(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 2 146 555 A1

(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
20.01.2010 Bulletin 2010/03

(51) Int Cl.:
H05H 6/00 *(2006.01)*

(21) Application number: **08160763.2**

(22) Date of filing: **18.07.2008**

(84) Designated Contracting States:
AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MT NL NO PL PT RO SE SI SK TR
Designated Extension States:
AL BA MK RS

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(54) **Target apparatus for production of radioisotopes**

(57) A target apparatus for producing a radioisotope of interest from a target material irradiated by a beam of charged accelerated particles having an energy, the said target comprising a chamber (101) for containing a target material; a body (102) enclosing said chamber and forming a gap (107) between said chamber and said body adapted for the circulation of a cooling fluid, said body having an opening for leaving a passage for said beam of accelerated particles to said chamber (101), said opening being provided with a cooling window foil (106) retaining cooling fluid running inside said gap. Said chamber is a cylinder, with a thickness higher than 50μm, and internal diameter equal or higher than the penetration range of said charged particles in said target material at the energy of said charged particles when penetrating said target material and the said opening is parallel to the longitudinal axis of the cylinder. The invention also relates to a method for producing an isotope of interest.

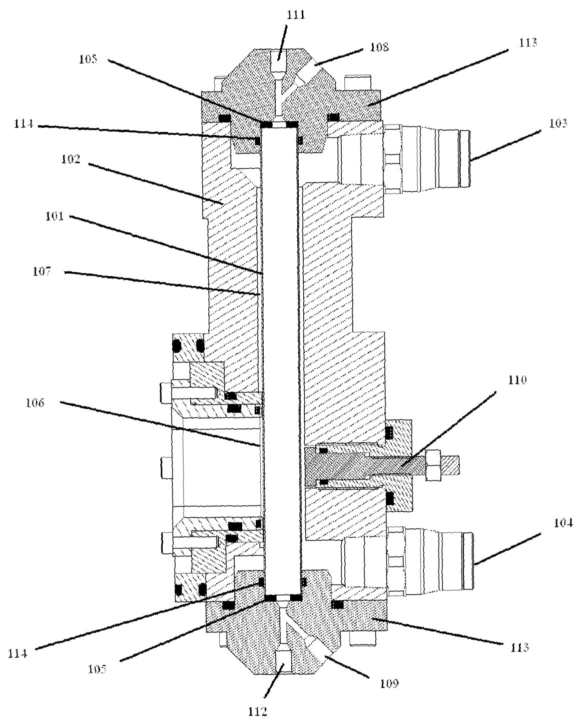

Fig. 1

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Description

TECHNICAL FIELD

[0001] The invention relates to a device for use as target for producing a radioisotope, such as ^{18}F, by irradiating with a beam of particles a target material that includes a precursor of said radioisotope.

[0002] One of the application of the present invention relates to nuclear medicine, and in particular to positron emission tomography.

DESCRIPTION OF RELATED ART

[0003] Positron emission tomography (PET) is a precise and non-invasive medical imaging technique. In practice, a radiopharmaceutical molecule labeled by a positron-emitting radioisotope, in situ disintegration of which results in the emission of gamma rays, is injected into the organism of a patient. These gamma rays are detected and analyzed by an imaging device in order to reconstruct in three dimensions the biodistribution of the injected radioisotope and to obtain its tissue concentration.

[0004] Fluorine 18(^{18}F, T1/2 = 109.6 min) is the only one of the four light positron-emitting radioisotopes of interest (^{ll}C, ^{l3}N, ^{15}O, ^{l8}F) that has a half-life long enough to allow use outside its site of production.

[0005] Among the many radiopharmaceuticals synthesized from the radioisotope of interest, namely fluorine 18, 2-[^{18}F]-fluoro-2-deoxy-D-glucose (FDG) is the radio-tracer used most often in positron-emission tomography. In addition to the morphology imaging, PET performed with ^{18}F-FDG allows to determine the glucose metabolism of tumors (oncology), myocardium (cardiology) and brain (psychology).

[0006] The ^{18}F radioisotope in its anionic form ($^{l8}F^-$) is produced by bombarding a target material, which in the present case consists of ^{18}O-enriched water ($H_2{}^{18}0$), with a beam of charged particles, more particularly protons.

[0007] To produce said radioisotope, it is common practice to use a device constituting an irradiation cell comprising a cavity "hollowed out" in a metal part and intended to house the target material used as precursor. This metal part is usually called an insert.

[0008] The cavity in which the target material is placed is sealed by a window, called "irradiation window" which is transparent to the particles of the irradiation beam. Through the interaction of said particles with the said target material, a nuclear reaction occurs which leads to the production of the radioisotope of interest.

[0009] The beam of particles is advantageously accelerated by an accelerator such as a cyclotron.

[0010] Because of an ever increasing demand for radioisotopes, and in particular for the ^{18}F radioisotope, efforts are made to increase the yield of the above mentioned nuclear reaction. This is done either by modifying the energy of the beam of particles (protons), making use of the dependence of thick target yield on the particle energy, or by modifying the intensity of the beam, thereby modifying the number of accelerated particles striking the target material.

[0011] However, the power dissipated by the target material irradiated by the accelerated particle beam limits the intensity and/or the energy of the particle beam that is being used. This is because the power dissipated by a target material is determined by the energy and the intensity of the particle beam through the following equation:

$$P\ (\text{watts}) = E\ (\text{MeV}) \times I\ (\mu A)$$

where:

- P = power expressed in watts;
- E = energy of the beam expressed in MeV ; and
- I = intensity of the beam expressed in pA.

[0012] In other words, the higher the intensity and/or the energy of the particle beam, the higher will be the power to be dissipated by a target material.

[0013] It will consequently be understood that the energy and/or the intensity of the beam of accelerated charged particles cannot be increased without rapidly generating, within the cavity of the production device, and at the irradiation window, excessive pressures or temperatures liable to damage said window.

[0014] Moreover, in the case of ^{18}F radioisotope production, given the particularly high cost of ^{18}O-enriched water, only a small volume of this target material, used as a precursor material, at the very most a few milliliters, is placed in the cavity. Thus, the problem of dissipating the heat produced by the irradiation of the target material over such a small volume constitutes a major problem to be overcome. Typically, the power to be dissipated for a 18 MeV proton beam with an intensity of 50 to 150 pA is between 900 W and 2700 W, and this in a volume of ^{18}O-enriched water of 0.2 to 5 ml, and for irradiation times possibly ranging from a few minutes to a few hours.

[0015] More generally, given this problem of heat dissipation in the target material, the irradiation intensities for producing radioisotopes are currently limited to 40μA for an irradiated target material volume of 2ml in a silver insert. Current cyclotrons used in nuclear medicine are however theoretically capable of accelerating proton beams with intensities ranging from 80 to 100μA, or even higher. The possibilities afforded by current cyclotrons are therefore under-exploited.

[0016] Solutions have been proposed in the prior art for overcoming the problem of heat dissipation by the target material in the cavity within the radioisotope production device. In particular, it has been proposed to provide means for cooling the target material.

[0017] Accordingly, document BE-A-1011263 discloses an irradiation cell comprising an insert made of silver (Ag) or titanium (Ti), said insert comprising a hollowed-out cavity sealed by a window, in which cavity the target material is placed. The insert is placed in co-operation with a diffuser element which surrounds the outer wall of said cavity so as to form a double-walled jacket allowing the circulation of a refrigerant for cooling said target material. For improving heat flow out of the cavity, a cavity having a wall as thin as possible is desirable. However, when silver is used as material for the cavity, wall porosity becomes a problem when wall thickness is smaller than 1, 5mm.

[0018] It is preferred to use niobium (Nb) for the insert, this material having a thermal conductivity two and a half times higher than titanium (53.7 W/m/K for Nb and 21.9 W/m/K for Ti), though eight times lower than silver (429 W/m/K). Niobium is chemically inert and produces few isotopes of long half-life. Therefore, niobium is a good compromise. However, niobium is a difficult material to use in an insert of complex design, as it is difficult to machine. A build-up edge may occur on the tools, leading to high tool wear. Eventually, the tool may break. The use of electrical discharge machining is not a solution either: the electrodes wear out without shaping the piece to be machined. In particular, the insert described in document BE-A-1011263 is of a complex structure, and is difficult to produce in niobium.

[0019] Tantalum (Ta) is also a material having interesting properties, but, which is, like niobium, difficult to machine. Tantalum has a thermal conductivity (57.5 W/m/K) slightly higher (better) than Niobium.

[0020] Document WO02101757 is related to an apparatus for producing ^{18}F-Fluoride, wherein a cylindrical chamber is present, for containing the gaseous or liquid target material which is to be irradiated. The chamber can be made from niobium and comprises an irradiation window on one extremity of the cylinder. The accelerated particle beam is directed following the longitudinal axis of the cylinder and passes trough the irradiation window. The same is true for the irradiation devices described in US5917874, US2001/0040223 and US5425063. In the case of gaseous target materials, the chamber length must be long enough to provide an efficient interaction between the accelerated particle beam and the gaseous target molecules. In the case of liquid target materials, the problem occurring during the beam irradiation is the water vaporization. In the vapor phase, water concentration is lower than in the condensed phase, so that not all the accelerated particle beam energy is absorbed by water molecules and a substantial part of the beam passes trough the cavity without interaction with the target material. This effect is called "tunneling" and it is a major cause of decreased ^{18}F production yield at high power.

[0021] In order to attempt to reduce the vaporization of water, document WO03/099374 describes a target chamber acting as a thermosiphon. The vapor is condensed in the upper part of the cavity target (condenser region CR, 32A) and falls down into the lower part of the said cavity (boiler region, 32B) where is located the beam strike region (34). In the same aim, document US2006/0291607 describes a target that comprises, inside the body cavity (112), an auxiliary cavity where the cooling is improved. This target comprises also two support grid in order to reinforcing the front and rear thin films of the cavity, when the target is irradiated by a high power beam, causing an internal pressure rising.

[0022] Nevertheless, for these kinds of targets, the maximum allowable internal pressure is limited to 40-60 bar, due to the irradiation window foil strength, even if a support grid is used. However higher pressures would be desirable for reducing the tunneling effect.

[0023] Zeisler et al. (Applied Radiation and Isotopes, vol. 53, 2000, pages 449-453) have built a spherical Niobium target without irradiation window, i.e. wherein the beam directly traverses the target chamber wall. The spherical design combined with the absence of irradiation window was conceived to permit to this target to be irradiated by a high power beam and to withstand a theoretical resulting internal pressure of maximum 253 bar. The lack of irradiation window induces an important loss of beam energy; that is why a more energetic beam than with a thin irradiation window must be employed to irradiate the target. Niobium tensile strength being high, it is not easy to produce such a sphere. The authors firstly built two niobium hemispheres with a hydraulic press, and then drilled a hole in their centers. Niobium tubes were electron-beam welded to the holes and then the two hemispheres were electron-beam welded together. Two major disadvantages of the electron-beam welding are:

- target embrittlement and the resulting important decrease of withstanding pressure capacity (authors did not work at internal pressures higher than 11 bar, although the theoretical maximum pressure would be 253 bar)
- Create lots of asperities where a non negligible amount of synthesized ^{18}F can be adsorbed.

AIMS OF THE INVENTION

[0024] The present invention aims to provide a target apparatus and method for producing a radioisotope of interest, such as ^{18}F, from a target material irradiated with a beam of accelerated particles, not having the drawbacks of the devices and methods of the prior art. In particular, it is an object of the present invention to provide a target apparatus and method that can withstand higher internal pressures than the prior art targets and methods, and therefore a higher production yield of radioisotopes.
[0025] It is further desirable to make the realization of the said target easier and less expensive.
[0026] It is further desirable to prevent or to reduce the tunneling effect and to provide to the said target means of monitoring of the tunneling, internal pressure and internal temperatures.
[0027] Due to the high temperatures reached by the said target, and the high pressure flow of the cooling fluid needed for cooling the said target, it is further desirable to provide an efficient fixation system of the cooling window ensuring the separation of the vacuum and the cooling fluid.

SUMMARY OF THE INVENTION

[0028] In a first aspect, the present invention relates to a target apparatus for producing a radioisotope of interest from a target material irradiated by a beam of charged accelerated particles having an energy, the said target comprising a chamber for containing a target material; a body enclosing said chamber and forming a gap between said chamber and said body adapted for the circulation of a cooling fluid, said body having an opening for leaving a passage for said beam of accelerated particles to said chamber, said opening being provided with a cooling window foil (106) retaining cooling fluid running inside said gap. According to the invention, said chamber is a cylinder, with a thickness higher than 50μm, and internal diameter equal or higher than the penetration range of said charged particles in said target material at the energy of said charged particles when penetrating said target material; and the said opening being parallel to the longitudinal axis of the cylinder.
[0029] Preferably, said chamber is sealed in the said body by means of crushing seals located in the two cylinder heads of the said body.
[0030] More preferably, the surface of the said cooling window foil is parallel to the longitudinal axis of said cylindrical chamber.
[0031] Said cooling window foil may be clamped between two flanges comprising an opening that fits with the width of the said chamber, the first flange being fixed in a tight manner with seals and screws on the body and the second flange being fixed in a tight manner on the first flange with seals and screws.
[0032] The target may preferably comprise an insulated conductor inserted in the back of said body in front of the said opening, in order to monitor the fraction of the beam of accelerated particles which passes trough the chamber.
[0033] The target apparatus may advantageously be pressurized and the upper leg of the filling loop of the chamber may be connected to a pressure transducer in order to monitor the internal pressure of the said chamber.
[0034] In a second aspect, the invention relates to a method for producing an isotope of interest, comprising the steps of:

- filling a cylindrical chamber with a target material;
- pressurizing the chamber with inert gas in order to prevent the tunnelling effect;
- irradiating the target chamber with an accelerated particle

beam perpendicular to the axis of said cylindrical chamber;
[0035] The method may advantageously comprise the step providing an insulated conductor for receiving any part of said charged particle beam traversing said chamber and monitoring the tunnelling effect by measuring the beam current incident on said insulated conductor.
[0036] The method may be performed using the target apparatus of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0037] Fig. 1 is a cross sectional view of a target apparatus of the present invention.
[0038] Fig. 2 is a perspective view of a part of the target apparatus of Fig. 1, comprising a cooling window foil.
[0039] Fig. 3 is a 3-dimensional exploded perspective view of the target apparatus of Fig. 1, wherein some O-rings are referenced as 301.
[0040] Figure 4 is a flow chart of a circuit for use with the target apparatus of the invention.

DETAILED DESCRIPTION OF THE INVENTION

[0041] Fig. 1 and fig. 3 are cross sectional and perspective representations respectively of the target apparatus used for the production of isotopes of interest such ^{18}F. The said target comprises a metallic cylindrical chamber (101), ideally in niobium for its excellent properties of tensile strength and its chemical inertness in corrosives environments. The cylindrical chamber does not comprise any window and the accelerated particle beam must have a sufficient energy to pass trough the wall of the cylindrical chamber and deposit its energy in the target material even if an important part of the energy dissipates in the cylinder wall. A beam of charged particles is directed unto the cylinder, in a direction perpendicular to the cylinder axis. The cylindrical chamber (101) external diameter is selected in order to obtain a high conversion of ^{18}O enriched water in ^{18}F. It is known that for a 20MeV energetic proton beam, the range of protons (i.e. the Bragg peak depth) in water is approximately 4.2mm. Thus, for a 20MeV energetic beam entering into the cylinder, the cylinder inner diameter must be of at least 4.2 mm. According to the known hoop stress formula:

$$P= (2t \times \sigma)/(d+t)$$

where P is the internal pressure in a cylinder, t is the cylinder wall thickness, σ is the tensile strength and d is the cylinder inner diameter, the wall thickness of the cylinder must be of 182μm for a Niobium cylinder (σ = 330MPa) to withstand a pressure of 275 bar. To withstand a lower pressure, but still high enough for preventing tunnelling, such as 60bar, the cylinder wall thickness must be of 50μm for the same external cylinder inner diameter as cited above. A good compromise is to withstand a strong pressure and to not decrease too much the beam energy.
Example values for Niobium cylinder with a cylinder wall thickness of 400μm and various cylinders outer diameters (D), are calculated in table 1, according to an equivalent hoop stress formula:

$$P= (2t \times \sigma)/(D-t)$$

Table 1:

t=0,4mm		
D (mm)	p (bar)	D/t
0,8	6600	2
0,81	6439	2,025
2	1650	5
4	733	10
7	400	17,5
10	275	25
12	227	30
20	135	50
30	89	75
40	67	100
44	60	110

It is understood that an internal pressure higher than 60 bar may be employed for a ratio D/t inferior to 110 and strictly superior to 2.
To permit an efficient natural convection of the fluid in order to facilitate its cooling and to prevent the tunnelling, the authors have worked with a 10 cm long cylindrical chamber. Such cylindrical chamber is easier to produce than the prior art spherical chamber since it can be extruded in the selected dimension. Such a chamber does not need any welding.
[0042] The cylindrical chamber (101) is enclosed in a body (102), for example in aluminium, but that is not a limitation of the present invention. An insulator (304, fig 3) is fixed by mean of insulated screws (302, fig.3) on the body. The body

comprises an opening, comporting a cooling window foil (106) fixed on the said body, to permit the passage of a particle beam and retaining the cooling fluid running into the annular gap (107) created between the cylindrical chamber and the body.

[0043] The chamber of the present invention makes it possible to utilise high currents and/or energetic particles beam produced for example by a cyclotron. The use of high current and/or high energy beam causes a more important heating of the chamber, thus an efficient cooling system must be employed. That cooling system passes trough the annular gap (107) and comprises an inlet (103) for the arrival of the cooling fluid and an outlet (104) for its evacuation. Depending on the cooling loop, for example with a flow of 19l/min and an annular gap of 1 mm, the resulting pressure inside the cooling system may be of about 4-5 bar, so the conventional sticking of a thin metallic window to separate the vacuum and the cooling fluid is not able to withstand that pressure difference. A cooling window foil (106), advantageously in niobium, is fixed by a system represented on Fig. 2. The cooling window foil (106) as represented on the fig.2. is a plane disc, but that form is not a limitation of the present invention. The cooling window foil (106) is clamped between two flanges (211 and 213). The first flange (211) is fixed in a watertight manner with O-rings (212) and screws on the body. The second flange (213) is fixed on the first flange (211) with O-rings (212) and screws. The two flanges comprise an opening (214) that fit with the width of the chamber.

[0044] The said cylindrical chamber (101) is maintained in the body (102) by O-rings (114) located on the wall of the cylinder heads (113), and sealed in the body (102) with crushing seals (105) which can resist to high temperatures in an order of magnitude of 300°C, even higher and high pressures in an order of magnitude of 300-400 bar, even higher. The said crushing seals are made ideally in Vespel® but that is not a limitation of the present invention. Thus, extremities of the cylindrical chamber are not electron beam welded, that welding presenting a weak point for the resistance of the chamber and for the adsorption of fluoride on the asperities created by that welding.

[0045] When a target material contained in the cylindrical chamber (101) is irradiated with a particle beam, the target material, for example enriched ^{18}O water, is vaporised along the beam strike region. In vapour phase, water molecules concentration being lower than in the condensed phase, a decreasing of the number of water molecules hit by the particle beam occurs and a higher number of particles pass trough the cylindrical chamber without encountering water molecules. This effect is called tunnelling effect. This tunnelling effect causes an important decreasing of production yield of radioisotopes. The design of the target apparatus described in the present invention permits to the cylindrical chamber (101) to withstand a higher internal pressure than prior art target chambers. For example it was calculated that for a niobium cylinder of a 400 μm thickness and 10 mm of outer diameter, the maximal internal pressure allowed is of 275 bar. Moreover, contrary to the prior art, the cylindrical chamber (101) is not weakened by any welding. In order to suppress the tunnelling effect, high pressurization with an inert gas, of an order of magnitude of more than 20 bar is provided inside the cylindrical chamber (101). A gas inlet connection (108) is located at the upper cylinder head (113) for performing high pressurization of the cylindrical chamber (101).

[0046] In a preferred version of the invention, in order to monitor the tunnelling, a conductor (110) isolated by an insulator (303, fig. 3) is inserted in the back of the body (102) and opposite to the cooling window foil (106). In case of tunnelling, the protons have sufficient energy to hit the insulated conductor (110). The corresponding measured current, the tunnelling current, is an estimate of the magnitude of the tunnelling phenomenon and of the exact conditions when it sets on.

[0047] In order to monitor the internal pressure, a pressure transducer (402, Fig. 4) is connected to the upper part of the cylindrical chamber (101).

[0048] Since an over pressure is applied inside the cylindrical chamber in order to suppress the tunnelling, it is not possible to infer the temperature of the target material comprised inside the cylindrical chamber (101) from the internal pressure. The internal temperature is monitored by the mean of two mineral insulated thermocouples (403) inserted via two ports, in the upper (111) and lower (112) region of the cylindrical chamber. The lower thermocouple tip is at least 6 mm under the beam strike region, whereas the upper thermocouple tip is 6 mm above the beam strike region. The two thermocouples are submerged in the target material.

[0049] In the present invention, the successive steps for the production of radioisotopes are:

- loading of the target material inside the cylindrical chamber;
- at least 20 bar pressurization of the cylindrical chamber by an inert gas in order to prevent the tunnelling effect. The authors have seen that the optimal pressurisation in order to prevent the tunnelling must be provided in the chamber before irradiation, because once the tunnelling is installed, it is no more possible to suppress it with a further increasing of pressure;
- irradiation of the loaded cylindrical chamber with an accelerated particle beam;
- monitoring of the different parameters as temperatures, pressures and tunnelling current;
- unloading of the produced radioisotope solution.

[0050] A double three-way valve actuated by compressed air, for example the commercial Rheodyne valve model

7030 (401, Fig 4), makes possible the target loading and unloading procedures. The three-position actuator that makes the valve rotate into position is designed and manufactured by the applicant. The actuators rotates the valve into positions (with an angle of either +30°, 0° or -30°), by supplying 24 V DC pulse to one solenoid 5/2-way valve. The position is maintained when power is interrupted. The system operation is shown on fig. 4. The valve body is made in stainless steel while the rotor seals are made in PEEK. The maximum allowable pressure is 483 bar. The valve is located inside the irradiation vault, close to the target.

[0051] A software controlled and pneumatically actuated syringe (406), connected to a three-way valve, draws a fixed amount of enriched water from a reservoir (407). The liquid is then delivered to the cylindrical chamber (101) through the rheodyne valve (401). The syringe mechanism is located inside the irradiation vault as close as possible to the target. When port B to port A is open the liquid is loaded inside the chamber by an inlet (109, Fig1) and port E to port D is open, to evacuate the overflow liquid in an overflow reservoir (409) advantageously located inside the irradiation vault as close as possible to the chamber, in order to minimise the loop volume.

[0052] The chamber is connected to a loop for the unloading of the products and for the pressurization of the chamber. The loop comprises a bottle of helium outside the vault connected to a pressure regulator connected to two lines. A first line is connected to the chamber via a valve V1, in order to provide the over pressure into the chamber before irradiation and while all the ports are closed. The second line is connected to the rheodyne valve via a valve V2 in order, after irradiation, to push the produced radioisotopes solution, from the chamber to the lab dispensing (408), while port B to C and port E to F are open.

[0053] Typical experiments were performed on a target apparatus comprising a cylindrical chamber having the following dimensions: 100 mm length, 10 mm cylinder outer diameter, 0.4 mm cylinder wall thickness. Deionised water flowed at 19 ml/min in a 1 mm annular gap between the cylinder chamber (101) and the body (102). The cooling window was made of a 50μm thick niobium foil clamped into two flanges fixed on an aluminum body. It is assumed that the minimal distance between the plane cooling window foil and the cylindrical chamber is of 700μm. The window surface seen by the beam was of 6mm X 26mm. The total volume of the cylindrical chamber is approximately 6.65ml and the target was filled up to 6 ml. 28MeV protons with different current intensities ranging from 15μA to 160μA were accelerated on the target by a cyclotron. In that target configuration, the proton beam passes trough the 50μm niobium cooling window foil, the 700μm cooling water gap, the 400μm thick niobium tube wall and enters the niobium cylinder at approximately 20MeV. At this energy the proton range in liquid water is 4.2 mm. Table 2 reprises the different experiments performed on 6 ml of natural water, the values of the yield of ^{18}F production at the end of bombardment (EOB) being extrapolated to water having 100% H_2O^{18} enrichment.

Average beam current [µA]	Volume [ml]	Irradiationtime [min]	He over pressure [bar]	SaturationYield [mCi/µA]	F^{-18}yield EOB [mCi]	F^{-18}yield [a]for a 2hr -irradiation [mCi]	P_{max} [bar]	P_{res} [bar]	T_{water} [°C]	Tunneling current [µA]
15	0	5	NA	NA	NA	NA	NA	NA	NA	1,4
40	6	15	0	NA	NA	NA	1,2	1	90	0,3
80	6	62	20	225,8	5916	9690	45-48	29	170	0
140	6	44	20	133,6	4752	10000	50-56	29,5	213	0,5
160	6	36	40	160,9	5268	13700	82-86	42	240	0,5
156	6	60	40	160,8	7968	13400	82-86	43	230	0,5

Table 2: test results

A first experiment was performed without water and without over pressure in order to monitor the tunneling current passing trough the empty chamber. A second experiment was realized to monitor the tunneling for a water filled chamber without over pressure. In this case the tunneling current is a quite low because of the low beam current used. For 80µA beam current, with a 20 bar over pressure, and a resulting internal pressure of 45-48 bar, the tunneling was successfully removed.

However at higher beam currents, 40 bar of over pressure and a resulting internal pressure of 82-86 bar, the tunneling was not efficiently removed, but it is still possible to increase the over pressure in order to reach a internal pressure close to maximal permitted pressure of 275 bar.

[0054] Other parameters values may be selected in the framework of the invention. A cylinder chamber may be designed by first setting the cylinder wall thickness (t). Knowing the cooling window foil thickness, the water thickness between the cooling window foil and the cylinder, and setting the cylinder wall thickness, it is possible to calculate theoretically the energy of the beam entering the cylindrical chamber. Knowing this, it is possible to calculate the range of protons in water, which can be assimilated to a minimal inner diameter (d_{min}) of the cylindrical chamber. One can obtain a maximal internal pressure (P_{max}) for a thickness combined with the corresponding minimal inner diameter. Some non-limitative examples are shown in table 3 for an accelerated proton beam of 30MeV.

Table 3

t (µm)	beam Energy inside the chamber (MeV)	proton range (mm)	d_{min} (mm)	P_{max} (bar)
300	25	6,2	6,2	305
400	24	5,8	5,8	426
500	23	5,4	5,4	560
700	20	4,2	4,2	943

Others designs of the target comprising a cylindrical chamber with a thinner thickness suitable for irradiation with 18MeV protons may be constructed according to the same way, in order to withstand a needed pressure to suppress or reduce the tunnelling and in order to have a sufficient beam energy entering inside the chamber. Some non-limitative examples are shown in table 4 for an accelerated proton beam of 18MeV.

Table 4

t (μm)	beam Energy inside the chamber (MeV)	proton range (mm)	d_{min} (mm)	P_{max} (bar)
50	14	2,2	2,2	143
100	13	1,9	1,9	326
150	12	1,7	1,7	546
200	11	1,4	1,4	815
400	7	0,7	0,7	2400

[0055] By using the insulated conductor (110) one can now select the inner gas pressure necessary for minimising the tunnelling current for given beam energy and current. Therefore one can select optimal operation parameters for obtaining a high radioisotope production yield.

Claims

1. A target apparatus for producing a radioisotope of interest from a target material irradiated by a beam of charged accelerated particles having an energy, the said target comprising:

   - a chamber (101) for containing a target material;
   - a body (102) enclosing said chamber and forming a gap (107) between said chamber and said body adapted for the circulation of a cooling fluid, said body having an opening for leaving a passage for said beam of accelerated particles to said chamber (101), said opening being provided with a cooling window foil (106) retaining cooling fluid running inside said gap;

   characterized in that :
   said chamber is a cylinder, with a thickness higher than 50μm, and internal diameter equal or higher than the penetration range of said charged particles in said target material at the energy of said charged particles when penetrating said target material;
   and the said opening being parallel to the longitudinal axis of the cylinder.

2. The target apparatus according to claim 1, **characterized in that** said chamber (101) is sealed in the said body by means of crushing seals (105) located in the two cylinder heads (113) of the said body.

3. The target apparatus according anyone of claim 1 or 2, **characterized in that** the surface of the said cooling window foil (106) is parallel to the longitudinal axis of said cylindrical chamber (101).

4. The target apparatus according to any of preceding claims, **characterized in that** said cooling window foil (106) is clamped between two flanges comprising an opening (214) that fits with the width of the said chamber, the first flange (211) being fixed in a tight manner with seals and screws on the body and the second flange (213) being fixed in a tight manner on the first flange with seals and screws.

5. The target apparatus according to any of preceding claims, **characterized in that** it comprises an insulated conductor (110) inserted in the back of said body in front of the said opening, in order to monitor the fraction of the beam of accelerated particles which passes trough the chamber (101).

6. The target apparatus according to claim 1, **characterised in that** it is pressurised and wherein the upper leg of the filling loop of the chamber (108) is connected to a pressure transducer (402) in order to monitor the internal pressure of the said chamber.

7. A method for producing an isotope of interest, comprising the steps of:

- filling a cylindrical chamber with a target material;
- pressurizing the chamber with inert gas in order to prevent the tunnelling effect;
- irradiating the target chamber with an accelerated particle beam perpendicular to the axis of said cylindrical chamber;

8. The method of claim 7 further comprising the steps of

- providing an insulated conductor for receiving any part of said charged particle beam traversing said chamber;
- monitoring the tunnelling effect by measuring the beam current incident on said insulated conductor.

9. The method of claim 7 or 8, comprising utilization of target apparatus of claim 1.

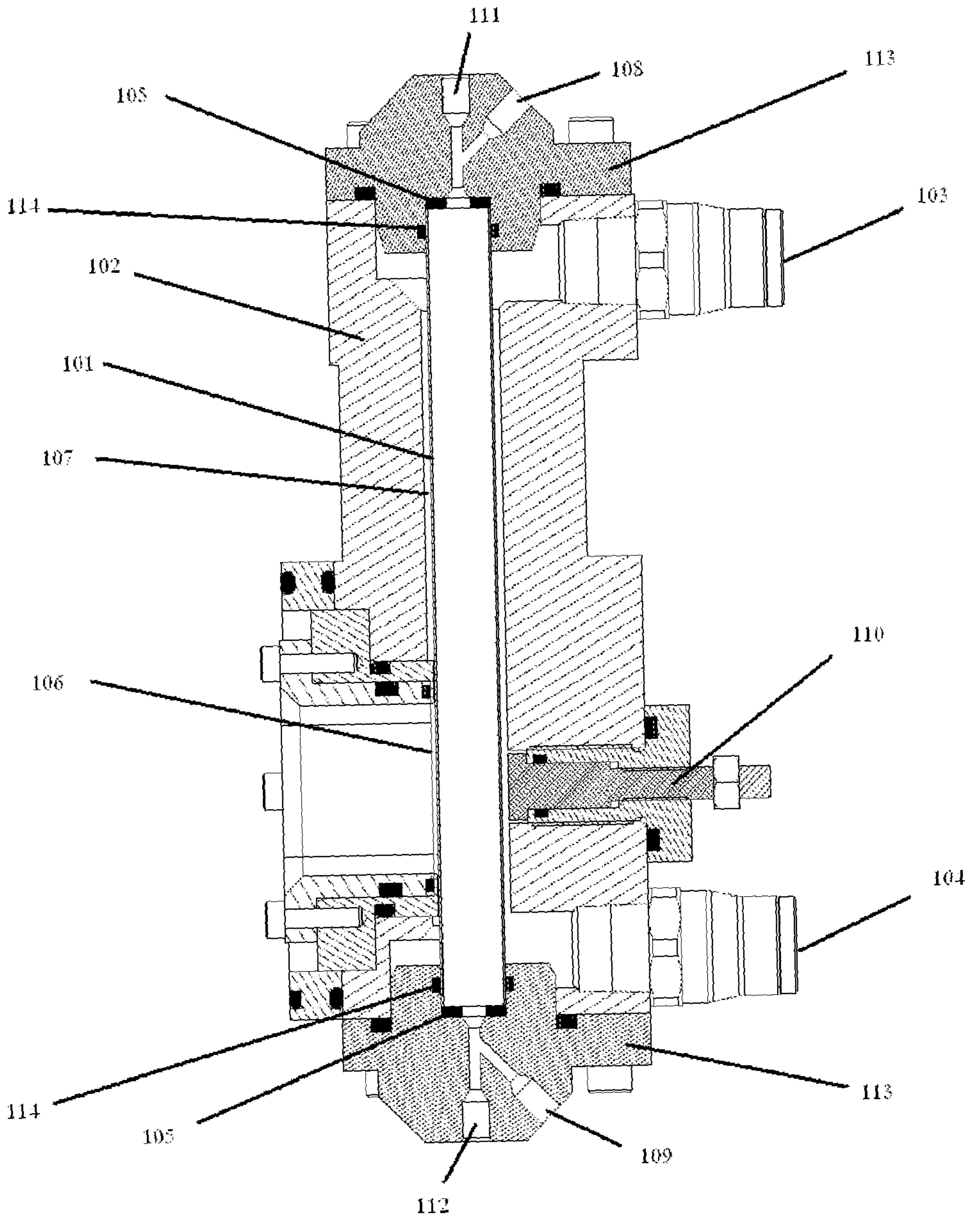
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Fig. 1

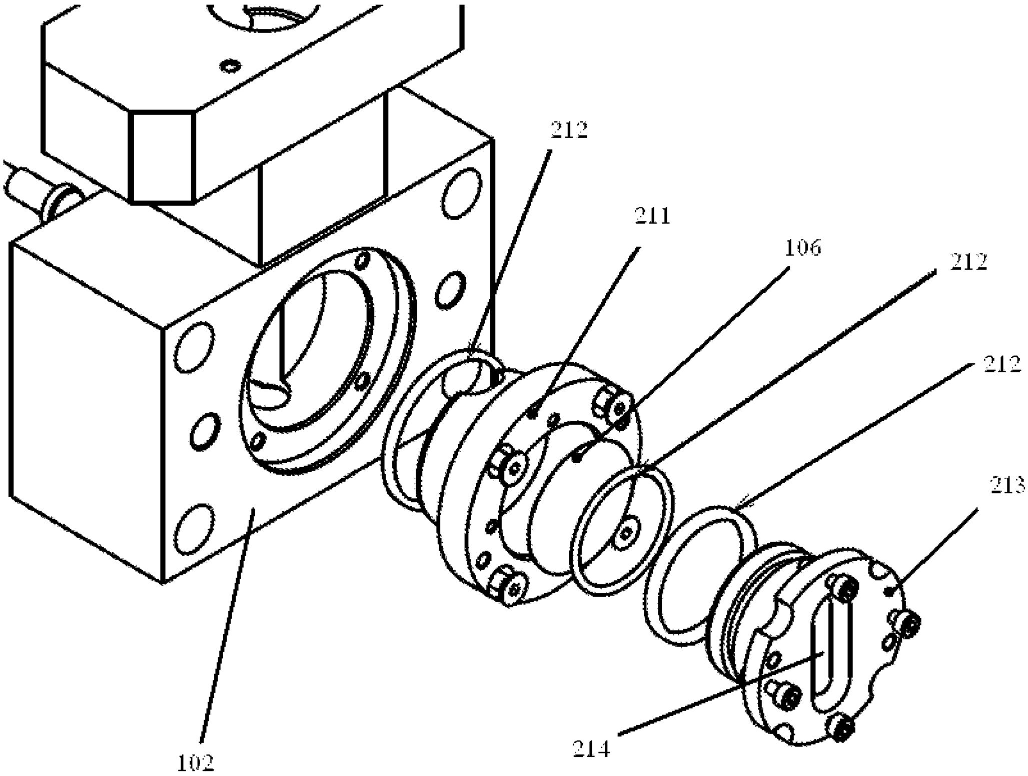

Fig. 2

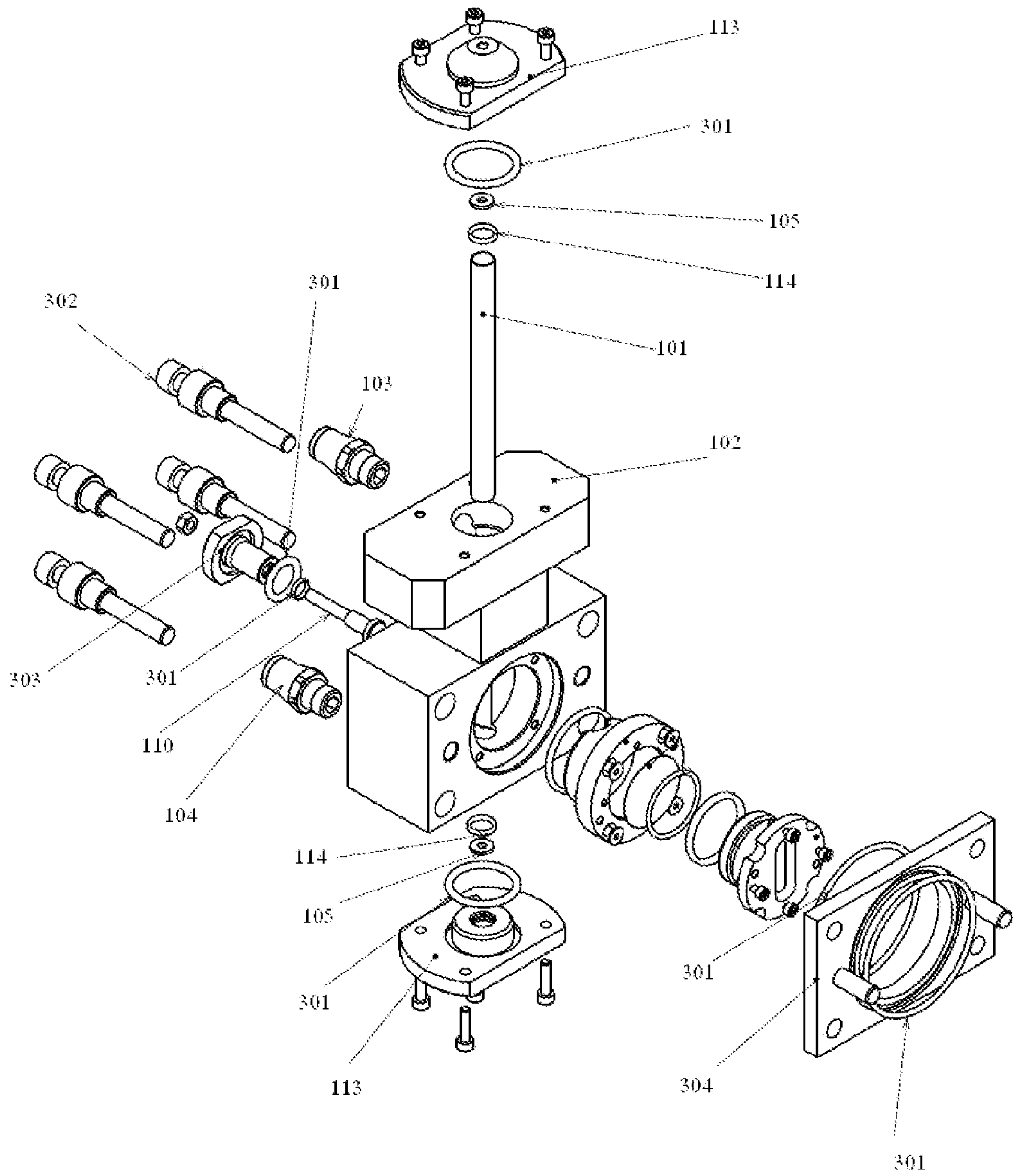
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Fig. 3

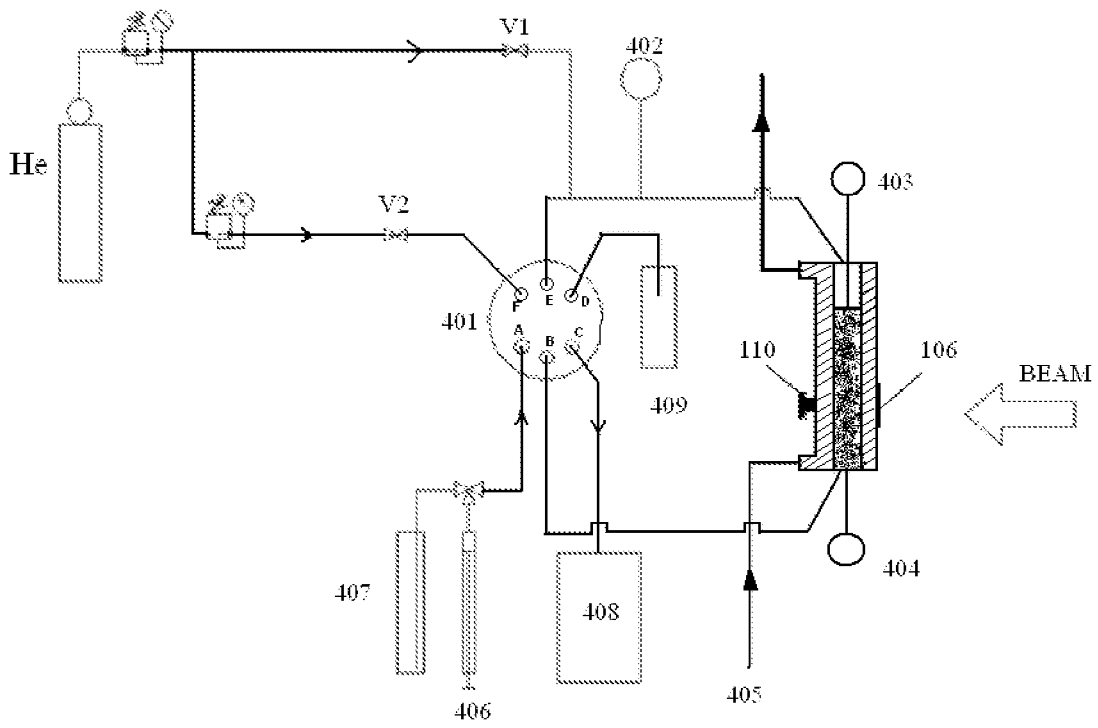

Fig. 4

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EUROPEAN SEARCH REPORT

Application Number
EP 08 16 0763

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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
The Hague	10 December 2008	Crescenti, Massimo

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CATEGORY OF CITED DOCUMENTS

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EUROPEAN SEARCH REPORT

Application Number
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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
The Hague	10 December 2008	Crescenti, Massimo

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