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PATENT SPECIFICATION

(11) 1 577 615

(21) Application No. 19681/76 (22) Filed 13 May 1976

(23) Complete Specification filed 27 April 1977

(44) Complete Specification published 29 Oct. 1980

(51) INT. CL.³ G01N 23/06

(52) Index at acceptance
H4F D12X D18X D27K D27M D30K D56X D61 D83B L

(19) THE PATENT OFFICE LONDON

(72) Inventor GODFREY NEWBOLD HOUNSFIELD

(54) IMPROVEMENTS IN OR RELATING TO RADIOGRAPHY

(71) We, E. M. I. LIMITED, a British company of Blyth Road, Hayes, Middlesex, 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:

The present invention relates to radiography, and it relates more particularly to that branch of radiography which has become known as computerised axial tomography, or briefly C.A.T. Apparatus for performing C.A.T. has the aim of producing a representation of the absorption coefficients, with respect to penetrating radiation, at a plurality of elemental locations distributed over a cross-sectional slice of a body under investigation. Such apparatus is disclosed and claimed in British Patent No. 1,283,915.

The technique of performing C.A.T. involves deriving signals indicative of the absorption suffered by penetrating radiation, such as X-radiation, on traversing many beam paths through the aforementioned slice of the body and in alignment with said slice. These signals are then processed to evaluate the aforementioned coefficients.

In order to project the radiation through the slice along the many beam paths referred to above, a source of one or more beams of the radiation is scanned, relative to the body, around the outside of the slice. If the source produces just one pencil-like beam of radiation, or if it produces a number of mutually divergent beams within a fan-shaped distribution of relatively small angular spread, such as 10°, it is usual for the scanning to consist of alternate lateral traverses, during which the source is scanned from one side to the other across the body, and rotational steps. Such scanning is described in more detail in the aforementioned British Patent No. 1,283,915 and in British Patent No. 1,478,124.

The present invention, however, has especial relevance to circumstances when more rapid scanning is desired, and the source is arranged to produce a fan-shaped distribution of radiation which has a considerable angular spread, such as 30° or more, so that the scanning can be effected by mere rotation of the source around the body, about an axis intersecting the aforementioned slice. The lateral scanning can be omitted because the angular spread of the distribution of radiation is sufficient to encompass at least a substantial part of the slice.

In order that signals indicative of the absorption suffered by the radiation on traversing each of said paths can be determined, it is necessary to detect the amount of radiation emergent from the body along each path. This can be done, for example, by means of an array of radiation detectors, distributed across the breadth of the distribution of radiation, disposed at the opposite side of the body to the source, and arranged to roate, with the source, around the body. The detectors are arranged to provide electrical output signals indicative of the amounts of radiation emergent from the body along the various beam paths; output signals relating to adjacent paths viewed by the same detector being segregated by periodic sampling, typically effected by reading and re-setting of integrator circuits to which the detectors are coupled. The reading and re-setting occurs at a rate which is considerably higher than that at which the source and detectors rotate around the body.

It will be appreciated that, in the above circumstances, each detector always receives radiation projected along a respective beam within the spread; the beams being equi-angularly spaced. As the source and the detectors are rotated relative to the body, each detector is repeatedly sampled at intervals which correspond to rotational movements corresponding to the inter-beam angle, and by this means a sequence of signals indicative of the absorption suffered by the radiation on traversing each of a group of beam paths is derived from each detector. The group of beam paths to which the signals derived from any one detector relate will not, of course, be parallel to one another; they will be angularly spaced from one another at substantially the aforementioned inter-beam angle. These paths are, however, characterised by having a common perpendicular distance to the axis of the rotational scan.

It is convenient to process the signals derived from all of the detectors by means of the technique of convolution described and claimed in British Patent No. 1,471,531 but this technique is most conveniently and accurately applied to output signals relating to sets of equally spaced, parallel beam paths.

The signals obtained as described above can be sorted into sets relating to parallel beam paths; it being appreciated that the signals of a set are all derived from different detectors and obtained at different times during the scanning. However these beam paths are not equally spaced and when it is desired to evaluate the aforementioned coefficients with high accuracy, it has been found necessary to allow for this lack of equal spacing, which arises because the perpendicular distances to the axis of rotation for the various detectors vary in a substantially sinusoidal fashion from the axis outwards; the paths being more closely spaced towards the edges of the region of interest than they are at the centre thereof.

The above-mentioned inequality of beam spacing occurs also when the detectors are not rotated, with the source, around the body under examination but instead are fixed and distributed around a circular path centred on said axis of rotation. More detectors are required in this case because instead of merely extending across the breadth of the fan-shaped distribution of radiation, it is necessary for the detectors to be sufficient to subtend an angle, at the said axis, of at least 180° plus the angle of the distribution of radiation. Preferably the detector array subtends a full 360° angle at said axis.

The object of this invention is to allow for the aforementioned inequality of beam spacing.

According to the invention there is provided computerised axial tomographic apparatus for examining cross-sectional slices of the bodies of patients, the apparatus including a source of a substantially planar spread of penetrating radiation, the radiation diverging in its plane as it moves away from the source and causing the spread to conform to a fan shape, scanning means for moving the source angularly around the edge of a body slice under examination to irradiate the slice from many positions distributed angularly therearound, detector means for detecting radiation projected across the slice from the source along a plurality of divergent, substantially linear paths from each of said positions, and for producing respective electrical output signals indicative of the amount of radiation detected in respect of each path, reordering means for reassembling said output signals in groups relating to sets of parallel paths at each of many orientations in the slice, neighbouring paths of each set being non-uniformly spaced apart, and processing means for operating on the reordered output signals to evaluate the absorption (or transmission) coefficients at each of many elemental locations distributed over the slice, wherein said processing means operates upon said sets of output signals as if neighbouring paths were uniformly spaced apart, to evaluate provisional coefficients for said elemental locations, a factor store is provided containing a correcting factor for each location to allow for errors introduced by processing the signals relating to non-uniformly spaced paths as if they related to uniformly spaced paths, and a multiplying circuit is provided for multiplying each provisional coefficient with its respective correcting factor.

In order that the invention may be clearly understood and readily carried into effect, some embodiments thereof will now be described with reference to the drawings accompanying the Provisional Specification of which:—

Figure 1 shows, in front elevational view, some of the components of the C.A.T. apparatus in which the only mechanical scanning movement is a rotational one, and shows how the aforementioned non-uniformity of spacing of parallel beam paths occurs, and

Figure 2 shows circuits for accepting output signals from the apparatus shown in Figure 1, and operating upon them in accordance with one example of the invention.

Referring now to Figure 1, a ring-like rotatable support structure 1, is mounted for rotation about an axis 2. The structure 1 comprises an annular member which can be rotated relative to a static main frame 3 by an electric motor 4. The motor 4 is mounted on the main frame 3 and drives a gear wheel 5 which co-operates with gear teeth (not shown) formed all around the inner periphery of the ring-like structure 1. The main frame 3 has an aperture 6 formed therein, the aperture 6 being concentric with the ring-like structure 1, and also supports a number of guides 7, 8, 9, 10 which act as bearings during rotation of structure 1 about the axis 2 and thus support the load of that structure; the guides 7 through 10 being also formed with flanges to limit fore-and-aft movement of the structure 1.

The structure 1 supports an X-ray tube 11, arranged to produce a planar fan-shaped distribution 12 of X-radiation, and a bank 13 of detectors, the detectors being sensitive to said radiation and being distributed across the breadth of the distribution 12. The individual detectors, which may comprise thallium activated sodium iodide crystals, are numbered 13_1, 13_2 . . . . 13_5; only five detectors being shown in this case for clarity, although more typically, for a fan-shaped distribution of angle 40° as shown, 120 detectors would be used, adjacent detectors being angled at 1/3° to each other. Each detector in the array 13 views the radiation source 11 through a respective collimator 14 so as to reduce the amount of scattered radiation received by the detectors and thus each detector receives radiation along a respective beam 15 in the distribution 12; the beams being indicated in the drawing by their centre lines, although it will be appreciated that the beams are actually of finite width as determined by the collimator and detector dimensions. It will also be appreciated that, in this example, and prior to its incidence upon the collimators 14, the distribution 12 is continuous across its breadth. This need not be the case, however, and the radiation distribution could, if desired, be sectioned up into beams prior to its incidence on the body.

The body 16 to be examined is supported on a bed 17 and held firmly thereon by means of a strap 18 secured to the sides of the bed. Packing material 19 is inserted in gaps between the body and the bed in order to reduce, so far as is possible, the entrapment of air between the patient and the bed. The material 19 is preferably contained in one or more flexible bags and absorbs the radiation to an extent similar to human body tissue. The bed is supported on either side of the main frame 3; one of the supports being shown at 20. It will be appreciated, of course that the aperture 6 in the main frame 3 must be sufficiently large to enable the body 16 to be positioned as required relative to the distribution 12.

As will be seen, when the structure 1 is in the position shown in the drawing, so that the source 11 projects the distribution 12 through the body from the direction indicated in solid lines, and each of the beams 15 traverses a respective path through the body 16, and the corresponding detector 13 provides an output signal indicative of the absorption suffered by the radiation on traversing the relevant path. In practice, an output signal relates not to a beam as irradiated from a single point, but to a broader beam path irradiated during rotation of the structure 1 through a finite angle. This matter, however, will be ignored henceforth, because it is not relevant to the understanding of the invention, and it will be assumed that the output signals relate to beam paths irradiated at unique angular positions of the structure 11.

It will be observed that the various beams 15, and consequently the corresponding beam paths through the body, diverge from one another at equal angles and so the group of output signals obtained in any one position of the structure 1 do not relate to a parallel set of beam paths.

If the structure 1 is rotated through an angle corresponding to the angle between adjacent beams 15, so that the swath 12 assumes the position indicated by dotted lines, then the beams 15 will irradiate a new group of beam paths through the body 16. In this case, the beam path $15_2'$ viewed by detector 13_2 from its new position is parallel with the beam path 15_1 which was viewed by detector 13_1 in its original position. Likewise the path $15_3'$ which was viewed by detector 13_3 in its new position is parallel to the path 15_2 viewed by detector 13_2 in its original position, and so on. Further rotational movement of the structure 1 about the axis 2 causes the various detectors to provide output signals relating to beam paths parallel to paths for which output signals have previously been provided by other detectors. Typically the angular movement of the structure 1 takes place through an angle which substantially equals or exceeds the sum of 180° and the fan angle; the object being to obtain signals relating to sets containing equal numbers of parallel beam paths, the sets being uniformly distributed in angle over 180°.

As the mechanical movement is purely rotational, however, the beam paths of a parallel set are not uniformly spaced across the irradiated region of the body. This can be seen by comparing the perpendicular distance from the axis 2 to two parallel beam paths as irradiated by beams 15_1 (detected by detector 13_1) and $15'_2$ (detected by detector 13_2), the structure 1 having rotated through an angle corresponding to the inter-beam angle between the irradiation of the two beam paths. If the distance from the point source of x-rays, within tube 11, to the axis 2 is designated r, and if the inter-beam angle is 10°, then the perpendicular distances from axis 2 to beams 15_1 and $15_2'$ respectively are $r \sin 20°$ and $r \sin 10°$ respectively. Since the third beam of the parallel set in question will pass through the axis 2 and be detected by detector 13_3 after the structure 1 has rotated through a further 10°, it will be seen that the values $r\sin 10°$

and r(sin 20° – sin 10°) represent the distances between respective pairs of beam paths in a parallel set and that these distances are not equal. Clearly the same thing will happen for beam paths on the other side of the axis 2 to those irradiated by beams 15_1 and $15_2'$, and clearly also the non-uniformity of distance will be the same for all parallel sets of beam paths. For a fan angle of 40°, the overall departure from uniformity of spacing amounts to some 3% and, if it is desired to use a processing technique of the convolution kind described and claimed in the aforementioned British Patent No. 1,471,531, and if it is desired to evaluate the aforementioned absorption coefficients with high accuracy, this departure should be allowed for. Figure 2 indicates one way in which this can be achieved.

In Figure 2 there are shown blocks 20_1, $20_2 \ldots 20_5$ which represent photomultiplier tubes disposed to receive the light output from respective ones of the detectors 13 (see Figure 1). Each photomultiplier feeds a respective pre-processing circuit 21, of which only the circuit 21_1, associated with photomultiplier 20_1, is shown in detail since the others are all the same.

The circuit 21_1 comprises four components, namely an amplifier 22_1, an integrator 23_1, an analogue-to-digital converter 24_1 and a logarithmic converter circuit 25_1; all of these circuits being of conventional construction. The integrators such as 23_1 are all read and reset periodically, at times related to the rotation of the structure 1 (Figure 1) through the inter-beam angle. As mentioned previously, in the simplified example shown the inter-beam angle is 10°, but a more realistic inter-beam angle, as used in practice, is 1/3°. The integrators are read and reset by timing pulses generated in known manner by the progress of graticule markings carried by the structure 1 (Figure 1) past a fixed photocell and detector unit (not shown).

The signals issuing from the pre-processing circuits 21 are applied to a random access digital store 26, whence they can be derived, under the influence of timing pulses generated by a main timing circuit 27, in groups relating to parallel sets of beam paths. These paths, as has been established, are not equally spaced apart, but nevertheless the groups of signals relating thereto are applied to a convolution processing circuit 28, which is of the kind described and claimed in British Patent No. 1,471,531, and which processes the groups of signals as if they did relate to uniformly spaced sets of parallel beam paths. Thus absorption coefficients are evaluated which are applicable to various locations distributed over the examined slice of the body 16, though these evaluated coefficients are potentially in error because no account has been taken of the aforementioned non-uniformity of beam path spacing.

In accordance with this example of the invention, the body 16 is replaced by a phantom having a known absorption coefficient at each of the locations corresponding to the locations for which evaluation is effected by the apparatus. The phantom is scanned by the apparatus, as previously described, and the circuit 28 evaluates the absorption coefficients applicable to the various locations distributed over the phantom. The evaluated coefficient for each location is compared with the known coefficient for that location to ascertain, for each location, a multiplying factor which, when multiplied by the evaluated coefficient for the location, equals the known coefficient for that location. The multiplying factors so evaluated are stored in a digital store 29 and are used when the apparatus scans a real body to compensate for the errors mentioned above. The store 29 is controlled by the main timing circuit 28 and is effective to apply the multiplying factors, in a predetermined sequence, to a multiplying circuit 30 with correct timing to multiply the evaluated coefficients relating to the respective locations. The corrected coefficients are applied to a visual display device 31, such as a cathode ray tube with facilities for photographing the image displayed thereon, and to a long term store 32, such as a magnetic tape or disc store. Usefully, the device 31 contains means of known kind for varying the mean level and/or the dynamic range of signals displayed thereby.

The invention may also be applied to apparatus of the kind described in British Patent No. 1,529,799 or in British Patent application No. 43984/75 (Serial No. 1 558 062) in which, in addition to the rotational mechanical motion imparted to the source and detectors, the x-ray tube contains means for deflecting the electron beam thereof over an elongated anode so as to effectively provide a limited (e.g. 2.5 cm to 10 cm) translational movement of the spread 12 of radiation relative to the body.

If required, as mentioned in the introductory paragraphs of this specification, the detectors 13 need not participate in the rotational movement, but instead they may be fixed and distributed around a more extensive circular path centred on the axis 2. Typically, the circular path is of large enough diameter to permit tube 11 to rotate inside it.

The phantom preferably is constructed of material, such as that known by the Registered Trade Mark "Perspex", having similar absorption properties to the mean absorption of human tissue. The phantom may be constructed to have substantially constant absorption over the whole of the cross-sectional slice thereof which is irradiated. Alternatively, the phantom may comprise annular bands of different radii and different absorption characteristics, the bands being arranged contiguously with one another to form a continuous body.

The correction effected by means of the invention constitutes, in effect, a post-processing redistribution of beam paths. It will be appreciated that the magnitudes of the errors, due to the non-uniformity of beam path spacing, which would otherwise occur would not constitute gross misalignment of true beam paths with those assumed for the purposes of processing, but that the errors could affect the evaluation of absolute absorption coefficients over part at least of the body slice.

It will be appreciated, of course, that the aforementioned redistribution is based on the measurements taken from the phantom and thus does not allow for any differences in absorption which may occur between paths of the original, non-uniformly spaced sets and adjacent paths of the uniformly spaced sets during examination of a human patient.

WHAT WE CLAIM IS:—

1. Computerised axial tomographic apparatus for examining cross-sectional slices of the bodies of patients, the apparatus including a source of a substantially planar spread of penetrating radiation, the radiation diverging in its plane as it moves away from the source and causing the spread to conform to a fan shape, scanning means for moving the source angularly around the edge of a body slice under examination to irradiate the slice from many positions distributed angularly therearound, detector means for detecting radiation projected across the slice from the source along a plurality of divergent, substantially linear paths from each of said positions, and for producing respective electrical output signals indicative of the amount of radiation detected in respect of each path, reordering means for reassembling said output signals in groups relating to sets of parallel paths at each of many orientations in the slice, neighbouring paths of each set being non-uniformly spaced apart, and processing means for operating on the reordered output signals to evaluate the absorption (or transmission) coefficients at each of many elemental locations distributed over the slice, wherein said processing means operates upon said sets of output signals as if neighbouring paths were uniformly spaced apart, to evaluate provisional coefficients for said elemental locations, a factor store is provided containing a correcting factor for each location to allow for errors introduced by processing the signals relating to non-uniformly spaced paths as if they related to uniformly spaced paths, and a multiplying circuit is provided for multiplying each provisional coefficient with its respective correcting factor.

2. Apparatus according to Claim 1 wherein said detector means comprises an array of detectors extending across said fan-shaped distribution of radiation and mounted so as to partake in said angular movement with said source.

3. Radiographic apparatus including compensating means substantially as herein described, with reference to Figure 2 of the drawings filed with the Provisional Specification.

4. A method of examining a body by means of penetrating radiation comprising the steps of:

a) irradiating a cross-sectional slice of the body, from each of many locations distributed angularly around the slice, with radiation projecting across the slice, and in the plane thereof, along a group of mutually divergent and substantially linear beam paths,

b) detecting the radiation emergent from the body along each of said paths,

c) generating electrical signals indicative of the absorption suffered by the radiation on traversing each of said paths,

d) reordering the output signals so that they relate to sets of parallel paths, each set including paths distributed, with non-uniform spacing, across the slice and the paths of each set being disposed at a respective orientation, with respect to the body, in said slice,

e) processing the reordered output signals to produce a first approximation to the absorption (or transmission) coefficients of the elements of a two-dimensional matrix notionally delineated in said slice, the processing being effected as though the paths of each of said sets were distributed with uniform spacing across the slice, and

f) multiplying the first approximations to the coefficients of each of said elements by a respective correcting factor to allow for the fact that the paths of said sets are distributed with non-uniform spacing across said slice to produce a second approximation to the corresponding coefficients of each of said elements;

the correction factors being determined by performing steps (a) to (e) with the body slice replaced by a phantom, the absorption (or transmission) coefficients of which at each element thereacross are known, and comparing the first approximation to the coefficient for each element evaluated in respect of the phantom with the known value for that element of the phantom.

R. G. MARSH,
Chartered Patent Agent,

Agent for the Applicants.

Printed for Her Majesty's Stationery Office by The Tweeddale Press Ltd., Berwick-upon-Tweed, 1980. Published at the Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from which copies may be obtained.

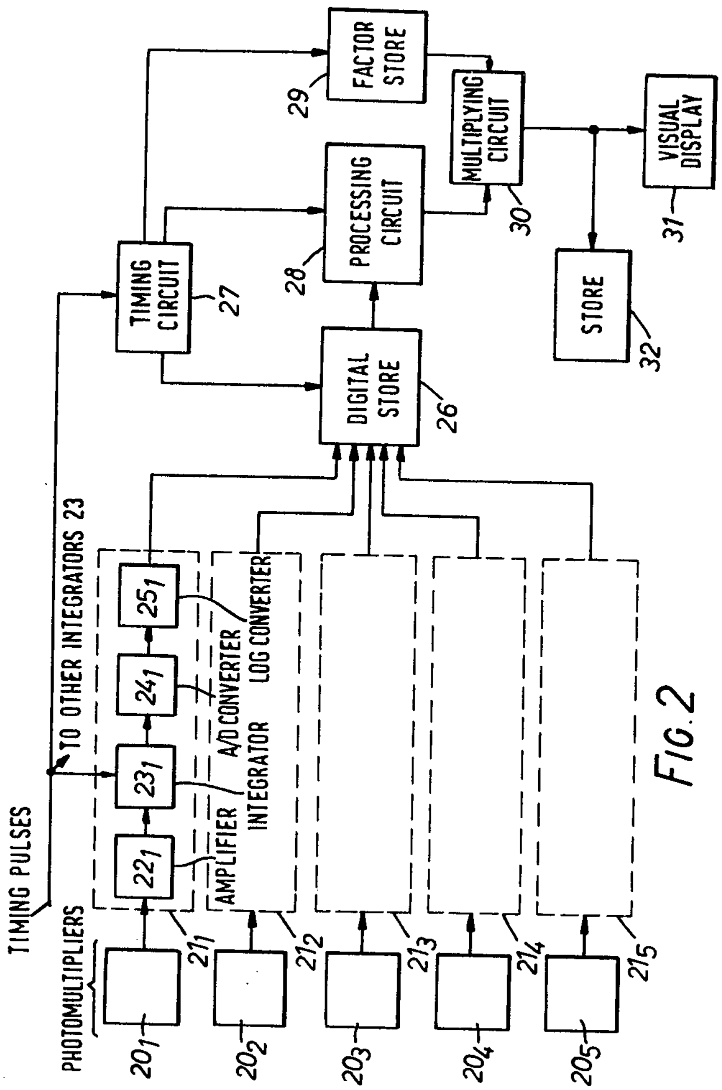
TIMING PULSES
TO OTHER INTEGRATORS 23
PHOTOMULTIPLIERS
AMPLIFIER
INTEGRATOR
A/D CONVERTER
LOG CONVERTER
TIMING CIRCUIT
DIGITAL STORE
PROCESSING CIRCUIT
FACTOR STORE
MULTIPLYING CIRCUIT
VISUAL DISPLAY
STORE
26
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FIG. 2

1577615 PROVISIONAL SPECIFICATION

2 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 2

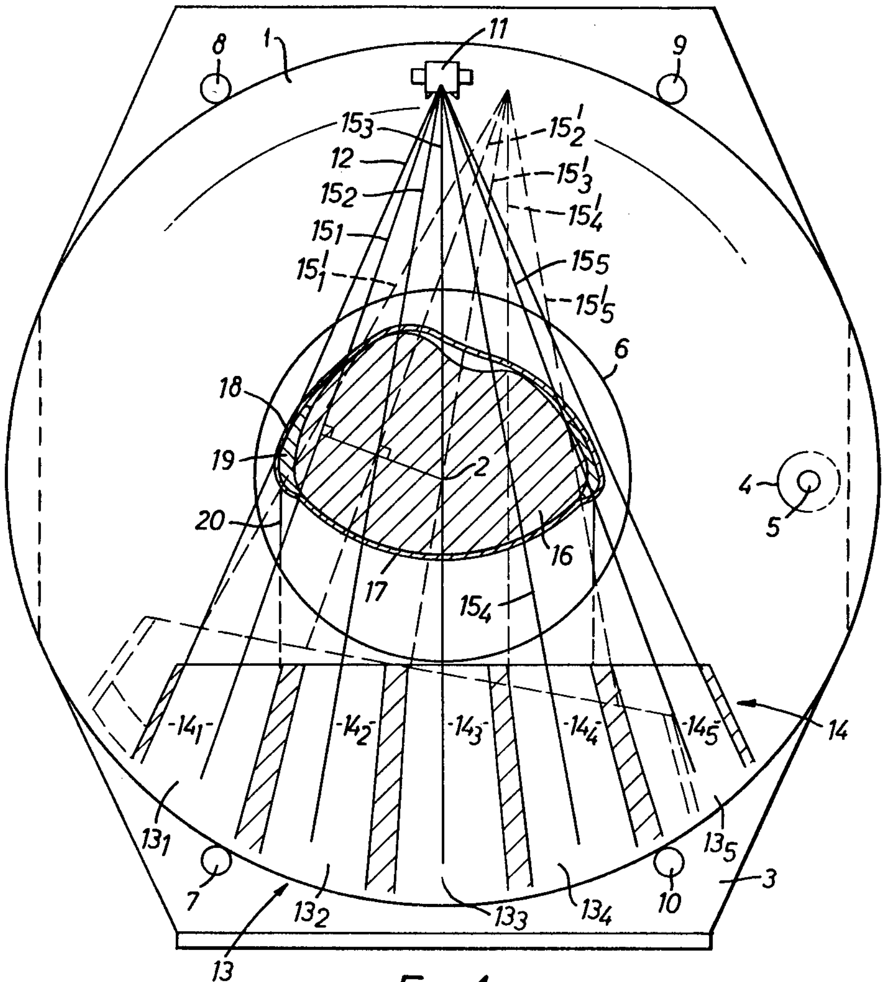

FIG. 1