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(54) **SCANNING SYSTEMS**

SCANNING-SYSTEME

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Description

[0001] The present invention relates to scanning systems. It has particular application in scanning systems for cargo, but can also be used in scanners for other applications such as security and high energy medical scanners.

[0002] There is a requirement for screening of cargo for the purpose of identifying the presence of illicit materials and objects. Currently, such screening is often performed using X-ray scanners.

[0003] X-ray scanners for cargo inspection typically comprise a high energy X-ray source (usually based on an X-ray linear accelerator) with a beam quality of 4MeV to 9MeV. The X-ray output from the X-ray linear accelerator is then collimated down to a narrow fan-beam of radiation which is shone through the item of cargo under inspection. A linear array of X-ray detector elements is then positioned opposite to the X-ray source such that it is irradiated by the fan-beam of radiation after attenuation of the X-ray beam by the object under inspection.

[0004] International Patent Publication Number WO 2004/010127 discloses a scanning unit for identifying contraband within objects moving through the unit. A source of a beam of radiation is provided and a detector that detects radiation transmitted through the object during scanning. The detectors may be energy sensitive and the radiation sources may emit radiation of different energy distributions.

[0005] UK Patent Application GB 2409268 discloses X-ray material discrimination detectors including a relatively thin front scintillation crystal, optical signals from which are read out from opposite sides by photodiodes of optical fibres.

[0006] An aspect of the invention comprises a scanning method for scanning an object comprising: providing a first detector region and a second detector region wherein the second detector region is arranged to receive radiation that has passed through the first detector region; irradiating the object with radiation having a first energy profile; detecting the first profile radiation after it has interacted with or passed through the object in order to provide information relating to the object, wherein detecting the first profile radiation comprises: detecting the first profile radiation at the first detector region; receiving the first profile radiation that has passed through the first detector region at the second detector region; detecting the first profile radiation at the second detector region; the scanning method further comprising: irradiating the object with radiation having a second energy profile, different to the first energy profile; detecting the second profile radiation after it has interacted with or passed through the object in order to provide information relating to the object, wherein detecting the second profile radiation comprises: detecting the second profile radiation at the first detector region; receiving the second profile radiation that has passed through the first detector region at the second detector region; detecting the second profile radiation at the second detector region, the scanning method further comprising: determining information relating to the object based upon information from the first and second detector regions relating to the first and second energy profile radiation, and calculating the ratio, $(A/B)_1/(A/B)_2$ in order to the determine information relating to the object based upon the calculated ratio, wherein A is indicative of the amount of radiation detected at the first detector region, B is indicative of the amount of radiation detected at the second detector region, $(A/B)_1$ is the ratio of first profile radiation detected at the first detector region relative to first profile radiation detected at the second detector region, and $(A/B)_2$ is the ratio of second profile radiation detected at the first detector region relative to second profile radiation detected at the second detector region.

[0007] The independent claims define aspects of the invention for which protection is sought. The dependent claims define preferable inventive features.

[0008] Embodiments of the invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

Figure 1 is a flowchart outlining a method according to an embodiment of the invention;

Figure 2 schematically shows a scanning system according to an embodiment of the invention;

Figure 3 graphically illustrates an output radiation profile from a radiation source used in an embodiment of the present invention;

Figure 4 schematically illustrates a detector arrangement according to an embodiment of the invention;

Figure 5 is a graph illustrating different characteristics of high and low atomic mass objects as seen by the scanning system of an embodiment of this invention;

Figure 6 is a graph illustrating different characteristics of high and low atomic mass objects as seen by the scanning system of an embodiment of this invention;

Figure 7 is a graph illustrating the change in response relative to the energy of received radiation;

Figure 8 is a graph illustrating the change in response relative to intensity of received radiation for high and low atomic mass objects;

Figure 9 schematically shows a data acquisition system for use with this invention;

Figure 10 illustrates a timing pattern for the data acquisition system of Figure 9 in one embodiment; and

Figure 11 is a representation of overlapping objects which can be distinguished using this invention.

[0009] Referring to figures 1 and 2, a method of the invention provides a method 10 and system 30 for scanning an object 32. The system 30 comprises a radiation source 36 arranged to irradiate the object 32 with radiation. In this embodiment, the source 36 is a switchable energy linear accelerator source. Other suitable sources will be apparent to the skilled person. In this embodiment the object 32 moves in the direction of arrow 34 through a scanning zone. The object 32 might be a lorry carrying cargo for example, driving through a scanning zone, which the source 36 is arranged to irradiate. In other embodiments, the object 32 might be stationary. The radiation source 36 is arranged to operate at at least two different levels. In this example, the source 36 is able to operate at a high level to provide radiation having a peak energy of at least 1 MeV and at a low level to provide radiation having a peak energy of at least 0.5 MeV. In this particular example the high level radiation has a peak value of 6 MeV, and the low level radiation has a peak value of 3 MeV. In this context peak value is the energy value at which the highest intensity of radiation is emitted by the source 36.

[0010] The scanning system 30 also comprises a detector arrangement 38. The detector arrangement is arranged to detect radiation after it has interacted with or passed through the object 32 in order to provide information to scan the object. The detector arrangement 38 comprises a first detector 40 and a second detector 42. The first detector 40 has a thickness of at least 2 mm. In this embodiment the thickness of the first detector is about 15 mm. In other embodiments the thickness may be more or less and can be tuned as required by a skilled person. The second detector 42 has a thickness of at least 5 mm. In this embodiment the thickness of the second detector 42 is about 30 mm. Once again, it will be clear to the skilled person that this detector thickness can be varied by experimentation in order to tune the detector arrangement 38 as required. For example, in some embodiments, the detectors may be tuned to detect the same amount of radiation as each other, to provide more efficient signal processing. In this embodiment, referring to figure 3, the first detector 40 is positioned between the object 32 and the second detector 42. In other embodiments, the skilled person may envisage a different arrangement. In this particular embodiment, this arrangement provides a simple geometry in order to achieve the desired detector configuration such that radiation passing through the first detector 40 reaches the second detector 42 after it has interacted with the object 32. In this embodiment, the detector arrangement 38 is a linear detector array with front 40, A, and rear 42, B, detectors.

[0011] The system 30 in its broadest embodiment does not include a movement sensor. The system 30 may include movement sensor (not shown). The movement sensor 44 is arranged to measure any one or more of the position, speed, velocity or acceleration of the object 32, and data gathered using the movement sensor may be used to coordinate timing of data capture as the object is scanned.

[0012] Referring to figure 1, the scanning method 10 comprises the step of providing 12 a first detector region having a thickness of at least 2 mm, and a second detector region having a thickness of at least 5 mm. The method 10 also comprises the steps of irradiating 14 an object to be scanned with radiation having a peak energy value of 1 MeV or more, detecting 16 radiation at the first detector region 40, and then detecting 18 radiation at the second detector region 42 (the second detector region is arranged to receive radiation that has passed through the first detector region). The method 10 comprises detecting the radiation after it has interacted with or passed through the object in order to provide information relating to the object.

[0013] The method 10 further comprises irradiating 20 the object with radiation having a peak energy value of 0.5 MeV or more (but less than the peak energy value of the energy irradiated at step 14), and again detecting 22 radiation at the first detector region 40, and then detecting 24 radiation at the second detector region 42.

[0014] In this example the object is scanned with higher energy profile radiation prior to scanning with lower energy profile radiation. In other embodiments, the object may be scanned with lower energy profile radiation prior to scanning with higher energy profile radiation. In yet further embodiments, there may be scanning at more than two different levels (each level providing radiation having a different energy profile).

[0015] In this embodiment, the object is irradiated in discrete bursts. The skilled person will realise that radiation levels can be varied gradually, or in a combination of bursts and gradual variation and the data collection signal processing should be amended accordingly (this is discussed in more detail below).

[0016] In some embodiments, the method 10 comprises sending detected information received in response to a burst from the detector regions before the next burst occurs. This helps to simplify signal processing.

[0017] The primary equation that governs X-ray attenuation in matter is

$$I(E) = I_0(E)\exp\left(-\int_l \mu(E)dl\right) \quad (1)$$

where *I(E)* = intensity of radiation transmitted through the object at energy *E, Io(E)* = intensity of radiation emitted by the source at energy *E*, $\mu(E)$ = linear attenuation coefficient of object at energy *E* and *l* = line taken by the pencil beam of radiation through the object.

[0018] The X-ray output from an X-ray linear accelerator is polychromatic having an energy distribution substantially as shown in figure 3. The maximum X-ray energy (Ep) results from those electron interactions in the target of the linear accelerator where all of the electron energy is transferred to a single X-ray photon. Typically, less than the full electron energy is transferred to a photon resulting in the broad range of X-ray energies in the X-ray beam. At low energy, the peaks shown in figure 3 are due to fluorescence interactions between the electrons and the target atoms so resulting in X-rays which are characteristic of the target material.

[0019] It is customary to use an integrating detector to measure the X-ray signal that is described in equation 1. In this case, the detected signal can be written as

$$I_d = \int_0^{E_p} I(E)\left[1-\exp\left(-\int_s \mu_d(E)ds\right)\right] \quad (2)$$

where I_d = detected signal, $\mu_d(E)$ = linear attenuation coefficient of the detector material at energy *E* and *s* = path length of the X-ray beam through the detector.

[0020] It is therefore clear that I_d retains no knowledge of the energy distribution of the incoming X-ray beam, only of the cumulative effect of all X-ray energies.

[0021] However, it can also be seen that unless the path through the detector material, s, is very large indeed, some energy will be transmitted through the detector (i.e. it will not have a 100% detection efficiency). Referring to figure 4, if a second detector, B, is placed at the output of the first detector, A, then the energy transmitted through the first detector has a chance of being absorbed in the second detector. In this case we can write:

$$I_{dB} = \int_0^{E_p} I(E)\exp\left(-\int_s \mu_{dA}(E)ds\right)\left[1-\exp\left(-\int_t \mu_{dB}(E)dt\right)\right] \quad (3)$$

where I_{dB} = intensity recorded in detector B, $\mu_{dA}(E)$ = linear attenuation coefficient of detector A material at energy *E*, $\mu_{dB}(E)$ = linear attenuation coefficient of detector B material at energy *E* and *t* = path taken by the X-ray beam through detector B.

[0022] Inspection of equation 3 shows that the energy spectrum that is incident on detector B is not the same as the energy spectrum that is incident on detector A. Therefore, detector A can be thought to have retained some energy information even though the integrated output alone is not sufficient to tell what this energy information is. The same is true of detector B.

[0023] In this invention, it is recognised that the measurements that are produced by detector A and detector B are spatially and temporally correlated and that the ratio of the intensity recorded in detector A to that recorded in detector B will necessarily provide some information about the energy distribution of the incident X-ray beam, i.e.

$$\frac{I_{dA}}{I_{dB}} = f\{I(E)\} \quad (4)$$

where *f*{ } = function operator.

[0024] It can further be seen through inspection of equation (1), that the ratio of detector measurements also includes a factor that is due to attenuation in the object.

[0025] Three object parameters will affect the ratio of detectors (equation 4) and these are the linear attenuation coefficient of the object, $\mu(E)$, the path l taken by the X-ray beam through the object and the energy distribution of the primary beam, $Io(E)$. In this situation, there are three unknowns and two measurements and therefore it is impossible to uniquely determine a value for the three object unknowns.

[0026] In another aspect of this invention, it is recognised that if the X-ray linear accelerator can be tuned to produce more than one primary beam distribution then two pairs of detector results can be collected, one with a lower energy primary beam distribution, $I_{dA}(lo)$ and $I_{dB}(lo)$, and one with a higher primary beam energy distribution, $I_{dA}(hi)$ and $I_{dB}(hi)$. There are now four measurements with the same three unknowns and it is therefore possible to determine a mathematically unique solution. This solution can be determined using an appropriate numerical technique such as least squares minimisation. In other embodiments any other similar or suitable numerical technique can be used as an alternative or in combination.

[0027] The present invention is concerned with high energy scanning. At low energies (for example most medical scanners), the photo-electric effect is a mechanism by which X-rays interact with matter within objects being scanned. In contrast, the present invention is concerned with much larger X-ray source energies - namely, lower energy primary beam distribution mentioned above has a peak value of 500 keV or above (and the higher energy beam has a value higher than this). The predominant mechanism governing interactions of radiation within matter at these energies is Compton scattering.

[0028] The attenuation in matter of X-rays affected by the photo-electric effect shows a dependence proportional to Z^4 (where Z = atomic number). In contrast, Compton scattering produces a Z^1 dependence. Some Compton scattering is also present at low energies.

[0029] The detector regions of the present invention are configured such that in the front detector, there is an approximately Z^4 dependence arising from a combination of the photo-electric and Compton scattering effects. The second, rear detector has a Z^1 dependence. As a result there are significantly different considerations compared to low energy X-ray scanning, due to the different physical laws governing the interaction of matter. The inventor has realised that for high energy X-ray scanning applications, the front and rear detectors in the claimed arrangement are governed by different physical laws with regards to their interaction with high energy radiation. As a result of the different physical relationships, different detector arrangements are required, relative to low energy X-ray scanners. Accordingly, a first detector is specified as being at least 2 mm thick, whilst the second detector is specified as being at least 5 mm thick. Also, different signal processing is required to account for the combination of the photo-electric effect and Compton scattering occurring at the first detector, and the predominantly Compton scattering effect at the second detector. As a result conventional cargo scanners do not have a dual detector region arrangement as specified in this invention.

[0030] The detector arrangement for use in a scanning system of this type (i.e. the system comprises a radiation source arranged to irradiate an object to be scanned, wherein the detector arrangement is arranged to detect radiation after it has interacted with or passed through the object in order to scan the object)may be a stacked detector, wherein the detector arrangement comprises a first detector region arranged to detect radiation and a second detector region arranged to detect radiation wherein the second detector region is arranged to receive radiation that has passed through the first detector region. In this example the first detector region is positioned between the object to be scanned and the second detector region. The first detector region and the second detector region are configured to detect a predetermined amount of radiation relative to each other - in this example, the first detector region and the second detector region are configured to detect substantially the same amount of radiation as each other - in this example this is achieved by configuring the lengths s, t of the detectors A, B.

[0031] The or each of the first detector and the second detector may comprise a linear detector array.

[0032] An example of the data that can be recorded using a system with stacked detectors as exemplified in this invention (and as shown in figure 4) is given in figures 5 to 8. In these figures, 1 is the total integrated intensity of radiation detected, i.e. the sum of the intensity at the first detector, A, and the second detector, B. F/R is a measure of the ratio of intensity of radiation detected at the front and rear detectors. L/H is a measure of the ratio of intensity of radiation detected at low and high source energy profile.

[0033] At lower energies, the front detector absorbs most of the radiation which reaches it. As a result there is a good distinction relative to the absorption at the rear detector between high Z and low Z objects, where Z = atomic mass. Therefore the ratio, F/R provides particularly useful information at low energies.

[0034] At higher energies, the L/H ratio provides good distinction between high Z and low Z objects. Therefore the ratio, L/H provides particularly useful information at high energies.

[0035] In combination these two ratios help to provide comprehensive information across the energy spectrum.

[0036] Figure 8 shows the percentage difference between the two curves in figures 5 and 6. As a guide the difference between the intensity ratios at low and high energies can be as large as 10 percent. Given that the noise floor in a good quality detection system should be on the order of 10 parts per million, a several percent change in intensity ratio is very measureable.

[0037] A suitable data acquisition system 90 for use with the scanning system is shown in figure 9. Here a pulsed X-ray accelerator 92 has two inputs, Trigger and Energy. X-rays from the accelerator 92 pass through the object under inspection and intercept sensor arrays 94 that have front and rear sensor elements. The analogue signal is integrated and converted to a digital form prior to transmission to a set of concentrator cards 96 which format Ethernet packets that contain the digitised sensor data. These Ethernet packets are passed from each Concentrator card back through an Ethernet Switch 98 to a controlling computer 100 where they are formatted into lines in an image which are then displayed on a human readable monitor 102. Each line in the image corresponds to one accelerator pulse worth of sensor data. Of course, other data acquisition system architectures are quite workable and will be apparent to the skilled person, and figure 9 is presented as an example of good practice in data acquisition design.

[0038] Figure 10 presents an example of a timing diagram for acquisition of quad-energy X-ray data. A trigger pulse trigger switching of the energy level of the radiation source between its high and low levels. Detection events are integrated at each detector co-ordinated in time with the high and low energy states, and readout from each detector occurs prior to the next integration event.

[0039] It is advantageous to use an offset staggered row detector to improve scanning speed, to increase detection efficiency and to provide improved spatial correlation between the high and low energy X-ray measurements. This may be done to achieve Nyquist sampling rates for example.

[0040] It can be advantageous to utilise non-periodic pulse sequences of radiation from the source in order to assist in reducing dose rates and to provide superior object penetration performance.

[0041] It is is observed that the analysis provided in equations 1 through 4 above relates to a single homogeneous object. In a real object, there are often multiple objects which may overlap in the image. An example of overlapping objects is shown in figure 11. Here a first object 110 is partially overlapped by a second object 112. In each case, the overall shape of the objects is visible to the human eye, even in the overlap region 114. In this invention it is claimed that automated image processing methods can be used to segment the projected quad-energy X-ray image to resolve the materials characteristics of the region to the left of the first object 110 and the region to the right of the second object 112. This information about the objects 110 and 112 can then be used to analyse the overlapping area 114. Knowing the beam quality, thickness and attenuation coefficient of the first object 110 and the thickness and attenuation coefficient of the second object 112, it is possible to calculate the expected intensity that should be detected in the overlap region using the following equation:

$$I(E) = I_0(E)\exp\left(-\left\{\int_0^{t_1}\mu_1(E)dl + \int_0^{t_2}\mu_2(E)dl\right\}\right) \qquad (5)$$

where t_1 = thickness of the first object 110, $\mu_1(E)$ = attenuation coefficient of the first object 110 at energy E, t_2 = thickness of the second object 112 and $\mu_2(E)$ = attenuation coefficient of the second object 112 at energy E. Note that the detected values, $I_{dA}(lo)$, $I_{dB}(lo)$, $I_{dA}(hi)$ and $I_{dB}(hi)$ are then determined through equations 3 and 4. The measured values can then be compared to the associated calculated values to ensure that noting else is present in the overlap region 114.

[0042] It is noted that the techniques discussed here can be extrapolated to further more complex situations. For example, an X-ray source could be developed to operate at more than two beam energies and more than two detector layers could be assembled to give finer still sampling of the energy distribution of the transmitted X-ray signals. The data analysis methods are the same, but there are further measurements of the same number of unknowns and it is therefore in principle possible to generate a better determined solution.

[0043] Metal filter layers could be interposed between the detector elements in order to further shape the X-ray spectrum. This method is not recommended since no signal is recorded from the metal filter layer and the net result is a higher dose image than when an active detector is used as a filter for the equivalent purpose.

[0044] The high and low energy x-rays may be sent in a different order, e.g. low energy, then high energy.

[0045] Different ratios may be calculated with the four elements of information. The ratio described in the above example: $(A/B)_{lo}/(A/B)_{hi}$ is particularly useful since it takes away the need for calibration of the detectors. Other unique ratios which can be used are A_{hi}/A_{lo}, A_{hi}/B_{lo}, A_{lo}/B_{hi}, A_{hi}/B_{hi}) A_{lo}/B_{lo}. These are unique ratios - B_{hi}/A_{lo} can be used but offers no advantage above A_{lo}/B_{hi} since it is merely its inverse - similarly for other ratio examples.

[0046] In some embodiments more than two detector regions may be provided and more than two radiation energy levels may be used for irradiation of the object. For example instead of two, three or four or five or six or any other suitable number of energy levels may be used.

[0047] Exactly the same detector array principle can be used with other imaging probes including thermal neutrons and fast neutrons which can provide additional diagnostic benefit.

[0048] It will be clear to the skilled person that different peak values for the lower energy profile and/or the higher energy profile may be used within the bounds specified by the claims. For the example the lower profile peak energy value may be 4 MeV, and the higher profile peak energy value may be 7 or 8 MeV.

Claims

1. A scanning method for scanning an object comprising:

providing a first detector region (40) having a thickness of at least 2 mm and a second detector region (42) having a thickness of at least 5 mm wherein the second detector region is arranged to receive radiation that has passed through the first detector region,
irradiating the object (32) with radiation having a first energy profile and having a peak energy of at least 1MeV,
detecting the first profile radiation after it has interacted with or passed through the object (32) in order to provide information relating to the object (32) wherein detecting the first profile radiation comprises:

detecting the first profile radiation at the first detector region (40),
receiving the first profile radiation that has passed through the first detector region at the second detector region (42),
detecting the first profile radiation at the second detector region,

the scanning method further comprising:

irradiating the object (32) with radiation having a second energy profile, relatively lower than the first energy profile, and having a peak energy of at least 0.5 MeV,
detecting the second profile radiation after it has interacted with or passed through the object in order to provide information relating to the object, wherein detecting the second profile radiation comprises:

detecting the second profile radiation at the first detector region (40),
receiving the second profile radiation that has passed through the first detector region at the second detector region,
detecting the second profile radiation at the second detector region (42),

the scanning method further comprising:

determining information relating to the object based upon information from the first and second detector regions relating to the first and second energy profile radiation, and **characterized in that** the scanning method further comprises:

calculating the ratio, $(A/B)_1/(A/B)_2$ in order to the determine information relating to the object based upon the calculated ratio, wherein A is indicative of the amount of radiation detected at the first detector region, B is indicative of the amount of radiation detected at the second detector region, $(A/B)_1$ is the ratio of first profile radiation detected at the first detector region relative to first profile radiation detected at the second detector region, and $(A/B)_2$ is the ratio of second profile radiation detected at the first detector region relative to second profile radiation detected at the second detector region.

2. The method of claim 1 comprising positioning the first detector region (40) between the object and the second detector region (42).

3. The method of claim 1 or claim 2 comprising determining information by inputting the information from the first and second detector regions relating to the first and second energy profile radiation into a least squares minimisation technique to obtain information relating to the object.

4. The method of any preceding claim comprising irradiating and detecting the first profile radiation before the second profile radiation, or vice versa.

5. The method of any preceding claim wherein irradiating the object comprises irradiating the object in discrete bursts, and optionally
comprising sending detected information received in response to a burst from the detector regions before the next

burst occurs.

6. The method of any preceding claim wherein the low energy profile radiation comprises 3 MeV x-ray radiation and the high energy profile radiation comprises 6 MeV x-ray radiation.

7. The method of any preceding claim comprising configuring the first detector region and the second detector region to detect a predetermined amount of radiation relative to each other, and optionally
configuring the first detector region and the second detector region to detect substantially the same amount of radiation as each other, and optionally
comprising configuring any one or more of size, shape or material of the or each detector region so that the first detector region and the second detector region detect the predetermined amount of radiation relative to each other.

8. The method of any preceding claim comprising providing a first detector including the first detector region and a second detector including the second detector region.

9. The method of any preceding claim comprising irradiating the object with radiation at more than two energy profiles, such as at three energy profiles or four energy profiles or five energy profiles or six energy profiles or seven energy profiles.

10. A method of scanning overlapping objects comprising using the method of any preceding claim to determine information relating to each overlapping object in a region of the object which does not overlap another object and using the determined information to calculate a reference detection value or values relating to a value or values expected to be detected in the region in which the objects overlap in the absence of further objects that are not present outside the overlapping region and using the method of any preceding claim to ascertain information relating to the region in which the objects overlap and comparing the ascertained information to the expected values to determine whether an additional object is present within the region in which the objects overlap.

11. A scanning system for scanning an object comprising a variable energy level radiation source (36) arranged to irradiate an object (32) with radiation having a plurality of different energy profiles including a first energy profile having a peak energy of at least 1 MeV and a second relatively lower energy profile having a peak energy of at least 0.5 MeV, a detector arrangement arranged to detect radiation after it has interacted with or passed through the object, wherein the detector arrangement comprises a first detector region (40) having a thickness of at least 2 mm and arranged to detect radiation and a second detector region (42) having a thickness of at least 5 mm and arranged to detect radiation wherein the second detector region (42) is arranged to receive radiation that has passed through the first detector region (40) the system further comprising a controller arranged to determine information relating to the object (32) based upon information from the first and second detector regions relating to the first and second energy profile radiation, and **characterized in that** wherein the controller is arranged to calculate the ratio, $(A/B)_1/(A/B)_2$ in order to the determine information relating to the object based upon the calculated ratio, wherein A is indicative of the amount of radiation detected at the first detector region, B is indicative of the amount of radiation detected at the second detector region, $(A/B)_1$ is the ratio of first profile radiation detected at the first detector region relative to first profile radiation detected at the second detector region, and $(A/B)_2$ is the ratio of second profile radiation detected at the first detector region relative to second profile radiation detected at the second detector region.

12. The scanning system of claim 11 comprising a controller arranged to coordinate timing of irradiation events such that detected information obtained in response to an irradiation event is sent from the detector regions before the next event occurs, and optionally
wherein the first detector region (40) is positioned between the object and the second detector region (42).

13. The scanning system of claim 11 or claim 12 wherein the controller is arranged to determine information by inputting the information from the first and second detector regions relating to the first and second energy profile radiation into a least squares minimisation technique to obtain information relating to the object.

14. The scanning system of any of claims 11 to 13 comprising a plurality of detector arrays, each detector array comprising a first detector region and a second detector region, and optionally
comprising a concentrator and switch arranged to coherently relay gathered information from the detector regions.

15. The scanning system of any of claims 11 to 14 wherein the first detector region and the second detector region are configured to detect substantially the same amount of radiation as each other.

Patentansprüche

1. Ein Scan-Verfahren zum Scannen eines Objekts, das Folgendes beinhaltet:

    Bereitstellen eines ersten Detektorbereichs (40) mit einer Dicke von mindestens 2 mm und einem zweiten Detektorbereich (42) mit einer Dicke von mindestens 5 mm, worin der zweite Detektorbereich angeordnet ist, um eine Strahlung zu erhalten, die durch den ersten Detektorbereich gegangen ist,
    Bestrahlen des Objekts (32) mit Strahlung, die ein erstes Energieprofil sowie ein Profil der Energiespitzenwerte von mindestens 1 MeV aufweist,
    Erkennen der Strahlung mit dem ersten Profil nach einer Wechselwirkung mit dem Objekt oder nach dem Durchgang durch das Objekt (32), um Informationen zum Objekt (32) zu liefern, wobei das Erkennen der Strahlung mit dem ersten Profil Folgendes umfasst:

        Erkennen der Strahlung mit dem ersten Profil am ersten Detektorbereich (40),
        Empfangen der Strahlung mit dem ersten Profil, die durch den ersten Detektorbereich am zweiten Detektorbereich (42) gegangen ist,
        Erkennen der Strahlung mit dem ersten Profil am zweiten Detektorbereich,

    wobei das Scan-Verfahren überdies Folgendes umfasst:

    Bestrahlen des Objekts (32) mit Strahlung, die ein zweites Energieprofil, welches verhältnismäßig geringer ist als das erste Energieprofil, sowie eine Spitzenenergie von mindestens 0,5 MeV aufweist,
    Erkennen der Strahlung mit dem zweiten Profil nach einer Wechselwirkung mit dem Objekt oder nach dem Durchgang durch das Objekt, um Informationen zum Objekt zu liefern, wobei das Erkennen der Strahlung mit dem zweiten Profil Folgendes umfasst:

        Erkennen der Strahlung mit dem zweiten Profil am ersten Detektorbereich (40),
        Empfangen der Strahlung mit dem zweiten Profil, die durch den ersten Detektorbereich am zweiten Detektorbereich gegangen ist,
        Erkennen der Strahlung mit dem zweiten Profil am zweiten Detektorbereich (42), wobei das Scan-Verfahren überdies Folgendes umfasst:

    Ermitteln von Informationen, die sich auf das Objekt beziehen, basierend auf Informationen aus dem ersten und zweiten Detektorbereich, die sich auf die Strahlung mit dem ersten und zweiten Energieprofil beziehen, **dadurch gekennzeichnet, dass** das Scan-Verfahren Folgendes umfasst:

        Berechnen des Verhältnisses $(A/B)_1/(A/B)_2$, um Informationen zu ermitteln, die sich auf das Objekt beziehen und auf den Informationen aus dem ersten und zweiten Detektorbereich basieren, worin A die Menge der Strahlung anzeigt, die am ersten Detektorbereich erkannt wird, B die Menge der Strahlung anzeigt, die am zweiten Detektorbereich erkannt wird, und $(A/B)_1$ das Verhältnis ist zwischen der Strahlung mit dem ersten Profil, die am ersten Detektorbereich erkannt wird, und der Strahlung mit dem ersten Profil, die am zweiten Detektorbereich erkannt wird, und $(A/B)_2$ das Verhältnis ist zwischen der Strahlung mit dem zweiten Profil, die am ersten Detektorbereich erkannt wird, und der Strahlung mit dem zweiten Profil, die am zweiten Detektorbereich erkannt wird.

2. Das Verfahren aus Anspruch 1, welches das Positionieren des ersten Detektorbereichs (40) zwischen dem Objekt und dem zweiten Detektorbereich (42) beinhaltet.

3. Das Verfahren aus Anspruch 1 oder Anspruch 2, wozu die Ermittlung von Informationen gehört, indem die Informationen aus dem ersten und zweiten Detektorbereich im Hinblick auf die Strahlung mit dem ersten und zweiten Energieprofil in eine Methode der kleinsten Quadrate eingegeben werden, um Informationen über das Objekt zu erhalten.

4. Das Verfahren aus einem der vorhergehenden Ansprüche, welches das Bestrahlen und Erkennen der Strahlung mit dem ersten Profil umfasst, bevor die Strahlung mit dem zweiten Profil erkannt wird, oder umgekehrt.

5. Das Verfahren aus einem der vorhergehenden Ansprüche, worin das Bestrahlen des Objekts das Bestrahlen des Objekts in einzelnen Stößen beinhaltet, und wahlweise das Versenden der ermittelten Informationen, die als Reaktion

auf einen Strahlungsstoß aus den Detektorbereichen empfangen wurden, bevor es zum nächsten Stoß kommt.

6. Das Verfahren aus einem der vorhergehenden Ansprüche, worin die Strahlung mit dem energiearmen Profil eine 3 MeV-Röntgenstrahlung und die Strahlung mit dem energiereichen Profil eine 6 MeV-Röntgenstrahlung umfasst.

7. Das Verfahren aus einem der vorhergehenden Ansprüche, wozu die Konfiguration des ersten Detektorbereichs und des zweiten Detektorbereichs gehört, um eine vorher festgelegte Strahlungsmenge im Verhältnis zueinander zu erkennen, und wahlweise die Konfiguration des ersten Detektorbereichs und den zweiten Detektorbereichs, um im Wesentlichen dieselbe Strahlungsmenge wie beim jeweils anderen zu erkennen, und wahlweise
die Konfiguration eines oder mehrerer Detektorbereiche hinsichtlich Größe, Form oder Material, sodass der erste Detektorbereich und der zweite Detektorbereich die vorher festgelegte Strahlungsmenge im Verhältnis zueinander erkennen.

8. Das Verfahren aus einem der vorhergehenden Ansprüche, welches die Bereitstellung eines ersten Detektors, einschließlich des ersten Detektorbereichs, sowie eines zweiten Detektors, einschließlich des zweiten Detektorbereichs, beinhaltet.

9. Das Verfahren aus einem der vorhergehenden Ansprüche, welches die Bestrahlung des Objekts mit Strahlung bei mehr als zwei Energieprofilen beinhaltet, wie etwa drei Energieprofile oder vier Energieprofile oder fünf Energieprofile oder sechs Energieprofile oder sieben Energieprofile.

10. Ein Verfahren zum Scannen von überlappenden Objekten, wozu die Verwendung des Verfahrens aus einem vorhergehenden Anspruchs gehört, um Informationen zu jedem überlappenden Objekt in einem Bereich des Objekts, das kein anderes Objekt überlappt, zu ermitteln, und die Verwendung der ermittelten Informationen, um einen Referenzerkennungswert oder Werte zu berechnen, die sich auf einen Wert oder Werte beziehen, deren Nachweis in jenem Bereich zu erwarten ist, in dem die Objekte überlappen, in Abwesenheit von weiteren Objekten, die nicht außerhalb des überlappenden Bereichs vorhanden sind, und Verwendung des Verfahrens eines vorhergehenden Anspruchs zum Nachprüfen von Informationen in Bezug auf den Bereich, indem die Objekte überlappen, sowie Vergleich der überprüften Informationen mit den erwarteten Werten, um festzustellen, ob sich ein zusätzliches Objekt innerhalb des Bereichs, in dem die Objekte überlappen, befindet.

11. Ein Scan-System zum Scannen eines Objekts, das eine Strahlungsquelle (36) mit einem variablen Energieniveau umfasst, welche angeordnet ist, um ein Objekt (32) mit einer Strahlung zu bestrahlen, die eine Vielzahl von verschiedenen Energieprofilen aufweist, einschließlich eines ersten Energieprofils mit einer Spitzenenergie von mindestens 1 MeV und eines zweiten verhältnismäßig geringeren Energieprofils mit einer Spitzenenergie von mindestens 0,5 MeV, einer Detektoranordnung zum Erkennen von Strahlung nach einer Wechselwirkung mit dem Objekt oder dem Durchgang durch das Objekt (32), worin die Detektoranordnung einen ersten Detektorbereich (40) mit einer Dicke von mindestens 2 mm umfasst, der dazu dient, Strahlung zu erkennen, sowie einen zweiten Detektorbereich (42) mit einer Dicke von mindestens 5 mm, der dazu dient, Strahlung zu erkennen, wobei der zweite Detektorbereich (42) angeordnet ist, um Strahlung zu empfangen, die durch den ersten Detektorbereich (40) gegangen ist, und wobei das System überdies eine Steuerung beinhaltet, die dazu dient, Informationen in Bezug auf das Objekt (32) basierend auf Informationen aus dem ersten und zweiten Detektorbereich zu ermitteln, die sich auf Strahlung mit dem ersten und zweiten Energieprofil beziehen, und **dadurch gekennzeichnet, dass** die Steuereinheit darin dazu dient, das Verhältnis $(A/B)_1/(A/B)_2$ zu berechnen, um Informationen im Hinblick auf das Objekt basierend auf dem berechneten Verhältnis zu ermitteln, und **dadurch gekennzeichnet, dass** darin A die Menge der Strahlung anzeigt, die am ersten Detektorbereich erkannt wird, B die Menge der Strahlung anzeigt, die am zweiten Detektorbereich erkannt wird, und $(A/B)_1$ das Verhältnis ist zwischen der Strahlung mit dem ersten Profil, die am ersten Detektorbereich erkannt wird, und der Strahlung mit dem ersten Profil, die am zweiten Detektorbereich erkannt wird, und $(A/B)_2$ das Verhältnis ist zwischen der Strahlung mit dem zweiten Profil, die am ersten Detektorbereich erkannt wird, und der Strahlung mit dem zweiten Profil, die am zweiten Detektorbereich erkannt wird.

12. Das Scan-System aus Anspruch 11, das eine Steuerung umfasst, die dazu dient, die Zeitsteuerung von Bestrahlungsvorgängen zu koordinieren, sodass die erkannten Informationen, die als Reaktion auf die Bestrahlungsvorgänge erfasst wurden, von den Detektorbereichen gesendet werden, bevor es zum nächsten Vorgang kommt, und wobei wahlweise der erste Detektorbereich (40) zwischen dem Objekt und dem zweiten Detektorbereich (42) positioniert ist.

13. Das Scan-System aus Anspruch 11 oder Anspruch 12, worin die Steuerung dazu dient, Informationen zu ermitteln,

indem die Informationen aus dem ersten und zweiten Detektorbereich im Hinblick auf die Strahlung mit dem ersten und zweiten Energieprofil in eine Methode der kleinsten Quadrate eingegeben werden, um Informationen über das Objekt zu erhalten.

14. Das Scan-System aus Anspruch 11 bis 13, das eine Vielzahl von Detektoranordnungen umfasst, wobei jede Detektoranordnung einen ersten Detektorbereich und einen zweiten Detektorbereich beinhaltet, und wahlweise einen Konzentrator und Schalter beinhaltet, die dazu dienen, die gesammelten Informationen kohärent von den Detektorbereichen zu übertragen.

15. Das Scan-System aus einem der Ansprüche 11 bis 14, worin der erste Detektorbereich und der zweite Detektorbereich dazu dienen, im Wesentlichen dieselbe Strahlungsmenge zu erkennen.

Revendications

1. Un procédé de balayage destiné à balayer un objet comprenant :

la fourniture d'une première zone de détection (40) possédant une épaisseur d'au moins 2 mm et d'une deuxième zone de détection (42) possédant une épaisseur d'au moins 5 mm où la deuxième zone de détection est agencée de façon à recevoir un rayonnement qui a traversé la première zone de détection,
l'irradiation de l'objet (32) avec un rayonnement possédant un premier profil d'énergie et possédant une énergie de crête d'au moins 1 MeV,
la détection du premier rayonnement à profil après qu'il ait interagi avec ou traversé l'objet (32) afin de fournir des informations relatives à l'objet (32), où la détection du premier rayonnement à profil comprend :

la détection du premier rayonnement à profil au niveau de la première zone de détection (40),
la réception du premier rayonnement à profil qui a traversé la première zone de détection au niveau de la deuxième zone de détection (42),
la détection du premier rayonnement à profil au niveau de la deuxième zone de détection,

le procédé de balayage comprenant en outre :

l'irradiation de l'objet (32) avec un rayonnement possédant un deuxième profil d'énergie, relativement plus faible que le premier profil d'énergie, et possédant une énergie de crête d'au moins 0,5 MeV,
la détection du deuxième rayonnement à profil après qu'il ait interagi avec ou traversé l'objet afin de fournir des informations relatives à l'objet, où la détection du deuxième rayonnement à profil comprend :
la détection du deuxième rayonnement à profil au niveau de la première zone de détection (40),
la réception du deuxième rayonnement à profil qui a traversé la première zone de détection au niveau de la deuxième zone de détection,
la détection du deuxième rayonnement à profil au niveau de la deuxième zone de détection (42).

le procédé de balayage comprenant en outre :

la détermination d'informations relatives à l'objet en fonction d'informations provenant des première et deuxième zones de détection relatives aux premier et deuxième rayonnements à profil d'énergie, et **caractérisé en ce que** le procédé de balayage comprenant en outre :

le calcul du rapport $(A/B)_1/(A/B)_2$ afin de déterminer des informations relatives à l'objet en fonction du rapport calculé, où A est indicatif de la quantité de rayonnement détectée au niveau de la première zone de détection, B est indicatif de la quantité de rayonnement détectée au niveau de la deuxième zone de détection, $(A/B)_1$ est le rapport du premier rayonnement à profil détecté au niveau de la première zone de détection sur le premier rayonnement à profil détecté au niveau de la deuxième zone de détection, et $(A/B)_2$ est le rapport du deuxième rayonnement à profil détecté au niveau de la première zone de détection sur le deuxième rayonnement à profil détecté au niveau de la deuxième zone de détection.

2. Le procédé selon la Revendication 1 comprenant le positionnement de la première zone de détection (40) entre l'objet et la deuxième zone de détection (42).

3. Le procédé selon la Revendication 1 ou 2 comprenant la détermination d'informations par la saisie des informations provenant des première et deuxième zones de détection relatives aux premier et deuxième rayonnements à profil d'énergie dans une technique de minimisation des moindres carrés de façon à obtenir des informations relatives à l'objet.

4. Le procédé selon l'une quelconque des Revendications précédentes comprenant l'irradiation et la détection du premier rayonnement à profil avant le deuxième rayonnement à profil, ou vice versa.

5. Le procédé selon l'une quelconque des Revendications précédentes où l'irradiation de l'objet comprend l'irradiation de l'objet en rafales discrètes, et éventuellement comprenant l'envoi d'informations détectées reçues en réponse à une rafale provenant des zones de détection avant que la rafale suivante ne se produise.

6. Le procédé selon l'une quelconque des Revendications précédentes où le rayonnement à profil faible énergie comprend un rayonnement de rayons x de 3 MeV et le rayonnement à profil forte énergie comprend un rayonnement de rayons x de 6 MeV.

7. Le procédé selon l'une quelconque des Revendications précédentes comprenant la configuration de la première zone de détection et de la deuxième zone de détection de façon à détecter une quantité prédéterminée de rayonnement pour l'une et l'autre, et éventuellement
la configuration de la première zone de détection et de la deuxième zone de détection de façon à détecter sensiblement la même quantité de rayonnement pour l'une et l'autre, et éventuellement
comprenant la configuration d'un quelconque ou plusieurs éléments parmi taille, forme ou matériau de la ou de chaque zone de détection de sorte que la première zone de détection et la deuxième zone de détection détectent la quantité prédéterminée de rayonnement pour l'une et l'autre.

8. Le procédé selon l'une quelconque des Revendications précédentes comprenant la fourniture d'un premier détecteur incluant la première zone de détection et d'un deuxième détecteur incluant la deuxième zone de détection.

9. Le procédé selon l'une quelconque des Revendications précédentes comprenant l'irradiation de l'objet avec un rayonnement à plus de deux profils d'énergie, par exemple à trois profils d'énergie ou quatre profils d'énergie ou cinq profils d'énergie ou six profils d'énergie ou sept profils d'énergie.

10. Un procédé de balayage d'objets en chevauchement comprenant l'utilisation du procédé selon l'une quelconque des Revendications précédentes de façon à déterminer des informations relatives à chaque objet en chevauchement dans une zone de l'objet qui ne chevauche pas un autre objet et, au moyen des informations déterminées, de façon à calculer une valeur ou des valeurs de détection de référence relatives à une valeur ou des valeurs attendues à être détectées dans la zone dans laquelle les objets se chevauchent en l'absence d'autres objets qui ne sont pas présents à l'extérieur de la zone de chevauchement et, au moyen du procédé selon l'une quelconque des Revendications précédentes, de façon à établir des informations relatives à la zone dans laquelle les objets se chevauchent et à comparer les informations établies aux valeurs attendues de façon à déterminer si un objet additionnel est présent à l'intérieur de la zone dans laquelle les objets se chevauchent.

11. Un système de balayage destiné à balayer un objet comprenant une source de rayonnement à niveau d'énergie variable (36) agencée de façon à irradier un objet (32) avec un rayonnement possédant une pluralité de profils d'énergie différents comprenant un premier profil d'énergie possédant une énergie de crête d'au moins 1 MeV et un deuxième profil d'énergie relativement plus faible possédant une énergie de crête d'au moins 0,5 MeV, un ensemble détecteur agencé de façon à détecter un rayonnement après qu'il ait interagi avec ou traversé l'objet, où l'ensemble détecteur comprend une première zone de détection (40) possédant une épaisseur d'au moins 2 mm et agencée de façon à détecter un rayonnement et une deuxième zone de détection (42) possédant une épaisseur d'au moins 5 mm et agencée de façon à détecter un rayonnement où la deuxième zone de détection (42) est agencée de façon à recevoir un rayonnement qui a traversé la première zone de détection (40), le système comprenant en outre un système de commande agencé de façon à déterminer des informations relatives à l'objet (32) en fonction d'informations provenant des première et deuxième zones de détection relatives aux premier et deuxième rayonnements à profil d'énergie, et où le système de commande est agencé de façon à calculer le rapport $(A/B)_1/(A/B)_2$ afin de déterminer des informations relatives à l'objet en fonction du rapport calculé, où A est indicatif de la quantité de rayonnement détectée au niveau de la première zone de détection, B est indicatif de la quantité de rayonnement détectée au niveau de la deuxième zone de détection, $(A/B)_1$ est le rapport du premier rayonnement à profil détecté au niveau de la première zone de détection sur le premier rayonnement à profil détecté au niveau de la deuxième

zone de détection, et $(A/B)_2$ est le rapport du deuxième rayonnement à profil détecté au niveau de la première zone de détection sur le deuxième rayonnement à profil détecté au niveau de la deuxième zone de détection.

12. Le système de balayage selon la Revendication 11 comprenant un système de commande agencé de façon à coordonner une synchronisation d'événements d'irradiation de sorte que des informations détectées obtenues en réponse à un événement d'irradiation sont envoyées à partir des zones de détection avant que l'événement suivant ne se produise, et éventuellement
où la première zone de détection (40) est positionnée entre l'objet et la deuxième zone de détection (42).

13. Le système de balayage selon la Revendication 11 ou 12 où le système de commande est agencé de façon à déterminer des informations par la saisie des informations provenant des première et deuxième zones de détection relatives aux premier et deuxième rayonnements à profil d'énergie dans une technique de minimisation des moindres carrés de façon à obtenir des informations relatives à l'objet.

14. Le système de balayage selon l'une quelconque des Revendications 11 à 13 comprenant une pluralité de réseaux de détecteurs, chaque réseau de détecteurs comprenant une première zone de détection et une deuxième zone de détection, et éventuellement
comprenant un concentrateur et un commutateur agencés de façon à relayer de manière cohérente des informations recueillies provenant des zones de détection.

15. Le système de balayage selon l'une quelconque des Revendications11 à 14 où la première zone de détection et la deuxième zone de détection sont configurées de façon à détecter sensiblement la même quantité de rayonnement pour l'une et l'autre.

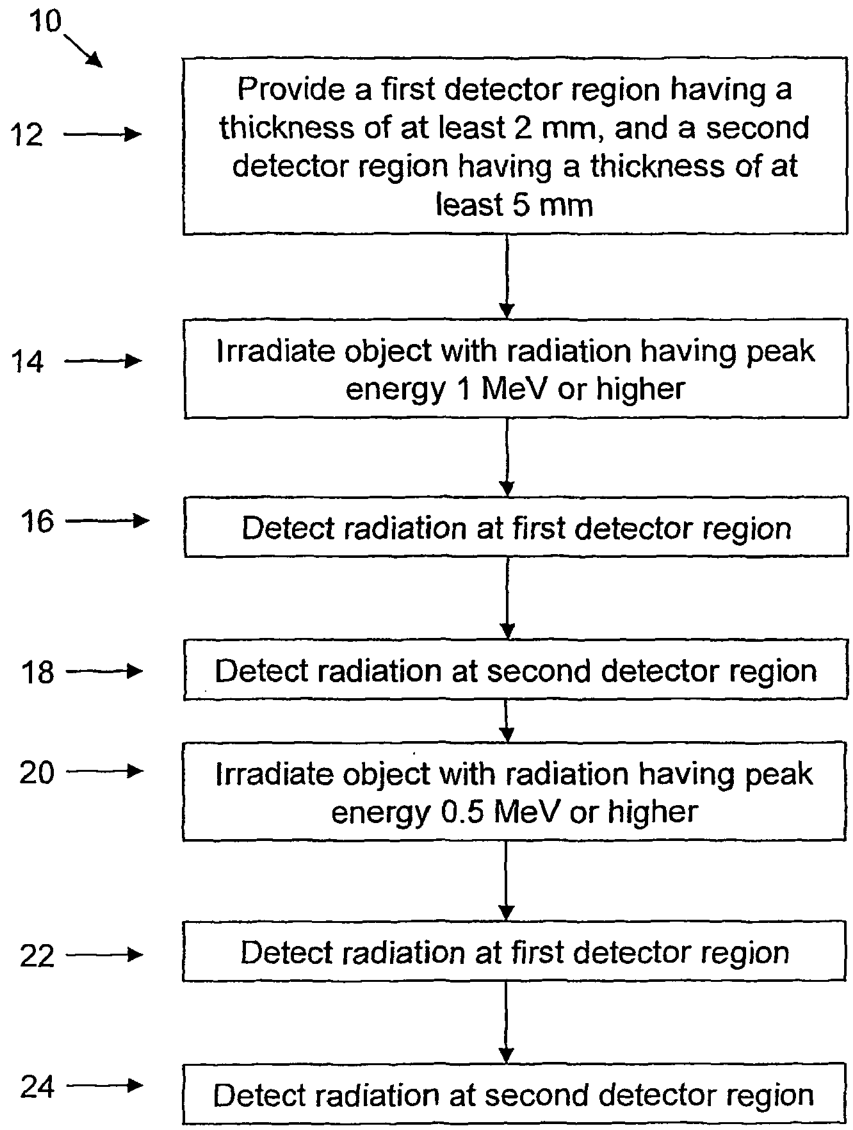
10
12
Provide a first detector region having a thickness of at least 2 mm, and a second detector region having a thickness of at least 5 mm
14
Irradiate object with radiation having peak energy 1 MeV or higher
16
Detect radiation at first detector region
18
Detect radiation at second detector region
20
Irradiate object with radiation having peak energy 0.5 MeV or higher
22
Detect radiation at first detector region
24
Detect radiation at second detector region

Figure 1

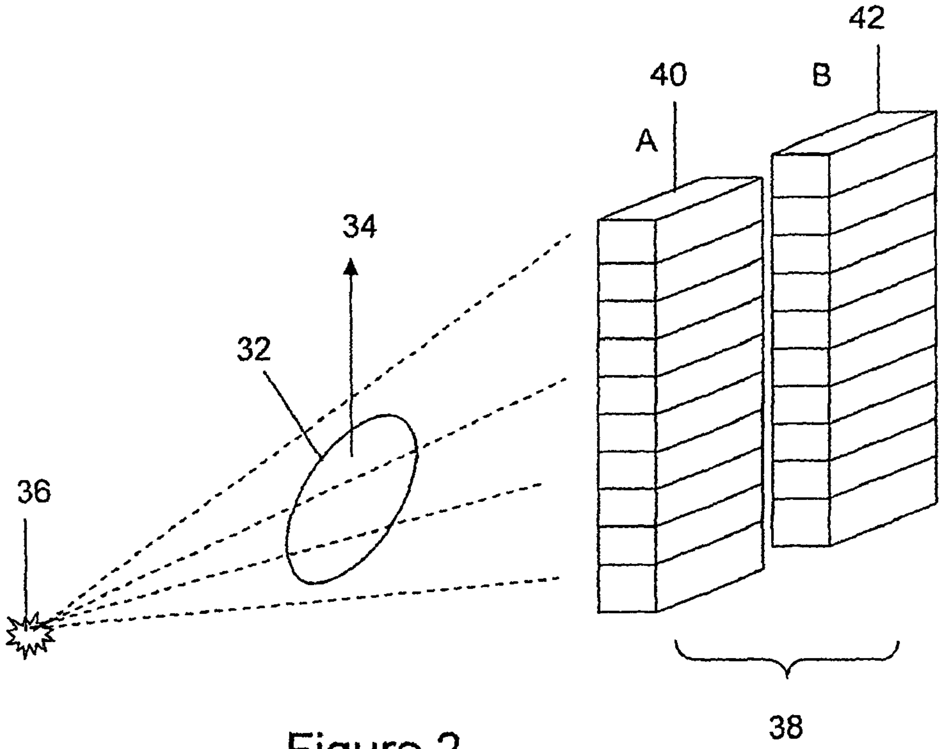

Figure 2

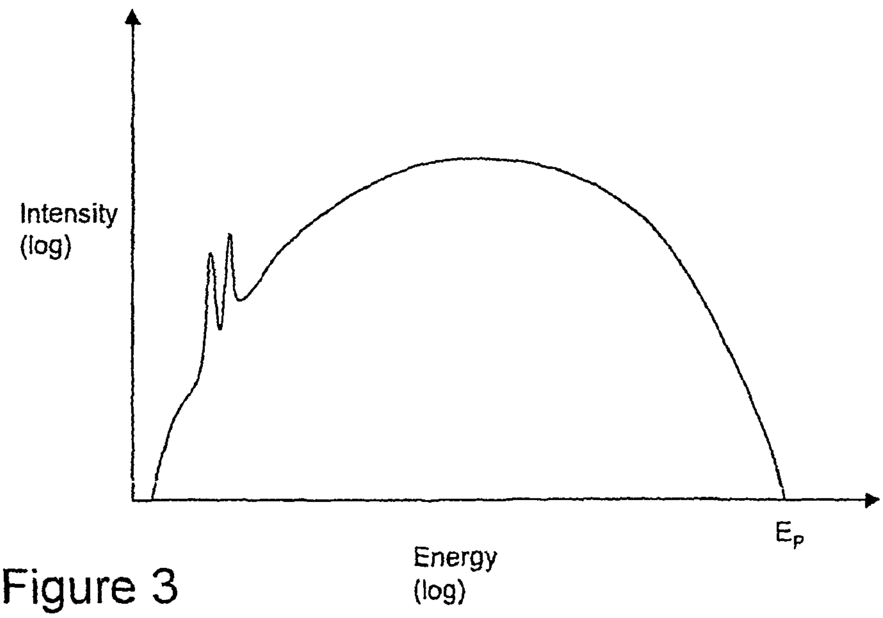

Figure 3

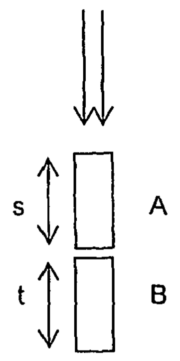

Figure 4

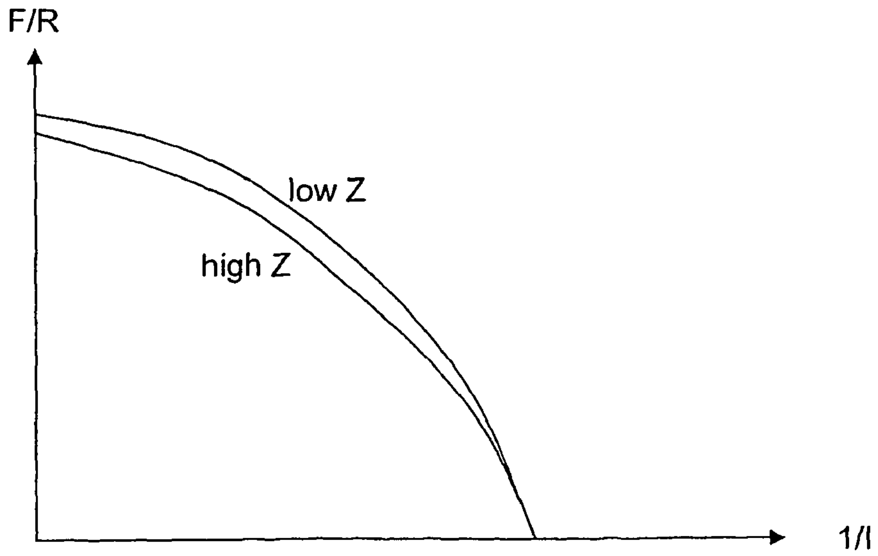

Figure 5

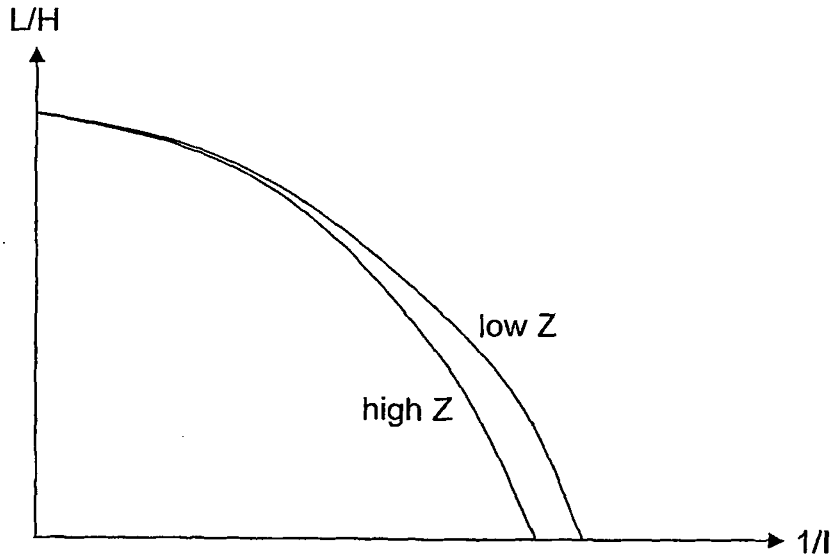

Figure 6

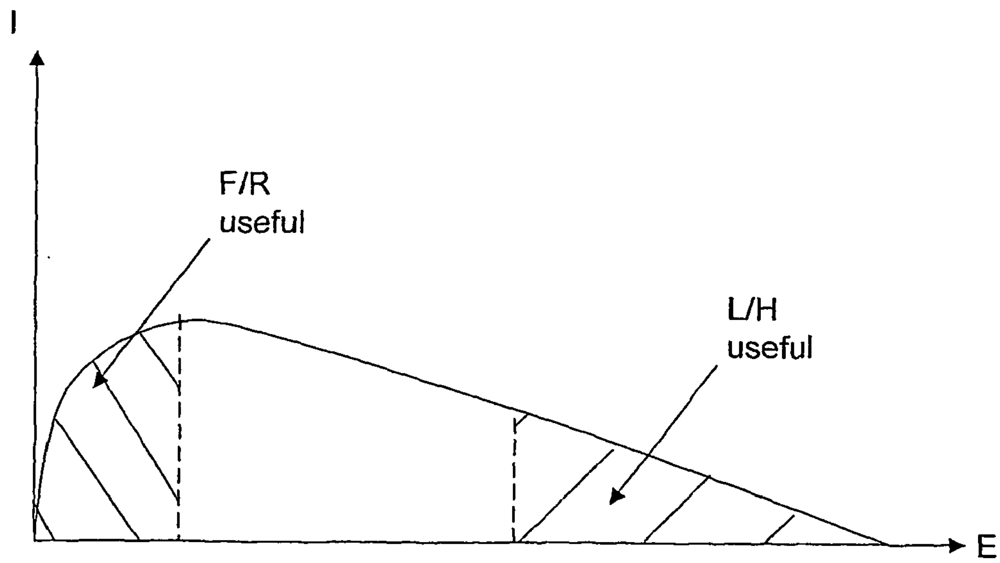

Figure 7

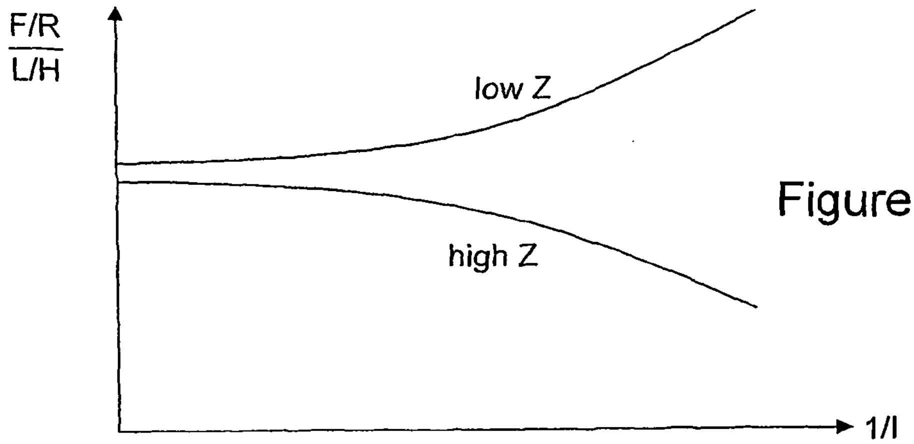

Figure 8

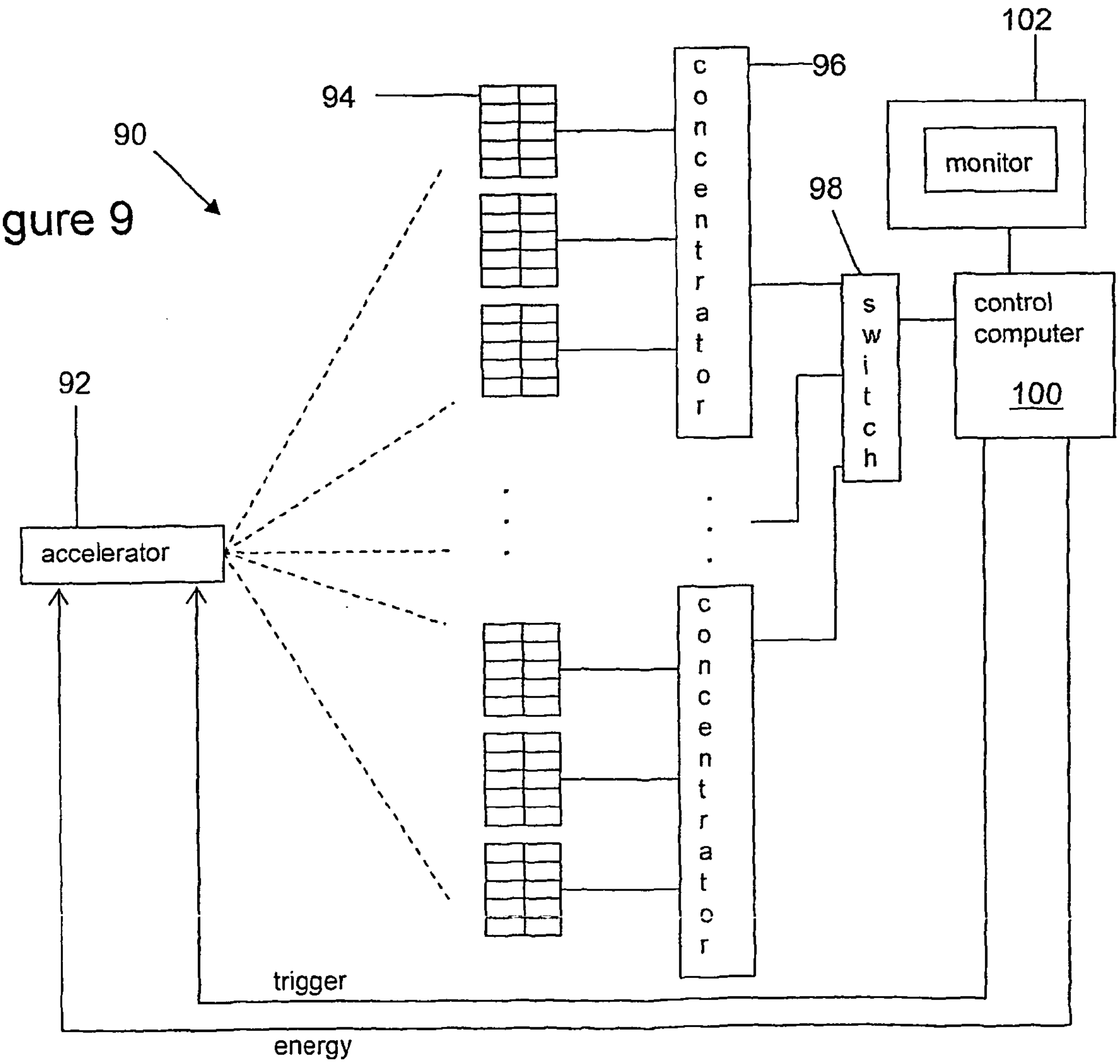

Figure 9

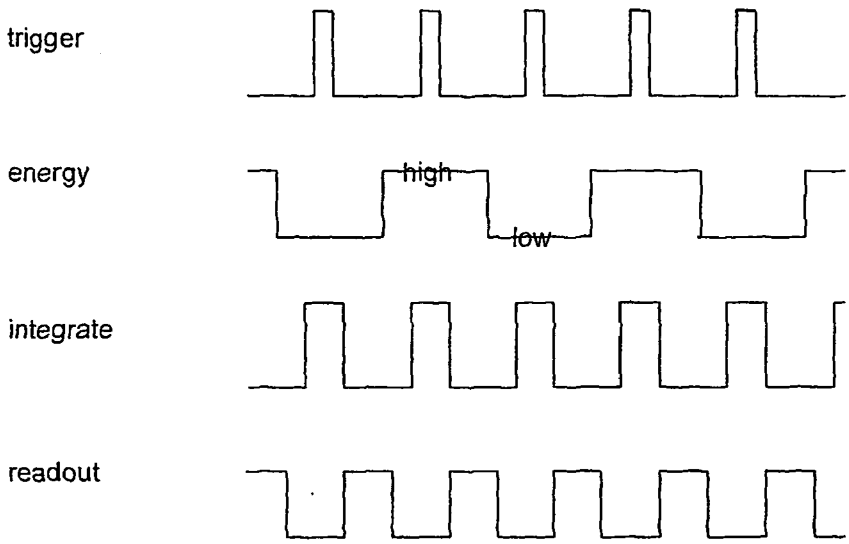

Figure 10

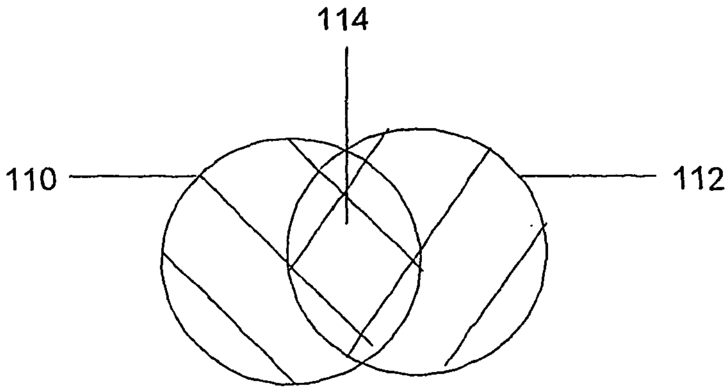

Figure 11

REFERENCES CITED IN THE DESCRIPTION

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