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X and γ-rays emission probabilities of ^{131}I and ^{133}Xe

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ABSTRACT

Radioactive nuclides as ^{131}I and ^{133}Xe are increasingly used for both clinical diagnosis and therapeutic treatment of the patient. For example, ^{131}I is used for the treatment of thyroid gland cancer. Otherwise, ^{133}Xe is used in ventilation studies to assess and evaluate pulmonary function and to provide images of the lungs in both cardiac and pulmonary diseases, such as asthma, pulmonary emphysema, bronchiectasis, carcinoma of the lung, and pulmonary embolism [1,2]. Furthermore, cerebral blood flow is measured using ^{133}Xe inhalation. In this study, the X and γ-rays emission probabilities in the decay of ^{131}I and ^{133}Xe were precisely measured with a calibrated Si(Li) detector. Results of this study were compared using available results in the literature. Good agreement was observed between our results and available results in the literature.

Keywords: ^{131}I; ^{133}Xe; X-Rays Emission Probabilities; γ-Rays Emission Probabilities

1. INTRODUCTION

Radioactive decay occurs as a consequence of the relative values of a number of basic nuclear parameters. Decay data are defined as those parameters relating to the normal radioactive decay modes of a nuclide and include, such as: half-life; total decay energies and branching fractions; alpha-particle energies and emission probabilities; beta-particle energies, emission probabilities, and transition types; electron-capture (and positron) energies, transition probabilities and transition types; gamma-ray energies, emission probabilities and internal conversion coefficients; Auger and conversion-electron energies and emission probabilities; X-ray energies and emission probabilities; characteristics of spontaneous fission; delayed-neutron energies and emission probabilities; delayed-proton energies and emission probabilities[3].

Beta decay is one process that unstable atoms can use to become more stable. There are two types of beta decay: beta-minus and beta-plus. During beta-minus decay, a neutron in an atom's nucleus turns into a proton, an electron and an antineutrino ($n \rightarrow p + e^- + \bar{\upsilon}_e$). The electron and antineutrino fly away from the nucleus, which shares the momentum and energy of the decay and now has one more proton than it started with. Since an atom gains a proton during beta-minus decay, it changes from one element to another. For example, the radionuclides ^{131}I ($T_{1/2}$ = 8.020 d) and ^{133}Xe ($T_{1/2}$ = 5.243 d) undergo β^--decay to the excited states of ^{131}Xe and ^{133}Cs respectively, which further de-excite by gamma emission and the competing internal conversion process leading to X-rays or Auger electron emission.

Physicians and physicists must know the identity and amount of activity of each nuclide prior to administration. The possible presence of radiochemical impurities also has to be considered, because they may compromise the quality of the clinical results and increase the absorbed dose. Furthermore, the erroneous administration of a low amount activity in diagnostic studies may result in errors of diagnosis, whereas an excessively high activity leads to an unnecessary high dose to the patient. Both incorrect applications can delay adequate treatment, or cause discomfort and serious damage to the patient's health [4].

Separately, the emission probabilities of radionuclides with well-characterized γ- and X-rays have been used for the efficiency calibration of X-ray and gamma-ray detectors, elemental analysis, in environmental radioactive measurements, domestic computations and activity measurements [5].

In view of the above, we thought worthwhile to measure the emission probabilities of different *K* and *L* X-rays together with the γ-rays emitted in the decays of ^{131}I and ^{133}Xe using a calibrated and high resolution semiconductor detector.

2. EXPERIMENTAL

Emission probabilities of X and γ-rays following the decay of ^{131}I and ^{133}Xe were measured with the experimental arrangement shown in **Figure 1.** The γ-ray and

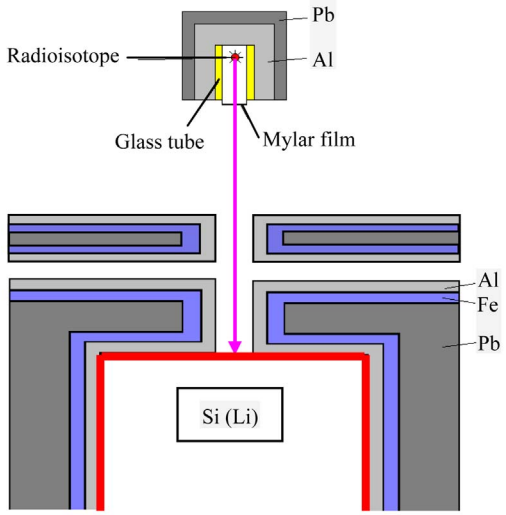

Figure 1. The experimental set-up.

X-ray intensity measurements were performed using a Si(Li) detector with an active area of 12.5 mm^2, a sensitive crystal depth of 3 mm and Be window of 0.025 mm thickness. The measured energy resolution of the detector system was 160 eV FWHM for the Mn K_α line at 5.96 keV. The energy resolution of the Si (Li) detector is high enough to resolve of the $K_{\alpha,\beta}$ and $L_{\alpha,\beta}$ X-rays for these radionuclides. The electronic set up was a standard one consisting of a stabilized detector voltage supply unit, FET, preamplifier, a main amplifier, an analogue to digital converter and 1024-multichannel analyzer. The liquid sources were housed at the center of a cylindrical shield of 1 cm diameter and 3.4 cm length. The cylindrical shield consists of a glass tube covered by Mylar film, located inside a cylindrical aluminum and lead cap as shown **Figure 1**.

The experiment was carried out using ^{131}I and ^{133}Xe sources in solution. The sources in a glass tube were prepared by putting a radioactive solution containing 1,169 MBq of ^{131}I or 4.810 MBq for ^{133}Xe (the purity of the ^{131}I exceeded 98.9% and ^{133}Xe exceeded 99.5%). The solution for ^{131}I contains copper sulphate pentahydrate ($CuSO_4.5H_2O$), ammonium dihdrogen phosphate ($(NH_4)_2HPO_4$), sodium chloride (NaCl), benzyl alcohol ($C_6H_5CH_2OH$) and water. Otherwise, the solution for ^{133}Xe contains sodium chloride (NaCl) and water. In this work, Si(Li) semiconductor detector's efficiency was determined by Yalçın *et al*. [6,7].

Two representative spectra of X and γ-rays emitted in the decay of ^{131}I and ^{133}Xe are given in **Figure 2.** The numbers of counts in the X and γ-ray peaks of the spectra were determined by fitting a convolution of a Lorentzian with a Gaussian. Step background functions were applied for all peaks. Losses due to dead-time and pile-up effects were corrected using the pulser method [8]. The peak resolution, the background subtraction, and the net peak area for both γ- and characteristic X-ray emissions were determined using the Microcal Origin 8.0 program. In order to reduce the statistical uncertainty in the measurement, each spectrum was recorded for time intervals ranging from 6 to 24 h. To obtain the net pulse height spectra of γ- and emitted X-rays, a background spectrum without the sources was stripped from the spectrum acquired over the same time interval and under the same experimental conditions.

3. RESULTS AND DISCUSSIONS

The emission probabilities of the principal X and γ-rays obtained from these measurements as well as previously measured and calculated values are given in **Table 1**. The X and γ-ray emission probabilities were determined from

$$P(E)=\frac{N(E_i)C(E_i)}{\varepsilon(E_i)A} \quad (1)$$

where $N(E_i)$ is net count rate in the peak corresponding to the energy E_i, $\varepsilon(E_i)$ is detector efficiency at the energy E_i obtained from photopeak efficiency curves given in [6,7]. A is source activity in Bq [for ^{131}I the activity = (1.17 ± 0.04) MBq and ^{133}Xe the activity = (4.81 ± 0.3) MBq], and $C(E_i)$ is the correction factor. The correction factors $C(E_i)$ relating to the effects coincidence summing and variations in detector geometry were calculated using GENIE-2000 (Canberra Industries) and the KORSUM computer programs, respectively [9]. The attenuation of the photons in the air between source and detector due to variations of atmospheric pressure, temperature and humidity was taken into account using KORSUM programs.

The emission probabilities for both ^{131}I and ^{133}Xe are compared with previously published values as shown in **Table 1.** It is clear from **Table 1** that the present experimental results are in general agreement with in the literature [10-12] except for the L_1 X-ray at 3.63 keV of Xe decay product and the γ-ray at 722.91 keV for ^{131}I. The Cs $K_{\beta 3}$ and Cs $K_{\beta 1}$ lines following the decay of ^{133}Xe strongly overlap with each other, so that these lines do not to show up as arising separate components in the spectrum as shown **Figure 2.** Therefore the total yield of the Cs $K_{\beta 3}$ and Cs $K_{\beta 1}$ lines is given in **Table 1.** Since Xe $K_{\beta 2}$ and Xe $K_{\beta 1}$ lines following the decay of ^{131}I would be discussed, the data are given separately in the **Table 1**. However, the closeness of there means that the uncertainties of the calculated peak areas are high. Also, in order to obtain good statistics, many of the counting times were comparable with the ^{131}I and ^{133}Xe half lives, so decay correction over the counting times was crucial.

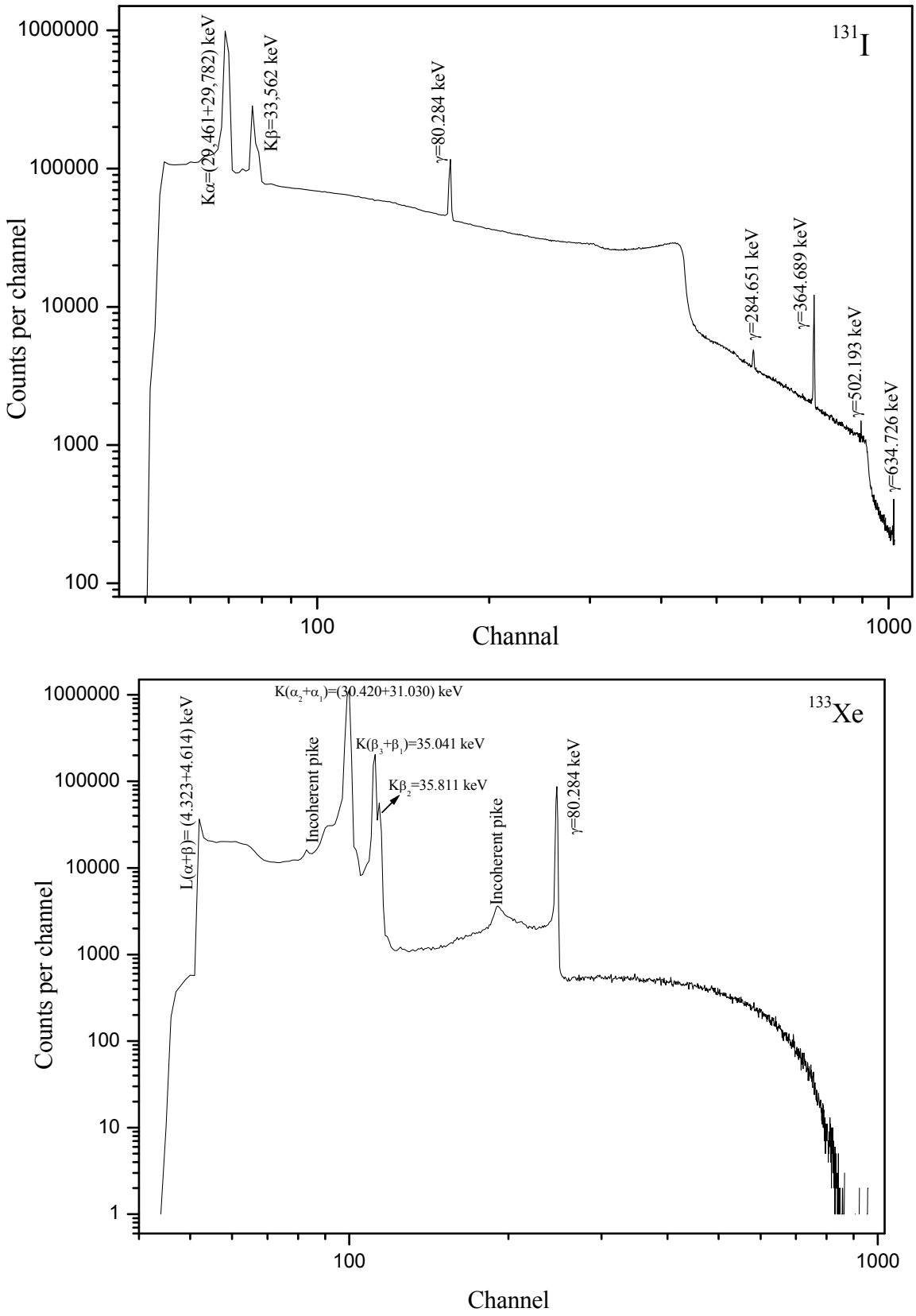

Figure 2. Two representative spectra of K, L X-rays and γ-rays emitted obtained from a Si(Li) detector.

Table 1. Emission probabilities of X and γ-rays following ^{131}I and ^{133}Xe decays.

	Measured Energy values (keV)	Emission Probabilities			
		This Work	ENSDF*	Literature [12]	Literature [11]
		For ^{131}I			
γ-β^-	80.19 ± 0.02	2.61 ± 0.06	2.62	2.63	2.60
γ-β^-	284.31 ± 0.05	5.98 ± 0.01	6.14	6.20	5.40
γ-β^-	364.49 ± 0.05	81.67 ± 0.04	81.70	81.60	82.00
γ-β^-	503.01 ± 0.04	0.36 ± 0.04	0.36		
γ-β^-	642.72 ± 0.05	7.14 ± 0.02	7.17	7.12	6.80
γ-β^-	722.91 ± 0.05	1.25 ± 0.05	1.77	1.78	1.60
Xe L_l	3.63 ± 0.09	0.02 ± 0.06	0.01		
Xe L_α	4.11 ± 0.07	0.23 ± 0.07	0.22		
Xe $K_{\alpha 2}$	29.46 ± 0.04	1.42 ± 0.08	1.40	1.37	
Xe $K_{\alpha 1}$	29.78 ± 0.02	2.58 ± 0.01	2.59	2.54	
Xe $K_{\beta 3}$	33.64 ± 0.09	0.25 ± 0.05	0.24		
Xe $K_{\beta 2}$	34.42 ± 0.05	0.14 ± 0.05	0.14		
		For ^{133}Xe			
γ-β^-	79.61 ± 0.03	0.27 ± 0.08	0.27		
γ-β^-	80.99 ± 0.01	38.20 ± 0.02	38.00		
γ-β^-	160.61 ± 0.08	0.06 ± 0.03	0.07		
Cs $L_{\alpha 1}$	4.29±0.01	2.27 ± 0.09	2.30		
Cs $L_{\beta 1}$	4.62 ± 0.07	1.54 ± 0.05	1.47		
Cs $K_{\alpha 2}$	0.625 ± 0.03	14.35 ± 0.11	14.40		
Cs $K_{\alpha 1}$	31.97 ± 0.02	26.64 ± 0.03	26.50		
Cs ($K_{\beta 3}$ + $K_{\beta 1}$)	35.04 ± 0.12	4.65 ± 0.07	4.76		
Cs $K_{\beta 2}$	35.81 ± 0.08	1.44 ± 0.07	1.48		

ENSDF*: Evaluated Nuclear Structure Data File, Table of Radioactive Isotopes, Nuclide search, http://ie.lbl.gov/toi/nucSearch.asp.

As a consequence, the discrepancies between the present measurements and previously published values of emission probabilities are within the experimental uncertainties.

4. CONCLUSIONS

In this paper, we have given a number of data for photon-emission probabilities characterizing the K and L X and γ-rays following the detail of the nuclides ^{131}I and ^{133}Xe. The values tabulated here can be utilized application in the analysis of nuclear materials, in nuclear medicine, determining the efficiency calibration of X and γ-ray detectors, elemental analysis, in environmental radioactive measurements, domestic computations and activity measurements.

We considered the self absorption of X-rays in sources which include Cl and Cu in solution that is essential for absorption X-ray. t is the areal mass of the sample in g/cm^2 and β is the self absorption correction factor given by

$$\beta_{Ki} = \frac{1-\exp\left\{-\left[\mu(E_0)\sec\theta_1 + \mu_{Ki}(E)\sec\theta_2\right]t\right\}}{\left[\mu(E_0)\sec\theta_1 + \mu_{Ki}(E)\sec\theta_2\right]t} \quad (2)$$

where $\mu(E_0)$ and $\mu_{Ki}(E)$ are the attenuation coefficients (cm^2/g) of incident photons and emitted characteristic X-rays, respectively. The angles of incident photons and emitted X-rays with respect to the normal at the surface of the sample θ_1 and θ_2 were equal to 45° in the present setup.

Emission probabilities for K and L X and γ-rays emitted in the radioactive disintegration processes were calculated by using the equation 1. When we compared the calculated K and L X and γ-rays emission probabilities for ^{131}I and ^{133}Xe with the measured data, as well as with previously published results, and an agreement within 0.8% to 4.8% was observed [10-12].

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