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(54) MATRIX 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

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

DISPOSITIF À MATRICE ET PROCÉDÉ POUR DÉTERMINER LE LIEU ET LE TEMPS DE RÉACTION DES QUANTAS 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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Description

[0001] The subject matter of the invention are a matrix 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. 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] A French patent application FR2925698A1 discloses a device for determining the location and time of interaction of gamma quanta, the device comprising a scintillation chamber. The scintillation chamber contains crystal scintillator bars , wherein a surface of the scintillation bars is configured to reflect photons incident to the surface from the inside of the scintillation chamber at an angle greater than the a boundary angle. Each bar comprises photodetectors on its ends and along its length. The resulting light pulses are converted into electrical signals by means of photodetectors . The device further comprises an electronic system configured to determine the location of quantum reaction in a plane of the scintillation plate and to determine the depth of gamma quantum interaction (DOI) and LOR lines. The system is further configured to define the point of annihilation along the LOR line and to provide a tomographic picture from the delivered set of the reconstructed LOR lines and the location of annihilation points along these lines. The photomultipliers are connected optically to the scintillator strip, which results in that some photons (which impact the scintillator side at a point between the photomultipliers at an angle within a cone formed by a ray emitted at a critical angle) exit the scintillator without being detected by the photomultipliers. Such photons are lost and deteriorate the precision of measurement.

[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 matrix device for determining the location and time of interaction of gamma quanta and a method for determining the location and time of interaction of gamma quanta according to the appended claims.

[0013] Preferably, when the voltage is distributed to the photomultiplier dynodes by the voltage dividers, which are matched to the type of photomultiplier, and that the voltage divider is supplied via voltage cables by the power supply placed in the housing for the electronics adjacent to the casing of photomultipliers, and signals from the photomultipliers are delivered to electronic circuits using signal cables.

[0014] Preferably, the scintillation plates are connected by an optical cement whose refractive index is similar to the refractive index of the material from which the scintillator plates are made, while similar refractive indexes minimize the reflection of photons in the place of connection.

[0015] Preferably, the scintillator plates are separated from the interior chamber with a lightproof foil.

[0016] Preferably, when the plastic cover is seen from the patient's side.

[0017] Preferably, the walls of photomultipliers can be divided into the right (P), left (L), top (G) and bottom (D), and registering the light in front (F) and rear (T) part.

[0018] Preferably, when the device is presented in Figures 1 to 7.

[0019] The next subject of the invention is a method to determine the location and time of interaction of gamma quantum, characterized in that the surface of the scintillator plate reflects photons incident to the surface from the inside at an angle greater than the so-called boundary angle, and in that the photomultipliers constitute a detector wall registering on each side light pulses emerging from the scintillator plates, and also in that the resulting light pulses are converted into electrical signals by means of matrix of photomultipliers situated between scintillation plates and casing of the whole device, while photons of light, resulting from absorption of the gamma quantum in the scintillator material that reach the surface of the plate at an angle smaller then the boundary angle fly out and are registered by the photomultipliers surrounding the scintillation chamber, and in the first step of data analysis those events are selected for which signals were registered in at least three side layers and in front (F) and back (T) layer of photomultipliers and then for further processing only those signals are taken, which appeared within a fixed time interval, after which the location of quantum reaction in a plate plane is determined, whereupon based on the distribution of amplitudes of the signals in side photomultipliers the depth of gamma quantum interaction (DOI) and LOR lines are determined, where on the basis of the point of annihilation and knowledge about amplitudes and times of signals registered by photomultipliers one determines the energy deposited in the scintillation material by gamma quantum and the time of reaction, one calculates the location of annihilation along the LOR line, one determines the point of annihilation, whereupon the delivered set of reconstructed LOR lines and the location of annihilation points along these lines provides a tomographic picture.

[0020] Preferably, when a layer of air is left between the photomultipliers and scintillation chamber, and that light signals are registered by a larger number of photomultipliers due to refraction of the line of light coming out of the scintillation plate into the air.

[0021] Preferably, when the electronic circuit converts the amplitude and time of emergence of signals to digits, which are sent to the computer in binary form, where on its basis the distribution of density of radioactive marker in the patient's body is reconstructed. Preferably, when the location of quantum reaction in a plate plane (x-y) is determined with three independent methods based on the position of the photomultipliers and on amplitudes of the signals from the front (F) and rear (R) photomultiplier layers, on amplitudes of signals from side photomultiplier layers, on time of photomultiplier signals from the front and back layers while as the final result the average weighted with appropriate measurement uncertainties is taken.

[0022] Preferably, when one determines the depth of gamma quantum interaction (DOI) from the distribution of signal amplitudes in the photomultipliers in side panels of the plates, where on the basis of the point of reaction and knowledge about amplitudes and times of signals registered by photomultipliers one determines the energy deposited in the scintillation material by gamma quantum and the time of reaction, one calculates the location of annihilation along the LOR line, whereupon the delivered set of reconstructed LOR lines and the location of annihilation points along these lines provides a tomographic picture. Preferably, when the energy deposited by gamma quantum in scintillator material and the reaction time is determined taking into account the total number of photomultipliers, which gave a signal due to the reaction of the gamma quantum, the distance between the point of the reaction and the middle of photomultiplier window (Δr_i), the calibration constant (ν_S) corresponding to the speed of the light signal in the scintillator, and the calibration constant (λ) indicating attenuation of signal, uncertainty of determination of the amplitude (σ).

[0023] Preferably, when it is used in Positron Emission Tomography.

[0024] The next subject of the invention is application of the device as described above in positron emission tomography.

[0025] The attached figure provides a better explanation of the substance of a solution, whereby:

figure 1 shows a general scheme of the device, which consists of a scintillation chamber, into which the patient, after inserting the radio-pharmaceuticals, is placed 7;

figure 2 shows a sample arrangement of scintillation plate 8;

figure 3 shows the photomultipliers 10, which form the detection walls registering on each side the light pulses emerging out of the scintillation chamber;

figure 4 shows a sample photomultiplier mounting, while **figure 4a** presents a set of photomultiplier and voltage divider, and **figure 4b** a part of the plate 11 for mounting the photomultiplier;

figure 5 shows a horizontal section of the scintillation chamber with casing 2 and photomultiplier 10;

figure 6 shows exemplary light-proof photomultiplier attachment to mounting plate with the handle connected to the photomultiplier tube;

figure 7 shows an exemplary logic diagram of the electronic system, which allows to obtain the information about amplitude and time of the impulses generated by photomultipliers.

[0026] Where various markings on the figures indicate:

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 plates, 9 - plates are connected by an optical cement whose refractive index is similar to the refractive index of the scintillator n ≈ 1,58, 10 - photomultiplier, while 10 D, 10 G, 10 P, 10 L, 10 F, 10 T - are the lower, upper, right, left, front and rear wall of photomultipliers, 11 - plate for mounting photomultipliers, 12 - frame for fixing the scintillation chamber, 13 - layer of air, 14 - voltage divider, 15, 16 - high voltage cables and signal cables; where 15 - power cable, 16 - signal cable, 17 - light-proof foil, 18 - plastic shield of the inside of the scintillation chamber, 19 - bracket, 20 - photomultiplier shield, 21 - seal, 22 - bolt, 23 - light-proof exit of power and signal cables, 24 - signal cables, 25 - system for signals separation, 26 - time-delay system, 27 - ADC - charge-to-digit converter, 28 - TDC - time-to-digit converter, 29 - multichannel discriminator, 30 - system to count the multiplicity of signals, 31 - coincidence system.

[0027] For a better understanding of the solutions below an exemplary embodiment of the invention is presented.

Example

[0028] 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 matrix of photomultipliers located 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 the 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 (18).

[0029] 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 plates (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. Plates are connected by an optical cement (9) whose refractive index is similar to the refractive index of the material from which the scintillation plates are made. Similar coefficients of light minimize the reflection of photons in the place of connection. Photons of light, resulting from absorption of the gamma quantum in the scintillator material that reach the surface of the plate at an angle smaller then the boundary angle fly out and are registered by the photomultipliers surrounding the scintillation chamber.

[0030] As illustrated in figure 3, the photomultipliers 10 constitute detection walls registering from each side light pulses going out from the scintillation chamber. Walls of photomultipliers could be divided into: the side right (10 P), and left (10 L), upper (10 G) and lower (10 D), and recording the light in front (10 F) and rear (10 T).

[0031] In Figure 4 the lower-right corner of the device is shown as an example of photomultipliers mounting.

[0032] Photomultipliers are attached to the mounting plate 11, which is attached to the housing which shelter and maintain the entire device 2. To this housing also a frame 12 is attached, in which scintillator plate are embedded 8. The mounting plate for supporting of the photomultipliers has a net of cutted holes, whose size and shape are matched to the size of photomultipliers and the shape of the casing, and the relative arrangement and distance can be optimize in view of the required resolution and cost of the device. Between the photomultipliers and scintillation plates air layer is left 13. It causes, due to refraction of the line of light coming out of the scintillation plate into the air, that light signals are registered by a larger number of photomultipliers, which consequently contributes to the improvement of spatial resolution of the device. Voltage to the photomultiplier dynodes 10 is distributed by the voltage dividers 14, which are matched to the type of photomultiplier. The voltage divider 14 is supplied via voltage cables 15 by the power supply placed in the housing for the electronics adjacent to the casing of photomultipliers, labeled as 3 in Fig. 1. Signals from the photomultipliers are delivered to electronic circuits using signal cables 16.

[0033] Scintillation chamber must be optically isolated from the room in which the tomograph operates. Therefore, both the photomultipliers mounting and mounting of the plastic inner of the chamber have to be light-proof. Exemplary schematic solutions are shown in Figures 5 and 6.

[0034] Figure 5 shows horizontal section through the scintillation chamber with housing 2 and photomultipliers 10. Scintillation plates 8 are separated from the interior of the chamber with light-proof foil 17. The plastic cover 18 can be seen from the patient's side.

[0035] Figure 6 presents an exemplary light-proof photomultiplier mounting 10 to the plate 11 made by means of handle 19 connected to the shield of photomultiplier 20. Light-proofing is provided by seals 21.

[0036] Figure 7 shows an exemplary logic diagram of the electronic system that allows to obtain information about the amplitude and time of impulses generated by photomultipliers.

[0037] These in turn are closely connected with time and amplitude of light signals reaching the photomultipliers.

[0038] Software to analyze the data in the first step selects those events, for which signals were registered in at least three side layers and in front and back layer of photomultipliers. For further processing only those signals are taken, which appeared within a fixed time interval (several nanoseconds). Then the location of quantum reaction in a plate plane (xy) is determined with three independent methods according to formulas I, II and III, where

$$x = \alpha \cdot \frac{\sum_{i=1}^{N_F} A_F^i - \beta}{\sum_{i=1}^{N_F} A_F^i + \sum_{i=1}^{N_T} A_T^i - \gamma} \qquad \text{(formula I)},$$

where

N_F and N_T - the number of photomultipliers, which gave a signal in the front (F) and rear (T) layer,
α, β, γ - calibration constants
A^i_F - amplitude of signal of the ith photomultiplier in the front layer,
A^i_T - amplitude of signal of the ith photomultiplier in the back layer;

$$x = \frac{\sum_{i=1}^{N_P} x_i A_P^i}{\sum_{i=1}^{N_P} A_P^i} \qquad \text{(formula II)},$$

where
x_i - x coordinate of the position of ith photomultiplier in a plane P;

$$x = \left(\frac{1}{N_F} \sum_{i=1}^{N_F} t_i^F - \frac{1}{N_T} \sum_{i=1}^{N_T} t_i^T \right) \cdot v + \Delta \qquad \text{(formula III)},$$

where
v, Δ - calibration constants

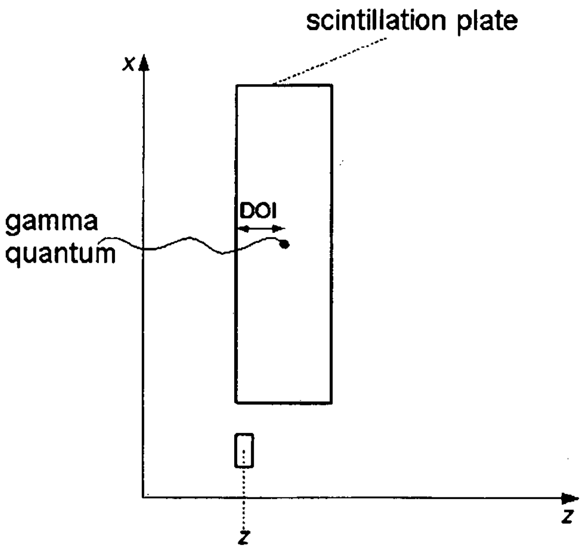
t_i^F i t_i^T - time of signal of the photomultiplier in the front and rear layer, respectively while as the final result the average weighted with appropriate measurement uncertainties is calculated.

[0039] Formulas I and II take into account information about the amplitudes of signals, while formula III uses arrival times of light signals to the photomultipliers. Formula III is based only on time information and is characteristic for this invention. Knowledge of the amplitudes distribution of signals in photomultipliers on the sides of plates allow to determine the depth of the interaction of the gamma quantum (DOI). For the calculation one use in the first approximation formula IV:

$$\mathrm{DOI} = \frac{1}{4} \left[\frac{\sum_i^{N_F} z_i A_F^i}{\sum_i^{N_F} A_F^i} + \frac{\sum_i^{N_T} z_i A_T^i}{\sum_i^{N_T} A_T^i} + \frac{\sum_i^{N_G} z_i A_G^i}{\sum_i^{N_G} A_G^i} + \frac{\sum_i^{N_D} z_i A_D^i}{\sum_i^{N_D} A_D^i} \right] \qquad \text{(formula IV)},$$

where

z_i - denotes the centre of ith photomultiplier along z axis (thickness of the plate).



[0040] Determination of the depth of interaction (DOI) of quantum is also an important feature of this invention. Knowing the coordinates r = (x, y, z) for the point of reaction for both gamma quanta r1 and r2 the LOR lines are determined.

[0041] Determination of the reaction point and knowledge of the amplitude and times of signals registered in photomultipliers allows calculation of the energy deposited by the gamma quantum in the scintillator material and time when the reaction occured. This can be roughly calculated according to formulas V and VI, where the formula V:

$$t = \frac{1}{N}\sum_{i=1}^{N} t_i - \frac{\Delta r_i}{v_s} \quad \textbf{(formula V),}$$

where

N - number of all the photomultipliers, which gave a signal by the reaction of a gamma quantum,
Δr_i - the distance between the point of the reaction and the middle of the window of the ith photomultiplier $\Delta r_i = |\vec{r} - \vec{r}_i|$
v_s - calibration constant corresponding to the speed of light of the signal in the scintillator, the formula VI:

$$E = \frac{\sum_{i=1}^{N} A_i |\Delta r|^2 \cdot e^{\frac{\Delta r}{\lambda}} / \sigma_i^2(A_i)}{\sum_{i=1}^{N} \frac{1}{\sigma_i^2(A_i)}} \quad \textbf{(formula VI),}$$

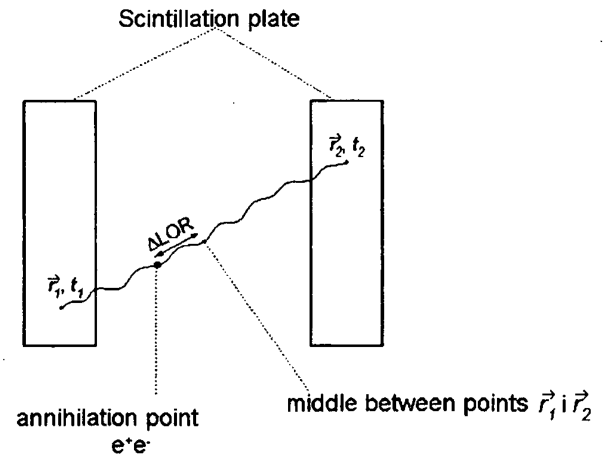
where
λ - the calibration constant denoting attenuation of the signal,
σ - uncertainty of determination of the amplitude.

[0042] Knowing r1, r2, t1 and t2 we can calculate using TOF method the point of annihilation along the LOR line from the formula VII:

$$\Delta\text{LOR} = \frac{t_2 - t_1}{2} c \quad \textbf{(formula VII),}$$

where

c - speed of light.



[0043] Then the annihilation point $\vec{r}_a$ can be determined using the formula VIII,:

$$\vec{r}_a = \frac{\vec{r_1}+\vec{r_2}}{2} + \frac{\vec{r_1}-\vec{r_2}}{|\vec{r_1}-\vec{r_2}|}\cdot \Delta \mathrm{LOR} \qquad \text{(formula VIII).}$$

[0044] The described device provides a set of reconstructed LOR lines and the position of annihilation points along these lines. Based on these data one can obtain the tomographic image using image reconstruction techniques.

Claims

1. A matrix device for determining the location and time of interaction of gamma quanta, the device comprising a scintillation chamber, **characterized in that** the scintillation chamber (1) contains scintillation plates (8) constructed out of plastic scintillator preferably doped with atoms with an atomic number of at least 50, and **in that** a surface of the scintillation plates (8) is configured to reflect photons incident to the surface from the inside of the scintillation chamber at an angle greater than the a boundary angle, and **in that** it further comprises photomultipliers (10) which constitute detector walls (10F, 10T, 10L, 10G, 10P, 10D) registering on each side (L, G, P, D) of the scintillation chamber and on the front (F) and back (T) of the scintillation chamber light pulses emerging from the scintillation chamber, and also **in that** the resulting light pulses are converted into electrical signals by means of a matrix of photomultipliers (10) forming the detector walls (10F, 10T, 10L, 10G, 10P, 10D) situated between scintillation plates (8) and a housing of the device (2), wherein the photomultipliers (10) are attached to a mounting plate (11) which is attached to the housing which shelters and maintains the entire device (2), wherein to the housing of the device (2) there is attached a frame (12) in which the scintillation plates (8) are embedded, and wherein the mounting plate (11) for supporting the photomultipliers (10) has a net of cutted holes, whose size and shape are matched to the size and shape of a casing of photomultipliers (10), and wherein between the photomultipliers (10) and the scintillation plates (8) an air layer (13) is present, and wherein the device further comprises an electronic system configured to:

    - in the first step of data analysis, to select those events for which signals were registered in at least three side layers (L, B, P, D) and in the front (F) and back (T) layer of the photomultipliers (10),
    - and then to include in further processing only those signals, which appeared within a fixed time interval,
    - and next to determine the location of quantum reaction in a plane (xy) of the scintillation plate (8) with three independent methods:

        - based on the amplitude of the signals from the front (P) and rear (T) photomultiplier layers (10),

  - based on amplitudes of signals from side photomultiplier layers (L, G, P, D),
  - and based on time of photomultiplier signals (10) from the front (P) and back (T) layers

- and to take as the final result the average weighted with appropriate measurement uncertainties,
- and to determine the depth of gamma quantum interaction (DOI) and LOR lines for two coincident gamma quanta from the distribution of signal amplitudes in the photomultipliers in side panels of the plates,
- and next to define the point of annihilation along the LOR line based on the time of signals from all the photomultipliers,
- and to provide a tomographic picture from the delivered set of the reconstructed LOR lines and the location of annihilation points along these lines.

2. The device according to claim 1, **characterized in that** voltage is distributed to photomultiplier dynodes (10) by voltage dividers (14), which are matched to the type of photomultiplier, and that the voltage divider (14) is supplied via voltage cables (15) from a power supply placed in the housing for the electronics adjacent to the casing of photomultipliers, and wherein signals from the photomultipliers are delivered to electronic circuits (3) using signal cables (16).

3. The device according to claim 1, **characterized in that** the scintillation plates (8) are connected by an optical cement (9) whose refractive index is similar to the refractive index of the material from which the scintillation plates (8) are made, while similar refractive indexes minimize the reflection of photons in the place of connection.

4. The device according to claim 1, **characterized in that** the scintillation plates (8) are separated from the interior chamber with a light-proof foil (17).

5. The device according to claim 1, **characterized in that** a plastic cover (8) can be seen from the patient's side.

6. The device according to claim 1, **characterized in that** the scintillator walls comprise a right (P), left (L), top (G) and bottom (D) wall, and walls registering the light in front (F) and rear (T) part.

7. A method for determining the location and time of interaction of gamma quanta, **characterized in that** the method is performed by using a matrix device according to claim 1.

8. The method according to claim 7, **characterized in that** an electronic circuit converts the amplitude and time of emergence of signals to digits, which are sent to the computer (4) in binary form, where on their basis the distribution of density of radioactive marker in the patient's body is reconstructed.

9. The method according to claim 7, **characterized in that** one determines the depth of gamma quantum interaction (DOI) from the distribution of signal amplitudes in the photomultipliers (10) in side panels of the plates, where on the basis of the point of reaction and knowledge about amplitudes and times of signals registered by photomultipliers (10) one determines the energy deposited in the scintillation material by gamma quantum and the time of reaction, one calculates the location of annihilation along the LOR line, whereupon the delivered set of reconstructed LOR lines and the location of annihilation points along these lines provides a tomographic picture.

10. The method according to claim 7, **characterized in that** the energy deposited by gamma quantum in scintillator material and the reaction time is determined taking into account the total number of photomultipliers (10), which gave a signal due to the reaction of one gamma quantum, the distance between the point of the reaction and the middle of photomultiplier window (Δri), the calibration constant (v_s) corresponding to the speed of the light signal in the scintillator, and the calibration constant (λ) indicating attenuation of signal, uncertainty of determination of the amplitude (σ).

11. The method according to any of claims from 7 to 8, **characterized in that** it is used in positron emission tomography.

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

Patentansprüche

1. Matrixvorrichtung zum Bestimmen des Ortes und der Zeit einer Interaktion von Gammaquanten, wobei die Vorrichtung eine Szintillationskammer umfasst, **dadurch gekennzeichnet, dass** die Szintillationskammer (1) Szintillationsplatten (8) enthält, die aus Plastikszintillator aufgebaut sind, der vorzugsweise mit Atomen dotiert ist, die eine Atomzahl von mindestens 50 aufweisen, und dadurch, dass eine Oberfläche der Szintillationsplatten (8) so gestaltet ist, dass sie Photonen reflektiert, die aus dem Inneren der Szintillationskammer in einem Winkel, der größer ist als ein Grenzwinkel, auf die Oberfläche auftreffen, und dadurch, dass sie ferner Photovervielfacher (10) umfasst, die Detektorwände (10F, 10T, 10L, 10G, 10P, 10D) bilden, die auf jeder Seite (L, G, P, D) der Szintillationskammer Lichtimpulse registrieren, die aus der Szintillationskammer kommen, und außerdem dadurch, dass die resultierenden Lichtimpulse mittels einer Matrix aus Photovervielfachern (10), welche die Detektorwände (10F, 10T, 10L, 10G, 10P, 10D) bilden und welche zwischen Szintillationsplatten (8) und einem Gehäuse der Vorrichtung (2) angeordnet sind, in elektrische Signale umgewandelt werden, wobei die Photovervielfacher (10) an einer Befestigungsplatte (11) befestigt sind, die am Gehäuse angebracht ist und die gesamte Vorrichtung (2) schützt und hält, wobei am Gehäuse der Vorrichtung (2) ein Rahmen (12) angebracht ist, in dem die Szintillationsplatten (8) eingebettet sind, und wobei die Befestigungsplatte (11), welche die Photovervielfacher (10) trägt, ein Netz aus Einschnitten aufweist, deren Größe und Form der Größe und Form eines Gehäuses von Photovervielfachern (10) entspricht, und wobei zwischen den Photovervielfachern (10) und den Szintillationsplatten (8) eine Luftschicht (13) vorhanden ist, und wobei die Vorrichtung ferner ein elektronisches System umfasst, dass so gestaltet ist, dass es:

- im ersten Schritt einer Datenanalyse diejenigen Ereignisse auswählt, für die Signale in mindestens drei Seitenschichten (L, B, P, D) und in der vorderen (F) und hinteren (T) Schicht der Photovervielfacher (10) registriert worden sind,
- und dann in eine weitere Verarbeitung nur diejenigen Signale einbezieht, die innerhalb eines festgelegten Zeitintervalls erschienen sind,
- und dann den Ort einer Quantenreaktion in einer Ebene (xy) der Szintillationsplatte (8) mit drei unabhängigen Verfahren bestimmt:

    - basierend auf der Amplitude der Signale von den vorderen (P) und hinteren (T) Photovervielfacherschichten (10),
    - basierend auf Amplituden von Signalen von seitlichen Photovervielfacherschichten (L, G, P, D),
    - und basierend auf der Zeit der Photovervielfachersignale (10) aus den vorderen (P) und hinteren (T) Schichten,

- und als Endergebnis den Durchschnitt nimmt, der mit geeigneten Messungenauigkeiten gewichtet ist,
- und die Tiefe der Gammaquanteninteraktion (DOI) und die LOR-Linien für zwei koinzidente Gammaquanten aus der Verteilung der Singalamplituden in den Photovervielfachern in Seitenfeldern der Platten bestimmt,
- und dann den Punkt der Vernichtung entlang der LOR-Linie auf Basis der Zeit von Signalen aus sämtlichen Photovervielfachern definiert,
- und ein tomographisches Bild des gelieferten Satzes der rekonstruierten LOR-Linien und den Ort der Vernichtungspunkte entlang dieser Linien ausgibt.

2. Vorrichtung nach Anspruch 1, **dadurch gekennzeichnet, dass** von Spannungsteilern (14), die auf die Art des Photovervielfachers abgestimmt sind, eine Spannung an Photovervielfacherdioden (10) verteilt wird, und dass der Spannungsteiler (14) über Spannungskabel (15) aus einer Leistungsquelle versorgt wird, die im Gehäuse für die Elektronik angeordnet ist, die an das Gehäuse von Photovervielfachern angrenzt, und wobei Signale aus den Photovervielfachern unter Verwendung von Signalkabeln (16) an elektronische Schaltungen (3) geliefert werden.

3. Vorrichtung nach Anspruch 1, **dadurch gekennzeichnet, dass** die Szintillationsplatten (8) durch einen optischen Zement (9) verbunden sind, dessen Brechungsindex dem Brechungsindex des Materials ähnelt, aus dem die Szintillationsplatten (8) bestehen, während ähnliche Brechungsindizes die Reflexion von Photonen an der Verbindungsstelle minimieren.

4. Vorrichtung nach Anspruch 1, **dadurch gekennzeichnet, dass** die Szintillationsplatten (8) mit einer lichtundurchlässigen Folie (17) von der Innenkammer getrennt sind.

5. Vorrichtung nach Anspruch 1, **dadurch gekennzeichnet, dass** eine Kunststoffabdeckung (8) von der Seite des Patienten aus sichtbar ist.

6. Vorrichtung nach Anspruch 1, **dadurch gekennzeichnet, dass** die Szintillatorwände eine rechte (P), eine linke (L), eine obere (G) und eine untere (D) Wand umfassen und dass die Wände das Licht im vorderen (F) und hinteren

(T) Teil registrieren.

7. Verfahren zum Bestimmen des Ortes und der Zeit einer Interaktion von Gammaquanten, **dadurch gekennzeichnet, dass** das Verfahren unter Verwendung einer Matrixvorrichtung nach Anspruch 1 durchgeführt wird.

8. Verfahren nach Anspruch 7, **dadurch gekennzeichnet, dass** eine elektronische Schaltung die Amplitude und die Zeit der Entstehung von Signalen in digitale Elemente umwandelt, die in binärer Form an den Computer (4) geschickt werden, wo auf ihrer Basis eine Verteilung der Dichte eines radioaktiven Markers im Körper des Patienten rekonstruiert wird.

9. Verfahren nach Anspruch 7, **dadurch gekennzeichnet, dass** man die Tiefe einer Gammaquanteninteraktion (DOI) aus der Verteilung von Signalamplituden in den Photovervielfachern (10) in Seitenfeldern der Platten bestimmt, wobei auf Basis der Reaktionsstelle und des Wissens um Amplituden und Zeiten von Signalen, die von den Photovervielfachern (10) registriert werden, die Energie, die durch ein Gammaquantum in das Szintillationsmaterial eingebracht wird, und die Zeit der Reaktion bestimmt werden, die Stelle der Vernichtung entlang der LOR-Linie berechnet wird, wonach der gelieferte Satz aus rekonstruierten LOR-Linien und der Ort der Vernichtungspunkte entlang dieser Linien ein tomographisches Bild liefern.

10. Verfahren nach Anspruch 7, **dadurch gekennzeichnet, dass** die Energie, die vom Gammaquantum in das Szintillationsmaterial eingebracht wird und die Reaktionszeit unter Berücksichtigung der Gesamtzahl an Photovervielfachern (10), die aufgrund der Reaktion eines Gammaquantums ein Signal ausgegeben haben, des Abstands zwischen dem Reaktionspunkt und der Mitte des Photovervielfacherfensters (Δri), der Kalibrierungskonstante (v_s), die der Geschwindigkeit des Lichtsignals im Szintillator entspricht, und der Kalibrierungskonstante (λ), die eine Dämpfung des Signals anzeigt, eine Unsicherheit der Bestimmung der Amplitude (σ), bestimmt wird.

11. Verfahren nach einem der Ansprüche 7 bis 8, **dadurch gekennzeichnet, dass** es in der Positronsemissionstomographie verwendet wird.

12. Verwendung der Vorrichtung nach einem der Ansprüche 1 bis 6 in der Positronsemissionstomographie.

Revendications

1. Dispositif de matrice pour la détermination de l'emplacement et du temps d'interaction des quanta gamma, le dispositif comprenant une chambre de scintillation, **caractérisé en ce que** la chambre de scintillation (1) comporte des plaques à scintillation (8) construites à partir de scintillateur plastique de préférence dopée avec des atomes de numéro atomique d'au moins 50, et **en ce que** la surface des plaques à scintillation (8) est configuré pour réfléchir les photons incidents à des surface de l'intérieur de la chambre de scintillation à un angle supérieur à la limite, et **en ce qu'**il comprend en outre des photomultiplicateurs (10) qui constituent des parois de détection (10F, 10T, 10L, 10G, 10P, 10D) s'inscrivant sur chaque côté (L, G, P, D) de la chambre de scintillation et à l'avant (F) et arrière (T) de la chambre de scintillation des impulsions lumineuses sortant de la chambre de scintillation, et aussi **en ce que** les impulsions de lumière résultantes sont converties en signaux électriques au moyen d'une matrice de photomultiplicateurs (10) formant les parois de détection (10F, 10T, 10L, 10G, 10P, 10D) situées entre des plaques à scintillation (8) et un boîtier de l'appareil (2), dans lequel les photomultiplicateurs (10) sont fixés à une plaque de montage (11) qui est fixé au boîtier et qui maintient abris l'ensemble du dispositif (2), dans lequel le boîtier de l'appareil (2) est fixé un châssis (12) dans laquelle les plaques à scintillation (8) sont noyées, et dans lequel des plaque de montage (11) pour supporter les photomultiplicateurs (10) présente un filet de trous découpés, dont la forme et la taille sont adaptées à la taille et la forme d'un boîtier de photomultiplicateurs (10), et dans lequel entre les photomultiplicateurs (10) et les plaques à scintillation (8) une couche d'air (13) est présent, et dans lequel des dispositif comprend en outre un système électronique configuré pour:

- Dans la première étape de l'analyse des données, choisir les événements pour lesquels les signaux ont été enregistrés dans au moins trois couches latérales (L, B, P, D), l'avant (F) et arrière (T), la couche de photomultiplicateurs (10),
- Et ensuite d'inclure dans un traitement ultérieur uniquement les signaux, qui apparaissent à l'intérieur d'un intervalle de temps fixe,
- Et ensuite pour déterminer l'emplacement de réaction quantique dans un plan (xy) de la plaque de scintillation (8) avec trois modes indépendants:

    - basée sur l'amplitude des signaux à partir de l'avant (P) et arrière (T) des couches de photomultiplicateurs (10),
    - basée sur l'amplitude des signaux provenant de photomultiplicateurs de couches latérales (L, G, P, D),
    - et basée sur temps de signaux de photomultiplicateurs (10) de l'avant (P) et arrière (T) des couches

- Et de prendre le résultat final à la moyenne pondérée par les incertitudes de mesure appropriée,
- Et à déterminer la profondeur d'interaction gamma quantique (DOI) et de deux lignes LOR coïncident quanta gamma à partir de la distribution des amplitudes de signal des photomultiplicateurs dans les panneaux latéraux des plaques,
- Et ensuite de définir le point de destruction le long de la ligne LOR en fonction du temps de signaux de tous les photomultiplicateurs,
- Et de donner une image tomographique de l'ensemble livré des lignes LOR reconstruits et l'emplacement des points d'annihilation le long de ces lignes.

2. Le dispositif selon la revendication 1, **caractérisé en ce que** la tension est répartie de dynodes photomultiplicateurs (10) par des diviseurs de tension (14), qui sont adaptées au type de photomultiplicateur, et que les diviseur de tension (14) est alimenté par des câbles de tension (15) à partir d'une alimentation électrique placée dans le boîtier pour les composants électroniques adjacents à l'enveloppe de photomultiplicateurs, et dans lequel les signaux provenant des photomultiplicateurs sont livrés à des circuits électroniques (3) à l'aide de câbles de signaux (16).

3. Le dispositif selon la revendication 1, **caractérisé en ce que** les plaques à scintillation (8) sont reliées par un ciment optique (9) dont l'indice de réfraction est proche de l'indice de réfraction du matériau à partir duquel les plaques de scintillation (8) sont faits, tandis que les indices de réfraction similaires minimiser la réflexion des photons dans le lieu de connexion.

4. Le dispositif selon la revendication 1, **caractérisé en ce que** les plaques à scintillation (8) sont séparées de la chambre intérieure d'un film étanche à la lumière (17).

5. Le dispositif selon la revendication 1, **caractérisé en ce qu'**un couvercle en plastique (8) peut être vu à partir du côté du patient.

6. Le dispositif selon la revendication 1, **caractérisé en ce que** les parois comprennent un scintillateur à droite (P), gauche (L), de dessus (G) et inférieure (D) paroi, et l'enregistrement des parois les lumière en avant (F) et arrière (T) partie.

7. Une méthode pour la détermination du lieu et de l'heure de l'interaction des quanta gamma, **caractérisé en ce que** le procédé est réalisé à l'aide d'un dispositif de matrice selon la revendication 1.

8. La méthode selon la revendication 7, **caractérisé en ce qu'**un circuit électronique convertit l'amplitude et le temps d'émergence de signaux de chiffres, qui sont envoyées à l'ordinateur (4) sous forme binaire, où sur la base de la distribution de densité des marqueurs radioactifs dans le corps du patient sont reconstruits.

9. La méthode selon la revendication 7, **caractérisé en ce qu'**on détermine les profondeur d'interaction gamma quantique (DOI) à partir de la distribution des amplitudes du signal dans les photomultiplicateurs (10) dans les panneaux latéraux des plaques, où, sur la base du point d'réaction et la connaissance des amplitudes et des temps de signaux émis par les photomultiplicateurs (10), on détermine l'énergie déposée dans le matériau de scintillation par gamma quantique et les temps de réaction, on calcule les position de l'annihilation le long de la ligne de LOR, après quoi l'ensemble livré de reconstruire lignes LOR et l'emplacement des points d'annihilation le long de ces lignes fournissent une image tomographique.

10. La méthode selon la revendication 7, **caractérisé en ce que** l'énergie déposée par gamma quantique en matériau scintillateur et le temps de réaction est déterminé en tenant compte du nombre total de photomultiplicateurs (10), ce qui a donné un signal dû à la réaction d'une gamma quantique, la distance entre le point de la réaction et le milieu de la fenêtre photomultiplicateur (Δri), la constante d'étalonnage (v_s) correspondant à la vitesse du signal de lumière dans le scintillateur, et la constante d'étalonnage (λ) indiquant une atténuation de signaux, incertitude de détermination de l'amplitude (a).

11. La méthode selon l'une quelconque des revendications 7-8, **caractérisé en ce qu'**il est utilisé dans la tomographie

par émission de positons.

12. L'utilisation de l'appareil tel que défini dans les revendications 1 à 6, dans la tomographie par émission de positons.

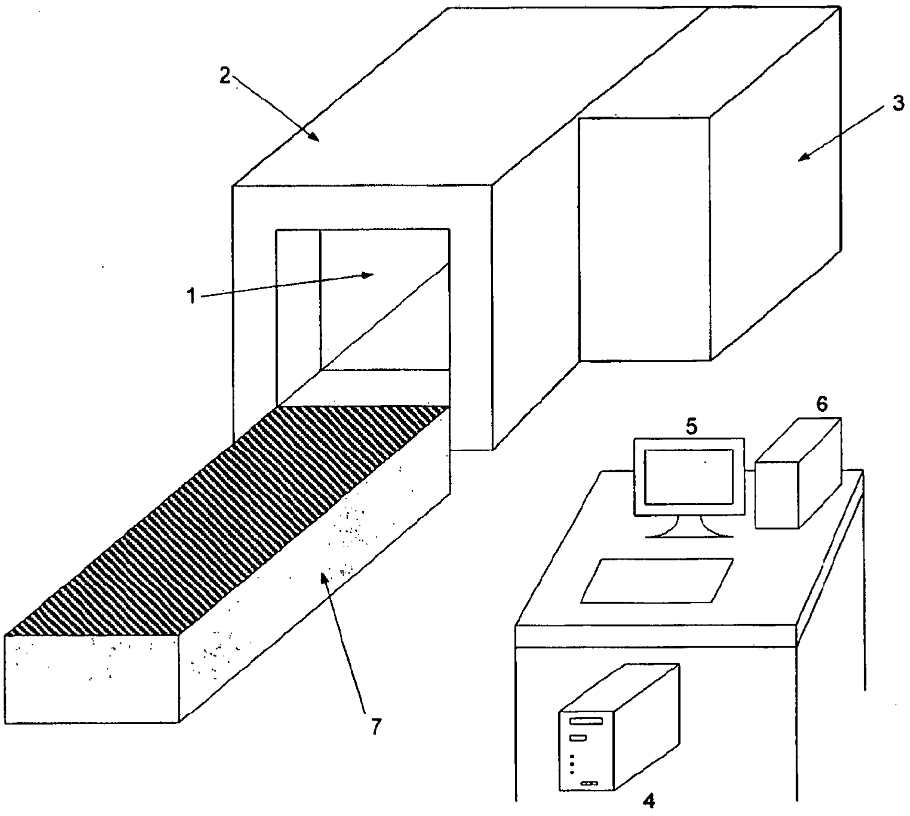


Fig. 1

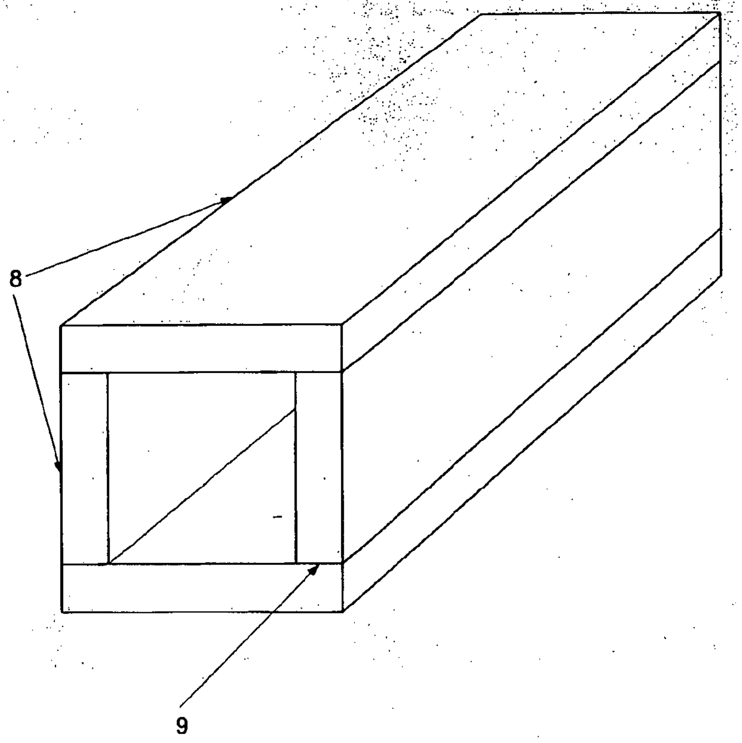


Fig. 2

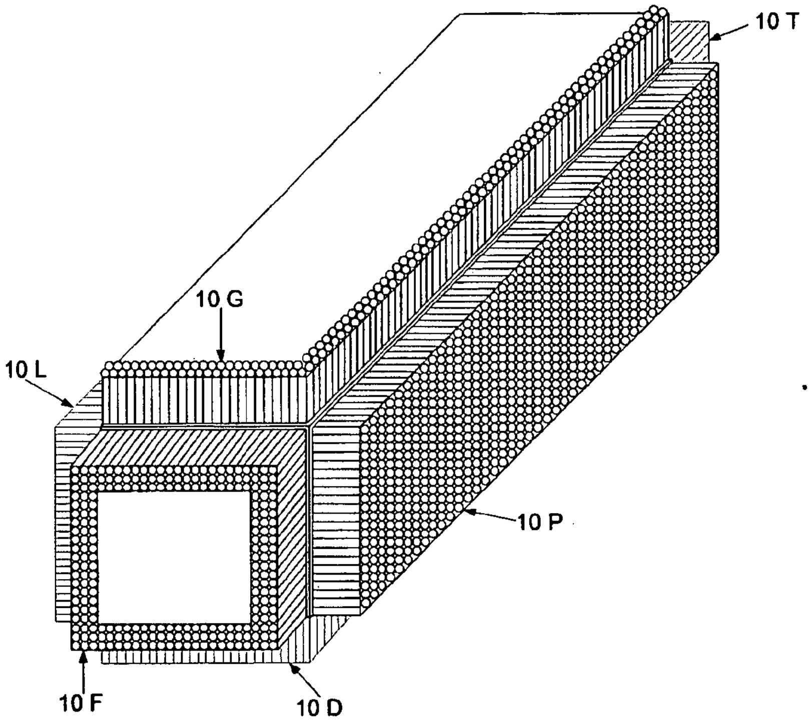


Fig. 3

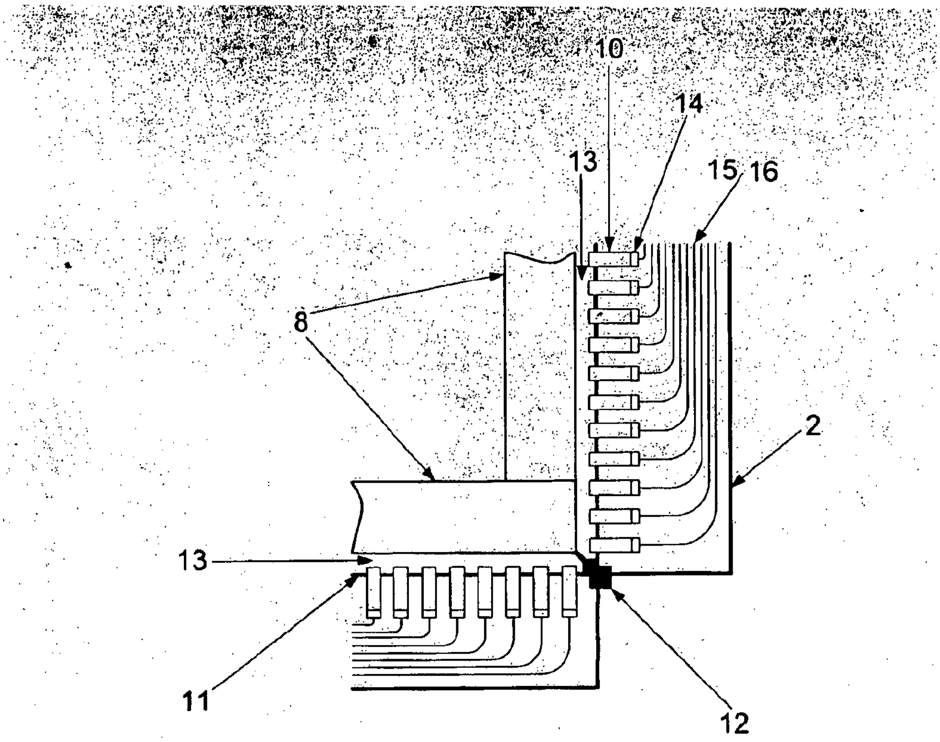


Fig. 4

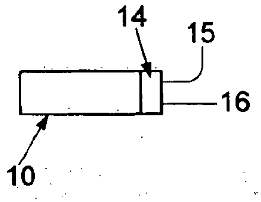


Fig. 4a

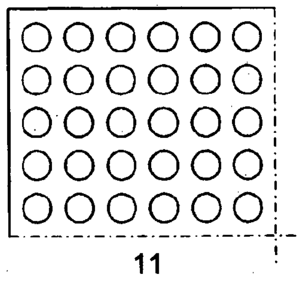


Fig. 4b

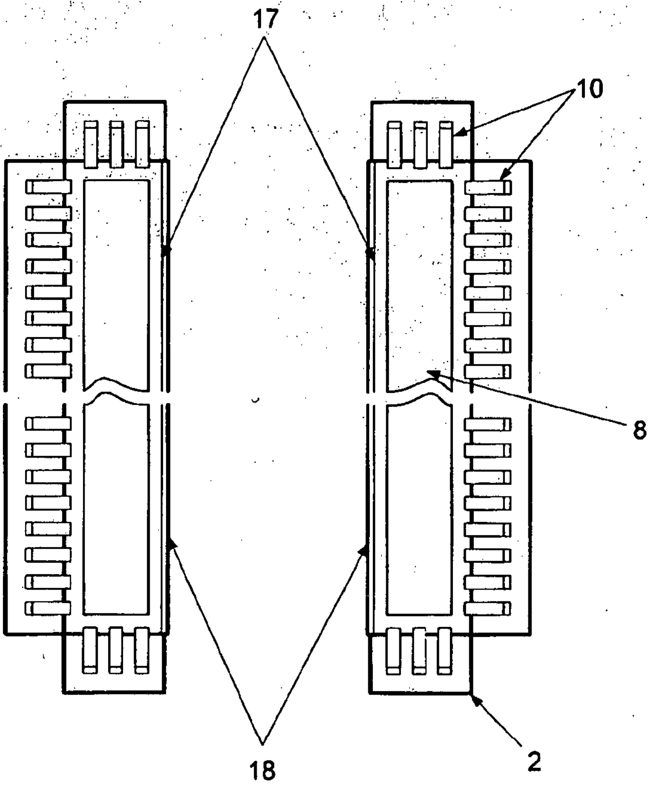


Fig. 5

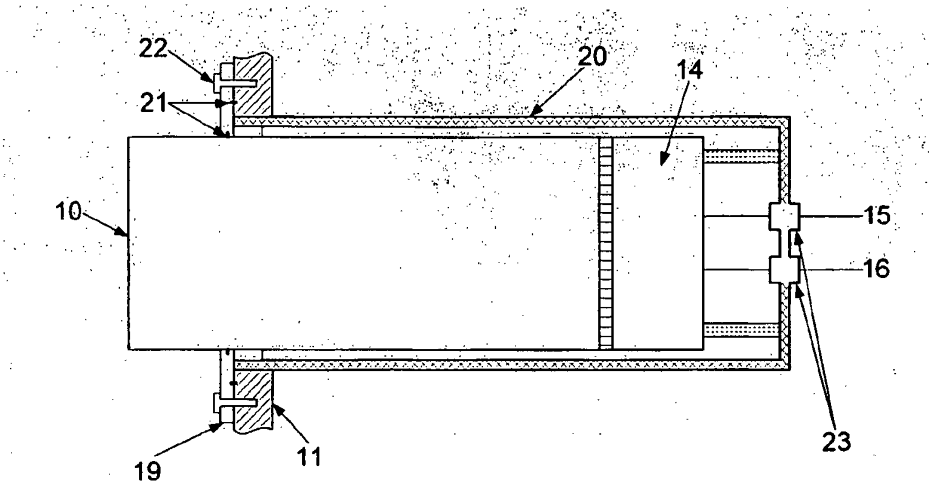
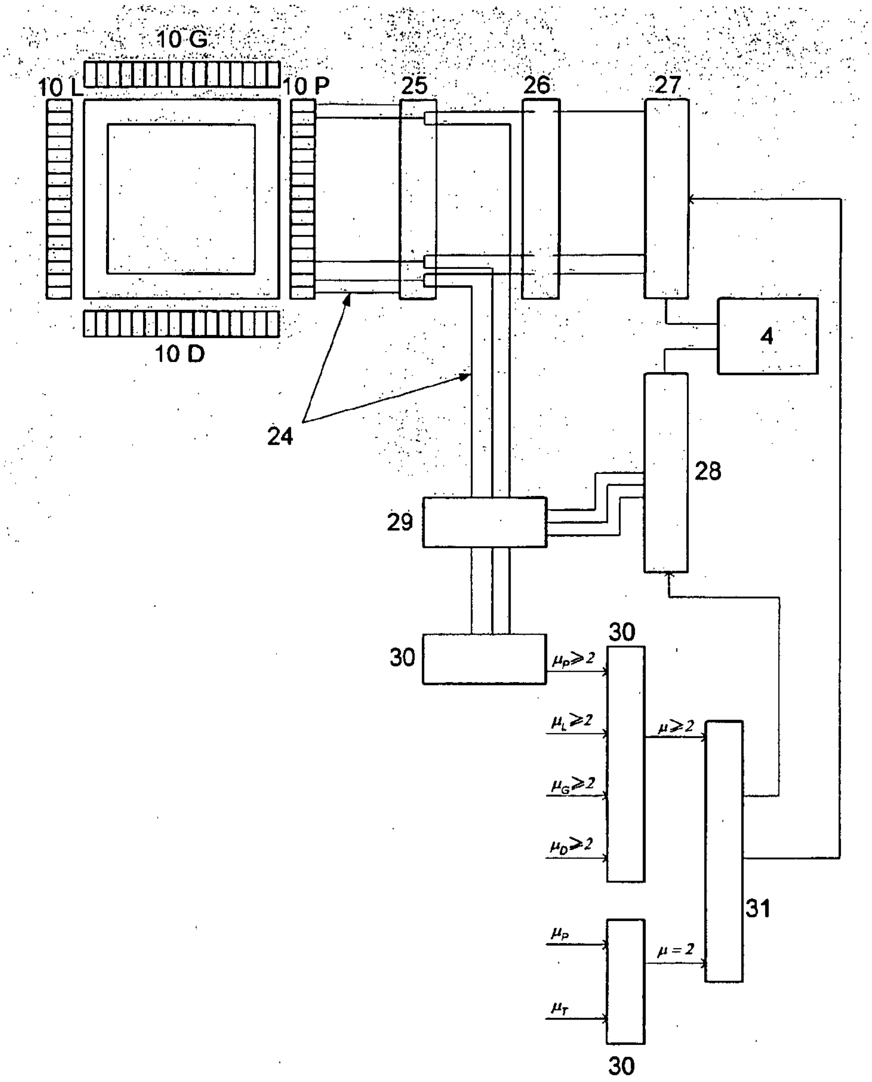


Fig. 6


10 G
10 L
10 P
25
26
27
4
10 D
24
28
29
30
30
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$\mu_L \geq 2$
$\mu_G \geq 2$
$\mu_D \geq 2$
$\mu \geq 2$
31
μ_P
$\mu = 2$
μ_T
30

Fig. 7

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