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(56) Documents Cited:
EP 1121957 A2 **EP 0814869 A**
WO 2003/008986 A2 **WO 1999/032189 A1**
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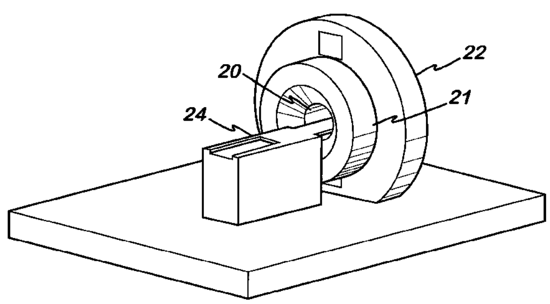
Other: **Online: EPODOC, WPI, PAJ.**

(54) Abstract Title: **MRI in guided radiotherapy and position verification**

(57) A magnetic resonance imaging (MRI) system 21 is integrated with a linear accelerator 22 in order to provide target position verification in radiotherapy. In one embodiment the MRI system 21 includes a magnetic field compensator means to adapt the magnetic field to provide minimal magnetic field strength at the location of the accelerator, so as to minimise the influence of the magnetic field on the particles emitted by the accelerator. An alternative embodiment provides a filter to compensate for any heterogeneity in the particle beam caused by the MRI magnetic field. Both the magnetic field compensation means and particle beam filter may be provided. The linear accelerator may include an X-ray gun for the production of X-rays for irradiation therapy. Figure 1 shows an open ring arrangement of the apparatus.

Fig. 2



At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

This print takes account of replacement documents submitted after the date of filing to enable the application to comply with the formal requirements of the Patents Rules 1995

Fig. 1

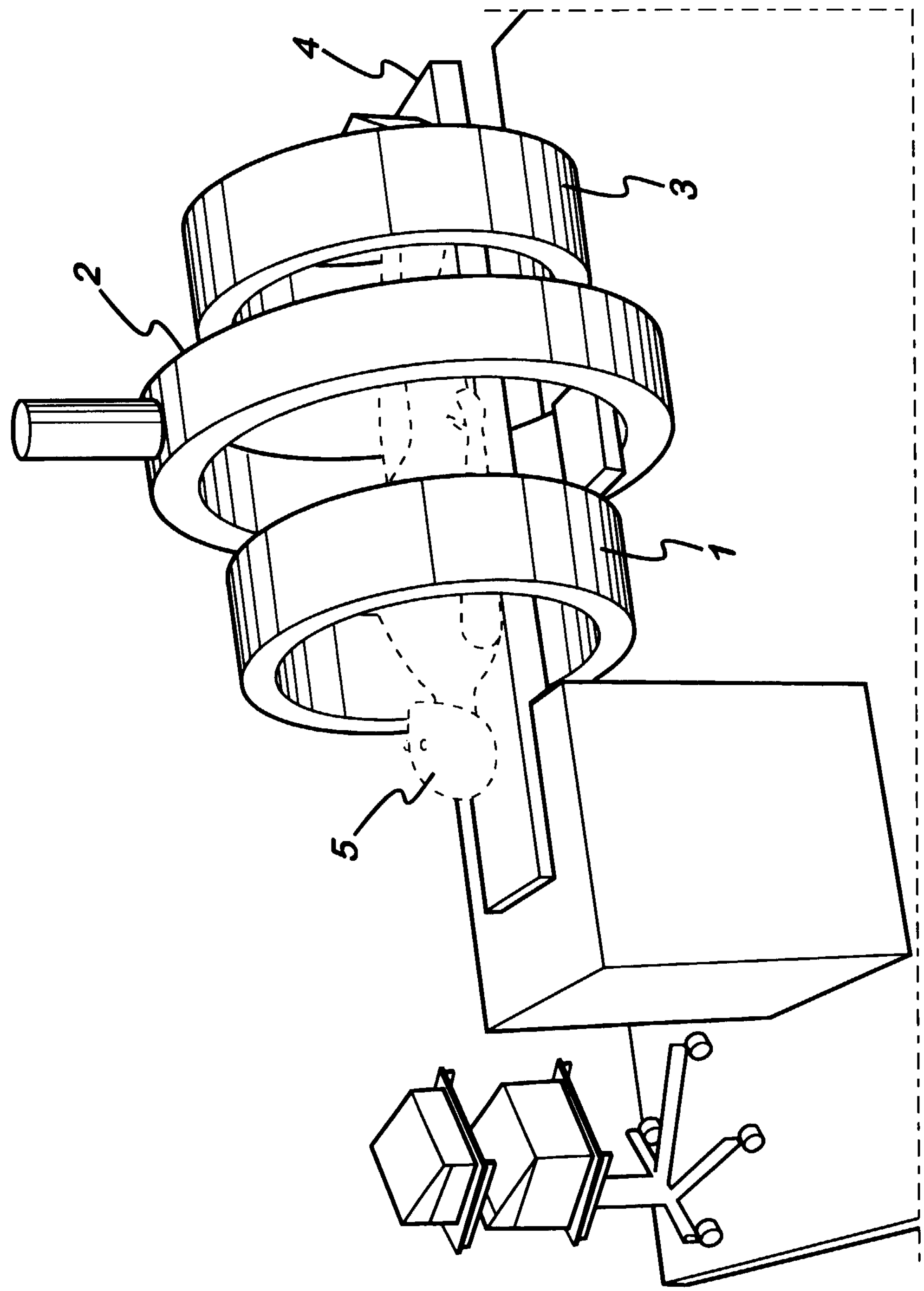


Fig. 2

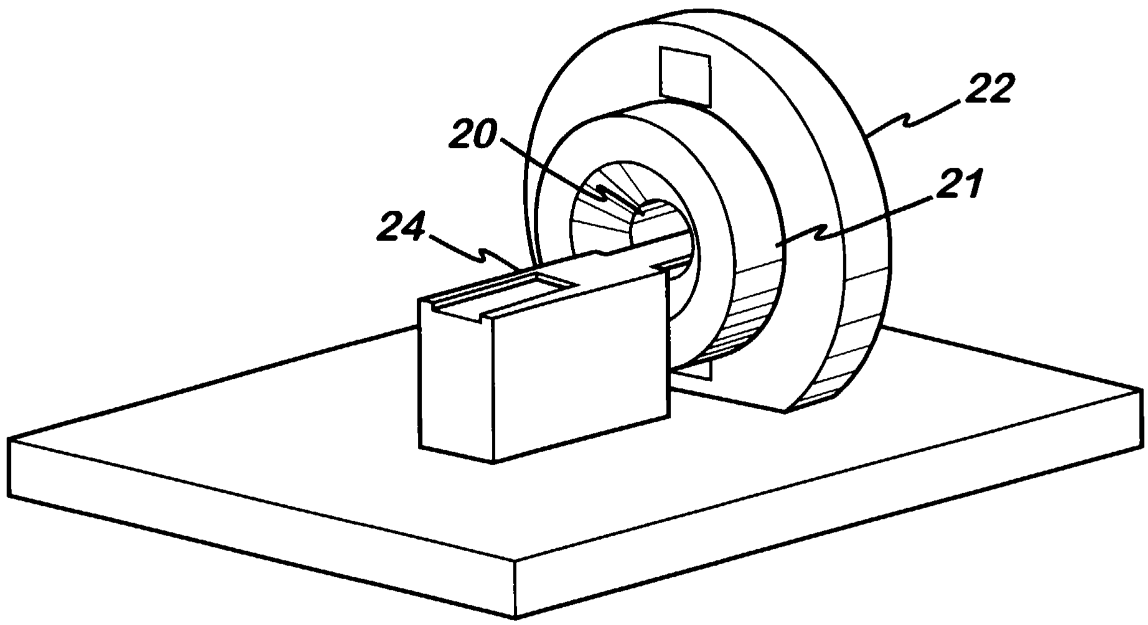


Fig. 3

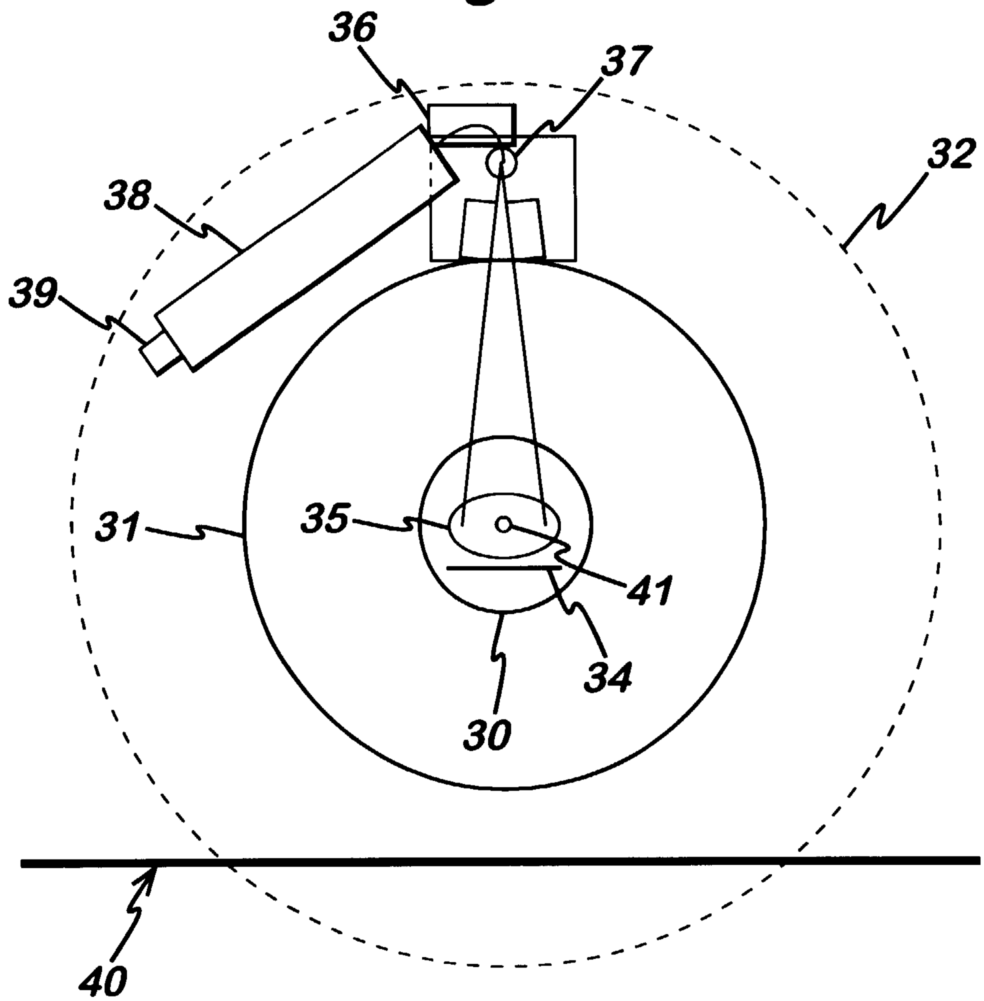


Fig. 4a

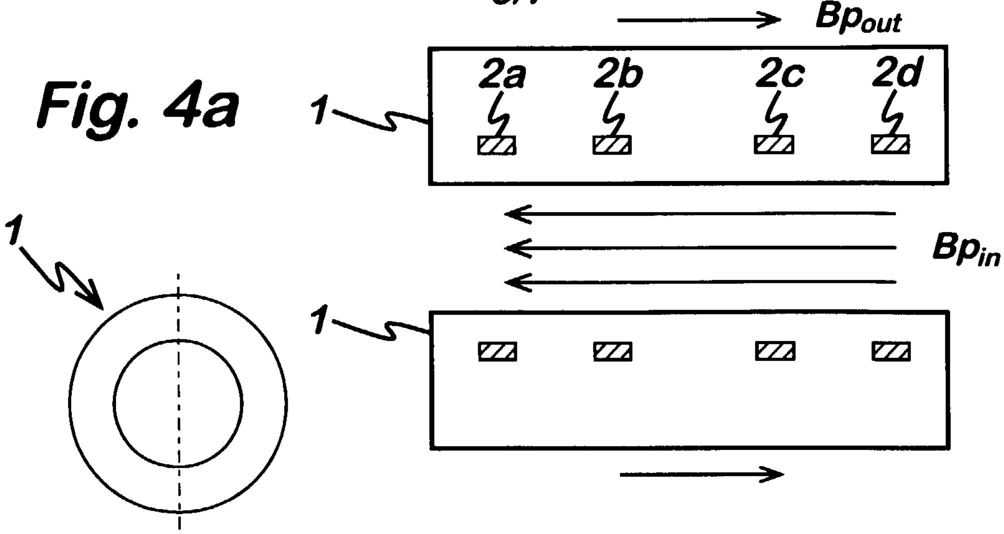


Fig. 4b

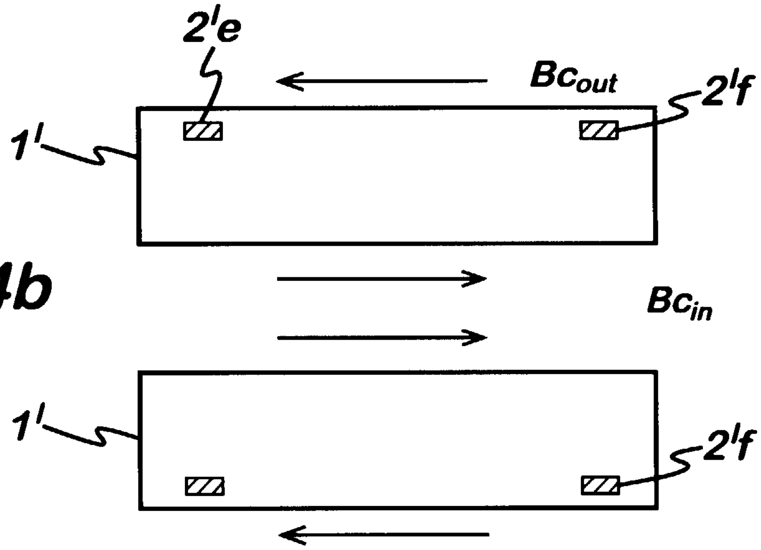


Fig. 4c

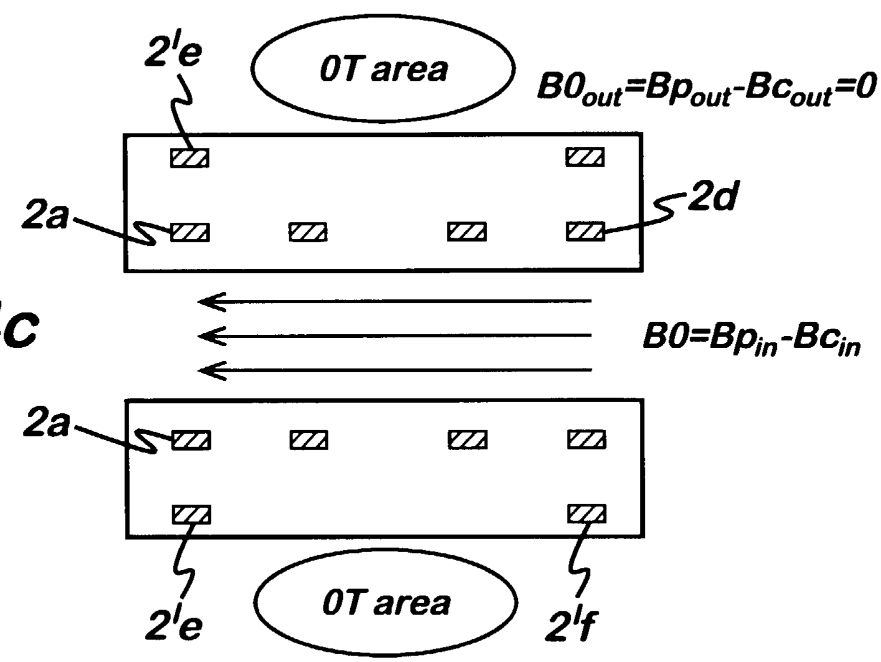


Fig. 5

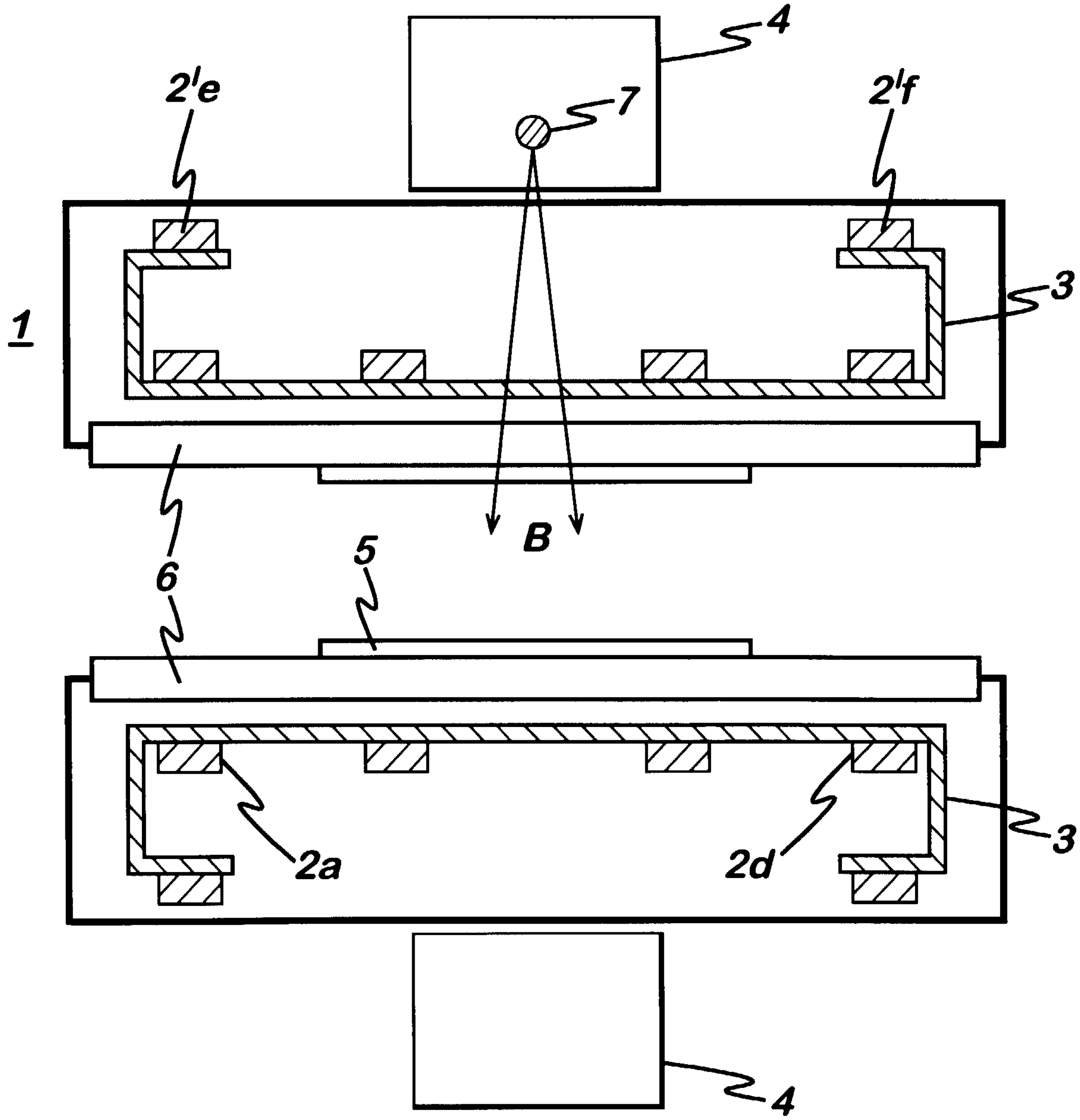


Fig. 6

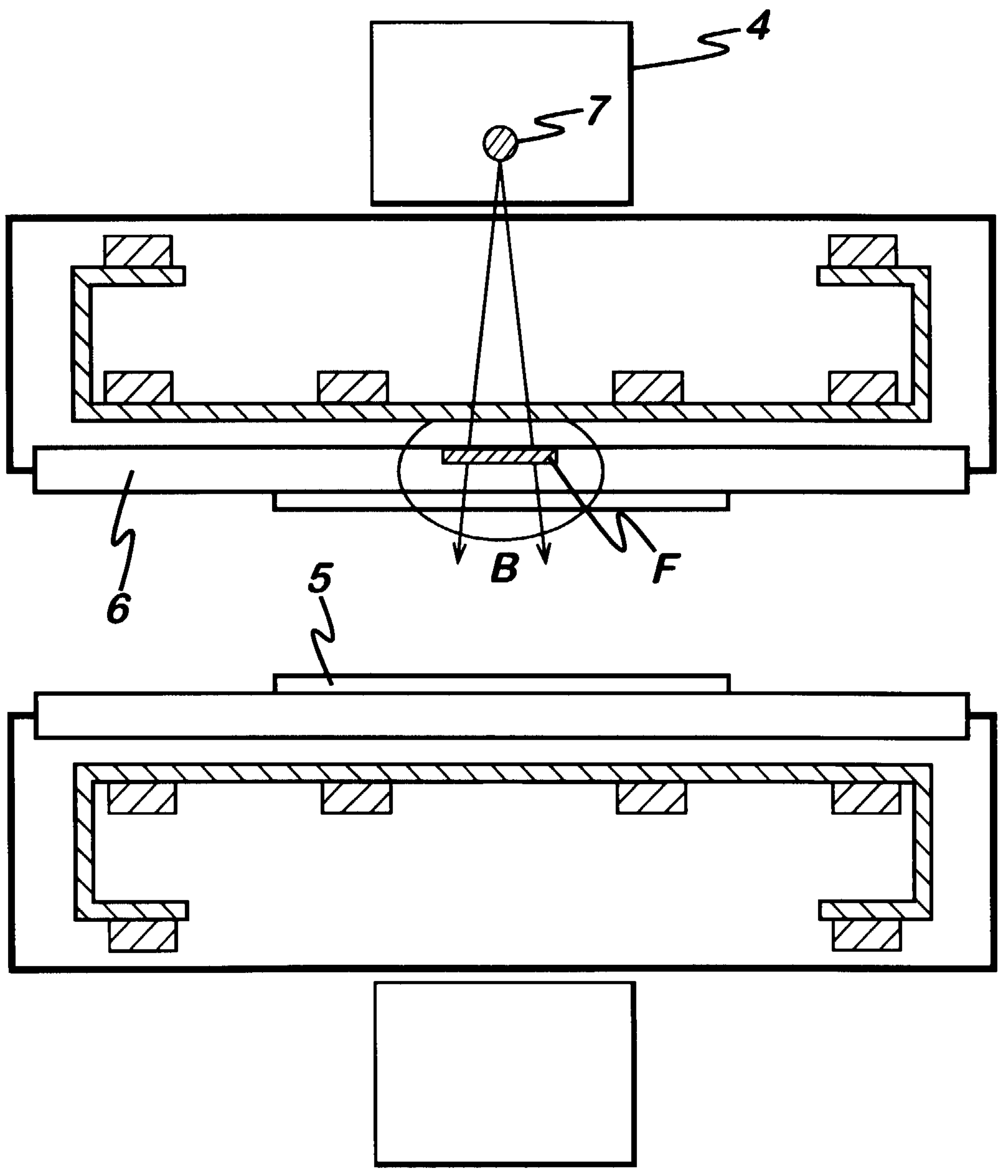


Fig. 7

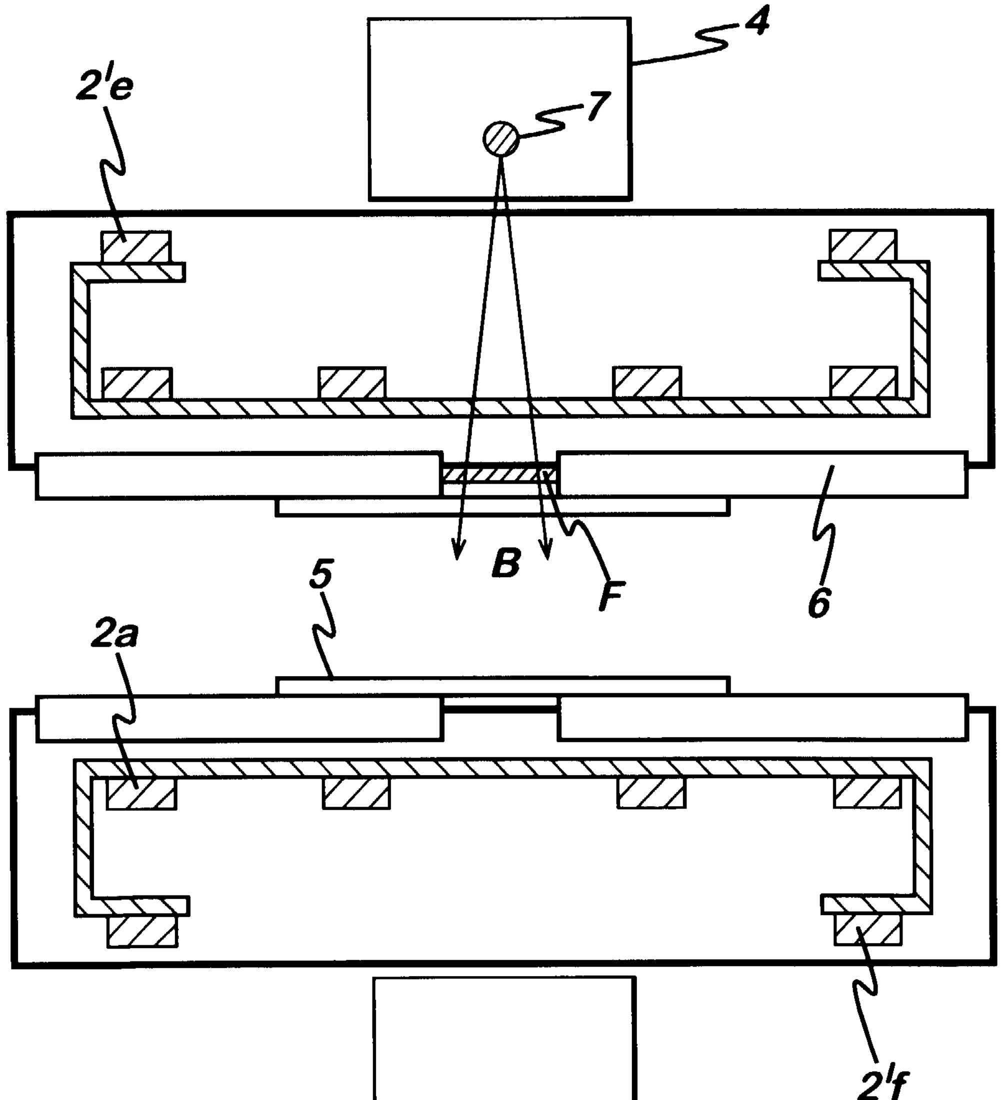
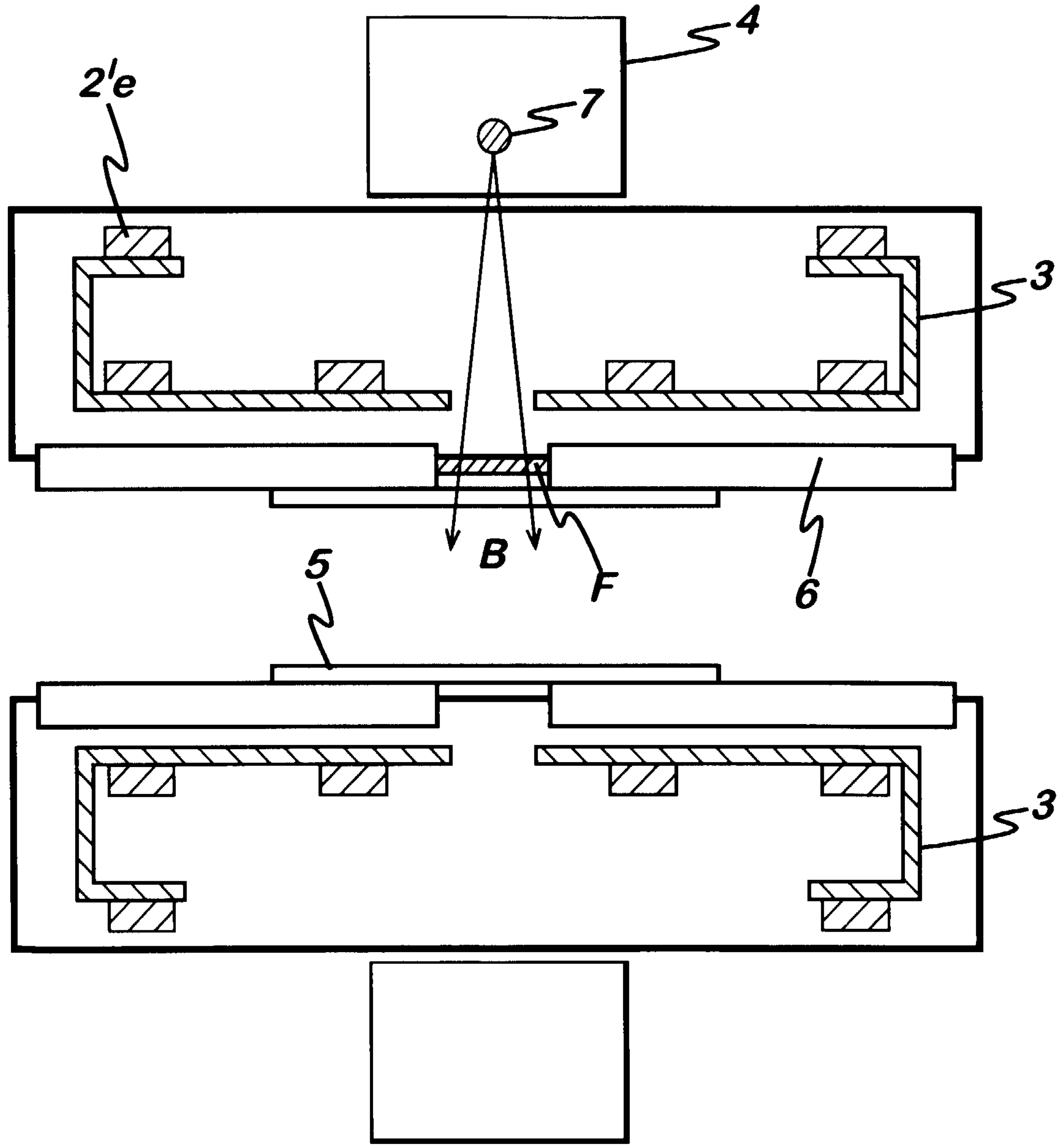


Fig. 8



MRI IN GUIDED RADIOTHERAPY AND POSITION VERIFICATION

This invention relates to improvements in radiotherapy techniques and position verification in radiotherapy. In particular, the invention relates to the use of Magnetic Resonance Imaging (MRI) in radiotherapy and position verification.

Existing radiotherapy treatments are commonly carried out by means of a linear accelerator which bombards cancerous tissues with high energy X-rays or electron beams to inhibit growth and spreading of the malignant tissues. An essential parameter monitored in existing radiotherapy treatments is the exact daily position and extension of the target volume of tissue, including variations in position and size both during the treatment session and throughout the whole treatment course. Tumour control probability analyses indicate that dose escalation, which can be performed in case of an exactly known tumour position, may greatly enhance tumour control.

Present treatment position verification systems are based on external markers made on the body surface and/or on megavoltage imaging which produces low quality images particularly of bony structures. As a result, the daily position of soft tissues (tumours) cannot easily or accurately be verified. For instance, the internal position uncertainty of lung, prostate, cervical, and oesophageal tumours currently results in too large treatment fields.

In a limited number of special cases the positioning problems can be solved with invasive radio opaque markers inside the tumour, which are visible on amorphous silicon flat panel megavoltage imaging. One example of such markers is gold seeds of 1.0 mm diameter and 5 mm length used for prostate position verification as reported by Nederveen et al in Phys. Med. Biol. 46(4), 2001, 1219-30.

Another known approach to position verification is CT. Major disadvantages of the use of integrated CT for daily radiotherapy position verification are the inherent slow data acquisition (gantry rotation), the inferior soft-tissue visibility and the 2D, transversal slide, imaging.

MRI is commonly used in the 3 dimensional imaging of soft tissues such as the brain and spinal cord to detect abnormalities without the need to expose the subject to harmful radiation such as X-rays.

Co-pending International Patent Application PCT/GB2002/03339 discloses a radiotherapy apparatus comprising a magnetic resonance imaging device integrated with
a linear accelerator.

This invention aims to improve upon the concept described in PCT/GB2002/03339 and to provide an apparatus having improved properties over that disclosed therein.

In accordance with a first aspect the invention provides a radiotherapy apparatus comprising a magnetic resonance imaging device integrated with a linear accelerator wherein a B-field compensator means is associated with the magnetic resonance imaging device which, in use, adapts the B-field produced by the magnetic resonance imaging device in the vicinity of the linear accelerator thereby to minimise the influence of the B-field on the particles emitted by the accelerator.

It will be understood that a magnetic resonance imaging device (MRI) typically comprises a large ring shaped magnet, typically comprised of electromagnetic coils wound on a core of magnetisable material. Where the coils are arranged closer to the inner surface of the ring, than the outer surface, the B-field (Bp_{in}) at the centre of the magnet is substantially greater than that (Bp_{out}) at the outer surface of the ring and directed in an opposing direction. In such an arrangement, the B field of the unadapted magnet (Bp) can be compensated by the introduction of additional coils of opposing polarity. For example, these additional coils may be placed in alignment with one or more existing coils of the MRI at a position closer to the outer surface of the ring. The result of these added coils is to create a compensation field (Bc) at the outer and inner surfaces of the ring consisting of an outer field Bc_{out} and an inner field Bc_{in}. The compensated field (B0) resulting from the adapted MRI is consequently composed of an outer field equal to $Bp_{out} - Bc_{out}$ and an inner field equal to $Bp_{in} - Bc_{in}$. By suitable choice of size and position of the additional coils, the compensated field B0 can be controlled. Desirably, the coils are selected and positioned so as to produce an area of zero (or minimal) Tesla in the region about the MRI where the particle source of the linear accelerator is to be located.

It is well known that whilst slow moving charged particles (such as electrons) emitted from a source in a linear particle accelerator are quite adversely affected by a magnetic field, faster moving particles such as those exiting the accelerator tube are much less so affected. Consequently, the inventors have found that by suitable compensation of the field produced by a conventional MRI, it is possible to maintain accuracy of targeting of a subject located in the $B0_{in}$ field of the compensated MRI with the linear particle accelerator, whilst maintaining sufficient a strength of the $B0_{in}$ field to enable magnetic resonance imaging of the subject to be done either simultaneously with, or independently of, the operation of the linear accelerator.

In one embodiment (which will be described in more detail later in this specification) the compensator means is selected and positioned such that the compensation field Bc_{out} at the outer surface of the magnetic ring of the MRI is approximately equal, but oppositely directed to the field Bp_{out} of the uncompensated magnetic ring providing an area of substantially zero Tesla in or near to which the particle source of a linear particle accelerator can be positioned.

In a second aspect the invention provides a radiotherapy apparatus comprising a magnetic resonance imaging device integrated with a linear accelerator wherein the particle source of the linear accelerator is positioned a fixed radial distance from the subject to be targeted and has associated therewith a compensation filter for compensating heterogeneity of the beam induced by the magnetic resonance imaging device, thereby to provide a substantially homogenous beam at the target to be treated.

This second aspect may be used in conjunction with the first aspect to provide an improved system, or it may be used independently thereof.

The inventors have recognised that the physical construction of an MRI can affect the beam quality of a linear accelerator. The inventors have found that deterioration of beam quality can be corrected by suitable positioning of the accelerator and the introduction of a compensation filter. A preferred arrangement has been found to comprise positioning the accelerator at a fixed radial position outside of the solenoid drum of an MRI and positioning a compensation filter in radial alignment with the accelerator, on an inner surface of the solenoid drum, that is adjacent the centre space reserved for receiving the target. The characteristics of the compensation filter are defined by first measuring the heterogeneity induced in the accelerator beam by the structure of the MRI. The filter is designed to introduce heterogeneity which, when added to the heterogeneity introduced by the active MRI, results in a substantially uniform radiation field.

The compensation filter may, optionally, be used in conjunction with intensity modulation techniques to further reduce the incidence of radiation scatter in the beam.

In a further option, the gradient coils of the drum of the MRI may be split to provide a gap through which the beam emitted by the linear accelerator may pass. This adaptation to a standard drum arrangement has been found to significantly reduce attenuation of the beam and result in a lower incidence of beam scattering. Furthermore it reduces the copper content of the gradient coils (for example by replacement of 3cm copper with 6cm epoxy, the latter of which provides a more homogeneous transmission of the linear accelerator beam) thus reducing the number of items to be compensated for by the compensation filter rendering the compensation task more simple. This splitting of the gradient coils has been found to have no significant debilitatory affect on the performance of the MRI.

In order that the beam produced by the linear accelerator may always be accurately compensated for, the rotatable gantry on which the accelerator is mounted is desirably configured to have a plurality of fixed locating positions for the accelerator all having a fixed radial distance from the target. Spaces in the gradient coils and compensation filters can then be positioned in the non-moving MRI to align with each of the fixed locating positions of the accelerator.

Desirably there is provided an odd number of fixed locating positions for the accelerator. Preferably these positions are equally spaced apart about the circumference of the MRI. Preferred numbers of fixed locating positions are 7, 9 or 11. In a preferred embodiment, the number of fixed locations is 11 each spaced at an angle of about 33 degrees from the two adjacent positions.

In order to further reduce the size and weight of the integrated MRI and linear accelerator system, the support structure of the MRI may optionally have material removed adjacent the fixed locating positions of the accelerator. This further simplifies the task for the compensation filter. It has been found that the size (including the radius of the gantry which carries the linear accelerator) and weight of the integrated system can be further reduced by removing material from the cryostat (for example from 4cm Aluminium to 2cm Aluminium).

For the purposes of clarification and exemplification, some embodiments of the invention will now be further described with reference to the following drawings in which:

Figure 1 illustrates schematically an open ring type embodiment of the invention;

Figure 2 illustrates schematically a closed drum type embodiment of the invention;

Figure 3 illustrates in further detail an embodiment of the type shown in Figure 2;

Figure 4 illustrates the B fields of a) a standard MRI as known from the prior art; b) a compensation field produced by compensations means in accordance with the second aspect of the invention; and c) the resultant field of an MRI compensated by compensation means in accordance with the invention;

Figure 5 illustrates an embodiment of the invention incorporating compensation means in the form of additional electromagnetic coils;

Figure 6 illustrates the embodiment of Figure 5 further incorporating a compensation filter;

Figure 7 illustrates the embodiment of Figure 5 further incorporating a split gradient coil;

Figure 8 illustrates the embodiment of Figure 7 further incorporating gaps in the support structure.

As can be seen from Figure 1, an open ring arrangement comprises 3 rings 1, 2 and 3 arranged linearly along a common centre and slightly spaced apart. A table 4 is arranged slightly below the centre line of the rings and in parallel therewith. A subject 5 lies on the table 4, encircled by the rings 1,2 and 3 for treatment. Rings 1 and 3 represent the MRI, whilst ring 2 incorporates the linear accelerator. The table 4 is moveable linearly through the rings 1, 2 and 3 so that the subject tissue may be located, imaged (using the MRI) and treated (using the linear accelerator. The MRI rings 1 and 3 create an imaging volume which encompasses the accelerator isocentre of ring 2.

Figure 2 illustrates a closed drum arrangement of the invention. The drum comprises two main portions, an outer portion 22 which incorporates the gantry on which the linear accelerator is mounted and an inner portion 21 incorporating the MRI. A common bore 20 extends concentrically through the centre of the two cylindrical portions 23, 21. A table 24 is positioned within the bore, slightly below the centre, and is slideable into and out of the bore 20.

Figure 3 shows a more detailed outline sketch of an embodiment of the form shown in Figure 2. The arrangement comprises outer portion 32 which incorporates a linear accelerator having a head including an X-ray gun 39, tube 38 magnet 36 and focus 37. The inner portion 31 of the drum consists of the MRI and surrounds a central bore 30, common to both the MRI and accelerator which share a common isocentre 41. Within bore 30, there is again provided a table 34 above which a subject may be positioned in an area 35 for treatment or analysis. The line 40 indicates the typical floor level relative to the apparatus.

Figure 4a) shows a primary field configuration for a drum 1 of a conventional drum type MRI. The drum has a plurality of coils 2a, 2b, 2c, 2d encircling its isocentre and positioned towards the inner surface of the magnetic drum of the MRI. As can be seen the field has a component in an area surrounding the outer surface of the ring Bp_{out} and a component passing through the centre of the drum Bp_{in}. The first component Bp_{out} is relatively less strong than and in a direction opposing that of the second component

Bp_{in}.

Figure 4b) shows the field produced by a drum of similar configuration to that of 4a) but equipped only with a pair of coils 2'e and 2'f positioned toward opposing faces of the drum and near the outer surface thereof. As can be seen from that Figure the field has components Bc_{out} which is of similar strength but in an opposing direction to Bp_{out} and Bc_{in} which is of significantly lower strength than Bp_{in} and oppositely directed thereto.

Figure 4c) illustrates the field pattern resulting when the fields of Figures 4a) and 4b) are combined in an MRI compensated in accordance with the first aspect of the invention. As can be seen the opposing, but substantially equal strength field components Bp_{out} and Bc_{out} cancel each other creating an area of substantially zero Tesla towards the central region of the outer surface of the ring.

Figure 5 shows an embodiment of the invention in further detail. In particular the components of the MRI are further illustrated. As can be seen the MRI comprises a cryostat containing a support structure 3 onto which are mounted both the primary coils 2a,...2d and the compensation coils 2'e to 2'f. Positioned around the inner circumference of the drum 1 are gradient coils 6 and RF coils 5. Positioned in the zero Tesla area (as shown in Figure 4c)) is a rotatable gantry 4 on which is mounted a linear accelerator 7. The accelerator emits particles (for example X-rays or electrons) in a beam B to be targeted at a subject introduced into the central bore at the common isocentre of the gantry 4 and drum 1.

Figure 6 shows an embodiment broadly similar to that of Figure 5 but incorporating a compensation filter F in alignment with the linear accelerator 7 and the beam B. Whilst only a single filter is shown in the Figure it is to be understood that in practice, the system would be provided with a plurality of such filters positioned at fixed locations about the inner circumference of the drum so as to provide compensation at a plurality of fixed locations for the linear accelerator when the gantry is rotated about the isocentre of the system

Figure 7 shows an embodiment broadly similar to that of Figure 6 but incorporating split gradient coils. As can be seen the gradient coil is split into two substantially even sized portions with a gap between them. The gap aligns with the linear accelerator 7 and the beam B such that the beam B can pass through the gap. The filter F is located in the gap, behind the RF coil.

Figure 8 shows a further embodiment of the invention. This embodiment is broadly similar to that of Figure 7 but incorporates a split or perforated support structure 3. As can be seen, a gap or hole is provided in the support structure in radial alignment with the gap in the gradient coil, the compensation filter F and the linear accelerator 7 such that the beam B can pass therethrough.

CLAIMS

1. A radiation therapy apparatus comprising a magnetic resonance imaging device integrated with a linear accelerator wherein a B-field compensator means is associated with the magnetic resonance imaging device which, in use, adapts the B-field produced by the magnetic resonance imaging device in the vicinity of the linear accelerator thereby to minimise the influence of the B-field on the particles emitted by the accelerator.

2. A radiation therapy apparatus comprising a magnetic resonance imaging device integrated with a linear accelerator wherein the particle source of the linear accelerator is positioned a fixed radial distance from the subject to be targeted and has associated therewith a compensation filter for compensating heterogeneity of the beam induced by magnetic resonance imaging device, thereby to provide a substantially homogenous beam at the target to be treated.

3. A radiation therapy apparatus as claimed in claim 1 wherein the particle source of the linear accelerator is positioned a fixed radial distance from the subject to be targeted and has associated therewith one or more compensation filters for compensating heterogeneity of the beam induced by the magnetic resonance imaging device, thereby to provide a substantially homogenous beam at the target to be treated.

4. A radiation therapy apparatus as claimed in any preceding claim wherein the apparatus is configured such that magnetic imaging device and linear accelerator may be operated both independently and simultaneously.

5. A radiation therapy apparatus as claimed in any preceding claim wherein the magnetic imaging device and linear accelerator are so

integrated such that the MRI system creates an imaging volume which encompasses the linear accelerator isocentre.

6. A radiation therapy apparatus as claimed in any preceding claim wherein the apparatus has an open ring configuration.

7. A radiation therapy apparatus as claimed in any of claims 1 to 5 wherein the apparatus has a closed drum configuration.

8. A radiation therapy apparatus as claimed in any preceding claim incorporating an independent world coordinate isocentre calibration system consisting of fiducial table MR-markers and an independent table position verification system.

9. A radiation therapy apparatus as claimed in any of claims 1 or 3 to 8 wherein the B-field compensator means comprises one or more additional pairs of coils positioned with one of each pair at opposing ends of the MRI and having a polarity which opposes the polarity of the magnetic field of the uncompensated MRI.

10. A radiation therapy apparatus as claimed in claim 9 wherein the additional coil(s) are configured to create a B-field at the outer surface of the MRI which is substantially equal but oppositely directed to the B-field of the uncompensated MRI at the outer surface of the MRI thereby creating an area of substantially zero Tesla in a region to the centre of the outer surface of the MRI.

11. A radiation therapy apparatus as claimed in claim 10 wherein the linear accelerator is positioned in the region of substantially zero Tesla.

12. A radiation therapy apparatus as claimed in any of claims 2 to 11 wherein the one or more compensation filters is positioned adjacent the inner surface of the MRI device.

13. A radiation therapy apparatus as claimed in any of claims 2 to 12 wherein the linear accelerator is mounted on a gantry which is rotatable between a plurality of fixed locating positions all of the same fixed radial distance from the centre of the apparatus.

14. A radiation therapy apparatus as claimed in claim 13 wherein the plurality of fixed locating positions is an odd number.

15. A radiation therapy apparatus as claimed in claim 13 or 14 wherein the plurality of fixed locating positions are equi-spaced about the circumference of the gantry

16. A radiation therapy apparatus as claimed in any of claims 13 to 15 wherein the plurality of fixed locating positions is between 5 and 13.

17. A radiation therapy apparatus as claimed in claim 16 wherein the plurality of fixed locating positions is selected from 7, 9 or 11.

18. A radiation therapy apparatus as claimed in any of claims 13 to 17 wherein the gradient coil of the MRI is configured to provide one or more gaps in alignment with one or more fixed locating positions of the gantry.

19. A radiation therapy as claimed in claim 18 wherein one or more compensation filters are positioned in the one or more gaps in the gradient coil.

20. A radiation therapy apparatus as claimed in any of claims 13 to 19 wherein the support structure for the coils of the MRI is configured to provide one or more gaps in alignment with one or more fixed locating positions of the gantry.

21. A radiation therapy apparatus substantially as described herein and with reference to the Figures 1 to 8.

INVESTOR IN PEOPLE

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Application No:	GB 0221174.6	**Examiner:**	Eleanor Thurston
Claims searched:	1 & 3-21	**Date of search:**	12 March 2003

Patents Act 1977 : Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance	
X, E	1 & 4-7 at least.	WO 03/008986 A2	(ELEKTA ONCOLOGY) see whole document.
X	1, 4 & 6 at least.	WO 99/32189 A1	(VARIAN ASSOCIATES, INC.) see abstract, figure 1 and page 13.
A		EP 1121957 A2	(ST. LOUIS UNIVERSITY)
A		EP 0814869 A	(PHILIPS)
A		WO 96/15717 A1	(PHILIPS)

Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC[V]:

G1N; H5R.

Worldwide search of patent documents classified in the following areas of the IPC[7]:

A61B; A61N; G01R.

The following online and other databases have been used in the preparation of this search report:

EPODOC, WPI, PAJ.

14

Application No: GB 0221174.6
Claims searched: 2-20
Examiner: Alison Stransom
Date of search: 5 February 2004

Patents Act 1977 : Further Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
A, E	-	WO 03/008986 A2 ELEKTA
A	-	US 5713357 MEULENBRUGGE

Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC^{W}:

G1N, H5R

Worldwide search of patent documents classified in the following areas of the IPC^{7}:

A61N, A61B, G01R

The following online and other databases have been used in the preparation of this search report :

EPODOC, WPI, JAPIO