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(54) STRIP DEVICE AND METHOD FOR DETERMINING THE LOCATION AND TIME OF REACTION OF THE GAMMA QUANTA AND THE USE OF THE DEVICE TO DETERMINE THE LOCATION AND TIME OF REACTION OF THE GAMMA QUANTA IN POSITRON EMISSION TOMOGRAPHY

STREIFENVORRICHTUNG UND VERFAHREN ZUR ORTS- UND REAKTIONSZEITBESTIMMUNG VON GAMMAQUANTEN SOWIE VERWENDUNG DER VORRICHTUNG ZUR ORTS- UND REAKTIONSZEITBESTIMMUNG VON GAMMAQUANTEN IN DER POSITRONENEMISSIONSTOMOGRAFIE

DISPOSITIF À BANDELETTES ET PROCÉDÉ POUR DÉTERMINER LE LIEU ET LE TEMPS DE RÉACTION DES QUANTSA GAMMA, ET UTILISATION DU DISPOSITIF POUR DÉTERMINER LE LIEU ET LE TEMPS DE RÉACTION DES QUANTSA GAMMA EN TOMOGRAPHIE PAR ÉMISSION DE POSITRONS

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- **Knoll, Glenn F: "Radiation detection and measurement", 1999, XP000002656880, pages 224-225, page 224, paragraph 5.**

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Description

[0001] The subject of the invention are a strip device and a method for determining the location and time of reaction of the gamma quanta and the use of the device to determine the location and time of reaction of the gamma quanta in positron emission tomography. More specifically the invention describes a solution to determine the spatial distribution of concentration of selected substances in the body and changes of their concentration in time.

[0002] Positron emission tomography is based on the determination of the spatial distribution of concentration of selected substances in the body and the changes of this concentration in time. To this end, the patient is administered pharmaceuticals marked with radioactive isotope emitting positrons. Radioactive marker is chosen so that it decays with the emission of positrons. The tomography uses the fact that the positron from the marker and electron from an atom of the body annihilate in contact with each other and their mass is converted into energy in the form of gamma quanta. Most frequently these are two gamma quanta flying back to back along the line with an exactly defined energy equal to 511 keV. The annihilation occurs typically only a few millimeters from the decay of the marker. This fact determines a natural limit of sharpness of the PET image. PET tomograph allows to locate the radioactive marker by measuring the direction of flight of the annihilation quanta. Radiation detectors are usually arranged in layers forming a ring around the patient. Currently, all commercial PET tomographs use inorganic scintillator material for detection. The energy of gamma quantum hitting the scintillator can be transferred partially or entirely to an electron of the material, which then produces flash of lights through ionization and deexcitation of atoms or molecules of the scintillator. These flashes are then converted to electrical pulses by photomultipliers connected to the scintillators. The number of photons generated in scintillator material is proportional to the energy that a quantum transferred to the electron. In turn, charge of electrical signal generated by photomultipliers is proportional to the number of photons incident on the photomultiplier window. For the energy of gamma quanta amounting to 511 keV there are two significant processes called photoelectric effect and Compton effect. In the first process gamma quantum transfers to the electron its entire energy, while in the second process only part of the energy is transferred depending also on the electron scattering angle. As a result of these processes, the spectrum of charge of registered signals consists of a continuous distribution corresponding to Compton effect and a peak corresponding to the photoelectric effect. Separation of this maximum allows to distinguish the cases where the annihilation quanta of energy 511 keV reached scintillator undisturbed from all the others cases. In the current tomographs one use scintillating crystals, made usually in size of about 5cm x 5cm and which are additionally blazed into smaller pieces with dimensions of 0.5 cm x 0.5 cm separated from each other with reflecting material. The end of each scintillating module is connected to photomultipliers which convert light into electrical impulses. This arrangement permits to determine, with the accuracy equal to the size of the small unit, the position where the gamma quantum reacted. Therefore, in the further analysis, one assumes that the quantum was absorbed in the middle of the unit. This causes the smearing of the image, the greater, the farther from the axis of the tomograph the annihilation occured, and the larger is the scintillator module. One try to improve the image resolution by calculating the point of annihilation along the line of flight of the quanta by measurement of the time difference between the arrival of the gamma quanta to the detectors. In the literature this technique is known as TOF (time of flight), and tomographs which use the time measurements are termed PET-TOF. For efficient application of this technique one requires the time resolution in order of tens of picoseconds, unattainable in the current tomographs based on inorganic scintillators.

[0003] In Patent Application US 2006060823 (published at 2006-03-26) an invention for a radiation detection scintillator using a flexible composite is described. This composite is created by the rapid mixing of dense, doped with rare earth elements oxyorthosilicate (eg, LSO: Ce, LSO: Sm, or GSO: Ce) with a binder which is transparent to the radiation emitted from the scintillator. Composites are uniform and can be made in large sizes and different shapes. Importantly, such a composite can emit radiation in the range of responses corresponding to the photomultiplier (400 nm) which increases the efficiency of the detector.

[0004] In Patent Application US 2008237470 (published at 2008-10-02) a scintillation detector containing nanoparticles of scintillation component embedded in a matrix of plastic material is presented. The nanoparticles can be made from materials such as metal oxides, metal oxohalides, oxysulphides metals or metal halides. New ways of producing nanoparticles were developed in which particles can be coated by organic material or polymers before setting into a plastic matrix. The technique of matching the reflectance of the plastic matrix by the use of titanium dioxide nanoparticles was also developed. Scintillator can be joined with at least one photo-detector system forming a scintillation detector, which can be adapted for use in X-ray imaging systems, such as digital X-ray imaging, mammography, CT, PET or SPECT, or in safe detectors of radiation and detectors of the underground radiation.

[0005] In patent applications US 2008296505 (published at 2008-12-04) and WO 2007082126 (published at 2007-07-19) the way to reconstruct the image of the time of flight (TOF) is described. It includes obtaining of the outline of the investigated object in the test area (14) of imaging system (10). Events related to the radiation emitted from the object are recorded and converted into electronic data. The electrical signals corresponding to the incident radiation from outside the object are removed, thus the final images are reconstructed from the remaining electronic data.

[0006] In Patent Application US 2004173752 (published at 2004-09-09) one has demonstrated that in case of certain hybrid organic / inorganic perovskite as the scintillator material, radiation is generated in the optical range at a rate of around subnanoseconds, and the same scintillator can be used as a detector of gamma radiation in PET tomography. PET scanner, according to the invention, contains a scintillator-based hybrid organic/inorganic perovskite compounds selected from the compounds of specific formula. Speed of response known for scintillators presently used in PET tomography is very limited, because there is a restriction of resolution obtained by this method. In order to solve this problem, one has estimated that the scintillator response rate should be approximately 0.1 ns. The development of such scintillator allowed to limit temporal resolution obtained with this method. In the described application methods of manufacture and the composition of such scintillators on the order of several cubic centimeters are given. However, in order to achieve spatial resolution along the lines of response, that would be on the order of the natural uncertainty originating from the positron absorption in the body of the patient, the required time resolution should be better than 50 ps and the economic imaging of the entire human body needs fast scintillators on the order of meters in size.

[0007] In the Patent Application EP 2047297 (published at 2008-04-21) PET tomograph (100) based on time of flight measurement is presented. It includes the detector (106), system (120) of data acquisition, system of compliance (122) and reconstructing unit (129). Elements for imaging affect the time resolution of the system (100) so that the positron data, which are collected along different lines of response are characterized by different timing resolutions. These time resolutions are used for determining the position of registered events along the corresponding lines of response.

[0008] FR2925698 discloses a Positron emission tomography device comprising an annular chamber that is constituted by crystals for converting light energy of gamma photons : positron annihilation. The interior peripheral of the chamber is overlaid with parallelepiped single crystal scintillator bars. Each bar with longitudinal ends is equipped with solid state photomultipliers.

[0009] Despite the above described research focused on solutions for determination of the place and time of the interaction of gamma quanta used in positron emission tomography, there is a continuing need for an effective solution for detection of radiation using a plastic scintillator doped with atoms of high atomic number, which would allow to obtain time resolutions needed for the effective application of TOF techniques, as well as for substantial reductions in the cost of production of PET tomographs due to the relatively easy possibility to produce organic scintillators in any size.

[0010] The purpose of this invention is to provide resources that could be used to produce solutions for the determination of the place and time of reacting gamma quanta used in positron emission tomography.

[0011] The realization of such a particular purpose, and solution of problems described in the state-of-art techniques associated with measuring of time of flight and with limitations of the obtained time resolution, have been achieved in the present invention.

[0012] The object of the invention is a strip device for determining the location and time of the gamma quantum reaction according to appended claims 1-6 and a method for determining the location and time of the gamma quanta reaction in a device comprising a scintillation chamber according to appended claims 7-9. The invention also relates to the use of the device in positron emission tomography.

[0013] The attached figure allows for a better explanation of the substance of a solution, where:

figure 1 shows a general scheme of the device - strip tomograph;

figure 2 shows an example of the arrangement of strips 8 in the tomograph;

figure 3 shows the scheme of a single detector module;

figure 4 shows a sample mounting of photomultipliers 11;

figure 5 shows an example of the logic diagram of the electronic system that allows to obtain information about the amplitude and time of impulses generated by photomultiplier. The various markings on the figures indicate, respectively:

1 - Scintillation chamber for the examination of the patient, 2 - housing of the chamber and photomultipliers, 3 - housing for electronic circuits, 4 - computer for the reconstruction of the tomographic image, 5 - monitor, 6 - printer, 7 - a platform that allows the patient to move into the scintillation chamber, 8 - scintillation strip, 9 - foil, 10 - light-guide, 11 - photomultiplier, 12 - voltage divider, 13 - power cable, 14 - signal cable, 15 - plate for mounting photomultipliers, 16 - holes for the photomultiplier tubes, 17 - plastic cover, 18 - signal splitter, 19 - discriminator, 20 - coincidence system, 21 - delay line, 22 - TDC - time-to-digit converter, 23 - ADC - charge-to-digit converter, 24 - signal cables. For a better understanding of the solutions below an exemplary embodiment of the invention is presented.

Example

[0014] Figure 1 shows a general scheme of the device, which consists of a scintillation chamber (1), into which the patient, after inserting the radio-pharmaceuticals, is placed. Gammaquanta resulting from the decay of radioactive marker in the patient's body produce light flashes in the scintillation chamber. The resulting light pulses are converted into electrical signals by means of photomultipliers located at the front and rear part between the scintillation chamber and casing of the entire unit (2). The signals from the photomultipliers are sent using cables to the electronics located in the housing (3) sticking to the scintillation chamber casing. The electronic circuit converts the amplitude and time of emergence of signals to digits, which are sent to the computer in binary form (4), where on its basis the distribution of density of radioactive marker in the patient's body is reconstructed. This image can be viewed on the screen (5), printed (6), or saved to disk in the computer. In order to perform the examination the patient is placed on the platform (7), which can be slipped into the scintillation chamber (1) lined from the patient's side with plastic cover.

[0015] Scintillation chamber (1) consists of strips of plastic scintillator doped with atoms of high atomic number, in this case lead. Figure 2 shows an exemplary arrangement of scintillation strips (8). Surfaces of the scintillation strips should be cutted with diamond blade, or polished in order to reflect photons incident to the surface from the inside at an angle greater than the so-called boundary angle. Strips are separated optically by a light-tight foil (9). One way to do that is to wrap with the foil each strip separately. Photons of light, resulting from absorption of gamma quantum in the scintillator material, which reach to the front or the rear edge of the strip are conducted through light-guide (10) to photomultipliers (11). Schematic view of a single detector module is shown in figure 3. Optical light-guides (10) are attached to the scintillation strips with optical glue which refractive index is close to the refractive index of the material from which the scintillators are made. It should be noted that the light-guide material should be selected so that its refractive index is most similar to the refractive index of scintillator. Similar coefficients of light minimize the reflections of photons in the connection region. Combining the light-guide to the photomultiplier (11) can be obtained by appropriate gel or silicon rubber.

[0016] Voltage is distributed to the photomultiplier dynodes (11) using voltage dividers (12), which must be properly matched to the type of photomultiplier. The voltage divider is supplied using voltage cables (13) connected with the power supply located in the housing of the electronics labeled with the number (3) in Figure 1. The signals from the photomultipliers (11) are delivered to the electronics by signal cables (14).

[0017] In figure 4 an example of photomultipliers mounting is shown. Photomultipliers are attached to the mounting plate (15), which is in turn fastened to the housing of the entire device (2). Plate to maintain photomultipliers (15) have openings (16), whose size and shape is adjusted to the size and shape of the casing of photomultipliers, and the relative setup and distance can be optimized in terms of required resolution, thickness of the strips and costs of the device. From the patient side a plastic cover is seen (17).

[0018] Figure 5 shows an exemplary logic diagram of the electronic system that allows to obtain information about the amplitude and time of electric pulses generated by photomultipliers. These in turn are closely linked in time and amplitude of light signals reaching the photomultipliers.

[0019] A program to analyze the data in the first step would perform selection of these events, for which signals were registered in at least two strips with a proper relative distance. At the same time signals in each strip would have to be recorded in both, front and rear photomultipliers. In addition further treatment would be applied only to those signals that are within a fixed time interval (several nanoseconds). Then location of the reaction along the chamber (coordinate z) is determined on the basis of time difference between the signal reaching the front and rear of the strip according to the formula:

$$z = \text{beta} * \text{Delta}(t) / 2 + C1 = \text{beta} * (t\_\text{front} - t\_\text{back}) / 2 + C1,$$

where beta is the speed of light signal in the scintillator strip, and C1 is a calibration constant. Determination of the point of impact of gamma quantum along the scintillation chamber on the basis of time measurement is the main feature of this invention. The point of impact in a plane perpendicular to the axis of the strips (xy in Figure 2) is determined from the location of the module that registered the signal. Time of the interaction of quantum in the scintillation strip is determined as the arithmetic mean from the time measured in the front and rear photomultipliers:

$$t = (t\_\text{front} + t\_\text{back}) / 2 + C2,$$

where C2 is a calibration constant.

[0020] Knowledge of the signal amplitudes in photomultipliers on both sides allows to calculate the energy of the electron which reacted with the gamma quantum. For the calculation following formula can be used in the first approximation:

$$E = C3 * (A\_front + A\_back),$$

where C3 is a calibration constant.

[0021] Knowing the coordinates r = (x, y, z) for the reaction point for both gamma quantum r1 and r2 lines of LOR can be determined.

[0022] Knowing r1, r2, t1 and t2 one can calculate the place of annihilation along the LOR line using the formula Delta(LOR) = (t2 - t1) / 2 * c, where c is the speed of light. Consequently, the point of annihilation is determined by the following formula:

$$\vec{r_a} = \frac{\vec{r_1} + \vec{r_2}}{2} + \frac{\vec{r_1} - \vec{r_2}}{|\vec{r_1} - \vec{r_2}|} \cdot \Delta LOR$$

[0023] The described device provides a set of reconstructed LOR lines and the location of annihilation points along these lines. Based on these data the tomographic image is obtained by imaging reconstruction techniques.

[0024] The proposed solution allows to build a device for registering of gamma quanta in positron emission tomography, whose cost does not increase significantly with the size of the scanner, because the extension of the chamber to record the image is related only to the increase of the length of scintillation strips while keeping the number of photomultipliers, light-guides, and the number of electronic circuits for signal processing.

Claims

1. A strip device for determining the location and time of the gamma quantum reaction, the device comprising a scintillation chamber, wherein the scintillation chamber (1) has an internal cylindrical surface at which there are arranged a plurality of scintillator strips (8), wherein the surfaces of scintillator strips (8) are configured to reflect photons falling on it from the inside of the scintillation chamber at an angle greater than a boundary angle, each scintillator strip being optically connected to photomultipliers (11) for receiving, via light-guides (10) photons of light, resulting from gamma quantum absorbed in the scintillator material, wherein the energy of gamma quantum is transferred entirely to an electron of the scintillator via photoelectric effect or partially via a Compton effect, which reach the front or the rear edge of the strip (8), and wherein the device further comprises an electronic system for determining location of annihilation points along LOR lines, the system being **characterized in that** it is configured to:

- select events for which signals are registered within a fixed time interval in a pair of scintillator strips (8) spaced with a relative distance,
- and for each selected event,
    - determine the point of impact of the gamma quantum in a plane perpendicular to the longitudinal axis of the scintillator strip (8) from the position of the scintillator strip (8) that registered the signal,
    - and for each scintillator strip (8) of the pair of scintillator strips (8) which registered a signal for the selected event:
    - determine the impact position in the scintillator strip (8) along the scintillation chamber on the basis of the time difference (t_front - t_back) between the time (t_front) measured in the front photomultiplier (11) and the time (t_back) measured in the rear photomultiplier (11) of the scintillator strip (8),
    - determine the time (t1, t2) when gamma quantum interacted in each scintillator strip (8) as the arithmetic mean of the time (t_front) measured in the front photomultipliers (11) and the time (t_back) measured in the rear photomultiplier (11) of each scintillator strip (8),
    - determine the energy of the electron of the scintillator to which the energy of gamma quantum was transferred by means of Compton or photoelectric effect, on the basis of amplitudes of signals in the photomultipliers (11) on both sides of the scintillator strips (8),

- and for each selected event:

  - determine the LOR line on the basis of the determined positions of the point of impact in the two scintillator strips (8) of the pair of scintillator strips (8),
  - determine the place of annihilation along the LOR line based on the determined times (t1, t2) when gamma quanta interacted in scintillator strips (8),
  - provide a tomographic picture from a set of reconstructed LOR lines and the location of annihilation points along these lines determined for the selected events,

- and wherein the scintillator strips (8) are made of plastic doped with atoms with atomic number of at least 50.

2. The device according to claim 1, **characterized in that** the material of light-guide is selected so that its refractive index is most similar to the refractive index of scintillator, while similar coefficients of light minimize the reflections of photons in the connection region.

3. The device according to claim 1 or 2, **characterized in that** the generated light impulses are converted into electrical signals by means of photomultipliers (IJ) optically connected with light-guide, and the photomultipliers (U) are attached to the mounting plate (15), which is attached to the housing of the entire unit (2).

4. The device according to claim 1 or 2, **characterized in that** the coupling of light guide to the photomultiplier (11) is done by using gels or silicon rubber.

5. The device according to claim 1 or 2, **characterized in that** the strips (8) are separated from each other optically, preferably using light-proof foil.

6. The device according to claim 1 or 2, **characterized in that** each strip (8) is wrapped separately.

7. A method for determining the location and time of the gamma quanta reaction in a device comprising a scintillation chamber, wherein the scintillation chamber (1) has an internal cylindrical surface at which there are arranged a plurality of scintillator strips (8), wherein the surfaces of scintillator strips (8) are configured to reflect the photons falling on it from the inside of the scintillation chamber at an angle greater than a boundary angle, while the strips (8) are separated from each other optically, each scintillator strip being optically connected to photomultipliers (11) for receiving, via light-guides (10) photons resulting from absorption of the gamma quantum absorbed in the scintillator material, wherein the energy of gamma quantum is transferred entirely to an electron of the scintillatorvia photoelectric effect or partially via a Compton effect, which reach the front or the rear edge of the strip (8) wherein the method is **characterized in that** it comprises locating the annihilation points along LOR lines by:

- selecting events for which signals are registered within a fixed time interval in a pair of scintillator strips (8) spaced with a relative distance,
- and for each selected event,

  - determining the point of impact of the gamma quantum in a plane perpendicular to the longitudinal axis of the scintillator strip (8) from the position of the scintillator strip (8) that registered the signal,
  - and for each scintillator strip (8) of the pair of scintillator strips (8) which registered a signal for the selected event:
  - determining impact position in the scintillator strip (8) along the scintillation chamber on the basis of the time difference (t_front - t_back) between the time (t_front) measured in the front photomultiplier (11) and the time (t_back) measured in the rear photomultiplier (11) of the scintillator strip (8),
  - determining the time (t1, t2) when gamma quantum interacted in each scintillator strip (8) as the arithmetic mean of the time (t_front) measured in the front photomultiplier (11) and the time (t_back) measured in the rear photomultiplier (11) of each scintillator strip (8),
  - determining the energy of the electron of te scintillator to which the energy of gamma quantum was transferred by means of Compton or photoelectric effect, on the basis of amplitudes of signals in the photomultipliers (11) on both sides of the scintillator strips (8);

- and for each selected event:

  - determining the LOR line on the basis of the determined positions of the point of impact in the two scintillator

strips (8) of the pair of scintillator strips,
- determining the place of annihilation along the LOR line based on the determined times (t1, t2) when gamma quanta interacted in scintillator strips (8),
- provding a tomographic picture from a set of reconstructed LOR lines and the location of annihilation points along these lines determined for the selected events,

- and wherein the scintillator strips (8) are made of plastic doped with atoms with atomic number of at least 50.

8. The method according to claim 7, further comprising converting the amplitude and time of emergence of signals to digits, which are sent to the computer in binary form (4), and reconstructing on its basis the distribution of density of radioactive marker in the patient's body.

9. The method according to claim 7, **characterized in that** it is used in positron emission tomography.

10. The use of the device as defined in claims 1 to 6 in positron emission tomography.

Patentansprüche

1. Streifenvorrichtung zur Orts- und Reaktionszeitbestimmung von Gammaquanten, wobei die Vorrichtung eine Szintillationskammer umfasst, wobei die Szintillationskammer (1) eine innere zylindrische Oberfläche aufweist, an der eine Mehrzahl von Szintillatorstreifen (8) angeordnet ist, wobei die Oberflächen der Szintillatorstreifen (8) so konfiguriert sind, dass sie Photonen reflektieren, die von der Innenseite der Szintillationskammer in einem Winkel fallen, der größer ist als ein Grenzwinkel, wobei jeder Szintillatorstreifen mit Photomultipliern (11) optisch verbunden ist, um über Lichtleiter (10) Lichtphotonen zu empfangen, resultierend aus einem in Szintillatormaterial absorbierten Gammaquant, wobei die Energie des Gammaquant mittels photoelektrischem Effekt vollständig oder mittels Compton-Effekt teilweise zu einem Elektron des Szintillators übertragen wird, welche die vordere oder die hintere Kante des Streifens (8) erreichen, und wobei die Vorrichtung ferner ein elektronisches System zur Ortsbestimmung von Annihilationspunkten entlang LOR-Linien umfasst, wobei das System **dadurch gekennzeichnet ist, dass** es:

- Ereignisse auswählt, für welche Signale innerhalb eines festen Zeitintervalls in einem Paar von Szintillatorstreifen (8), die mit einem relativen Zwischenabstand angeordnet sind, registriert werden;
- und für jedes ausgewählte Ereignis:

- den Auftreffpunkt des Gammaquant in einer Ebene bestimmt, die senkrecht zu der Längsachse des Szintillatorstreifens (8) von der Position des Szintillatorstreifens (8) ist, welcher das Signal registriert hat;
- und für jeden Szintillatorstreifen (8) des Paars von Szintillatorstreifen (8), der ein Signal für das ausgewählte Ereignis registriert hat:
- die Auftreffposition in dem Szintillatorstreifen (8) entlang der Szintillationskammer auf der Basis der Zeitdifferenz (t_front - t_back) zwischen der in dem vorderen Photomultiplier (11) gemessenen Zeit (t_front) und der in dem hinteren Photomultiplier (11) des Szintillatorstreifens (8) gemessenen Zeit (t_back) bestimmt;
- die Zeit (t1, t2), wenn ein Gammaquant in jedem Szintillatorstreifen (8) interagiert hat, als arithmetisches Mittel der in dem vorderen Photomultiplier (11) gemessenen Zeit (t_front) und der in dem hinteren Photomultiplier (11) jedes Szintillatorstreifens (8) gemessenen Zeit (t_back) bestimmt;
- die Energie des Elektrons des Szintillators bestimmt, zu dem die Energie des Gammaquant durch Compton- oder photoelektrischen Effekt übertragen worden ist, auf der Basis der Amplituden der Signale in den Photomultipliern (11) auf beiden Seiten der Szintillatorstreifen (8);

- und für jedes ausgewählt Ereignis:

- die LOR-Linie auf der Basis der bestimmten Positionen des Auftreffpunkts in den beiden Szintillatorstreifen (8) des Paars von Szintillatorstreifen (8) bestimmt;
- den Ort der Annihilation entlang der LOR-Linie auf der Basis der bestimmten Zeiten (t1, t2) bestimmt, wenn Gammaquanten in Szintillatorstreifen (8) interagiert haben;
- ein tomographisches Bild aus einer Gruppe rekonstruierter LOR-Linien und der Position von Annihilationspunkten entlang dieser Linien bereitstellt, die für die ausgewählten Ereignisse bestimmt worden sind;
- und wobei die Szintillatorstreifen (8) aus Kunststoff bestehen, dotiert mit Atomen mit einer Atomzahl von mindestens 50.

2. Vorrichtung nach Anspruch 1, **dadurch gekennzeichnet, dass** das Material des Lichtleiters so ausgewählt ist, dass dessen Brechungsindex dem Brechungsindex des Szintillators möglichst ähnlich ist, wobei ähnliche Lichtkoeffizienten die Reflexionen von Photonen in der Verbindungsregion minimieren.

3. Vorrichtung nach Anspruch 1 oder 2, **dadurch gekennzeichnet, dass** die erzeugten Lichtimpulse durch Photomultiplier (IJ), die optisch mit dem Lichtleiter gekoppelt sind, in elektrische Signale umgewandelt werden, und wobei die Photomultiplier (U) an der Montageplatte (15) angebracht sind, die an dem Gehäuse der ganzen Einheit (2) angebracht ist.

4. Vorrichtung nach Anspruch 1 oder 2, **dadurch gekennzeichnet, dass** die Kopplung des Lichtleiters mit dem Photomultiplier (11) unter Verwendung von Gels oder Silikonkautschuk erfolgt.

5. Vorrichtung nach Anspruch 1 oder 2, **dadurch gekennzeichnet, dass** die Streifen (8) optisch voneinander getrennt sind, vorzugsweise unter Verwendung von lichtdichter Folie.

6. Vorrichtung nach Anspruch 1 oder 2, **dadurch gekennzeichnet, dass** jeder Streifen (8) separat gewickelt ist.

7. Verfahren zur Orts- und Reaktionszeitbestimmung von Gammaquanten in einer Vorrichtung, die eine Szintillationskammer umfasst, wobei die Szintillationskammer (1) eine innere zylindrische Oberfläche aufweist, an der eine Mehrzahl von Szintillatorstreifen (8) angeordnet ist, wobei die Oberflächen der Szintillatorstreifen (8) so konfiguriert sind, dass sie Photonen reflektieren, die von der Innenseite der Szintillationskammer in einem Winkel fallen, der größer ist als ein Grenzwinkel, wobei die Streifen (8) optisch voneinander getrennt sind, wobei jeder Szintillatorstreifen mit Photomultipliern (11) optisch verbunden ist, um über Lichtleiter (10) Photonen zu empfangen, resultierend aus einem in dem Szintillatormaterial absorbierten Gammaquant, wobei die Energie des Gammaquant mittels photoelektrischem Effekt vollständig oder mittels Compton-Effekt teilweise zu einem Elektron des Szintillators übertragen wird, welche die vordere oder die hintere Kante des Streifens (8) erreichen, wobei das Verfahren **dadurch gekennzeichnet ist, dass** es die Anordnung Annihilationspunkte entlang LOR-Linien umfasst durch:

   - Auswählen von Ereignissen, für welche Signale innerhalb eines festen Zeitintervalls in einem Paar von Szintillatorstreifen (8), die mit einem relativen Zwischenabstand angeordnet sind, registriert werden;
   - und für jedes ausgewählte Ereignis:

     - Bestimmen des Auftreffpunkts des Gammaquant in einer Ebene, die senkrecht zu der Längsachse des Szintillatorstreifens (8) von der Position des Szintillatorstreifens (8) ist, welcher das Signal registriert hat;
     - und für jeden Szintillatorstreifen (8) des Paars von Szintillatorstreifen (8), der ein Signal für das ausgewählte Ereignis registriert hat:
     - Bestimmen der Auftreffposition in dem Szintillatorstreifen (8) entlang der Szintillationskammer auf der Basis der Zeitdifferenz (t_front - t_back) zwischen der in dem vorderen Photomultiplier (11) gemessenen Zeit (t_front) und der in dem hinteren Photomultiplier (11) des Szintillatorstreifens (8) gemessenen Zeit (t_back);
     - Bestimmen der Zeit (t1, t2), wenn ein Gammaquant in jedem Szintillatorstreifen (8) interagiert hat, als arithmetisches Mittel der in dem vorderen Photomultiplier (11) gemessenen Zeit (t_front) und der in dem hinteren Photomultiplier (11) jedes Szintillatorstreifens (8) gemessenen Zeit (t_back);
     - Bestimmen der Energie des Elektrons des Szintillators, zu dem die Energie des Gammaquant durch Compton- oder photoelektrischen Effekt übertragen worden ist, auf der Basis der Amplituden der Signale in den Photomultipliern (11) auf beiden Seiten der Szintillatorstreifen (8);

   - und für jedes ausgewählt Ereignis:

     - Bestimmen der LOR-Linie auf der Basis der bestimmten Positionen des Auftreffpunkts in den beiden Szintillatorstreifen (8) des Paars von Szintillatorstreifen (8);
     - Bestimmen des Orts der Annihilation entlang der LOR-Linie auf der Basis der bestimmten Zeiten (t1, t2), wenn Gammaquanten in Szintillatorstreifen (8) interagiert haben;
     - Bereitstellen eines tomographischen Bilds aus einer Gruppe rekonstruierter LOR-Linien und der Position von Annihilationspunkten entlang dieser Linien, die für die ausgewählten Ereignisse bestimmt worden sind;
     - und wobei die Szintillatorstreifen (8) aus Kunststoff bestehen, dotiert mit Atomen mit einer Atomzahl von mindestens 50.

8. Verfahren nach Anspruch 7, wobei dieses ferner das Umwandeln der Amplitude und der Zeit des Signalemersion in Zeichen umfasst, die in binärer Form (4) an den Computer übermittelt werden, und das Rekonstruieren der Dichteverteilung radioaktiver Marker in dem Patientenkörper auf deren Basis.

9. Verfahren nach Anspruch 7, **dadurch gekennzeichnet, dass** es in der Positronemissionstomographie eingesetzt wird.

10. Einsatz der Vorrichtung nach einem der Ansprüche 1 bis 6 in der Positronenemissionstomographie.

Revendications

1. Dispositif à bande pour déterminer l'emplacement et le temps de la réaction du quantum gamma, le dispositif comprenant une chambre à scintillation, dans lequel la chambre à scintillation (1) a une surface cylindrique interne sur laquelle est disposée une pluralité de bandes de scintillateur (8), dans lequel les surfaces des bandes de scintillateur (8) sont conçues pour refléter les photons tombant sur elles à partir de l'intérieur de la chambre à scintillation à un angle supérieur à un angle limite, chaque bande de scintillateur étant connectée optiquement à des photomultiplicateurs (11) pour recevoir, par l'intermédiaire de guides de lumière (10), des photons de lumière, résultant du quantum gamma absorbé dans le matériau de scintillateur, dans lequel l'énergie du quantum gamma est transférée entièrement à un électron du scintillateur par l'intermédiaire de l'effet photoélectrique ou partiellement par l'intermédiaire d'un effet Compton, qui atteignent l'avant ou le bord arrière de la bande (8), et dans lequel le dispositif comprend en outre un système électronique pour déterminer l'emplacement de points d'annihilation le long de lignes LOR, le système étant **caractérisé en ce qu'**il est conçu pour :

sélectionner les événements pour lesquels les signaux sont enregistrés dans un intervalle de temps fixe dans une paire de bandes de scintillateur (8) espacées d'une distance relative,
et pour chaque événement sélectionné,

déterminer le point d'impact du quantum gamma dans un plan perpendiculaire à l'axe longitudinal de la bande de scintillateur (8) à partir de la position de la bande de scintillateur (8) qui a enregistré le signal,

et pour chaque bande de scintillateur (8) de la paire de bandes de scintillateur (8) qui a enregistré un signal pour l'événement sélectionné :

déterminer la position d'impact dans la bande de scintillateur (8) le long de la chambre à scintillation sur la base de la différence de temps (t_front - t_back) entre le temps (t_front) mesuré dans le photomultiplicateur avant (11) et le temps (t_back) mesuré dans le photomultiplicateur arrière (11) de la bande de scintillateur (8),
déterminer le temps (t1, t2) pendant lequel le quantum gamma a interagi dans chaque bande de scintillateur (8) comme la moyenne arithmétique du temps (t_front) mesuré dans le photomultiplicateur avant (11) et le temps (t_back) mesuré dans le photomultiplicateur arrière (11) de chaque bande de scintillateur (8),
déterminer l'énergie de l'électron du scintillateur auquel l'énergie du quantum gamma a été transférée au moyen de l'effet Compton ou photoélectrique, sur la base d'amplitudes de signaux dans les photomultiplicateurs (11) des deux côtés des bandes de scintillateur (8),

et pour chaque événement sélectionné :

déterminer la ligne LOR sur la base des positions déterminées du point d'impact dans les deux bandes de scintillateur (8) de la paire de bandes de scintillateur (8),
déterminer le lieu d'annihilation le long de la ligne LOR sur la base des temps déterminés (t1, t2) lorsque le quantum gamma interagissait dans les bandes de scintillateur (8),
fournir une image tomographique à partir d'un ensemble de lignes LOR reconstruites et de l'emplacement des points d'annihilation le long de ces lignes déterminés pour les événements sélectionnés,

et dans lequel les bandes de scintillateur (8) sont en plastique dopé avec des atomes de numéro atomique d'au moins 50.

2. Dispositif selon la revendication 1, **caractérisé en ce que** le matériau de guide de lumière est choisi de telle sorte que son indice de réfraction soit le plus proche de l'indice de réfraction du scintillateur, alors que des coefficients

similaires de lumière minimisent les réflexions des photons dans la région de connexion.

3. Dispositif selon la revendication 1 ou 2, **caractérisé en ce que** les impulsions de lumière générées sont converties en signaux électriques au moyen de photomultiplicateurs (IJ) optiquement connectés au guide de lumière, et les photomultiplicateurs (U) sont fixés à la plaque de montage (15), qui est fixée au boîtier de l'ensemble de l'unité (2).

4. Dispositif selon la revendication 1 ou 2, **caractérisé en ce que** le couplage du guide de lumière au photomultiplicateur (11) est fait à l'aide de gels ou de caoutchouc de silicone.

5. Dispositif selon la revendication 1 ou 2, **caractérisé en ce que** les bandes (8) sont séparées les unes des autres optiquement, en utilisant de préférence une feuille étanche à la lumière.

6. Dispositif selon la revendication 1 ou 2, **caractérisé en ce que** chaque bande (8) est enveloppée séparément.

7. Procédé pour déterminer l'emplacement et le temps de la réaction du quantum gamma dans un dispositif comprenant une chambre à scintillation, dans lequel la chambre à scintillation (1) a une surface cylindrique interne sur laquelle est disposée une pluralité de bandes de scintillateur (8), dans lequel les surfaces des bandes de scintillateur (8) sont conçues pour refléter les photons tombant sur elles à partir de l'intérieur de la chambre à scintillation à un angle supérieur à un angle limite, tandis que les bandes (8) sont séparées les unes des autres optiquement, chaque bande de scintillateur étant connectée optiquement à des photomultiplicateurs (11) pour recevoir, par l'intermédiaire des guides de lumière (10), des photons résultant de l'absorption du quantum gamma absorbé dans le matériau de scintillateur, dans lequel l'énergie du quantum gamma est transférée entièrement à un électron du scintillateur par l'intermédiaire de l'effet photoélectrique ou partiellement par l'intermédiaire d'un effet Compton, qui atteignent l'avant ou le bord arrière de la bande (8), dans lequel le procédé est **caractérisé en ce qu'**il comprend la localisation des points d'annihilation le long de lignes LOR par les étapes consistant à :

    sélectionner les événements pour lesquels les signaux sont enregistrés dans un intervalle de temps fixe dans une paire de bandes de scintillateur (8) espacées d'une distance relative,
    et pour chaque événement sélectionné,

        déterminer le point d'impact du quantum gamma dans un plan perpendiculaire à l'axe longitudinal de la bande de scintillateur (8) à partir de la position de la bande de scintillateur (8) qui a enregistré le signal,

    et pour chaque bande de scintillateur (8) de la paire de bandes de scintillateur (8) qui a enregistré un signal pour l'événement sélectionné :

        déterminer la position d'impact dans la bande de scintillateur (8) le long de la chambre à scintillation sur la base de la différence de temps (t_front - t_back) entre le temps (t_front) mesuré dans le photomultiplicateur avant (11) et le temps (t_back) mesuré dans le photomultiplicateur arrière (11) de la bande de scintillateur (8),
        déterminer le temps (t1, t2) pendant lequel le quantum gamma a interagi dans chaque bande de scintillateur (8) comme la moyenne arithmétique du temps (t_front) mesuré dans le photomultiplicateur avant (11) et le temps (t_back) mesuré dans le photomultiplicateur arrière (11) de chaque bande de scintillateur (8),
        déterminer l'énergie de l'électron du scintillateur auquel l'énergie du quantum gamma a été transférée au moyen de l'effet Compton ou photoélectrique, sur la base d'amplitudes de signaux dans les photomultiplicateurs (11) des deux côtés des bandes de scintillateur (8),

    et pour chaque événement sélectionné :

        déterminer la ligne LOR sur la base des positions déterminées du point d'impact dans les deux bandes de scintillateur (8) de la paire de bandes de scintillateur,
        déterminer le lieu d'annihilation le long de la ligne LOR sur la base des temps déterminés (t1, t2) lorsque le quantum gamma interagissait dans les bandes de scintillateur (8),
        fournir une image tomographique à partir d'un ensemble de lignes LOR reconstruites et de l'emplacement des points d'annihilation le long de ces lignes déterminées pour les événements sélectionnés,

    et dans lequel les bandes de scintillateur (8) sont en plastique dopé avec des atomes de numéro atomique d'au moins 50.

8. Procédé selon la revendication 7, comprenant en outre les étapes consistant à convertir l'amplitude et le temps d'émergence de signaux en chiffres, qui sont envoyés à l'ordinateur sous forme binaire (4), et à reconstruire sur sa base la répartition de densité de marqueur radioactif dans le corps du patient.

9. Procédé selon la revendication 7, **caractérisé en ce qu'**il est utilisé dans la tomographie par émission de positrons.

10. Utilisation du dispositif selon les revendications 1 à 6 dans la tomographie par émission de positrons.

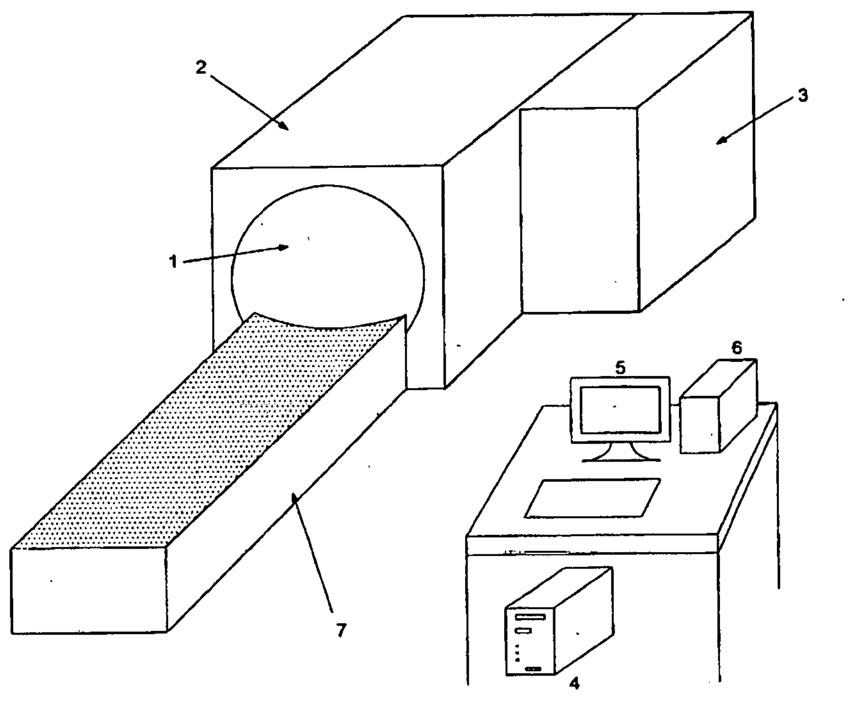

Fig. 1

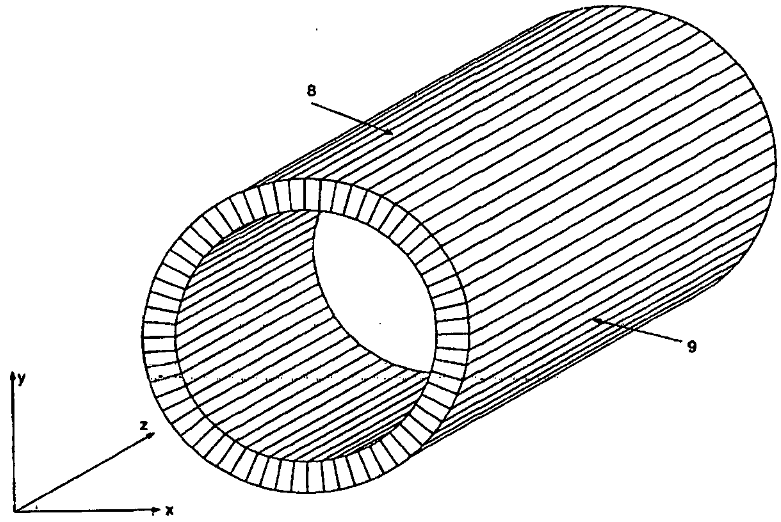

Fig. 2

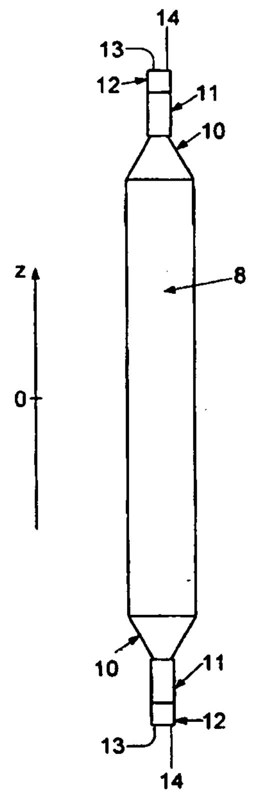

Fig. 3

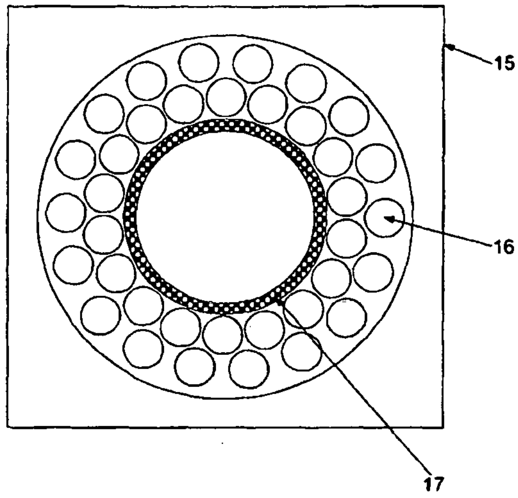

Fig. 4a

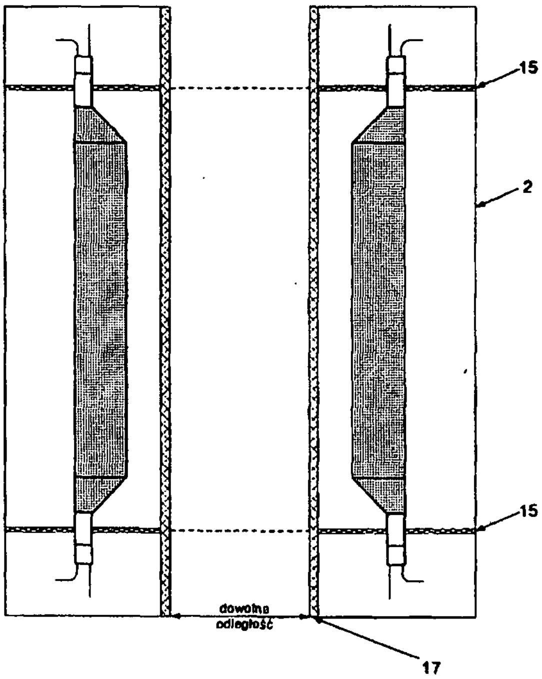

Fig. 4b

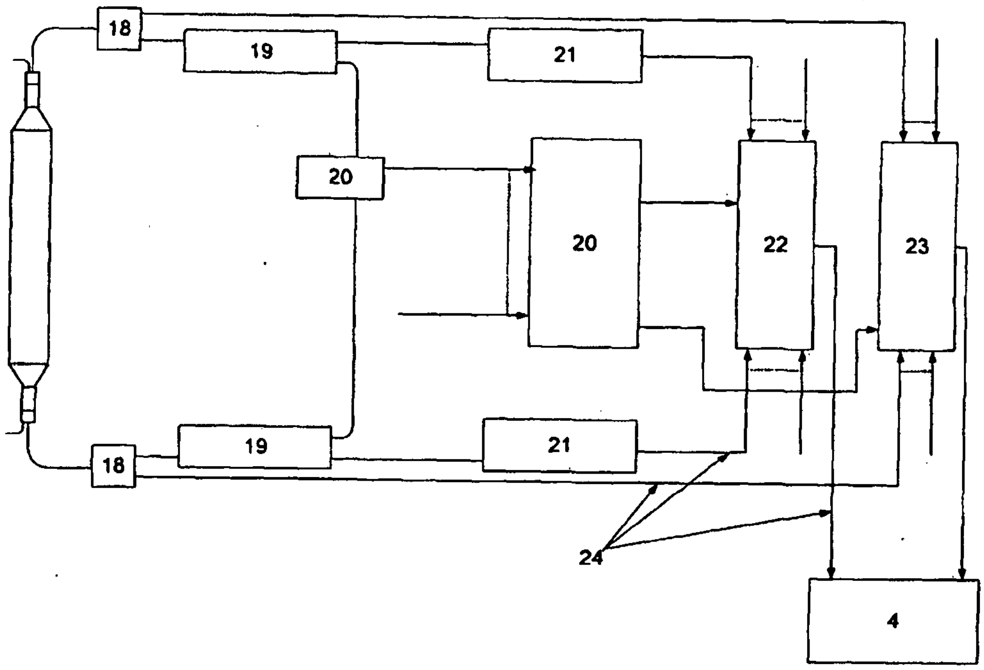

Fig. 5

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