The background calculation of the filter-fluorescer method

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Abstract For the measurement of X-ray energy spectrum with filter-fluorescer method, the high energy tail at the rearward of response function is the main source of background. There are, traditionally, two techniques for measuring the background contributions: the same element *Z* for the fluorescer and filter, or the same element *Z*−1 for them. Using the formula of fluorescence intensity, and the elemental combinations of cobalt and iron, the backgrounds which the two techniques provide and the real one for measuring black-body radiation at equilibrium temperature of 7×10^6 K, were calculated. The results show that the Co-Co combination for the filter-fluorescer spectrometer can achieve better effect. A semi-quantitative analysis for the calculation results is discussed.

Key words filter-fluorescer method, Background channel, Real background, Semiquantitative analysis

1 Introduction

The filter-fluorescer spectrometer (FFS) is widely used on various ICF (Inertial Confinement Fusion) facilities [1–6] for measuring spectrum of high intensity hard X-rays. An FFS data channel usually consists of a prefilter (atomic number *Z*) and a fluorescer (atomic number Z−1). After transmitting through the prefilter, X-rays at energies above the prefilter absorption edge are absorbed intensively, while most of those below the edge irradiate the fluorescer. Because X-rays at energies below the fluorescer absorption edge cannot activated fluorecsence, so there is a bandpass between the two absorption edges and generates secondary X-rays. By measuring the secondary X-rays, the structures of an X-rays spectrum can be obtained. Different from data channel, the elements of prefilter and fluorescer of background channel are the same one, thus allowing high-energy component which contributes to background to be fluoresced. This background can then be subtracted from the data channel to determine the pure X-ray bandpass.

The greatest benefit of filter-fluorescer method is the provision of a background channel to conjunct each data channel[7]. There are two techniques to configurate the background channel. Using a prefilter of the same material as fluorescer suggested by Burns *et al*.[7], the background energies are equal with that of signal fluorescence, and the components of high energy tail differ from the data channel. Another technique is to use a fluorescer of the same element as prefilter, reported by Kornblum *et al*.[8,9], but the features are opposite.

In this paper, the signal-to-noise ratio (SNR) of data channel with prefilter of different thicknesses are calculated for given equilibrium temperature and filter-fluorescer combination. Taking the prefilter thicknesses (which can get high SNR) as parameters, the two techniques are applied to fluorescer of different thicknesses to calculate the background, and the results are compared with the real background of data channel. Effects of the two techniques and the reasons are discussed, too.

2 Principle of FFS

Fig.1 shows schematically a data channel for FFS. Because of the isotropical fluorescence, the detector can be placed off the beam incidence, with an angle of usually over 90°, so that the background from γ-rays or neutrons can be reduced.

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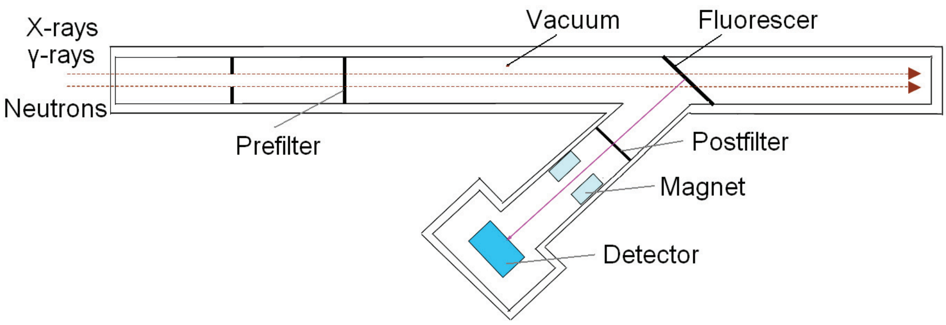

Fig.1 Schematics of an FFS channel. The detector is placed off the beam incidence and the magnet deflects the charged particles.

The target of FFS is generally blackbody radiation in thermodynamic equilibrium, and its spectral energy distribution is given by Planck radiation formula. After passing through the prefilter, the response function of source X-rays can be divided into two parts: the narrow band, of the signal, between two absorption edges; and the broad higher-energy regions of the background.

Configuration of the background channels and data channels are identical[7,10], except that the prefilter and fluorescer of the background channels are of fluorescer element Z–1[7] or prefilter element Z [8,9], whereas for the data channels, the prefilter is of element Z and the fluorescer is of element Z–1. Ref. [11] gives the calculation method of fluorescence intensity for an element, substituting Plank blackbody formula and considering that the blackbody is a cosine emitter, Eq.(1) can be obtained,

$$I = \frac{s_{\mathrm{de}} s_{\mathrm{Be}} 2hv^3}{r^2 c^2 \sin\varphi} \frac{1}{e^{hv/kT}-1} \frac{s}{4\pi R^2} \frac{S_q-1}{S_q} \omega_q p_i \tau_0 \frac{\lambda_1/\lambda_i}{\mu_0 \csc\varphi + \mu_i \csc\psi} (1-e^{-(\mu_0\csc\varphi+\mu_i\csc\psi)t}) \quad (1)$$

where I is blackbody radiation energy detected in unit time and in unit frequency by a detector, s_{de} is detecting area of the detector, s_{Be} is exit window area of initial X-rays, h is Planck constant, v is X-ray frequency, r is the distance between the exit window and fluorescer, c is speed of light, φ is incident angle of initial X-ray, k is Blotzmann constant, T is radiator equilibrium temperature, s is area of sample to be irradiated, $(S_q–1)/S_q$ is absorption edge jump ratio of energy level q, ω_q is fluorescence yield of q series spectral line, p_i is electron transition probability of spectral line i of q series, τ_0 is linear absorption coefficient of sample for incident X-rays, λ_1 is wave length of incident X-rays, λ_i is wave length of exit X-rays, μ_0 is linear attenuation coefficient of sample for incident X-rays, μ_i is linear attenuation coefficient for spectral line i, ψ is exit angle of secondary spectral line i of q series, and t is thickness of sample.

3 Calculation results

Using the element combination of $_{27}$Co-$_{26}$Fe, and considering black-body radiation at 7×10^6 K of the equilibrium temperature, the SNR can be calculated. The results show that the data channel can get higher SNR in a broad range of fluorescer thickness at the filter thickness of 20 μm. Fig.2(a) shows SNR the of data channel for fluorescer thicknesses of 1–50 μm in this condition.

The background channel uses Co-Co or Fe-Fe combination. The calculation parameters are identical with the data channel. Fig. 2(b) shows background intensity for filter thickness of 20 μm and fluorescer thicknesses of 1–50 μm. The intensities of two background channels are higher than that of the data channel. And the background intensity of Co-Co combination is closer than the Fe-Fe combination to that of the data channel, hence a better combination of Co-Co in designing the background channel of FFS.

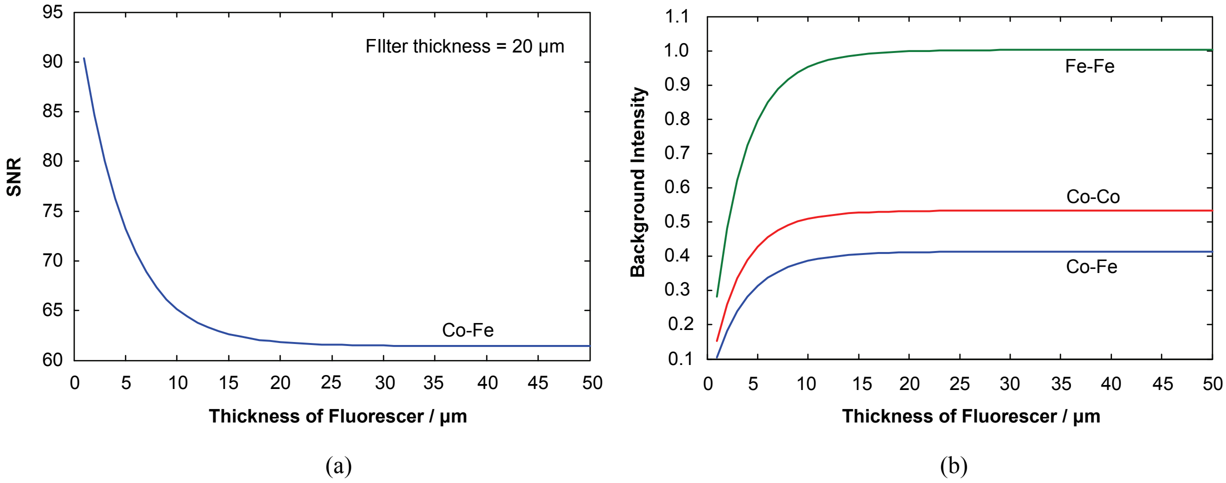

Fig.2 SNR of the data channel (a), and background intensities of three combinations (b). The background of Co-Fe combination is the real background, and the Co-Co and Fe-Fe curves are results of background channels.

4 Discussion

For the elements and energy band in this work, there is no pair production and the sum of cross-section of Compton-scattering and Rayleigh-scattering is less than that of photoelectric interaction by an order of magnitude, so we can assume that there is no scattered X-ray and the linear attenuation coefficient is photoelectric absorption coefficient. At the same time, the fluorescence yield of Co is approximately equal to that of Fe. Using linear attenuation coefficient, a semi-quantitative analysis can be performed for the calculation results above.

Considering the energy band of fluorescence background (energy higher than absorption edge of the prefilter), the fluorescer absorption energy of combinations of Co-Co and Fe-Fe are both greater than that of Co-Fe combination. Fig. 3 illustrates the absorption curves with 20-μm thicknesses of both the prefilter and fluorescer. The fluorescer absorption energy is the integration area below the curve. Obviously, the absorption energy of Fe-Fe combination is greater than that of Co-Co combination. That is, considering the approximate condition mentioned above, the fluorescence energy of Fe-Fe combination is greater than that of Co-Co combination.

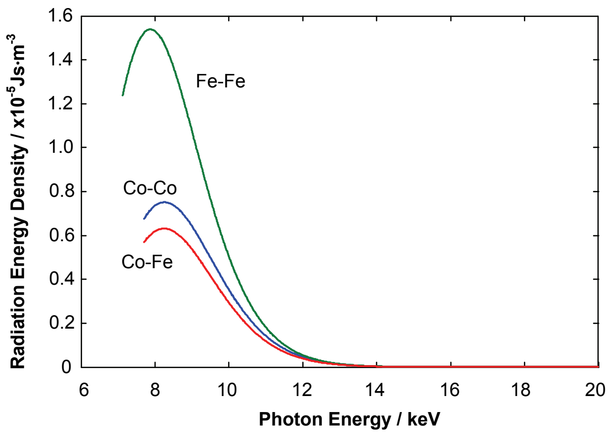

Fig.3 The absorption curves of three combinations (Fe-Fe, Co-Co and Co-Fe).

5 Conclusions

The calculation results show that conventional background measurement techniques of filter fluorescer method, using Co-Fe combination, are not accurate for the measurement of blackbody radiation of equilibrium temperature 7×10^6 K. the background intensities of Co-Co and Fe-Fe combinations are both greater than that of real background and the usage of Co-Co combination for background channel can get better effect. Assuming that there is no scattered X-ray, a semi-quantitative analysis shows that the fluorescence energy of Fe-Fe combination is greater than that of Co-Co combination. This can explain the phenomenon.

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