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(54) **TARGET ASSEMBLY FOR GENERATION OF RADIOACTIVE ISOTOPES**

(57) A target assembly (1) for generation of radio-isotopes is disclosed. The target assembly comprises at least a first reservoir (2) and a second reservoir (3) being interconnected by a tubular portion. The first resp. second reservoir (2, 3) each have a window (12, 13) for receiving the irradiation beam (8). The tubular portion (4) is configured for allowing passage of the target powder (9) between the reservoirs under gravity force. When

used in an ISOL system, the tubular portion (4) further is adapted for allowing escape of said radio-isotopes outside the tubular portion (4). The target assembly (1) further has a means for rotating the assembly such that in turn, each of the first respectively second reservoir (2, 3) can selectively be positioned above the other of the second respectively first reservoir (3, 2).

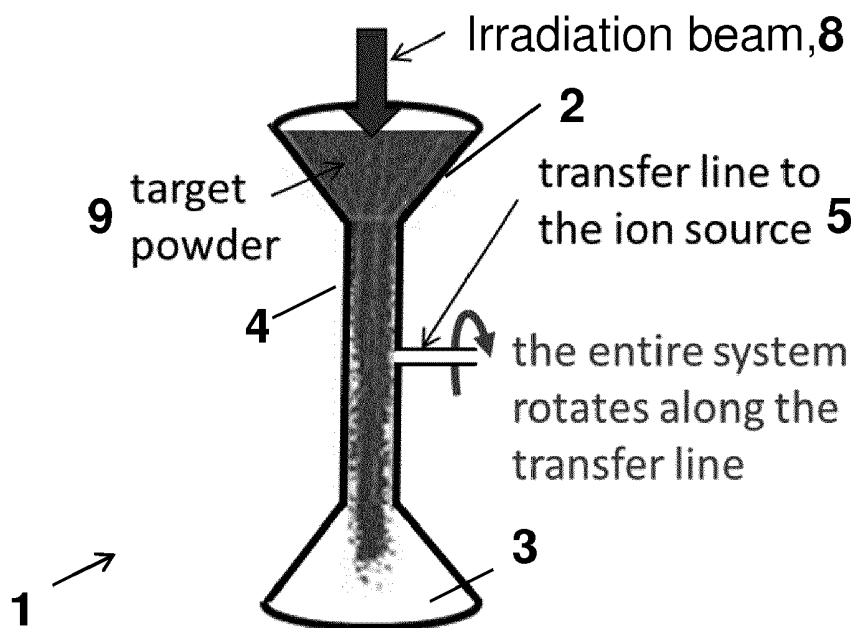


FIG 3

Description

Field of the invention

[0001] The invention relates to devices for and methods of producing radio-isotopes, as may be used for example for scientific and medical applications.

Background of the invention

[0002] The present invention is concerned with the development of high-power targets for the production of radio-isotopes by using the Isotope-Separation On-Line (ISOL) technique, which can be used for example for scientific experiments and medical applications.

[0003] As confirmed by US2006/0050832A1, the production of radioisotopes typically involves irradiating a target material (solid, gas or liquid) maintained within a target assembly with an energetic particle beam. The energetic particle beam may be characterized by one or more parameters such as particles per second, beam current (typically measured in microamps (μ A) or milliamps (mA)), particle velocity, beam energy (typically measured in kilo electron volts (KeV) or mega electron volts (MeV)), and beam power (typically measured in watts (W)). The interaction of one of the energetic particles from the particle beam with a target nucleus in the target material will, under the appropriate conditions, tend to produce a nuclear reaction that transforms the target nucleus into a different element.

[0004] The probability of a nuclear reaction occurring is expressed by the "cross-section" and is a function of the incoming particle energy and differs for each combination of target nuclei, incoming particle, and leaving particle. For the production of a particular radioisotope, type of particle, the beam current, beam energy, target nuclei and target density may be selected to increase the likelihood of the preferred nuclear reaction and the yield of the desired product.

[0005] The yield of the desired product can, therefore, be enlarged by increasing the number of incoming energetic particles, i.e., the beam current. Increasing the number of incoming energetic particles, while maintaining the same beam energy, will tend to increase the number of product nuclei generated. The range, or distance travelled through a medium, of a charged particle is a function of the energy of the charged particle and the properties of the medium or media through which it will travel. The range values for a wide range of particles, energies and media are generally known or readily available to those of skill in the art.

Radioactive ion beam research is one of the top priorities in nuclear physics. Furthermore, radioactive ion beams (RIBs) create a wide area of research opportunities in other fields of science, like nuclear astrophysics, condensed-matter, atomic physics, fundamental interactions and specific applications in nuclear medicine.

[0006] Advanced research often requires the produc-

tion of radioisotopes that live for only very short periods of time, which are a challenge to produce in large quantities. Samples cannot be made using techniques such as off-line chemical separation: given their short half-life, they would decay away during the time it takes to extract them. Over the years, this field has gained enough maturity to envisage the construction of facilities dedicated solely to RIB production. These facilities are based on two different methods: (1) the Isotope Separation On Line (ISOL) method (for the production of high-intensity, high-purity RIBs, though within an energy range from several keV's to several MeV's); (2) the in-flight method (for the production of high-energy beams, though with less intensity and purity). The ISOL method is based on the mass separation of chemically-clean radioisotope beams accelerated to a kinetic energy of typically 30-60 keV, or even higher, in the MeV range, should a post-accelerator be implemented.

[0007] FIG. 1 shows the principle of RIB production via the ISOL method.

[0008] In the ISOL method, the rare isotopes are being produced during the interaction of a light-particle beam with a thick high-Z target (whereby "Z" stands for the atomic number, which is equal to the number of protons of a nucleus). The process, depicted in FIG. 1, is summarized as follows: Lightweight particles (usually, protons) from a high-energy driver impinge on an ISOL-target material in an enclosed container that is directly connected to an ion source. Nuclear reactions take place in the target with the production of a large variety of isotopes that come to rest embedded in the target material. By operating the target at high temperatures, these isotopes diffuse through the target lattice (move between the atoms of the material) to the surface and then effuse from the target container to the ion source, where they can be ionized. The ions are then extracted, through a potential difference of several tens of kV, in a RIB, which undergoes mass purification in a mass separator. Should a post-accelerator be implemented, the RIBs are accelerated to energies in the range of several MeV/u.

[0009] As the power of the primary beam and the production rate are correlated, it is expected that, by increasing the primary-beam power, proportionally higher yields for the radioisotopes production will result. However, there is a challenge that the target design and target material should be capable to withstand reliably high beam-power deposition (e.g. 20 kW power deposition in the target or more) for long periods (e.g. for several weeks, preferably for several months).

Summary of the invention

[0010] It is an object of embodiments of the present invention to provide a method and a system for production of isotopes that can be used in continuous operation via the Isotope-Separation on-Line method with unprecedented-high intensities as well as the use thereof for production of the isotopes. It is an advantage of embod-

iments of the present invention that systems are provided for producing isotopes making use of a high power beam during a long period of time, thus resulting in efficient isotope production.

[0011] This objective is accomplished by a method and device according to embodiments of the present invention.

[0012] In a first aspect, the present invention relates to a target assembly for generation of radio-isotopes, comprising at least a first reservoir and a second reservoir being interconnected with a tubular portion together forming an enclosure for holding a target powder for generating said radio-isotopes when bombarded by an irradiation beam. The first respectively second reservoir each have a window configured for receiving the irradiation beam, the irradiation beam causing nuclear reactions when interacting with said target powder. The tubular portion is being configured for allowing passage of the target powder from one of the first respectively the second reservoir towards the other of the second respectively the first reservoir under gravity force, the longitudinal axis of the tubular portion being aligned with each of said windows for allowing the powder moving inside the tubular portion to be irradiated by said irradiation beam through said windows during use. The tubular portion is further adapted for allowing escape of said radio-isotopes outside the enclosure. The target assembly further has a means for rotating the enclosure such that in turn, each of the first respectively second reservoirs can selectively be positioned above the other of the second respectively first reservoir. The target powder may consist of a plurality of individual particles having an average diameter in the range of a few micrometers to 200 μm , and being made of a refractory metal or carbide powder for generating said radio-isotopes caused by said nuclear reaction. The enclosure/container holding said target powder typically is to be kept under very low pressure (e.g. in the order of 10^{-6} mbar), to allow the evaporation of the created radioisotopes and migration towards the ion source.

[0013] It is an advantage of a target assembly according to the present invention in that it can be used in an ISOL facility for producing radioactive isotopes over an envisioned period of several weeks.

[0014] It is an advantage that the produced radio-isotopes may e.g. be suitable for scientific research as well as for medical applications.

[0015] It is an advantage of using target material in free-falling powder form (as compared to e.g. compressed-powder target material), because it allows faster release of the radio-isotopes out of the target material.

[0016] It is an advantage of using refractory metals, because refractory metals have very high melting points and therefore the target can be operated at high temperatures (above 2000 deg C) to enhance the evaporation of radio-isotopes.

[0017] It is an advantage of providing a target assembly that can be rotated in its entirety, because of its simplicity, increased safety, and increased reliability.

[0018] It is an advantage of using the described geometry (which resembles an hour-glass), in that the flow of the powder through the tubular portion 4 is based on gravity and the flow-rate can be easily set by choosing appropriate dimensions, rather than by an active mechanism. In this way, the operating conditions of the mechanism for rotating the target assembly can be significantly improved: (a) roomtemperature conditions compared to temperatures around 2000 deg C for the target powder and (b) reduced radiation level by interposing shielding material in between the target assembly and the rotating mechanism.

[0019] It is an advantage that the longitudinal axis of the tubular portion is aligned (parallel) with the incident irradiation beam rather than being e.g. oriented perpendicular thereto, because it allows that the beam can irradiate the most part of the target material in a continuous manner. This is a major advantage over some prior art devices (such as for example US3094474), where the direction of movement of the "pellets" is perpendicular to the irradiation direction, requiring critical timing control. Depending on the energy of the beam on the target and the half lifetime of the isotope that is to be produced, in some embodiments the period for all powder to flow from one reservoir to the other may be for example between 200 and 300 milliseconds. Rotating of the assembly advantageously as short as possible in view of optimization of the beam, and may for example be within a few milliseconds.

[0020] The tubular portion is also referred to herein as "vertical column".

[0021] The particles of the target powder used may be microparticles having an average diameter smaller than 200 μm , preferably smaller than 100 μm . It is an advantage of using a target material in the form of microparticles, because it allows fast diffusion of the isotopes to the surface of the particle, where they can be desorbed.

[0022] The tubular portion may be a cylindrical or elliptical portion according to the transverse shape of the beam spot on target. In this embodiment the tubular portion has a circular cross-section of a constant diameter. The circular cross section offers the advantage of allowing a simpler rastering of the beam at high-power facilities, where the beam power is preferably uniformly distributed over a larger surface area on target.

[0023] The circular cross section of the tubular portion might not necessarily have a constant diameter for preventing the migration of the falling powder into the transfer line as shown in FIG.9.

[0024] The reservoirs 2,3 may consist of two conical segments tapering towards the extremities of the tubular portion in its length direction. It is an advantage of embodiments of the present invention that the powder can be moved also away from the direct irradiation with the beam, thus allowing cooling of the powder. When e.g. two truncated cone volumes are used, this allows ensuring a good flow of powder after rotation of the assembly, with uniform powder density in a plane perpendicular to

the beam axis.

[0025] The target assembly advantageously has a symmetrical shape. It is an advantage that the target assembly has a symmetrical shape, since the entire assembly has to rotate at high speed and the integrity of the system has to be kept during operation of several weeks continuously. An unbalanced design would lead to significant wearing of the bearings.

[0026] Each of the first and second reservoirs may have a conical or funnel-shaped portion for guiding the powder. The conical or funnel ensures that the powder in the upper reservoir flows towards the entrance of the vertical column.

[0027] Each of the first and second reservoirs may further comprise a volume portion having a substantially annular cross-section. It is an advantage of the annular portion in that the powder can be faster and more uniformly cooled (as compared to e.g. a simple conical reservoir). An optimization may be performed between the cooling rate on the one hand and the radio-isotopes production rate on the other hand.

[0028] The window of the first resp. second reservoir may be located in a cavity of said reservoir.

[0029] The target assembly will be rotated by a motor. One example of a motor that can be used is a pneumatic motor, etc. The motor may be coupled to the target assembly by means of a shaft. The motor typically may be positioned at large distance from the target, e.g. larger than 2,5 m, and behind shielding to avoid radiation damage.

The present invention also relates to a radioactive isotope generator comprising the target assembly as described above.

In yet another aspect, the present invention also relates to the use of a target assembly as described for production of radioactive isotopes.

Particular and preferred aspects of the invention are set out in the accompanying independent and dependent claims. Features from the dependent claims may be combined with features of the independent claims and with features of other dependent claims as appropriate and not merely as explicitly set out in the claims.

These and other aspects of the invention will be apparent from and elucidated with reference to the embodiment(s) described hereinafter.

Brief description of the drawings

[0030]

FIG. 1 shows the principle of RIB (Radioactive Ion Beam) production via the ISOL (Isotope Separation On Line) method, as known in the state of the art.

FIG. 2 is an example of a prior art ISOL target assembly. This target assembly (utilized at TRIUMF-ISAC facility) can operate at the highest beam-power on target so far.

FIG. 3 shows (the main components of) an embod-

iment of a target assembly according to the present invention.

FIG. 4 (left) shows a simulation model, and FIG. 4 (right) shows density curves of the target in the tubular section as a function of distance inside the tubular portion.

FIG. 5 shows a simulated example of power delivered by the irradiation beam to the powder in FIG. 4. FIG. 6 shows simulated results of ^{149}Tb production rate in function of the length of the tubular portion, for two different energy levels (600 MeV and 1 GeV) of the incident irradiation beam and for two different beam intensities (200 μA and 1 mA).

FIG. 7 shows an example of the target assembly according to an embodiment of the present invention.

FIG. 8 shows (part of) a variant of the target assembly of FIG. 7, as another embodiment of the present invention.

FIG. 9 shows (part of) a variant of the target assembly of FIG. 7, with non-constant diameter of the tubular section, as another embodiment of the present invention.

25 The drawings are only schematic and are non-limiting. In the drawings, the size of some of the elements may be exaggerated and not drawn on scale for illustrative purposes.

Any reference signs in the claims shall not be construed as limiting the scope.

30 In the different drawings, the same reference signs refer to the same or analogous elements.

Detailed description of illustrative embodiments

35 [0031] The present invention will be described with respect to particular embodiments and with reference to certain drawings but the invention is not limited thereto but only by the claims. The drawings described are only schematic and are non-limiting. In the drawings, the size of some of the elements may be exaggerated and not drawn on scale for illustrative purposes. The dimensions and the relative dimensions do not correspond to actual reductions to practice of the invention.

40 [0032] Furthermore, the terms first, second and the like in the description and in the claims, are used for distinguishing between similar elements and not necessarily for describing a sequence, either temporally, spatially, in ranking or in any other manner. It is to be understood that the terms so used are interchangeable under appropriate circumstances and that the embodiments of the invention described herein are capable of operation in other sequences than described or illustrated herein.

45 [0033] Moreover, the terms top, under and the like in the description and the claims are used for descriptive purposes and not necessarily for describing relative positions. It is to be understood that the terms so used are interchangeable under appropriate circumstances and

that the embodiments of the invention described herein are capable of operation in other orientations than described or illustrated herein.

[0034] It is to be noticed that the term "comprising", used in the claims, should not be interpreted as being restricted to the means listed thereafter; it does not exclude other elements or steps. It is thus to be interpreted as specifying the presence of the stated features, integers, steps or components as referred to, but does not preclude the presence or addition of one or more other features, integers, steps or components, or groups thereof. Thus, the scope of the expression "a device comprising means A and B" should not be limited to devices consisting only of components A and B. It means that with respect to the present invention, the only relevant components of the device are A and B.

[0035] Reference throughout this specification to "one embodiment" or "an embodiment" means that a particular feature, structure or characteristic described in connection with the embodiment is included in at least one embodiment of the present invention. Thus, appearances of the phrases "in one embodiment" or "in an embodiment" in various places throughout this specification are not necessarily all referring to the same embodiment, but may. Furthermore, the particular features, structures or characteristics may be combined in any suitable manner, as would be apparent to one of ordinary skill in the art from this disclosure, in one or more embodiments.

[0036] Similarly it should be appreciated that in the description of exemplary embodiments of the invention, various features of the invention are sometimes grouped together in a single embodiment, figure, or description thereof for the purpose of streamlining the disclosure and aiding in the understanding of one or more of the various inventive aspects. This method of disclosure, however, is not to be interpreted as reflecting an intention that the claimed invention requires more features than are expressly recited in each claim. Rather, as the following claims reflect, inventive aspects lie in less than all features of a single foregoing disclosed embodiment. Thus, the claims following the detailed description are hereby expressly incorporated into this detailed description, with each claim standing on its own as a separate embodiment of this invention.

[0037] Furthermore, while some embodiments described herein include some but not other features included in other embodiments, combinations of features of different embodiments are meant to be within the scope of the invention, and form different embodiments, as would be understood by those in the art. For example, in the following claims, any of the claimed embodiments can be used in any combination.

[0038] In the description provided herein, numerous specific details are set forth. However, it is understood that embodiments of the invention may be practiced without these specific details. In other instances, well-known methods, structures and techniques have not been shown in detail in order not to obscure an understanding

of this description.

[0039] Where in the present invention, the term "refractory metal" is used, reference is made to elements such as Nb, Mo, Ta and W. Alternatively, the ISOL targets also can be based on carbide powders, such as for example SiC, TaC, UCx.

[0040] FIG. 1 shows the principle of RIB (Radioactive Ion Beam) production via the ISOL (Isotope Separation On Line) method, known in the art.

[0041] FIG. 2 is an example of a high-power target currently being used at the ISAC facility in TRIUMF. ISAC operates at intensities up to 100 μ A with 500 MeV protons, the power deposited into the target usually going up to 9 kW. The ISAC target container shown in FIG. 2 has to be cooled (by means of fins, as shown in FIG. 2). Apart from the thermal constraints, another limitation of conventional ISOL direct targets comes from sintering of target material: Since the grains growth is proportional to temperature, pressure between grains and time, targets under operation show a rapid decrease of the RIB yield. Therefore, the target has to be changed very often,

[0042] To improve upon these state-of-the art targets and be able to reach higher beam-powers, new target systems need to be developed.

[0043] According to embodiments of the present invention, a high-power target assembly for generation of radio-isotopes is disclosed in FIG. 3. The target assembly comprises at least a first reservoir and a second reservoir being interconnected with a tubular portion forming an enclosure for holding a target powder for generating said radio-isotopes when bombarded by an irradiation beam. Although in use, typically the target powder will be present, embodiments of the present invention also encompass the assembly when the target powder is not present in the system, i.e. prior it has been filled with the target powder. Although also in these case reference is made to the target assembly, it will be clear that in that case the assembly does not correspond with the target, but only with the hardware wherein the target powder is positioned during use. The first respectively second reservoir each has a window configured for receiving the irradiation beam. The irradiation beam will be selected such that it is adapted, e.g. in energy and type, for causing the desired nuclear reaction when interacting with said target powder. The tubular portion is being configured for allowing passage of the target powder from one of the first respectively the second reservoir towards the other of the second respectively the first reservoir under gravity force, the longitudinal axis of the tubular portion being aligned with each of said windows for allowing the powder moving inside the tubular portion to be irradiated by said irradiation beam through said windows during the fall. The tubular portion is further adapted for allowing escape of said radio-isotopes outside the tubular portion. This opening will further be referred to as the transfer line towards the ion source. The target assembly also has a means for rotating the said enclosure such that in turn, each of the first respectively second reservoir can selec-

tively be positioned above the other of the second respectively first reservoir.

[0044] FIG. 3 shows (the main components of) an embodiment of a target assembly 1 according to the present invention. The target assembly 1 thus comprises a first reservoir 2 and a second reservoir 3 interconnected by a tubular portion 4. The two reservoirs 2, 3 and the tubular portion 4 together form an enclosure for containing a target powder 9 for generating said radio-isotopes when the powder is bombarded by a suitable high-energy irradiation beam. Each of the first resp. second reservoir 2, 3 has a first window 12, 13 (see FIG. 7) configured for receiving an irradiation beam 8 from an external source (not shown), the irradiation beam 8 is configured for causing the desired nuclear reaction when interacting with said powder 9. The target powder 9 consists of a plurality of individual particles having an average diameter in the range 5 micrometer to 200 micrometer. The actual size may be optimized depending on the particular radio isotope that is to be produced. The powder particles can for example be made of pure refractory metals or can be made of carbides. The tubular portion 4 is configured for allowing passage of the target powder 9 from one of the first resp. the second reservoir 2, 3 towards the other of the second resp. the first reservoir under gravity force, in a manner similar to the working of a well-known hourglass. The longitudinal axis of the tubular portion 4 is aligned with each of said first windows 12, 13 for allowing the "falling" powder 9 inside the tubular portion 4 to be irradiated by said irradiation beam 8, during actual use. The tubular portion 4 having an opening for allowing escape of said radio-isotopes towards the ion source via a transfer line 5. The size and geometry of the opening may be adapted to optimize the escape of desired radio isotopes and reduce the risk of powder migration into the transfer line. The target assembly 1 further has means, for example a shaft 6 (see FIG. 7), allowing the target enclosure to be rotated such that each of the first resp. second reservoir 2, 3 can selectively be positioned above the other in a manner similar to the classical hourglass.

[0045] The first windows 12, 13 and the second window (not shown) (also known as "ports") can for example be made of a single thin metal foil or a pair of thin metal foils, and is known per se in the art (see for example US2006/0050832A1 paragraph 22).

[0046] Preferably the target material 9 is made of fine solid grains in the form of small spherical particles (also referred to as microparticles), which are in motion (e.g. free fall due to gravity force) when being in front of the high-intensity primary beam 8, forming a substantially continuous flow. The incident beam 8 of lightweight particles (e.g. protons) interacting with said powder produces the radio-isotopes by causing a nuclear reaction.

[0047] The main advantages of this target assembly 1 are:

- 1) It has the ability to provide any isotope mentioned in the nuclear chart since any refractory materials

and carbides (available in different mass ranges) can be used for RIB production (e.g. Ta, W, UCx, TaC, SiC, ...).

- 2) Faster release of the produced radio-isotopes out of the target material compared to conventional ISOL targets (typically made of compressed powder or metallic foils), because the powder in the target assembly of the present invention is not compressed, favoring longer free path between collisions especially during the "free fall". Finally, small spherical particles are used, speeding the diffusion of the isotope from the matrix to the surface, from where it undergoes desorption and effusion. Where reference is made to small spherical particles, reference may for example be made to particles having an average diameter between 5 μm and 200 μm .

- 3) Cold and hot-spots in the target material are avoided, because the powder mixes continuously, favoring rapid heat-transfer between the individual particles.

- 4) Efficient heat management - the powder is exposed to the proton beam for only a fraction of the time and is in direct contact to the other particles and the walls of the reservoirs 2, 3 for most of the time.

- 5) By rotating the entire target assembly, a robust mechanical mechanism is provided for "transporting" the powder, and the risk of mechanical failure is drastically reduced (as compared e.g. to a belt system), because only a limited number of mechanical components are needed. The operating conditions of the mechanism for rotating the target assembly can be significantly improved: (a) roomtemperature conditions compared to temperatures in the range of 2000 deg C for the target powder and (b) reduced radiation level by interposing shielding blocks in between the target assembly and the rotating mechanism.

- 6) The target assembly of the present invention is expected to run longer periods than currently feasible (several weeks up to months).

- 7) The flow-rate of the powder 9 through the tubular portion 4 can be easily set by choosing appropriate dimensions of said tubular portion 4 and of the first and second reservoir 2, 3, rather than by an active mechanism.

[0048] Simulations have been performed for simulating the powder flow and power deposition in the powder for a system as shown in FIG. 3. FIG. 4 (left) shows a simplified model of the geometry. A funnel (20-mm diameter at the bottom and a slope of 45°) is filled with perfectly spherical particles, initially organized as a loosely-stacked cube which is allowed to settle in the funnel with the funnel-aperture closed. After the particles have settled down, the funnel aperture is opened and the particles are allowed to exit the funnel freely. The vertical tube has an inner diameter of 20 mm, and a length of 100 mm. After the tube there is no further restriction. Since the

final application is in vacuum, no air-resistance was modeled. In the simulation, the particle diameter was chosen as 0.8 mm, and the particle density was chosen as 16 kg/l. The resulting packing factor plot is shown in FIG. 4 (right). The uncertainty ranges given in FIG. 4 are not reflecting a simulation uncertainty; they are calculated from the density distributions at different times. In a fully steady-state system, with a constant particle flow rate, the uncertainty range would be zero. This effectively means that there are slight density fluctuations during the emptying of the funnel. These decrease with decreasing particle diameter, as the particle behavior becomes more "fluid" like. The decreasing density with increasing height can be explained with the conservation of mass law and the fact that the particles accelerate as they fall down. These curves were subsequently used in further simulations. An advantage of the variable density is that on the one hand faster effusion of isotopes to the transfer line can be obtained since there is at least temporarily a situation of low density, while at other points in space there is also a high density of the powder which allows for high radioisotopes production rates.

[0049] FIG. 5 shows an example of a simulation of a power-deposition profile in the vertical column of powder material. The axial distance "z" is given on the vertical axis, where $z=0$ corresponds to the top of the funnel (see FIG. 4 left). The radial distance in the vertical column (tubular portion 4) of powder is on the horizontal axis, where $r=0$ is the center of the tubular cylindrical portion 4. In the particular simulation of FIG. 5, Tantalum-carbide powder was considered with a density of 14.2 kg/l in the grain. The geometry as shown in FIG. 4 (left) was modeled and the funnel was filled with TaC particles over a height of 4 cm (above the entrance of the tubular cylindrical portion 4). To obtain a more uniform power deposition on the target material, the proton beam was assumed to rotate continuously on the target (describing a path around the center of the tubular portion), with high frequency. In the simulation, a Gaussian beam of FWHM = 3 mm and 5 mm sweeping radius was modeled. The simulations have been repeated for proton energies of 600 MeV and 1 GeV. FIG. 5 presents the half-symmetry plot of the obtained profile of the power-deposition in the target. This result corresponds to a proton beam of 1 mA and 600 MeV respectively. The power distribution was further used to roughly estimate the temperature profile, which shows a circular warm region at the position of the Gaussian centroid of the beam spot. A maximum ΔT of about 300 °C for a 0.2 mA, 600 MeV proton beam is obtained. Similarly, a ΔT of about 370 °C is obtained when repeating the calculations for 0.2 mA 1 GeV protons. However, after falling in the lower reservoir 3, the powder mixes, and the temperature becomes uniform almost immediately.

[0050] FIG. 6 shows a simulated ^{149}Tb production rate along the target length z. The horizontal axis represents the position in the vertical powder column 4, when the funnel is filled with TaC particles for its entire height of 4

cm. The end of the funnel is therefore at 4 cm on the horizontal axis in this plot. To get the production rates along the vertical falling-powder section of the target (FIG. 4 left) the target assembly was divided onto 12 zones of variable density which models the spatial behavior of packing factor for the tantalum carbide powder. In this rough estimation, the densities of each axial bin have been calculated assuming a 14.2 Kg/l TaC-grain density with similar packing factors as those calculated for the tungsten powder in FIG. 4 (right).

[0051] FIG. 7 shows an example of the target assembly for a system according to an embodiment of the present invention. It is to be noticed that advantageously the actuator moving the target container can be put at a distance behind shielding to avoid radiation damage. In one example, actuating can be done by a motor 7 via a shaft 6. The actuation could for example be performed using a pneumatic system, but is not limited thereto and can be any system allowing rotation of the container, whereby the actuation system can be positioned at a distance from the target container and behind shielding.

[0052] In some embodiments, the system may be provided with a cooling means, such as for example with cooling fins, using radiative cooling, or using water cooling channels around the target container.

[0053] When the powder has moved to the lower reservoir, the motor is typically driven such that the target assembly 1 is rotated over 180° for placing the "full" reservoir on top, and the "empty" reservoir below.

[0054] FIG. 8 shows part of a variant of the target assembly 1 according to an embodiment of the present invention, whereby a specific shape of the reservoirs is disclosed. In this embodiment, each of the reservoirs 2, 3 (only one being shown) comprises or consists of a conical segment 16 and an annular segment 17. By truncating the outer diameter d3 of the funnel-shape to outer diameter d2, the width dimensions of the target assembly 1 can be reduced, and the target assembly 1 can be made more compact.

[0055] Optionally, the window (or port) 12, 13 may be located in a cavity 19, e.g. a cylindrical cavity with diameter d1 and height d5, such that the window is located closer to the entrance 18 of the tubular section 4. This has the advantage that the incident irradiation beam 8 can travel to a position at a predefined distance from the entrance 18 of the tubular portion 4, irrespective of the amount of powder 9 present in the reservoir 2 (initially 4 cm in the example above). The skilled person can find suitable dimensions for the diameters d1 and distance d4, e.g. by thermal simulations (as discussed above with reference to FIG. 5). The skilled person can choose suitable dimensions for diameter d2 and distance d5 by geometrical constraints, and timing considerations (in particular the time required for the powder to flow from one reservoir to the other), and thus the time period during which radio-isotopes can be produced, before the target assembly is to be rotated over 180°.

[0056] Although shown together with the annular

shape 17, of course the principle of this window 12 in the cavity 19 can also be applied to the embodiment of FIG. 3 having conical reservoirs 2,3 (without an annular portion 17).

[0057] It may be advantageous to make the diameter d_1 of the cavity 19 larger than required for passage of the beam 8, in that the cavity 19 can also help cool the powder inside of the reservoir. This can further help to obtain a substantially constant temperature of the powder.

FIG. 9 shows part of a variant of the target assembly (1) according to an embodiment of the present invention, whereby a specific shape of the connection between the tubular section (4) and the transfer line (5) is disclosed. In particular it shows an adapted geometry of the connection with enlarged entry of the transfer line (5) to reduce the risk of powder (9) migration into the transfer line (5). The skilled person can choose suitable dimensions to optimize the escape of desired radio isotopes without allowing powder (9) migration into the transfer line (5).

Claims

1. A target assembly (1) for generation of radio-isotopes, comprising:

- at least a first reservoir (2) and a second reservoir (3) being interconnected with a tubular portion (4) together forming an enclosure for holding a target powder (9) for generating said radio-isotopes when bombarded by an irradiation beam (8);

- the first resp. second reservoir (2, 3) each having a window (12, 13) configured for receiving the irradiation beam (8), the irradiation beam (8) being configured for causing a nuclear reaction when interacting with said target powder (8),

- the tubular portion (4) being configured for allowing passage of the target powder (9) from one of the first resp. the second reservoir (2, 3) towards the other of the second resp. the first reservoir (3, 2) under gravity force, the longitudinal axis of the tubular portion (4) being aligned with each of said windows (12, 13) for allowing the powder (9) moving inside the tubular portion (4) to be irradiated by said irradiation beam (8) through said windows during the fall under gravity force;

- the tubular portion (4) further being adapted for allowing escape of said radio-isotopes from the tubular portion (4) to a transfer line (5) while preventing powder migration in the transfer line (5);

- the target assembly (1) further having a means for rotating the assembly such that in turn, each of the first respectively second reservoir (2, 3) can selectively be positioned above the other of

the second respectively first reservoir (3, 2).

2. The target assembly (1) according to claim 1, the target assembly comprising the particles of the target powder (9) being microparticles having an average diameter smaller than 200 μm .
3. The target assembly (1) according to any of the previous claims, wherein the tubular portion (4) is a cylindrical or elliptical portion.
4. The target assembly (1) according to any of the previous claims, having a symmetrical shape.
5. The target assembly (1) according to any of the previous claims, wherein each of the first and second reservoirs (2, 3) has a conical or funnel-shaped portion (16) for guiding the powder (8).
6. The target assembly (1) of claim 5, wherein each of the first and second reservoir (2, 3) further comprises a volume portion (17) having a substantially annular cross-section.
7. The target assembly (1) according to any of the previous claims, wherein the window (12, 13) of the first resp. second reservoir (2, 3) is located in a cavity (19a, 19b) of said reservoir.
8. The target assembly (1) according to any of the previous claims, wherein the means for being rotated comprises a motor (7).
9. A radioactive isotope generator comprising the target assembly (1) according to any of the previous claims.
10. Use of a target assembly according to any of claims 1 to 8 for production of radioactive isotopes.

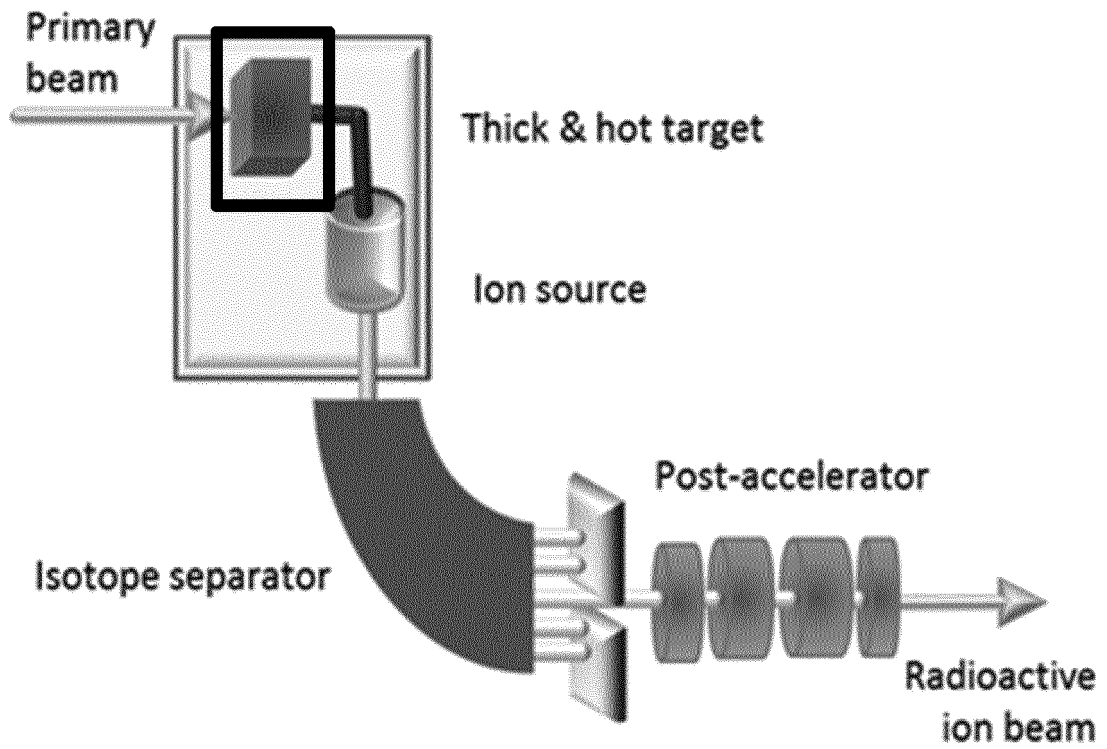


FIG 1 (prior art)

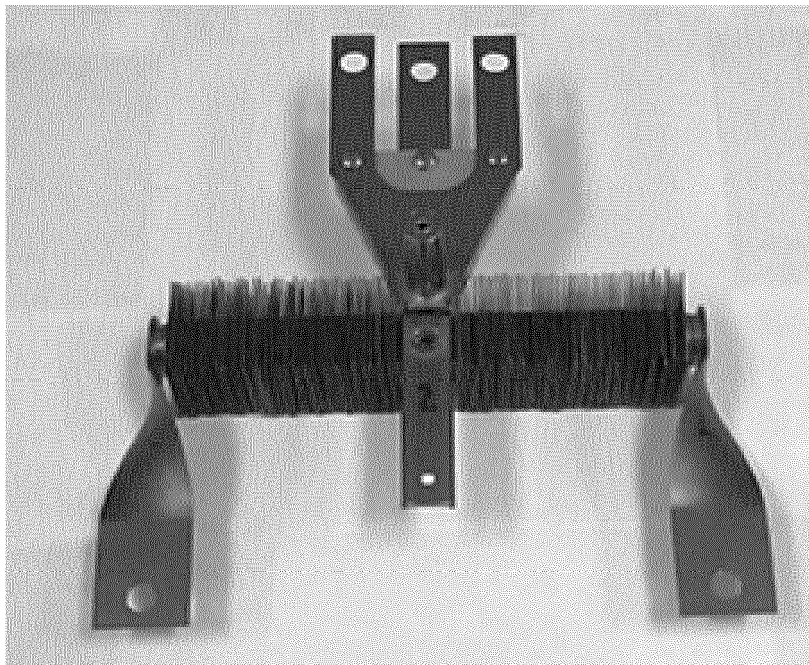
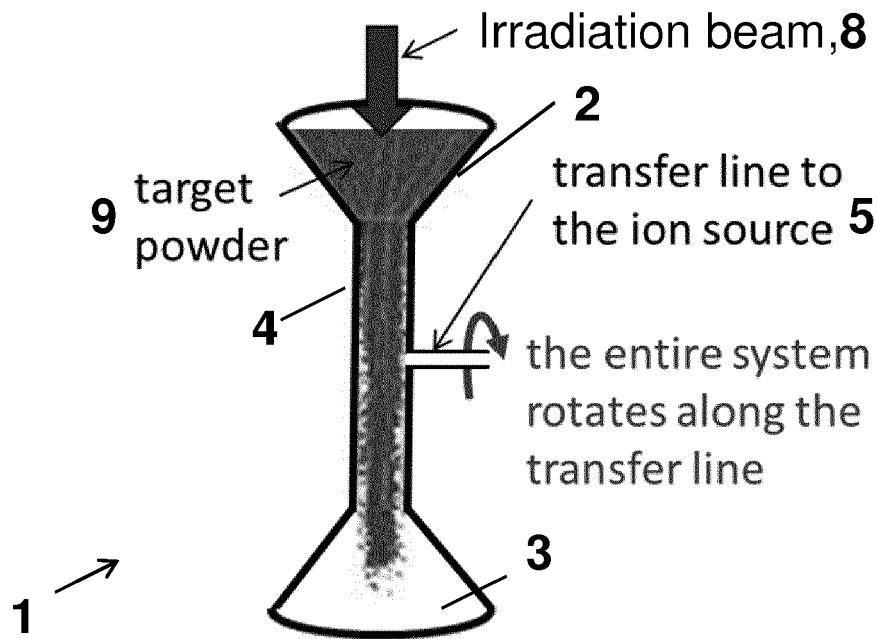
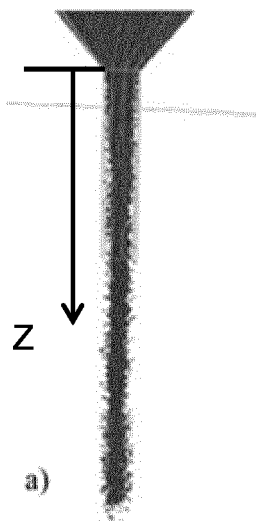


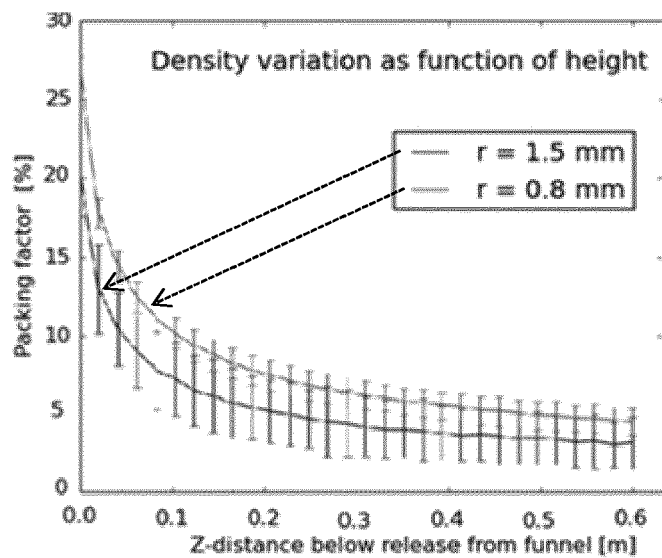
FIG 2 (prior art)

**FIG 3**

Simulation model:

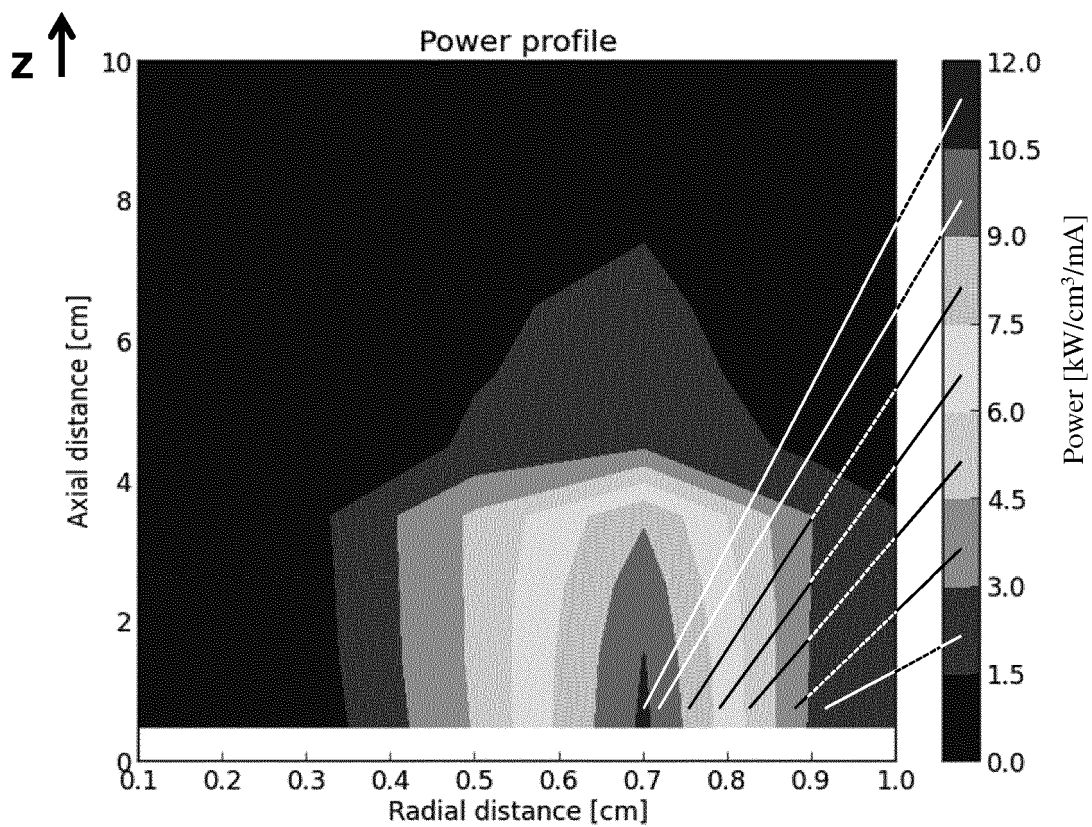
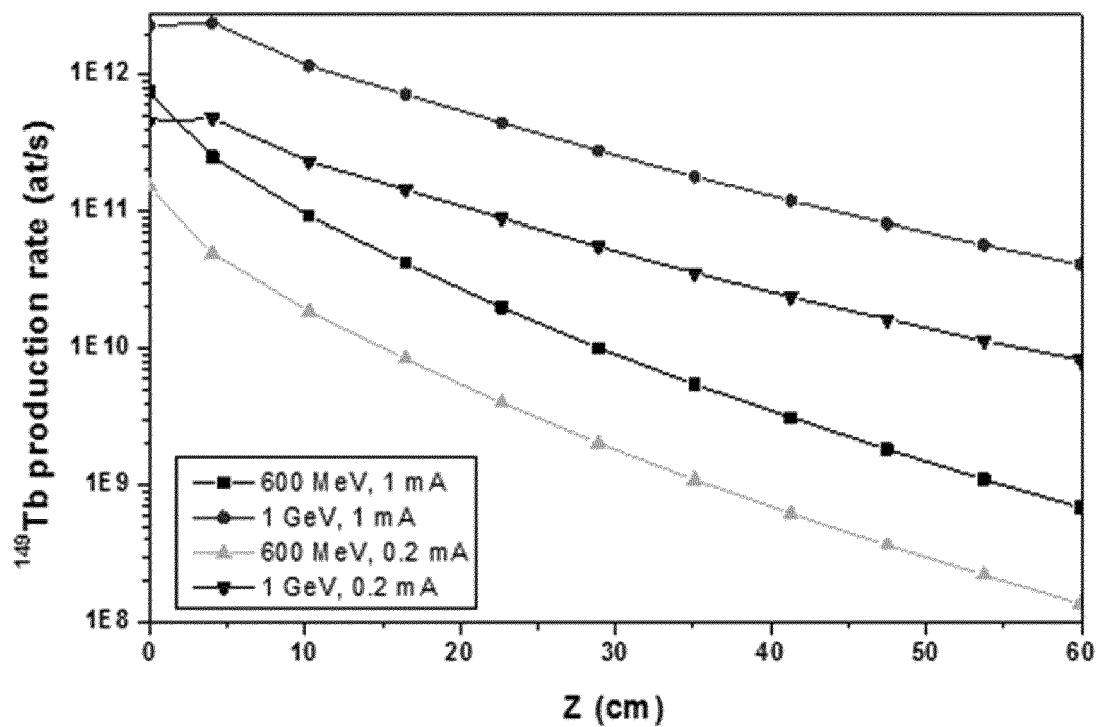


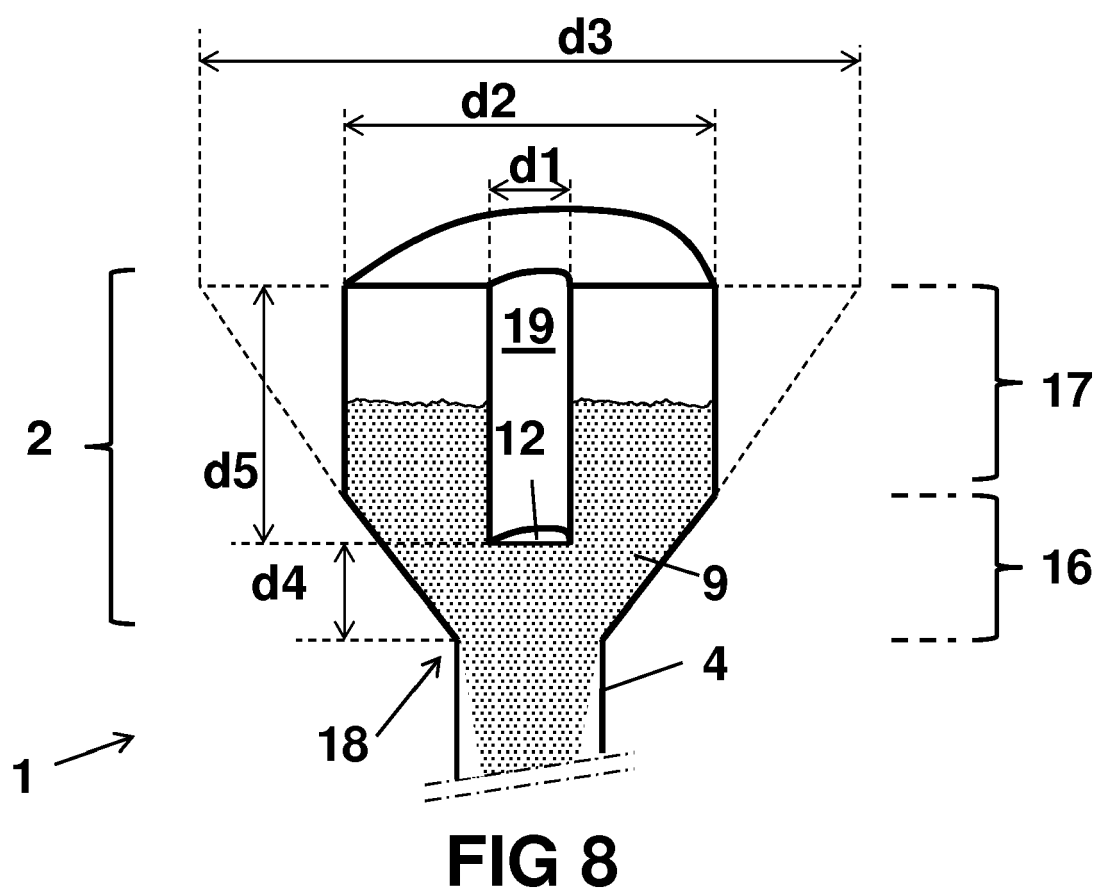
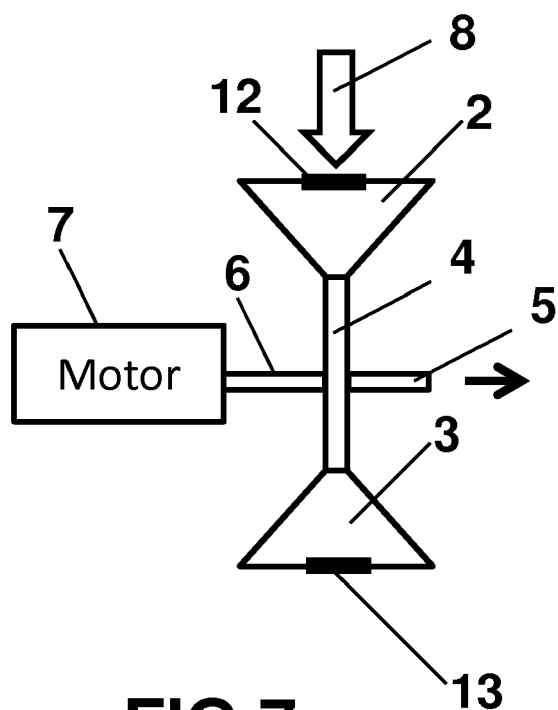
a)



b)

FIG 4

**FIG 5****FIG 6**



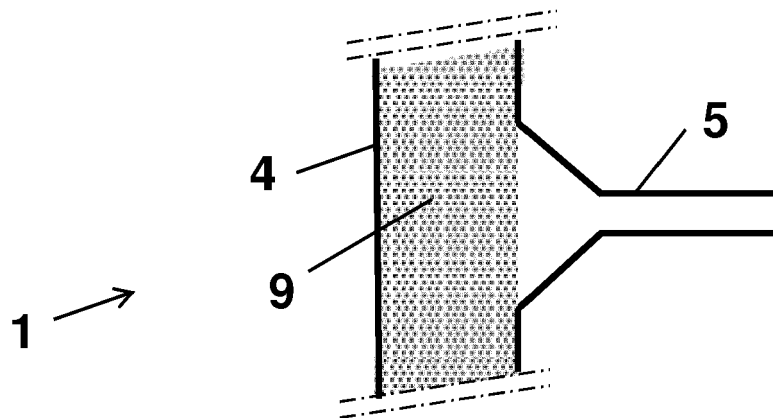


FIG 9



EUROPEAN SEARCH REPORT

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Place of search The Hague		Date of completion of the search 26 May 2017	Examiner Capostagno, Eros
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