



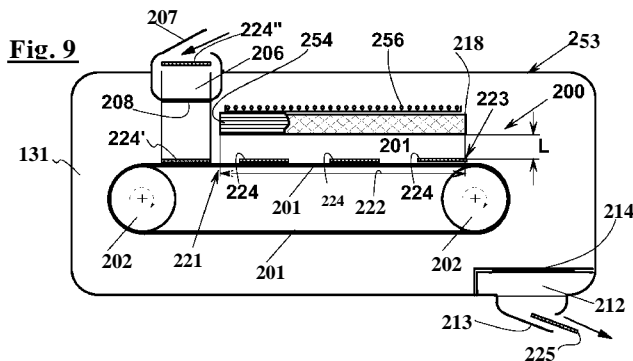
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(54) Title: A METHOD AND A DEVICE FOR TREATING RADIOACTIVE MATERIAL



(57) Abstract: A method and a device for treating a long half-life radioactive materials such as radioactive waste materials generated by power plants and radioactive residues of abandoned nuclear weapons, and mining processes, wherein an active core (118) includes a transition metal such as Ni, Cr, Mn, Fe, in the form of clusters nanostructures, which have a number of atoms lower than a predetermined number of atoms, so that once it is brought into contact with hydrogen and into suitable trigger conditions, a reaction with hydrogen can occur comprising a capture of H- ions, a proton generation and nuclear capture or expulsion of the latter from the nuclei of the transition metal. A second material comprising a long half-life radioactive material is arranged along with the first material in a treatment chamber (153), so that the reaction between the transition metal and hydrogen (131) causes transmutation reactions of the radioactive material. According to a first aspect of the invention (Fig. 1), the radioactive material belongs to active core (118) and is in contact with the transition metal, in particular it may be itself a further transition metal, arranged in initially existing cluster nanostructures or in cluster nanostructures that are formed during the reaction of the transition metal, which may react with hydrogen forming radioactive products whose half-life is shorter than the starting radioactive materials half-life. The radioactive materials may comprise also a material, for example ¹³⁷Cs, ⁹⁰Sr, that is suitable for reacting with the protons that are produced during the reaction of the transition metals with hydrogen. According to another aspect of the invention, the radioactive material, which is suitable for reacting with the protons produced during the reaction of the transition metals with hydrogen, is arranged at a distance from the transition metal, such that the protons can reach the radioactive materials and give rise to proton-dependent transmutation reactions.

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TITLE

A METHOD AND A DEVICE FOR TREATING RADIOACTIVE MATERIAL

DESCRIPTIONField of the invention

5 The present invention relates to a method and to a device for reducing and/or eliminating radioactive materials, for example long half-life radioactive waste materials produced by nuclear fission power plants.

 This method is an application of what is described in the international patent application WO2010058288, incorporated herein by reference. A
10 different implementation of the method is described in the international patent application PCT/IB2012/052100, not yet published at the time of filing the present patent application, also incorporated herein by reference.

Brief description of the prior art - Technical problem

 The production of energy by nuclear fission reaction has the well known
15 drawback of the disposal of radioactive waste materials, i.e. of the radioactive fission products. By now, substantially no industrially useful solutions have been developed in alternative to storing such materials in controlled places.

 The need is therefore felt of a process for reducing and/or eliminating
20 these long half-life fission products, thereby obtaining remarkably less dangerous materials. Such fission products are obtained from nuclear power plants, and from other devices such as medical and industrial devices. Other radioactive materials are present in abandoned nuclear weapons. Still other radioactive materials derive from mining industry waste.

 As well known, if some typical Uranium fission products such as ¹³⁷Cs and
25 ⁹⁰Sr are bombarded with suitably energetic protons, decay reaction can be triggered that are capable of transforming these fission products into less dangerous materials. In particular, these fission products can be transformed into radioactive materials that have a shorter half-life than the starting radionuclides, or even into stable materials. No industrial breakthrough of this
30 principle was possible since it is not be rentable, with the current techniques. In fact, a large amount of energy is required to produce high energy protons at present. Therefore, the costs are very high. In particular, particle accelerators

must be used, which involves construction and operation costs that are too high with respect to the value of the energy that can be obtained in a fission power plant.

5 Apart from the above fission fragments, high atomic number radionuclides have an extremely lower probability of being transmuted into other products that are stable or can be changed into stable products. In particular, this category comprises some isotopes of Pu, U, Ac, Th, and of other elements, which belong, for instance, to the three natural radioactive families and to the fourth artificial radioactive family.

10 It is also known that the process according to WO201 0058288 takes place with a proton generation.

WO20071 02860 describes methods of generating energetic particles, by contacting nanotubes with hydrogen in an isotopic form of the latter, in the presence of an activation energy, for example a thermal, electromagnetic, or
15 kinetic energy of the particles. Methods are also described for causing a transmutation of a material by exposing it to the so generated energetic particles. This solution has an approach very different from WO201 0058288, since the latter teaches exploiting the behaviour of crystals clusters, in the crystal lattice of which an H- ion can enter, while WO20071 02860 exploits the
20 geometry of the nanotubes. In particular, the transmutation is made through a neutron capture reaction and, in order to cause a neutron production, nanotubes must be fed with deuterium, so that a large amount of neutrons packed within the nanotubes are obtained, which can be captured by the radioactive material, thus triggering the transmutation.

25 In PCT/IB201 2/0521 00, not yet published at the time of filing the present application, and incorporated herein by reference, an application is described of the process according to WO201 0058288, in which a so-called secondary material, which is adapted to react with protons of an energy level higher than a predetermined threshold, is arranged facing an active core comprising a so-called primary material that comprises a transition metal, in a hydrogen
30 environment. This way, the protons produced in the active core during a reaction between hydrogen and the first material may reach the secondary material and trigger energy-releasing proton dependent nuclear reactions in the secondary material.

Also in the following description, by primary material a material is meant that comprises a predetermined amount of cluster nanostructures of a transition metal, such nanostructures having a number of atoms of the transition metal lower than a predetermined number of atoms. Furthermore, by secondary material a material is meant that can engage with protons coming from the first material by nuclear energy-releasing proton-dependent reactions, which normally occur with a release of significant amount of energy.

Summary of the invention

It is therefore a feature of the present invention to provide a method and a device for eliminating long half-life residues and radioactive waste materials, for example radioactive waste materials generated by power plants and by other devices based on nuclear fission reactions or on neutronic activation reactions, which are presently disposed in storage centres, by transforming these fission products into shorter half-life materials or stable materials.

It is also a feature of the invention to provide a method and a device for treating materials obtained from abandoned nuclear weapons, typically containing Plutonium, Uranium, Thorium, or from other devices that provide the production or the use of radioactive material, in particular from medical and industrial devices, or deriving from mining industry waste.

It is also a feature of the invention to provide such a device having an industrially acceptable production capacity.

It is also a feature of the invention to provide a method and a device that allow to use protons produced by a process as described in WO20 10058288 for triggering decay reactions of fission products or long half-life radioactive waste materials, transforming them into less dangerous products, in particular for transforming them into shorter half-life products or, in particular, into stable products.

It is then a feature of the invention to provide a method and a device that besides eliminating residues and long half-life radioactive waste materials, also allows producing significant amounts of energy.

These and other objects are achieved by a method for transforming long half-life radioactive material, in particular fission products, into shorter half-life products or into stable products, the method comprising the steps of:

- prearranging a first material comprising a transition metal;
 - forming an active core including the first material, the first material comprising a predetermined amount of cluster nanostructures, the clusters nanostructures having a number of atoms of the transition metal lower than a predetermined number of atoms;
 - creating a hydrogen environment in contact with the clusters at a predetermined pressure;
 - heating and maintaining the active core at a process temperature higher than a predetermined critical temperature responsive to the first material;
 - actuating an impulsive action on the active core,
- such that a reaction of the first material and of hydrogen is triggered, this reaction comprising an orbital capture of H⁻ ions by the cluster nanostructures of the first material, a generation of protons ¹H associated with the capture and then a repulsion of a part of the protons forming protons expelled by the first material;

the main features of this method being that a step is also provided of prearranging a second material comprising a long half-life radioactive material, wherein the second material faces the first material, so that the reaction of the first material triggers transmutation reactions in the radioactive material of the second material.

According to an aspect of the invention, the active core includes the second material arranged in contact with the first material. The condition of "contact" between the first and second material is to be understood in a wide sense, comprising a contact at the nanometric or micrometric level, for example in the case of alloys, solid solutions, solid mixture, bonding of various type, or also of layers or parts of the two materials in contact with one another.

This way, the protons obtained by the process according to WO201 0058288, have enough energy to engage with some radioactive material, and can therefore trigger transmutation reactions. In other words, they can cause the transformation of an isotope of a radioactive element into an isotope of a different element.

According to another aspect of the invention, the method also comprises the steps of:

- prearranging a support member for the second material;

wherein the support member and the active core are configured for carrying out a relative movement in which different surface portions of the support member are sequentially arranged in a region facing the active core,

- 5 - arranging the amount of the second material on the support member, at a predetermined distance from the active core;
- relatively moving the movable support and the active core so that the amount of the second material turns from an initial treatment condition to a final treatment condition in the exposed region, and in a time between the initial treatment condition and the final treatment condition transmutation reactions in
10 the radioactive material of the second material take place caused by the reaction of the active core and of hydrogen, wherein the long half-life radioactive material is transformed into a treated material;
- removing the treated material from the support member.

This way, the arrangement of the secondary material with respect to the
15 first material allows treating in an industrially acceptable way important amounts of such radioactive materials as radioactive fission waste materials produced by power plants. In fact, even if the protons cannot significantly penetrate the matter, and accordingly the proton-dependent reactions can take place only in a surface layer of a body that comprises the secondary material, and only in some
20 regions of the secondary material, the claimed method allows semicontinuously treating an amount of radioactive material. In other words, the active core is in a steady state during the whole useful life of the active core, i.e. the reactions between hydrogen and the cluster-structured transition metal of the first material occurs in a steady state, and provides protons that trigger the transmutation
25 reactions of the radioactive material of the second material, while predetermined amounts of the second material occupy in turn a treatment zone of the region facing the active core.

Preferably, the active core is stationary, and the support member for the second material is configured for sequentially arranging own different surface
30 portions into the region facing the active core, and the step of moving is carried out in such a way that the amount of the second material passes through the exposed region from an inlet section to an outlet section of the exposed region and undergoes the transmutation reactions during this passage, turning into the treated material.

Advantageously, a step is provided of segregating the active core with respect to said support member and/or with respect to a feeding/extraction chamber of said second material / treated material, said step of segregating actuated before said step of feeding / extraction and discontinued after said step of feeding / removal of said treated material from said support member.

If required, a step is also provided of restoring the hydrogen environment at the operating pressure at the support member or in the feeding / extraction chamber of the second material / of the material treated by the treatment chamber before discontinuing the step of segregating. This way, the hydrogen environment and the operating pressure at active core do not change substantially when interrupting the step of segregating. A step may also be provided of removing gas at the support member, in order to remove pollutants, i.e. gas substances different from hydrogen. This extraction step may comprise a vacuum step at a very low residual pressure, as possible in the art, and for a predetermined vacuum time. This way, the reaction between hydrogen and the first material of the active core is substantially unaffected by the steps of arranging the second material on the support member, nor by the step of removing the treated material from the support member. This serves to allow a steady operation of the device for treating radioactive materials according to the invention.

The step of heating and maintaining the active core at a process temperature higher than a predetermined critical temperature advantageously comprises a step of creating a gradient of temperature between a first region and a second region of the active core, wherein the gradient of temperature is selected responsive to the first material.

Advantageously, the first material is selected from the group consisting of: Nickel, Chromium, Manganese, Iron and other transition metals, as described in WO2010058288, i.e. among materials that are more prone for triggering the process of atomic capture, proton generation and nuclear capture/expulsion, than other transition metals. This makes it easier to cause the reaction which involves the first material and hydrogen, and the whole treatment process, in particular in the case of an active core in which the first material and the second material are in mutual contact. In particular, some of these transition materials stand out for a favourable electron configuration, for a favourable

crystallographic structure and for low values of the Debye temperature, above which the process of atomic capture and proton generation and nuclear capture/expulsion is easier to be triggered.

In particular, the second material may be obtained from radioactive waste materials or residue materials of an apparatus based on nuclear fission reactions, in particular of a nuclear fission power plant. In particular, radioactive waste materials comprise fission fragments such as ^{137}Cs , ^{90}Sr and other radioactive isotopes that are commonly present in radioactive nuclear waste materials. This way, the method according to the invention, in particular the method in which the second material is arranged on a support member spaced apart and releasable from the first material, serves to solve the old problem of treating radioactive waste materials, in particular radioactive waste materials that are presently disposed into special storage centres.

The radioactive material of the second material may comprise a further transition metal different from the transition metal of the first material, the further transition metal comprising cluster nanostructures. This way, the process of atomic capture and proton generation and nuclear capture/expulsion may take place also in this further transition metal, causing a transformation of at least one part of the radioactive materials into radionuclides having a half-life shorter than the further transition metal, or even into stable materials.

In particular the second material may be obtained from parts of abandoned weapons, or from impoverished Uranium or from mining industry waste, or from different radioactive products or residues. This way, the method according to the invention, in particular the method in which the second material is in contact with the first material, serves to solve the old problem of treating these residual material, which are presently disposed into special storage centres. In particular, the second material may comprise a transition metal selected among Pu, U, Th and "sons", i.e. it is selected among the elements of the respective radioactive families, which can give rise to the typical reactions of the process of atomic capture and proton generation and nuclear capture/expulsion. In other words, material such as Pu, U, Th and "sons" may behave as primary materials, according to the terminology used in PCT/IB2012/052100, i.e. they themselves undergo the reactions of the process of atomic capture and proton generation and nuclear capture/expulsion.

Besides transmutating into short half-life products or in particular into stable products, they can provide energy in the form of reaction heat.

In alternative to in addition, the second material may comprise a material suitable for reacting with protons coming from the first material, by performing
5 proton-dependent nuclear reactions, during the reactions of the process of atomic capture and proton generation and nuclear capture/expulsion. In this case, according to the terminology used in PCT/IB2012/052100, the second material behaves as a secondary material. Furthermore, the proton-dependent reactions may be energy-releasing reactions, therefore they take part in the
10 generation of energy as process heat. In addition, since the second material is in contact with the first material, i.e. with the transition metal that comprises cluster nanostructures, and is well-suited for the process of atomic capture and proton generation and nuclear capture/expulsion, a progressive transmutation occurs of the whole amount of the second material, finally obtaining short half-
15 life or stable products. As described, radioactive materials such as ^{90}Sr or ^{137}Cs are adapted to react with protons emitted by the first material, by performing proton-dependent nuclear reactions.

Advantageously, a step is provided of arranging a selective barrier material in the active core between the first material and the second material,
20 said selective barrier material arranged to prevent a migration of a gas towards the first material, and to allow a passage of protons from the first material to the second material. This way, a gas different from hydrogen, which may be produced during the transmutation reactions of the radioactive material, cannot reach the first material, and therefore it cannot hinder the adsorption of
25 hydrogen onto the clusters surface of the first material, nor can it hinder the subsequent orbital capture of H- ions by the cluster nanostructures. At the same time, the selective barrier allows the protons, which are formed during the reaction between hydrogen and the transition metal of the first material, to reach the secondary material and to allow the proton-dependent reactions of the
30 secondary material.

In a first exemplary embodiment,

- the step of prearranging the first material provides a step of preparing a base member of the first material, comprising cluster nanostructures of a

transition metal, said nanostructures having a number of atoms of the transition metal lower than a predetermined number of atoms;

- the step of prearranging the second material provides a step of vaporizing the second material, i.e. of long half-life radioactive material, thus obtaining vapours of the second material;

- the step of forming an active core comprises a step of depositing the second material on the base member of the first starting material from the vapours of the second material, such that an alloy or a solid solution or a stratification or a mutual diffusion of the first material and of the second material is formed.

Advantageously, the step of preparing a base member provides a step of pre-treating the first material, in order to obtain a porous base member. In particular, this step of pretreating may comprise a sintering treatment.

The step of preparing a base member may comprise steps of:

- mixing the first material with a leachable material, obtaining a composite base member;

- bringing the composite base member into contact with a leaching liquid which is adapted to bring into liquid phase the leachable material, thus removing the leachable material from the composite base member. In this case a step of leaching the leachable material is carried out, in order to obtain a porous base member, thus increasing the surface of the element available for step of depositing.

In particular the leachable material is selected among Aluminium and Zinc, and the leaching liquid is a solution of an alkali such as NaOH, i.e. caustic soda, or a solution of a mineral or organic acid, for example a solution 1-normal (1N) of the acid or of the alkali.

Preferably, the liquid is an aqueous solution of an acid having a predetermined concentration, in order to bring into solution the leachable material substantially leaving only the first material in the base member. This way, the step of leaching produces hydrogen that is incorporated within the porous base member, preparing the porous base member for being turned into an active core.

If the second material comprises the further transition metal in which the process of atomic capture and proton generation and nuclear capture/expulsion

can take place, the step of depositing the second material is carried out with a technique such that the transition metal of the second deposited material comprises cluster nanostructures of the further transition metal.

The technique of deposition of the transition metal of the first or of the second material may be one of the techniques that are mentioned in the publications WO201 0058288 and PCT/IB201 2/0521 00, cited in this patent application to obtain a transition metal in the form of clusters, i.e. such technique may be selected from the group consisting of:

- sputtering;
- 10 - spraying;
- evaporation and then condensation on the support member of the predetermined metal amount;
- epitaxial deposition.

In a second exemplary embodiment,

- 15 - the step of prearranging the second material provides a step of preparing a base member of the second material, i.e. of the long half-life radioactive material;
- the step of prearranging the first material provides a step of vaporizing the first material, comprising a transition metal in a shape suitable for the process of atomic capture and proton generation and nuclear capture/expulsion obtaining vapours of the first material;
- 20 - the step of forming an active core comprises a step of depositing the first material on the base member of the second starting material from the vapours of the first material, with a deposition technique such that the first deposited material comprises cluster nanostructures of the transition metal, in which the clusters comprise a number of atoms lower than a predetermined maximum number, and such that an alloy or a solid solution or a stratification or a mutual diffusion of the first material and of the second material is formed.
- 25

In particular, the base member of the second material comprises a rod of an exhausted nuclear fuel coming from a fission power plant. The rods of exhausted fuel contain relevant amount of materials such as radioactive isotopes of Uranium, as well as fractions of Plutonium and other fission products. These materials can give origin to reactions according to the process of atomic capture and proton generation and nuclear capture/expulsion, and

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can turn into shorter half-life radioactive materials or into stable materials. The rods normally contain also other fission products which may be transformed into shorter half-life radioactive materials to or into stable materials also or preferably through proton-dependent nuclear reactions, wherein emitted protons are involved.

Advantageously, the step of preparing a base member provides a step of pretreating the second material, in particular by sintering, in order to obtain a porous base member. In this case, even if the second material is not in the form of clusters, but of a sintered that normally does not contains clusters, the proximity with the first material may create conditions such that the process occurs also in the second material.

Alternatively, this step of preparing a base member may provide:

- a step of mixing the second material with a leachable material, in particular with Aluminium or Zinc, obtaining a composite base member, for example for sintering.

- a step of bringing the composite base member into contact with a leaching liquid which is adapted to bring into liquid phase the leachable material removing the leachable material by the composite base member; in which case the leachable material is leached and cavities are formed, in order to obtain a porous base member, thus increasing the surface of the element available for step of depositing.

In particular, the leachable material is selected among Aluminium and Zinc, and the leaching liquid is a solution of an alkali such as NaOH, i.e. caustic soda, or of a mineral or organic acid, for example a solution 1-normal (1N) of the acid or of the alkali.

Preferably, the liquid is an aqueous solution of an acid having a predetermined concentration, in order to solubilise the leachable material, substantially leaving only the second material in the base member. This way, the step of leaching produces hydrogen that is incorporated within the porous base member, preparing the porous base member for being turned into an active core.

The deposition technique may be one of the techniques mentioned in the publications WO2010058288 and PCT/IB2012/052100 to obtain a transition

metal in the form of clusters, i.e. the technique may be selected from the group consisting of:

- sputtering;
- spraying;

- 5 - evaporation and then condensation on the support member of the predetermined metal amount;
- epitaxial deposition.

In a third exemplary embodiment, the method comprises a step of

- 10 - prearranging a support member, in particular a porous support member, and
- the steps of prearranging the first material and the second material comprise a step of vaporizing the first material and the second material, possibly premixing the vapours of the first material and the vapours of the second material obtained from the step of vaporizing the first material and the
- 15 second material, thus obtaining mixed vapours;
- the step of forming an active core comprises a step of co-depositing the first material and the second material on the support member, starting from vapours that are maintained separated from each other until the contact with the support member occurs, or starting from the mixed vapours, with a deposition
- 20 technique such that the transition metal of the first material, once deposited, comprises cluster nanostructures of the transition metal, wherein the clusters comprise a number of atoms lower than a predetermined maximum number of atoms, and such that an alloy or a solid solution of the first material and of the second material is formed.

- 25 For example, also the technique of co-deposition may provide steps selected from the group consisting of: sputtering; spraying; evaporation and then condensation on the support member of the predetermined metal amount; epitaxial deposition.

The objects previously indicated are also reached by a device for

30 transforming long half-life radioactive materials, in particular fission products, into shorter half-life products or into stable products, said device comprising:

- an active core including a predetermined amount of a first material, the first material comprising cluster nanostructures having a number of atoms of a transition metal lower than a maximum predetermined number of atoms;

– a treatment chamber containing the active core and configured to contain a hydrogen environment in contact with the clusters at a predetermined operating pressure;

5 – a heating and temperature-maintaining means for heating and maintaining the active core in the generation chamber at a process temperature higher than a predetermined critical temperature responsive to the first material,

– a trigger means for actuating an impulsive action on the active core, the generation chamber and the trigger means configured to cause a formation of H- ions and an orbital capture of the H- ions by the cluster nanostructures of the first material, a generation of protons ^1H associated with the capture and then a repulsion of a part of said protons forming protons expelled from the first material;

10 the main feature of said device being that it also comprises a second material comprising a long half-life radioactive material, wherein the second material is arranged to face the first material, and to trigger transmutation reactions of the radioactive material of the second material by the reaction of the first material.

According to an aspect of the invention, the active core includes the second material, which is arranged in contact with the first material.

20 In some exemplary embodiments, the core comprises a base member of the first/second material and a deposit of the second/first material on the basis made starting from vapours of the second/first material, where the deposit is an alloy or a solid solution or a stratification or a mutual diffusion of the first/second material and of the second/first material is formed, or a combination of such types of depositions.

25 According to another aspect of the invention, the device comprises:

– a support member for the second material, which is arranged to receive said amount of said second material at a predetermined distance from said active core;

30 wherein the support member and the active core are configured to perform a relative movement by sequentially arranging different surface portions of the support member in a region facing the active core,

– arranging the amount of the second material on the support member, at a predetermined distance from the active core;

- a means for carrying out a relative movement of the movable support and the active core such that the amount of the second material turns from an initial treatment condition to a final treatment condition in the exposed region, and between the initial treatment condition and the final treatment condition
- 5 transmutation reactions of the radioactive material of the second material take place caused by the reaction of the active core, forming a treated material;
- a means for removing the treated material from the support member.

Preferably, the active core is stationary and the support member for the second material is movable and configured for sequentially arranging own

10 different surface portions of the support member in a region facing the active core, and the means for carrying out the movement of the movable support are configured to guide the amount of the second material in the exposed region between an inlet section and an outlet section, so that the radioactive materials of said secondary material that faces the active core undergoes the

15 transmutation reactions.

Brief description of the drawings

The invention will be now shown with the description of exemplary embodiments of the method according to the invention, exemplifying but not

20 limitative, with reference to the attached drawings, in which like reference characters designate the same or similar parts, throughout the figures of which:

— Fig. 1 is a longitudinal sectional view of a device or reactor for carrying out the method according to the invention, in a first aspect of the invention, for reducing and/or eliminating radioactive materials, for example long half-life radioactive waste materials produced by nuclear fission power plants;

25 — Figs. 2A-2B show a step of depositing a long half-time radioactive material on a base member of a material suitable for the process of atomic capture and proton generation and nuclear capture/expulsion, comprising cluster nanostructures of a transition metal, in which the nanostructures have a number of atoms of the transition metal lower than a predetermined number, in order to

30 provide an active core in which said first material and said second material are in contact with each other;

— Figs. 3A-3C show a step of deposit a long half-time radioactive material on a porous base member of a material suitable for the process of atomic capture

and proton generation and nuclear capture/expulsion, obtained by leaching a composite base member, in order to provide an active core in which said first material and said second material are in contact with each other;

— Figs. 4A-4B show a step of arranging a material suitable for the process of atomic capture and proton generation and nuclear capture/expulsion, on a base member of a long half-time radioactive material, in order to provide an active core in which said first material and said second material are in contact with each other;

— Figs. 5A-5C show a step of arranging a material suitable for the process of atomic capture and proton generation and nuclear capture/expulsion, on a porous base member of a long half-time radioactive material, obtained by leaching a composite base member, in order to provide an active core in which said first material and said second material are in contact with each other;

— Fig. 6 shows a spraying process of depositing on a substrate an alloy or a solid solution, in the form of clusters, of a metal suitable for the process of atomic capture and proton generation and nuclear capture/expulsion, and a radioactive material to be treated, starting from mixed vapour of the two materials;

— Fig. 7 shows a process of depositing on a substrate an alloy or a solid solution, in the form of clusters, of a metal suitable for the process of atomic capture and proton generation and nuclear capture/expulsion, and a radioactive material to be treated, starting from mixed vapour of the two materials, carried out by a magnetron process;

— Fig. 8 shows a process of depositing on a substrate an alloy or a solid solution, in the form of clusters, of a metal suitable for the process of atomic capture and proton generation and nuclear capture/expulsion, and a radioactive material to be treated, starting from a liquid vaporized to obtain mixed vapours of the two materials;

— Figs. 9-13 diagrammatically show a reactor for carrying out the method according to another aspect of the invention, and its operation, for reducing and/or eliminating radioactive materials, in particular long half-life radioactive waste materials produced by nuclear fission power plants;

— Figs. 14,15 show a reactor according to an alternative exemplary embodiment, for carrying out the method of Figs. 9-12;

— Fig. 16 is a diagrammatical view of the interactions between hydrogen and the clusters in a local enlarged view of the surface of the active core;

— Figs. 17 and 18 are diagrammatical views of the orbital capture of an H⁻ ion by an atom of a transition metal, and of the subsequent steps of fusion nuclear reactions of nuclear capture of a portion of the H⁻ ions by nuclei of the transition metal, with production of heat, and of transformation of further H⁻ ions into protons ¹H⁺, followed by coulombic expulsion from the atom of the transition metal and subsequent capture into a material suitable for capturing protons and for engaging with them proton-dependent nuclear reactions, with further production of energy in the form of heat.

Description of preferred exemplary embodiments

Methods will be described hereinafter for reducing and/or eliminating radioactive materials, by changing them into remarkably shorter half-life products or into stable products.

According to a first aspect of the invention, long half-life radioactive materials such as fission products, residues of nuclear weapons, impoverished Uranium, mining residues, are turned into shorter half-life products or into particularly stable products by the method the main steps of which are described below, with particular reference to Fig. 1. At first, an active core is prepared, for example in the form of a continuous solid body such as a bar, which comprises a predetermined amount of a transition metal, for example Ni, Cr, Mn, Fe, (Fig. 16) and a predetermined amount of the long half-life radioactive material to be transformed into a shorter half-life or into a stable material. The first material, or transition metal, comprises cluster nanostructures that have a number of metal atoms lower than a maximum predetermined number of atoms, according to what described in WO2010058288. The second material, i.e. the radioactive materials to be treated, are intimately mixed to each other. Such an active core may be obtained through the methods described more in detail hereinafter, with reference to Figs. 2A-8.

Active core, formed as previously described, is arranged in a treatment chamber of a reactor (Fig. 1), which is configured to contain hydrogen, in order to provide a contact between hydrogen and clusters of

transition metal 119. A heating means 156 is also provided that is dimensioned to be suitable for heating the active core 118 in a predetermined and industrially acceptable time, from a first temperature, typically room temperature, up to a second temperature or initial process temperature, higher than a predetermined critical temperature T_0 , which firstly depends upon the transition metal of the first material.

In the exemplary embodiment of Fig. 1, the pre-heating means comprises an electric winding 156, in use connected to a voltage source, not shown.

Two head portions of opposite end portions 152 and 159 house trigger means 161, 162, 167 for actuating an impulsive action on active core 118, i.e. for bringing core 118 to a trigger condition for a reaction between hydrogen 131 and cluster nanostructures 121 of transition metal 119. More in detail, treatment chamber 153 and trigger means 161, 162, 167 can cause the production of H-ions 135 and their orbital capture by the cluster crystal structure, and then by atoms 138 of clusters 121. The reaction between hydrogen 131 and cluster nanostructures 121 comprises, as well known from WO201 0058288, an orbital capture of hydrogen in the form of H-ions 135 by cluster nanostructures 121, a generation of protons ^1H associated with this capture and then a repulsion of a part of the protons 135' forming protons 135" expelled by a first material 11, 32. This reaction occurs with a production of energy in the form of heat Q_1 .

In an exemplary embodiment, as shown, electrodes 161, 162 extend respectively from head portions 152, 159, and have means for supporting and maintaining at its position active core 118, in treatment chamber 153. The trigger means may comprise electrodes 161, 162. In alternative or in addition, they may comprise trigger means 167, diagrammatically shown, for projecting a laser pulse on active core 118.

The reaction between first material 119 and hydrogen 131 triggers transmutation reactions of the radioactive material of second material 124.

In fact, the radioactive material may be a transition metal selected among those which are cited in WO201 0058288 as suitable for sustaining the above mentioned reaction with hydrogen. A large number of fission fragments of conventional nuclear fuel materials belongs to this group of transition metals. Therefore, during the reaction between first material 119 and hydrogen 131 conditions may be created such that also the radioactive transition metal of the

second material reacts in a similar way with hydrogen 131, turning into a remarkably lower half-life material or, in particular, into a stable material. This can occur because, in this embodiment of the invention, the first material and the second material are in contact with each other in the active core. In other words, since radioactive materials like Pu, U, Th, Ac are transition metals, they may in turn behave, with respect to hydrogen, as the first primary material, under stimulation of the energy delivered by the closely occurring primary reactions, wherein a subsequent propagation of the process of atomic capture, proton generation and nuclear capture/expulsion takes place from the first material to the second material. This may be caused by an increase of the temperature due to the heat Q_1 generated by the reaction between hydrogen and the first material. As it will be described hereinafter, active core 118 may be made in such a way that also the second material, i.e. the radioactive transition metal, comprises cluster nanostructures 121 arranged to react with hydrogen 131. However, the generation of clusters 121 comprising the radioactive transition metal of the second material may take place also during the reaction between first material 119 and hydrogen 131, above described.

Furthermore, the radioactive material of the second material may be adapted to react engaging proton-dependent nuclear reactions with protons 135" expelled by coulombic repulsion from the first material. In other words, it may work as a secondary material in the sense according to PCT/IB2012/052100, although it is intimately mixed with the first material, Instead of or besides working as a primary material through the hydrogen 131 capture reactions. This occurs, in particular, in the case of such materials as isotopes of Cs and Sr.

Reactor 150 advantageously also comprises advantageously a means 154 for removing at least one part of the thermal power, which is associated with reaction heat Q_1 , from treatment chamber 153, for example this means has the form of an external jacket, defined by an external wall 151 and by a heat exchange wall 155 of treatment chamber 153. In this case, the jacket is configured to receive a heat exchange fluid through an inlet port 164, and to release it through an outlet port 165, in order to maintain the temperature of active core 118 above critical temperature T_D . Device or reactor 150' may therefore provide or be used as a thermal energy generator, allowing to recover

energy from the reaction of hydrogen with the first material and from the transmutation reactions of the long half-life radioactive materials into a shorter half-life material and/or into a stable material.

5 The means 156 for setting and 154 for maintaining the temperature of active core 118 are made in such a way to cause a differential heat exchange with active core 118, so that the initial heating of active core 118 and then the step of maintaining the temperature T at a process temperature T1 create and maintain a gradient of temperature, i.e. of a non-uniform temperature profile, between a first region and a second region of active core 118, for example a
10 non-uniform profile between two ends 121 and 122 of elongated active core 118 of Fig. 1.

With reference to Figs. 2A-8, methods will be now described for preparing an active core that includes first material 11,32 and the second material, comprising a long half-life radioactive material, in which first material 11,32 and
15 the second material are in contact with each other.

In a first process, diagrammatically shown in Fig. 2A, a base member 10 is prepared of a first material 11 comprising cluster nanostructures of a transition metal, in which the nanostructures have a number of atoms of the transition metal lower than a predetermined number, for example Nickel, Chromium,
20 Manganese, Iron, or a different transition metal, so that the base member comprises cluster nanostructures. The base member may be made by any of the techniques indicated in the already cited documents WO201 0058288 and PCT/IB201 2/052 100.

In a possible embodiment, base member 10 may be an enlarged-surface
25 base member, in particular a porous base member.

Then, a radioactive material 12 is deposited on base member 10, in particular with a technique comprising sputtering, spraying, deposit of vapours, etc.

This way, an active core 118 is obtained, as shown in Fig. 2B, which
30 comprises a layer 14 of radioactive materials 12 in contact with first material 11, wherein first material 11 and second material 12 form, in an interface region, an alloy or a solid solution 14.

In a second process, as shown in Figs. 3A,3B,3C, a composite base member 20 is prepared which comprises first material 11 and a leachable

material 24, i.e. a material that can be removed by contacting it with a leaching liquid such as an alkaline solution or an acid solution, and bringing it into solution, for example a material such as Zinc or Aluminium. First material 11 is a transition metal that comprises cluster nanostructures, in which the nanostructures have a number of atoms of the transition metal lower than a predetermined number of atoms. The transition metal may be chosen, for instance, among those that were mentioned while describing the first process, in particular the transition metal may be Nickel. By bringing composite base member 20 into contact with a leaching liquid, the leachable material is solubilised and is removed from composite base member 20, which is turned into a porous base member 22 (Fig. 3B), in which the empty spaces left by the removed leachable material form pores 24' of porous base member 22. A step follows of depositing radioactive materials 12, which is carried out by techniques that are similar to those that were cited in the description of Figs. 2An and 2B. By this step of depositing an active core 118 is obtained (Fig. 3C) in which the two materials 11 and 12 have a large mutual interface surface.

In the above methods, radioactive materials 12 may be also a transition metal comprising cluster nanostructures with a number of atoms of the transition metal lower than a predetermined number of atoms. For example the radioactive materials may be Pu, U, Th or a different element of one of the respective radioactive families.

In a third process, as shown in Figs. 4A,4B, a base member 30 of a second radioactive material 31 is prepared, which is shown in black. Base member 30 may be prepared according to any of the techniques indicated in the above cited documents WO2010058288 and PCT/IB2012/052100. In an exemplary embodiment, base member 30 may be an enlarged-surface base member, in particular a porous base member. Then, a transition metal 32 as Nickel, Chromium, Manganese, Iron, is deposited on base member 30, with a technique that allows obtaining cluster nanostructures, in which each cluster has a number of atoms of the transition metal lower than a predetermined number of atoms. In particular, the technique used for depositing transition metal 32 may be selected among sputtering, spraying, metal vapour deposition, obtaining an active core 118 (Fig. 4B) comprising a layer 34 of first material 32 comprising cluster nanostructures with a number of atoms of the transition

metal lower than a predetermined number, in which first material 32 is in contact with second radioactive material 31, and where first material 32 and second material 31 form, in an interface region, an alloy or a solid solution.

In a fourth process, as shown in Figs. 5A,5B,5C, a composite base member 40 is prepared that comprises a radioactive material 31 and a teachable material 44, i.e. a material that can be removed by contacting it with a leaching liquid such as an alkaline solution or an acid solution, and bringing it into solution. By bringing composite base member 40 into contact with such a liquid, leachable material 44 is brought into liquid phase and removed from composite base member 40 that is turned into a porous base member 42. A step follows of depositing transition metal 32, selected for instance between those that were mentioned while describing the third process, on porous base member 42, with a technique that makes it possible to obtain cluster nanostructures of transition metal 32, in which each cluster has a number of atoms of the transition metal lower than a predetermined number of atoms. In particular, the technique used for depositing transition metal 32 may be selected among those that were cited when describing the third process. This way, an active core 118 is obtained (Fig. 5C) in which two materials 31 and 32 have a large mutual interface surface.

A fifth process is shown in Fig. 6. This process comprises a step of prearranging an amount of a first powder material, comprising a transition metal, and of an amount of a second powder material, comprising a radioactive material. The two materials are fed to a torch 50, for example a plasma torch 50, through two respective input ports 51 and 52. There follows a step of evaporating and atomizing the first material and the second material, in which the first material and the second material form mixed vapour 53 of the transition metal and of the radioactive material. The transition metal and the radioactive materials are deposited on a substrate 54, thus forming an active core 118 in which the transition metal comprises cluster nanostructures that have a number of atoms of the transition metal lower than a predetermined number of atoms. Active core 118 is suitable for the process of atomic capture, proton generation and nuclear capture/expulsion.

A sixth process is shown in Fig. 7. Such process comprises a step of prearranging a plate 61, for example a plate sintered of a first material, that

comprises a transition metal, and prearranging an amount of a second material that comprises a radioactive material. The plate of the two materials is mounted to a Magnetron 60 or, as an alternative, it is arranged within an induction heating system, not shown. There follows a step of evaporating and atomizing
5 the two metals in an evaporation and atomization zone 62, in order to form mixed vapour 63 of the two metals that deposit on a substrate 64 thus providing an active core 118 in which the transition metal comprises cluster nanostructures with a number of atoms of the transition metal lower than a predetermined number of atoms. active core 118 is adapted to process of
10 atomic capture, proton generation and nuclear capture/expulsion.

A seventh process is shown in Fig. 8. Such process comprises a step of prearranging an amount of a first material, comprising a transition metal, and of an amount of a second material, comprising a radioactive material, into a crucible 70, i.e. into a refractory container, configured for resisting to a
15 temperature as high as the melting temperature of the two materials. A step of heating the amount of the first material and of the second material is carried out in crucible 70, in order to form a liquid mixture 71 of the two materials. Heating may be carried out by a conventional means, such as an induction means, not shown. There follows a step of evaporating and atomizing liquid mixture 71,
20 wherein a mixed vapour 72 of the two metals is formed. The step of evaporation may be carried out by means of a power laser beam 73 that lights mixture 71 of the two materials. The transition metal and of the radioactive materials deposit on a substrate 74, thus forming an active core 118 in which the transition metal comprises cluster nanostructures with a number of atoms of the transition metal
25 lower than a predetermined number of atoms. Active core 118 is suitable for the process of atomic capture, proton generation and nuclear capture/expulsion.

Advantageously, a selective barrier material, not shown, is arranged between the first material and the second material in an active core of one of the above embodiments, which can block the passage of a gas different from
30 hydrogen, and is adapted to let protons pass from the primary material to the secondary material. The selective barrier material prevents gases different from hydrogen, for example Krypton and Xenon, which may be produced during the transmutation reactions of the radioactive material, from reaching the first material and hindering the adsorption of hydrogen onto the clusters surface of

the first material, and then also hindering the subsequent orbital capture of H-ions by the cluster nanostructures. However, the selective barrier allows the protons obtained during the reaction between hydrogen and the transition metal of the first material to reach the secondary material and to cause the proton-dependent reactions of the secondary material.

Active core 118, which may be obtained by one of the above described methods, may be used for carrying out the method according to the invention, as described hereinafter.

As shown in Fig. 1, active core 118 is put into a device or reactor 150', in which the clusters of the transition metal of the first material (for example Nickel) are brought into contact with a predetermined amount of hydrogen.

The radioactive materials may comprise Pu, U, Ac, Th, and other elements of the three natural radioactive families and of the fourth artificial radioactive family, i.e. material that can sustain the process of atomic capture and proton generation and nuclear capture/expulsion.

The radioactive materials may comprise ^{90}Sr or ^{137}Cs or other materials that, in the presence of a process of interaction between hydrogen and a transition metal located in the direct neighbourhood, such as one of the transition metal that are described in WO20 10058288, may behave as a secondary material. In other words, these materials can be transformed by proton bombarding, interacting with the protons according to proton-dependent reactions, without requiring that a specific energy threshold is exceeded.

The second/first material is deposited on base member 10,20,30,40 by bringing it into contact with the first/second material starting from the vapours of the second/first material, in order to create an alloy or a solid solution or a stratification or a mutual diffusion of the first/second material and of the second/first material. The transition metal is at least in part present in the form of cluster nanostructures 121 (Fig.9), in which the clusters substantially each cluster comprises a number of atoms 138 of the transition metal lower than a predetermined maximum number.

In a second aspect of the invention, long half-life radioactive materials such as fission products, residues of nuclear weapons, impoverished Uranium, mining residues, are turned into products of shorter half-life or, in particular, into stable products, by the method described below in its main steps, with particular

reference to Figs. 9-13. At first, an active core 218 is prepared, for example in the form of a continuous solid body such as a bar, which comprises a predetermined amount of a transition metal 119, for example Ni, Cr, Mn, Fe, of the type described in WO201 0058288. To this purpose, any of the techniques mentioned in the same document may be used to obtain cluster nanostructures 121 of the transition metal on the surface of the active core, in which cluster nanostructures 121 have a number of atoms 138 of the metal lower than a maximum predetermined number of atoms.

Active core, formed as previously described, is arranged in a treatment chamber 253 of a reactor 250 (Fig. 1), which is configured to contain hydrogen 131, at a predetermined operating pressure, in order to provide a between hydrogen 131 and clusters 121 of transition metal 119.

A heating means 256 is also provided that is dimensioned to be suitable for heating active core 218 in a predetermined and industrially acceptable time, from a first temperature, typically room temperature, up to a second temperature or initial process temperature, higher than a predetermined critical temperature T_D , according to the transition metal of the first material.

In the exemplary embodiment of Fig. 9, the pre-heating means comprises an electric winding 256, in use connected to a voltage source, not shown.

A trigger means, not shown, is also provided for actuating an impulsive action on active core 218, i.e. for bringing core 218 to a trigger condition for a reaction between hydrogen 131 and cluster nanostructures 121 of transition metal 119.

Like in the reactor described in WO201 0058288, the trigger means may comprise electrodes, and/or in addition trigger means configured for projecting a laser pulse on active core 218.

More in detail, treatment chamber 253 and the trigger means can cause a generation of H- ions 135 and their orbital capture by the cluster crystal structure, and subsequently by atoms 138 of clusters 121. The reaction between hydrogen 131 and cluster nanostructures 121 comprises, as well known from WO201 0058288, an orbital capture of hydrogen in the form of H- ions 135 by cluster nanostructures 121, a generation of protons ^1H associated with this capture and then a repulsion of a part of the protons 135', forming

protons expelled 135" by transition metal 119. Such reaction occurs with production of energy in the form of heat Q_1 ,

A means is also provided, not shown, for supporting and maintaining active core 118 in its position within treatment chamber 153.

5 A support 201 is also arranged in generation chamber 253 to receive a second material 224 containing the long half-life radioactive material to be treated, in such a way that second material 224 is arranged at a predetermined distance L by active core 218. Support 201 and active core 218 are configured for carrying out a relative movement 215 (Fig. 11), in which different surface
10 portions of support 201 are sequentially arranged in an exposed region 222 that faces active core 218. In a relatively advantageous embodiment, active core 218 is stationary with respect to generation chamber 253, while support 201 is movable and a movement actuation means 202 is provided such that support 202 is sequentially arranged with own different surface portions in exposed
15 region 222 that faces active core 218. As shown in Figs. 9-13, support 201 is a conveyor belt operated by actuation means 202 that comprises two cylinders, at least one of which is in turn operated by a motor, not shown, in such a way that cylinders 202 rotate at a rotation speed 203, displacing a tape support 201 according to a direction 215. This way, an amount of second material 224
20 arranged on tape 224 may be displaced between an inlet section 221 and an outlet section 223 of region 222 of the path of tape 201 facing active core 218.

The second material is preferably split into a plurality of portions 224, 224', 224" that are then fed to reactor 250, in order to cross exposed region 222 between inlet section 221 and outlet section 223.

25 Once the reaction in active core 228 has started, in this passage, high energy protons 135" coming from atoms 138 of transition metal 119 (Fig. 18) can reach the nuclei of the radioactive material of second material 224 and cause proton-dependent nuclear reactions in which the long half-life radioactive material is transformed into a treated material 225, which may comprise a
30 remarkably lower half-life radioactive material and/or a stable material.

In other words, the reaction between first material 119 and hydrogen 131 triggers transmutation reactions of the radioactive material of second material 124. In fact, the radioactive material of the second material can react engaging proton-dependent nuclear reactions with protons 135" that are expelled by

coulombic repulsion from the first material. In other words, it behaves as a secondary material in the sense according to PCT/IB2012/052100. This occurs, in particular, in the case of such materials as isotopes of Cs and Sr.

5 Treated material 225 is then removed from support 201 and extracted from treatment chamber 253, as shown, respectively, in Figs. 11 and 9. Advantageously, portions 224,224',224" have the thickness of a lamina, since the protons that activate the proton-dependent reactions cannot significantly penetrate the matter.

10 Reactor 250 advantageously comprises a feed chamber 206 for feeding portions 224,224',224" of the second material. Feed chamber 206 is configured for selectively communicating with external feed means of reactor 250, not shown, and with treatment chamber 253. To this purpose, an external stopping/opening means may be provided that comprises, for instance, a manlid 207 (Fig. 9), and a means may also be provided for segregating feed chamber 15 206 from treatment chamber 253 and, accordingly, from active core 218, for example a shutter 208.

Similarly, reactor 250 advantageously comprises, a treated material 225 extraction chamber that is configured to be selectively brought into communication with an accumulation or transfer means that is externally 20 arranged to reactor 250, not shown, and with treatment chamber 253. To this purpose, an external stopping/opening means may be provided that comprises, for instance a manlid 213 (Figs. 9,11), and a means may also be provided for segregating extraction chamber 212 from treatment chamber 253 and, accordingly, from active core 218, for example a shutter 214.

25 This way, the material to be treated / treated 224/225 may be fed/extracted into/away from reactor 250 maintaining the treatment chamber segregated with respect to the material to be treated / treated 224/225, in order to maintain the working conditions within treatment chamber 253 and of active core 253 unchanged, and to substantially prevent gases different from hydrogen 30 from entering into treatment chamber 253, and from contacting active core 218.

To this purpose, feeding chamber 206 and of extraction chamber 212 advantageously comprise, gas feeding/extraction passageways 230 configured to be selectively connected, in a conventional way, to a gas expulsion or suction means 232 for expelling/sucking the gas contained in transfer chambers

206,212, and to a hydrogen 131 feed means 231. As shown in Fig. 10, this is used for restoring hydrogen environment 131 in transfer chambers 206,212 after the operations of feeding/extracting. This way, if the step of segregating is discontinued hydrogen environment 131 and the operating pressure at active core 218 do not substantially change. In particular, the gas contained in the chambers 206,212 is removed by suction means such as vacuum pumps.

In Figs. 9 and 10, a plurality of portions 224 of the second material lays on the portion of tape 201 that is located in region 222, which faces active core 218, while a portion 224' lays on tape 221 in a temporary storage region of the treatment chamber. As shown in Fig. 11, by rotation 203 of cylinders 202 and by subsequent sliding of conveyor belt 201, portion 224' is displaced from the temporary storage region to exposed region 222 and travels beyond inlet section 221 of exposed region 222, while one of the portions of the second material is expelled as treated material 225 from exposed region 222 and discharged by gravity from tape support 201. Shutter 214 for separating treatment chamber 253 from expulsion chamber 212 is prearranged open, so that a passage section 214' is allowed between chambers 253 and 212, in order to receive the portion of treated material 225 within expulsion chamber 212.

As shown in Fig. 12, in which shutter 214 has been subsequently closed, whereas shutter 209 for separating treatment chamber 253 from feed chamber 206 is open so that a passage section 208' between chambers 253 and 206 is allowed, in order to allow the portion of material to be treated 224" enter into treatment chamber 253 and to arrange the same on tape support 201, in the temporary storage position previously occupied by portion 224'. To this purpose, a guided gravity transfer means 209 may be provided, or a mechanical handling means, not shown.

In another exemplary embodiment, support 201 may be segregated from active core 253 during the feeding/extraction of the material to be treat 224" or of the treated material 225 into/away from reactor 250.

The treatment chamber and the mutual arrangement of active core 218 and of second material 224 may differ from what is shown in Figs. 9-13, for instance, to take into account the amount of secondary material that can be treated contemporaneously, the storage capacity of the feeding chamber and/or of the extraction chamber and the frequency of the above described operations

of loading/unloading of support 201, as well as the state in which second material 224 is available. Furthermore, the movement 215 of support 201 may be carried out continuously instead of at the beginning / at the end of the treatment of each portion 224.

5 An alternative exemplary embodiment of reactor 250 is shown in Figs. 14 and 15, in which the portions of material to be treated have the shape of elongated sheets arranged along a cylindrical support 201 rotatable according to direction 215. An active core 218, that has the shape of a half-cylinder, is arranged to form an annular treatment region 222 between itself and cylindrical support 201. By the rotation 215, a portion of treated material 225 may be brought to outlet section 223 of exposed region 222, to be removed by gravity from cylindrical support 201, and transferred into extraction chamber 212, which is similar to the extraction chamber of Figs. 9-13.

10 As shown in Fig. 14, a lamina shaped portion 224" of material to be treated is arranged in treatment zone 222 at or near inlet section 221 by pushing means 211. A feed chamber, which is configured to be segregated from treatment chamber 253, which has an elongated shape and is advantageously equipped with a gas expulsion or suction means 232, not shown, may be also provided, similarly to the feed chamber of Figs. 9-13.

20 In other exemplary embodiments, not shown, support 201 for second material 224 is still a rotatable support with a screw conveyor surface. In further exemplary embodiments, second material 224 has is in a granular or in a powder state. In further exemplary embodiments, the outlet section and the inlet section of the treatment chamber are arranged on the same side with respect to the treatment region, which faces the active core, which provides, for example, a drawer-shaped structure of a treatment reactor.

25 Reactor 250 also comprises, advantageously, a means 254 for removing at least one part of the thermal power associated with reaction heat Q_1 from treatment chamber 253, for example in the form of an external jacket or of a plurality of ducts that are in contact with a portion of active core 218 that does not face displacement means 201, in which active core 218 has a considerable conductivity heat. The jacket or the ducts are arranged in such a way to receive a heat exchange fluid through an inlet port, not shown, and to release it through an outlet port, not shown, in order to maintain the temperature of active core

218 above critical temperature T_D . Device or reactor 250 may then provide or be used as a thermal energy generator, allowing to recover energy from the reaction of hydrogen with the first material.

Also in this case, the means 256 for setting and 254 for maintaining the temperature of active core 218 are made in such a way to cause a differential heat exchange with active core 218, so that the initial heating of active core 218 and then the step of maintaining the temperature T at a process temperature T_1 create and maintain a gradient of temperature, i.e. of a non-uniform temperature profile, between a first region and a second region of active core 118, for example a non-uniform profile between two opposite ends to elongated active core 218 of Fig. 9.

The process of atomic capture, proton generation and nuclear capture/expulsion in a transition metal is schematically described with reference to Figs. 16, 17 and 18. The description may refer both to the transition metal of the first material, both to a radioactive isotope of a transition metal of the second material.

By contacting clusters 121 of transition metal 119 with hydrogen 131, a population of molecules 133 of hydrogen H_2 is formed that are adsorbed on the surface 123 of the cluster structures. Due to the adsorption state and to the temperature, the bond between the atoms of the hydrogen molecules 133 is weakened, until the conditions are created for a homolytic or heterolytic scission of molecules 133, which yields, respectively, a couple of hydrogen atoms H 134 and a couple consisting of a negative hydrogen ion H^- 135 and of a positive hydrogen ion H^+ 136, from a hydrogen diatomic molecule H_2 133. More in particular, as already described in WO201 0058288, this process of bond weakening and of forming, in particular, H^- ions 135, is promoted by a step of heating clusters surface 123 from an initial process temperature, typically from room temperature, up to a temperature higher than critical temperature T_D . More in detail, near surface 123 of the crystals a dynamic equilibrium is established between molecular hydrogen H_2 133 and, in particular H^- and H^+ ions 135,136, and this equilibrium is more or less displaced towards ions H^+ and H^- according to the values of such parameters as hydrogen 131 temperature and pressure.

Clusters 121 and hydrogen 135 H⁻ ions form active core 118, in which hydrogen, in the form of H⁻ ions 135, is available for the orbital capture by the atoms of clusters 121 of transition metal 119 (Fig. 16) or, in other words, by a gigantic atom of the transition metal, which consists of all the atoms arranged in clusters.

Hydrogen may also give origin to an interstitial adsorption, at the grain boundaries and in the microfractures of the transition metal, however these adsorption modes are inessential for the purpose of the orbital capture of H⁻ ion 135.

After an impulsive action triggering step, the orbital capture step takes place of the process of atomic capture and proton generation and nuclear capture/expulsion. The impulsive action triggering step provides supplying an energy pulse, for example in one of the forms and with one of the procedures described in WO20 10058288. The energy pulse causes the orbital capture, in which an atom 138 of transition metal 119 of clusters 121 (Fig.9) captures an H⁻ ion 135, replacing an electron 143, as diagrammatically shown in Fig. 17 and in Fig. 18, detail (a,b). Since H⁻ ions 135 that are captured into the orbitals 137, 137', 137" (Fig. 10) of transition metal 119 have a mass that is three order of magnitude larger than the mass of an electron 143, the orbital capture goes on with a migration of the captured ion H⁻ to more deep layers, i.e. orbitals 137', 137", which occurs with an emission of Auger electrons 143' and of X-ray 144, as still diagrammatically shown in Fig. 17 and in Fig. 18, detail (c), i.e. the orbital capture goes on with a transformation of H⁻ ions 135 into protons ¹H 135', by loss of two electrons for each H⁻.

Since Bohr's radius of protons is comparable with the radius of the nucleus, protons ¹H 135' may be captured by the nucleus 138' of transition metal atom 138 and may undergo a step of nuclear capture and fusion reactions by with nuclei 138', as diagrammatically shown in Fig. 18, detail (d1), which causes a structural rearrangement by which forms a nucleus 142' is formed of an atom 142 of an element Me' different from transition metal Me, and causes a release of an energy Q₁ by mass defect, wherein the energy released appears in the form of heat, as diagrammatically shown in Fig. 18, detail (e1).

In particular, if transition metal Me is Nickel, comprising typically the isotopes ⁵⁸Ni(68.1%), ⁶⁰Ni(26.2%), ⁶¹Ni(1.14%), ⁶²Ni(3.64%), ⁶⁴Ni(0.93%), these

capture reactions, also called internal primary reactions of direct capture reactions may be written:



which are calculated by taking into account the conservation of the spin and of the parity, in addition to the Gamow coefficient.

- 10 All the reactions above indicated have the same probability factor [0] and occur preserving the spin and of the parity.

In alternatively to the orbital capture, as shows still Fig. 18, detail (d2), protons ${}^1\text{H}$ 135' may undergo a step of expulsion by coulombic repulsion from the nucleus of the transition metal, and may give rise to protons 135" expelled from respective atoms 138 in which the orbital capture has occurred. More in detail, if the H- ions are transformed into protons ${}^1\text{H}$ at a distance longer than the distance that allows the capture, which is of the order of 10^{-14} m, protons ${}^1\text{H}$ 135" are expelled due to the repulsion that arises between protons ${}^1\text{H}$ and nucleus 138' of transition metal, with an energy of 6.7 MeV, as it can be calculate, and as it is experimentally confirmed by cloud chamber measurements.

A part of protons 135" that are expelled by coulombic repulsion may engage with other nuclei 138 of the same cluster 121 in which they had been formed, or even with nuclei of other clusters 121 neighbouring the cluster from which they have been emitted. Therefore, if a radioactive material, for example Pu, U, Th, Ac, Cs, Sr, is present proximate to primary transition metal Me 119, a protons bombarding occurs on the radioactive material, and an energy irradiation occurs of 3.4 to 7.4 MeV, in average of about 4-5 MeV, which spreads over the contacting radioactive material.

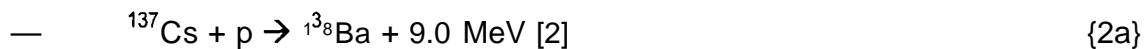
30 As described, radioactive materials such as Pu, U, Th, Ac, since they are transition metals, may behave in turn as primary materials, under stimulation of the energy delivered by the closely occurring primary reactions,, wherein a subsequent propagation of the process of atomic capture, proton generation

and nuclear capture/expulsion takes place from the first material to the second material.

In the case of ^{239}Pu , ^{238}U , ^{235}U , various transmutation reactions are also possible, which are induced by the orbital capture of the proton, as it can be established, for example, according to the method proposed in B. Pritychenko and A. Sonzogni, NNDC, Brookhaven National Laboratory, Atomic Mass data Centre (<http://www.nndc.bnl.gov/qcalc/>).

Another part of high energy protons $135''$, expelled from, i.e. emitted by atoms 138 of transition metal 119 may reach the nuclei of another radioactive material with which they can interact by can engaging secondary nuclear delayed, proton-dependent reactions, which occurs without the orbital capture intermediate step. A further energy release Q_2 is associated with these secondary reactions, which also gives a contribution to the overall energy generation $Q_1 + Q_2$ of the process.

For example, one of the radioactive materials that can behave as secondary material is Cesium 137, which can react as follows:



wherein a stable Barium isotope is produced in both cases. The number within square brackets is Gamow factor which indicates the probability of the reaction.

Another radioactive materials that behaves as a secondary material is Strontium 90, which can react as follows:



Wherein an isotope of Yttrium is produced that quickly decays into a short half-life Zirconium.

In Fig. 16 are diagrammatically shown atoms 140 distributed or dispersed in the structure of the transition metal. This way, it is intended diagrammatically show the case of a radioactive material Me'' , primary or secondary, which is in contact with the transition material 119 of the first material since form a solid solution or an alloy with transition metal 119.

In Fig. 18, detail (e2), an atom 128 of a radioactive material Me'' is diagrammatically shown, which is in contact with a transition metal Me or 119 of the first material, since it is engaged in a stratification or mutual penetration or side-arrangement with transition metal Me .

5 The foregoing description forms exemplary of the method according to the invention will so fully reveal the invention according to the conceptual point of view, so that others, by applying current knowledge, will be able to modify and/or adapt in various applications such forms exemplary specific without further research and without parting from the invention, and, accordingly, it is
10 therefore to be understood that such adaptations and modifications will have to be considered as equivalent to the specific embodiments. The means and the materials to realise the different functions described herein could have a different nature without, for this reason, departing from the field of the invention. It is meant that the expressions or the terminology used have object purely
15 descriptive and, for this, not limitative.

CLAIMS

1. A method for transforming long half-life radioactive materials (12,31,41), in particular fission products, into shorter half-life products or into stable products, said method comprising the steps of:

5 - prearranging a first material (11,32,119) comprising a transition metal;
- forming an active core (118,218) including said first material (11,32,119), said first material comprising a predetermined amount of cluster nanostructures, said cluster nanostructures (121) having a number of atoms (138) of said transition metal (119) lower than a predetermined
10 number of atoms;

- creating a hydrogen environment (131) in contact with said clusters (121) at a predetermined operating pressure;
- heating and maintaining said active core (118,218) at a process temperature (T_1) higher than a predetermined critical temperature
15 responsive to said first material (11,32,119);

- actuating an impulsive action on said active core (118,218), such that a reaction of said first material (11,32,119) and of said hydrogen (131) is triggered, said reaction comprising an orbital capture of H- ions (135) by said cluster nanostructures (121) of said first material
20 (11,32,119), a generation of protons ^1H associated with said capture and then a repulsion of a part of said protons (135') forming protons expelled (135'') from said first material (11,32,119);

characterised in that

- a step is provided of prearranging a second material (12,31)
25 comprising a long half-life radioactive material,
- wherein said second material (12,31) faces said first material (11,32) in such a way that said reaction of said first material (11,32,119) triggers transmutation reactions in the radioactive material of said second material (12,31).

30 2. A method according to claim 1, wherein said active core (118) includes said second material (12,31) arranged in contact with said first material.

3. A method according to claim 1, wherein the steps are provided of:
- prearranging a support member (201) for said second material (224);

wherein said support member (201) and said active core (218) are configured for carrying out a relative movement (215) in which different surface portions of said support member (201) are sequentially arranged in a region (222) facing said active core (218),

- 5
- arranging said amount of said second material (224) on said support member (201), at a predetermined distance (L) from said active core (218);
 - relatively moving (215) said movable support (201) and said active core (218), so that said amount of said second material (224) turns

10

 - from an initial treatment condition to a final treatment condition in said exposed region (222), and in a time between said initial treatment condition and said final treatment condition transmutation reactions in the radioactive material of said second material (224) take place caused by said reaction of said active core (218) and of

15

 - said hydrogen (231), wherein said long half-life radioactive material is transformed into a treated material (225);
 - removing said treated material (225) from said support member (201).
4. A method according to claim 3, wherein said active core (218) is stationary and said support member (201) is configured for sequentially arranging
- 20
- own different surface portions into said region (222) facing said active core (218), and said step of moving (215) is carried out in such a way that said amount of said second material passes through said exposed region (222) from an inlet section (221) to an outlet section (223) of said exposed region, and undergoes said transmutation reactions during this passage,
- 25
- turning into said treated material (225).
5. A method according to claim 1, wherein said step of heating and maintaining said active core (118,218) at a process temperature (T_1) higher than a predetermined critical temperature comprises a step of creating a gradient of temperature between a first region and a second region of said
- 30
- active core, wherein said gradient of temperature is selected responsive to said first material.

6. A method according to claim 1, wherein said first material (11,32,119) is selected from the group consisting of: Nickel, Chromium, Manganese and Iron.
- 5 7. A method according to claim 1, wherein the radioactive material of said second material (12,31,224) comprises an isotope selected among ¹³⁷Cs, ⁹⁰Sr and other radioactive isotopes that are commonly present in radioactive nuclear waste materials, in particular the radioactive material of said second material (12,31,224) comprises radioactive waste materials or residue materials of an apparatus based on nuclear fission reactions, 10 more in particular, residue materials of a nuclear fission power plant.
8. A method according to claim 1, wherein the radioactive material of said second material (12,31,224) comprises a further transition metal different from said transition metal of said first material, said further transition metal comprising cluster nanostructures (121), such that said reaction 15 comprising an orbital capture of H⁻ ions (135) takes place also in said cluster nanostructures (121) of said second material (12,31,224).
9. A method according to claim 1, wherein said second radioactive material (12,31,224) comprises a further transition metal selected among Pu, U, Th and the elements of the respective radioactive families.
- 20 10. A method according to claim 2, wherein said second material (12,31) comprises a material arranged to react, by way of proton-dependent nuclear reactions, with said protons expelled (135) from said first material (11,32).
- 25 11. A method according to claim 2, wherein a step is provided of arranging a selective barrier material in said active core (118) between said first material (11,32) and said second material (12,31), said selective barrier material arranged to prevent a migration of a gas different from hydrogen towards said first material (11,32), and to allow a passage of protons from said first material to said second material.
- 30 12. A method according to claim 2, wherein

- said step of prearranging said first/second material (11,32;12,31) provides a step of preparing a base member (10,20,30,40) of said first/second material;
 - said step of prearranging said second/first material provides a step of vaporizing said second/first material (12,32; 11,32), thus obtaining vapours of said second/first material;
 - said step of forming an active core (118) comprises a step of depositing said second/first material on said base member (10,20,30,40) of said first/second starting material from said vapour of said second/first material, such that an alloy or a solid solution or a stratification or a mutual diffusion of said first/second material and of said second/first material is formed.
13. A method according to claim 12, wherein said step of depositing is carried out with a technique selected from the group consisting of:
- sputtering;
 - spraying;
 - evaporation and then condensation of said predetermined amount of said second/first metal material on said support member;
 - epitaxial deposition.
14. A method according to claim 12, wherein said step of preparing a base member provides a step of pretreating said first/second material, in order to obtain a porous base member (22,42).
15. A method according to claim 12, wherein said step of pretreating comprises a step of sintering.
16. A method according to claim 12, wherein said step of preparing a base member comprises steps of:
- mixing said first/second material with a leachable material (24,44), obtaining a composite base member (20,40), in particular, by a step of sintering;
 - bringing said composite base member into contact with a leaching liquid which is adapted to bring said leachable material (24,44) into liquid phase, thus removing said leachable material from said

composite base member (20,40), i.e. a step of leaching said leachable material, in order to obtain a porous base member (22,42).

17. A method according to claim 16, wherein said leachable material (24,44) is Aluminium or Zinc.
- 5 18. A method according to claim 16, wherein said leaching liquid is an aqueous solution of an alkali such as NaOH or of an acid having a predetermined concentration, in order to bring into solution said leachable material (24,44) leaving substantially said first/second material (11,32; 12,31) in said base member (22,42).
- 10 19. A method according to claim 12, wherein said concentration is a 1N concentration.
20. A method according to claim 2, wherein said method comprises a step of:
- prearranging a support member (50),
- and:
- 15 - said steps of prearranging said first material and said second material comprise a step of vaporizing said first material and said second material, and
- said step of forming an active core comprises a step of co-depositing said first material and said second material on said support member
- 20 (54,64,74), starting from vapours (53,63,72) obtained in said step of vaporizing, with a deposition technique such that said transition metal of the first material, once deposited comprises cluster nanostructures (121) of said transition metal and such that an alloy or a solid solution of said first material and of said second material is formed.
- 25 21. A method according to claim 20, wherein a step is comprised of premixing vapours of said first material and vapours of said second material obtained by said step of vaporizing said first material and said second material, obtaining mixed vapours (53,63,72).
- 30 22. A method according to claim 20, wherein said technique of co-deposition provides steps selected from the group consisting of: sputtering; spraying; evaporation and then condensation on said support member of said predetermined amount of said metal; epitaxial deposition.

23. A method according to claim 20, wherein said support member is a porous support member.

24. A device (150,250) for transforming long half-life radioactive materials (12,31,41), in particular fission products, into shorter half-life products or
5 into stable products, said device comprising:

- an active core (118,218) including a predetermined amount of a first material (11,32,119), said first material comprising cluster nanostructures (121) having a number of atoms (138) of a transition metal lower than a maximum predetermined number of atoms;

10 - a treatment chamber (153,253) containing said active core (118,218) and configured to contain a hydrogen environment (131) in contact with said clusters (121), at a predetermined operating pressure;

- a heating (156,256) and temperature-maintaining (154,254) means for heating and maintaining said active core (118,218) in said treatment
15 chamber (153,253) at a process temperature (T) higher than a predetermined critical temperature responsive to said first material (11,32,119),

- a trigger means (161,162,167) for actuating an impulsive action on said active core (118,218),

20 said treatment chamber (153,253) and said trigger means (161,162,167) configured to cause a formation of H⁻ ions (135) and an orbital capture of said H⁻ ions (135) by said cluster nanostructures (121) of said first material (11,32,119), a generation of protons ¹H associated with said capture and then a repulsion of a part of said protons (135') forming protons expelled
25 (135'') from said first material (11,32,119);

characterised in that it also comprises a second material (12,31) comprising a long half-life radioactive material, wherein said second material (12,31) is arranged to face said first material (11,32) and to trigger transmutation reactions of the radioactive material of said second material
30 (12,31) by said reaction of said first material (11,32).

25. A device according to claim 24, wherein said active core (118) comprises said second material (12,31), which is arranged in contact with said first material.

26. A device according to claim 25, wherein said active core (118) comprises a base member (10,20,30,40) of said first/second material and a deposit of said second/first material on said base member (10,20,30,40) made starting from vapours of said second/first material, wherein said deposit is selected from the group consisting of: an alloy, a solid solution, a stratification, a mutual diffusion of said first/second material and of said second/first material, and a combination of the above deposits.
27. A device according to claim 25, comprising:
- a support member (201) for said second material (224), said support member (201) arranged to receive said amount of said second material at a predetermined distance from said active core (218); wherein said support member (201) and said active core (218) are configured to perform a relative movement by sequentially arranging different surface portions of said support member (201) in a region (222) facing said active core (218), wherein said support member (201) is arranged for receiving said amount of said second material (224) at a predetermined distance (L) from said active core (218);
 - a means (202) for carrying out a relative movement (215) of said support member (201) and of said active core (218), such that said amount of said second material (224) turns from an initial treatment condition to a final treatment condition in said exposed region, and between said initial treatment condition and said final treatment condition transmutation reactions of the radioactive material of said second material (224) take place caused by said reaction of said active core (218) forming a treated material (225);
 - a means (225) for removing said treated material from said support member (201).
28. A device according to claim 27, wherein said active core (218) is stationary and said support member (201) for said second material is movable and configured for sequentially arranging own different surface portions of said support member (201) in said region (222) facing said active core (218), and said means (202) for carrying but said movement (215) of said

- 41 -

movable support member (201) are configured to guide said amount of said second material (224) in said exposed region (222) between an inlet section (221) and an outlet section (223), so that said radioactive materials of said secondary material (224) that faces said active core (218) undergoes said transmutation reactions and is changed into said treated material (225).

Fig. 1

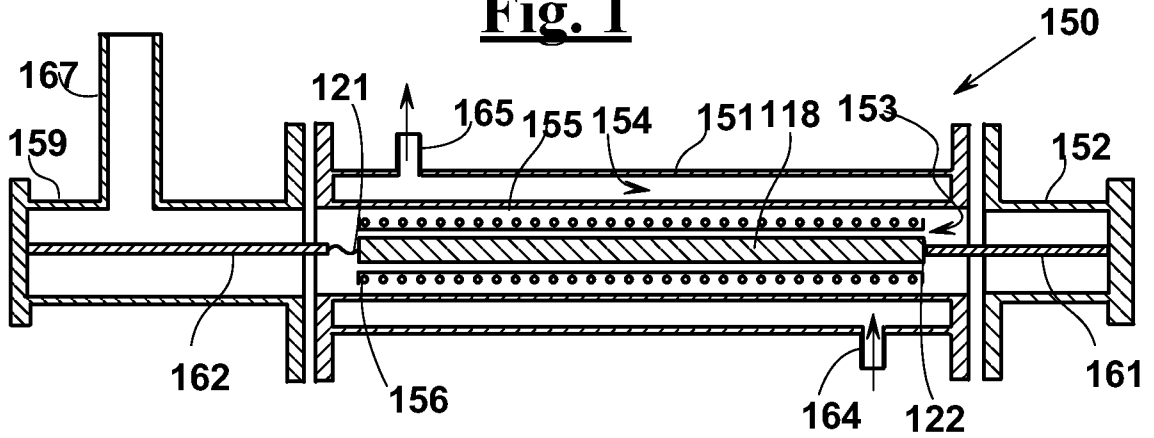


Fig. 2A

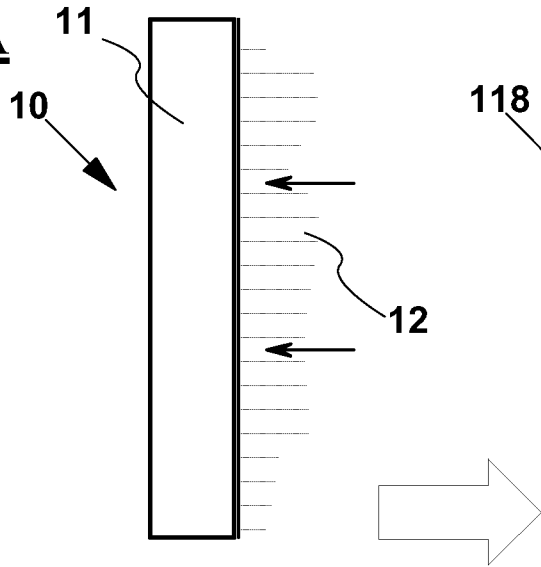


Fig. 2B

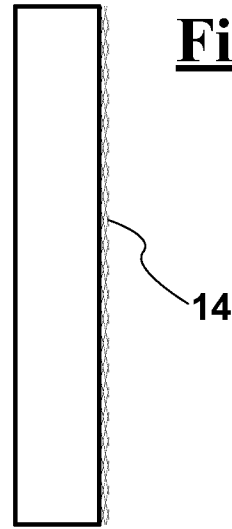


Fig. 3A

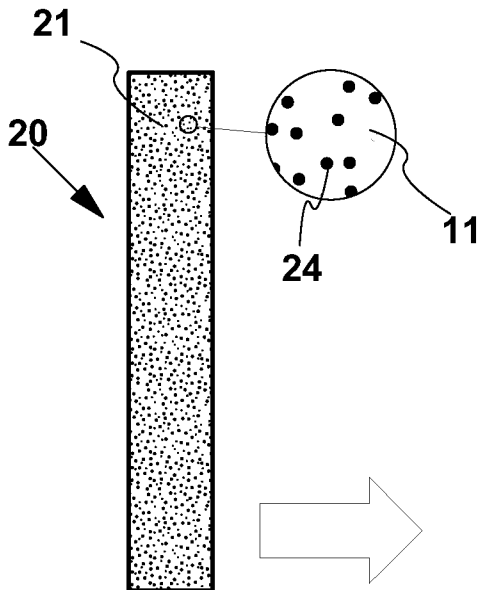


Fig. 3B

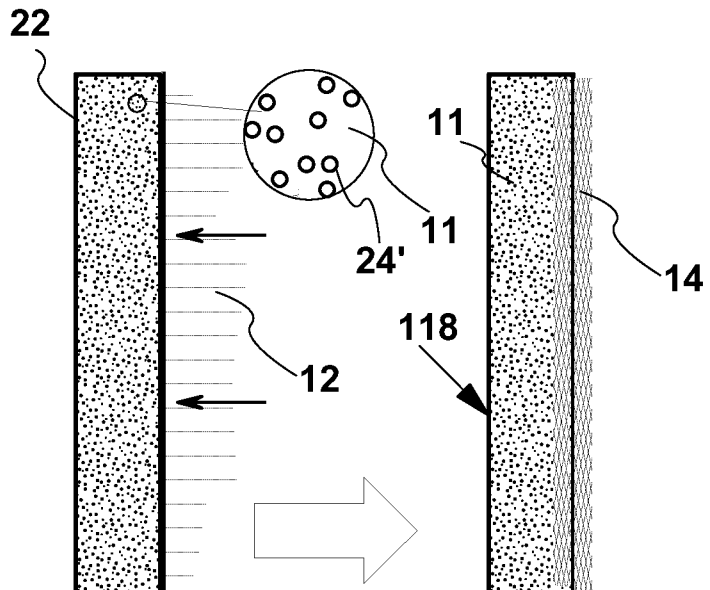


Fig. 3C

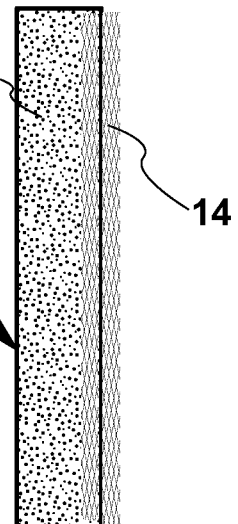


Fig. 4A

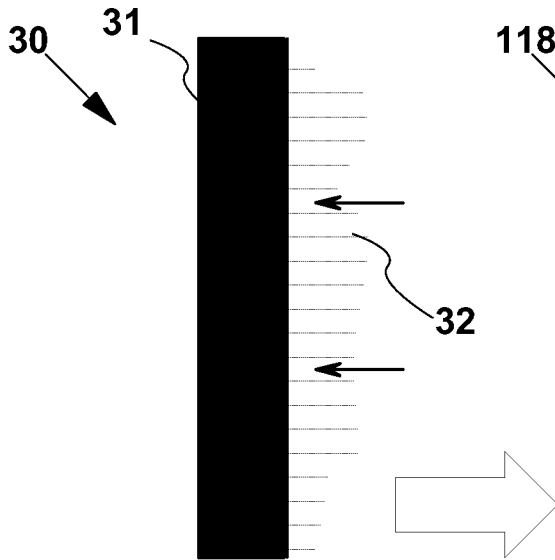


Fig. 4B

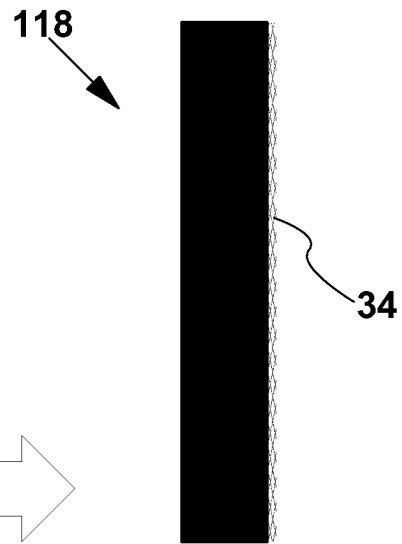


Fig. 5A

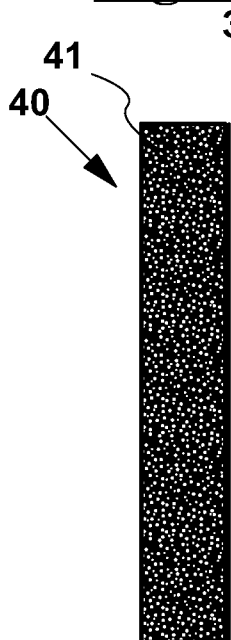


Fig. 5B

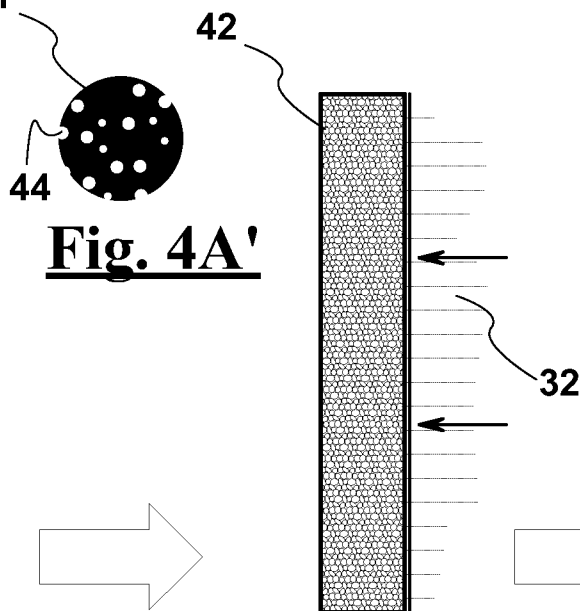


Fig. 5C

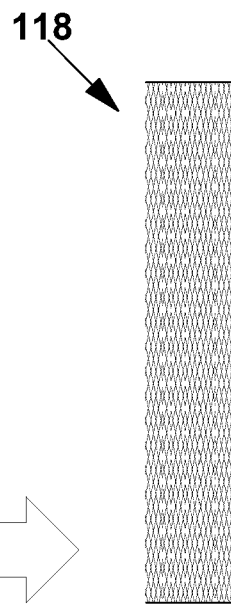
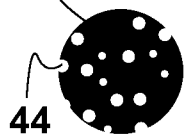
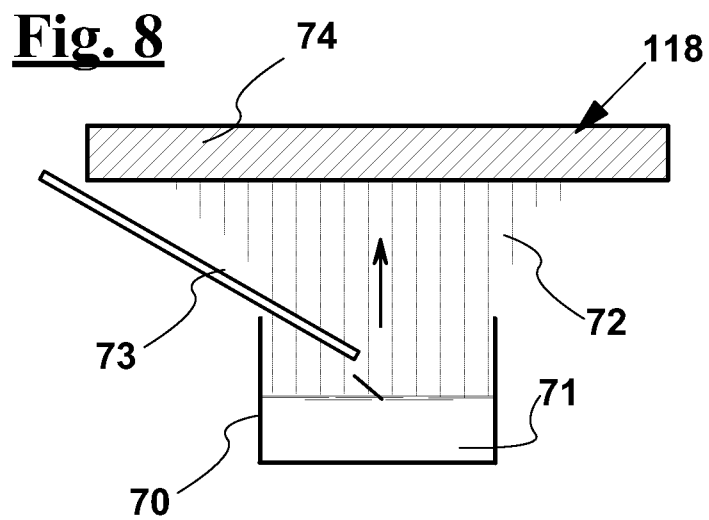
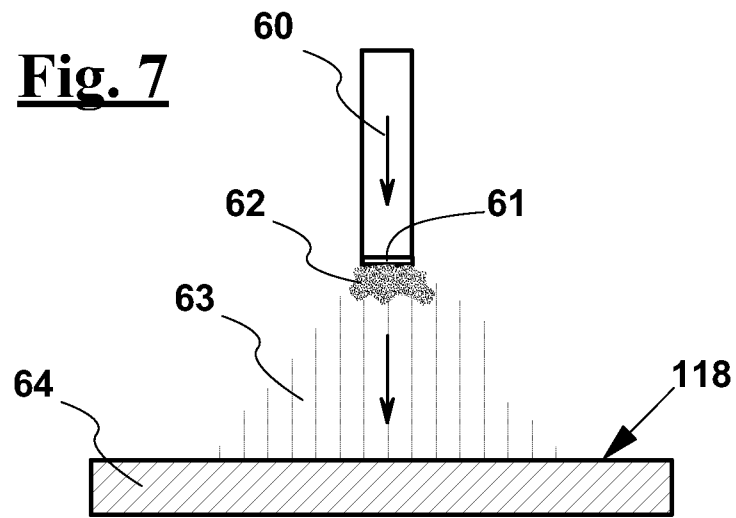
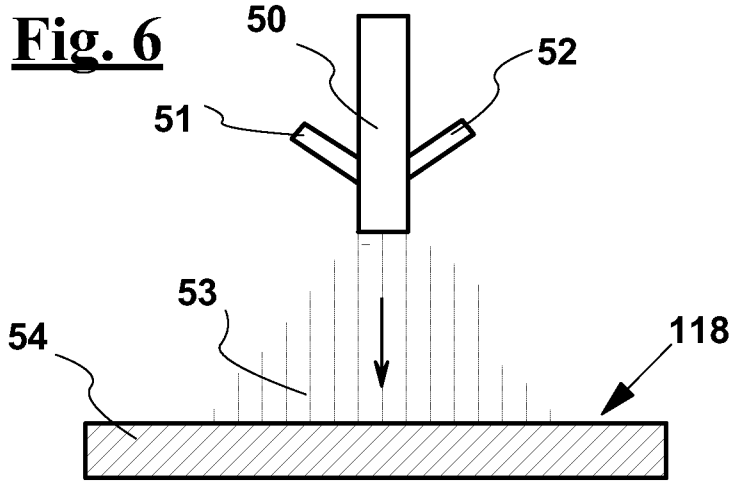


Fig. 4A'





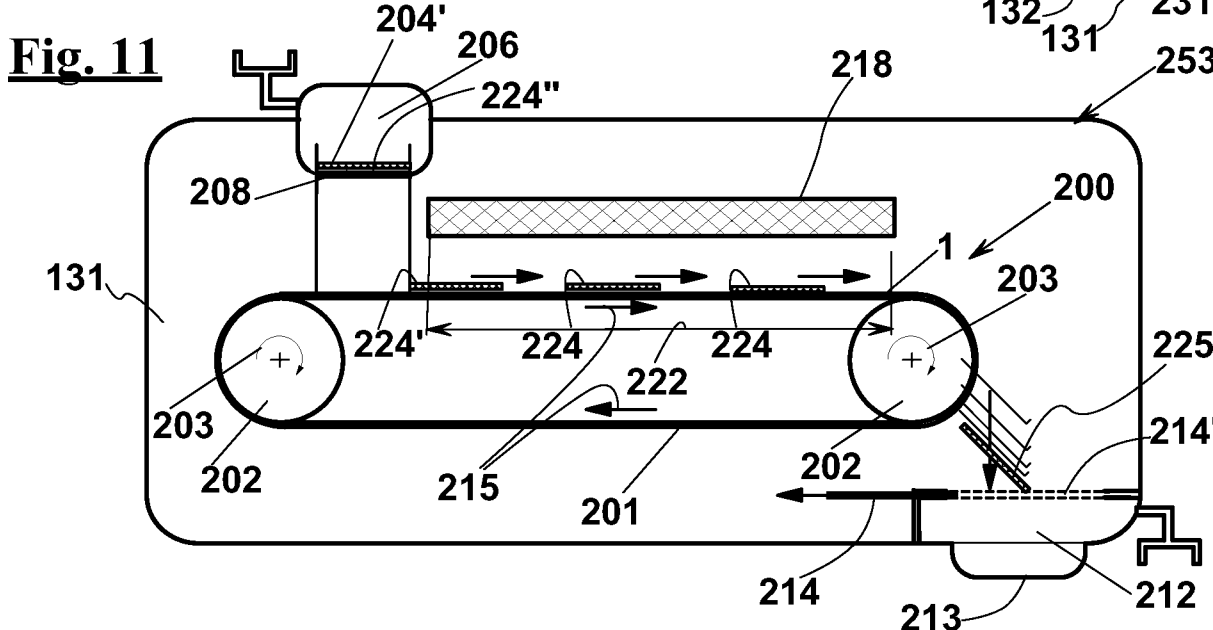
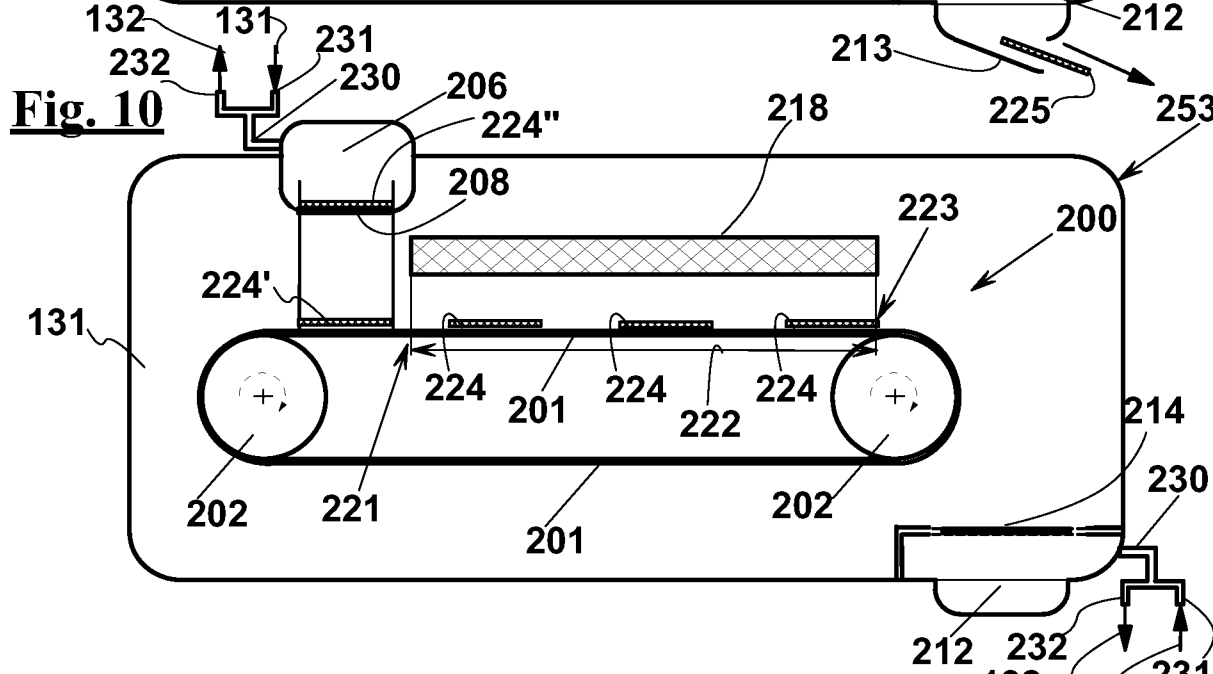
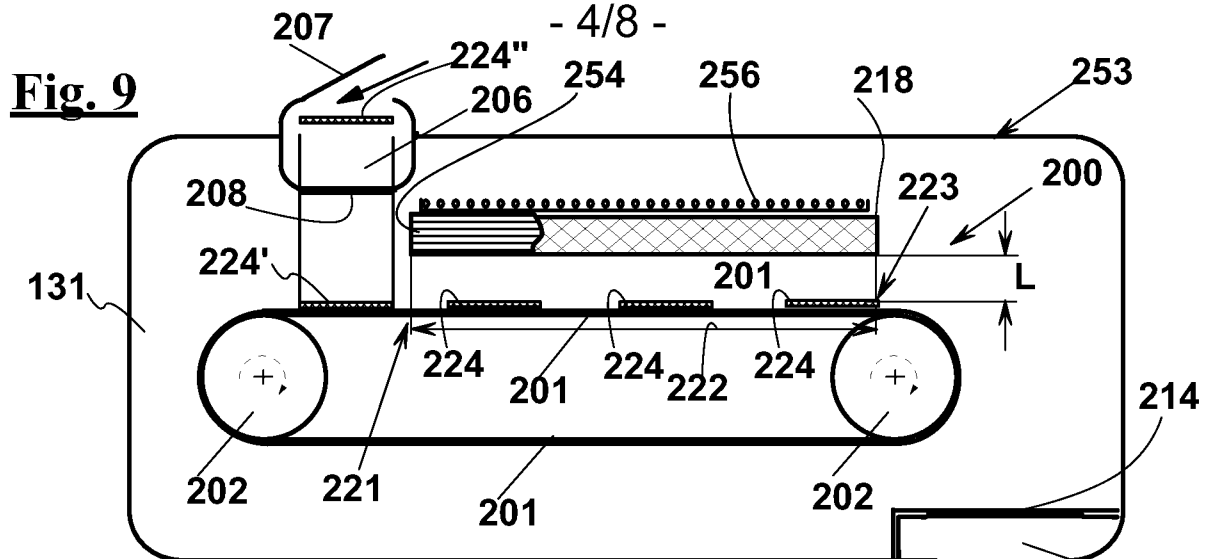


Fig. 12

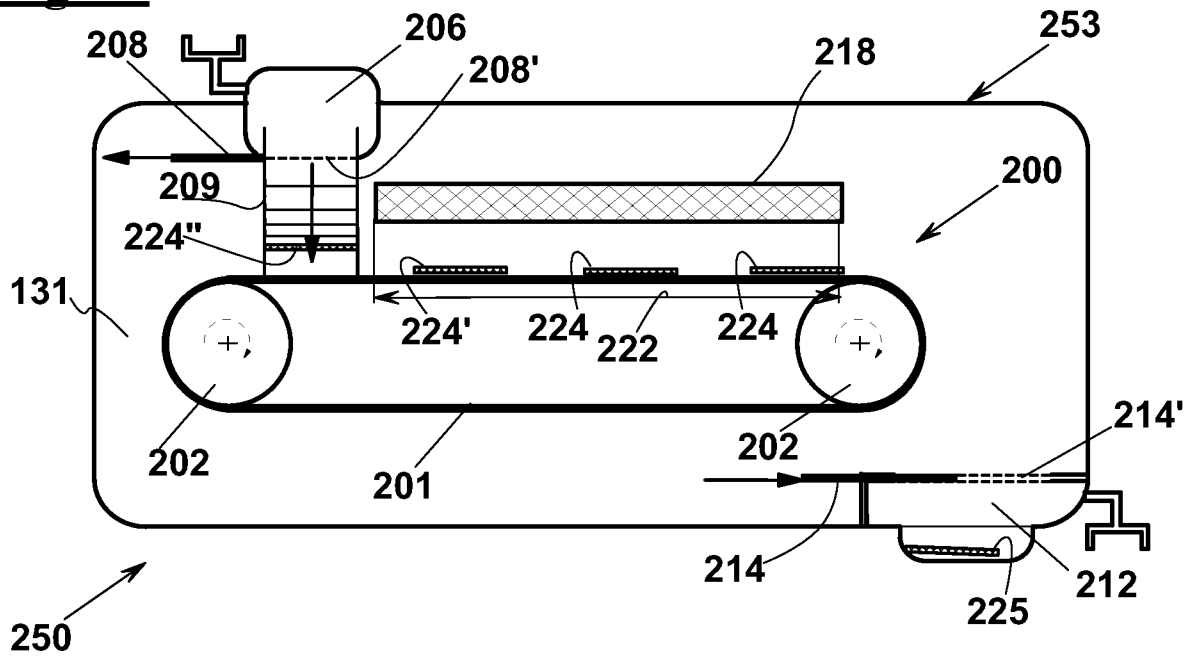
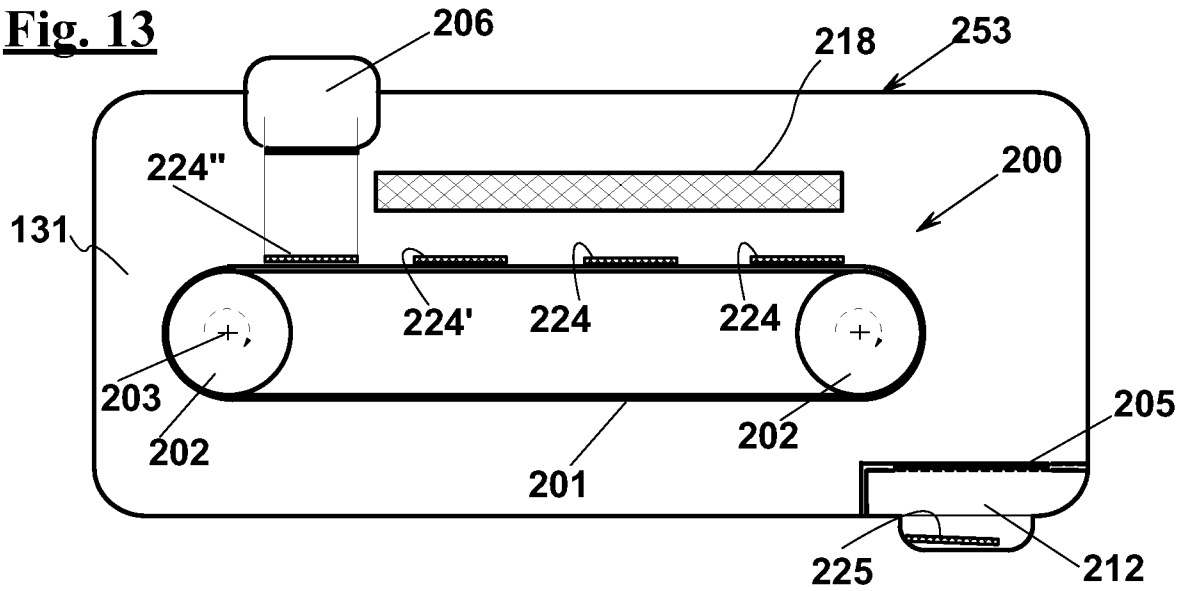


Fig. 13



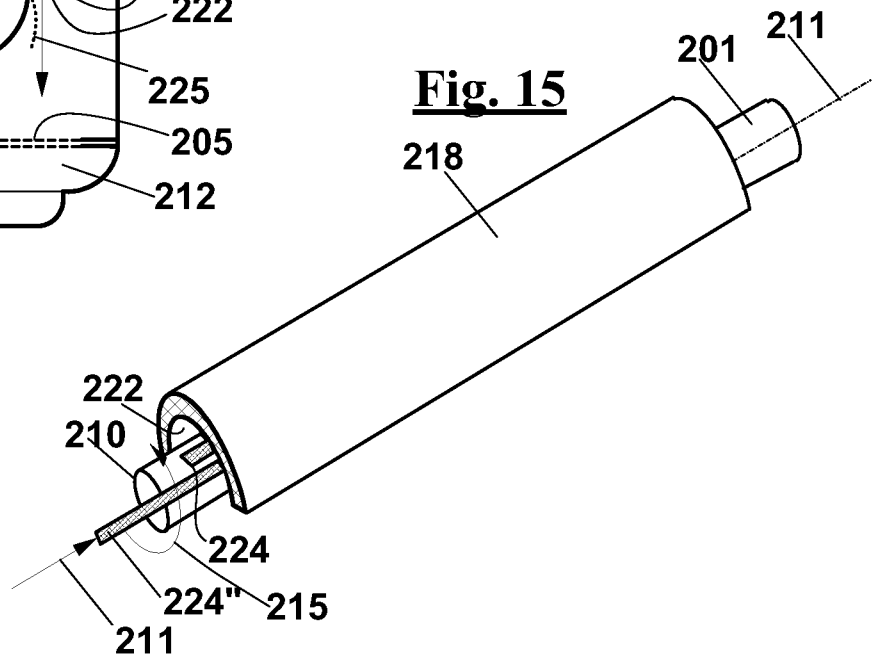
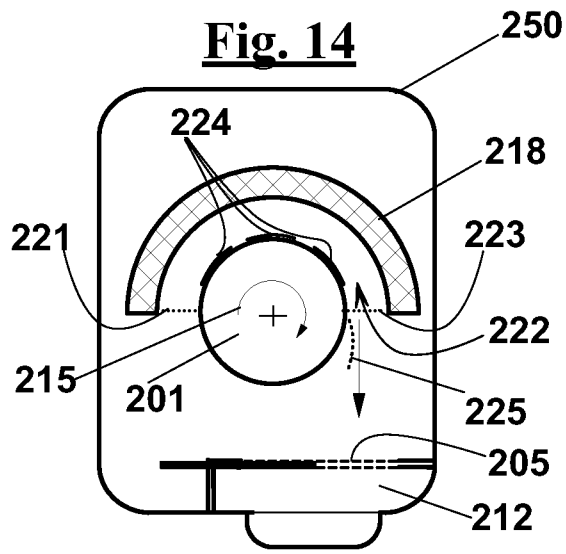


Fig. 16

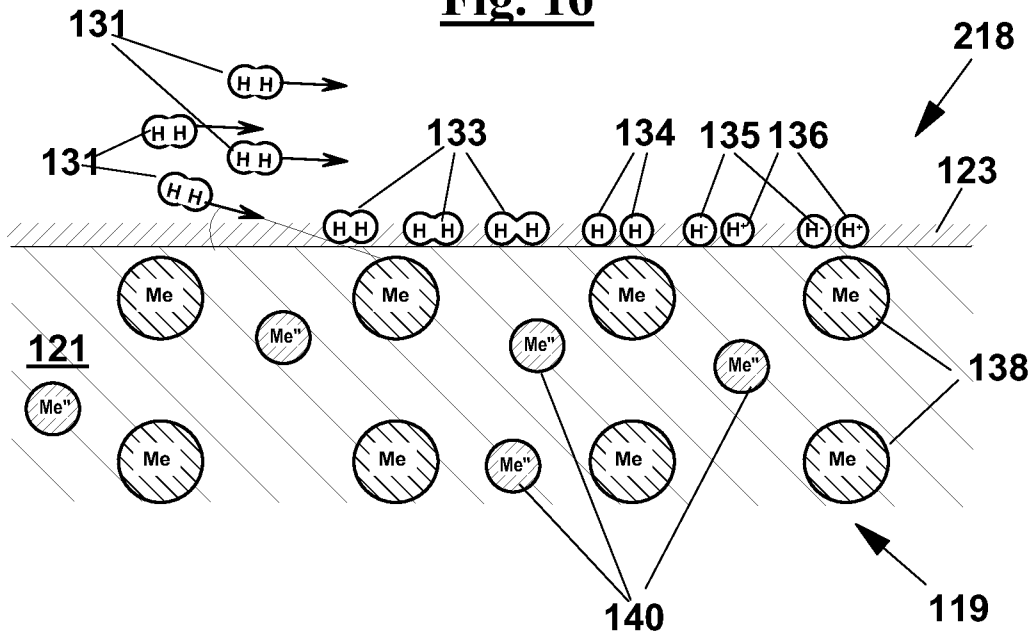


Fig. 17

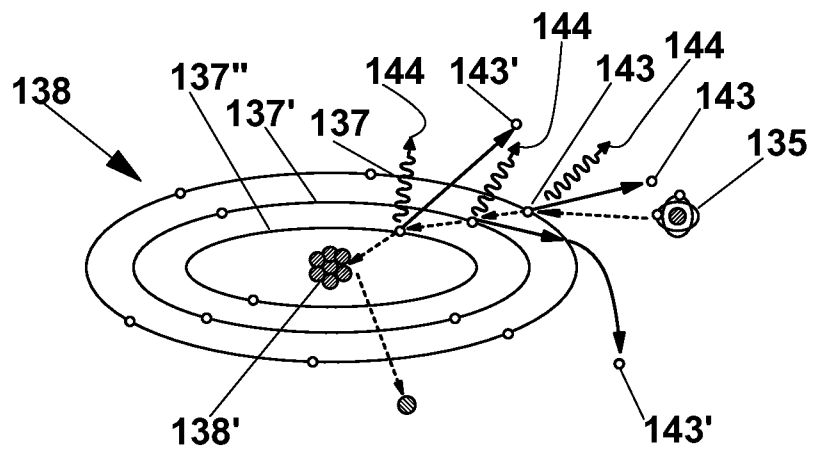
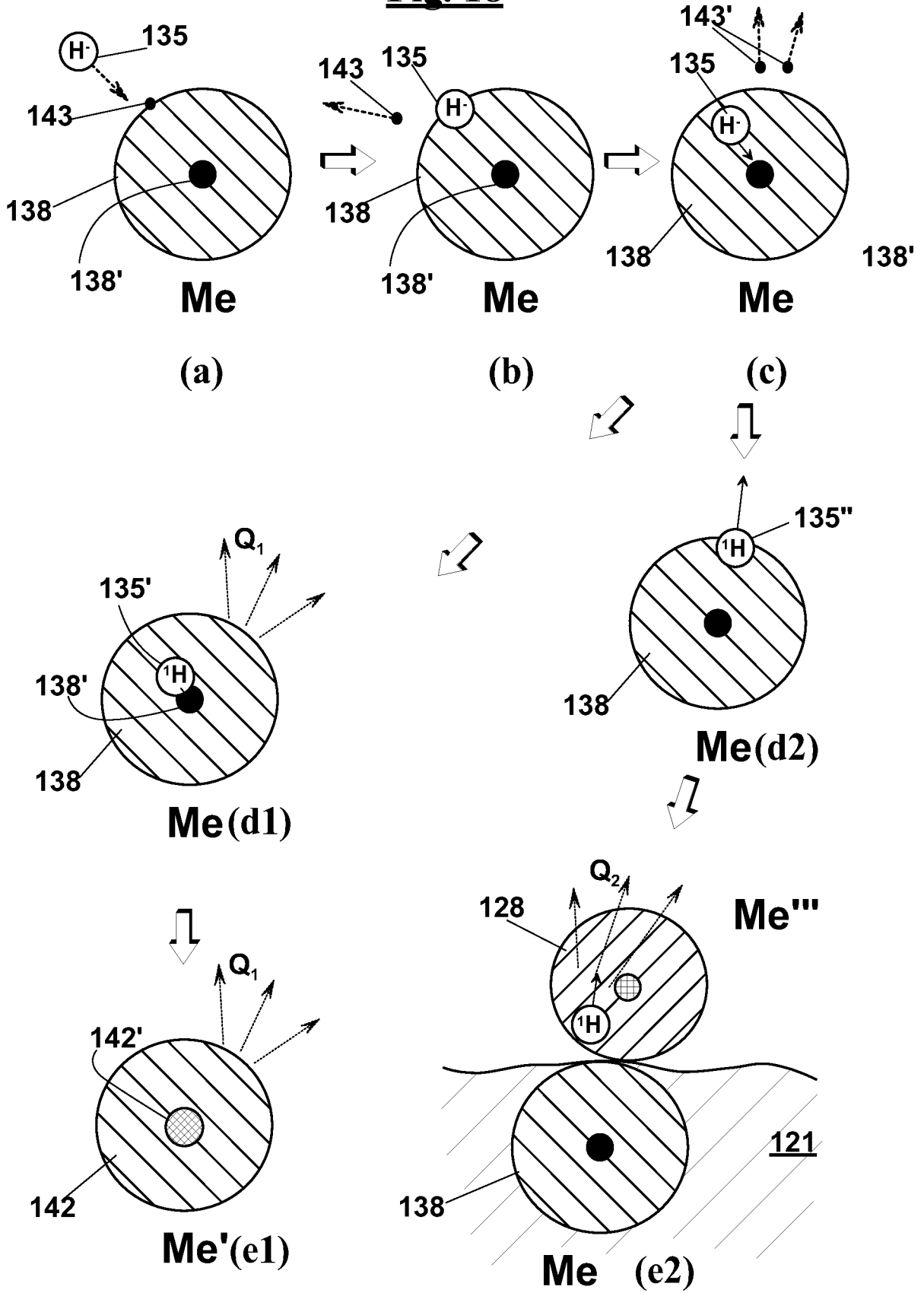


Fig. 18



INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2012/055246

A. CLASSIFICATION OF SUBJECT MATTER
INV. G21B3/00
ADD.
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED
Minimum documentation searched (classification system followed by classification symbols)
G21B H05H G21G

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal , WPI Data, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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Y	wo 2007/102860 A2 (SELDON TECHNOLOGIES LLC [US] ; LOAN JAMES F [US] ; COOPER WILLIAM K [US]) 13 September 2007 (2007-09-13)	1,5,6
A	paragraph [0002] paragraph [0006] paragraph [0029] paragraph [0057] - paragraph [0059] figure 5	10

Further documents are listed in the continuation of Box C.

See patent family annex.

* Special categories of cited documents :

- "A" document defining the general state of the art which is not considered to be of particular relevance
- "E" earlier application or patent but published on or after the international filing date
- "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- "O" document referring to an oral disclosure, use, exhibition or other means
- "P" document published prior to the international filing date but later than the priority date claimed

- "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
- "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
- "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
- "&" document member of the same patent family

Date of the actual completion of the international search 12 March 2013	Date of mailing of the international search report 19/03/2013
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Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Authorized officer Capostagno, Eros
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INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2012/055246

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
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A	the whole document	12, 13, 20,22

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Information on patent family members

International application No

PCT/IB2012/055246

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