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DEVELOPMENT OF A METHODOLOGY FOR LOW-ENERGY X-RAY ABSORPTION CORRECTION IN BIOLOGICAL SAMPLES USING RADIATION SCATTERING TECHNIQUES

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ABSTRACT

Non-destructive techniques with X-ray, such as tomography, radiography and X-ray fluorescence are sensitive to the attenuation coefficient and have a large field of applications in medical as well as industrial area [1,2]. In the case of X-ray fluorescence analysis the knowledge of photon X-ray attenuation coefficients provides important information to obtain the elemental concentration. On the other hand, the mass attenuation coefficient values are determined by transmission methods. So, the use of X-ray scattering can be considered as an alternative to transmission methods. This work proposes a new method for obtain the X-ray absorption curve through superposition peak Rayleigh and Compton scattering of the lines L_a e $L_ß$ of Tungsten (Tungsten L lines of an X-ray tube with W anode). The absorption curve was obtained using standard samples with effective atomic number in the range from 6 to 16. The method were applied in certified samples of bovine liver (NIST 1577B) , milk powder and V-10. The experimental measurements were obtained using the portable system EDXRF of the Nuclear Instrumentation Laboratory (LIN-COPPE/UFRJ) with Tungsten (W) anode.

1. INTRODUCTION

The attenuation of X-rays by material provides a wide variety of information about fundamental properties of matter in the atomic, molecular, and solid state In particular, relative and absolute measurements of the mass attenuation coefficients are very important in energy disperse X-ray fluorescence technique (EDXRF). Besides that, in the case of biologic samples the determination of the X-ray mass attenuation coefficients is an essential parameter for quantitative analysis, because of its basic composition that is formed by H, C, Mg, Na, S, Cl, P, K and Ca. In the literature there are some methods to correct the coefficient of X-ray absorption EDXRF. The transmission method of radiation [3] estimates the absorption factor of the sample making measures of the intensity of characteristic X-rays, emitted by a multi target, placed adjacent to the sample. The method of transmission-emission [4] is a variant of the transmission method of radiation. This method is based on the assumption that the absorption coefficient of radiation in the sample can be represented by a power of energy E of the radiation incident. Our work proposes the development of a new method for determination of the mass attenuation coefficient in samples with low atomic number through superposition peak Rayleigh and Compton scattering of the lines Lα e Lβ of Tungsten. We sought a semi-empirical relationship between peak scattering of the lines Lα e Lβ of Tungsten and the effective atomic number. Using known standards, we obtained the effective atomic number using the empirical relation [5] given below:

$$Z_{eff} = \{\sum f_i \, . (Z_i)^{2.94}\}^{\left(1/_{2.94}\right)} \quad (1)$$

where f_n is fraction of total number electrons associated with each element and Zn is the atomic number of each element.

2. MATERIALS AND METHODS

2.1. Transmission Method

A beam of gamma radiation when focused on a material of thickness *D*, a fraction of the beam is absorbed by the material. The intensity of the beam that emerges is linked to the intensity I_0 of the incident beam, the Beer-Lambert law, being valid for a monoenergetic beam of radiation [6]:

$$I = I_0 . e^{-\mu D} \quad (2)$$

where μ is called the linear attenuation coefficient. The linear attenuation coefficient is the probability of suffering beam attenuation to the processes of photoelectric absorption, Compton scattering or pair production and can be written as:

$$\mu = \tau(photoeletric) \; + \sigma(Compton) + \kappa(pair\ production) \quad (3)$$

The linear attenuation coefficient is limited by the fact that it varies with the density of the absorber, even though the absorber material is the same. Therefore, the mass attenuation coefficient is much more widely used and is defined as:

$$\mu_m = \mu/\rho \quad (4)$$

where ρ represents the density of the medium. For a given gamma-ray energy, the mass attenuation coefficient does not change with the physic state of a given absorber.

$$I = I_0 . e^{-\mu_m . \rho . D} \quad (5)$$

The transmission method used in this work consists in determining experimentally the mass attenuation coefficient by using the Beer-Lambert law:

$$\mu_m = \left(\frac{1}{\rho D}\right) . \ln \left(\frac{I}{I_0}\right) \quad (6)$$

3. EXPERIMENTAL

The measurements were carried out with a portable system developed by the Nuclear Instrumentation Laboratory, consisting of an Oxford TF3005 x-ray tube and a Si-PIN XR-100CR Amptek detector (with 6-mm2 active area and a 25-µm Be window). The X-ray tube has a tungsten (W) anode, a 127-µm Be window and maximum operating current and voltage of 0.5 mA and 30 kV respectively. The angle between the x-ray tube and the detector window is 60◦, the source–sample and the detector–sample distances are 4.0 cm. Samples were prepared in pellet form with superficial density of about 300 mg/cm². The samples used were: Plexiglas, H_3BO_3, Na_2CO_3, Si and $CaCO_3$. Each sample was measured during a period of 600s. Figure 1 shows the diagram of the portable system. Figure 2 shows the picture of the portable system

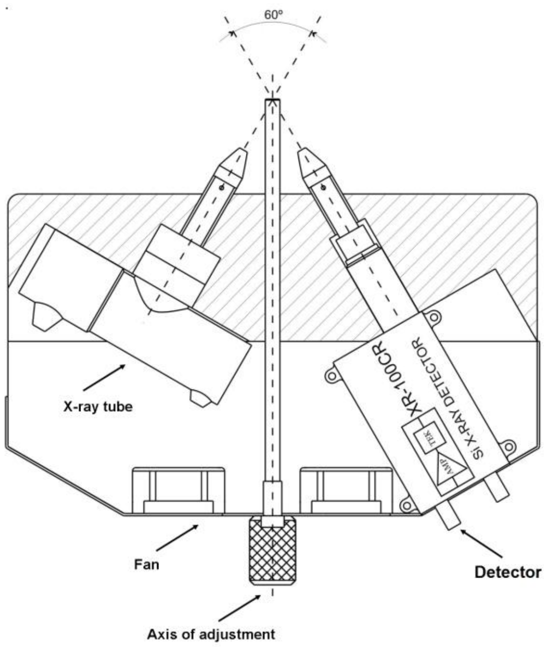

Figure 1. Diagram of the portable system.

For application the transmission method, the experimental set-up was composed by: an Oxford TF3005 x-ray tube, a target multielements, an ORTEC Si(Li) detector, with an energy resolution of about 180 eV at 5.9 keV and an ORTEC multichannel-analyser. This configuration, the Si(Li) detector and the target are aligned when the x-ray tube has a angle of 16° to the surface of the target. Figure 3 show the diagram experimental setup used transmission method.

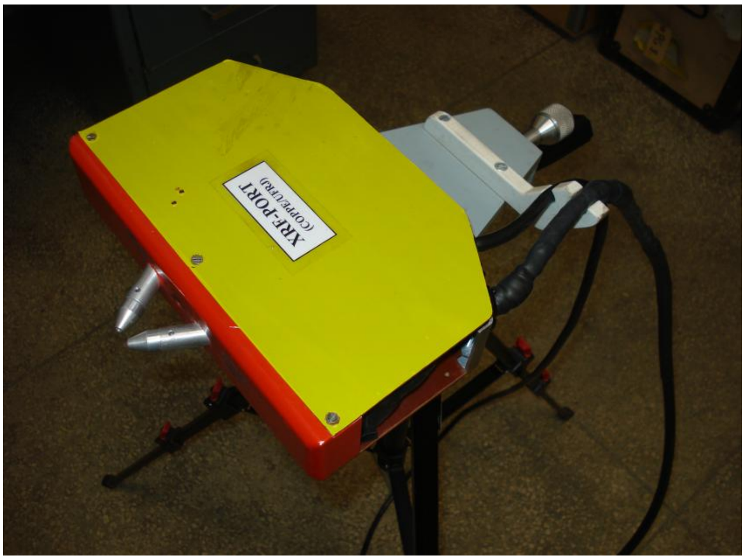

Figure 2. Picture of the portable system.

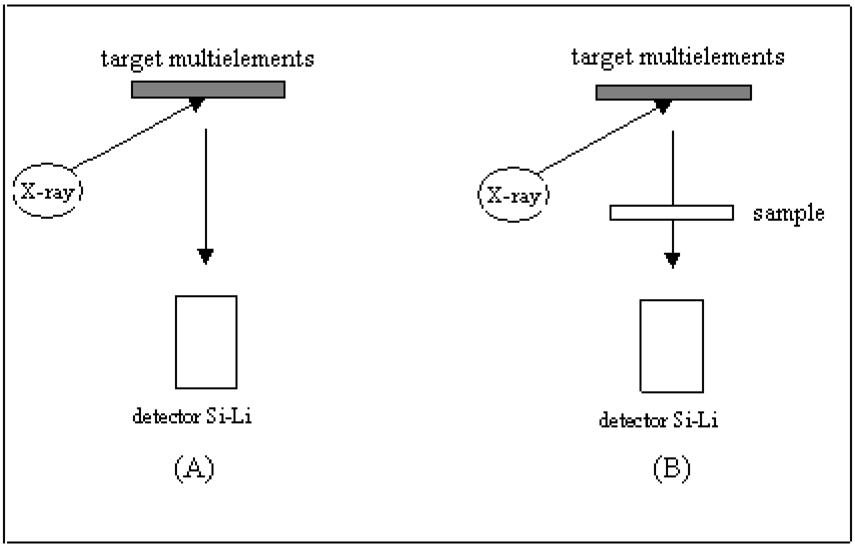

Figure 3. Diagram of the transmission method: (A) measure of I_0; (B) measure of I.

4. RESULTS AND DISCUSSION

The x-ray source spectrum is shown in Figure 4. Figure 5 shows the results of the semi-empirical into peak scattering of the lines $L\alpha$ and $L\beta$ of Tungsten and the effective atomic number calculated by equation 1. The Table 1 shows the values of the effective atomic number and peaks $L\alpha$ e $L\beta$ ratio.

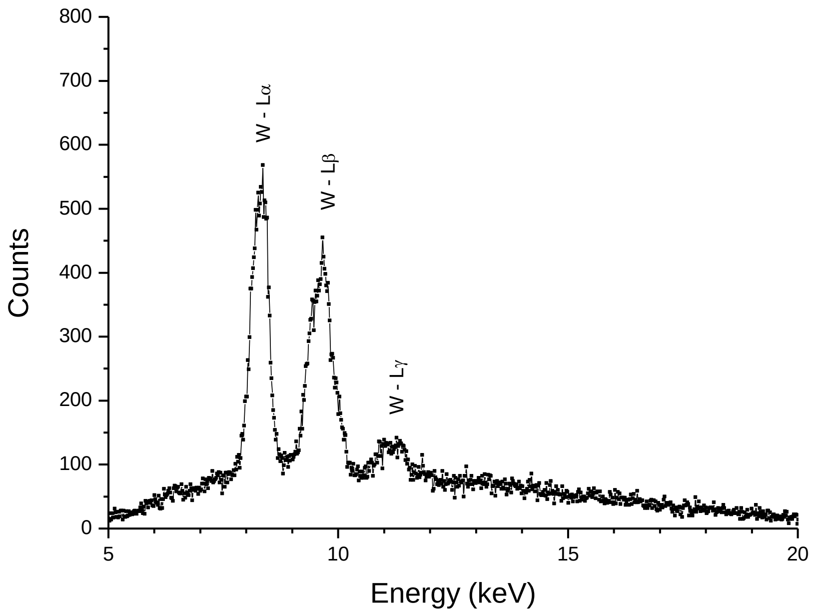

Figure 4. Spectrum x-ray tube with Tungsten (W) anode.

Table 1. Results of the Effective atomic number and peaks Lα to Lβ ratio.

Samples	Z_{eff}	Lα/Lβ	uncertainty
Plexiglas	6.5	1.0217	0.0005
H_3BO_3	7.4	1.1676	0.0005
Na_2CO_3	9.2	1.3177	0.0015
Si	14.0	2.1890	0.0034
$CaCO_3$	15.1	2.4171	0.0022

The effective atomic number found for the certified samples were: 7.6 (Milk powder), 7.0 (V-10) and 7.4 (Bovine liver). Using the XCOM program, we find the mass coefficient attenuation. The mass attenuation coefficients values were compared with the transmission method values. Figures 6, 7 and 8 show the comparison for energy of 4.509 keV, 4.932 keV, 5.895 keV, 6.491 keV, 8.041 keV and 8.905 keV.

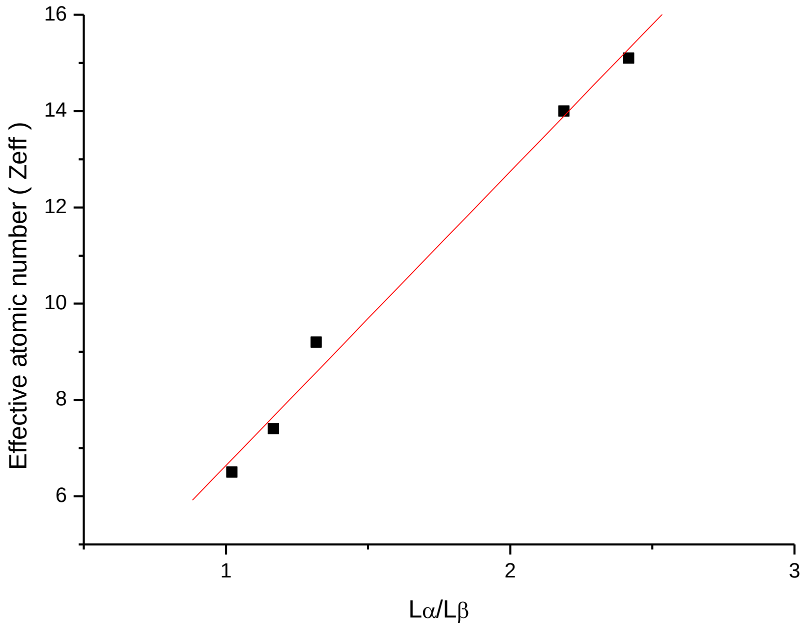

Figure 5. Graphic effective atomic number versus Lα to Lβ ratio.

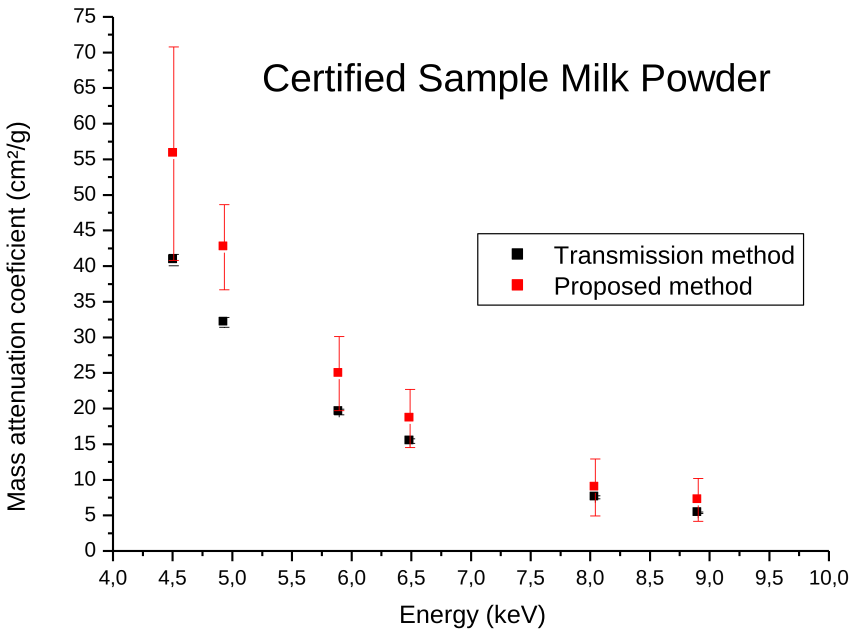

Figure 6. Comparison of the proposed method with the transmission method for certified sample milk powder

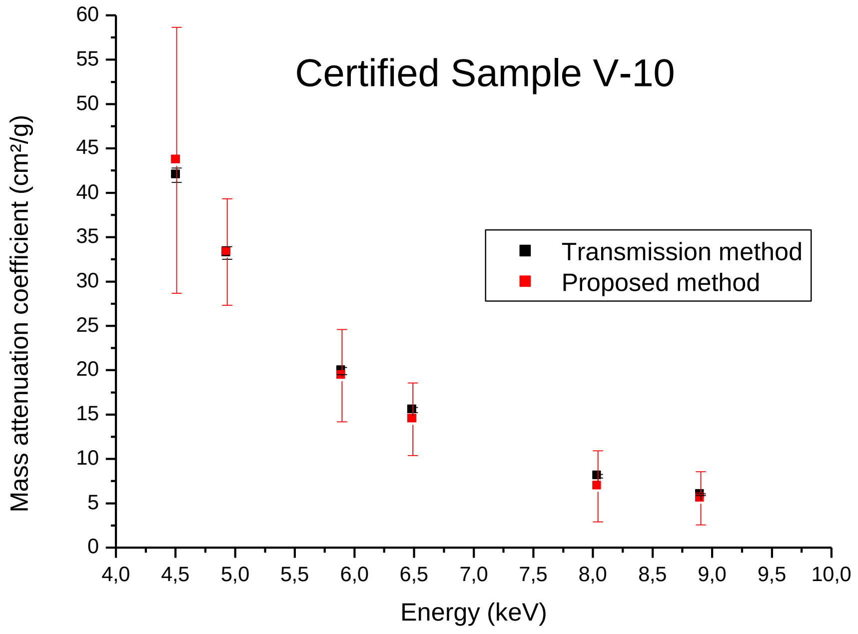

Figure 7. Comparison of the proposed method with the transmission method for certified sample V-10

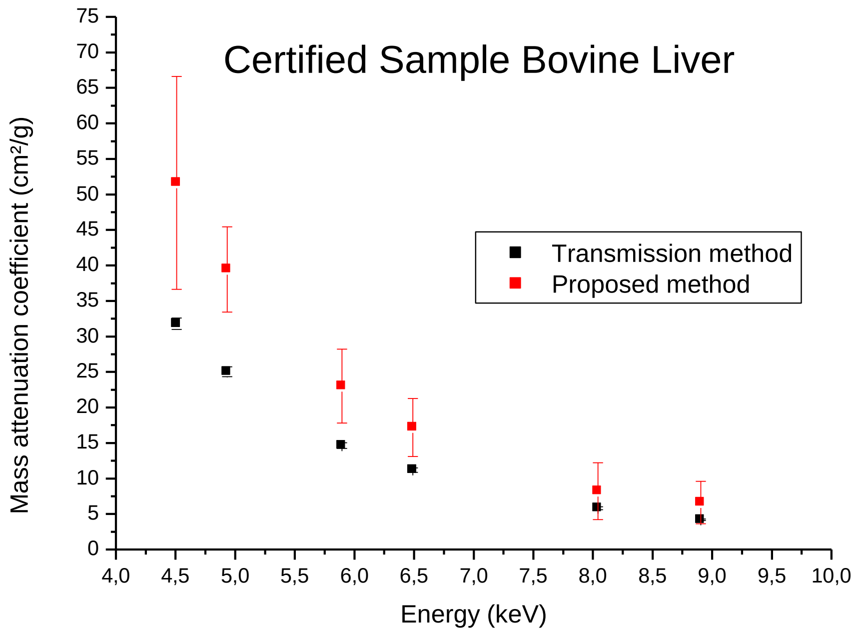

Figure 8. Comparison of the proposed method with the transmission method for certified sample bovine liver

5. CONCLUSIONS

The results obtained compared to the results transmission method show the feasibility of the presented technique. This study presents the preliminary results obtained. Other experiments will be performed in order to verify the possibilities of using the proposed method to different matrices.

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