally, background correction for all the analyzed spectra was performed using a gamma ray spectrum for empty Marinelli beakers (with the same geometry used for samples).

In order to calculate activity concentration, equation 3 was applied, as follows [10]:

$$Act=\frac{Net\ Area}{\epsilon\times(BR)\times T\times m}\times 100 \quad (3)$$

where *Net Area* denotes the net counts under the peak, *Act* (Bq/kg) is the activity concentration, $\varepsilon$ represents the energy efficiency for the gamma ray by the detector, *BR* signifies the branching ratio of gamma ray intensity (%), *T* (s)is the time of spectra, and *m* (kg)indicates sample mass. Considering the inadequacy of wild fungi contents, wild mushrooms were mixed with locust leaves (*Robiniapseudoacacia*) for standard sample preparation. Prepared samples included 124.5±0.1 and 33.0±0.1 g of *Cantharelluscibarius* (WCCM code sample) and *Coprinusmicaceus* (WCMM code sample), respectively. Spectrum of pure locust leaves was analyzed before mixing, and reduction of background radiation was carried out as well. In the current study, HPGe gamma-ray spectrometry was used to determine the specific activity of radionuclides of $^{238}$U, $^{232}$Th, $^{40}$K and $^{137}$Cs of locust leaves which were lower than MDA. Consequently, only the wild fungi could be containing the mentioned radioisotopes.

### *2.4. Transfer Factor Calculation*

Transfer factor (TF) values were determined in compliance with the definition proposed by Shyamal Ranjan et al., using equation 4, as follows [11]:

$$TF=\frac{\text{Concentration of radionuclides in crop } (Bq/kg \text{ dry crop mass})}{\text{Concentration of radionuclides in soil } (Bq/kg \text{ dry soil mass})} \quad (4)$$

### *2.5. Measurement of Averageannual Committed Effective Dose*

Due to the ingestion of naturally occurring radioactive materials (NORMs) in edible plants, the average annual committed effective dose (AACED) was estimated using the following equation [12]:

$$AACED=\sum_{i=1}^{i=4} Cr\times DCFi\times Ai \quad (5)$$

where *Cr* is the radionuclide consumption rate, *DCFi* represents the dose conversion factor for each radionuclide ($2.8\times10^{-7}$, $2.3\times10^{-7}$, $6.2\times10^{-9}$, and $1.3\times10^{-8}$Sv/Bq for $^{238}$U, $^{232}$Th, $^{40}$K, and $^{137}$Cs, respectively), and *Ai* signifies the activity concentration of each radionuclide.

According to equation 5, AACED of an individual is directly proportional to the consumption rate of the components of edible plants. Using the same equation, threshold consumption rate of edible plants was calculated, as follows [13]:

$$Cr = \frac{AACED}{\sum_{i=1}^{4}(DCF_i\times A_i)} \quad (6)$$

Where *AACED* (0.3 mSv/y) is the threshold due to the ingestion of NORMs in edible plants, *Ai* denotes the activity concentration of radionuclide i, and *DCFi* indicates the dose conversion factor of radionuclides.

### *2.6. Excess Lifetime Cancer Risk Assessment*

Assessment of excess lifetime cancer risk (ELCR) for the consumed foodstuff contaminated radionuclides was calculated, as follows:

$$ELCR=Aing.DL.RF \quad (7)$$

Where *Aing* denotes the annual consumption rate of radionuclides (Bq/kg), *DL* is the mean lifetime (year), and *RF* represents the risk factors of radionuclide ingestion (1/Bq). RF values of radionuclides $^{238}$U, $^{232}$Th, $^{40}$K, and $^{137}$Cs were determined to be $4.80\times10^{-8}$, $2.30\times10^{-7}$, $5.90\times10^{-9}$, and $1.3\times10^{-8}$, respectively [14].

## 3. Results

According to the results of fungi identification, all the examined species (n=3) were basidiomycetes. In this study, *Agaricusbispora* were the cultivated mushrooms, and *Coprinusmicaceus* and *Cantharelluscibarius* were the wild fungi species. Weighted mean values of the activity concentrations of $^{238}$U, $^{232}$Th, $^{40}$K, and $^{137}$Cs of all samples are presented in Table 1. In this study, Agaricusbispora were the cultivated mushrooms, and Coprinusmicaceus and Cantharelluscibarius were the wild fungi species.

Table1. Radionuclide concentrations (Bq/kg) in mushroom samples and their composts

| Sample code | $^{238}$U | $^{232}$Th | $^{40}$K | $^{137}$Cs |
|---|---|---|---|---|
| CBFC | <MDA | 7.45 ± 1.06 | 1166.12 ±33.21 | 0.75 ± 0.24 |
| CAFC | 3.4±0.81 | 6.59±1.63 | 1326.36 ±11.93 | 1.97 ± 0.27 |
| CASC | <MDA | 7.82±1.37 | 1428.27± 13.71 | 1.27 ± 0.25 |
| EMFC | <MDA | <MDA | 1920.24±14.71 | <MDA |
| EMSC | <MDA | <MDA | 1895.24 ± 14.21 | 0.72 ± 0.06 |
| WCCM | <MDA | <MDA | 426.42±42.41 | <MDA |
| WCMM | <MDA | <MDA | 1833.94±164.28 | <MDA |

Abbreviations: CBFC= Compost before first cultivation, CAFC=Compost after First cultivation, CASC=Compost after Second cultivation, EMFC =Edible mushroom first cultivated, EMSC = Edible mushroom Second, WCCM= Wild Cantharellus cibaruc, mushroom, WCMM = Wild Coprinus micaceuc mushroom.

## 4. Discussion

According to the results of this study, radionuclides concentrations of $^{238}U$ and $^{232}Th$ in different cultivated edible mushroom samples (EMFC, EMSC) were lower than the minimum detectable activity (MDA) showed by < symbol. For $^{40}K$ and $^{137}Cs$, these values were within the ranges of 1895.24±14.21-1920.24±14.71 and <MDA-0.72±0.06 Bq/kg, respectively. Furthermore, specific activities of $^{238}U$, $^{232}Th$, $^{40}K$, and $^{137}Cs$ in the composts were within the ranges of <0.44 - 3.40±0.81, 6.59±1.63-7.82±1.37, 1166.12±33.21-1428.27±13.71, and 0.75±0.24-1.97±0.27Bq/kg, respectively. Specific activity of137Cs in sample of composts before the first cultivation (CBFC code sample) was 0.75±0.24 Bq/kg, which was close to MDA (listed in Table 1 with the symbol<), while this value increased to1.97±0.27 (CAFC code sample) after the first cultivation. This increase could be attributed to the addition of covering soil to the composts during the first process of mushroom cultivation and vertical penetration of this radionuclide to composts.Moreover, in both species of the wild fungi, only $^{40}K$ was observed to be higher than MDA (four times higher in *Coprinusmicaceus* than *Cantharelluscibarius*) (Table 1). On the other hand, radionuclide contents of the edible mushrooms were lower compared to the standard limits recommended by the International Commission on Radiological Protection (ICRP) as 1000 Bq/kg in dry weight or 100 Bq/kg in wet weight [15]. Comparison of specific activities of radionuclides in mushrooms of some countries such Commonwealth of Independent States (CIS), Slovenia, Austria and Brazil is presented in Table 2 [16-18, 4]. Radio cesium pollution in these countries is higher than the two studied regions in Iran. This could be due to the fact that the first three of these countries are located in the proximity of Ukraine, and consequently, artificial radionuclides are found in greater concentrations in their soil. In the mentioned regions, measurement of radioactive contamination in wild plants and mushrooms has revealed that the level of contamination in most plant species is higher than the limits recommended by the International Commission on Radiological Protection (ICRP)(1000Bq/kg) [15]. In a study in this regard, Teherani (1988) measured the level of $^{137}Cs$ in several European mushroom species within one year after the Chernobyl disaster and reported the concentration to range between 18-3852 Bq/kg [18]. Results of another study conducted by Changizi et al. regarding the radioactivity contamination of edible mushrooms in Tehran province (Iran) have been presented in Table 2, which are in congruence with our findings [19]. Furthermore, measurement of specific activities in the tea plant samples of Guilan province (Iran) by Poursharif et al. indicated that the specific activity of $^{40}K$ in edible mushrooms is about five times higher than the tea plant samples [20]. In the present study, mean TF value of $^{40}K$ and $^{137}Cs$ in composts and edible mushrooms was estimated at 1.54 and 0.36, respectively. Moreover, AACED value of edible mushrooms (one kg) was calculated to be 0.012 mSv, the permissible consumption rate of which was obtained at 26.7 kg/y in dry weight. With the assumption that the per capita consumption of fresh mushrooms in Iran is approximately one kg per year, the evaluated ELCR value would be $1.28\times10^{-4}$, which is significantly lower than the maximum acceptable value ($10^{-3}$) and average international value ($0.29\times10^{-3}$) [21]. As further lines of inquiry, it is recommended that researchers evaluate $^{137}Cs$ radionuclide activity in wild fungi species growing in different regions of Iran.

## 5. Conclusion

According to the results of this study, measured radionuclide activity concentrations in edible mushrooms were close to or lower than MDA. Therefore, consumption of these mushrooms is associated with no health risks for consumers. With the exception of $^{40}K$, radionuclide concentrations of the two wild

fungi species examined in this study did not exceed MDA**.**

## Acknowledgements

Hereby, we extend our gratitude to the Department of Research of Arak University, Iran for the financial support of this study.

## References

1. UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation).Sources and effects of ionizing radiation report to general assembly with scientific Annexes. New York, United Nation Publication, 1993.
2. Singh P, Rana N, Naqavi A and Rivastava D. Levels of uranium in water from some Indian cities determined by Fission Track Analysis. Radiation Measurements. 1996; 26(5): 683-7. DOI:10.1016/S1350-4487(97)82882-X.
3. Firestone RB, Shirley VS, Baglin CM. Table of isotopes CD-ROM. Eight Edition Version. 1996 Mar.1.
4. De Castro LP, Maihara VA, Silva PS, Figueira RC. Artificial and natural radioactivity in edible mushrooms from Sao Paulo, Brazil. J Environ Radioact. 2012; 113:150-4. DOI: 10.1016/j.jenvrad.2012.05.028.
5. Kalač P. A review of edible mushroom radioactivity. Food Chemistry. 2001; 75 (1): 29-35. DOI:10.1016/S0308-8146(01)00171-6.
6. Dupre de Boulois H, Joner EJ, Leyva C. Role and influence mycorrhizal fungi on radiocesium accumulation by plant. J Environ Radioact. 2008; 99(5): 785-800. DOI: 10.1016/j.jenvrad.2007.10.008
7. Tsvetnova OB, Shcheglov AI. Cs-137 content in the mushrooms of radioactive contaminated zones of the European part of the CIS. Sci Total Environ. 1994 Sep 30;155(1):25-9. DOI:10.1016/0048-9697(94)90358-1.
8. Svrček M. A Color Guide to Familiar Mushrooms: Octopus Books; 1975.
9. Aziz A. Methods of Low-Level Counting and Spectrometry Symposium. Berlin, 1981; 221.
10. International Atomic Energy Agency. Collection and preparation of bottom sediment samples for analysis of radio nuclides and trace elements, IAEA-TECDOC- 1360,2003; IAEA,Vienna.
11. Chakraborty SR, Azim R, Rahman A, Sarker R. Radioactivity Concentrations in Soil and Transfer Factorsof Radionuclides from Soil to Grass and Plants in the Chittagong City of Bangladesh. Journal of Physical Science. 2013; 24(1): 95–113.
12. Lordford TL, Emmanuel OD, Cyril S, Alfred AA. Natural radioactivity levels of some medicinal plants commonly used in Ghana. SpringerPlus 2013; 2(1):157. DOI: 10.1186/2193-1801-2-157.
13. UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation). Sources and effects of ionizing radiation. Report to General Assembly with Scientific Annexes. New York, United Nation Publication; 2000.
14. Keser R, Gorur Fk, Akcay N, Okumusoglu. Radionuclide concentration in tea, cabbage, orange, kiwi and soil and lifetime cancer risk due to gamma radioactivity in Rize, Turkey. Journal of the Science of Food and Agriculture. 2011; 91(6):987-91. DOI: 10.1002/jsfa.4259.
15. ICRP (International Commission of Radiation Protection). Protecting people against radiation exposure in the aftermath of a radiological attack. Final TG draft,2004.
16. Tsvetnova OB, Shcheglov AI. Cs-137 content in the mushrooms of radioactive contaminated zones of the European part of the CIS. Sci Total Environ.1994; 155(1): 25-9. DOI: 10.1016/0048-9697(94)90358-1.
17. Byrne A R. Radioactivity in fungi in Slovenia, Yugoslavia flowing the Chernobyl accident. Journal of Environmental Radioactivity, 1998; 6:177-83. DOI: 10.1016/0265-931X(88)90060-4.
18. Teherani DK. Determination of 137Cs and 134Cs radioisotopes in various mushrooms from Austria one year after the Chernobyl incident. Journal of Radioanalytical of Nuclear Chemistry. 1988; 126 (6): 401- 6. DOI: 10.1007/BF02164543.
19. Changizi V, Angaji M, Zare MR, Abbasnejad Kh. Evaluation of $^{226}$Ra, $^{232}$Th, $^{137}$Cs and $^{40}$K "Agaricus Bisporus" Activity in Cultivated Edible Mushroom farmed in Tehran Province- Iran. Iranian Journal of Medical Physics, 2012;9(4): 239-44.
20. Pourshrif Z, Ebrahiminia A, Asadinezhad M,Nickfarjam A, Haeri A, Khoshgard K. Determination of Radionuclide Concentrations in Tea Samples Cultivated in Guilan Province, Iran. Iranian Journal of Medical Physics .2015; 12(4): 271-7.
21. Patra A, Mohapatra S, Sahoo S, Lenka P, Dubey J, Tripathi R, et al. Age-dependent dose and health risk due to intake of uranium in drinking water from Jaduguda, India. Radiat Prot Dosimetry. 2013;155(2): 210-6. Doi: 10.1093/rpd/ncs328.