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(54) DEVICES FOR OBTAINING INFORMATION ABOUT RADIATION SOURCES

(71) We, GALILEO ELECTRO-OPTICS CORP., a corporation organised under the laws of the State of Delaware, United States of America, of Galileo Park, Sturbridge, Massachusetts, 01518, 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 devices for obtaining information about radiation sources.

Visible light can be both reflected and refracted. The ordinary camera takes advantage of refraction by using an optical lens to refract and focus the visible light coming from an object, in order to produce an image of the object on film. However, electromagnetic radiation of higher frequency than vacuum ultraviolet (such as X rays and gamma rays, together referred to hereinafter as "gamma radiation") cannot be efficiently either reflected or refracted. Therefore the formation of an image of a source of gamma radiation has been achieved with the use of a collimator, which operates in somewhat similar fashion to the old pinhole camera. The pinhole camera permits the light from an object to pass in a straight line through a pinhole in the camera box, to produce an inverted image on the film.

Collimators with an array of parallel channels, such as the one depicted in Fig. 1, have been used in the imaging of gamma radiation sources. With the axes of the channels pointed toward a gamma radiation source, the channels are generally of the same order of magnitude dimensions normal to the axis; usually the channels are circular, triangular, or square in cross section. In Fig. 1, with the walls or septa of each channel made of lead to absorb gamma radiation, and with a radiation detector (not shown) placed on the side of the collimator opposite the source, the radiation that can pass from a point source through a particular channel and reach the detector is defined by the solid angle (A) subtended by the base of a collimating channel 2. Spatial resolution of such a collimator is improved by reducing the solid angle. However, the sensitivity of each channel, which increases the amount of radiation passing through the channel, is improved by increasing the solid angle. Of course it is desirable to improve both spatial resolution and sensitivity, the latter particularly so that the necessary time of observation may be reduced.

Turning to the radiation detector, it is known to use the photoconductor as the basic element of such a detector. However, in known arrays of photoconductor detector elements the photon absorption distance and the interelectrode distance correspond to the same photoconductor dimension, and thus are generally the same length. It would be desirable to make the photon absorption distance large with respect to the interelectrode distance, for the larger the absorption distance, the better the sensitivity, because a larger fraction of the incident photons are collected, and the smaller the interelectrode distance, the greater the efficiency, and also the rapidity, of collection at the electrodes of electrical signals created in the photoconductor body by incident photons.

According to the invention there is provided an instrument for obtaining positional source information which comprises: a slit collimator containing a multiplicity of slits for reception therein of beam components emanating from a source; each slit of said slits including an open end for orientation toward said source and slit-defining walls extending away from said source and from said open end; each said wall extending in the same longitudinal direction as the other walls; said walls including material of character and thickness to absorb those of said beam components impinging thereon; and said slits extending further in one transverse direction than in the other transverse direction; a detector for separately detecting beam components passing through said slits and for providing detection data output signals; said detector being fixedly mounted relative to said collimator; said detector comprising a plurality of radiation transducing portions, each of said radiation transducing portions being correlated with, and positioned to close the end of, a respective slit opposite each end; and a positioner simultaneously changing the transverse position of said slits and radiation transducing portions relative to said source; wherein each said radiation transducing portions is a photoconductor element.

The invention provides a sensitive, fast, high resolution, and convenient-to-use device for obtaining information about the distribution of gamma radiation source, and further provides a radiation detector useful in such a device.

The information-obtaining device of the invention has high sensitivity without sacrifice of resolution. The device includes a collimator that is easy to construct, without the necessity for an intricate honeycomb of separate channels, and the septa of the collimator can be conveniently made of tungsten foil, tungsten being a better radiation-absorbing material than lead, and thus can be thinner than lead septa, thereby improving the effective collimator transparency. The output of the device can be readily and rapidly transformed by conventional computer techniques to provide highly resolved images of gamma radiation sources. The device has substantial present application in the field of nuclear medicine, and also has industrial application.

The detection device of the invention is easy to construct, and has an improved resolution and signal-to-noise ratio. It has a high uniformity of response to a given incident photon energy so that noise and spurious signals caused by Compton effect scattered, lower energy photons originating at sites remote from the primary radiation sources can be rejected. It also has a high photon collection efficiency, for improved sensitivity, and a brief output pulse, for improved temporal resolution.

The invention features in one aspect obtaining information about positional source of, for example, a gamma ray source, by slit collimating and detecting beam components from the source in a multiplicity of varying slit locations, and using the resulting data to plot the source position.

Preferred embodiments of the invention feature in this aspect a collimator including a frame having an axis of rotation and a plurality of flat sheets of gamma-radiation-absorbing material maintained by the frame in parallel, spaced-apart relation with respect to each other and parallel with the axis of rotation, adjacent pairs of the sheets defining slits therebetween, each of the slits having an opening at one end thereof and being unimpeded, for permitting passage of gamma radiation therethrough, in a first direction parallel to the axis of rotation, and being unimpeded, within the frame, in a second direction perpendicular to the axis of rotation and parallel with the sheets, means for positioning the collimator to maintain the axis of rotation pointed at a gamma radiation source so that the slits are disposed to receive gamma radiation therefrom while the collimator is rotated about the axis, each of the slits subtending, in the plane defined by the first and second directions, a much larger angle for receiving radiation passing therethrough to the base i.e. the end thereof remote from said open from the source that it subtends in a second plane perpendicular to the second direction, a detector effectively connected to the frame for common rotation with the collimator and positioned adjacent the ends of the slits for detecting radiation passing through each slit to the base thereof and providing an output representative of intensity of detected radiation over the whole base of each slit as a function of the angle of rotation of the collimator, and means for accumulating a matrix of such outputs, the matrix being ordered according to the particular slit in which the radiation causing the output was detected and according to the particular angle of rotation of said collimator at the time the radiation was detected, the matrix being suitable for transformation to a matrix corresponding to the image of the source.

The invention features in embodiment a detector for detecting gamma radiation and for providing an ouput in response to the radiation, the detector comprising a plurality of detector elements of photoconductor material sensitive to gamma radiation, the elements being strips arranged in parallel, spaced-apart relation, to expose to incident gamma radiation from a source of the same a generally planar surface made up of one face from each of the elements, each of the elements having a pair of electrodes affixed thereto, each one of the pair of electrodes being positioned between adjacent elements, the planes of electrodes being perpendicular to the planar surface exposed to incident radiation, and the thickness of each detector element measured from the surface exposed to incident radiation along a perpendicular line therefrom is large with respect to the distance between each pair of electrodes.

Certain preferred embodiments feature a detector comprising a plurality of detector elements equal in number to the slits, the elements being effectively connected to the frame so that they remain positioned adjacent their respective bases while the collimator is rotated about the axis; processing circuitry including an amplifier for amplifying detector outputs and an amplitude discriminator for discarding from the outputs any components having below a minimum amplitude; a housing as the maintaining means, the housing including a tube, a plate rotatably mounted in the tube, and means for rotating the plate, the plate containing an aperture for receiving the frame so that when the plate is rotated, the frame is rotated together therewith; an indexed motor adapted to rotate the plate in discrete angular steps as the rotating means and collimator sheets made of tungsten foil. Other preferred embodiments feature detector elements composed of cadmium telluride; photoconductor detector elements the planes of whose electrodes are parallel to the collimator sheets and the distance through the photoconductor element in the first direction is large with respect to the distance between each pair of electrodes in a third direction perpendicular to the first and second directions; a distance through the photoconductor element in the first direction no less than 5 mm and the distance through the photoconductor element in the third direction no greater than 0.75 mm; and photoconductor elements in the form of strips.

Other advantages and features of the invention will be apparent from the description and drawings herein of a preferred embodiment thereof.

Fig. 1 is a sectional view, in a plane transverse to its face of a typical known collimator;

Fig. 2 is a view in perspective of one embodiment of the invention of our co-pending Application No. 16593/78 Serial No. 1603714;

Fig. 3 is an enlarged plan view of a portion of the embodiment of Fig. 2;

Fig. 4 is a view through 4—4 of Fig. 3, with portions broken away;

Fig. 5 is a view through 5—5 of Fig. 3, with portions broken away;

Fig. 6 is an exploded isometric view of a portion of the embodiment of Fig. 3;

Fig. 7 is a diagrammatic view of the embodiment of Figs. 2 through 6, with associated circuitry;

Fig. 8 is a greatly enlarged sectional view, in a plane transverse to its face, or a portion of an embodiment of the present invention;

Fig. 9 is a sectional view, in a plane perpendicular to the plane of Fig. 8 and to the face of the collimator, of said embodiment, with portions broken away and with associated circuitry shown diagrammatically; and

Fig. 10 is an exploded isometric view of a portion of embodiment.

A camera 10 is shown in Fig. 2, and comprises an integrated collimator 12 and a detector 14 mounted for rotation together in a housing 16. The collimator 12, as better shown in Figs. 3 to 6, includes a frame 18 made of steel and a series of fifty-one parallel sheets 20 of tungsten foil held in tension in the frame 18. The frame 18 has two opposite sides 22, which are 80 mm by 55 mm by 15 mm. A set of three steel 5 mm diameter rods 24 connects the sides 22 at each end thereof through holes 26 drilled through sides 22. Screws 28 when tightened in the holes 20, which intersect the holes 26 transversely, hold the rods 24 in place in sides 22, and form a square having an outer dimension of about 80 mm by 80 mm. The sheets 20 also have a set of three holes 32 (Fig. 6) at each of their ends, to receive rods 24, which thereby maintain the sheets 20 in tension with the assistance of lead spacers 34, which separate adjacent sheets 20 at the sheet ends, and are held in position by rods 24 passing through holes in the spacers. Each sheet 20 is 0.15 mm thick, 30 mm wide, and 80 mm long. The lead spacers 34 are 0.85 mm by 15 mm by 30 mm plates. The spacers 34 and rods 24 together form the two other sides of frame 18 in addition to sides 22.

The sheets 20 are equidistantly spaced 0.85 mm from each other to define fifty slits 36, which are 50 mm by 30 mm by 0.85 mm. The previously described tensioning of sheets 22 maintains these slit dimensions.

The detector 14 comprises fifty detector elements 38, which are scintillating sheets made of commercially available scintillating plastic is material composed mainly of polyvinyl toluene and manufactured and sold by Nuclear Enterprises, San Carlos, California. Each sheet 38 is 50 mm by 10 mm by 0.85 mm, and is fitted between each pair of adjacent tungsten sheets 20. With the frame 18 directed toward a radiation source so that the slits 36 are most favourably positioned to receive radiation from the source, each slit has an opening closest to the source to receive radiation and a base at the opposite end of the slit and the edges of the sheets 38 that are farthest from the radiation source are positioned flush with the edges of the tungsten sheets 20 that likewise are farthest from the radiation source (Figs. 4 and 5).

Attached by transparent epoxy to the rear face of each scintillating sheet 38 is a ribbon 50 of optical fibres (diagrammatically shown in Figs. 4 and 5) having the same dimensions in cross-sectional area as does the rear face of sheet 38 (50 mm by 0.85 mm). Each ribbon 50 is composed of approximately 8 layers of 0.1 mm diameter fibres, about 500 fibres per layer, all produced by conventional fibre optic techniques. The fibres extend perpendicularly away from the rear face of sheet 38. All fifty ribbons 50, one for each sheet 38, are potted together in transparent epoxy, forming a block 42, which extends 25 mm outwardly from the rear faces of sheets 38. Frame sides 22 likewise extend 25 mm below the rear faces of the sheet 38, to provide a frame for the block of potted fibres. Conventional clamps (not shown) can be used to assist the frame sides 22 in gripping the block 42, which extends the length of sides 22. As they extend out of the block 42, the fibres making up each ribbon 50 are independently flexible, and are gradually drawn together into a circular bundle, maintained in that position by a ferrule 52. The ends of each circular fibre bundle are bonded to the sensor face of a photomultiplier 54, which converts light signals to electrical ones for transmission to a preamplifier 56 (Fig. 7). The optical fibre connection between the detector array 14 and each photomultiplier 54 is flexible enough to accept a 180° rotation of a plate 60 (see below).

The collimator 12, detector 14, fibre ribbons 50, photomultipliers 54, and preamplifiers 56 are all mounted in the housing 16. The housing 16 includes a circular steel mounting plate 60, steel tube 62, plate drive 64, a support arms 66. The frame 18 fits within a square hole centrally placed in the mounting plate 60, clamps 68 holding the frame 18 in place in the plate 60. The plate 60 is fitted within the forward opening of the tube 62, and is rotatable with respect to the tube 62, a conventional bearing arrangement (not shown) permitting the rotation. The plate drive 64, including a reversible, indexed electric motor and timer, rotates the plate 60, whose outer rim is toothed to provide a gear linkage (not shown) with drive 64. The frame 18, collimator 12, and detector array 14 all rotate with plate 60, which is driven discontinuously by the drive 64.

The tube 62 is itself pivotally mounted on support arms 66 so that the tube can be tilted toward a particular radioactive source. A locking knob 44 is adjusted to hold the tube 62 in the position chosen. Support arms 66 are mounted on a base (not shown), which conveniently includes casters, so that the camera 10 as a whole can be wheeled to different positions.

Fig. 7 shows in block diagram conventional circuitry for processing electrical signals from the photomultipliers 54. Signals from photomultipliers 54 are in the form of electrical pulses, each pulse corresponding to the absorption of a gamma ray by the corresponding scintillating sheet 38. These electrical pulses are transmitted to preamplifiers 56 through fifty leads 70 from the fifty photomultipliers 54. Preamplifiers 56 are located in the rear portion of tube 62, just forward of a steel circular backplate (not shown) covering the rear opening of tube 62. A hole through the centre of the tube backplate permits fifty leads 72 channeled through a flexible conduit 74 to pass from the preamplifiers 56 out of the tube 62. The preamplifiers 56 amplify all pulses coming from the photomultipliers 54, and are placed in the tube 62 to shield them from noise. The rest of the circuitry of Fig. 7 is conveniently housed in the mobile base. The amplifier pulses travel through leads 72 to fifty pulse amplifiers 76, one for each lead, where the pulses are further amplified. The pulses are then transmitted from the fifty pulse amplifiers 76 to fifty pulse-height discriminators 78, which reject pulses having less than a predetermined amplitude (such as pulses caused by Compton effect photons), and permit the rest of the pulses to pass. Finally, the pulses are counted, and their number entered, in a register 80. Register 80 is a 50x50 register, and is synchronously connected to the plate drive 64, so as to count the pulses coming from the fifty pulse-height discriminators for each discrete angular position of the collimator 12 and detector 14. This data made up of pulse counts is stored in the register 80, and, when all counts have been made, is subsequently reduced by known computer techniques, to be explained in more detail below, to a form which identifies the two-dimensional location of the radiation sources impinging on the collimator 12 and detector 14.

In operation, the camera 10 is positioned so that the front of collimator 12 is as close to the radiation source as possible. The source itself is composed of Technetium 99, a radioisotope that emits gamma radiation with a characteristic energy of 140 Kev, or of some other radioisotope suited to clinical or other useful service. If the source is within a patient, the collimator 12 is preferably brought into contact with the patient in the vicinity of the source. The source itself, for purposes of data analysis, may be regarded as a three-dimensional array of point sources randomly emitting gamma photons. Camera 10 in effect takes a picture of the two-dimensional array resulting from the orthogonal projection of this three-dimensional source array upon detector 14.

The collimator sheets 20 and collimator slits 36 are initially vertically aligned, and the axis of the tube 62 is then aimed directly at the source volume (usually at the part of the patient body to which the isotope has traveled). The locking knob 44 maintains the tube orientation. The photomultipliers 54 are activated, ready to respond to light signals from the detector 14, and the signal processing equipment of Fig. 7 is energized. The collimator 12 remains in the initial position for of the order of 10 seconds, during which time gamma photons travel from the source to collimator 12, and enter the most favorably positioned slits 36. The plate drive 64 then rotates the collimator 12 through 3.6°, followed by a ten-second pause, followed by another 3.6° step, and so on until fifty such steps of 3.6°, amounting to 180°, have been taken. The number of rotational steps for each 180° turn (here, fifty) is chosen to equal the number of slits 36 in the collimator 12. During each ten-second interval, the tungsten sheets 20 absorb any photons hitting the sheets. Photons passing from a particular point source through a particular slit solid angle subtended by the area of the incident face of a scintillating sheet 38 will pass into that scintillating sheet, and most will be absorbed therein, thereby exciting visible photons in the sheet. These visible photons are transmitted through the sheet 38, and illuminate optical fibres in the ribbon 50 attached to the particular scintillating sheet. All faces of the scintillating sheet 38 except the face bonds to the ribbon 50 are coated with a substance reflective of visible light so that all visible light pulses excited within the sheet 38 are eventually transmitted toward the rear face of the sheet 38 and ribbon 50, though with higher attenuation of pulses undergoing one or more reflections before reaching the ribbon 50. Attenuation of the visible light signals also occurs within the ribbon 50, and about 1% of the visible light photons generated in the sheets 38 reaches the photomultipliers 54. However, the signals reaching the photomultipliers are sufficient to provide a basis for accurately determining the location of the sources of radiation.

The scintillating sheet 38 gives an output indicative of the energy of the incident gamma photon; thus photons of energy lower than the primary gamma photons arising from Compton scattering and originating at sites remote from the primary radiation sources can be rejected in the pulse-height discriminator 78. During the ten-second interval before the collimator 12 takes its first 3.6° step, and during each of the forty-nine subsequent ten-second intervals between subsequent 3.6° steps, each scintillating sheet 38 is collecting gamma photons from all radioactive point sources lying in a lamina of space created by projecting the pair of tungsten sheets 20 bounding sheet 38 toward the sources. Likewise during the interval each sheet 38 is collecting all the radiation emitted by each point source within the solid angle subtended by the area of the frontal face of sheet 38 with respect to that point source. The output of each scintillating sheet 38 at each rotational position is thus a series of visible light pulses corresponding to a series of gamma photon absorptions within the sheet, the photons coming from the various point sources.

The procedure for processing the data stored in the register 80 to construct an image of the radioisotope source distribution is grounded preliminarily on the assumption that the distribution to be imaged will appear in the plane perpendicular to the first direction as a two-dimensional array of 50x50 source elements. The problem then becomes that of constructing an image with 50x50 resolution elements, i.e., solving for 50x50=2500 unknowns. The isotope will be located wherever the value of the source element is nonzero, and will be absent where the value of the source element is zero. In principle, when there are 50x50 unknowns, it is always possible to solve for those unknowns with a system of 50x50 simultaneous linear equations. The steps of setting up the equations in matrix form and solving by the procedures of matrix algebra constitute a well-known direct approach to finding the unknowns. The register 80 provides the data from which 50 (slits)x50 (angles)=2500 equations can be constructed Computer-performed mathematical techniques are presently at a point where expedited solution of this number of simultaneous equations can be accomplished. The following references set forth for such expedited solutions: Ramachandran and Lakshminarayanan, "Three Dimensional Reconstruction From Radiographs and Electron Micrographs: Applications of Convolutions Instead of Fourier Transforms," Proceedings of the National Academy of Sciences of the United States, 1968, pp. 2236—2240; Gordon and Herman, "Threee Dimensional Reconstruction from Projections: A view of Algorithms," International Review of Cytology, Vol 38 (1974); DeRosier and Klug, "Reconstruction of Three Dimensional Structures from Electron Micrographs," 217 Nature 130 (1968); and M. M. Woolfson, An Introduction to X Ray

Crystallography, Chapter 4, "Fourier Transforms" (Cambridge Univ. Press 1970).

It is clear that radiation emitted from the peripheral regions of the source area will enter the camera with a somewhat lower probability of being accepted by the detector array than will radiation emitted from regions close to the axis of rotation of the collimator. Therefore it will be necessary to "weight" the data processing procedure so as to compensate for this bias. In the quoted references it is shown how this compensation may be achieved.

Because the resultant image created by these computer techniques is a two-dimensional one, though the radioisotope itself actually occupies three-dimensional space, the further technique, well-known in the field of radiation therapy, of taking additional pictures from different spatial positions of the collimator and combining them to produce a three-dimensional image is used. In the case in which the radioisotope is in the brain, the simplest method of carrying out this technique would be to take one picture with the axis of the collimator directed between the patient's eyes and to take a second picture with the collimator axis shifted 90° so as to be directed through the patient's ears.

A comparison of the camera 10 with a conventional static channel collimator-detector system shows that sensitivity is improved with the camera 10 and thus exposure time reduced without any impairment of resolution.

Furthermore, integration of detector 14 with the collimator 12 improves the overall spatial resolution of the image in two respects. First, if the detector 14 and collimator 12 be considered as separately constructed devices without attempt at registration between individual slits 36 and detector elements 38, as is normally the case with existing channel collimating structures, then the effective resolution of the complete system is generally considered to be the square root of the sum of the squares of the minimum resolution distances of the two devices (the collimator and the detector) taken separately. Therefore if the spatial resolutions of the two devices are similar, integration of the detector with the collimator will yield an overall resolution improvement by a factor of the square root of two. Second, and more important, integration of the detector 14 with collimator 12 will essentially eliminate the loss of resolution incurred through scattering of radiation either within the collimator or within the detector array itself.

Figs. 8 to 10 show an embodiment of the present invention using the same collimator 12 but a different detector 46. The detector 46 is composed of fifty detector elements 88, which are strips of photoconductors 90, five of which are spaced by polyethylene terephthalate insulation spacers 91 to form each strip. Each cadmium telluride photoconductor 90 is a rectangular crystal wafer measuring 10 mm by 5 mm by 0.75 mm, and each strip 88 of wafers is thus approximately 50 mm long. Deposited on the two largest faces of each photoconductor 90 is a pair of electrodes 92. Each electrode 92 itself comprises a thin layer of platinum deposited directly on the cadmium telluride body, thereby forming an electrode-cadmium telluride-electrode sandwich. The deposited layers 92 are each on the order of a micron in thickness. Resting flush against one side of strip 88 and extending parallel to the strip is a ground connector 98. The ground connector 98 is a strip of polyethylene terephthalate manufactured and sold by du Pont under trademark Mylar on which a thin aluminium coating has been deposited. The thickness of this Mylar-aluminium strip is approximately fifty microns, with the Mylar accounting for most of the thickness. An aluminium-Mylar ground finger 100 extends downward from the strip 98 toward one end thereof. The aluminium face of the ground connector 98 is positioned on one side of the strip 88. The Mylar gives strength to the aluminium connector while serving as an insulator between an adjacent tungsten sheet 20 and the aluminium connector. A similar connector 102 is positioned on the other side of the strip 88, but the aluminium coating has been divided, by prior removal of narrow vertical bands of aluminium, into five electrically isolated regions 104 corresponding to the five photoconductors 90 making up the strip 88. Each of the five aluminium regions 104 has an aluminium-Mylar finger 106 extending downward from the region. The whole connector-electrode-photoconductor - electrode - connector sandwich that results when all these elements are brought together is positioned between each pair of adjacent tungsten sheets 20 of collimator 12 as well as between one frame side 22 and an adjacent tungsten sheet 20. This sandwich structure measures 50 mm by 5 mm by 0.85 mm, and takes the place of the scintillating sheet 38 in the slit 36. A strip 88 of photoconductors 90 accounts for most of the thickness of the connector electrode-photoconductor sandwich in each slit 36 so that only a small fraction of the incident gamma photons in slit 36 will be lost by entering the connectors 98 and 102 or the electrodes 92. The photoconductor strips 88 and conductors 98 and 102 are supported by a printed circuit board 108. The board 108 is slotted at appropriate locations to receive the ground fingers 100 and fingers 106. The fingers pass to the underside of board 108, where a printed ground lead (not shown) connects the ground fingers 100 for all the ground connectors of the detector array and where separate printed leads (not shown) are individually connected to each of fingers 106. The photoconductor strips 88 rest along their lower faces on the board 108. The tungsten sheets 20 are also grounded by connection to the ground lead of the board 108 (the connections are not shown). The strips 88, by virtue of Mylar spacers inserted at the strip ends, and the aluminium portions of the connectors 98 and 102, by removal of bands of aluminium at the ends, are also insulated from the lead spacers 34, which as before are fitted between the sheets 20, and for two borders for the detector array. The board 108 is itself secured to the frame sides 22 by brackets (not shown).

A voltage source 110 (50 volts) (Fig. 9) is connected through the board 108 and connectors 98 and 102 so as to apply its voltage through each pair of electrodes 92 across each photoconductor 90 (there are 5x50=250 photoconductors 90). The output signal from each photoconductor 90 is carried out through the connectors 98 and 102 to printed leads in the board 108 and from there through flexible leads 112 to a preamplifier 56a. There are 250 preamplifiers in all, one for each photoconductor 90. The output signals from five preamplifiers 56*a* corresponding respectively to the five photoconductors 90 in a strip 88 are combined and fed into a pulse amplifier 76. As with the embodiment using detector array 14 and photomultipliers 54, there are fifty pulse amplifiers 76, fifty pulse-height discriminators 78, and one register 80. Each preamplifier 56*a* is an operational amplifier with a field effect transistor input, a open-loop of 10^5, and an input current sensitivity of 10^{-11} ampere.

An incident gamma photon producing a charge of 10^{-14} coulombs in the photoconductor crystal, and with the entire charge collected at the pair of electrodes 92 in a micro-second, the current output is

$$\frac{10-14}{10-6}=10-8$$

ampere, which can be recognized and amplified in preamplifier 56. Because the Mylar insulation on the connectors 98 and 102 is kept thin so that the area of the radiation-exposed surface of photoconductor 90 can be maximized, a large capacitance (in relation to the capacitance across the photoconductor 90) is developed across the Mylar between each tungsten sheet 20 and the aluminium coating of the connectors 98 and 102. This capacitance might ordinarily reduce the voltage excursion of any signal coming from the electrodes 92 below limits detectable by the preamplifier 56, but the segmenting of the detector strip 88 into five separate photoconductors 90 results in an overall capacitance for each photoconductor 90 one-fifth as large as the total capacitance of the strip 88, an acceptable value as far as retrieval of signals from the photoconductor 90 is concerned. In regard to sensitivity, with a preamplifier 56*a* capable of detecting incoming signals down to 10^{-11} ampere, accurate measurement of the magnitude of expected signals on the order of 10^{-8} ampere is possible. Thus it is possible to screen out the lower energy Compton photons downstream in the pulse-height discriminators 78. The overall background noise is approximately equivalent to a 10 Kev signal so that the discrimination between genuine source photons and noise is possible, using radiation sources of more than about 20 Kev.

The thin strip design of the photoconductors 90, with electrodes 92 positioned parallel to the collimator sheets 20, though bringing with it a capacitance problem as just described, offers simultaneously the advantages of a short interelectrode distance and a long photon absorption distance. By having a relatively short distance between opposing electrodes 92 (about 0.75 mm), the current carrier (electron or hole) collection efficiency of the electrodes is improved, with resultant improvement in obtaining uniformity of response for photon excitations, and the carrier collection time is reduced, with resultant improvement in temporal resolution. By having a relatively deep photoconductor crystal (5 mm), most incoming photons from a 140 Kev or less isotope source will be absorbed by the crystal, providing better camera sensitivity. In general, with use of photoconductors signal losses are far lower than with scintillating sheets and optical fibres, and energy resolution is much improved. With more of the signal actually reaching preamplifer 56*a*, more accurate imaging is the result.

Methods for processing the data received in the register 80 are as previously described, and the improvement in sensitivity over the channel collimator is also as previously described.

Regarding modifications in procedure and structure, the collimator 12 can be continuously rotated rather than discontinuously rotated, or even operated moving its axis along another curved or other configuration or without rotation. Symmetry about the axis is preferred but not essential. Appropriate modification in the data reduction procedures will then be required, of course. If harder radiation sources than Technetium 99 are used, the scintillating sheets 38 and photoconductors 90 will need to be deeper from top to bottom (i.e., have a longer photon absorption distance). If, for example, the source is on the order of Mev's, the photoconductor 90 may need to be 40 or 50 mm deep rather than only 5 mm. If greater resolution is desired, the number of slits in collimator 12 can be increased accordingly, to at least a total of 250 slits; assembly of such a collimator would understandably be somewhat more involved than in the case of the fifty-slit collimator. Tantalum can be used in place of tungsten in the sheets 20. Polystyrene can be used in place of polyvinyltoluene in the scintillating sheets 38. Finally, in the photoconductor detector 46, copper can be used instead of aluminium in the connectors 98 and 102, electrodes 92 can be made thicker, for better uniformity of response (though possibly at the sacrifice of effective photoconductor area), the electrodes 92 can include a thin layer of conductor such as indium deposited on the platinum to improve contact between the platinum and the metallic coating of connectors 98 and 102, and the photoconductor strips 88 can be continuous instead of segmented if the excited signals are strong enough to overcome the capacitance problem. Additionally, instead of a photoconductor detector 46, a detector comprising a continuous planar sheet of photoconductor material having electrodes formed in strips and deposited on top and bottom instead of one of the sides, as in detector 46, could be employed. Construction is made easier, but such a detector does not have the combined advantage of both high photon collection efficiency and improved charge carrier collection efficiency of detector 46.

Other embodiments within the invention will be apparent to those skilled in the art.

While we have shown and described for simplicity, a 50 mm by 50 mm device, our most preferred embodiment is a 250 mm by 250 mm device, each slit being the same width as in the embodiment shown and described, but five times as long, and there being 250 slits rather than fifty. Our most preferred detector is the semiconductor structure disclosed. Preferably after stepping through 180° our camera through a flyback returns to its initial position. In preferred embodiments slit length is at least ten times slit width; in our most preferred embodiments it is at least fifty times slit width.

While it might be thought, as it was by some to whom we initially disclosed our invention, that the increased flux available in each position with slits instead of holes would be an advantage neutralized by the increased number of positions required to be used, surprisingly this proved untrue, owing to improved signal to noise ratios, permitting increasing speed as well as resolution.

WHAT WE CLAIM IS:—

1. An instrument for obtaining positional source information which comprises: a slit collimator containing a multiplicity of slits for reception therein of beam components emanating from a source; each slit of said slits including an open end for orientation toward said source and slit-defining walls extending away from said source and from said open end; each said wall extending in the same longitudinal direction as the other walls; said wall including material of character and thickness to absorb those of said beam components impinging thereon; and said slits extending further in one transverse direction than in the other transverse direction; a detector for separately detecting beam components passing through said slits and for providing detection data output signals; said detector comprising a plurality of radiation transducing portions, each of said radiation transducing portions being correlated with, and positioned to close the end of, a respective slit opposite each said end; and a positioner simultaneously changing the transverse position of said slits and radiation transducing portions relative to said source; wherein each said radiation transducing postions is a photoconductor element.

2. An instrument as claimed in claim 1 wherein said radiation transducing portions are positioned at the base of said slit opposite said open end and are constituted as a continuous planar sheet of photoconductor material.

3. An instrument as claimed in claim 1 or 2 in which each said slit extends at least ten times as far in said one transverse direction as in said other transverse direction.

4. An instrument as claimed in claim 3 in which each said slit extends fifty times as far in said one transverse direction as in said other transverse direction.

5. An instrument as claimed in claim 1, 2, 3 or 4 in which said walls include gamma-radiation-absorbing material.

6. An instrument as claimed in any one of the preceding claims and further comprising processing circuitry including

an amplifier for amplifying said detection data output signals, and

an amplitude discriminator for transmitting said beam components having at least a minimum amplitude and discarding the rest.

7. An instrument as claimed in claim 6 in which said processing circuitry further includes means for accumulating the output signals amplified by said amplifier and transmitted by said discriminator.

8. An instrument as claimed in any one of the preceding claims in which said positioner is adapted to rotate said slits and radiation transducing portions.

9. An instrument as claimed in claim 8 in which said positioner includes a housing for said collimator, said housing including a tube, a plate rotatably mounted in said tube, and means for rotating said plate.

10. An instrument as claimed in claim 9 wherein said rotating means is an indexed motor adapted to rotate said plate in discrete angular steps.

11. An instrument as claimed in any one of the preceding claims wherein said walls of said collimator are made of tungsten foil.

12. An instrument as claimed in any one of the preceding claims wherein said collimator has from fifty to two hundred and fifty slits and said detector has an equal number of radiation transducing portions.

13. An instrument as claimed in claim 12 wherein said collimator has fifty slits and said detector has fifty radiation transducing portions.

14. An instrument as claimed in any one of the preceding claims wherein said photoconductor element is composed of cadmium telluride.

15. An instrument as claimed in any one of the preceding claims wherein said photoconductor element includes a pair of electrodes the planes of which are parallel to the walls of said collimator and the distance through said photoconductor in the depth direction of said slit is large with respect to the distance between said pair of electrodes.

16. An instrument as claimed in claim 15 wherein each said photoconductor element is positioned within one of said slits between said slit-defining walls.

17. An instrument as claimed in claim 15 or 16 wherein said distance through said photoconductor in the depth direction of said slit is no less than 5 mm and said distance between said pair of electrodes is no greater than 0.75 mm.

18. An instrument as claimed in any one of the preceding claims wherein said collimator includes a frame that is rectangular and composed of two opposite side pieces joined by a rod at each end thereof, said slit-defining walls being formed by sheets having holes at their ends for receiving a said rod through each end thereof.

19. An instrument as claimed in any one of the preceding claims wherein each said radiation tranducing portion is a strip.

20. An instrument as claimed in claim 19 wherein each said strip is made up of a plurality of detector crystals bonded together.

21. An instrument as claimed in claim 20 wherein said plurality of detector crystals are electrically insulated with respect to each other.

22. A device for detecting radiation substantially as hereinbefore described with reference to Figures 8 to 10 of the accompanying drawings.

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FIG 1

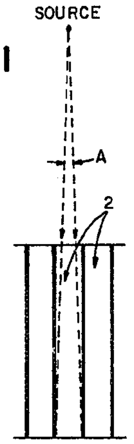


FIG 2

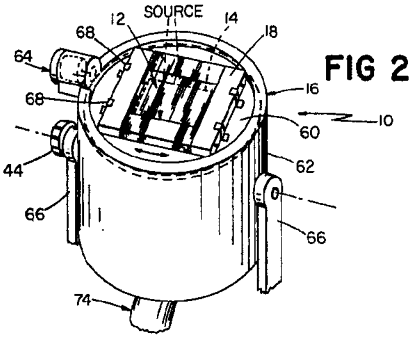


FIG 3

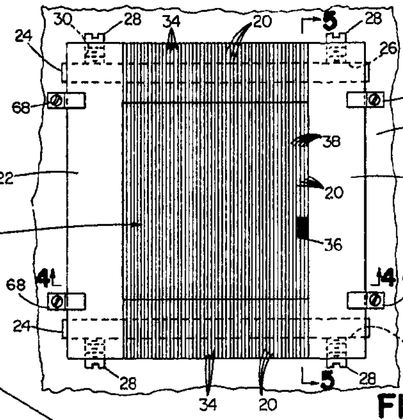
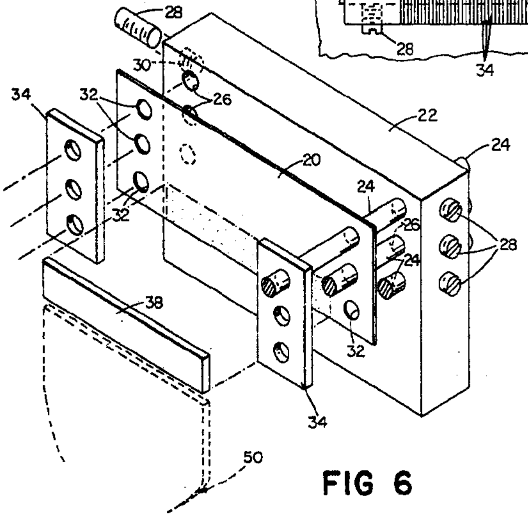
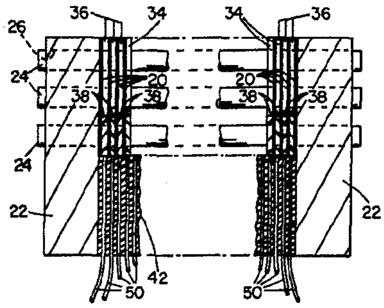


FIG 6





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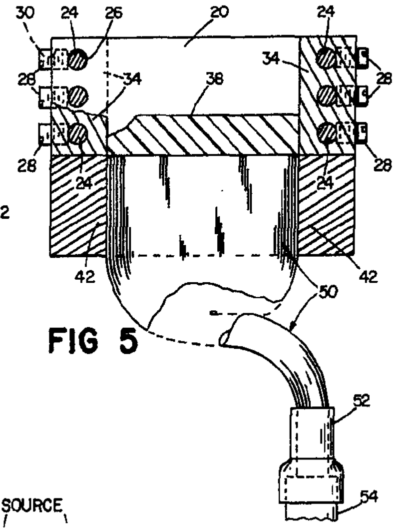
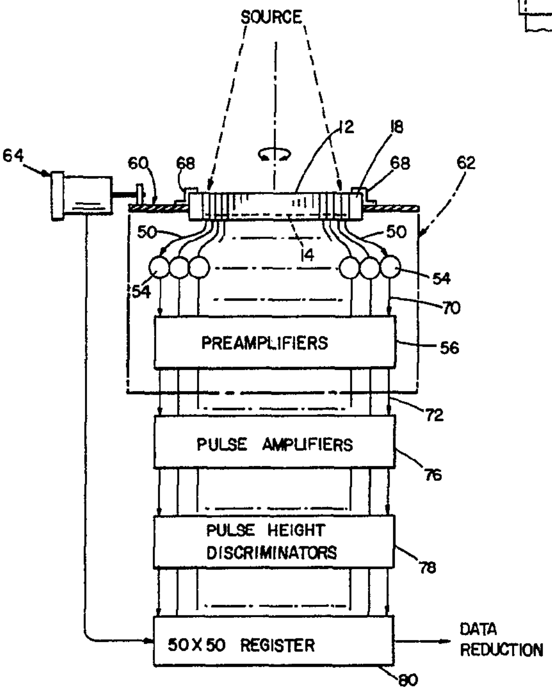


FIG 5

FIG 7



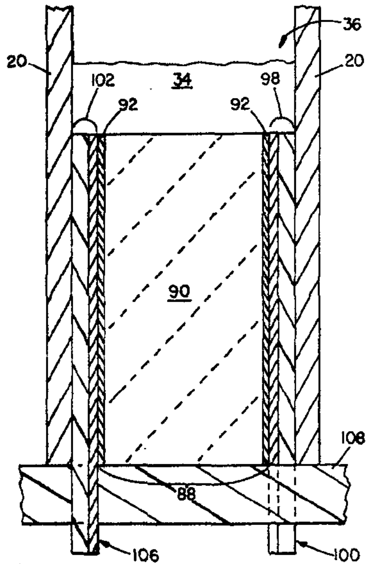


FIG 8

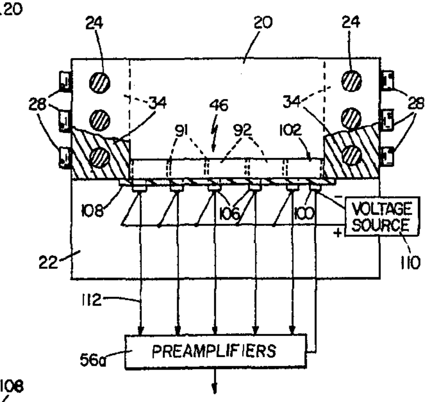


FIG 9

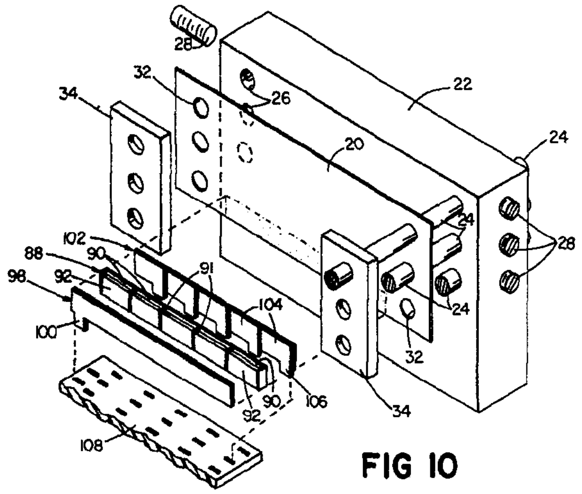


FIG 10