United States Patent [19]

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[11] 3,927,318

[45] Dec. 16, 1975

[54] **CROSS-SECTIONAL FLUORESCENT IMAGING SYSTEM**

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[22] Filed: **May 6, 1974**

[21] Appl. No.: **467,446**

[52] **U.S. Cl.** **250/272;** 250/274

[51] **Int. Cl.** **G01N 23/20**

[58] **Field of Search** .... 250/272, 273, 274, 275, 250/445 T

[56] **References Cited**

UNITED STATES PATENTS

3,769,507 10/1973 Kenney 250/272

OTHER PUBLICATIONS

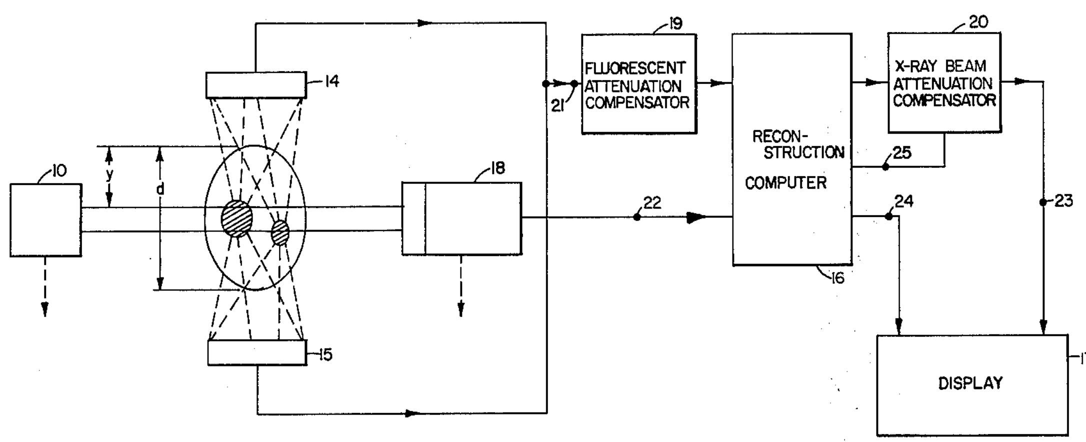
"Fluorescent Thyroid Scanning Without Radioisotopes," Hoffer, et al., Radiology, Vol. 99, Apr., 1971, p. 117.

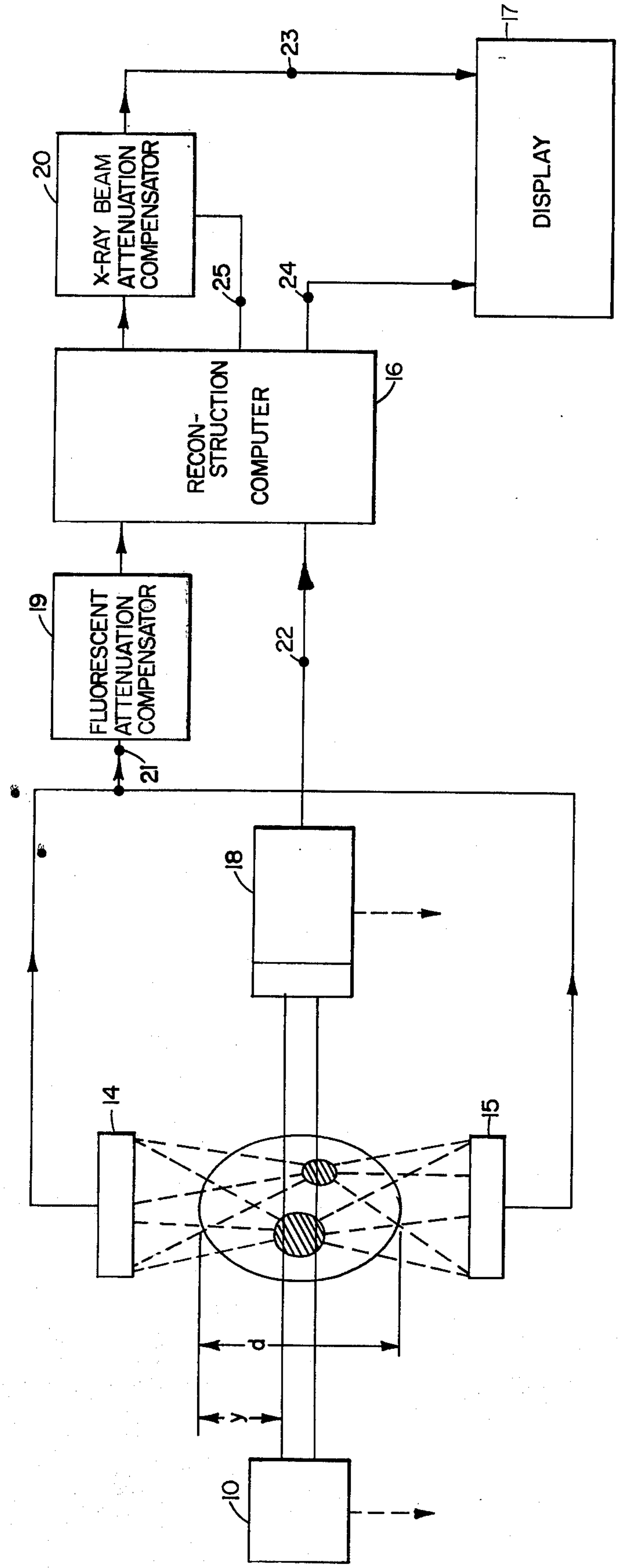
Primary Examiner—Craig E. Church

[57] **ABSTRACT**

A narrow x-ray beam is scanned across a cross section containing a relatively high atomic number material. When excited by the x-ray beam the material fluoresces and emits its characteristic radiation lines. The emission information along the entire line is collected to create a signal indicative of the line integral of the emission information. This line integral information, taken from many positions and angles in the cross section, is applied to a computer which reconstructs a cross-sectional image of the fluorescing material. The transmitted narrow beam, which represents the line integral of the density information, can simultaneously be used to create a reconstruction of the cross-sectional density pattern.

13 Claims, 1 Drawing Figure




X-RAY BEAM ATTENUATION COMPENSATOR
DISPLAY
RECON-STRUCTION COMPUTER
FLUORESCENT ATTENUATION COMPENSATOR
20
23
17
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d
y

FIGURE 1

CROSS-SECTIONAL FLUORESCENT IMAGING SYSTEM

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to systems for selectively imaging trace amounts of specific materials. In a primary application the invention relates to systems for imaging the fluorescent radiation from materials which are excited by x-rays.

2. Description of Prior Art

Existing systems for imaging fluorescent radiation from excited materials usually include a collimated x-ray source for producing an x-ray beam. A selective detector is used having a pulse-height analyzer which is tuned to the energy of the particular material under study. This detector includes a collimator or focusing structure for examining each region along the x-ray beam. The detector and its collimator are normally scanned along the x-ray beam so as to sequentially measure the emission from each region along the beam. This is an inefficient process since, while emissions are occurring along the entire beam, only one portion at a time is being collected. In addition, the focusing collimators used to collect the radiation from a specific region are relatively inefficient. A system of this type is described by P. B. Hoffer and A. Gottschalk in a paper entitled, "Fluorescent Thyroid Scanning Without Radioisotopes" appearing in Radiology, Vol. **99**, p. 117, April, 1971.

The imaging of fluorescent radiation is used in medicine for making images of the natural iodine in the thyroid or for imaging the selective uptake of administered materials in diseased areas such as tumors. Another important system for the diagnosis of diseased regions is computerized tomography which provides an accurate cross-sectional density image. In this system accurate x-ray projections of a particular cross section are taken at many angles. This projection information, which is a number of line integrals of the density information, is applied to a computer which reconstructs the desired density image. A system of this type is presently manufactured by EMI in England and is described by J. Ambrose in the British Journal of Radiology, Vol. 46, p. 1016, 1973. Although this instrument provides an accurate cross-sectional density image, many disease processes do not result in a significant density change and are thus better diagnosed by detecting the selective uptake of a material into the diseased region.

SUMMARY OF THE INVENTION

An object of this invention is to provide an efficient system for imaging specific materials by their fluorescent radiation.

It is also an object of this invention to provide an efficient system for imaging fluorescent emissions by simultaneously collecting the integrated emission information along the entire x-ray beam.

It is a further object of this invention to provide a combined display indicating the density information and the amounts of a specific material.

Briefly, in accordance with this invention, one or more unfocused detectors are used to collect the fluorescent radiation emitted along the entire x-ray beam. This information is collected for large numbers of positions and angles of the beam. This line-integral fluorescent information is applied to a computer to reconstruct a cross-sectional image of the fluorescing regions. The transmitted x-ray beam can also be collected and used to provide a cross-sectional density image of the same area.

BRIEF DESCRIPTION OF THE DRAWINGS

For a more complete disclosure of the invention, reference may be made to the following detailed description of an illustrative embodiment thereof which is given in conjunction with the accompanying drawing, of which FIG. **1** is a schematic diagram illustrating an embodiment of the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

An understanding of the broad aspects of the invention may best be had by reference to FIG. **1** of the drawings. A collimated x-ray source **10** can be derived using a conventional x-ray tube or an isotope source. These divergent sources are collimated using one or more metal absorbers having appropriate apertures to form a collimated beam **11.** This beam is projected through the object under study **12** which would normally be the human anatomy. The object is known to contain amounts of a relatively high atomic number material which will fluoresce when excited by the x-ray beam **11** and emit its characteristic radiation. The material should have a relatively high atomic number so that the fluorescent emission will be sufficiently high energy to escape the object without excessive attenuation. The materials used are similar to those employed in nuclear medicine, except non-radioactive, which are selectively taken up in diseased areas such as tumors. Structures **13** in the object **12** represent regions which have selectively taken up the material and will thus fluoresce at their characteristic radiation energy when excited.

In present fluorescent imaging systems, a focused collimator would be used to collect the radiation from a specific region along beam **11.** This is an inefficient process since only a small portion of the total fluorescent radiation is detected at any one time. This inefficiency results in excessive radiation to the patient and insufficient photons to provide a good image. In the system described here, the radiation is collected along the entire x-ray beam. No focusing structures are required. One or more gamma-ray detectors, such as **14** and **15,** can be used to capture photons emitted along the length of the x-ray beam and create signal **21** representing the integrated emission along the beam. Ordinarily, an image could not be formed in this manner since the integrated emission along the entire line is being measured rather than the emission from a small region. An image can be formed, however, by providing these integrated measurements at a variety of angles. Thus the x-ray source **10** is linearly scanned, as shown by the dotted line, over an entire cross section of object **10.** This same scan is repeated at a plurality of angles with the integrated fluorescent emission detected at every position for every angle. Depending on the configuration of gamma-ray detectors, **14** and **15**, they can also be moved to aid in the photon collection. Thus, for each region in a cross section of object **10**, a number of integrated emission measurements are made for lines which go through that region at different angles.

The general mathematical problem of reconstructing a cross-sectional image from line-integral information taken at many angles has been studied for many years in connection with many applications. A comprehensive bibliography on this subject is available from Richard Gordon of the National Institutes of Health, Building **31**, Bethesda, Maryland. An example of some of the procedures which can be used is given in a paper by G. T. Herman in, "Two Direct Methods for Reconstructing Pictures from Their Projections: A Comparative Study," in Computer Graphics and Image Processing, Vol. 1, p. 123–144, 1972. A general computer technique known as ART (Algebraic Reconstruction Technique) has received wide usage in this field. The most recent use of reconstructions of this type is in a recently released brain-scanning instrument known as the EMI-Scanner. In this instrument the x-ray transmission through a cross section of the brain at a number of angles are recorded and applied to a computer. The computer reconstructs the cross-sectional density image, with great accuracy, using the ART technique. This system is described in a paper by J. Ambrose in the British Journal of Radiology, Vol. 46, 1973. Any one of the many reconstruction algorithms can be applied to signal **21** to create a reconstructed cross-sectional image of fluorescent radiation. Leaving optional boxes **19** and **20** for subsequent discussion, the signal **21** can be applied directly to reconstruction computer **16** where the cross section is reconstructed from the integrated measurements by one of many known systems. The resultant fluorescent radiation information **23**, indicating the presence of the materials **13**, is displayed on display **17**.

In the system described thusfar the x-ray beam transmitted through the object is not measured or used in any way since only the resultant fluorescent radiation was detected. This transmitted beam can be detected, however, and used to form a cross-sectional density image as does the EMI-scanner. This density information would be very valuable in medical diagnosis for accurately defining the anatomy so that the relative positions of the diseased areas which take up the administered material can be well-defined. To create this cross-sectional density display, detector **18** is used to measure the transmitted beam at every position and angle of x-ray beam **10** to form transmission signal **22**. The detector **18** can either be mechanically scanned in synchronism with the source **10** or an array of detectors can be used to collect the transmitted beam at all of its positions. Transmission signal **22** is applied to the same reconstruction computer **16** to reconstruct the density image signal **24** in one of the many known ways. The reconstructed density image signal **24** can be displayed in display **17** either separately or in conjunction with the fluorescent radiation signal **23**. A number of combinational display configurations can be used including having the fluorescent radiation information displayed as a color overlay on the black and white density information. In this way the diseased areas, which have selectively taken up the administered material, will become very apparent and be readily localized.

The detectors **14** and **15** which measure the fluorescent radiation can be one of a variety of gamma-ray detectors including scintillating crystals, proportional counters or solid state detectors. For improved discrimination they can employ energy spectrum analyzers for extracting the energy region corresponding to the characteristic fluorescent emission energy of the material being studied. The energy spectrum analyzer can be a pulse-height discriminator where the size of the de-

tected pulse associated with each received photon indicates its energy. The detector **18** which measures the transmitted x-ray beam can also be any of the gamma-ray detectors previously listed.

The system has two potential sources of error; the attenuation of the fluorescent radiation through the object **12**, and the attenuation of the x-ray beam **10** as it transverses the object. The fluorescent attenuation is determined by the energy of the radiation and the absorption coefficient of the various materials in the object. If a very large number of fluorescent radiation detectors, such as **13** and **14**, are used the effect of this attenuation will be minimized since there will usually be some path or combination of paths of relatively low attenuation. A compensation system **19** can be used to minimize the effect of the absorption. The object can be assumed to have a specific absorption coefficient, for example that of soft tissue or water. The specific compensation would then be based on the geometry of the scanning and detecting configuration. For example, as shown in FIG. **1**, the distance from the beam to the top edge of object **12** is y while the distance to the bottom edge is *d–y*. Thus the transmission of the radiation to detector **14** will be $e^{-\mu y}$ while that to detector **15** will be $e^{-\mu (d-y)}$ where μ is the linear absorption coefficient of the assumed material. Thus the effect of the attenuation can be minimized if compensation system **19** has a gain function $[e^{-\mu y} + e^{-\mu (d-y)}]^{-1}$. The size of the object d can be initially provided to the system while the distance y is made available by the mechanical scanning system. The variable compensating gain function can be accomplished by a small analog or digital circuit arrangement.

A more exact compensation for fluorescent attenuation can be achieved through the separation of the various components of the fluorescent radiation. For example, excited materials produce K_α and K_β emissions at specific energies having specific relative amplitudes when emitted. Compensation system **19** can include a pulse-height discriminator which separates and measures the K_α and K_β components. The measured intensity at each energy region, I_α and I_β, are given by

$$I_\alpha = Ie^{-\mu_\alpha Z}$$
$$I_\beta = CIe^{-\mu_\beta Z}$$

where μ_α and μ_β are the absorption coefficients of the object at the two energies, Z is the effective path length, I is the desired initial fluorescent output at the K_α energy and C is known initial ratio of the K_β emission energy to that of the K_α emission. Eliminating Z in the two equations and solving for I we obtain

$$I = \left[I_\alpha^{\mu_\beta} \left(\frac{C}{I_\beta} \right)^{\mu_\alpha} \right]^{(\mu_\alpha - \mu_\beta)}$$

which is an expression for the desired emitted intensity independent of the path length. Thus compensator **19** can be pre-programmed with the known values of μ_α, μ_β, and C to calculate the desired I signal from the measured values of I_α and I_β.

The second source of error is the attenuation that x-ray beam **11** receives before exciting the fluorescent structures **13**. One method of correcting this error is to again assume that the object consists of a given material such as soft tissue which is equivalent to water. The attenuation of each beam after transversing a distance S is thus $e^{-\mu S}$ where μ is the assumed absorption coefficient of the object. Thus the calculated fluorescent emission can be corrected at each region by correcting for the beam attenuation to that region. Thus compensator **20** will modify the value of each region by dividing the calculated value by

$$\sum_n e^{-\mu S_n}$$

where n is the number of beams going through each region in the cross section and S_n is the path length through the object to the particular region. This summation is calculated for every region and used to compensate the reconstructed fluorescent emission signal to obtain corrected signal **23** which is applied to display **17.**

A more accurate correction for the x-ray beam attenuation can be obtained by using the actual attenuation or density values in the cross section rather than assumed values. The actual density values have been calculated in the reconstruction computer **16** and appear in signal **24.** The attenuation of each beam to a given region is given by

$$g(S_1) = \int_0^{S_1} f(S)dS$$

where $g(S_1)$ is the attenuation to the region at S_1 and $f(S)$ is the calculated density values along the path. Thus the total attenuation to point S_1 is given by

by $\sum_n g_n(S_1)$

where $g_n(S_1)$ represents the attenuation of each of the n beams which intersect point S_1. The value of

$$\sum_n g_n(S_i)$$

is calculated for every region i in the cross section and becomes correction signal **25.** Compensator **20** divides each calculated fluorescent emission signal by the correction signal **25** to obtain the corrected fluorescent emission signal **23** which is applied to display **17.**

While particular embodiments of the invention have been shown and described, it will of course be understood that the invention is not limited thereto since many modifications in the x-ray scanning arrangements and electronic processing can be made. It is contemplated that the appended claims will cover any such modifications as fall within the true spirit and scope of the invention.

What is claimed is:

1. Apparatus for imaging fluorescent radiation from a specific material in a cross section of an object comprising:

an x-ray beam directed through the cross section of the object;

means for translating the x-ray beam so that all regions of the cross section are excited at a plurality of angles;

means for detecting the integrated fluorescent radiation emitted along the entire x-ray beam at each position of the x-ray beam and forming a plurality of integrated emission signals;

a computer for reconstructing the fluorescent radiation information of the cross section of the object from the plurality of integrated emission signals; and

means for displaying the reconstructed fluorescent radiation information.

2. Apparatus as recited in claim **1** including means for correcting the plurality of integrated emission signals for the attenuation of the fluorescent radiation in the object before reaching the detector means.

3. Apparatus as recited in claim **2** wherein the means for correcting for attenuation includes an energy spectrum analyzer for separately measuring the K_α and K_β components of the fluorescent radiation and means for comparing their amplitudes to their initial emitted relative amplitudes to compute the required correction.

4. Apparatus as recited in claim **2** wherein the means for correcting for attenuation includes a pre-programmed compensator based on an object having an assumed size and absorption where the pre-programmed compensator is varied according to the distance of the x-ray beam to the edge of the object.

5. Apparatus as recited in claim **1** wherein the means for detecting the fluorescent radiation includes a plurality of gamma-ray detectors whereby a large percentage of the radiation is received.

6. Apparatus as recited in claim **1** wherein the means for detecting the fluorescent radiation includes an energy spectrum analyzer for isolating the energy level of the fluorescent radiation from the specific material.

7. Apparatus as recited in claim **6** wherein the spectrum analyzer is a pulse-height discriminator.

8. Apparatus as recited in claim **1** including:

means for detecting the x-ray beam after transmission through the object at each position of the x-ray beam to form a plurality of transmission signals;

means for computing the density information of the cross section of the object from the plurality of transmission signals; and

means for displaying the reconstructed density information.

9. Apparatus as recited in claim **8** wherein the means for displaying the reconstructed density information includes a composite display of the density and fluorescent radiation information.

10. Apparatus as recited in claim **9** wherein the composite display is a color display having the density and fluorescent radiation information in different colors.

11. Apparatus as recited in claim **1** including means for correcting the fluorescent radiation information for the attenuation of the x-ray beam in the object.

12. Apparatus as recited in claim **11** wherein the means for correcting for the attenuation of the x-ray beam includes a pre-programmed compensator based on an object having an assumed absorption where the attenuation at each position of the x-ray beam to each region of the cross section is calculated.

13. Apparatus as recited in claim **11** wherein the means for correcting for the attenuation of the x-ray beam comprises:

means for detecting the x-ray beam after transmission through the object to form a plurality of transmission signals;

means for computing the attenuation of the x-ray beam to each region of the cross section from the plurality of transmission signals; and

means for correcting the fluorescent radiation information at each region of the cross section using the computed attenuation of the x-ray beam to that region.

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