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(54) METHOD AND APPARATUS FOR IMPROVING THE DISCRIMINATION OF A SCINTILLATION DETECTOR

(71) We, GEORGETOWN UNIVERSITY, a corporation organized under the laws of the United States of America, of 37th and 0 Streets, N.W., Washington, D.C. 20052, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to a method for improving the discrimination of a scintillation detector, and to a scintillation detector apparatus. The invention is particularly, but not exclusively, for use in tomography.

Tomographic images obtained by scanning bodies with high energy radiation and detecting absorption by a scintillating crystal detector have not been completely sharp and clear, especially at the edges or boundaries. Heretofore, attempts have been made to improve image definition, especially at the boundaries, by surrounding the scanning body by a bag of water or employing a shutter to cut off the radiation when the scanning beam leaves the edge of the body being scanned. It was known that a portion of the incident radiation on a scintillation detector is converted into phosphorescent radiation of approximately the same wavelength as the fluoroescent radiation and that this might be problematical. For a tellurium-doped sodium iodide scintillation crystal, 91 per cent of the absorbed radiation is converted into fluorescent radiation and 9 per cent is converted into phosphorescent radiation. See S. Koicki, A. Koicki and V. Ajdacic "The Investigation of the 015 s Phosphorescent Component of NaI(TI) and its Application in Scintillation Counting", and Nuclear Instruments and Methods, 108: pages 198—9 (1973). The production of phosphorescent radiation interferes with the measurment of the intensity of the high-energy radiation. According to the Koicki et al. article, the fluorescent decay time for a tellurium-doped sodium iodide crystal of 225 nanoseconds compares to a phosphorescent decay time of 150 milliseconds. When photons strike the detector with relatively high frequency, the phosphorescence produced by photons prior in time will persist and interfere with the detection and resolution of the more-or-less instantaneous fluorescent events.

When the fluorescent and phosphorescent radiation are of about the same frequency and wavelength, a photomultiplier tube (PMT) positioned to detect the lower-energy radiation produced by the scintillator cannot readily distinguish the fluorescent event from the phosphorescent event. The electrical output signal of the PMT is, therefore, the summation of the fluorescence produced by the immediate photons and the phosphorescence produced by the prior photons.

It was, however, not heretofore understood or appreciated that phosphorescent afterglow is the primary cause of poor image definition of tomographic images, especially at the boundaries. The present invention seeks to provide a simple and economical method and apparatus for improving the discrimination of a scintillation detector and, more particularly, for sharpening the definition of tomographic images obtained from tomographic scanning and scintillation counter detection.

In accordance with a first aspect of the invention, there is provided a method of improving the discrimination of a scintillation detector, such method comprising the steps of: adding to a store of electrical energy proportionately and synchronously as potential phosphorescent energy is accumulated in said scintillation detector by the capture of high energy photons; implementing the decay of the stored electrical energy at the same rate as said potential phosphorescent energy is transmuted into visible phosphorescence; deriving from said decay a compensating signal which is proportional to that component of the output signal of said scintillation detector which is due to said visible phosphorescence; combining said compensating signal with said output signal in such a manner as to substantially cancel said component.

In accordance with a second aspect of the invention, there is provided a scintillation detector apparatus comprising a scintillation detector, a first means connected to said detector and operable to store electrical energy therefrom and a second means operable to accomplish: the adding to of said stored electrical energy proportionately and synchronously - as potential phosphorescent energy is accumulated in said scintillation detector by the capture of high energy photons; the implementing of the decay of said stored electrical energy at the same rate as said potential phosphorescent energy is transmuted into visible phosphorescence; the deriving from said decay a compensating signal which is proportional to that component of the output signal of said scintillation detector which is due to said visible phosphorescence; and the combining of said compensating signal with said output signal in such a manner as to substantially cancel said component.

Using this invention, the image outline obtained from tomographic scintillation detection can be improved, to the extent that water bags or shutters can be eliminated.

In an embodiment of the invention, the electronic network has an input and comprises a pair of variable resistors and a capacitor, one of the variable resistors being connected directly across and in parallel with the input, the other variable resistor being connected in parallel with the capacitor, the parallel-connected variable resistor and capacitor being connected in series with the input.

The variable resistors are adjusted until the image sharpens to the maximum. The value of the resistors is preferably relatively small with respect to that of the capacitor, which is as large as possible (such as 10 microfarads). The capacitor is preferably a non-electrolytic type having a low dissipation factor or low loss factor. The first-mentioned resistor is preferably much larger in value than that of the other resistor which is in parallel with the capacitor. The actual value of the resistors depends upon the phosphorescent characteristics of the scintillating crystal. For example, a ratio of about 10 to 1 is suitable for a sodium iodide (NaI) crystal and about 100 to 1 for a calcium fluoride (CaF_2) crystal. Approximate relative sizes can be roughly predicted by mathematical analysis based on transfer functions.

In order that the invention may be better understood, several embodiments thereof will now be described by way of example only and with reference to the accompanying drawings in which:—

Figure 1 is a schematic block diagram of a scintillation crystal detecting device employing one embodiment of this invention; and

Figures 2a, 2b, and 2c are circuit diagrams of 3 embodiments of the electronic network which is used as part of the detecting device of Figure 1.

Referring to Figure 1, high-energy radiation 12 impinges on a scintillation crystal 14 forming part of a scintillation crystal detecting device 10. The incident radiation produces a light flash at the crystal 14 which is detected by a photoelectric transducer in the form of a photomultiplier tube (PMT) 16. The PMT output signal is passed through an electronic compensating network 18 comprising an afterglow compensation circuit. The output signal, modified by circuit 18 to compensate for detected scintillator phosphorescence, is passed to a low input impedance amplifier 20 which amplifies the signal to a level detectable by a counter or intensity detector 22.

Figures 2a, 2b and 2c illustrate three simple filter circuits for network 18, the three networks having transfer functions which can be approximated by utilizing mathematical computations and equations, to be described hereinafter.

The afterglow effect can be mathematically described in the following manner. The conversion efficiency for most scintillators is about 100 percent. However, due to losses in the optics and the detector response, the energy actually detected is only a fraction of the incident energy. For practical purposes, the detected energy is a constant proportion of the incident energy. Representing the time function of a high-energy incident radiation beam as $W_{in}(T)$, the detectable energy $W_{det}(T)$ is a constant fraction k of the incident radiation, i.e. $W_{det}(T)=kW_{in}(T)$. Of the detectable energy, a constant fraction g is converted into fluorescent energy $W_{fl}(T)$

and the remainder $(1-g)$ is converted into phosphorescent energy $W_{ph}(T)$. Therefore, for each incident photon $W_{det}(T)=W_{fl}(T)+W_{ph}(T)$ with $W_{fl}(T)=gW_{det}(T)$ and $W_{ph}(T)=(1-g)W_{det}(T)$.

Because the phosphorescent decay time is relatively large with respect to the fluorescent decay time, phosphorescent energy is effectively stored in the scintillator as potential energy, $W_{st}(T)$. The potential energy stored in the detector is incremented by an amount of energy $W_{ph}(T)$ for each absorbed photon and is continuously diminished by the release of phosphorescent energy at a rate proportional to the magnitude of stored phosphorescent energy. Therefore, the increase of potential energy with respect to time is represented by the following differential equation:

$$\frac{dW_{st}}{dT}(T)=\frac{dW_{ph}}{dT}(T)-\frac{W_{st}(T)}{u}=(1-g)\frac{dW_{det}}{dT}(T)-\frac{W_{st}(T)}{u} \qquad (1)$$

where u is the scintillator phosphorescence decay time constant and is defined by the equation $I=I \, . \, e^{-ut}$ relating the change in radiation intensity with time (t).

Representing power p as

$$\frac{dW}{dT},$$

then from Equation 1:

$$\frac{dW_{st}}{dT}(T)=(1-g)p_{det}(T)-\frac{W_{st}(T)}{u} \qquad (2)$$

The power released by the scintillator at a point in time, p_{out}, is necessarily the sum of the fluorescent power p_{f1} and the stored phosphorescent power simultaneously emitted. Hence, the scintillator power $p_{out}(T)$ can be represented as:

$$P_{out}=p_{f1}(T)+\frac{W_{st}(T)}{u}=gp_{det}(T)+\frac{W_{st}(T)}{u} \qquad (3)$$

Taking a Laplace transform of Equation 2 and Equation 3, where the Laplace transform is defined by:

$$F(s)=\int_{o}^{\infty} f(T)e^{-st}dT$$

Yields:

$$sW_{st}(s)=(1-g)p_{det}(s)-\frac{W_{st}(s)}{u} \qquad (4)$$

and

$$p_{out}(s)=gp_{det}(s)-\frac{W_{st}(s)}{u} \qquad (5)$$

Combining these two Laplace transform equations (Equation 4 and Equation 5) produces a transfer function for the released power with respect to the detectable power as follows:—

$$\frac{p_{out}}{p_{det}}=g\frac{s+\frac{1}{gu}}{s+\frac{1}{u}} \qquad (6)$$

Thus, the effect of the persisting phosphorescence can be compensated for by incorporating an electronic network in the detector circuitry which has a transfer function whose complex part, involving s, is the reciprocal of the complex part of the derived Equation 6, i.e.:—

$$\frac{s+\dfrac{1}{u}}{s+\dfrac{1}{gu}}$$

Referring now to the circuit illustrated in Figure 2a, where R_1 and R_2 are resistors and L is an inductor, the current/current transfer function is:

$$\frac{I_{out}}{I_{in}}=\frac{s+\dfrac{R_1}{L}}{s+\dfrac{(R_1+R_2)}{L}}$$

If the circuit elements are chosen such that

$$\frac{L}{R_1}=u$$

and

$$R_2=R_1\frac{(1-g)}{g},$$

then the transfer function becomes:

$$\frac{I_{out}}{I_{in}}=\frac{s+\dfrac{1}{u}}{s+\dfrac{1}{(gu)}}$$

The voltage/current transfer function of the circuit illustrated in Figure 2b is:

$$\frac{V_{out}}{I_{in}}=R_2\frac{s+\dfrac{R_1}{L}}{s+\dfrac{(R_1+R_2)}{L}}$$

with elements chosen as above for Figure 2a, the transfer function becomes:

$$\frac{V_{out}}{}=R_2\frac{s+\dfrac{1}{u}}{s+\dfrac{1}{(gu)}}$$

The current/current transfer function of the circuit shown in Figure 2c is:

$$\frac{I_{out}}{I_{in}}=\frac{s+\frac{1}{R_2C}}{s+\frac{1}{R_1C}+\frac{1}{R_2C}}$$

where R_1 and R_2 are resistors and C is a capacitor. If the circuit elements are chosen such that $R_2C=u$ and

$$R_1=R_2\frac{g}{(1+g)}$$

then the transfer function becomes

$$R=\frac{I_{out}}{I_{in}}=\frac{s+\frac{1}{u}}{s+\frac{1}{gu}}$$

It should be noted that, if the parameters u and g are not known exactly, then the circuit elements of Figure 2 can be made variable and adjusted to optimum values with the detector in operation.

For a sodium iodide scintillation crystal, the values for the preferred network of Figure 2c are as follows. Capacitor C is 10 microfarads and is constituted by a nonelectrolytic capacitor, such as a Mylar capacitor having a low dissipation or loss factor, such as, for example, 0.1%.

Mylar is a trademark for a polyester film made and sold by E. I. duPont DeNemours & Co., of Wilmington, Delaware. It is a highly durable, transparent, water-repellent film of polyethylene terephthalate resin, characterized by outstanding strength, electrical properties, and chemical inertness. Mylar may be used in the temperature range from 60° to 150°C. because of its inherent thermal stability. It is available in thicknesses from 0.0025" to 0.0075", and in several types for specific applications. Its primary use is as electrical insulation for capacitors, motors, generators and transformers, and as a barrier tape for wire and cable; however it may also be used for many non-electrical applications such as decorative laminations, vapor-barrier materials, as printed cover for acoustic tiles, and in various types of industrial tapes and magnetic recording tapes.

In Figure 2c, resistor R_1 resolves by computation and empirical testing to have a value between about 50kΩ and 250kΩ. Resistor R_2 resolves to a value ranging from about 5kΩ and 15kΩ. The mathematical computations only provide a starting point for resolving the network for cancelling the phosphorescent afterglow. The operative values are only obtained by empirically varying the resistors to obtain the best and sharpest image.

WHAT WE CLAIM IS:—

1. A method of improving the discrimination of a scintillation detector, such method comprising the steps of: adding to a store of electrical energy proportionately and synchronously as potential phosphorescent energy is accumulated in said scintillation detector by the capature of high energy photons; implementing the decay of the stored electrical energy at the same rate as said potential phosphorescent energy is transmuted into visible phosphorescence; deriving from said decay a compensating signal which is proportional to that component of the output signal of said scintillation detector which is due to said visible phosphorescence; combining said compensating signal with said output signal in such a manner as to substantially cancel said component.

2. A scintillation detector apparatus comprising a scintillation detector, a first means connected to said detector and operable to store electrical energy therefrom and a second means operable to accomplish: the adding to of said stored electrical energy proportionately and synchronously as potential phosphorescent energy is accumulated in said scintillation detector by the capture of high energy photons;

the implementing of the decay of said stored electrical energy at the same rate as said potential phosphorescent energy is transmuted into visible phosphorescence; the deriving from said decay a compensating signal which is proportional to that component of the output signal of said scintillation detector which is due to said visible phosphorescence; and the combining of said compensating signal with said output signal in such a manner as to substantially cancel said component.

3. Apparatus as claimed in Claim 2 wherein said first means comprises one or more reactive circuit elements.

4. Apparatus as claimed in either of Claims 2 or 3 wherein said second means comprises two or more resistive circuit elements.

5. Apparatus as claimed in any one of Claims 2, 3 or 4 wherein said first and second means together comprise an electrical network whose Laplace-transform transfer function is as follows:

$$R=\frac{s+1/u}{s+1/(gu)}$$

where u represents the time constant of the rate at which said potential phosphorescent energy is transmuted into said visible phosphorescence, g represents that fraction of the energy of said high energy photons which is converted into fluorescence, R represents an amplification or attenuation factor, s is the transfer function variable of transformation.

6. Apparatus as claimed in Claims 3, 4 and 5 wherein the reactive circuit element is an inductor L connected in series with a first R_1 of said resistive circuit elements across the input of the electrical network and wherein a second R_2 of said resistive circuit elements is in series with the input.

7. Apparatus as claimed in Claim 3, 4 and 5 wherein the reactive circuit element is an inductor L connected in series with a first R_1 of said resistive circuit elements across the input of the electrical network, and wherein a second R_2 of said resistive circuit elements is connected in parallel with the series combination of resistive element R_1 and inductor L.

8. Apparatus as claimed in either one of Claims 6 or 7 wherein the values of the components are such that:

$$\frac{L}{R_1}=u;$$

and

$$R_2=R_1\frac{(1-g)}{g}$$

9. Apparatus as claimed in Claims 3, 4 and 5 wherein the reactive circuit element is a capacitor C, and wherein a first one R_1 of the resistive circuit elements is connected directly across and in parallel with the input of the electrical network, and a second one R_2 of the resistive circuit elements is connected in parallel with the capacitor C, the parallel-connected resistor R_2 and capacitor C being connected in series with the input.

10. Apparatus as claimed in Claim 9 wherein the values of the components are such that:

$$R_2C=u;$$

and

$$R_1=R_2\frac{g}{(1-g)}$$

11. Apparatus as claimed in either one of Claims 9 or 10 wherein said resistors are variable resistors.

12. Apparatus as claimed in any one of Claims 9 to 11 wherein the capacitor has a capacitance of about ten microfarads and a dissipation factor of about 0.1%.

13. Apparatus as claimed in any one of Claims 9 to 12 wherein the capacitor is a non-electrolytic type.

14. Apparatus as claimed in any one of Claims 9 to 13 wherein the first-mentioned resistor R_1 has a much greater resistance than the other resistor R_2, which is in parallel with the capacitor.

15. Apparatus as claimed in Claim 14 wherein the scintillation detector incorporates a sodium iodide crystal, and the first-mentioned resistor R_1 has about ten times the resistance of the other resistor R_2.

16. Apparatus as claimed in Claim 14 wherein the scintillation detector incorporates a calcium fluoride crystal and the first-mentioned resistor R_1 has about one hundred times the resistance of the other resistor R_2.

17. A method of improving the definition of a scintillation detector, as claimed in Claim 1 substantially as hereinbefore described.

18. Scintillation detector apparatus substantially as hereinbefore described with reference to the accompanying drawings.

19. A tomographic scintillation detector incorporating apparatus as claimed in any one of the preceding claims.

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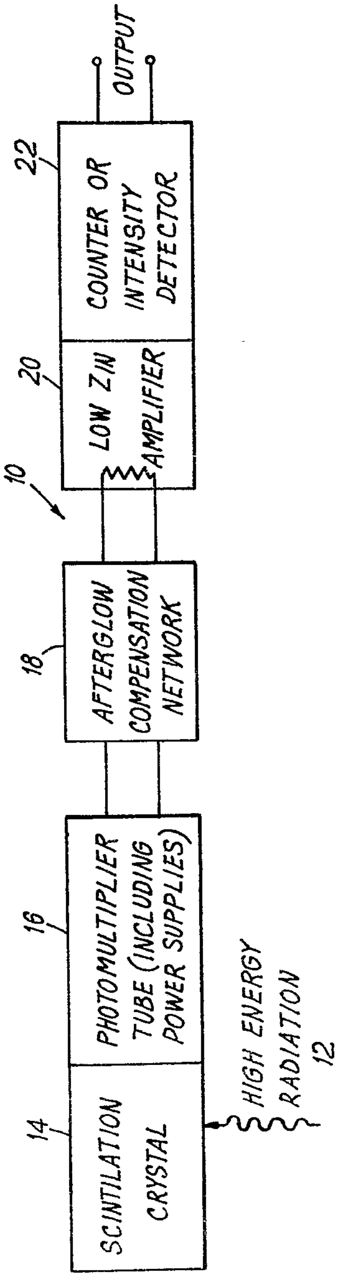

FIG. 1

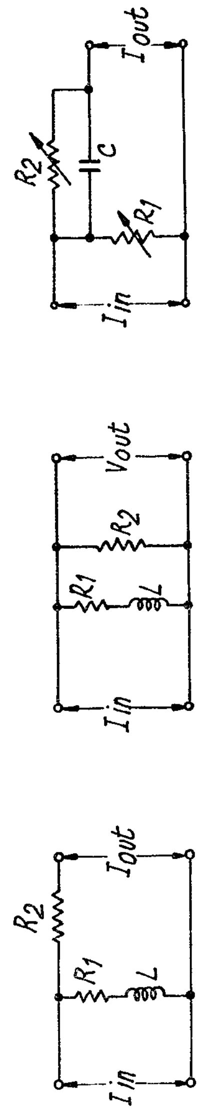

FIG. 2a FIG. 2b FIG. 2c