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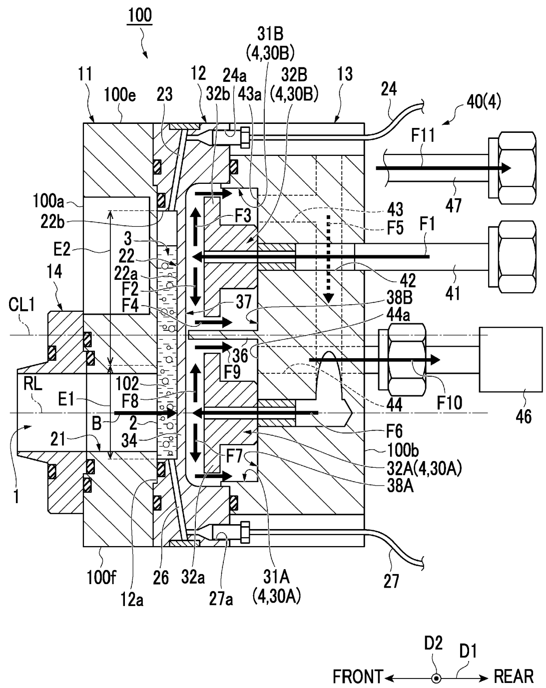
(54) TARGET DEVICE

(57) Provided is a target device (100) capable of improving the cooling performance of a cooling mechanism (4). According to the target device (100), a target accommodation unit (3) has a first region (E1) that accommodates a target liquid (101) and a second region (E2) that receives a boiled gas-liquid mixture (102) of the target liquid (101). In contrast, the cooling mechanism (4) includes a first cooling unit (30A) that cools at least the first region (E1) and a second cooling unit (30B) that cools at least the second region (E2) . Moreover, the second cooling unit (30B) forms a flow (flow F2 in FIG. 2) of the refrigerant from top to bottom in the second region (E2). The cooling performance obtained by the refrigerant flowing from top to bottom can be made higher than the cooling performance in a case where the refrigerant used in the first cooling unit (30A) is used as it is.

FIG. 2



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Description

BACKGROUND OF THE INVENTION

Field of the Invention

[0001] The present invention relates to a target device.

Description of Related Art

[0002] Radioisotopes used in test agents for PET tests using positron emission tomography (PET) are produced using a radiation source such as a cyclotron installed in a location close to a laboratory in a hospital. Specifically, the radiation (for example, a particle beam such as a proton beam or heavy proton beam) from the radiation source is guided to a target device, and radioisotopes are produced by the nuclear reaction with a target liquid (for example, target water (^{18}O water)) accommodated in the target device. Then, the produced radioisotopes are incorporated into a predetermined compound (for example, Fluoro-Deoxy-Glucose (FDG)) or some thereof are replaced and synthesized to produce a test agent.

[0003] As a device that accommodates the target liquid for producing such radioisotopes, a device including a cooling mechanism that cools a portion that accommodates the target liquid and a portion that receives a boiled gas-liquid mixture of the target liquid from a back surface is known (refer to, for example, Japanese Unexamined Patent Publication No. 2011-220930).

SUMMARY OF THE INVENTION

[0004] Here, in a case where the intensity of the radiation irradiated to the target liquid is increased, the cooling unit that cools the target accommodation unit is required to have high cooling performance. The cooling mechanism of the above-described target device injects the refrigerant to the back surface (heat transfer wall portion) of the portion where the target liquid is accommodated so as to be coaxial with the radiation. The cooling mechanism of the target device cools the target accommodation unit from the back surface of the portion that receives the gas-liquid mixture of the target liquid with the refrigerant diffused radially after striking the heat transfer wall portion by the injection (an upward flow toward the portion receiving the gas-liquid mixture from the portion accommodating the liquid). However, in this configuration, there is a case where sufficient cooling performance is not obtained. Therefore, target devices capable of improving the cooling performance of the cooling mechanism have been demanded.

[0005] The present invention has been made in view of the above, and an object of the present invention is to provide a target device capable of improving the cooling performance of a cooling mechanism.

[0006] To achieve the above object, a target device according to an aspect of the present invention includes a target accommodation unit having a first region that accommodates a target liquid, and a second region that is located above the first region and receives a boiled gas-liquid mixture of the target liquid; and a cooling mechanism that cools the target accommodation unit with a refrigerant on a side opposite to an irradiating direction of an irradiation beam with respect to the target liquid, the cooling mechanism includes a first cooling unit that cools at least the first region and a second cooling unit that cools at least the second region, and the second cooling unit forms a flow of the refrigerant from top to bottom in the second region.

[0007] According to the above target device, the target accommodation unit has the first region that accommodates the target liquid, and the second region that is located above the first region and receives the boiled gas-liquid mixture of the target liquid. In contrast, the cooling mechanism includes the first cooling unit that cools at least the first region and the second cooling unit that cools at least the second region. Moreover, the second cooling unit forms the flow of the refrigerant from top to bottom in the second region. The cooling performance obtained by the refrigerant flowing from top to bottom can be made higher than the cooling performance in a case where the refrigerant used in the first cooling unit is used as it is. From the above, the cooling performance of the cooling mechanism can be improved.

[0008] The first cooling unit may include a first nozzle unit that injects the refrigerant onto a partition wall between the first cooling unit and the first region, the second cooling unit may include a second nozzle unit that injects the refrigerant onto the partition wall between the second cooling unit and the second region, and in the second cooling unit, a flow of the refrigerant from top to bottom may be formed below an injection point by the second nozzle unit. The cooling by the injection has a high heat transfer coefficient and excellent cooling efficiency as compared to other forced convection. Therefore, in addition to the cooling of the first region by the injection of the first nozzle unit, the second nozzle unit cools the second region by the injection, thereby further enhancing the cooling performance of the cooling mechanism.

[0009] A first internal space through which the refrigerant flows in the first cooling unit and a second internal space through which the refrigerant flows in the second cooling unit may be partitioned from each other. In this case, cooling can be performed in a state in which the first cooling unit and the second cooling unit are independent of each other. In this case, it is possible to suppress that the flow of the refrigerant in one cooling unit interferes with the flow of the refrigerant in the other cooling unit.

[0010] According to the present invention, the target device capable of improving the cooling performance of the cooling mechanism is provided.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011]

FIG. 1 is a cross-sectional view of a target device according to the present embodiment.
FIG. 2 is a cross-sectional view of a target device in a state in which a target liquid is irradiated with a beam.
FIG. 3 is a view of the target device as viewed from a rear surface side.
FIGS. 4A and 4B is a view illustrating a detailed configuration of a target accommodation unit.

DETAILED DESCRIPTION OF THE INVENTION

[0012] Hereinafter, an embodiment for carrying out the present invention will be described in detail with reference to the accompanying drawings. In addition, in the description of the drawings, the same reference numerals will be assigned to the same elements, and repeated description will be omitted.

[0013] FIG. 1 is a cross-sectional view of a target device 100 according to the present embodiment. FIG. 1 is a cross-sectional view of the target device 100 cut at the position of an irradiation axis RL. FIG. 1 illustrates a state before a target liquid 101 is irradiated with a beam B. FIG. 2 is a cross-sectional view of the target device 100 in a state in which the target liquid 101 is irradiated with the beam B. FIG. 3 is a view of the target device 100 as viewed from a rear surface side.

[0014] As illustrated in FIG. 1, the target device 100 according to the present embodiment includes a beam introduction unit 1, a foil 2, a target accommodation unit 3, and a cooling mechanism 4. A radioisotope production apparatus includes the above-described target device 100 and an accelerator (not illustrated) . For example, a cyclotron or the like is adopted as such an accelerator, the accelerator generates a charged particle beam (hereinafter, referred to as a "beam"), and the generated beam B (refer to FIG. 2) is emitted the target device 100 along the irradiation axis RL. Examples of the beam B emitted to the target device 100 include particle beams such as a proton beam and a heavy proton beam. The target device 100 is mounted on an outlet port from which the beam B of the accelerator is led out via a manifold (not illustrated) disposed between the target device 100 and the accelerator. In addition, in the following description, a direction in which the irradiation axis RL extends may be referred to as a depth direction D1 of the target device 100. Additionally, a side (an upstream side in a traveling direction of the beam) to which the beam B is emitted in the depth direction D1 may be referred to as a front side of the target device 100, and a side opposite thereto may be referredto as a rear side of the target device 100. Additionally, a direction perpendicular to the depth direction D1 of the target device 100 and an up-down direction may be referred to as a width direction D2.

[0015] The target device 100 has, for example, a square columnar outer shape. The target device 100 includes a front flange 11 mainly for forming the beam introduction unit 1, a target container 12 mainly for forming the target accommodation unit 3, and a flow path forming member 13 mainly for forming the cooling mechanism 4. The front flange 11, the target container 12, and the flow path forming member 13 are made of a metallic block body. Additionally, the front flange 11, the target container 12, and the flow path forming member 13 are superimposed on each other in order rearward from the front side in the depth direction D1.

[0016] The target device 100 includes a front surface 100a and a rear surface 100b parallel to each other in the depth direction D1, a side surface 100c and a side surface 100d parallel to each other in the width direction D2 (refer to FIG. 3), and an upper surface 100e and a lower surface 100f parallel to each other in the up-down direction. The front surface 100a is constituted by a front surface of the front flange 11 in the depth direction D1. In addition, a ring member 14 that introduces the beam B is attached to the front surface 100a at a position corresponding to the irradiation axis RL. The rear surface 100b is constituted by a rear surface of the flow path forming member 13 in the depth direction D1. The side surfaces 100c and 100d are constituted by a combination of the front flange 11, the target container 12, and end surfaces of the flow path forming member 13 in the width direction D2. The upper surface 100e is constituted by a combination of the front flange 11, the target container 12, and an upper surface of the flow path forming member 13. The lower surface 100f is constituted by a combination of the front flange 11, the target container 12, and a lower surface of the flow path forming member 13.

[0017] The beam introduction unit 1 is a portion that introduces the beam B into the target device 100. The beam introduction unit 1 is constituted by an introduction hole 21 centered on the irradiation axis RL of the beam B. The introduction hole 21 is constituted by a combination of a through-hole formed in the ring member 14 and a through-hole formed in the front flange 11. The foil 2 is exposed at a rear opening portion of the introduction hole 21. Therefore, the beam B introduced into the introduction hole 21 of the beam introduction unit 1 is emitted to the foil 2. In addition, the ring member 14 and the front flange 11 constituting the beam introduction unit 1 can be formed of, for example, an aluminum alloy.

[0018] The foil 2 is a member that partitions the beam introduction unit 1 and the target accommodation unit 3 from each other. The foil 2 is sandwiched between the front flange 11 and the target container 12. The foil 2 is pressed against and fixed to the target container 12 by the front flange 11. The foil 2 allows the beam B to pass therethrough, while blocking the passage of fluids such as the target liquid 101 and He gas. Therefore, after the beam B is emitted to the foil 2, the beam B passes through the foil 2 and is emitted to the target liquid 101. For example, the He gas is blown against the front surface of the foil 2 and used as a cooling gas for the foil 2. The foil 2 is, for example, a thin foil formed from metals or alloys of Ti or the like, and the thickness thereof is about 10 μm to 50 μm. The foil 2 is provided so as to cover at least the entire region of the introduction hole 21 of the beam introduction unit 1. Additionally, the foil 2 is provided so as to cover the entire region of an opening portion of a recessed portion 22 (described below) of the target accommodation unit 3.

[0019] The target accommodation unit 3 is a portion that accommodates the target liquid 101. The target accommodation unit 3 is constituted by a space surrounded by the recessed portion 22 formed in the target container 12 and the foil 2. The target container 12 can be formed of, for example, Nb. ^{18}O (target water) is enclosed as the target liquid 101 in the target accommodation unit 3. The recessed portion 22 is recessed rearward in the depth direction D1 from, for example, a fixing surface 12a sandwiching the foil 2 in the front surface of the target container 12. The recessed portion 22 has a bottom surface 22a, and a peripheral surface 22b extending forward in the depth direction D1 from an outer peripheral edge of the bottom surface 22a. The target accommodation unit 3 has a symmetrical shape with respect to a center line CL1 of the target device 100 (except for a point where fins 29 described below are provided) as viewed from the width direction D2.

[0020] The target container 12 is formed with a gas introduction hole 23 for introducing an inert gas (for example, He gas) into the target accommodation unit 3. The gas introduction hole 23 communicates with the target accommodation unit 3 and extends to an opening portion 24a provided on a back surface of the target container 12. A pipe route 24 extending further rearward is connected to the opening portion 24a of the back surface of the target container 12. The inert gas passes through the pipe route 24 and the gas introduction hole 23 and is introduced into the target accommodation unit 3. By introducing a high-pressure (for example, 3 MPa) inert gas into the target accommodation unit 3 in this way, the pressure inside the target accommodation unit 3 can be increased and the boiling temperature of the target liquid 101 can be raised.

[0021] The target container 12 is formed with a circulation hole 26 that is used when the target liquid 101 is filled into the target accommodation unit 3 and used when the target liquid 101 in the target accommodation unit 3 is discharged. The circulation hole 26 communicates with the target accommodation unit 3 and extends to an opening portion 27a provided on the back surface of the target container 12. A pipe route 27 extending further rearward is connected to the opening portion 27a of the back surface of the target container 12. Then, the target liquid 101 passes through the pipe route 27 and the circulation hole 26 and is introduced into the target accommodation unit 3. Additionally, the target liquid 101 in the target accommodation unit 3 is discharged through the circulation hole 26 and the pipe route 27.

[0022] The target accommodation unit 3 has a first region E1 that accommodates the target liquid 101, and a second region E2 that is located above the first region E1 and receives a boiled gas-liquid mixture 102 of the target liquid 101 (refer to FIG. 2). In addition, a state in which the second region E2 receives the boiled gas-liquid mixture 102 means a state in which the target liquid 101 is not accommodated before the irradiation with the beam B and the gas-liquid mixture 102 is accommodated during the irradiation with the beam B. The second region E2 is continuously formed above the first region E1. The liquid level of the target liquid 101 before the boiling is set to a boundary portion between the first region E1 and the second region E2. In the present embodiment, the boundary portion is set to be above the irradiation axis RL and below the center line CL1. Therefore, the volume of the second region E2 is larger than the volume of the first region E1. However, a relationship between the volume magnitudes of the first region E1 and the second region E2 is not particularly limited, and the volumes of both may be the same, or the volume of the first region E1 may be larger. In the gas-liquid mixture 102, the liquid level rises due to the generation of air bubbles inside and reaches the second region E2 (refer to FIG. 2).

[0023] A more detailed structure of the target accommodation unit 3 will be described with reference to FIGS. 4A and 4B. As illustrated in FIG. 4A, the target accommodation unit 3 has a track shape in which an upper end portion and a lower end portion are semicircular. The plurality of fins 29 are provided in the second region E2. The plurality of fins 29 extend upward from the vicinity of a boundary portion with the first region E1 to an upper end portion of the second region E2. The plurality of fins 29 are arranged at a predetermined pitch in the width direction W1. The fins 29 extend forward in the depth direction D1 from the bottom surface 22a of the recessed portion 22. The fins 29 are fixed to the bottom surface 22a. Although the height of the fins 29 is not particularly limited, the fins 29 may extend to the position of the foil 2 (refer to FIG. 4B). In addition, the fins 29 are not provided in the first region E1, and the bottom surface 22a spreads in a planar shape.

[0024] As described above, when the fins 29 are provided in the second region E2, the contact area between the gas-liquid mixture 102 and the cooling surface can be increased. Therefore, the cooling performance of a second cooling unit 30B can be improved. On the other hand, the fins 29 are not provided in the first region E1 in order to prevent the beam B from hitting the fins 29. Additionally, since there is much gas component in the second region E2 due to evaporation, the cooling effect by providing the fins 29 is enhanced. Compared to that, when the fins 29 are provided in the first region E1 having a large amount of liquid component, it is necessary to secure a volume for accommodating the target liquid 101 accordingly. There is a possibility that the influence of increasing the outer shape of the entire target accommodation unit 3 will be larger than the influence of improving the cooling performance. Therefore, the fins 29 are not provided in the first region E1.

[0025] Returning to FIG. 1, the cooling mechanism4 cools the target accommodation unit 3 with a refrigerant on a side (that is, the rear surface side) opposite to the irradiating direction of the beam B emitted to the target liquid 101. The cooling mechanism 4 includes a first cooling unit 30A that cools the first region E1 and a second cooling unit 30B that cools the second region E2. The first cooling unit 30A includes a nozzle unit 32A disposed in a first internal space 31A. Additionally, the second cooling unit 30B includes a nozzle unit 32B disposed in a second internal space 31B.

[0026] The first internal space 31A and the second internal space 31B are spaces for allowing the refrigerant to flow thereinto. The first internal space 31A is formed on the rear side in the depth direction D1 with respect to the first region E1 of the target accommodation unit 3. The second internal space 31B is formed on the rear side in the depth direction D1 with respect to the second region E2 of the target accommodation unit 3. That is, the second internal space 31B is provided above the first internal space 31A. A heat transfer wall portion 34 (partition wall) is provided between the internal spaces 31A and 31B and the target accommodation unit 3.

[0027] Additionally, the first internal space 31A and the second internal space 31B are partitioned from each other by a partition wall 36. Accordingly, the internal spaces 31A and 31B has a shape such that a track shape, in which an upper end portion and a lower end portion are semicircular as viewed from the front side, is divided at a central position in the up-down direction (an upper end portion side corresponds to the internal space 31B and a lower end portion side corresponds to the internal space 31A) (refer to FIG. 3). The internal spaces 31A and 31B have the above-described shape and extend parallel to the depth direction D1. In addition, the partition wall 36 is provided at the position of a center line CL1 of the target device 100. For that reason, the first internal space 31A approaches a part of a lower end side of the second region E2. In addition, the target container 12 has a recessed portion 37 on a rear surface thereof. Additionally, the flow path forming member 13 has recessed portions 38A and 38B on a front surface thereof. The partition wall 36 is provided between the recessed portion 38A and the recessed portion 38B. The first internal space 31A is formed by a combination of the recessed portion 37 of the target container 12 and the recessed portion 38A of the flow path forming member 13. The second internal space 31B is formed by a combination of the recessed portion 37 of the target container 12 and the recessed portion 38B of the flow path forming member 13.

[0028] The first nozzle unit 32A is a member that injects the refrigerant onto the heat transfer wall portion 34 between the first nozzle unit 32A and the first region E1. The first nozzle unit 32A injects the refrigerant perpendicularly to the heat transfer wall portion 34. The first nozzle unit 32A injects the refrigerant onto the heat transfer wall portion 34 at a position intersecting the irradiation axis RL (a position facing the introduction hole 21 and coaxial with the beam B). In this case, the nozzle center of the first nozzle unit 32A is disposed within the diameter of the beam B as viewed from the depth direction D1. The first nozzle unit 32A is a cylindrical member that extends parallel to the depth direction D1. The first nozzle unit 32A is provided on a bottom surface of the recessed portion 38A. The first nozzle unit 32A is spaced apart from the heat transfer wall portion 34. A diameter-enlarged portion 32a having an enlarged diameter is formed at a tip part (front end portion in the depth direction D1) of the first nozzle unit 32A. An outer peripheral surface of the diameter-enlarged portion 32a is spaced from the recessed portion 37, an inner peripheral surface of the recessed portion 38A, and the partition wall 36.

[0029] The second nozzle unit 32B is a member that injects the refrigerant onto the heat transfer wall portion 34 between the second nozzle unit 32B and the second region E2. The second nozzle unit 32B injects the refrigerant perpendicularly to the heat transfer wall portion 34. An injection point by the second nozzle unit 32B is preferably in the vicinity of the interface of the gas-liquid mixture 102. The second nozzle unit 32B is a cylindrical member that extends parallel to the depth direction D1. The second nozzle unit 32B is provided on a bottom surface of the recessed portion 38B. The second nozzle unit 32B is spaced from the heat transfer wall portion 34. A diameter-enlarged portion 32b having an enlarged diameter is formed at a tip part (front end portion in the depth direction D1) of the second nozzle unit 32B. An outer peripheral surface of the diameter-enlarged portion 32b is spaced from the recessed portion 37, an inner peripheral surface of the recessed portion 38B, and the partition wall 36.

[0030] The cooling mechanism 4 includes a refrigerant circulation mechanism 40 for injecting the refrigerant from the nozzle units 32A and 32B. First, a supply pipe 41 for supplying the refrigerant is inserted into a rear surface 100b. The supply pipe 41 communicates with an injection port of the second nozzle unit 32B via a flow path 42 formed in the flow path forming member 13. A flow path 43 for recovering the refrigerant in the second internal space 31B is open to the bottom surface of the recessed portion 38B of the second internal space 31B. The flow path 43 extends in the flow path forming member 13 and communicates with an injection port of the first nozzle unit 32A. A flow path 44 for recovering the refrigerant in the first internal space 31A is open to the bottom surface of the recessed portion 38A of the first internal space 31A. The flow path 44 is connected to a recovery pipe 46 inserted in a rear surface of the flow path forming member 13. The recovery pipe 46 extends to one side in the width direction D2 (refer to FIG. 3), and the refrigerant passes through a pipe (not illustrated) and is recovered by the recovery pipe 47 provided on an upper side of the target device 100.

[0031] Next, the flow of the refrigerant in the cooling mechanism 4 at the time of the irradiation with the beam B will be described in detail with reference to FIGS. 2 and 3. When the target liquid 101 (refer to FIG. 1) is irradiated with the beam B, the target liquid 101 boils and the gas-liquid mixture 102 is drawn into the second region E2. Accordingly, F-18 is generated in the first region E1. In this case, as the refrigerant is supplied from the supply pipe 41, the second nozzle unit 32B injects the refrigerant to the position (specifically, the vicinity of the interface) of the heat transfer wall portion 34 corresponding to the second region E2 (flow F1). The refrigerant that has collided against the heat transfer wall portion 34 spreads radially from a collision point. Accordingly, a flow (flow F2) of the refrigerant from top to bottom in the second region E2 is formed between the second nozzle unit 32B and the heat transfer wall portion 34. In addition, a flow (flow F3) of the refrigerant from top to bottom is also formed in the second region E2. The refrigerant, which has spread in the heat transfer wall portion 34, is turned back at the diameter-enlarged portion 32b, flows toward the opening portion 43a of the flow path 43, and is recovered (flow F4). The refrigerant recovered from the second internal space 31B passes through the flow path 43 and flows toward the first nozzle unit 32A (flow F5). Accordingly, the first nozzle unit 32A injects the refrigerant to the position (specifically, a position coaxial with the beam B) of the heat transfer wall portion 34 corresponding to the first region E1 (flow F6).

[0032] The refrigerant that has collided against the heat transfer wall portion 34 spreads radially from a collision point. Accordingly, a flow of the refrigerant (flow F7) from top to bottom in the first region E1 is formed between the first nozzle unit 32A and the heat transfer wall portion 34. Additionally, a flow of the refrigerant (flow F8) from top to bottom in the first region E1 is also formed. In addition, since the second region E2 also partially approaches the first internal space 31A, a part on the upper side of the flow F8 also approaches the second region E2 (refer to FIG. 2). The refrigerant, which has spread in the heat transfer wall portion 34, is turned back at the diameter-enlarged portion 32a, flows toward the opening portion 44a of the flow path 44, and is recovered (flow F9). The refrigerant recovered from the first internal space 31A passes through the flow path 44 and flows toward the recovery pipe 46 (flow F10). Additionally, the refrigerant is recovered by the recovery pipe 47 (flow F11).

[0033] Next, the actions and effects of the target device 100 according to the present embodiment will be described.

[0034] According to the target device 100 according to the present embodiment, the target accommodation unit 3 has the first region E1 that accommodates the target liquid 101, and the second region E2 that receives the boiled gas-liquid mixture 102 of the target liquid 101 (a region that does not accommodate the target liquid 101 before the irradiation with the beam B). In contrast, the cooling mechanism 4 includes the first cooling unit 30A that cools at least the first region E1 and the second cooling unit 30B that cools at least the second region E2. Moreover, the second cooling unit 30B forms a flow (flow F2 in FIG. 2) of the refrigerant from top to bottom in the second region E2. The cooling performance obtained by the refrigerant flowing from top to bottom can be made higher than the cooling performance in a case where the refrigerant used in the first cooling unit 30A is used as it is. From the above, the cooling performance of the cooling mechanism 4 can be improved.

[0035] In the target accommodation unit 3, the vapor component of the target liquid that is heated and rises is abundantly present at an upper portion of the second region E2. However, it is expected that a large amount of heat is taken away by the transfer of condensation heat at that point. Therefore, the second cooling unit 30B can keep the heat transfer wall portion 34 at a lower temperature by applying the refrigerant to the heat transfer wall portion 34 at an upper portion of the second region E2. Therefore, the cooling performance can be improved.

[0036] The first cooling unit 30A includes the first nozzle unit 32A that injects the refrigerant onto the heat transfer wall portion 34 between the first cooling unit 30A and the first region E1. The second cooling unit 30B includes the second nozzle unit 32B that injects the refrigerant onto the heat transfer wall portion 34 between the second cooling unit 30B and the second region E2. In the second cooling unit 30B, a flow of the refrigerant (flow F2 in FIG. 2) from top to bottom may be formed below the injection point by the second nozzle unit 32B. The cooling by the injection has a high heat transfer coefficient and excellent cooling efficiency as compared to other forced convection. Therefore, in addition to the cooling of the first region E1 by the injection of the first nozzle unit 32A, the second nozzle unit 32B cools the second region E2 by the injection, thereby further enhancing the cooling performance of the cooling mechanism 4.

[0037] The first internal space 31A through which the refrigerant flows in the first cooling unit 30A and the second internal space 31B through which the refrigerant flows in the second cooling unit 30B maybe partitioned from each other. In this case, cooling can be performed in a state in which the first cooling unit 30A and the second cooling unit 30B are independent of each other. In this case, it is possible to suppress that the flow of the refrigerant in one cooling unit interferes with the flow of the refrigerant in the other cooling unit.

[0038] In a case where the cooling is performed by the injection, in the vicinity of the nozzle center, the heat transfer coefficient is larger and the thermal efficiency is excellent. However, the heat transfer coefficient is small at a point away from the nozzle center. Therefore, a point where the cooling can be efficiently performed is limited to a radius of about 2 cm at a flow rate of the refrigerant of 5 to 10 liters per minute. For example, in a case where the second region E2 is also cooled by the refrigerant from the first cooling unit 30A as in a comparative example described below, the second region E2 is radially separated from the first nozzle unit 32A. Therefore, there is a case where sufficient cooling is not be performed. In contrast, when the first cooling unit 30A and the second cooling unit 30B are made independent of each other and the flow of the refrigerant dedicated to the second region E2 is formed by the second cooling unit 30B, the cooling efficiency for the second region E2 can be greatly improved.

[0039] As the comparative example, the target device 100 according to the above-described embodiment is prepared by removing the second cooling unit 30B and the partition wall 36. A target device according to the comparative example cools the second region by using an upward flow of the refrigerant (corresponding to the flow F8 in FIG. 2) generated by the injection of the first nozzle unit 32A. In the target device according to such a comparative example, in a case where the target liquid 101 was irradiated with a beam B of 18 MeV and an average of 95 μA for 2 hours, the target accommodation unit 3 reached a maximum of 3.5 MPa, and F-18 of 416 GBq was generated. When the beam current is increased more than that, there is a possibility that the pressure of the target accommodation unit 3 exceeds a recommended upper limit of 4.2 MPa and the target is damaged. In contrast, in the target device 100 according to the present embodiment, in a case where the target liquid 101 was irradiated with a beam B of 18 MeV and an average of 95 μA for 2 hours, the target accommodation unit 3 reached a maximum of 2.3 MPa, and F-18 of 450 GBq was generated. Moreover, in a case where the target liquid 101 was irradiated with the beam B having an average of 167 μA for 2 hours, the target accommodation unit 3 reached a maximum of 3.4 MPa, and F-18 of 755 GBq was generated. In this way, in the target device 100 of the present embodiment, the intensity of the beam B can be made higher than that of the comparative example because the cooling performance of the cooling mechanism 4 is high.

[0040] The present invention is not limited to the above-described embodiment.

[0041] For example, the second cooling unit includes the second nozzle unit that injects the refrigerant onto the partition wall between the second cooling unit and the second region. However, the second cooling unit may form a flow of the refrigerant from top to bottom in the second region and may not necessarily have the second nozzle unit. For example, a flow of the refrigerant may be formed from an upper end of the second internal space so as to flow from top to bottom in the heat transfer wall portion 34. That is, in the above-described embodiment, the second cooling unit also forms a flow from bottom to top by the injection (flow F3 in FIG. 2), but may form only a flow from top to bottom.

[0042] The refrigerant circulation mechanism in the cooling mechanism is not limited to the above-described embodiment. For example, in the above-described embodiment, only one refrigerant supply pipe is used, and the refrigerant used for the injection of the second cooling unit is also used for the injection of the first cooling unit. Instead of this, a dedicated supply pipe may be provided for the first cooling unit and a dedicated supply pipe may be provided for the second cooling unit. Additionally, the configuration of the flow path or pipe for the refrigerant may be appropriately changed.

Brief Description of the Reference Symbols

[0043]

3	Target accommodation unit
4	Cooling mechanism
30A	First cooling unit
30B	Second cooling unit
31A	First internal space
31B	Second internal space
32A	First nozzle unit
32B	Second nozzle unit
34	Heat transfer wall portion (partition wall)
100	Target device

Claims

1. A target device (100) comprising:

   a target accommodation unit (3) having a first region (E1) that accommodates a target liquid (101), and a second region (E2) that is located above the first region (E1) and receives a boiled gas-liquid mixture (102) of the target liquid (101); and
   a cooling mechanism (4) that cools the target accommodation unit (3) with a refrigerant on a side opposite to an irradiating direction of an irradiation beam with respect to the target liquid (101),
   wherein the cooling mechanism (4) includes a first cooling unit (30A) that cools at least the first region (E1) and a second cooling unit (30B) that cools at least the second region (E2), and
   the second cooling unit (30B) forms a flow of the refrigerant from top to bottom in the second region (E2).

2. The target device (100) according to claim 1,

   wherein the first cooling unit (30A) includes a first nozzle unit (32A) that injects the refrigerant onto a partition wall (34) between the first cooling unit (30A) and the first region (E1),
   the second cooling unit (30B) includes a second nozzle unit (32B) that injects the refrigerant onto the partition wall (34) between the second cooling unit (30B) and the second region (E2), and
   in the second cooling unit (30B), the flow of the refrigerant from top to bottom is formed below

an injection point by the second nozzle unit (32B).

3. The target device (100) according to claim 1 or 2, wherein a first internal space (31A) through which the refrigerant flows in the first cooling unit (30A) and a second internal space (31B) through which the refrigerant flows in the second cooling unit (30B) are partitioned from each other.

FIG. 1

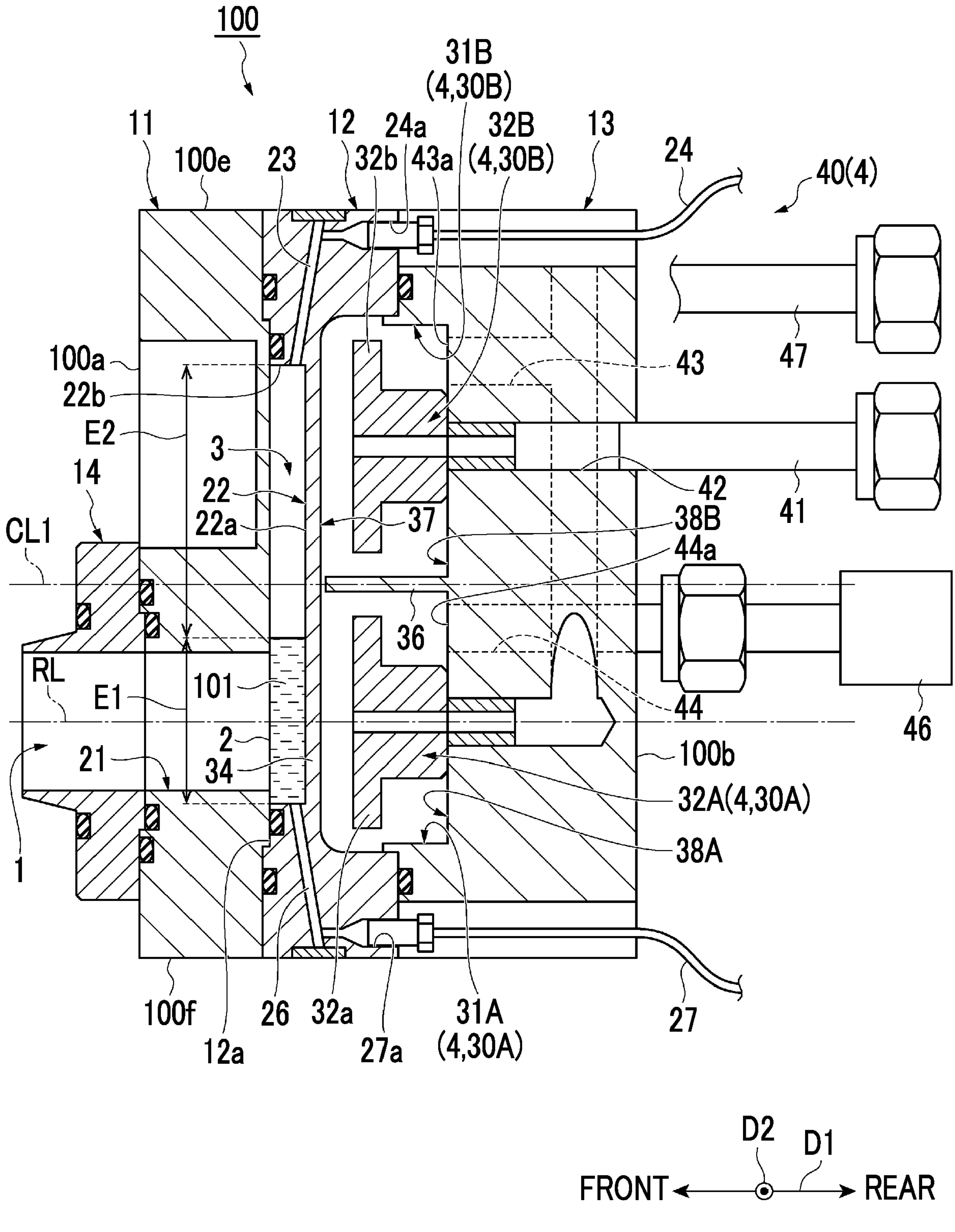

100
11
100e
23
12
24a
32b
43a
31B
(4,30B)
32B
(4,30B)
13
24
40(4)
100a
22b
E2
3
14
22
22a
37
CL1
RL
E1
101
2
21
34
1
43
47
42
41
38B
44a
36
44
46
100b
32A(4,30A)
38A
100f
12a
26
32a
27a
31A
(4,30A)
27
D2
D1
FRONT
REAR

FIG. 2

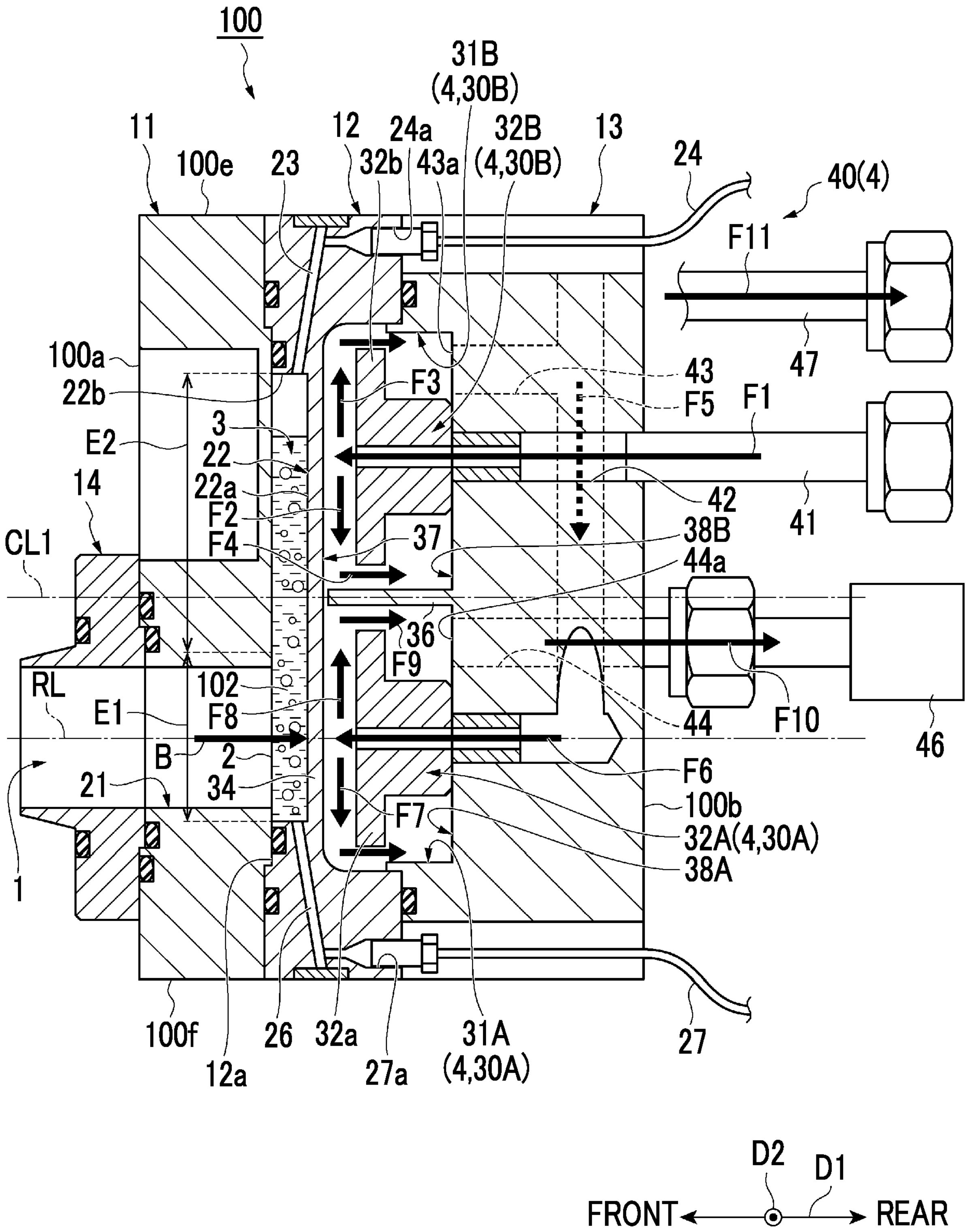

100
11
100e
23
12
24a
32b
43a
31B
(4,30B)
32B
(4,30B)
13
24
40(4)
F11
47
100a
22b
43
F5
F1
F3
E2
3
22
22a
14
F2
F4
42
41
37
38B
CL1
44a
36
F9
RL
102
E1
F8
B
2
21
34
44
F10
46
F6
100b
F7
32A(4,30A)
38A
1
100f
26
32a
31A
(4,30A)
27
12a
27a
D2
D1
FRONT
REAR

FIG. 3

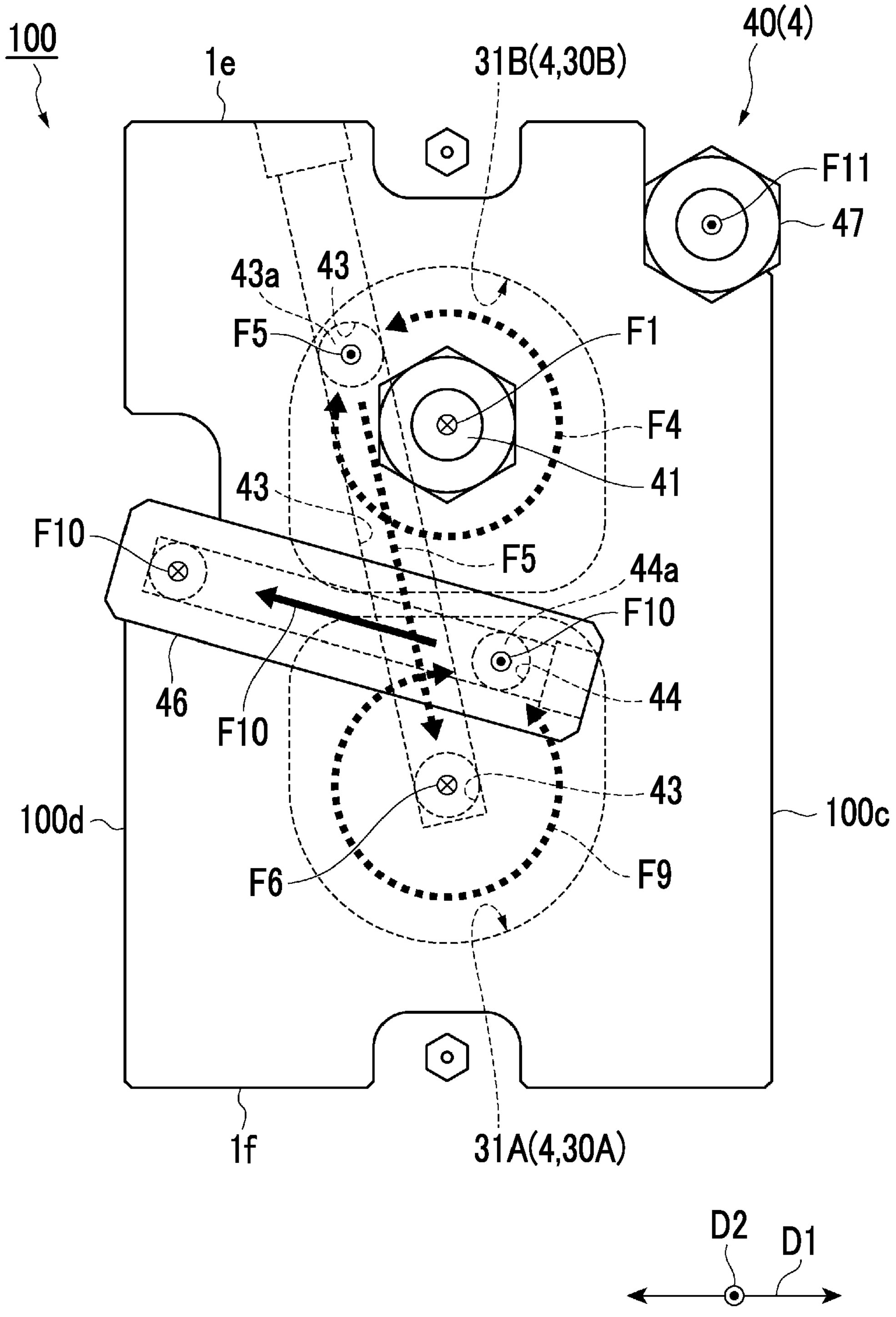

100
1e
31B(4,30B)
40(4)
F11
47
43a
43
F5
F1
F4
41
43
F10
F5
44a
F10
44
46
F10
43
100d
100c
F6
F9
1f
31A(4,30A)
D2
D1

FIG. 4A

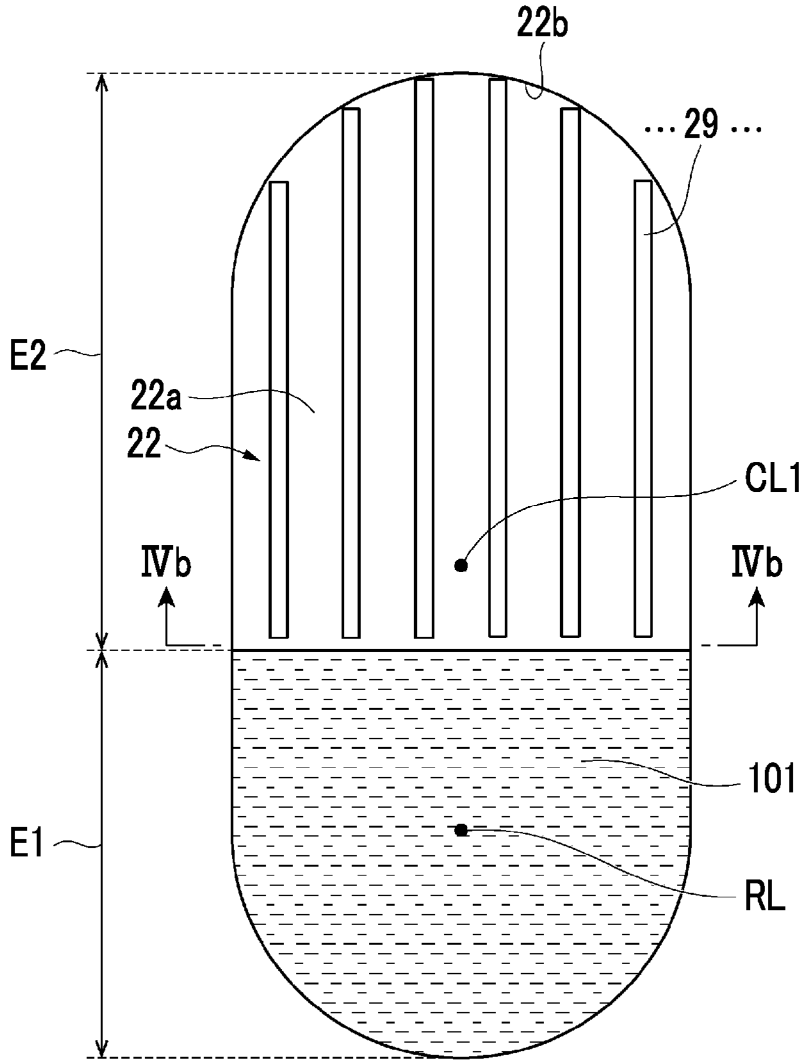
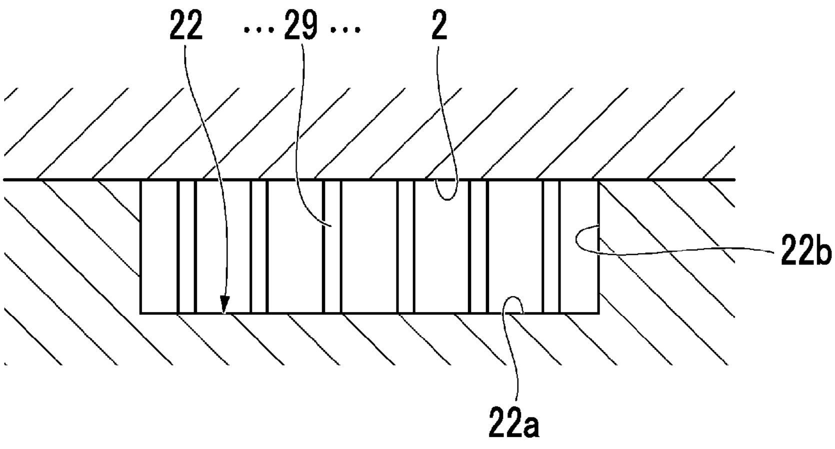


FIG. 4B



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EUROPEAN SEARCH REPORT

Application Number
EP 21 16 1664

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The present search report has been drawn up for all claims

2

Place of search	Date of completion of the search	Examiner
The Hague	29 July 2021	Clemente, Gianluigi

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