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(54) PHANTOM AND METHOD FOR THE QUALITY ASSURANCE OF A HADRON THERAPY APPARATUS

PHANTOM UND VERFAHREN ZUR QUALITÄTSSICHERUNG EINER HADRON-THERAPIE-VORRICHTUNG

FANTÔME ET PROCÉDÉ D’ASSURANCE QUALITÉ D’UN APPAREIL DE THÉRAPIE À L’HADRON

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Description

Field of the invention

[0001] The invention is related to the field of hadron therapy. More particularly, the invention is related to a phantom and method for quality assurance of a hadron therapy apparatus used in the intensity modulated particle therapy (IMPT) mode also known as pencil beam scanning (PBS) technique.

Description of prior art

[0002] Hadron therapy comprises the treatment of a tumour by irradiation with an energetic hadron beam. Preferred hadrons are typically protons and carbon ions. In current proton beam facilities, the Pencil Beam Scanning technique (PBS) involves the irradiation of separate spots in a target, each spot having a predefined position and depth, with a pre-defined dose being prescribed for each spot. In each treatment room of the facility, various characteristics of the delivered beam are subjected to a daily verification routine. These characteristics are:

- beam range: the position (depth) of the Bragg peak at a given beam energy in a given target, usually a water phantom or multi-layer ionization chamber;
- spot position, spot size and spot symmetry, measured by a suitable 2D-detector, for example an array of ionization chambers or a scintillator screen equipped with a CCD camera;
- the deposited dose, measured by an absolute ionization chamber, for checking the output factor of the irradiation installation;
- the position of the proton beam with respect to the X-ray imaging system;
- when a Spread-out Bragg peak (SOBP) is used, the compliance of the planned SOBP to the actual SOBP.

[0003] Each of these characteristics are commonly measured at a number of distinct beam energy levels, by a separate measurement device. A complete verification involves many manual operations, including entrance in the treatment room for adapting a phantom or a measuring device. Therefore, the time needed to complete a verification routine is in the order of 30 to 60 minutes. Such long verification times are reducing the efficiency of the treatment facility in terms of the number of treatments that can be performed per day. Typical times spent on quality assurance (QA) in a proton beam facility are as follows : daily QA : 30 minutes, i.e 16 days per year in total; monthly QA : 3 hours per month, i.e. 4.5 days per year in total; yearly QA 16 hours, i.e. 2 days per year. It is therefore important to reduce the time needed for performing daily QA.

[0004] A Phantom and Method for Quality Assurance of a Particle Therapy Apparatus is known from document WO 2016/170115. This phantom comprises a frame structure; one or more wedges, a first and second block of material each having a first block face and a second block face parallel thereto, an absolute dosimeter arranged at said first block face, a plurality of beads of high density material located in said blocks and a 2D detector. The components are arranged in a known fixed position in relation to the frame structure. A central bead is maintained in a central known fixed position in relation to the frame structure. The components are arranged in the frame structure so that a beam will traverse the phantom, through the central bead, without traversing any material besides said central bead. The product "Sphinx PT" provided by IBA Dosimetry is built according to this document. The wedges of this phantom are made of a water-equivalent materiel, i.e. RW3, having a relative density of 1,045. This phantom is preferably used with a 2D detector having a scintillator screen and a CCD camera.

Summary of the invention

[0005] It is an object of the present invention to provide a phantom and method for quality assurance of a hadron therapy apparatus used in the intensity modulated particle therapy (IMPT) mode, allowing to perform a fast and reliable verification of the particle therapy apparatus. More precisely, there is a need for a phantom allowing performing the verification of the compliance of the planned SOBP with the actual SOBP, while minimizing the time and effort needed to perform the verification.

[0006] The invention is defined by the independent claims. The dependent claims define advantageous embodiments.

[0007] According to a first aspect of the invention there is provided a phantom for quality assurance of a hadron therapy apparatus usable in the intensity modulated particle therapy (IMPT) mode, said hadron therapy apparatus being configured for producing a hadron beam having an energy comprised between a low energy limit and a high energy limit. The phantom may comprise:

a) a frame structure comprising a base plate, the base plate having a first edge and a second edge parallel to said first edge;

b) one or more energy wedges each having an energy wedge base face, an energy wedge first face inclined with respect to said energy wedge base face and an energy wedge second face perpendicular to said energy wedge base face, said one or more energy wedges being mounted on said base plate, said energy wedge second face being parallel to said second edge;

c) a 2D detector arranged at said second edge, and being mounted perpendicular to said base plate;

said one or more wedges, and 2D detector being in known fixed positions in relation to said frame structure. According to the invention, the phantom comprises a

Spread-Out Bragg Peak (SOBP) wedge, said SOBP wedge having a SOBP wedge base face, an SOBP wedge first face inclined with respect to said SOBP wedge base face, and a SOBP wedge second face, perpendicular to said SOBP wedge base face, said SOBP wedge being mounted on said base plate, said SOBP wedge second face being parallel to said second edge, said SOBP wedge being made of a material having a relative density higher than 1.3, preferably higher than 1.5, more preferably higher than 1.7,

a distance between said first and said second SOBP wedge face, measured along a line parallel to said SOBP wedge base face varying between zero and the penetration depth in said material of a hadron beam having an energy equal to said high energy limit.

[0008] Hadron therapy apparatuses, when using proton beams, typically produce beams having an energy in the range of 35 MeV to 230 MeV. When carbon ions are used, the energy of the beam typically is in the range of 100 Mev/nucleon to 400 MeV/nucleon.

[0009] Preferably, at least one of said energy wedges is made of same material having a relative density higher than 1.3, preferably higher than 1.5, more preferably higher than 1.7.

[0010] Preferably, said material is selected from polyvinylidene fluoride, polyimides, polyetheretherketone polymers and mixtures thereof, known respectively as PVDF, PI, PEEK.

[0011] The frame structure may advantageously comprise one or two handles affixed to the base plate and to the 2D detector.

[0012] The 2D detector may comprise an amorphous silicon active flat panel detector.

[0013] The base plate and one or more of said wedge base faces and/or said SOBP wedge base face may comprise securing means for fixing said wedges to said base plate.

[0014] A distance between said first and said second energy wedge face of one of said energy wedges, measured along a line parallel to said energy wedge base face being the penetration depth in said material of a hadron beam having a nominal energy between said high energy limit, and said low energy limit, at mid height of said wedge, and being less than 15 mm at the bottom height of said wedge, and less than 15 mm higher at the top height of said energy wedge, the height being measured perpendicularly to said energy wedge base face.

[0015] According to a second aspect of the invention there is provided a method for quality assurance of a hadron therapy apparatus usable in the intensity modulated particle therapy (IMPT) mode, said apparatus comprising a patient positioner having a reference position, comprising the steps of:

a) providing a phantom according to the invention;
b) positioning the phantom on said patient positioner;
c) irradiating the phantom with a modulated beam, said modulated beam comprising a plurality of beams each having a different energy and having a dose selected in order to produce an SOBP in matter, said modulated beam being directed at said SOBP wedge first face, in a direction parallel to the SOBP wedge base face and at a height measured perpendicularly to said SOBP wedge base face;
d) acquiring an image of said modulated beams on said 2D detector;
e) repeating steps and for a plurality of heights between the bottom height of said SOBP wedge, and the top height of said SOBP wedge;
f) from said plurality of responses at each height, reconstructing the SOBP.

Thereby, the compliance of the planned SOBP with the actual SOBP can be determined.

[0016] According to a third aspect of the invention there is provided a computer program comprising code for performing steps c) to f) of the method of the invention.

[0017] According to a fourth and last aspect of the invention there is provided a system comprising a phantom according to the invention and a controller comprising a computer program according to the invention, for the quality assurance of a hadron therapy apparatus.

Short description of the drawings

[0018] These and further aspects of the invention will be explained in greater detail by way of example and with reference to the accompanying drawings in which:

Fig.1	is a perspective view of a phantom according to an embodiment of the invention;
Fig.2a and 2b	are a side view and a perspective view of an SOBP wedge ;
Fig.3a and 3b	are a side view and a perspective view of an energy wedge for a first nominal energy ;
Fig.4a and 4b	are a side view and a perspective view of an energy wedge for a second nominal energy ;
Fig.5a and	5b are a side view and a perspective view of an energy wedge for a third nominal energy ;
Fig.6	is a schematic view of a modulated beam configured for producing an SOBP, traversing the SOBP wedge, at different heights;
Fig.7	is a schematic view of a modulated beam configured for producing an SOBP, traversing the SOBP wedge, at different heights, wherein a defect is present in the modulated beam;

[0019] The drawings of the figures are neither drawn to scale nor proportioned. Generally, identical components are denoted by the same reference numerals in the figures.

Detailed description of embodiments of the invention

[0020] Fig.1 is a perspective view of a phantom 10 according to an embodiment of the invention. A frame structure 30 comprises a base plate 35, having a first edge 50, and a second edge 60. A plurality of elements may be mounted on the base plate: Energy wedges 70, an SOBP wedge 170, a block of material 100. Three energy wedges are represented but more or less energy wedges may be used. An SOBP wedge 170 is also present. A block of material 100 may be used for supporting an absolute dosimeter and/or markers for positioning the phantom. A 2D detector 200 is arranged at the second edge 60 of the base plate 35 and mounted perpendicularly thereto. One or two handles 32 may be arranges at the lateral sides of the phantom 10, in order to facilitate the handling, and to improve the stiffness of the phantom 10.

[0021] The SOBP wedge 170 , and optionally the energy wedges 70 are made of a material having a relative density higher than 1.3, preferably higher than 1.5, preferably higher than 1.7. The applicant has determined that a suitable material for these wedges is polyvinylidene fluoride also known as PVDF. Use of a water-equivalent material such as RW3, known from prior art phantoms would require a large size for the SOBP wedge, leading to difficulties in handling the phantom. A relative density at or above 1.7 was found suitable for obtaining a phantom having a preferred size. Metals were found unsuitable because of the activation produced by the hadron beam. PTFE (Teflon) was found unsuitable because it is not radiation-resistant. Graphite was also found unsuitable because it became brittle under irradiation. Polyvinylidene fluoride was found to meet all requirements regarding density, radiation hardness and mechanical properties. Other suitable materials are polyimide polymers. Polyimide polymers have densities in the range of 1.3 to 1.4. A suitable polyimide polymer is sold under the brand name TECASINT by Ensinger Plastics. Other suitable materials are PEEK (Polyetheretherketone) materials. The PEEK material sold by Ensinger Plastics under the brand name TECAPEEK has a relative density of 1,31 and was also found suitable.

[0022] The 2D-detector may advantageously be a flat panel used for X-ray imaging. Such panels have a matrix of 1024X1024 sensor cells, each comprising a diode as sensor and a TFT (Thin film transistor) for addressing the lines and transmit the signals. At a pitch of 200 μm, such a panel has a sensitive area of 200 mm X 200 mm. When using protons or carbon ions, the scintillator used for X-ray imaging may be removed. A suitable flat panel is the XRD 0822 AO, AP provided by PerkinElmer.

[0023] Fig.2a and 2b are a side and perspective view of an SOBP wedge 170. The width Wsobp of the SOBP wedge 170 at its basis is determined in order that a pencil beam directed along this width, from the first face 180 to the second face 190 and parallel to the base 175 of the SOBP wedge 170, will have a Bragg peak inside the SOBP wedge, upstream of the second face 190 of the SOBP wedge 170. The height Hsobp of the SOBP wedge is determined in order that a beam directed at the top of the SOBP wedge will reach the upper region of the 2D detector 200. When a material having a relative density of 1.7 is selected, such as PVDF, a value of Wsobp =151 mm for use with a hadron therapy apparatus using protons up to an energy of 230 MeV. The skilled person will know how to determine the value of Wsobp for other ions, other energies and other relative densities of the material. The SOBP wedge base 195 is used for fixing the wedge to the base plate, as described hereunder. A typical 2D detector may have a sensitive area of 200 mm X 200 mm. Therefore, the height Hsobp, may be 220 mm, including a height F of 20 mm for the SOBP wedge base 195. The thickness of the SOBP wedge 170 may be in the range of 20 mm to 30 mm. The value selected was 28 mm. The angle α, for the SOBP wedge depicted is 36,7°.

[0024] Fig.3a and 3b, 4a and 4b, 5a and 5b are a side views and perspective views of energy wedges for a three nominal energies. The purpose of these energy wedges is the precise determination of the energy of a pencil beam having a nominal energy. Referring to Fig3a and 3b, the energy wedge 70 has an energy wedge first face 80 (beam entry), and energy wedge second face 90 (beam exit), and an energy wedge base face 75. The energy wedge base 95 is used for fixing the wedge to the base plate, as described hereunder. The energy wedges of Fig.4 and Fig.5 are similar, but with different sizes. The heights He1, He2, He3 of the three energy wedges are equal to 100 mm, including the height of the energy wedge base 95 of 20 mm. The widths of the base Wbei and of the top Wtei, of the energy wedges are as follows:

WEDGE	NOMINAL ENERGY MeV	Wbei mm	Wtei mm
1	100	34	58
2	150	85	109
3	200	151	175

The thickness of the energy wedge 70 may also be in the range of 20 mm to 30 mm. The value selected was 28 mm, being the same as the SOBP wedge.

[0025] Preferably, the SOBP wedge, the energy wedges, and other components of the phantom, such as the block of material 100 may be fastened to the base plate 35 of the frame structure 30. In one embodiment of these securing means, the components, have a base section 195 (for the SOBP wedge) or 95 (for the energy wedges). Holes are drilled in the base plate 35 and corresponding holes are drilled in the base sections. The components may then be fastened with screws. The lengths screws are limited to the bottom region of the components so that the beams are not disturbed by these screws. A height of 20 mm was found suitable, represented by F on Fig. 2a. Holes and screws having a diameter of 4 mm were used and found convenient. Other fastening may be conceived. Successive rows of holes may be drilled in the base plate, at a distance corresponding to the thickness of the wedges, i.e. 28 mm, in order to give modularity, and allow various combinations of wedges.

[0026] Fig.6 is a schematic view of a modulated beam configured for producing an SOBP, traversing the SOBP wedge, at different heights. A modulated beam 220 is depicted at three different heights, entering the SOBP wedge first face 180 at three entry point 225, 225', 225" and exiting the SOBP wedge at the SOBP wedge second face 190, where they impinge the 2D detector. Therefore, the response of the 2D detector for that modulated beam, at that height, corresponds to the value of the SOBP for a depth corresponding to the width of the SOBP wedge at that height in the material of the SOBP wedge. For each modulated beam, the value representative of the response of the 2D detector, in function of the penetration depth in the wedge, is represented at the right-hand side of Fig. 6, and represents the shape of the SOBP.

[0027] Fig.7 is similar to Fig. 6 with the difference that the SOBP has a defect 230, represented by a drop in the level of the SOBP at a certain depth, in dashed line. This might occur, e.g. if there was an error in the determination of the weight of one or more of the individual pencil beams used for making the modulated beam. This might occur also if there was a defect in the means used for modulating the energy such as a defect in the energy degrader. By using the device and method of the invention, such defects can be detected easily; as can be seen on the curve depicted at the right-hand side of Fig. 7, which shows a corresponding drop in the level of the response.

[0028] The phantom of the invention may be used as follows:

- the phantom is positioned on the patient positioner. The phantom being light, and small this is an easy task. The phantom built according to the above description weights about 11 kg, including the 2D detector. The overall size of the phantom is 30 X 36 X 18 cm.
- a modulated beam is directed at the SOBP wedges at a series of heights along the height of the SOBP wedged.
- For each modulated beam, the response of the 2D detector is acquired, together with the corresponding heights.
- From these acquired data, the actual SOBP is reproduced.

The steps of directing a series of modulated beams, acquiring the data and displaying the resulting curve may be performed automatically under control of a controller.

[0029] Using the phantom of the invention, it is possible to efficiently and rapidly verify the functioning of components of the radiation therapy apparatus, including the means used for providing an SOBP. The acquired 2D doses may be processed by a program in order to compute a correction to be applied to the beams forming the SOBP.

[0030] The presence of a frame structure 30 in the phantom 10 of the invention has many advantages: the phantom may be manipulated easily, the frame is a reliable and precise reference for position of the various components of the phantom. Marks may be provided on the frame and used for aligning the phantom to laser beams or for visually aligning the phantom.

[0031] By using the phantom and method of the invention, it is possible to perform a daily verification of the functioning of a particle therapy apparatus, including components of said apparatus such as the positioning system, X-ray imaging system, beam directing system, dose, spot characteristics, uniformity in a reliable way. When performed under program control, the method is particularly efficient and fast, allowing to perform a full quality assurance in less than 10 minutes. With the method of the invention, the therapists save many time-consuming operations such as entering the treatment room for performing a change to a phantom, and exiting the treatment room for performing the measurements.

[0032] The present invention has been described in terms of specific embodiments, which are illustrative of the invention and not to be construed as limiting. More generally, it will be appreciated by persons skilled in the art that the present invention is not limited by what has been particularly shown and/or described hereinabove. In the example embodiment discussed and shown on the figures, the inclined face of the wedges is oriented towards the beam source, while the perpendicular face of the wedges is oriented towards the 2D detector. However, it will be understood that positioning the wedges in the other orientation is equivalent. Also, the longest or the shortest side of the wedges may indifferently be positioned against the base plate.

[0033] Reference numerals in the claims do not limit their protective scope. Use of the verbs "to comprise", "to include", "to be composed of", or any other variant, as well as their respective conjugations, does not exclude the presence of elements other than those stated. Use of the article "a", "an" or "the" preceding an element does not exclude the presence of a plurality of such elements.

Claims

1. A phantom (10) for quality assurance of a hadron therapy apparatus usable in the intensity modulated particle therapy (IMPT) mode, said hadron therapy apparatus being configured for producing a hadron beam having an energy comprised between a low

energy limit and a high energy limit, comprising:

a) a frame structure (30) comprising a base plate (35), the base plate having a first edge (50) and a second edge (60) parallel to said first edge;
b) one or more energy wedges (70) each having an energy wedge base face (75), an energy wedge first face (80) inclined with respect to said energy wedge base face and an energy wedge second face (90) perpendicular to said energy wedge base face (75),
said one or more energy wedges (70) being mounted on said base plate (35), said energy wedge second face (90) being parallel to said second edge (60);
c) a 2D detector (200) arranged at said second edge (60) , and being mounted perpendicular to said base plate (35);

said one or more wedges (70), and 2D detector (200) being in known fixed positions in relation to said frame structure (30),
characterized in that said phantom (10) comprises a Spread-Out Bragg Peak (SOBP) wedge (170), said SOBP wedge (170) having a SOBP wedge base face (175), an SOBP wedge first face (180) inclined with respect to said SOBP wedge base face, and a SOBP wedge second face (190), perpendicular to said SOBP wedge base face (175) , said SOBP wedge (170) being mounted on said base plate (35), said SOBP wedge second face being parallel to said second edge,
said SOBP wedge (170) being made of a material having a relative density higher than 1.3, preferably higher than 1.5, more preferably higher than 1.7, a distance between said first (180) and said second (190) SOBP wedge face, measured along a line parallel to said SOBP wedge base face (175) varying between zero and the penetration depth in said material of a hadron beam having an energy equal to said high energy limit.

2. The phantom (10) according to claim 1, **characterized in that** at least one of said energy wedges is made of same material having a relative density higher than
1.3, preferably higher than 1.5, more preferably higher than 1.7.

3. The phantom (10) according to any of claims 1 or 2, **characterized in that** said material is selected from polyvinylidene fluoride, polyimides, polyetheretherketone polymers and mixtures thereof.

4. The phantom (10) according to any of claims 1 to 3, **characterized in that** said frame structure comprises one or two handles (32) affixed to said base plate (35) and to said 2D detector (200).

5. The phantom (10) according to any of claims 1 to 4, **characterized in that** said 2D detector (180) comprises an amorphous silicon active flat panel detector.

6. The phantom (10) according to any of claims 1 to 5, **characterized in that** said base plate (35) and one or more of said wedge base faces (75) and/or said SOBP wedge base face (175) comprise securing means for fixing said wedges to said base plate.

7. The phantom (10) according to any of claims 1 to 6, **characterized in that** a distance between said first (80) and said second (90) energy wedge face of one of said energy wedges (70), measured along a line parallel to said energy wedge base face (75) being the penetration depth in said material of a hadron beam having a nominal energy between said high energy limit, and said low energy limit, at mid height of said wedge, and being less than 15 mm lower at the bottom height of said wedge, and less than 15 mm higher at the top height of said energy wedge, the height being measured perpendicularly to said energy wedge base face (75).

8. A method for quality assurance of a hadron therapy apparatus usable in the intensity modulated particle therapy (IMPT) mode, said hadron therapy apparatus comprising a patient positioner having a reference position, comprising the steps of:

a) providing a phantom (10) according to any of claims 1 to 7;
b) positioning said phantom (10) on said patient positioner;
c) irradiating said phantom (10) with a modulated beam, said modulated beam comprising a plurality of beams each having a different energy and having a dose selected in order to produce an SOBP in matter, said modulated beam being directed at said SOBP wedge first face, in a direction parallel to the SOBP wedge base face(175) and at a height measured perpendicularly to said SOBP wedge base face(175)
d) acquiring the response of said modulated beams on said 2D detector (200);
e) repeating steps c) and d) for a plurality of heights between the bottom height of said SOBP wedge, and the top height of said SOBP wedge;
f) from said plurality of responses at each height, reconstructing the SOBP.

9. Computer program comprising code for performing steps c) to f) of claim 8, when executed by a processor of a hadron therapy apparatus usable in the intensity modulated particle therapy (IMPT) mode, said hadron therapy apparatus being configured for producing a hadron beam having an energy comprised between a low energy limit and a high energy limit, said hadron therapy apparatus comprising a patient positioner having a reference position, wherein a phantom according to any of claims 1 to 7 is positioned on said patient positioner.

10. System comprising a phantom (10) according to any of claims 1 to 7 and a controller comprising a computer program according to claim 9, for the quality assurance of a hadron therapy apparatus.

Patentansprüche

1. Phantom (10) zur Qualitätssicherung einer Hadron-Therapievorrichtung, die im intensitätsmodulierten Partikeltherapiemodus (IMPT-Modus) einsetzbar ist, wobei die Hadron-Therapievorrichtung dazu konfiguriert ist, einen Hadronstrahl zu erzeugen, der eine Energie zwischen einer niedrigen Energiegrenze und einer hohen Energiegrenze aufweist, umfassend:

a) eine Rahmenstruktur (30), umfassend eine Grundplatte (35), wobei die Grundplatte eine erste Kante (50) und eine zweite Kante (60) parallel zur ersten Kante aufweist;
b) einen oder mehrere Energiekeile (70), wobei jeder eine Energiekeilgrundfläche (75), eine erste Energiekeilfläche (80), die bezüglich der Energiekeilgrundfläche geneigt ist, und eine zweite Energiekeilfläche (90), die senkrecht zur Energiekeilgrundfläche (75) verläuft, aufweist,
wobei einer oder mehrere Energiekeile (70) auf der Grundplatte (35) montiert sind, wobei die zweite Energiekeilfläche (90) parallel zur zweiten Kante (60) verläuft;
c) einen 2D-Detektor (200), der an der zweiten Kante (60) angeordnet ist und senkrecht zur Grundplatte (35) montiert ist;

wobei sich einer oder mehrere Keile (70) und der 2D-Detektor (200) in bekannten festen Positionen bezüglich der Rahmenstruktur (30) befinden,
dadurch gekennzeichnet, dass das Phantom (10) einen Keil für ausgebreiteten Bragg-Peak (Spread-Out Bragg Peak - SOBP) (170) umfasst, wobei der SOBP-Keil (170) eine SOBP-Keilgrundfläche (175), eine erste SOBP-Keilfläche (180), die bezüglich der SOBP-Keilgrundfläche geneigt ist, und eine zweite SOBP-Keilfläche (190), die senkrecht zur SOBP-Keilgrundfläche (175) verläuft, aufweist, wobei der SOBP-Keil (170) auf der Grundplatte (35) montiert ist, wobei die zweite SOBP-Keilfläche parallel zur zweiten Kante verläuft,
wobei der SOBP-Keil (170) aus einem Material hergestellt ist, das eine relative Dichte aufweist, die höher als 1,3, bevorzugt höher als 1,5, noch bevorzugter höher als 1,7 ist, wobei ein Abstand zwischen der ersten (180) und der zweiten (190) SOBP-Keilfläche, gemessen entlang einer Linie parallel zur SOBP-Keilgrundfläche (175), zwischen null und der Eindringtiefe eines Hadronstrahls, der eine Energie gleich der hohen Energiegrenze aufweist, in das Material variiert.

2. Phantom (10) nach Anspruch 1, **dadurch gekennzeichnet, dass** mindestens einer der Energiekeile aus demselben Material hergestellt ist, das eine relative Dichte höher als 1,3, bevorzugt höher als 1,5, noch bevorzugter höher als 1,7 aufweist.

3. Phantom (10) nach einem der Ansprüche 1 oder 2, **dadurch gekennzeichnet, dass** das Material aus Polyvinylidenfluorid, Polyimiden, Polyetheretherketonpolymeren und Mischungen daraus ausgewählt ist.

4. Phantom (10) nach einem der Ansprüche 1 bis 3, **dadurch gekennzeichnet, dass** die Rahmenstruktur einen oder zwei Griffe (32) umfasst, die an der Grundplatte (35) und am 2D-Detektor (200) befestigt sind.

5. Phantom (10) nach einem der Ansprüche 1 bis 4, **dadurch gekennzeichnet, dass** der 2D-Detektor (180) einen aktiven Plattendetektor aus amorphem Silizium umfasst.

6. Phantom (10) nach einem der Ansprüche 1 bis 5, **dadurch gekennzeichnet, dass** die Grundplatte (35) und eine oder mehrere der Keilgrundflächen (75) und/oder die SOBP-Keilgrundfläche (175) Befestigungsmittel zum Befestigen der Keile an der Grundplatte umfassen.

7. Phantom (10) nach einem der Ansprüche 1 bis 6, **dadurch gekennzeichnet, dass** ein Abstand zwischen der ersten (80) und der zweiten (90) Energiekeilfläche von einem der Energiekeile (70), gemessen entlang einer Linie parallel zur Energiekeilgrundfläche (75) die Eindringtiefe eines Hadronstrahls, der eine Nennenergie zwischen der hohen Energiegrenze und der niedrigen Energiegrenze aufweist, in das Material in mittlerer Höhe des Keils ist und weniger als 15 mm niedriger in der unteren Höhe des Keils und weniger als 15 mm höher in der oberen Höhe des Energiekeils ist, wobei die Höhe senkrecht zur Energiekeilgrundfläche (75) gemessen wird.

8. Verfahren zur Qualitätssicherung einer Hadron-Therapievorrichtung, die im intensitätsmodulierten Partikeltherapiemodus (IMPT-Modus) einsetzbar ist, wobei die Hadron-Therapievorrichtung eine Patientenpositioniereinheit mit einer Referenzposition umfasst, umfassend die folgenden Schritte:

a) Bereitstellen eines Phantoms (10) nach einem der Ansprüche 1 bis 7;

b) Positionieren des Phantoms (10) auf der Patientenpositioniereinheit;

c) Bestrahlen des Phantoms (10) mit einem modulierten Strahl, wobei der modulierte Strahl eine Vielzahl von Strahlen umfasst, die jeweils eine unterschiedliche Energie aufweisen und eine Dosis aufweisen, die ausgewählt wird, um einen SOBP in Materie zu erzeugen, wobei der modulierte Strahl zur ersten SOBP-Keilfläche gerichtet wird in einer Richtung parallel zur SOBP-Keilgrundfläche (175) und in einer Höhe, die senkrecht zur SOBP-Keilgrundfläche (175) gemessen wird;

d) Erfassen der Antwort der modulierten Strahlen am 2D-Detektor (200);

e) Wiederholen der Schritte c) und d) für eine Vielzahl von Höhen zwischen der unteren Höhe des SOBP-Keils und der oberen Höhe des SOBP-Keils;

f) aus der Vielzahl von Antworten in jeder Höhe Rekonstruieren des SOBPs.

9. Computerprogramm, umfassend Code zur Durchführung der Schritte c) bis f) von Anspruch 8 bei Ausführung durch einen Prozessor einer Hadron-Therapievorrichtung, die im intensitätsmodulierten Partikeltherapiemodus (IMPT-Modus) einsetzbar ist, wobei die Hadron-Therapievorrichtung dazu konfiguriert ist, einen Hadronstrahl zu erzeugen, der eine Energie zwischen einer niedrigen Energiegrenze und einer hohen Energiegrenze aufweist, wobei die Hadron-Therapievorrichtung eine Patientenpositioniereinheit mit einer Referenzposition umfasst, wobei ein Phantom nach einem der Ansprüche 1 bis 7 auf der Patientenpositioniereinheit positioniert wird.

10. System, umfassend ein Phantom (10) nach einem der Ansprüche 1 bis 7 und eine Steuereinheit, umfassend ein Computerprogramm nach Anspruch 9, zur Qualitätssicherung einer Hadron-Therapievorrichtung.

Revendications

1. Fantôme (10) pour l'assurance qualité d'un appareil de thérapie par hadrons utilisable dans le mode de thérapie par particules à modulation d'intensité (IMPT), ledit appareil de thérapie par hadrons étant configuré pour produire un faisceau de hadrons ayant une énergie comprise entre une limite de faible énergie et une limite d'énergie élevée, comprenant :

a) une structure de cadre (30) comprenant une plaque de base (35), la plaque de base ayant un premier bord (50) et un second bord (60) parallèle audit premier bord ;

b) un ou plusieurs coins pour énergie (70) ayant chacun une face de base de coin pour énergie (75), une première face de coin pour énergie (80) inclinée par rapport à ladite face de base de coin pour énergie et une seconde face de coin pour énergie (90) perpendiculaire à ladite face de base de coin pour énergie (75), lesdits un ou plusieurs coins pour énergie (70) étant montés sur ladite plaque de base (35), ladite seconde face de coin pour énergie (90) étant parallèle audit second bord (60) ;

c) un détecteur 2D (200) agencé au niveau dudit second bord (60), et étant monté perpendiculairement à ladite plaque de base (35) ;

lesdits un ou plusieurs coins (70), et le détecteur 2D (200) étant dans des positions fixes connues par rapport à ladite structure de cadre (30),
caractérisé en ce que ledit fantôme (10) comprend un coin pour pic de Bragg étalé (SOBP) (170), ledit coin pour SOBP (170) ayant une face de base de coin pour SOBP (175), une première face de coin pour SOBP (180) inclinée par rapport à ladite face de base de coin pour SOBP, et une seconde face de coin pour SOBP (190), perpendiculaire à ladite face de base de coin pour SOBP (175), ledit coin pour SOBP (170) étant monté sur ladite plaque de base (35), ladite seconde face de coin pour SOBP étant parallèle audit second bord,
ledit coin pour SOBP (170) étant constitué d'un matériau ayant une densité relative supérieure à 1,3, de préférence supérieure à 1,5, plus préférablement supérieure à 1,7,
une distance entre ladite première (180) et ladite seconde (190) face de coin pour SOBP, mesurée le long d'une ligne parallèle à ladite face de base de coin pour SOBP (175) variant entre zéro et la profondeur de pénétration dans ledit matériau d'un faisceau de hadrons ayant une énergie égale à ladite limite d'énergie élevée.

2. Fantôme (10) selon la revendication 1, **caractérisé en ce qu'**au moins un desdits coins pour énergie est constitué du même matériau ayant une densité relative supérieure à 1,3, de préférence supérieure à 1,5, plus préférablement supérieure à 1,7.

3. Fantôme (10) selon l'une quelconque des revendications 1 et 2, **caractérisé en ce que** ledit matériau est choisi parmi le fluorure de polyvinylidène, des polyimides, des polymères de polyétheréthercétone et leurs mélanges.

4. Fantôme (10) selon l'une quelconque des revendications 1 à 3, **caractérisé en ce que** ladite structure de cadre comprend une ou deux poignées (32) fixées à ladite plaque de base (35) et audit détecteur

2D (200).

5. Fantôme (10) selon l'une quelconque des revendications 1 à 4, **caractérisé en ce que** ledit détecteur 2D (180) comprend un détecteur à panneau plat actif en silicium amorphe.

6. Fantôme (10) selon l'une quelconque des revendications 1 à 5, **caractérisé en ce que** ladite plaque de base (35) et une ou plusieurs desdites faces de base de coin (75) et/ou ladite face de base de coin pour SOBP (175) comprennent des moyens de fixation pour fixer lesdits coins à ladite plaque de base.

7. Fantôme (10) selon l'une quelconque des revendications 1 à 6, **caractérisé en ce qu'**une distance entre ladite première (80) et ladite seconde (90) face de coin pour énergie de l'un desdits coins pour énergie (70), mesurée le long d'une ligne parallèle à ladite face de base de coin pour énergie (75), est la profondeur de pénétration dans ledit matériau d'un faisceau de hadrons ayant une énergie nominale comprise entre ladite limite d'énergie élevée et ladite limite de faible énergie, à mi-hauteur dudit coin, et est inférieure de moins de 15 mm à la hauteur inférieure dudit coin, et supérieure de moins de 15 mm à la hauteur supérieure dudit coin pour énergie, la hauteur étant mesurée perpendiculairement à ladite face de base de coin pour énergie (75).

8. Procédé d'assurance qualité d'un appareil de thérapie par hadrons utilisable dans le mode de thérapie par particules à modulation d'intensité (IMPT), ledit appareil de thérapie par hadrons comprenant un positionneur de patient ayant une position de référence, comprenant les étapes de :

a) fourniture d'un fantôme (10) selon l'une quelconque des revendications 1 à 7 ;
b) positionnement dudit fantôme (10) sur ledit positionneur de patient ;
c) irradiation dudit fantôme (10) avec un faisceau modulé, ledit faisceau modulé comprenant une pluralité de faisceaux ayant chacun une énergie différente et ayant une dose sélectionnée afin de produire un SOBP dans la matière, ledit faisceau modulé étant dirigé vers ladite première face de coin pour SOBP, dans une direction parallèle à la face de base de coin pour SOBP (175) et à une hauteur mesurée perpendiculairement à ladite face de base de coin pour SOBP (175) ;
d) acquisition de la réponse desdits faisceaux modulés sur ledit détecteur 2D (200) ;
e) répétition des étapes c) et d) pour une pluralité de hauteurs entre la hauteur inférieure dudit coin pour SOBP, et la hauteur supérieure dudit coin pour SOBP ;
f) à partir de ladite pluralité de réponses à chaque hauteur, reconstruction du SOBP.

9. Programme informatique comprenant un code pour réaliser les étapes c) à f) selon la revendication 8, lorsqu'il est exécuté par un processeur d'un appareil de thérapie par hadrons utilisable dans le mode de thérapie par particules à modulation d'intensité (IMPT), ledit appareil de thérapie par hadrons étant configuré pour produire un faisceau de hadrons ayant une énergie comprise entre une limite de faible énergie et une limite d'énergie élevée, ledit appareil de thérapie par hadrons comprenant un positionneur de patient ayant une position de référence, un fantôme selon l'une quelconque des revendications 1 à 7 étant positionné sur ledit positionneur de patient.

10. Système comprenant un fantôme (10) selon l'une quelconque des revendications 1 à 7 et un dispositif de commande comprenant un programme informatique selon la revendication 9, pour l'assurance qualité d'un appareil de thérapie par hadrons.

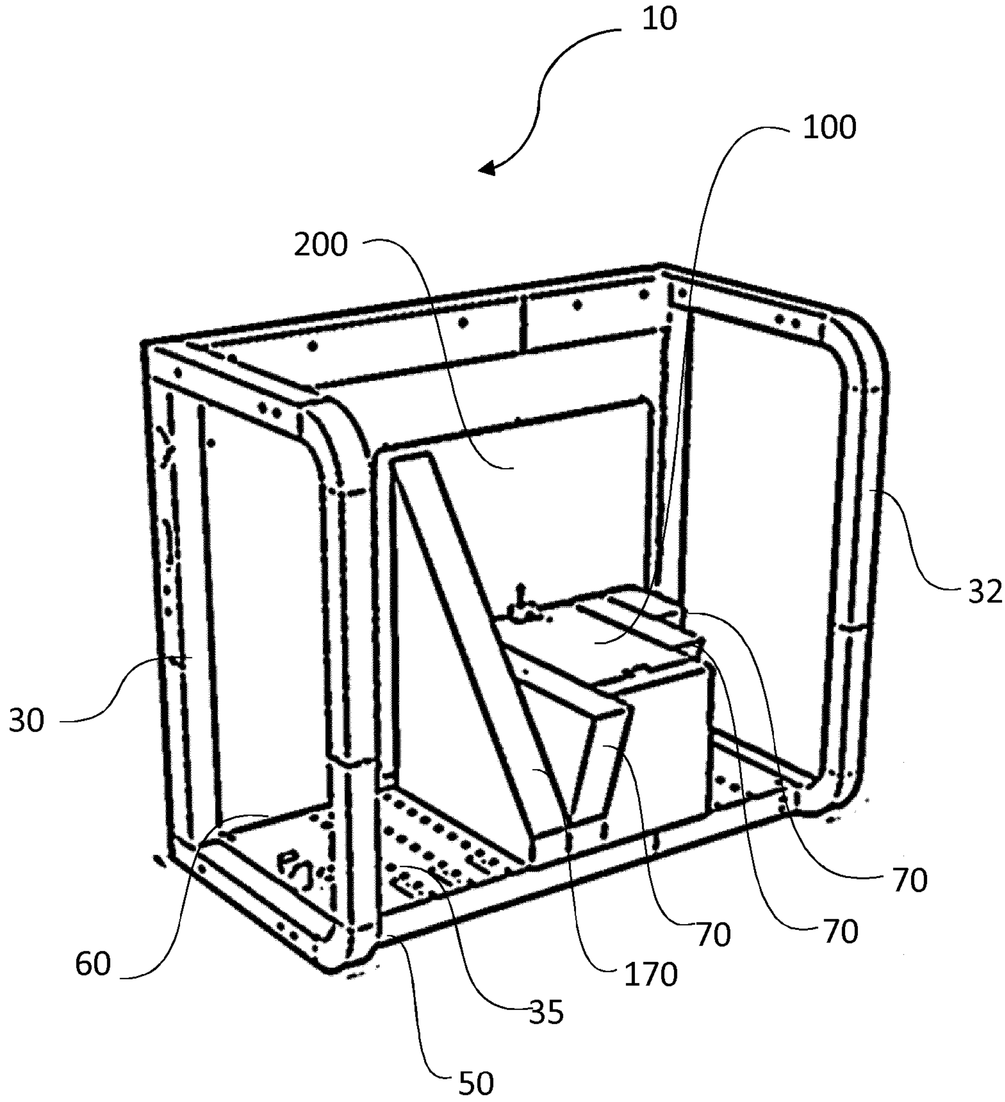

FIG.1

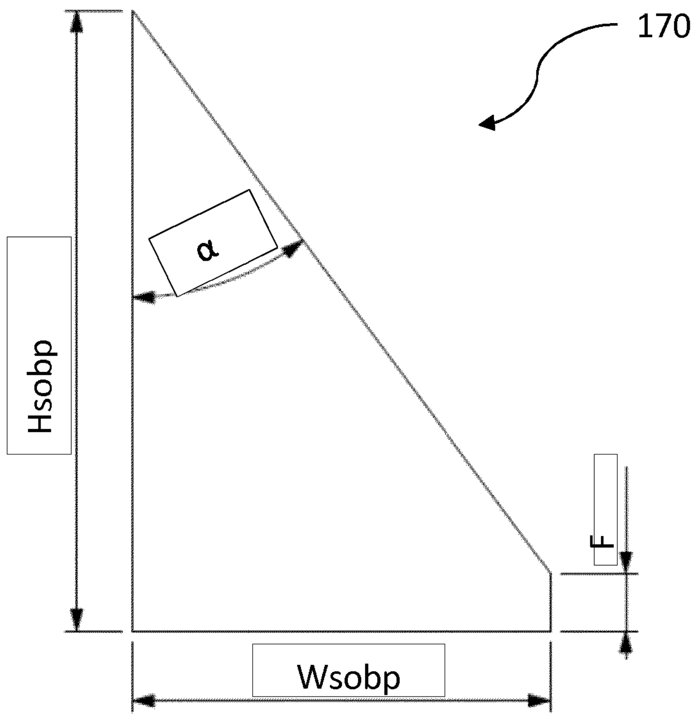

FIG.2a

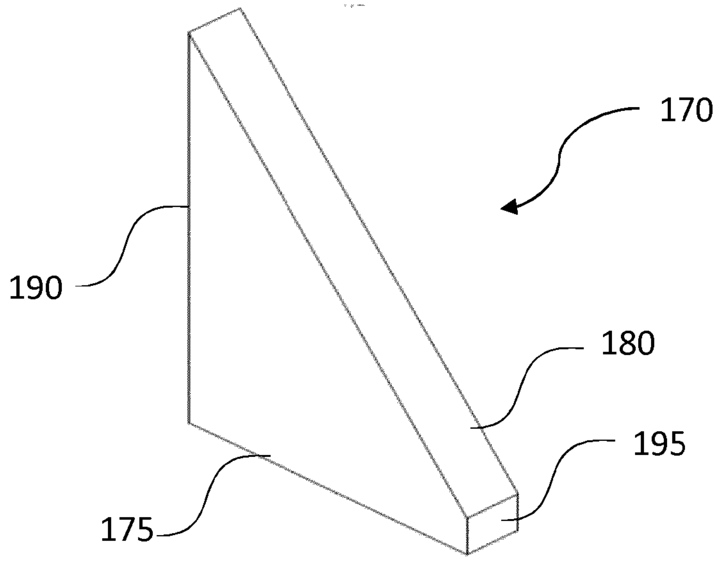

FIG.2b

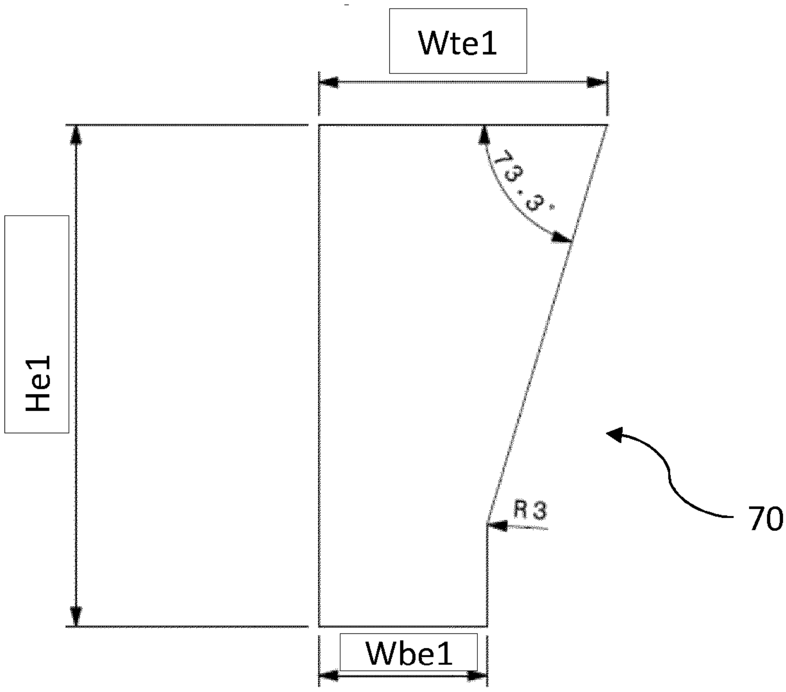

FIG.3a

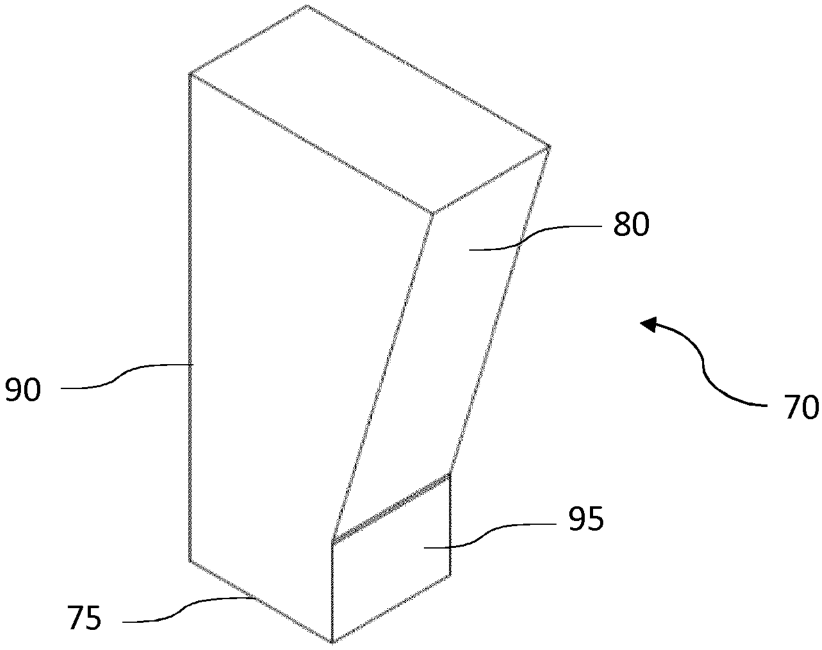

FIG.3b

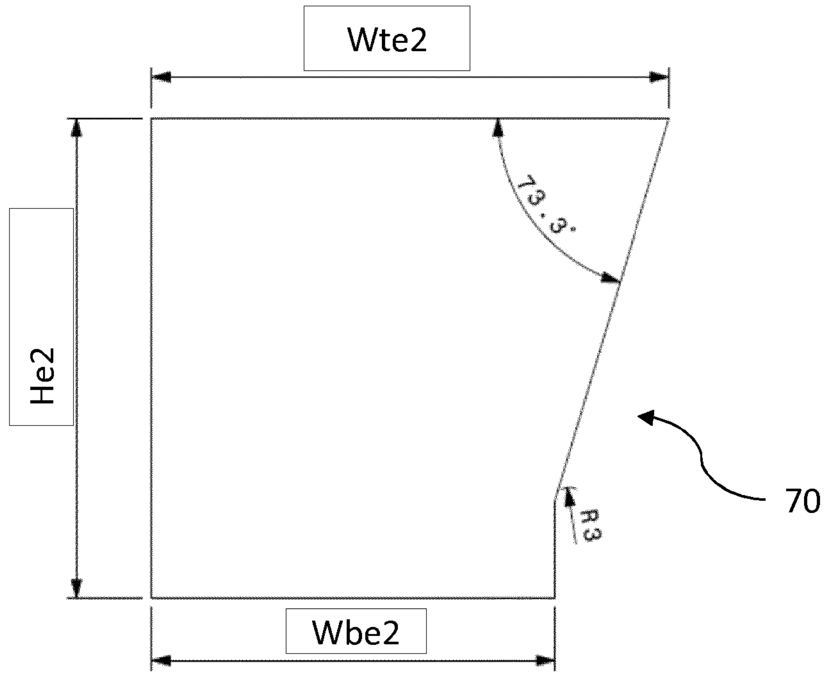

FIG.4a

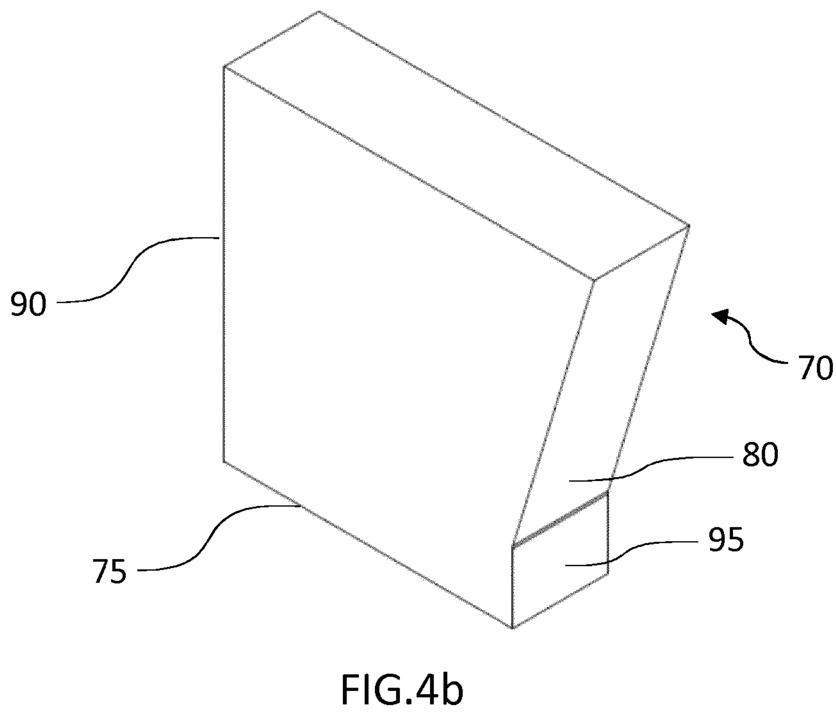

FIG.4b

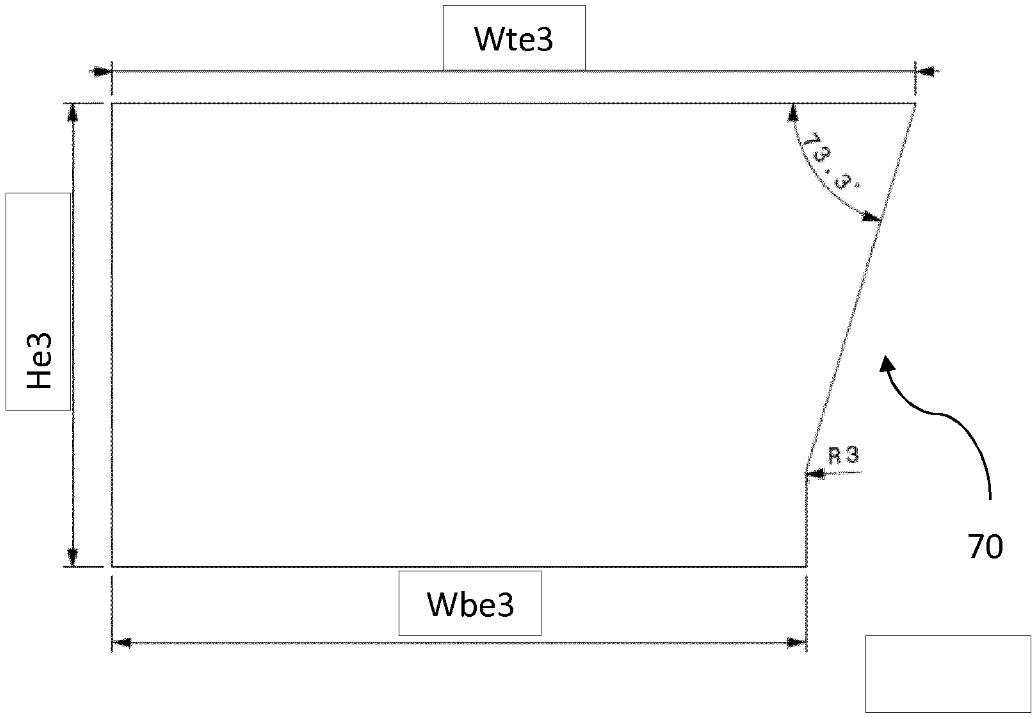

FIG.5a

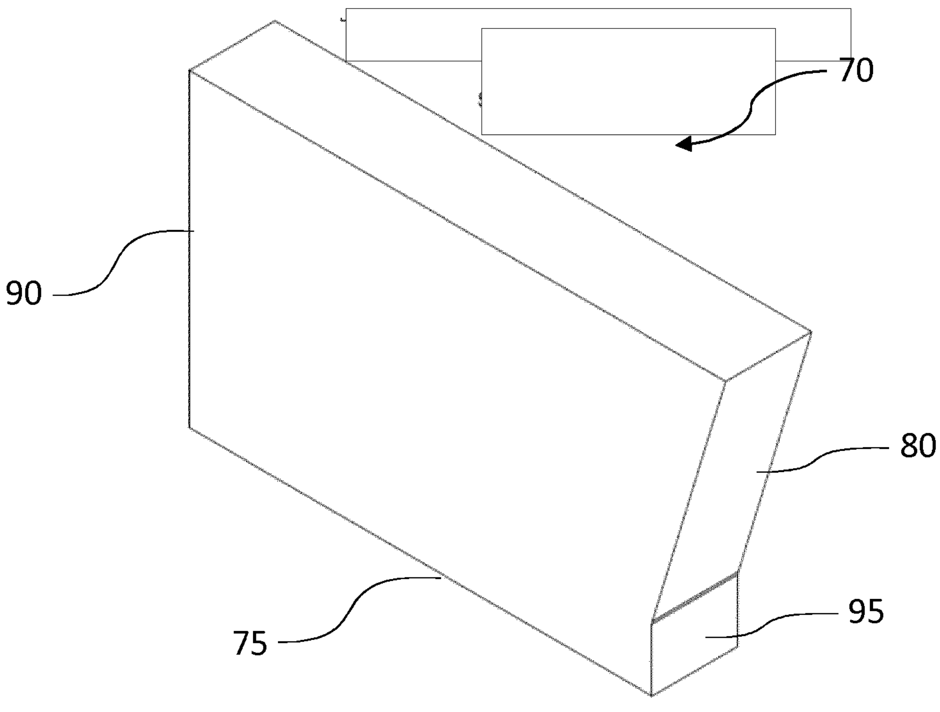

FIG.5b

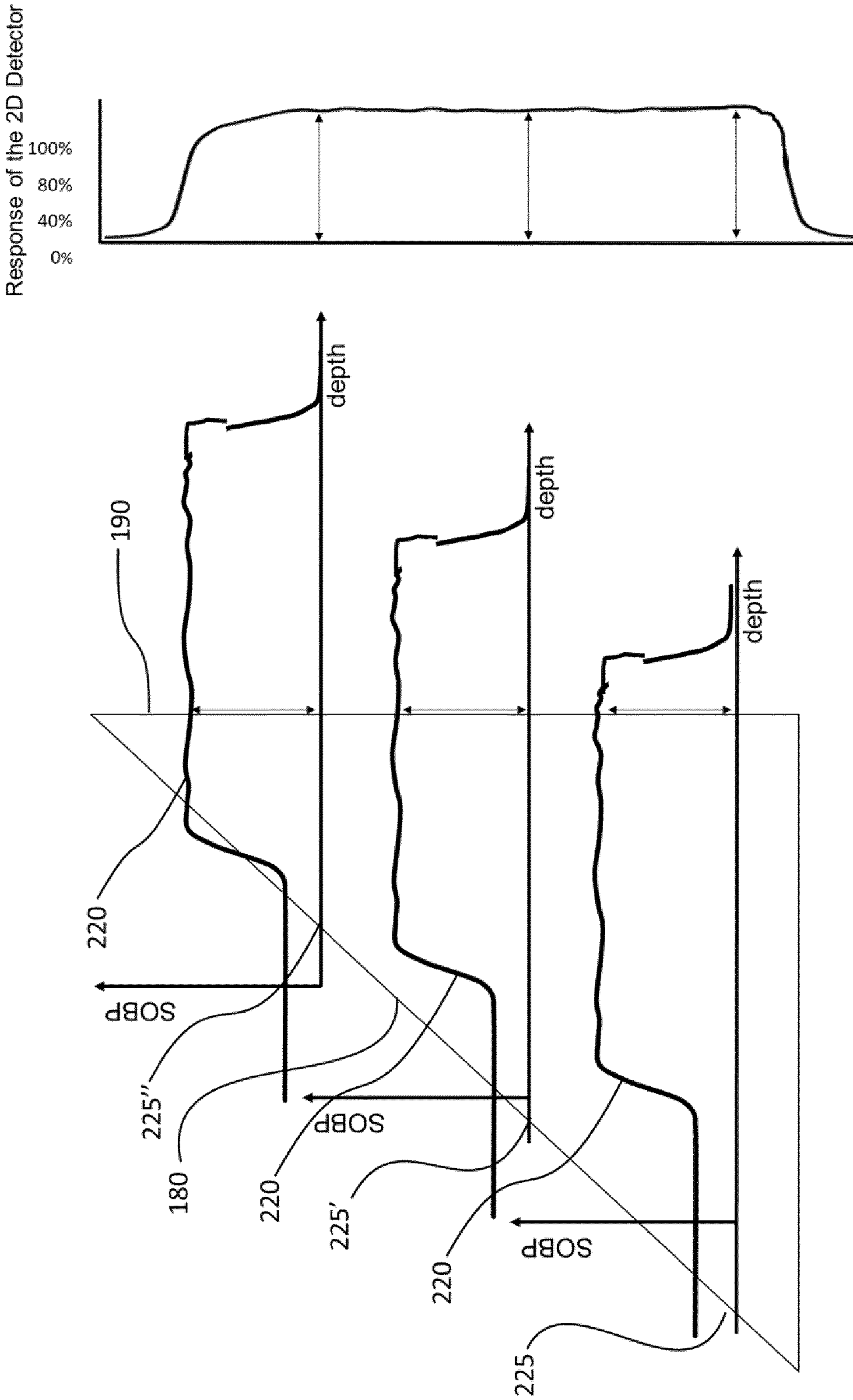
Response of the 2D Detector
100%
80%
40%
0%
depth
depth
depth
190
220
SOBP
225''
180
220
SOBP
225'
220
SOBP
225

FIG.6

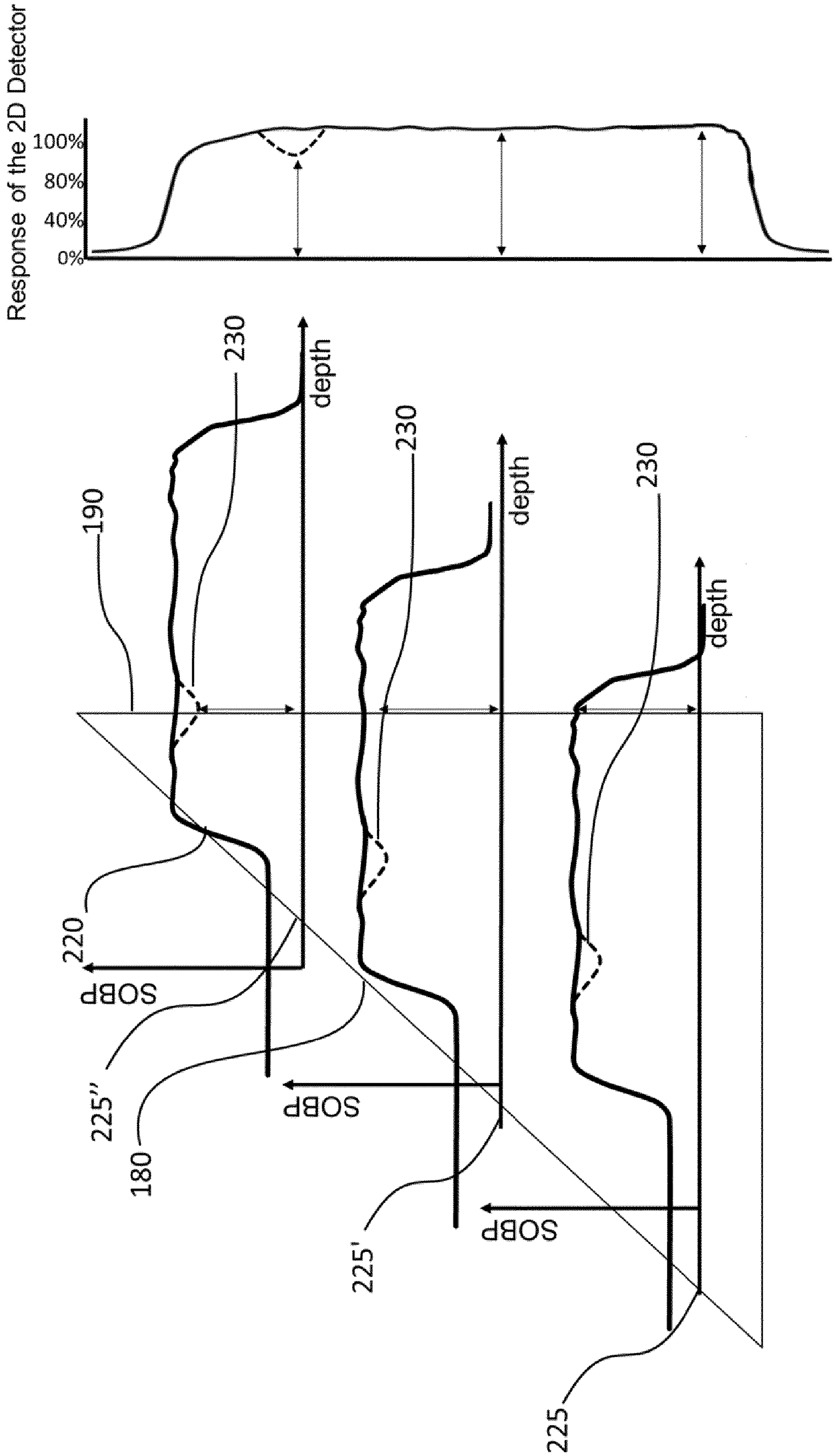
Response of the 2D Detector
100%
80%
40%
0%
depth
depth
depth
230
230
230
190
220
SOBP
SOBP
SOBP
225''
180
225'
225

FIG.7

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- WO 2016170115 A **[0004]**