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(71)
COMISION NACIONAL DE ENERGIA ATOMICA,
8250, Av. Del Libertador
1429, CAPITAL FEDERAL, XX (AR).

(72)
FLORIDO, PABLO CARLOS (AR).
DELMASTRO, DARIO FABIAN (AR).
BRASNAROF, DANIEL OSCAR (AR).
BERGALLO, JUAN ESTEBAN (AR).
CIRIMELLO, ROBERTO OMAR (AR).
JUANICO, LUIS EDUARDO (AR).
MARINO, ARMANDO CARLOS (AR).
GONZALEZ, JOSÉ HECTOR (AR).

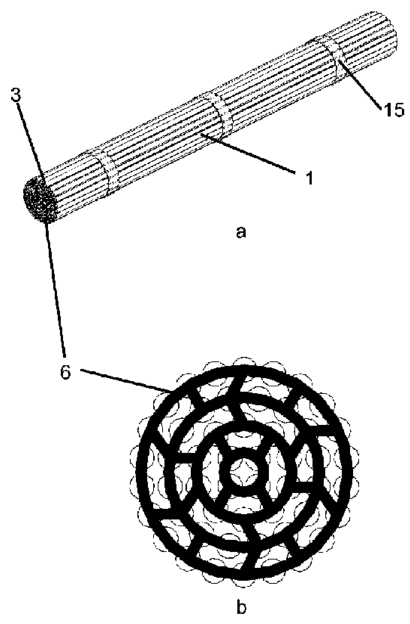
(74)
SWABEY OGILVY RENAULT

(54) ELEMENT COMBUSTIBLE MODULAIRE ADAPTABLE A DIFFERENTES CENTRALES NUCLEAIRES MUNIES DE CANAUX DE REFROIDISSEMENT

(54) MODULAR FUEL ELEMENT ADAPTABLE TO DIFFERENT NUCLEAR POWER PLANTS WITH COOLING CHANNELS

(57)

The present invention relates to a modular nuclear fuel element, which can be adapted by an assembly system allowing it to be used in different nuclear power plants with horizontal and vertical cooling channels. The module is a cluster of parallel fuel rods mounted as circular concentric crowns and supported by a structural system. It has a single diameter fuel rod array where the ratio of the heat transfer area to the transverse rod area is higher than 330. It also has self-supporting fuel element spacer grids, which are collapsible sheaths attached to them with fewer than 13 welded end stoppers, The number of these fuel rods is higher than 43. The length of the module is the largest compatible length with the refuelling machine, to reduce the hydraulic restrictions caused by structural endings, and to be able to balance this by providing a fuel element having a larger cooling area. This will maintain the hydraulic restriction and the current total fuel mass in the channel. The modular fuel element may contain fuel material combinations with different uranium and/or plutonium isotopic concentrations, and/or any other nuclear fuel material (actinides, nuclear poisons, fission products or fuel material coming from other nuclear reactors. The utilisation of the fuel modules individually in the pressurised heavy water reactors with horizontal fuel channels is an application of the present invention. Another application would involve the assembling of several fuel modules in nuclear reactors with vertical fuel channels.



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(72) FLORIDO, PABLO CARLOS, AR
(72) CIRIMELLO, ROBERTO OMAR, AR
(72) BERGALLO, JUAN ESTEBAN, AR
(72) MARINO, ARMANDO CARLOS, AR
(72) BRASNAROF, DANIEL OSCAR, AR
(72) DELMASTRO, DARIO FABIAN, AR
(72) GONZALEZ, JOSÉ HECTOR, AR
(72) JUANICO, LUIS EDUARDO, AR
(71) COMISION NACIONAL DE ENERGIA ATOMICA, AR

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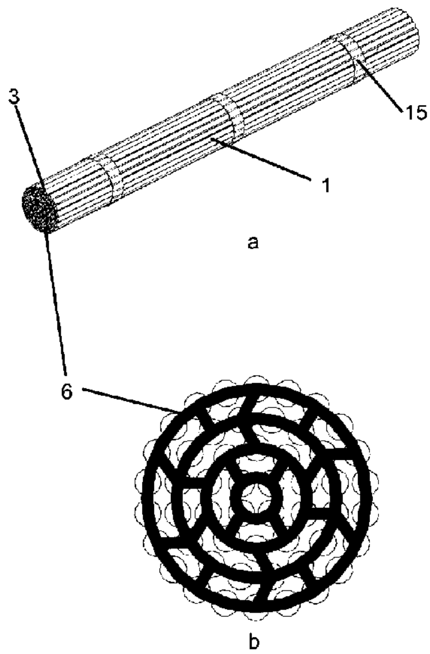
(54) **ELEMENT COMBUSTIBLE MODULAIRE ADAPTABLE A DIFFERENTES CENTRALES NUCLEAIRES MUNIES DE CANAUX DE REFROIDISSEMENT**

(54) **MODULAR FUEL ELEMENT ADAPTABLE TO DIFFERENT NUCLEAR POWER PLANTS WITH COOLING CHANNELS**



(57) The present invention relates to a modular nuclear fuel element, which can be adapted by an assembly system allowing it to be used in different nuclear power plants with horizontal and vertical cooling channels. The module is a cluster of parallel fuel rods mounted as circular concentric crowns and supported by a structural system. It has a single diameter fuel rod array where the ratio of the heat transfer area to the transverse rod area is higher than 330. It also has self-supporting fuel element spacer grids, which are collapsible sheaths attached to them with fewer than 13 welded end stoppers, The number of these fuel rods is higher than 43. The length of the module is the largest compatible length

ABSTRACT

The present invention relates to a modular nuclear fuel element, which can be adapted by an assembly system allowing it to be used in different nuclear power plants with horizontal and vertical cooling channels. The module is a cluster of parallel fuel rods mounted as circular concentric crowns and supported by a structural system. It has a single diameter fuel rod array where the ratio of the heat transfer area to the transverse rod area is higher than 330. It also has self-supporting fuel element spacer grids, which are collapsible sheaths attached to them with fewer than 13 welded end stoppers, The number of these fuel rods is higher than 43. The length of the module is the largest compatible length with the refuelling machine, to reduce the hydraulic restrictions caused by structural endings, and to be able to balance this by providing a fuel element having a larger cooling area. This will maintain the hydraulic restriction and the current total fuel mass in the channel.

The modular fuel element may contain fuel material combinations with different uranium and/or plutonium isotopic concentrations, and/or any other nuclear fuel material (actinides, nuclear poisons, fission products or fuel material coming from other nuclear reactors.

The utilisation of the fuel modules individually in the pressurised heavy water reactors with horizontal fuel channels is an application of the present invention. Another application would involve the assembling of several fuel modules in nuclear reactors with vertical fuel channels.

The present invention relates to a modular nuclear fuel element, which can be adapted by an assembly system allowing it to be used in different nuclear power plants with cooling channels. The module is a cluster of parallel fuel rods mounted as circular concentric rings and supported by a structural system. This assembly system in turn makes it possible to arrange a group of fuel elements having a length and a hydraulic pressure loss that can be adapted.

The possibility of using these modules individually in the pressurized heavy water reactors with horizontal fuel channels must be mentioned as the first application of this invention. In this case, the fuel elements are simply supported in the channels and placed one after the other in such a way so as to complete the required length. It is also possible to assemble several modules and to use them in the pressurized heavy water reactors with vertical fuel channels, as yet another application.

Although the Argentine nuclear power plants are of a similar (physical) conception with heavy water cooled fuel channels, they have two quite different designs particularly for the fuel elements. The designs of the fuel elements currently being used in the Embalse and Atucha I nuclear power plants belong to the Argentine National Atomic Energy Commission. These designs, which are included in this description, are the immediate antecedents and the state of the prior art of the fuel elements whose patent is applied for. The fuel used in both designs is natural uranium, therefore, the (replacement) burn-up and consequently the thermomechanic requirements were less than 8 000 Mwd/ Ton UO_2.

In Figures 1(a) and 1(b), respectively, the side and the three-dimensional views of a fuel element from the Embalse nuclear power plant (horizontal type) are shown. This element will be called fuel element 1 (FE 1). In Figures 2 (a) and 2(b) the main view and the cross-section of a fuel element in Atucha I nuclear power plant (vertical type) can also be seen. The second element will be called fuel element 2 (FE 2).

The FE 1 is a group of 37 cylindrical tubes or zircaloy sheaths (1) with thin walls so that will collapse onto the uranium dioxide pellets (2) during normal operation. Each sheath is sealed at both ends by a plug (3), thus forming a fuel rod. Also welded to these sheaths are rigid appendices to provide support on the fuel channel - so-called bearing pads- (4) and other pads – so-called spacers- (5) to avoid their relative transverse displacement. To hold the cluster of fuel rods in place a grid (6) is attached to each end of the array. These three elements are the structural system, which hold the module together.

In Figures 2 (a) and 2 (b) the FE2 is shown. This fuel element has 37 non-collapsible rods attached to a supporting plate (7) by the upper end, which is joined to a cluster of 6 tubes or lower rods (8) that are in turn attached to an intermediate ring (9). Three stainless steel rods (10) or upper rods are mounted on this ring, and they are joined to the coupling element (body) (11) which supports the whole array by its upper end. To fasten them to the fuel channel, rigid pads (12) and flexible pads (13) are provided. The cluster of fuel rods is held together by self-supporting spacer grids (14), which are built by adjacent concentric rings placed in intermediate longitudinal positions. These spacer grids fix the rods transversally and fasten the cluster of rods tightly, thus providing greater mechanical strength suitable to withstand the mechanical requirements due to the vertical position.

In both nuclear power plants, Atucha I and Embalse, the fuel channels are also different. The internal diameter of the fuel channel in the first nuclear power plant is greater than that in the second one. The fuel channels in Embalse are horizontal and the fuel elements are supported on the pressure reactor vessel by bearing pads, whereas the fuel channels in Atucha I are vertical and the fuel elements are suspended from the upper lid of the pressure reactor vessel.

Although both nuclear power plants use on-load refuelling, they differ in the number and length of the refuelled elements. In Embalse, out of a total of twelve fuel elements, which form the 6-meter-long channel, two fuel elements are refuelled at a time. This enables their axial exchange. On the contrary, this axial exchange (shuffling) is not possible in Atucha I, where the active portion is a single 5,25-meter-long fuel element.

The design of the fuel element is a fundamental step in the nuclear reactor layout and it is the result of a compromise mainly among neutron, thermohydraulic and thermomechanic phenomena. In short, the neutron performance will improve when the fuel mass is increased, since the neutrons generated in a fuel atom have a greater probability of producing fission in another one. On the contrary, to improve the thermohydraulic and thermomechanic performances it is advisable to reduce the fuel mass and to spread out the fuel elements (i.e. a far greater coolant transfer area and flow, and a smaller rod diameter). It should be pointed out that an opposite trend to these phenomena appears if the cluster of fuel elements is more spread out (smaller diameter) to increase the heat transfer area, while at the same time maintaining the fuel mass (more fuel rods). This causes a reduction in the coolant flow because there will be greater hydraulic restrictions and, consequently, a reduction in the thermohydraulic safety limits of the nuclear power plant.

A new fuel element devised to be used in the current nuclear power plants with channels should simultaneously enhance the three above-mentioned requirements. However, the fuel mass and the hydraulic loss in the channels must be maintained so that the distribution of the neutron flux and the coolant flow in the reactor core will not be disturbed. This enables the presence of several types of fuel elements in the core and their progressive exchange during the routine replacement without upsetting the operating time and the operation of the reactor.

In the first fuel element (FE1), the ratio of the heat transfer area to the rod transverse area approximately equals 300, whereas in the second fuel element

(FE2) is 313, and in the third one is 327. From this it can be inferred that with the previous designs it was impossible to achieve a higher ratio than 330.

The problem to solve with a single design of the high performance fuel element, which can be adapted to the different current nuclear power plants, is to simultaneously maintain the neutron and hydraulic compatibility, as well as the compatibility with the refuelling machine in every plant. However, the ratio of the heat transfer area to the rod transverse area will have to be improved to obtain a value higher than 330. At the same time, the thermohydraulic and thermomechanic safety limits will also have to be enhanced to obtain larger fuel burnups with enriched uranium.

Nowadays a new fuel element, which will be known as fuel element 3 (FE3), has been proposed to be used in nuclear reactor with horizontal channels. Two different fuel rod diameters have been employed, while maintaining the same length of the first fuel element (FE1), to be able to fulfil the above-mentioned requirements. This design enlarges a 5.4 per cent the fuel and coolant exchange area as compared to the FE1, but maintains the hydraulic restriction in the channel. Nevertheless, the fuel mass will be more reduced than that in the FE1; consequently, the previous problems will not be totally solved. While maintaining the spacers welded to the sheaths, the FE3 has more collapsible fuel rods and therefore, more welds on the sheaths, which reduces the mechanical strength. On the other hand, the constituents of this fuel element are more varied, as they will require two different kinds of sheaths, pellets, fuel elements and plugs, among other elements.

With the fuel element and the assembly system of the invention herein described these obstacles are eliminated, and substantial improvements are also made in the neutron, thermohydraulic and thermomechanic performances when compared to the previous fuel elements (FE1, FE2 and FE3). The coolant area is enlarged, while the fuel rod diameter is reduced, and at the same time it is possible to maintain the mass of the fuel element which is denser (FE1). In this case the fuel mass equals that of the first fuel element; and it is 21% and 1% higher than that of the second and third fuel elements respectively. As regards the contact area with the coolant, it is 20%, 18% and 12% higher than that in FE1, FE2 and FE3 respectively. These (values) are reached, however, maintaining both reactors in operation.

The thermomechanic requirements of the fuel element, whose patent is applied for, are reduced because of a smaller pellet diameter and a larger quantity of fuel rods and, consequently a lower operating temperature. Besides, by using self-supporting spacer grids instead of the appendices welded to the sheaths it is possible to avoid degradation of the fuel rods mechanical properties caused by the welds. Thus, the number of welds on the sheaths is reduced twenty times when compared with the first fuel element and that is one of the factors enabling to increase the fuel burnup of the array. Moreover, with the innovative incorporation of the self-supporting spacer grids on collapsible rods it is possible to fasten the whole array. From the mechanical point of view this is very convenient, since it can be included in the vertical channels suspended by one end, as is the case with the FE2.

This characteristic is used in the fuel element assembly system of this invention to provide longer fuel modules and an adaptable hydraulic pressure loss by regulating the azimuthal disalignment angle among modules. Thus, the group of fuel elements can conveniently be used in nuclear reactors with vertical channels and a more restricted pressure loss, as is the case in Atucha I.

The principal purpose of this invention is to obtain a modular fuel element having a ratio of the heat transfer area to the rod transverse area higher than 330 and roughly equal to 364.

The second purpose of the invention is to obtain a modular fuel element, which, when compared to the current designs, will increase the thermohydraulic and thermomechanic safety limits and the fuel burnup. At the same time it will maintain the fuel mass and the total hydraulic restrictions in the channel, especially in those nuclear plants with horizontal channels, providing a collapsible single diameter fuel rod array.

The third purpose of the invention (again having the current designs as a reference) is to reduce the number of welds not only in the fuel sheaths, but also in every structural component, thus simplifying the manufacturing process.

A further purpose of this invention is to adapt the fuel element to nuclear power plants with longer vertical fuel channels and lower hydraulic restrictions. It will be attached to a single end by an assembly system of modular fuel elements enabling them to be reused and improving the fuel burnup.

To accomplish all these purposes, some very innovative improvements were utilised. Among them it can be mentioned the reduction of the structural endings between adjacent elements to maximise (and thus to double) the length of the fuel modules so as to obtain the compatibility with the refuelling machine in every nuclear power plant with channels. In this way it is possible to reduce the hydraulic pressure loss in the structural element of the channel. This improvement enables the construction of a new rod array having the same fuel mass and a more spread out layout (more rods of smaller diameter). That in turn balances the pressure loss increase along the rods (due to a larger heat exchange area) causing a reduction in structural elements. Therefore, by maintaining the coolant flow and increasing its transfer area it is possible to reduce the heat flux per unit area (superficial heat flux) and enhance the thermohydraulic safety limits. Moreover, if there are more fuel rods of smaller diameter, the linear power density and the temperature difference within the fuel pellet decrease. Consequently the thermomechanic performance is improved (it reduces thermal expansion, fission gas release, and the mechanical interaction/reaction between the fuel pellets and the sheath) and the fuel burnup can be notably prolonged. Furthermore, the innovative inclusion of the self-supporting spacer grids with collapsible rods (rods with a 3.2% lower thickness/diameter ratio) during operation greatly reduced the number of welds in the sheath (improving thermomechanic safety limits) and favours the fuel element utilisation in the vertical channels. The number and mass of the structural components is also reduced when the length of the fuel rod for horizontal channels is twice the current. For example the number of plugs welded per unit length to the end plates is reduced 30%, the number of end plates 50%, and so on, when compared with the previous designs. Both these last characteristics simplify the manufacturing process, as there will be fewer steps involved in the fuel rods making.

It can be concluded, therefore, that the degree of dispersion of a fuel element, if the fuel mass and hydraulic restrictions are maintained, is the defining parameter of the design that has been attained. To this it may be added that in the case of the ratio of the heat transfer area between the fuel and the coolant to the transverse area of the rod array, both areas are defined per unit length in the channel. Indeed, in those fuel elements maintaining the fuel mass encapsulated, it is advisable to maximise the heat transfer area and to minimise the transverse area of the fuel array (by using collapsible thin sheaths and by enlarging the active portion when the number of structural endings is diminished), since the heat flux will be reduced and the coolant area will be enlarged. Accordingly, it will be extremely advantageous to obtain a fuel element design having higher values for this area relationship, as long as they maintain the hydraulic loss in the channel. The ratio of the heat transfer area to the transverse area of the newly invented fuel element is higher than 330 and roughly equal to 364. When these values are compared with those for the FE1, FE2 and FE3, which were 300, 313 and 327, respectively, it can be concluded that with the previous designs it was impossible to obtain a higher ratio than 330 for this area relationship.

In the case of the nuclear power plants with vertical channels, if an assembly system with several modules is used, it will enable the attainment of a longer fuel element supported on a single end. Besides, with the devised assembly system, it is also possible to fix the azimuthal disalignment angle among adjacent modules and to adapt the fuel to coolant channels with different hydraulic pressure loss. If the modules are completely aligned, the hydraulic pressure loss in the channels will be reduced to the values obtained in Atucha I.

As a result of all this, when compared with the previous designs, the fuel element and the assembly system described herein have the following advantages:

- the thermomechanic and thermohydraulic safety limits can be increased;
- it is possible to extend the fuel burnup up to 35 000 Mwd/TonUO_2;
- the pressure loss can be adapted to different channel reactors;
- the density of the currently most dense fuel element can be maintained (FE1);
- there is compatibility with the refuelling machine of the vertical and horizontal channel reactors;
- the number of structural components as well as the manufacturing process is reduced by using a single diameter fuel element and less welds on the sheaths.

With this invention a single diameter fuel rod array satisfying every consideration formerly mentioned and which has not been improved by the previous designs, is devised. The module is a cluster of 52 parallel fuel rods (this is only one of the many different possible arrays) mounted as four compact concentric rings. It is attached by a structural system to a couple of grids placed at both ends and to self-supporting spacer grids having rigid and flexible spacers located in intermediate axial positions. Flexible and rigid pads welded to the spacers or to the assembly system are also provided to fix the position of the fuel element to the channel.

A detailed description is provided together with the included drawings to illustrate better this invention.

In Figures 3 (a) and (b) the three-dimensional and side views, respectively of the invention scheme can be seen. The fuel elements are a group of zircaloy collapsible sheaths (1) whose ends are sealed by plugs (3) welded to an end plate (6). The total length of this fuel element is exactly the same as two FE1 or FE3 added together. Self-supporting spacer grids (15) of low hydraulic pressure loss have been attached to separate the fuel rods.

In Figures 4 (a), (b) and (c) the side view as well as the main view of one spacer grid are shown. The spacer grids consist of supporting structures (16) to which rigid (17) and flexible (18) spacers that hold the sheath in place are attached. In the nuclear power plants with horizontal channels, the channels rest on several pads (19) which have been welded to the outer supporting structures, whereas the axial position of each spacer has been secured by a weld of less than 13 stoppers on the rods.

The active portion of the FE2 (the portion containing the fuel pellets) is longer than that of the invented fuel module. It also differs with the Embalse nuclear power plant, because it has vertical channels. In Atucha I to assemble the fuel element, five-fuel modules like the one being described were axially coupled, before its inclusion inside the core.

There are several possible methods to assemble these five fuel modules.

The modules can be fastened with outer straps (20)), as shown in Figure 5. In this case the total length is obtained by adding the five fuel elements together and attaching them to a low hydraulic loss stopper (21) by its lower end. In the other end there is an intermediate coupling system (22) containing a spring, which binds the module together. There is also a coupling element (body), which is similar to that in the current FE2 design; to ensure its adaptability with the intermediate body, which is also incorporated in the upper part of the channel. The section of the intermediate coupling is characterised by having low hydraulic pressure loss. Mixing fins can also be added to the outer straps. This type of assembly would enable the axial relocation of the fuel elements which are not totally burned in a pool outside the core. Rigid or flexible spacers (23) can be attached to the straps or to the spacer grids of the channels in Atucha I. In Figure 5 a fuel module like the one being outlined is shown. It depicts the outer straps, the stopper at the lower end, and the intermediate coupling system and the coupling body.

Another method to fasten the fuel modules is by placing a low hydraulic pressure loss fitting piece or body between the end plate grids or around them. In Figure 6, one end of the fuel element and a fitting body located between the grids (24) are shown. In this case, the sheaths of the fuel elements would be the supporting elements of the whole assembly, since they are welded to the grids. A fitting body is attached to one end of the assembly, between the grid and an intermediate low hydraulic pressure loss coupling having the fitting body at the other end, as in the FE2.

An outer supporting tube with windows or openings (25) would be a third alternative to bind the fuel elements (see Figure 7). It has been design to support all the fuel elements together and it enables the coolant to circulate lightly through the fuel elements and the channel. At the same time, it would be able to reduce the mean coolant flow rate and, consequently, to balance the pressure losses. These windows or openings would provide a physical space big enough to place fixed and flexible pads, in the improbable event that the gap between the tube and the channel would be insufficient for these bodies. A stopper and an intermediate coupling mechanism with a fitting system and a coupling body are attached to both ends of the tube, in a fashion similar to that described for the outer straps.

A further alternative would be to use one or several inner rods, which by benefiting from the sections of least generated power, or by changing one or more fuel rods would provide further rigidity to the whole assembly. In this case, the best option would be to place the module in the centre of the assembly, which is the portion with least linear power density and, therefore its cooling ability is not overloaded. Such fuel rods have a stopper attached to one end, and in the other end a low hydraulic pressure loss fitting mechanism is provided holding the assembly together. A coupling body is mounted to this mechanism, as the one in the current FE2 design.

Fourteen claims are detailed on page 13.

CLAIMS

The nature and the purpose of the present invention having been described and determined as well as the methods to put it into practice, I herewith claim as an invention of my exclusive property:

1. A modular fuel element adaptable to different nuclear power plants with cooling channels comprising a cluster of parallel fuel rods mounted as circular concentric crowns and supported by structural systems, which can be used in said nuclear power plants with horizontal channels. It comprises a cylindrical bar or fuel rod array placed so that the ratio of the heat transfer area to the fuel rod transverse area (both defined per unit length) is higher that 330. These cylindrical fuel rods have a single diameter.

2. A modular fuel element as claimed in claim **1**, wherein said ratio of the heat transfer area to the rod transverse area is higher than 360.

3. A nuclear modular fuel element as claimed in claim **1** or **2**, wherein the length of the fuel element is the largest compatible length with the refuelling machine.

4. A modular fuel element as claimed in claim **3**, wherein said length of the fuel element is higher than o.5 metre, and smaller or equal to approximately 1.0 metre.

5. A modular fuel element as claimed in claim **1, 2, 3,** or **4**, further comprising self-supporting fuel element spacer grids. These are collapsible sheaths attached to them by fewer than 20 welded end stoppers, whereas the intermediate longitudinal positions are not welded to the sheaths.

6. A modular fuel element as claimed in claim **1, 2, 3, 4,** or **5** wherein said number of welded end stoppers is smaller than 13.

7. A modular fuel element adaptable to different nuclear power plants with channels as claimed in claim **1, 2, 3, 4, 5**, or **6** claims, wherein said number of the fuel rods is higher than 43, and its single diameter is smaller than 11 mm.

8. A modular fuel element as claimed in claim **7**, further comprising 52 parallel fuel rods, which are arranged in four concentric rings, said arrangement comprising three self-supporting spacer grids with rigid and flexible fuel rod pads fixing their relative position.

9. A modular fuel element as claimed in claim **1, 2, 3, 4, 5**, **6**, **7**, or **8** wherein bearing pads are welded to said self-supporting spacer grids therein providing a supporting place on the fuel channels, when used in horizontal channel nuclear power plants.

10. A modular fuel element as claimed in claim **1 2, 3, 4, 5**, or **6**, wherein said modular fuel element can be adapted to nuclear power plants with heavy water vertical channels. Further comprising a dismountable coupling between modules adaptable to the total length of said fuel elements.

11. A modular fuel element as claimed in claim **10**, wherein said coupling system provides a fitting media between the end plates, further enabling several fuel elements to be bound together to form a longer fuel element.

12. A modular fuel element as claimed in claim **10**, wherein said coupling system is an outer body, forming a longer fuel element by attaching several said fuel modules

13. A modular fuel element as claimed in claim **10**, wherein said coupling system has an inner-fitting element, adaptable to another said fuel module, therein forming a longer fuel element.

14. A modular fuel element as claimed in claim **1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12,** or **13**, containing fuel material combinations with different uranium and/or plutonium isotopic concentrations, and/or any other nuclear fuel material (actinides, nuclear poisons, fission products or fuel material coming from other nuclear reactors).

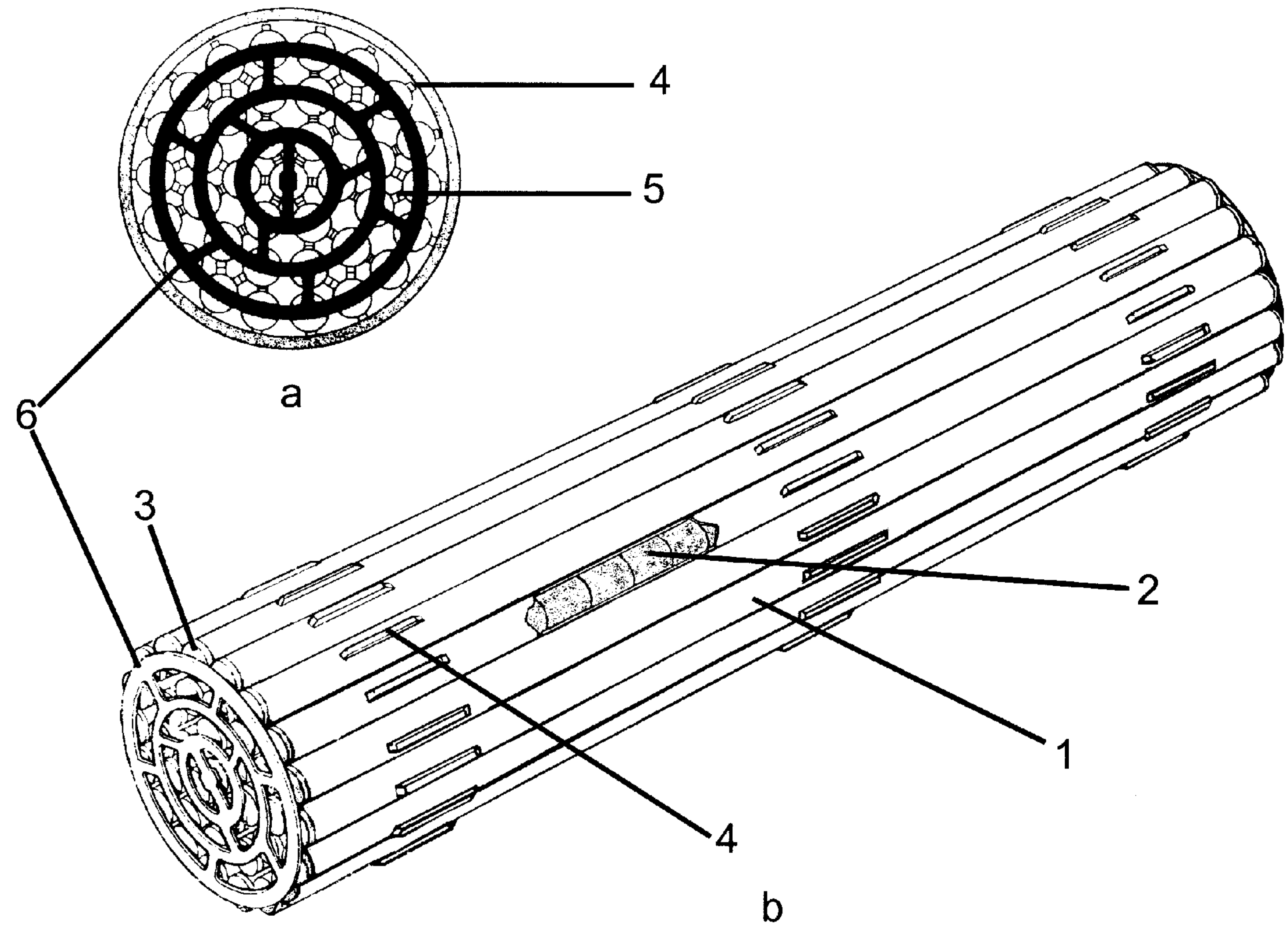
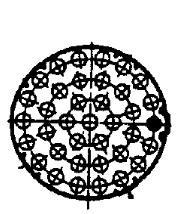


Figure 1 Prior Art



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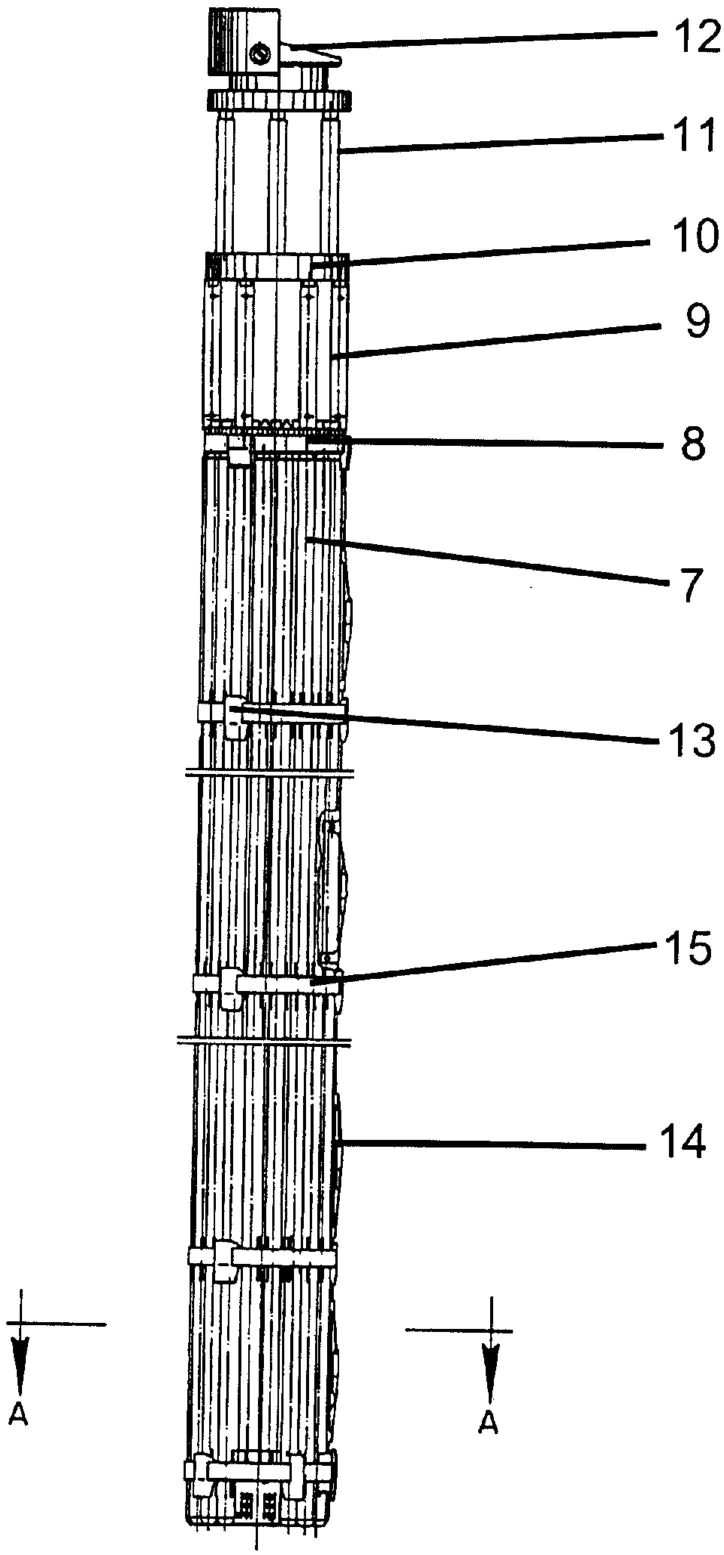

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Figure 2 Prior Art

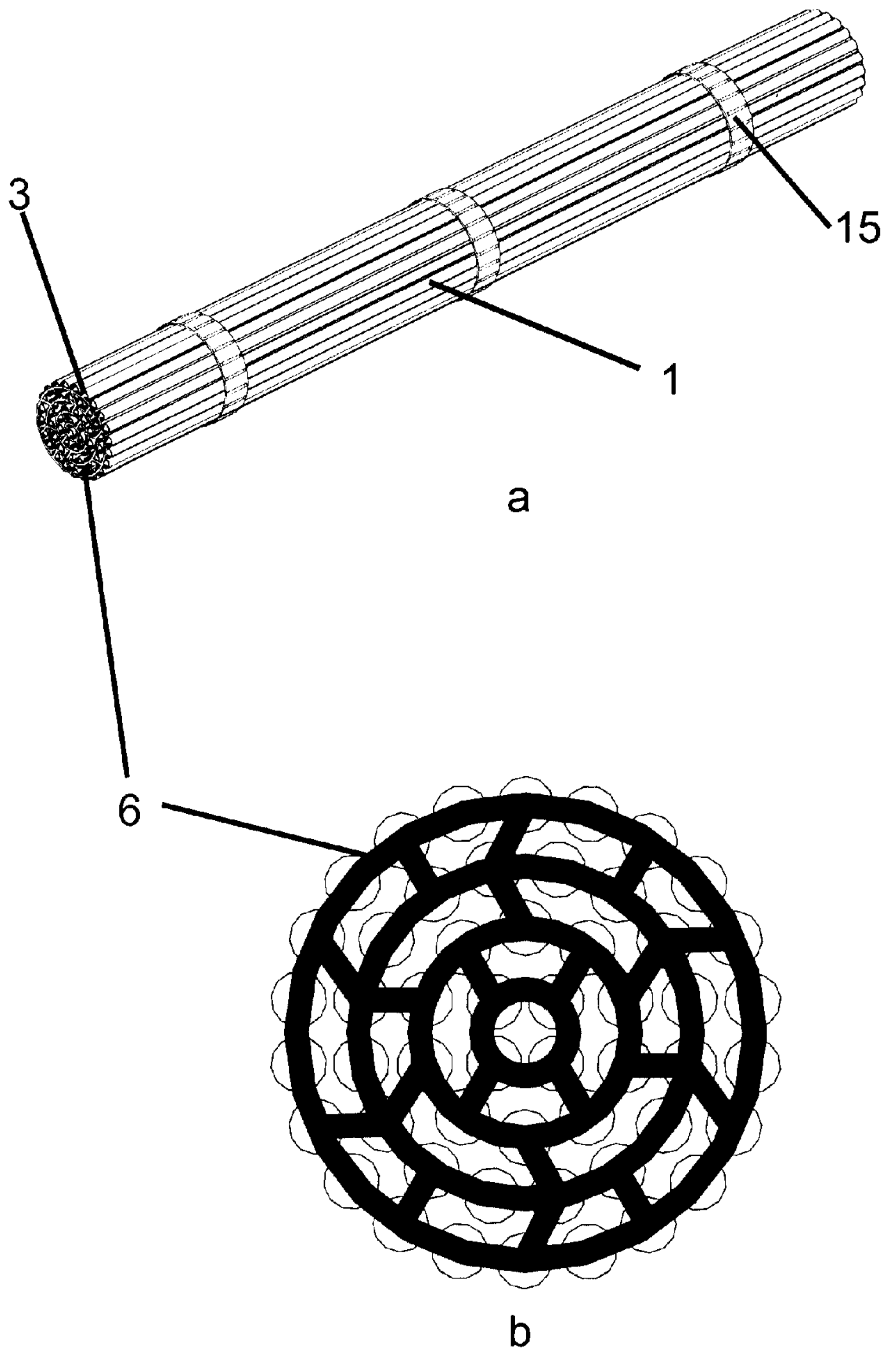

Figure 3

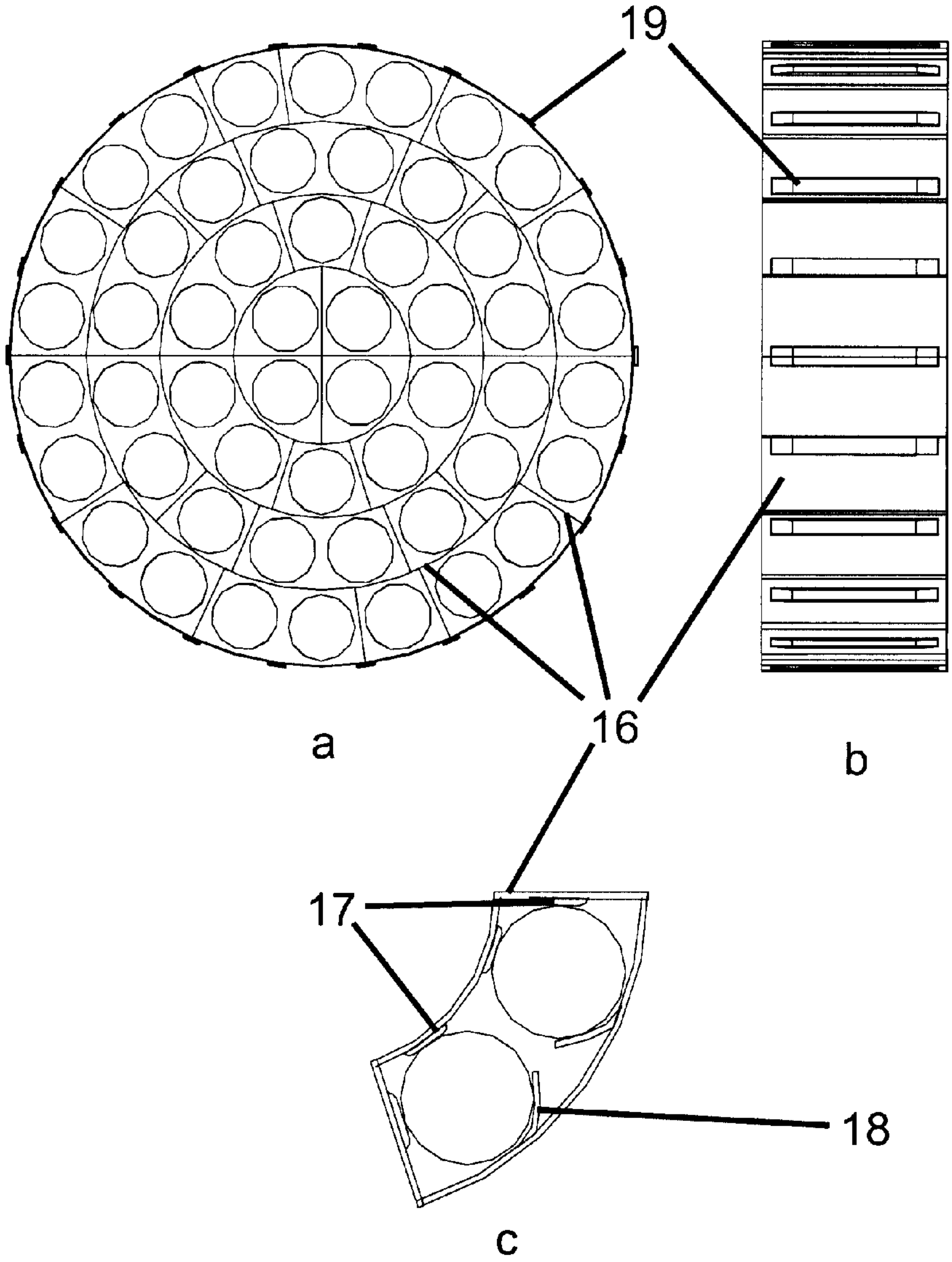

Figure 4

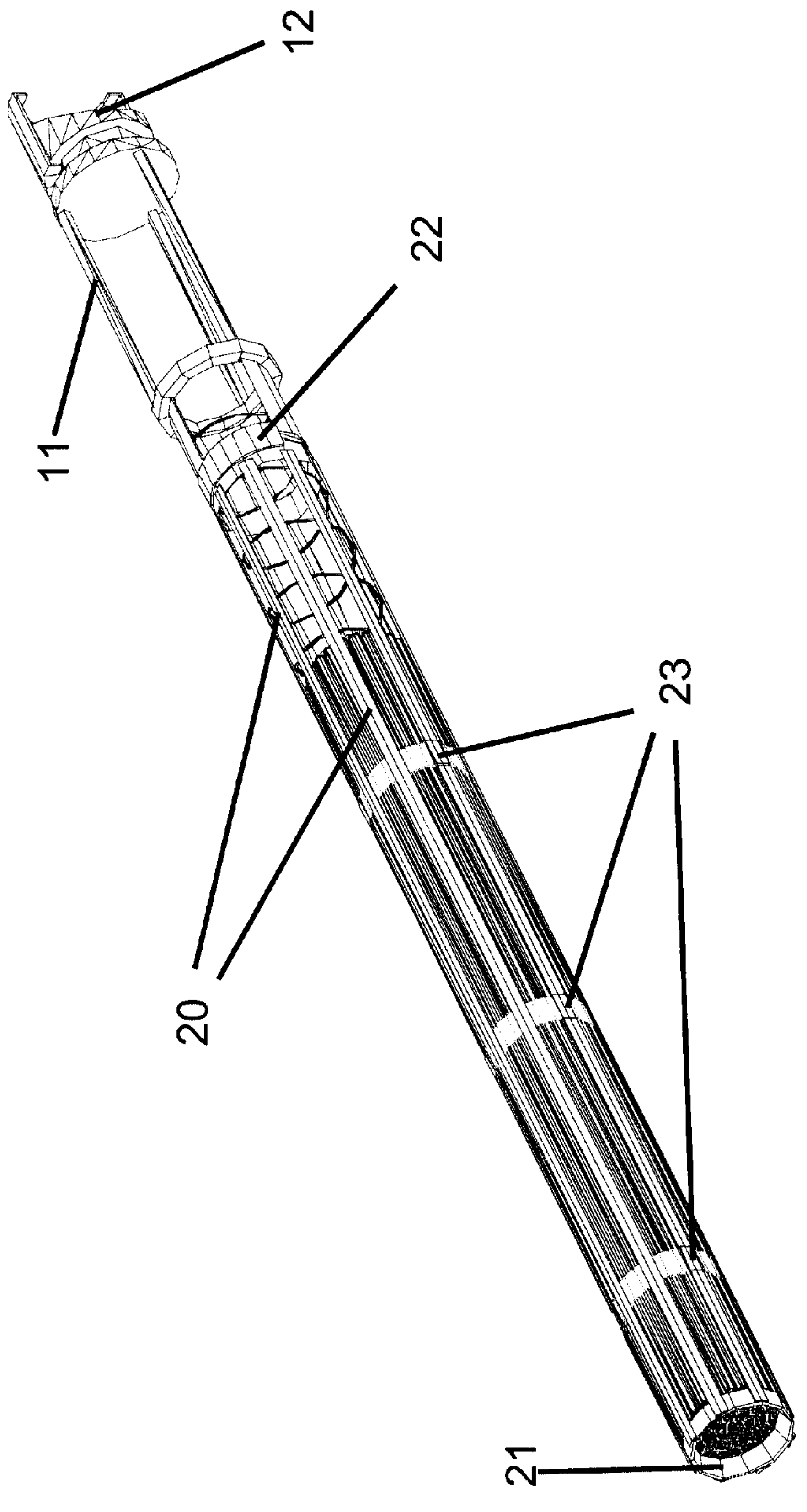

Figure 5

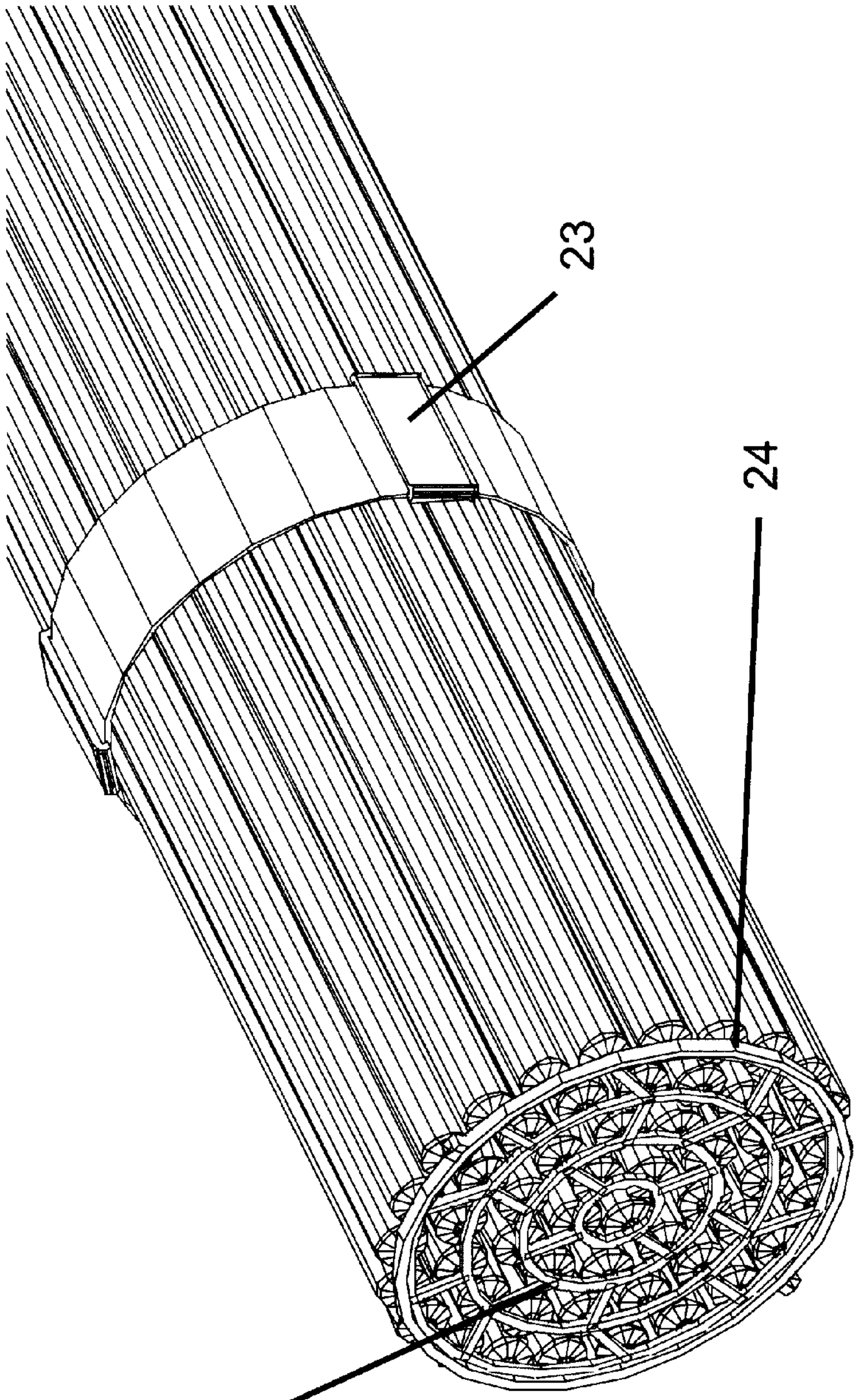

Figure 6

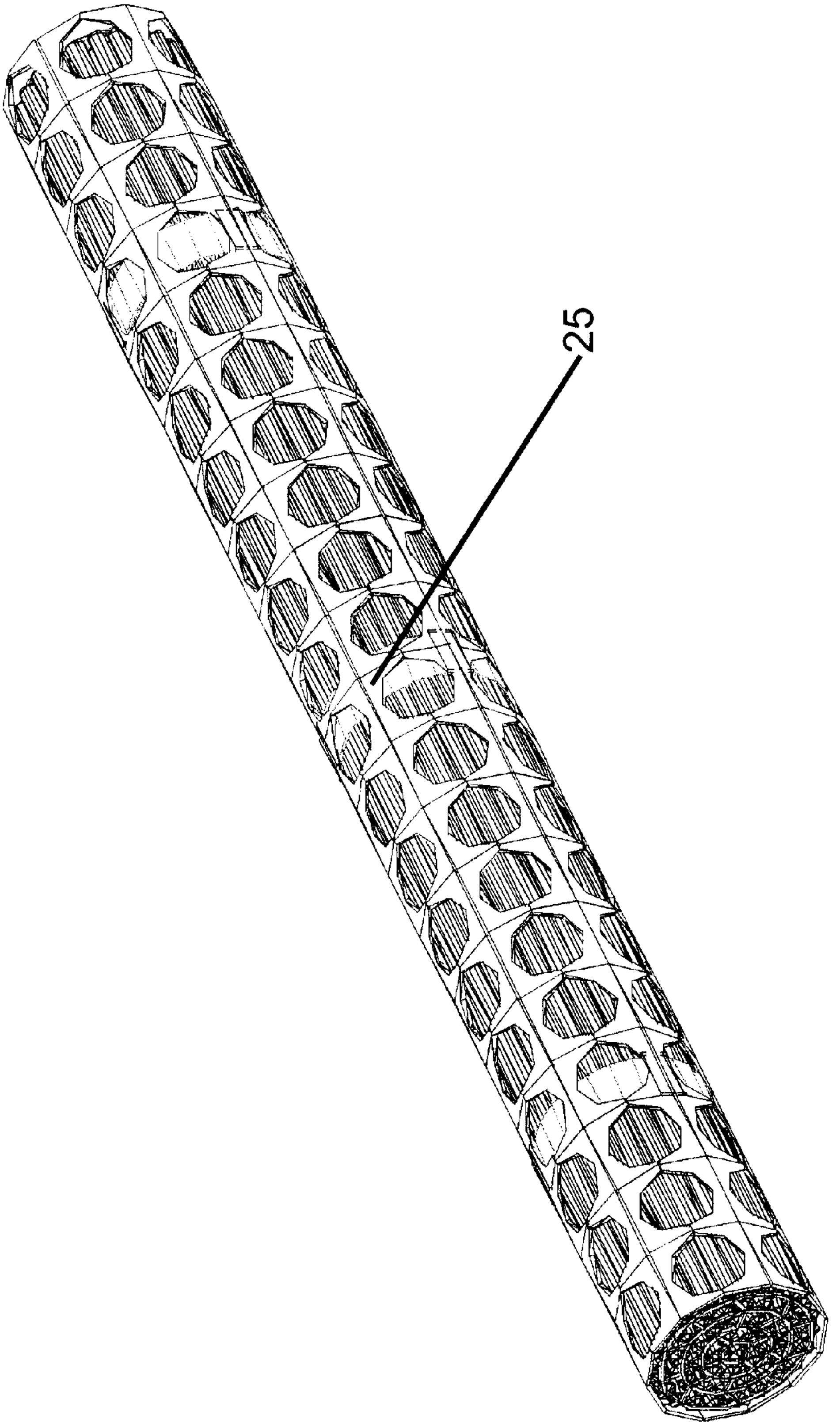

Figure 7