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As the physics lying behind is complicated we will only give the final expressions.

$$\Phi_{0,h\nu}(\nu_0) = N_{h\nu}(\nu_c) / (N_e 1/2 r_0^2 A(\nu_0, \nu_c) (\nu_c/\nu_0 + \nu_0/\nu_c - \sin^2 \theta) \Delta \Omega) \quad (E1)$$

In the equation (E1) $N_{h\nu}(\nu_c) d(\nu_c)$ is the number of photons registered by the detector between the energies $h\nu_c$ and $h\nu_c + d(\nu_c)$ after correction for the distortion of the detector itself (detector response).

N_e = the total number of electrons in the scatterer

r_0 = the standard electron radius = $2.82 \cdot 10^{-15} \text{ m}$

$$A(\nu_0, \nu_c) = \exp(-l(a) \mu_a(\nu_c) - (8r/3\pi) (\mu_s(\nu_0) + \mu_s(\nu_c))) \quad (E2)$$

gives the radiation damping in the scatterer and in the air (attenuation).

$l(a)$ = the distance in air between the scatterer and the detector.

μ_a = the attenuation coefficient of air.

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μ_s = the attenuation coefficient of the scatterer.
 r = the radius of the circular and filamentous scatterer
 $h\nu_c$ = the energy of the Compton-scattered radiation
 $h\nu_0$ = the incoming energy resulting from the relation

$$h\nu_c = mc^2 h\nu_0 / (mc^2 + h\nu_0(1 - \cos\theta)) \quad (E3)$$

The scattering angle θ is found in the equations (E1) and (E3). The self energy of the electron = mc^2 .

In equation (E1) $\Delta\Omega$ is the solid angle element subtend by the detector from a point in the scatterer on an average.

In equation (E1) $\bar{\Phi}_{0,h\nu}(h\nu_0)$ represents the approximately reconstructed radiation intensity (before scattering). This corresponds to Fig. 2, dotted line. except the peaks.

We also reconstruct the peaks and must then work with a complicated expression containing numerical derivatives of $\bar{\Phi}_{0,h\nu}(h\nu_0)$, equation (E1).

The average kinetic energy T of the electrons in the scatterer is also included. The expression reads:

$$\begin{aligned} \Phi_{1,h\nu}(h\nu_0) = & \bar{\Phi}_{0,h\nu}(h\nu_0) - (T/3mc^2)(\nu_0/\nu_c)^2 \{ (d^2\bar{\Phi}_{0,h\nu}(h\nu_0)/d(h\nu_0)^2)((h\nu_0)^2 + \\ & (h\nu_c)^2 - 2h\nu_0h\nu_c\cos\theta) + 2(d\bar{\Phi}_{0,h\nu}(h\nu_0)/d(h\nu_0))(h\nu_0 - h\nu_c\cos\theta) \} \quad (E4) \end{aligned}$$

$\Phi_{1,h\nu}$ in equation (E4) is only used for reconstruction on and around the peaks. Fig. 2, dotted curve, shows the total result when the equations (E1) and E4) are combined. As is apparent, the reconstruction is very good. The difference between the continuous and dotted lines is very small.

CLAIM

1. A method for measuring high energy electromagnetic radiation by means of scattering, characterized in that a scatterer in the form of a long and narrow filament or a

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long and narrow rod is placed in the beam path of the high-energy radiation and the spectrum of the scattered radiation is measured at an angle to the beam path and an original spectrum is thereafter reconstructed, from a measured spectrum in accordance with equations E1, E2, E3 and E4 hereinbefore defined.

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COMPLETE SPECIFICATION

(ORIGINAL)

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Int. Class

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Complete Specification for the invention entitled:

METHOD FOR MEASURING X-RAYS OR GAMMA RADIATION AND DEVICE
FOR THIS

The following statement is a full description of this invention, including the best method of performing it known to : us

Method for measuring X-rays or gamma radiation
and device for this

Clinical use of quantitative X-ray methods such as the determination of bone mineral content or tissue density for dose planning purposes demand a knowledge of the energy distribution of the x-rays. Spectrometry with germanium detectors requires counting rates of about 50 000 pulses/second or less in order to avoid overlapping pulses (pile ups). With the high fluence from clinical x-ray tubes appropriate counting rates is attained only if the distance between the x-ray source and the detector is several meters and the collimators have diameters that are as small as 0.025-0.5 mm.

This direct measuring method cannot be used in practice in clinical x-ray laboratories due to space limitations. Fig 2, the upper continuous line, shows a spectrum measured directly.

Due to the practical difficulties of the direct measuring method it is only used to a small extent. Moreover, there will be problems with the alignment of the detector because it is easy to measure, by mistake, beside or on the edge of the x-ray focus which, of course, is not intended.

An extremely efficient method for reduction of the pulse rate is utilizing Compton scattering i.e. the radiation is scattered of the electrons in a material. However, when the radiation is scattered in this way energy is lost to the electrons and as a result of this the original spectrum will be distorted, the consequence being, in turn, that this is no longer representative. Accordingly Compton scattering has not been utilized so ^{far} ~~far~~ as a basis of spectrometry. Fig 2, the lower curve, shows a Compton scattered spectrum.



However, we have developed this method further to get a very good energy resolution and to make the method applicable in clinical connections. By a special choice of scatterer (a long and narrow filament or a long and narrow rod) a very well-defined scattering angle is obtained optimizing the geometrical energy resolution. Moreover, as distinguished from what has been done in previous embodiments, correct scattering algorithms are used. We have i.e. taken into consideration that the incoming x-ray radiation is polyenergetic.

Against the background of the above needs and set of problems it is the object of the invention to enable spectrometry for high energy electromagnetic radiation by means of Compton scattering. This is done by utilizing as scattering element a long and narrow filament or a long and narrow rod.

The present invention provides a method for measuring high energy electromagnetic radiation by means of scattering, characterized in that a scatterer in the form of a long and narrow filament or a long and narrow rod is placed in the beam path of the high-energy radiation and the spectrum of the scattered radiation is measured at an angle to the original beam path and the original spectrum is thereafter reconstructed, from the measured spectrum.

The present invention also provides a device for carrying out the above method characterized in that it comprises a chamber in which a scattering element in the form of a long and narrow filament or a long and narrow rod is arranged in the beam path and that a detector is arranged at an angle to this first beam path to measure scattered radiation.

Of course a distortion of the measured spectrum is obtained also here but it will be possible by the very use of such a rod or filament to reconstruct by calculations the original spectrum with a very good accuracy. Firstly, by using a filament or rod a very well-defined scattering angle is obtained. Secondly, the scattering from the surrounding



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medium (air) is minimized as it is measured from the volume determined by the intersecting beam paths of the beam incident from the source and the beam path of the detector. Moreover, by using a very long and narrow filament or a very long and narrow rod having a circular cross-sectional area a possibility of varying direction is obtained as the scattering volume does not vary with the scattering angle.

By using in a suitable further development of the invention a material for the rod or filament having a low average atomic number the Doppler effect is reduced which, in turn, brings a better reproduction of adjacent peaks in the spectrum. As suitable materials polyethylene, lucite or another material having a low average atomic number is suggested. The reconstruction of the primary spectrum from the



measured spectrum is carried out by means of the following formulas which have recently been produced by the inventors.

As the physics lying behind is complicated we will only give the final expressions.

$$\Phi_{0,h\nu}(h\nu_0) = N_{h\nu}(h\nu_c) / (N_e 1/2r_0^2 A(h\nu_0, h\nu_c) (\nu_c/\nu_0 + \nu_0/\nu_c - \sin^2\theta) \Delta\Omega) \quad (E1)$$

In the equation (E1) $N_{h\nu}(h\nu_c)d(h\nu_c)$ is the number of photons registered by the detector between the energies $h\nu_c$ and $h\nu_c + d(h\nu_c)$ after correction for the distortion of the detector itself (detector response).

N_e = the total number of electrons in the scatterer

r_0 = the standard electron radius = $2.82 \cdot 10^{-15} \text{ m}$

$$A(h\nu_0, h\nu_c) = \exp(-l(a)\mu_a(h\nu_c) - (8r/3\pi)(\mu_s(h\nu_0) + \mu_s(h\nu_c))) \quad (E2)$$

gives the radiation damping in the scatterer and in the air (attenuation).

$l(a)$ = the distance in air between the scatterer and the detector.

μ_a = the attenuation coefficient of air.

μ_s = the attenuation coefficient of the scatterer.

r = the radius of the circular and filamentous scatterer

$h\nu_c$ = the energy of the Compton-scattered radiation

$h\nu_0$ = the incoming energy resulting from the relation

$$h\nu_c = mc^2 h\nu_0 / (mc^2 + h\nu_0(1 - \cos\theta)) \quad (E3)$$

The scattering angle θ is found in the equations (E1) and (E3). The self energy of the electron = mc^2 .

In equation (E1) $\Delta\Omega$ is the solid angle element subtend by the detector from a point in the scatterer on an average.

In equation (E1) $\Phi_{0,h\nu}(h\nu_0)$ represents the approximately reconstructed radiation intensity (before scattering).

This corresponds to Fig. 2, dotted line, except the peaks.

We also reconstruct the peaks and must then work with a complicated expression containing numerical derivatives of $\Phi_{0,h\nu}(h\nu_0)$, equation (E1).

The average kinetic energy T of the electrons in the scatterer is also included. The expression reads:

$$\Phi_{1,h\nu}(h\nu_0) = \Phi_{0,h\nu}(h\nu_0) - (T/3mc^2)(\nu_0/\nu_c)^2 \left\{ (d^2\Phi_{0,h\nu}(h\nu_0)/d(h\nu_0)^2)(h\nu_0)^2 + (h\nu_c)^2 - 2h\nu_0h\nu_c \cos\theta + 2(d\Phi_{0,h\nu}(h\nu_0)/d(h\nu_0))(h\nu_0 - h\nu_c \cos\theta) \right\} \quad (E4)$$

$\Phi_{1,h\nu}$ in equation (E4) is only used for reconstruction on and around the peaks. Fig. 2, dotted curve, shows the total result when the equations (E1) and E4) are combined. As is apparent, the reconstruction is very good. The difference between the continuous and dotted lines is very small.

A practical illustrative example of the invention is apparent from the following description. Fig. 1 shows schematically a scattering chamber according to the invention and Fig. 2 shows the radiation curves already treated. The scattering chamber shown in Fig. 1 is substantially angular. In the first angle arm there is an aperture for incident, highly intensive x-radiation. Within the chamber there are a first collimator 2 and a second collimator 3 defining the radiation which thereafter hits the filament 4. The radiation passing the filament and past it passes out through an aperture 5 on the other side of the scattering chamber. At right angles to the direction of radiation through the collimators and the filament two collimators 6 and 7 are arranged and the radiation scattered in the filament passes through the collimators to a detector 8 in the other arm of the scattering chamber. In this case the detector is a High purity Ge-detector connected to a multichannel analyzer. This, in turn, is connected to a data processing unit reconstructing spectra according to the equations (E1) - (E4). a-c are collimators of the dimensions 3mm x 25 mm. d is a collimator of the diameter 3 mm. D is the Ge-detector. O is the scatterer. The drawing is made almost on a correct

scale. It is apparent from this that the chamber can easily be used on place in most existing x-ray equipments. The material of the filament is polyethylene, lucite or another material of a low average atomic number providing rapid and precise reconstructions. In the example shown air scattering corresponds to a very small portion of the totally detected intensity.

In the practical embodiment of the invention our calculation algorithms are preferably implemented in a computer so that a handy measuring instrument is obtained.

THE CLAIMS DEFINING THE INVENTION ARE AS FOLLOWS:

1. A method for measuring high energy electromagnetic radiation by means of scattering, characterized in that a scatterer in the form of a long and narrow filament or a long and narrow rod is placed in the beam path of the high-energy radiation and the spectrum of the scattered radiation is measured at an angle to the beam path and an original spectrum is thereafter reconstructed, from a measured spectrum in accordance with equations E1, E2, E3 and E4 hereinbefore defined.



~~THE CLAIMS DEFINING THE INVENTION ARE AS FOLLOWS:~~

Claims

1. A method for measuring high energy electromagnetic radiation by means of scattering, characterized in that a scatterer in the form of a long and narrow filament or a long and narrow rod is placed in the beam path of the high-energy radiation and the spectrum of the scattered radiation is measured at an angle to the original beam path and the original spectrum is thereafter reconstructed, from the measured spectrum.

2. The method of claim 1, characterized in that a material having a low average atomic number is used as scatterer.

3. The method of claim 1 or 2, characterized in that the scattered radiation is measured at a well-defined angle to the incoming radiation.

4. The method of any one of the preceding claims, characterized in that the incident and/or measured radiation is defined by means of collimators.

5. A device for carrying out the method of claim 1, characterized in that it comprises a chamber in which a scattering element in the form of a long and narrow filament or a long and narrow rod is arranged in the beam path and that a detector is arranged at an angle to this first beam path to measure scattered radiation.

6. The device of claim 5, characterized in that the long and narrow rod or the long and narrow filament is made of polyethylene, lucite or another material having a low average atomic number.

7. The device of any one of claims 5 or 6, characterized in that the detector angle is 90° relative to the incoming beam ~~passage~~ path.



8. The device of any one of claims 5 to 7, characterised in that the long and narrow filament or the long and narrow rod has a circular cross-sectional area.

9. A method as claimed in claim 1, substantially as herein described with reference to the accompanying drawings.

10. A device as claimed in claim 5, substantially as herein described with reference to the accompanying drawings.

DATED this 2nd day of January 1990.
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FIG.1



