K X-ray fluorescent source for energy-channel calibration of the spectrometer

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Abstract A new K X-ray fluorescent source for calibrating the X or γ-ray multichannel analyzer spectrometer is introduced. A detailed description of the K fluorescent source device is given. The calibration method used and experimental results obtained are presented. The purity and efficiency of K fluorescence photons from this device are discussed. This new fluorescent source may be used as a substitute for radioactive nuclides for the energy-channel calibration of some MCA spectrometers.

Keywords K X-ray fluorescence, Energy-channel calibration

CLC numbers O572.21, O434.1, O434.12 A

1 INTRODUCTION

In the study of radiation physics, the detector and multichannel analyzer (MCA) spectrometer are often used to measure and analyze X or γ-ray spectra emitted from samples. A calibration, the relation between energy and channel (or pulse height), is important in those measurements.

Usually, a spectrometer system is calibrated by using standard sources such as ^{241}Am, ^{57}Co, ^{113}Sn etc. However, many disadvantages are brought out for dealing with these radioactive nuclides. First, the X and γ-ray energy that a radioactive nucleus emits is fixed, so that each radioactive nucleus can only be used to calibrate one or two energies. When a range of energies needs to be calibrated, several radioactive nucleuses are needed. Secondly, the store of the radioactive sources, protection and waste disposal etc. are very inconvenient. Thirdly, the radioactive nucleus will decay. In the end, they will become waste and then be disposed, which may cause the environmental pollution.. Hence new methods without using radioactive nucleus are highly recommended.[1]

For these reasons, the present work proposes a method in which we substituted the radioactive nucleus by energy-channel calibration. That is a K fluorescence X-ray device.

Design and application of the K fluorescence method have been studied since 1970 s. In Ref.[2], the production of K fluorescence from 8 to 87 keV was studied for the application to health physics.[3,4] However, the K fluorescence device used for the energy-channel calibration has not been discussed yet. Besides the advantage of environment protection,

Manuscript received date: 2001-03-14

this new method used for the energy-channel calibration has the following advantages: (1) Changing different fluorescent targets can produce monoenergy beams of different energies. When a wide energy region needs to be calibrated, it is enough to change the fluorescent target. (2) Photon fluxes can be easily controlled in a wide range. (3) The X-ray generator can be conveniently shut off when not in use. The store and protection etc. need not to be considered. However, the only limitation of this kind of device is that it can only be used to calibrate energies under 108 keV (energy of Th $K_{\beta 2}$ X-ray).

2 K FLUORESCENCE DEVICES AND EXPERIMENTAL ARRANGEMENT

The main idea of the experiment design is to reduce the volume of experimental arrangement, enhance the production efficiency of K fluorescent sources and at the same time reduce the power of the primary X-ray device. The arrangement used in the experiment is illustrated in Fig.1.

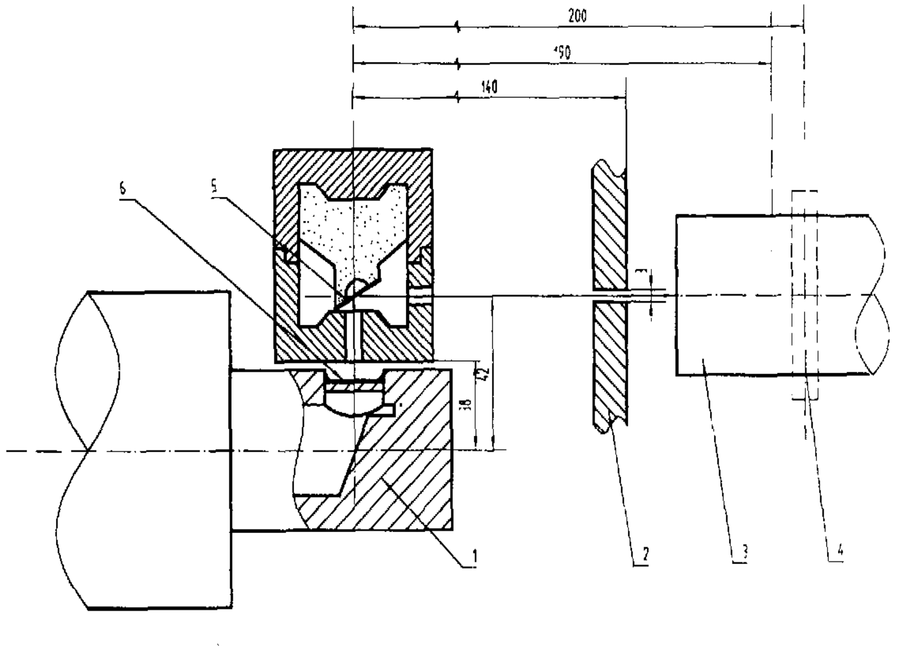

Fig.1 Schematic diagram of the K fluorescence devices and experimental arrangement
1 X-ray tube, 2 Collimator, 3 NaI detector, 4 Ionization chamber, 5 K fluorescent target, 6 0.5 mm-thick aluminum. (When the efficiency needs to be measured, the collimator made of lead is taken away and an ionization chamber is used as a substitute for the NaI detector)

2.1 X-ray sources

A ceramic X-ray tube with an anode connected to the earth is employed. The X-ray tube used in this study works at a potential range of 0~300 kV (accuracy of 1%) and a current range of 0~2 mA. The experimental results show that 150 kV potential and less than 50 μA current are enough for this application.

A 0.5 mm thick aluminum filter is attached to the exit window of the primary X-ray beam in order to absorb the lower energy X-rays.

2.2 K fluorescence device

The photons emitted from the primary target of the X-ray tube excite K X-rays of a secondary target (radiator). Positioned against the exit window diaphragm of the X-ray tube is a lead cylinder that serves as a holder of the K fluorescent target and absorbs the transmitted primary beam. The thicknesses of K fluorescent targets were chosen as discussed in Ref.[3].

The K fluorescent target is placed in the holder made of plastics (Fig.1). The design is convenient for changing different targets. The fluorescent target is at an angle of θ=60° to the central ray of the primary beam. The center of the fluorescent target is about 42 mm from the X-ray focal spot. This arrangement reduces the area of light spot and enhances the luminosity of the radiator. The X-ray beam goes through a circular hole in the lead cylinder to excite the K fluorescence. The diameter of the hole is 3 mm when the spectrum needs to be measured and the diameter is 5 mm when the efficiency needs to be measured. No filter was added at the fluorescent beam exit hole.

2.3 Detector and Multichannel analyzer (MCA)

Since the limitation of our experimental equipment, a photoelectron multiplier tube with a ϕ45 mm NaI crystal, a preamplifier and a H.V. supplier were used in the experiment, which were all made by Beijing Nuclear Instrument Plant. The MCA equips with a MCA card and related software in computer PC386. The detector arrangement is shown in Fig.1. To minimize the influence of leakage and scatter rays, some lead pieces were mounted. A $\phi 60\times 6\,\mathrm{cm}^3$ ionization chamber and a dosimeter were used to measure the K fluorescent X-ray intensity and its production efficiency.

3 EXPERIMENT AND RESULTS

3.1 Energy-channel calibration

Because of the poor energy resolution of the NaI detector, the four peaks of $K_{\alpha 1}$,

$K_{\alpha2}$, $K_{\beta1}$ and $K_{\beta2}$ X-rays from the fluorescent target used were merged into one peak. This is $K_{\alpha\beta}$. Four different elements, i.e. Ag, Gd, W and Pb, were used as fluorescent targets in the calibration.

Under the H.V. and gain condition used, the weighted-average energy $E_{K_{\alpha\beta}}$ and the central channel of the measured peak are given in Table 1.

Table 1 Weighted-average energies of the $K_{\alpha\beta}$ X-rays and their corresponding channel numbers for the target elements

Element	$E_{K_{\alpha\beta}}$/keV	Channel
Pb	76.2	569
W	60.4	398
Gd	43.8	128
Ag	22.7	(Peak can only be found at higher H.V. and gain)

Then a linear regression for the calibration is used to find out the relation between the energy and channel. For the detector and MCA system used in this experiment, the regression expression

$$E = 33.7 + 0.00724C_h \tag{1}$$

where E is the weighted-average K photon energy and C_h is the central channel of the measured peak. The correlation coefficient r=0.993.

Four calibrated spectra of the primary X rays at different tube voltages are shown in Fig.2 (The angle of the primary target is 17°. A 2 mm-thick aluminum filter is added). It is shown that the calibrated energy scale is coincident with corresponding tube voltages (constant with accuracy of <1%).

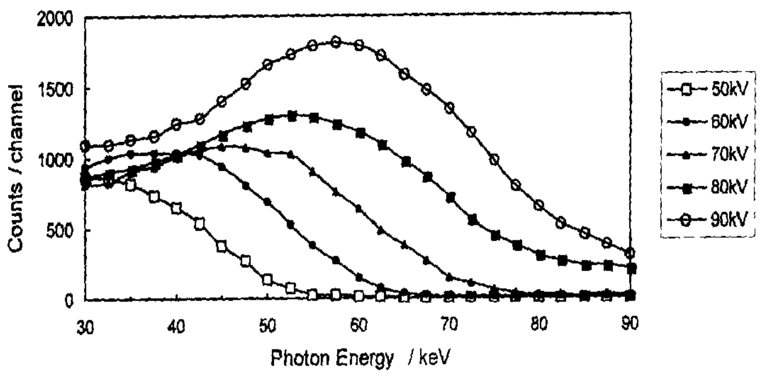

Fig.2 Calibrated primary X-ray spectra at the tube voltages of 50, 60, 70, 80 and 90 kV

3.2 Purity

The photon flux purity was worked out from the measured spectra for Ag, W, Gd and Mo at different tube voltages. The purity of W foil, which was the lowest of the four targets, is better than 60% as the accelerating potential varied from 75 kV to 120 kV. The purity of Mo target is 93.3%, which is the highest when the potential U is about 30 kV.

The result shows that for a same U/E_K value ($U/E_K > 1$), the purity will drop when the Z of the target is increasing. The purity of the same elemental target will also drop when the U/E_K value is increasing.

3.3 Efficiency

The efficiency was also measured. The following formula[5] was used to calculate the K fluorescent production efficiency.

$$I = F_K(U/E_K - 1)^n \tag{2}$$

where I is the intensity of K fluorescent X rays measured at certain distance when the tube current is 1 mA, U is the tube voltage in kV, F_K is the efficiency, and E_K is the binding energy of the K shell in keV. The measured values of n range from 1.27~1.72. According to the above formula and the measured data, the F_K and n were then worked out. In comparison with the data in Ref.[3], the K fluorescence efficiency of Ag target is 5.67 cGy/(min·mA) at 200 mm distance from the K fluorescent target. The value of n is 1.35.

4 DISCUSSION

4.1 K fluorescence purity

The measured purifies of the K fluorescence are a little lower comparing with that reported in the Ref.[3] Hence, a further study was carried out. An experiment was done to measure the counting rate of Gd material at the same accelerating potential and at currents of 75 μA and 150 μA. The two counting rates were calculated respectively for each 1 μA and then compared. The results show that the counting rate per 1 μA at 75 μA current was about two times as large as that at 150 μA current. So the dead time of the measurement instrument is the main cause for deteriorating the measured purity.

4.2 K fluorescence efficiency

The K fluorescence efficiency of the experiment is much higher than that reported in the Ref.[3]. Under the same conditions, the efficiency given in Ref.[3] is only 0.0017 cGy/(min mA) at 200 mm distance from the K fluorescent target. The main cause is that the center of the K fluorescent target (or radiator) is located only about 42 mm from the X-ray focal spot in the present experiment, whereas this distance is about 150 mm in Ref.[3].

4.3 Energy

Although the measured spectrum displays only one $K_{\alpha\beta}$ peak, yet in fact, there are four main energies for one elemental target. If a HPGe detector is used, the spectrum shows four characteristic lines which are $K_{\alpha 1}$, $K_{\alpha 2}$, $K_{\beta 1}$ and $K_{\beta 2}$.

5 CONCLUSION

The experimental result indicates that a monoenergetic K fluorescent device with small power and size has been developed to substitute several radioactive nuclear sources for calibrating the X or γ ray spectrometer in the photon energy range of 8~108 keV. Designed with different power level, the device may also be used as a monoenergyetic X-ray source for other wider applications.

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