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Macovski

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[54] **SELECTIVE MATERIAL X-RAY IMAGING SYSTEM**

[76] Inventor: **Albert Macovski,** 4100 Mackay Dr., Palo Alto, Calif. 94306

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[51] **Int. Cl.** **G01t 1/20**

[58] **Field of Search** 250/336, 363, 366, 369, 250/482, 510

[56] **References Cited**

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3,755,672 8/1973 Edholm et al. 250/482

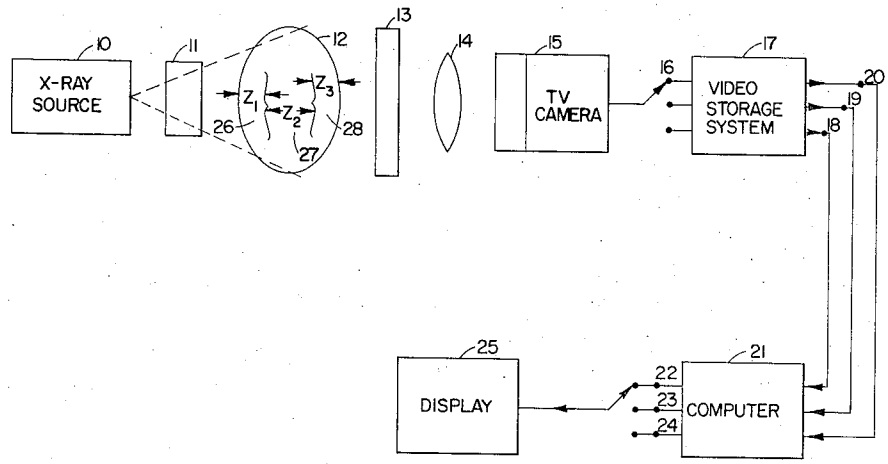
Primary Examiner—James W. Lawrence

Assistant Examiner—Davis L. Willis

[57] **ABSTRACT**

An array of x-ray images are obtained each representing a different spectral energy distribution. These images are scanned with the output signals applied to a computer. The computer is used to produce signals representing the absorption due to specific materials. These are displayed individually or in a composite color display.

15 Claims, 3 Drawing Figures



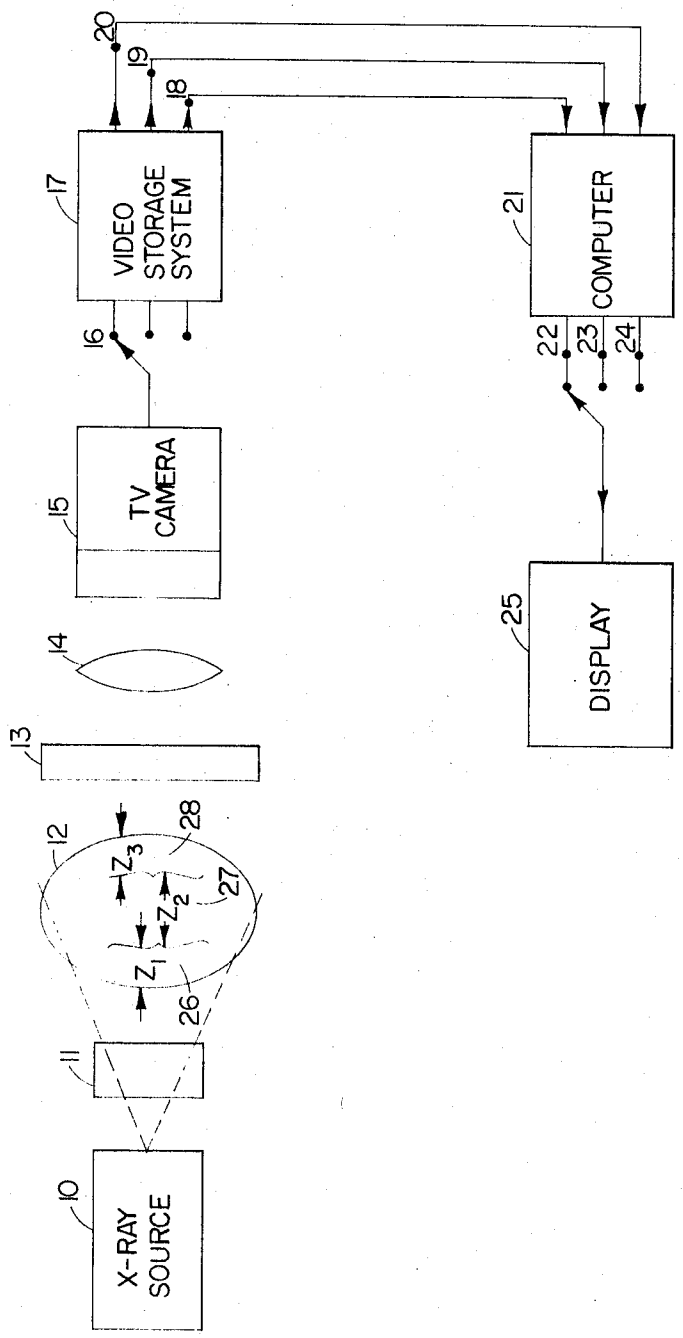

20
19
18
17
VIDEO STORAGE SYSTEM
21
COMPUTER
16
22
23
24
15
TV CAMERA
14
25
DISPLAY
13
12
28
Z_3
Z_2
27
Z_1
26
11
10
X-RAY SOURCE

FIGURE 1

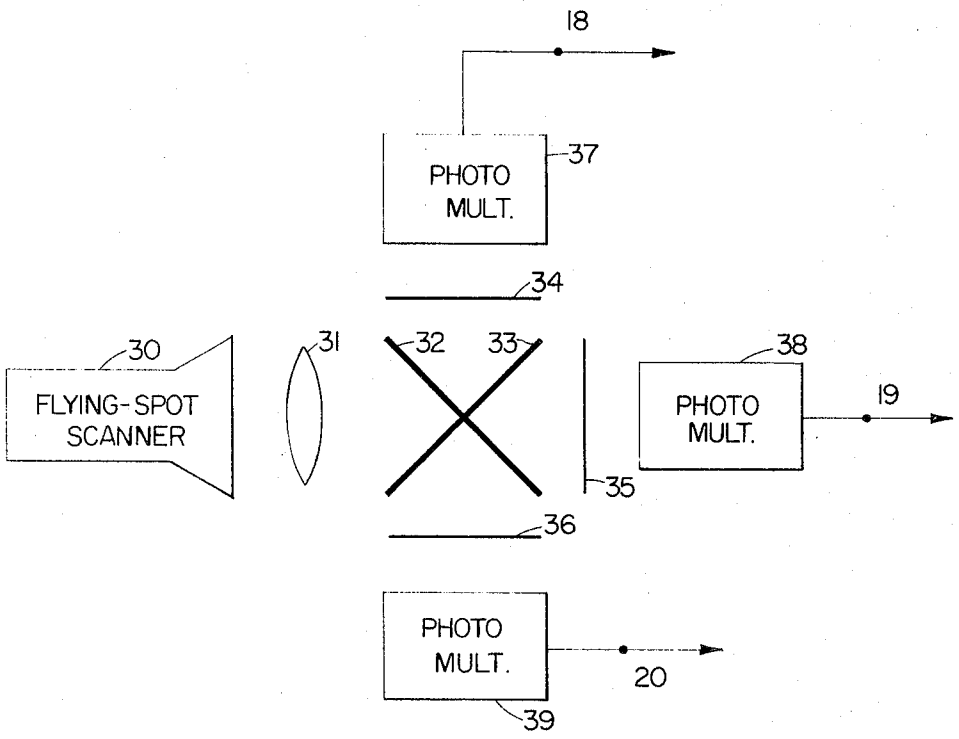

18
PHOTO MULT.
37
34
30
FLYING-SPOT SCANNER
31
32
33
38
PHOTO MULT.
19
35
36
PHOTO MULT.
20
39

FIGURE 2

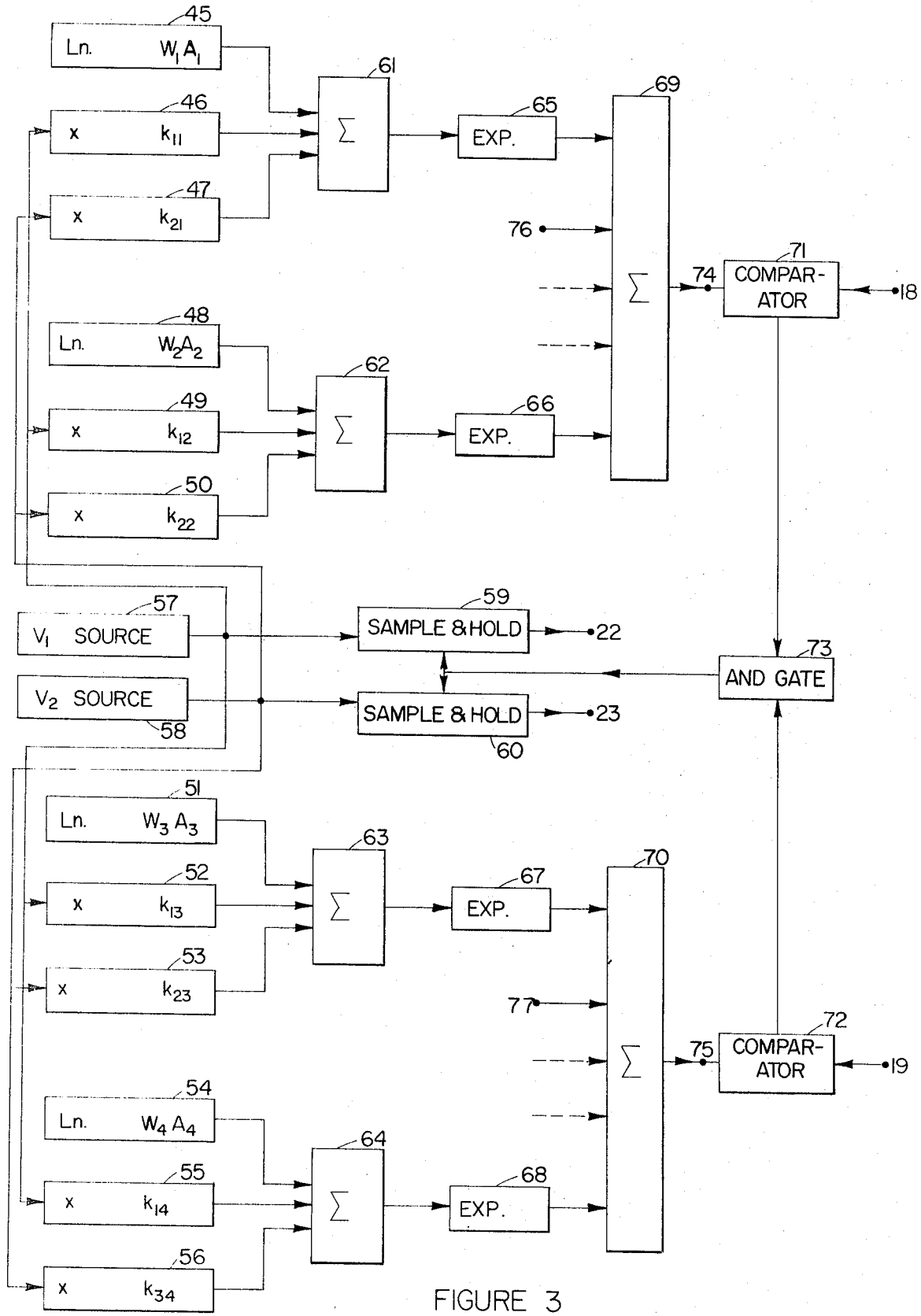

45
Ln. $W_1 A_1$
46
x k_{11}
47
x k_{21}
61
Σ
65
EXP.
69
76
Σ
74
71
COMPAR-ATOR
18
48
Ln. $W_2 A_2$
49
x k_{12}
50
x k_{22}
62
Σ
66
EXP.
57
V_1 SOURCE
V_2 SOURCE
58
59
SAMPLE & HOLD
22
SAMPLE & HOLD
23
60
73
AND GATE
51
Ln. $W_3 A_3$
52
x k_{13}
53
x k_{23}
63
Σ
67
EXP.
70
77
Σ
75
72
COMPAR-ATOR
19
54
Ln. $W_4 A_4$
55
x k_{14}
56
x k_{34}
64
Σ
68
EXP.

FIGURE 3

SELECTIVE MATERIAL X-RAY IMAGING SYSTEM

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to x-ray imaging systems. In a primary application the invention relates to diagnostic x-ray systems where separate images are created representing specific body materials and administered contrast material.

2. Description of Prior Art

X-ray images are widely used for industrial testing and for medical diagnosis. A conventional x-ray image or radiograph records the transmission of the object to a broad spectrum of x-rays. These x-rays are normally generated by a high energy electron-beam stiking a metallic target. The broad-band radiation generated by this process is called Bremsstrahlung. Different human tissue, such as soft tissue and bone, have differing absorption vs. energy characteristics. The bone is highly absorbent at relatively low energies because of the photoelectric effect where materials with higher atomic number are dominant. At very high energies, however, absorption due to Compton scattering is dominant so that absorption depends almost exclusively on density alone. Thus bone and soft tissue have similar absorption. The administered contrast materials, iodine and barrium, have their K absorption edges in about the middle of the diagnostic x-ray spectrum. It would be highly desirable if separable images could be made of these various materials. For example, tumors underlying bone would be made much more visible on a soft tissue image where the bone structure has been deleted. Separate images could be made of iodine administered to the heart and circulatory system which would significantly aid in medical diagnosis.

Some efforts have been made to provide isolated images of specific materials. These have been relatively awkward and have involved mechanically scanned x-ray beams, low-power monochromatic sources, and mechanical analog computers. A system of this type is described in Vol. VI of the "Advances in Biological and Medical Physics" published by the Academic Press in the chapter by B. Jacobson and R. Stuart Mackay on Radiological Contrast Enhancing Methods. The section labeled Dichromography, from pages 224 to 231 describes a system using a x-ray tube having two secondary emitters which alternately generate two monochromatic x-ray beams. This beam is mechanically scanned across the region of interest. At each point, wedge shaped materials of known composition are translated across the beam until the output beam reaches its predetermined value. The thickness of the wedges is then a direct indication of the amounts of the particular material present. A similar approach is described by B. Jacobson in the American Journal of Roentgenology, Vol. 91, January 1964, entitled, "X-ray Spectrophotometry in Vivo." In this article the source was mechanically rotated so as to oscillate between three monochromatic wavelengths. Wedges representing soft tissue or water, bone, and iodine were used in a mechanical analog computer to determine the thickness of these body materials at each point in the scan.

Although these systems gave interesting results they suffered from using slow mechanical scans which required a long time to create an image. Normal heart and respiratory motions during the scanning time resulted in a blurred, low-resolution image. In addition, the use of a mechanical analog computer resulted in a relatively long computation time for each element.

SUMMARY OF THE INVENTION

An object of this invention is to provide images of specific body materials from x-ray images taken at different spectral energy distributions.

It is also an object of this invention to create the x-ray images at different spectral energy distributions in a parallel fashion whereby every region is recorded simultaneously.

Briefly, in accordance with the invention an array of x-ray images are recorded using a different x-ray energy spectrum with each image. The recorded images are scanned providing an array of output signals for each point. These are processed by a computer to provide signals representing the thickness of the different materials. The resultant signals are displayed either individually or in a composite image.

BRIEF DESCRIPTION OF THE DRAWINGS

For a more complete disclosure of the invention, reference may be made to the following detailed description of several illustrative embodiments thereof which is given in conjunction with the accompanying drawings, of which:

FIG. **1** is a block diagram illustrating an embodiment of the invention using a fluorscope;

FIG. **2** illustrates an embodiment using a flying-spot scanner scanning x-ray films; and

FIG. **3** is a block diagram illustrating an embodiment of a computer for processing the scanned signals.

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. An x-ray source **10,** of the conventional electron beam variety generates a diverging beam of x-rays having a braod energy spectrum. The energy spectrum of the beam is filtered by filter **11** which represents any of a wide selection of filters which can be utilized. The object under study **12** is normally a portion of the human anatomy. It is shown as being composed of regions of different materials **26, 27,** and **28.** For example **26** might be a bony region, **27** a soft tissue region, and **28** a large vessel into which iodine contrast material had been administered. The thicknesses of these various regions is given by Z_1, Z_2, and Z_3 respectively. Each of these thickneses are functions of the lateral coordinates and represent the desired processed images. The transmitted x-rays impinge on scintillating screen **13** and generate a visible image. As in conventional fluorscopic practice, this scintillation image is imaged onto television camera **15** using lens **14.** An image intensifier is often used with the television camera. A separate image is created for each different filter **11** which is used. For each image the scanned output signal of television camera **15** is stored in a different region of video storage system **17** by switching switch **16.** This video storage system can be a few tracks of a magnetic video disc, or a few video storage tubes such as the Lithicon made by Princeton Electronic Products. The stored scanned video signals, **18, 19,** and **20,** represent the

transmission of the object **12** to various energy spectra as determined by the particular filter **11.** These are applied to computer **21** to calculate the processed signals which represent thicknesses, Z_1, Z_2, and Z_3 of the individual materials making up the object **12.** The computer **21** performs the desired calculations and generates the appropriate processed thickness-indicating signals **22, 23,** and **24** representing specific materials. These are displayed either individually on display **25,** or in some composite fashion such as in color.

The recorded intensity pattern $I_n(x,y)$ due to filter n is given by

$$I_n = \int a_n(\lambda) \exp -[k_1(\lambda)Z_1 + k_2(\lambda)Z_2 + k_3(\lambda)z_3]d\lambda$$

where $a_n(\lambda)$ is the transmitted x-ray energy spectrum as modified by the inserted filter **11** and the spectral sensitivity of the screen **13.** The various $k_m(\lambda)$ represent the linear absorption coefficients of the body materials **26, 27,** and **28.** Three different materials are given as an example. Each of the thickness values Z_m are functions of x and y and represent the desired processed images. A different integral equation will exist for each new filter **11,** which provides a unique $a_n(\lambda)$. To obtain a unique solution, the number of integral equations must be to equal or greater than the number of materials to be identified. Thus the number of images I_n taken with different filters **11** providing different spectra $a_n(\lambda)$ must be equal to or larger than the number of regions in the object **12.**

In addition, to obtaining the different images by fluoroscope, as illustrated in FIG. **1,** x-ray films may be used. Fluoroscopic screen **13** in FIG. **1** is replaced by either x-ray film or the conventional x-ray screen-film cassettes. As before an array of films are recorded with each using a different x-ray energy spectrum as determined by the filter **11.** The resultant developed films **34, 35,** and **36** are processed as shown in FIG. **2.** Each of the films is scanned simultaneously. This can be accomplished by a number of synchronous scanners or, as shown in FIG. **2,** using a single scanner with appropriate beam splitters. Flying spot scanner **30** produces a scanning spot which is imaged using lens **31** and partially silvered mirrors **32** and **33** onto x-ray film transparencies **34, 35,** and **36.** The transmitted light through each of these films is collected by photomultipliers **37, 38,** and **39** respectively. These produce scanned signals **18, 19** and **20** which are applied to computer **21** exactly as the stored signals in FIG. **1.** Care must be taken to insure that the films are properly registered with respect to the raster of flying spot scanner **30.**

Many alternate configurations can be used. The films can be scanned in sequence with the resultant signals stored on a magnetic disc as shown in FIG. **1.** The films could also be mounted on a rotating drum scanner with a pickup device for each film.

The scanning signals **18, 19** and **20,** giving the intensities due to the different x-ray spectra at every point in the image are then applied to computer **21** as shown in FIG. **1.** This computer must be capable of solving the integral equation given previously and thus find the processed Z_m values when given the scanned signals representing the intensity values I_n. The solution of this equation is quite straightforward if monochromatic x-ray sources are used. In that case the various a_n and k_m values become constants so that the integral equation becomes an algebraic equation. For example, using two monochromatic sources a_1 and a_2 for an object containing two material regions z_1 and Z_2 the equations are given by

$$ln\ I_1 = ln\ a_1 - [k_{11}Z_1 + k_{21}Z_2]$$

and

$$ln\ I_2 = ln\ a_2 - [k_{12}Z_1 + k_{22}Z_2],$$

where k_{12} is the absorption coefficient in the Z_1 region at the wavelength of the a_2 source. Solving for Z_1 and Z_2 we have

$$Z_1 = k_{22} ln\ a_1 - k_{21} ln\ a_2/(k_{11}k_{22} - k_{12}k_{21}) - k_{22}\ ln\ I_1 - k_{21}\ ln\ I_2/(k_{11}k_{22} - k_{12}k_{21})$$
$$= A - B\ ln\ I_1 + C\ ln\ I_2$$
$$Z_2 = k_{11} ln\ a_2 - k_{12} ln\ a_1/(k_{11}k_{22} - k_{12}k_{21}) - k_{11}\ ln\ I_2 - k_{12}\ ln\ I_1/(k_{11}k_{22} - k_{12}k_{21})$$
$$= D - E\ ln\ I_2 + F\ ln\ I_1.$$

Thus, using monochromatic sources, a simple computer can be built for finding the processed images Z_1 and Z_2 using I_1 and I_2 scanned signals. The logarithmic operation can be done in digital fashion using well-known algorithms or with analog components. One straightforward analog approach is the use of the forward characteristic of a semiconductor diode where the voltage is the log of the diode current. The constant terms A,B,C,D,E and F are all precalculated and built into the computer since only the scanned signals I_1 and I_2 will vary from point to point. The extension into more Z regions with more monochromatic sources is straightforward algebra with the solution for each processed Z region again requiring the sum of constant terms plus the logs of the I_n signals.

Monochromatic x-ray sources can be obtaned using radioactive materials, although these are often relatively weak. To obtain stronger monochromatic x-ray sources secondary or fluorescent excitation can be used. Here broad-band x-ray radiation from an x-ray tube impinges on a target containing an element having a relatively high atomic number. The bombarded element fluoresces and emits a monochromatic x-ray beam at its K absorption wavelength. Thus iodine emits at about 33kev when bombarded with a broad-band source. The secondary emitter thus becomes filter **11** in FIG. **1** where the emission rather than the transmission of the filter is used. It is preferable to use the secondary emitted beam which is emitted at about 90° to that of the source. Thus the fluorescing element is placed at a 45° angle to the beam to maximize the energy of the secondary excitation. The references cited in the "Description of Prior Art" give detailed information on the generation of monochromatic radiation in the manner.

Significantly stronger sources, however, are obtained with broad-band filtered sources as shown in FIG. **1.** Here again a number of images I_n are obtained with different spectral regions $a_n(\lambda)$. As before the number of scanned images must be at least as great as the number of distinct Z regions to be processed. However, since the spectral regions are now broad-band, it requires the solution of a set of integral equations to evaluate the various processed Z regions. One method of solution is the use of a special purpose computer as shown in FIG. **3.** Here the integral equation is divided up into an array of sub-regions of the energy spectrum where $a(\lambda)$ and $k(\lambda)$ are approximately constant.

Again, using two I_n values and two Z regions for an example, these equations are given by

$$I_1 = {}_i\sigma\ w_i a_i \exp -(k_{1i}Z_1 + k_{2i}Z_2),$$

and

$$I_2 = {}_j\sigma\ w_j a_j \exp -(k_{1j}Z_1 + k_{2j}Z_2),$$

where w is the integration interval, $\lambda_2 - \lambda_1$, in which a and k are relatively constant. In FIG. **3**, as an example, two sub-computers which compute each integration region are shown for each summation. In the computer two oscillatory signals **57** and **58** supplying V_1 and V_2 are used to cycle through all possible values which processed signals Z_1 and Z_2 might have. For each set of V_1 and V_2 values, a set of I_1 and I_2 trial signals, **74** and **75** are computed. These trial signal values are compared with the actual values of scanning signals I_1 and I_2, **18** and **19** obtained by scanning the appropriate stored images. The comparison takes place in comparators **71** and **72** which are standard comparator circuits, such as longtail pairs, which generate a pulse when a successful comparison is obtained. These comparator output pulses are both applied to And Gate **73** which, as with any coincidence circuit, generates an output coincidence signal or pulse only when both input comparator output pulses are present. The presence of a coincidence signal thus indicates that the V_1 and V_2 values at that instant are the correct ones. The coincidence signal is then applied to sample and hold circuits **59** and **60** which clamp the V_1 and V_2 values to provide the desired processed Z_1 and Z_2 output signals **22** and **23.** These are used in the final display **25** as shown in FIG. **1.**

In the computer itself an array of sub-computers are used for each integration interval. For example in one subsection **45, 46,** and **47** provide the three terms $ln\ w_1a_1$, $k_{11}V_1$ and $k_{21}V_2$. The first term is provided by **45,** a constant or bias term, while the second two, **46** and **47,** are provided by amplifiers having gains of k_{11} and k_{21} respectively with inputs of oscillatory signals V_1 and V_2 from sources **57** and **58.** These are added in subadder **61.** The resultant sum becomes the argument of an exponent in **65.** This exponential device **65** can either be a digital system or an analog device such as a semiconductor diode where the diode current is the exponential of the diode voltage. The sub-computer output **65** thus represents one term of the summation of regions of integration in which the a and k values are relatively constant. A similar term is calculated by adding constant term $ln\ w_2a_2$ in **48** to $k_{12}\ V_1$ the output of amplifier **49** and $k_{22}V_2$ the output of amplifier **50** in subadder **62.** The exponential of the output of adder **62** is derived in **66.** The output of all of the exponent devices **65, 66,** and the output of similar structures not shown, such as **76** are all added together in final adder **69** to provide the computed intensity signal **74** for comparison. An identical complete system is provided for each intensity signal. For example in FIG. **3,** where two scanned intensity signals are used to define two processed Z regions, sub-adder **63** takes the sum of constant term $ln\ w_3a_3$ from **51,** $k_{13}V_1$ from amplifier **52** and $k_{23}V_3$ from amplifier **53.** The exponential of this sum is taken by system **67** which is identical to those of **65** and **66.** This outout plus that of **68** and of others, such as **77** are added in final adder **70** to provide the second computed trial signal **75** for comparison.

Each of the blocks in FIG. **3** can be well-known analog or digital circuitry. The number of regions used, where a_n and k are assumed constant, will determine the resultant accuracy. The sources of oscillatory signals, **57** and **58,** can be a low and high frequency sawtooth waveform, respectively. Thus, as one waveform is being varied over its entire range, the other is being rapidly cycled over its range so as to assume all of its values for every value of the slow waveform. The processing time for each picture element will be one cycle of the low frequency sawtooth. With high speed circuitry this could, for example, be about 10 usec. with the period of the high frequency sawtooth being about a factor of one hundred less or about 0.1 usec.

Many variations can be made on the computer shown in FIG. **3.** For example, instead of using regions where the k values are constant, each region can represent a linear part of the $k(\lambda)$ curve where $k(\lambda)$ is given by

$$k(\lambda) = k_o \pm k_1\lambda$$

Although each region would be somewhat more complex, the number of separate integration regions would be less since a curve can be broken up into considerably fewer linear values than constant values. Other variations include approximating $a(\lambda)$ in a linear form for greater accuracy.

Another approach to the computation is the use of a table-look-up system where the integral equation is solved beforehand using a variety of processed Z values. Thus, for each scanned intensity value, an array of possible combinations of processed Z values which can produce that particular scanned intensity value are selected. This is done for each scanned intensity signal I_n. The various listings of combinations of processed Z values are compared to determine which most closely fits. For example, assume we are evaluating a two-material region by recording two intensity values, I_1 and I_2. At each position the values I_1 and I_2 are each used to bring forth a set of Z_1 and Z_2 values which can produce the values I_1 and I_2 as determined by pre-calculation. The Z_1, Z_2 set for the particular I_1 is compared to the Z_1, Z_2 set for the particular I_2 to determine the closest match, and thus determine Z_1 and Z_2 for that point. This operation is best accomplished on a digital computer using a pre-calculated read-only memory. As an alternative to pre-calculation, the various Z values corresponding to I values can be determined experimentally using known materials.

A more rapid digital computation method can be used which also uses a read-only memory but avoids the comparison of the sets of processed Z values. A multi-deminsional read-only memory is used with the number of dimensions determined by the number of scanned intensity signals used. For each set of scanned intensity signals, the corresponding set of processed Z values are stored. For example, if the scanned signals at some point are I_{1d}, I_{2d}, and I_{3d}, the memory would be addressed using those three dimensions. The Z values corresponding to those I values would be read out directly without requiring a comparison operation. As before, the stored Z values can be pre-determined by calculation or experiment. For scanned intensity signals which are intermediate the pre-determined stored values, a system of interpolation can be used to determine the most accurate set of processed Z values.

The various systems described are capable of converting the information from an array of scanned inten-

sity patterns representing the transmission at different x-ray energies to an array of processed images representing specific materials within an object. In medical diagnosis, for most studies, the delineation of three materials would be very significant. These are bone, soft tissue which is mostly water, and contrast material containing iodine or barium. When choosings filters **11** or monochromatic sources to get the required three intensity pattern, it is preferable that each spectrum produces relatively different absorption characteristics in the materials of interest. In theory, the three material regions can be isolated as long as the three spectral regions used are, in any way, different. Insufficient differences, between energy spectra however, will lead to a noise problem in reconstructing the three material regions. Assume that the region of interest consists of soft tissue, bone and iodine contrast material. An example of three energy spectra for this case is an unfiltered spectrum, a spectrum filtered with iodine material and a spectrum filtered with tantalum foil. The latter two materials would each form filter **11** in FIG. **1.** The broad unfiltered spectrum would have significantly higher absorption for bone than soft tissue in the lower energy regions while having comparable absorption for the two in the higher energy region dominated by Compton scattering. The spectrum filtered by tantalum foil however would have negligible transmission beyond its *K* edge at about 65 Kev and thus transmit primarily in the region where the bone absorbs significantly more than does soft tissue. Thus the unfiltered spectrum and the spectrum with a tantalum filter can reasonably separate bone and soft tissue. The iodine filter has a strong absorption-edge at about 33 Kev as does the iodine within the body. Thus, when the iodine material is used as filter **11,** the iodine contrast in the body is relatively low. When the other two spectra are used, the unfiltered and the tantalum filter, the output around 33 Kev is relatively high, causing significant contrast due to the absorption of iodine within the body. Thus the three spectra chosen will provide significant absorption differences for the three materials of interest to be able to isolate these materials using the computer systems shown. A variety of other filters can be used to allow a variety of materials to be isolated. For example, certain materials such as phosphorus are known to be selectively taken up in diseased regions of the body such as tumors. The system described here can be used to make an isolated image of this selectively taken up material to allow tumors to be found at a relativelyy early stage.

What is claimed is:

1. Apparatus for providing a plurality of processed x-ray images represening specific materials in an object comprising:

a plurality of sources each having a different x-ray energy spectrum;

means for recording a plurality of images each representing the different x-ray energy spectrum transmitted through the object with the number of recorded images being at least as great as the number of processed images;

means for scanning each of the plurality of recorded images to generate a plurality of scanned signals;

a computer for processing the plurality of scanned signals to generate the plurality of processed signals represent specific materials in the object; and

mean for displaying the processed signals whereby processed x-ray images are formed representing specific materials in the object.

2. Apparatus as recited in claim **1** wherein the means for recording the plurality of images each representing the different x-ray spectrum transmitted through the object comprises:

a scintillating screen for converting the x-rays transmitted through the object into visible light image; and

means for recording the visible light image.

3. Apparatus as recited in claim **2** wherein the means for recording the visible light comprises a television camera whose target receives the light image from the scintillating screen and a video storage device for storing the electrical video signal generated by the television camera.

4. Apparatus as recited in claim **2** wherein the means for recording the visible light comprises photographic film.

5. Apparatus as recited in claim **4** wherein the means for scanning each of the plurality of recorded film images includes a flying spot scanner whose light output is imaged onto each of the recorded film images and a photocell for collecting the transmitted light and generating the scanned signal.

6. Apparatus as recited in claim **1** wherein the plurality of x-ray sources comprises an x-ray emitter and a plurality of filters positioned in the path of the emitted x-rays where each filter includes materials having a different x-ray transmission spectrum.

7. Apparatus as recited in claim **1** wherein the plurality of x-ray sources comprises an x-ray emitter and a plurality of secondary - emitters positioned in the path of the emitted x-rays each of which fluoresces and emits a monochromatic spectrum.

8. Apparatus as recited in claim **1** wherein the computer for processing the plurality of scanned signals to generate a plurality of processed signals includes means for taking weighted sums of a pre-calculated constant term and the logarithms of each of the scanned signals.

9. Apparatus as recited in claim **1** wherein the computer for processing the plurality of scanned signals to generate a plurality of processed signals includes means for solving a plurality of simultaneous integral equations each representing the relationship between all of the processed signals and a different one of the scanned signals the relationship specifying each scanned signal being equal to the integral, over the energy spectrum used, of the products of the absorptions of each of the specific materials in the object.

10. Apparatus as recited in claim **9** wherein the means for solving the plurality of integral equations comprises:

an array of sub-computers for each of the plurality of integral equations with each sub-computer computing the output for a different subregion of the energy spectrum;

a plurality of oscillatory signals representing all possible values of the processed signals which are connected to each of the sub-computers;

a plurality of final adders for adding the outputs of each of the sub-computers to generate a plurality of trial signals;

a plurality of comparators for comparing each of the plurality of trial signals with the scanned signals

and generating a comparator output signal when the trial signal equals the scanned signal;

a coincidence circuit for generating a coincidence signal when all of the comparator output signals are present; and

a sampling circuit for sampling all of the plurality of oscillatory signals with the coincidence signal to generate each of the plurality of processed signals.

11. Apparatus as recited in claim **10** wherein each of the array of subcomputers comprises:

a source of bias voltage representing the spectral amplitude of the filtered source in that region of the energy spectrum;

a plurality of amplifiers for each of the plurality of processed signals having a gain proportional to the absorption coefficient for the specific material in that region of the energy spectrum and having the oscillatory signal, representing all values of the processed signal, as an input;

a sub-adder for adding the source of bias voltage and the output voltages of each of the plurality of amplifiers; and

means for deriving the exponential of the output of the sub-adder to form the output of the sub-computer.

12. Apparatus as recited in claim **9** wherein the computer further comprises:

a memory in which are stored an array of predetermined values of each of the plurality of processed signals for each value of each of the plurality of the scanned signals;

means for addressing the particular arrays of predetermined values of each of the plurality of processed signals corresponding to the particular set of scanned signals being received by the computer;

means for comparing the particular arrays of predetermined values of each of the plurality of processed signals with each other to determine a set of pre-determined values which provides the closest match of these signals amongst the arrays; and

means for utilizing the set of pre-determined values which provides the closest match to form the plurality of processed signals.

13. Apparatus as recited in claim **9** wherein the computer further comprises:

a memory in which are stored an array of predetermined values of sets of the plurality of processed signals for each set of values of the plurality of scanned signals;

means for addressing a particular set in the array of pre-determined values of the plurality of processed signals corresponding to a particular set of the plurality of scanned signals; and

means for utilizing the particular set of the plurality of processed signals to form the plurality of processed signals.

14. Apparatus as recited in claim **1** wherein the means for displaying the processed signals includes a monochrome display device which is connected to one of the plurality of processed signals whereby an image is displayed which represents the absorption due to one of the materials in the object.

15. Apparatus as recited in claim **1** wherein the means for displaying the processed signals includes a color display device where each color is modulated by one of the processed signals whereby an image is displayed which simultaneously represents the absorption due to the plurality of materials in the object.

* * * * *