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(54) CONTAINER FOR STORING AND TRANSPORTING SPENT NUCLEAR FUEL

(57) The invention relates to a container for storing and transporting spent nuclear fuel, which comprises a body formed by a cylindrical steel vessel (1), closed at the bottom and provided with an upper bolted closure system equipped with leaktight sealing means, which provides structural resistance of the container and neutron shielding to the fuel, the vessel accommodating an inner frame (4) formed by a grate of stainless steel sheets (41) that define a plurality of cells (42), each one being suitable to contain a tube (5) having a cross section equivalent to that of the cells, there being arranged around said cells (42) aluminium alloy guides (43, 44) having rectangular and triangular cross sections, which transfer decay heat from the frame (4) to the steel vessel (1), the outside of the vessel having a set of heat-dissipating aluminium profiles (2), a neutron shielding material (3) being contained in spaces between the profiles.

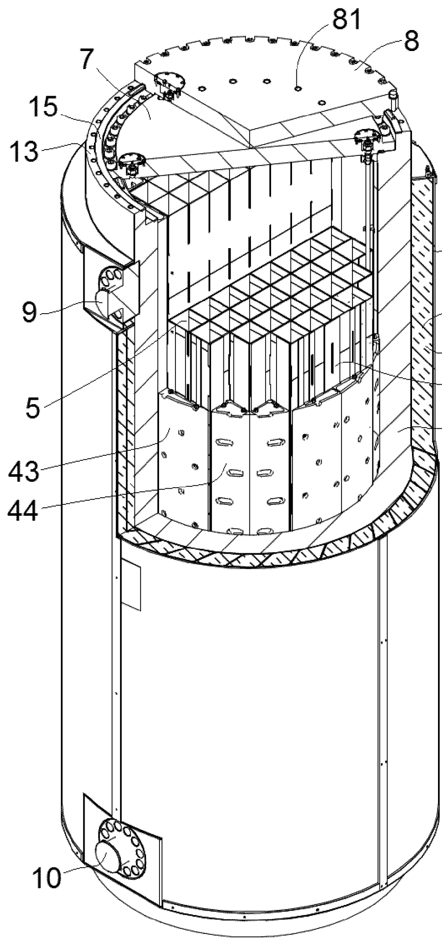

Fig. 1

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Description

Object of the invention

[0001] The object of the present invention is a dual-purpose compact metal container: storing and transporting spent nuclear fuel. More specifically, this container is intended for managing spent nuclear fuel coming from nuclear power plants with a pressurised water reactor (PWR) and a boiling water reactor (BWR), and for the possible transport of this spent nuclear fuel to an Individualised or Centralised Temporary Storage Facility.

Background of the invention

[0002] Once it is used in nuclear reactors, nuclear fuel is stored in nuclear power plant pools for the activity of the fuel to decay and for said fuel to cool down. Spent nuclear fuel can then be placed in dry storage until the final stage of management in storage containers or storage and transport containers, the latter referred to as dual-purpose containers. In Spain today highly active waste is not transported because it is kept in pools or in containers at power stations; however, for the creation of a Centralised Temporary Storage Facility there is a need to use suitable dual-purpose containers which minimise the risks associated with transporting waste of this type from nuclear power plants to the new facility.

[0003] These storage systems consist of a set of elements that ensure safe storage and transport of the spent fuel. They are designed for the purpose of ensuring compliance with the established safety functions required by law: maintain sub-criticality and confinement of the material and prevent its degradation; this is achieved, among other elements, with gamma and neutron radiation shielding and by removing residual heat generated by the irradiated fuel.

[0004] Depending on the type of nuclear fuel, a spent fuel container can store in most cases between 20 and 100 elements. The spent fuel elements that meet the requirements established in the container licence (cooling time, burn up and degree of enrichment, among other parameters) can be stored according to a reviewed and approved load plan.

[0005] Know dual-purpose metal containers are multi-walled. Typically, they consist of a cylindrical vessel with a leaktight closure system having walls of a considerable thickness so as to provide shielding for the radiation generated therein, sometimes using a layer of lead as special gamma radiation shielding; the second wall is formed by a neutron shielding which is achieved by an outermost moderator or poison layer. The outer surface of the container usually incorporates a series of fins made of copper, stainless steel or another metal arranged in the axial or radial position so as to facilitate cooling by natural convection, such that the fuel cladding temperature is lower than the authorised limits. The central cavity of the container consists of a stainless steel or aluminium basket, including components with a determined boron content for control of criticality, holding a determined number of spent fuel elements. The container is sealed by means of a double lid, where the innermost lid is made of steel and carries out containment and shielding functions, while the outer lid carries out structural integrity maintenance functions in the event of impacts resulting from potential accidents.

[0006] Some of the containers intended both for the storage and for the transport of spent nuclear fuel are manufactured from a single shell, with structural, confinement and shielding functions, primarily against gamma radiations.

Description of the invention

[0007] One of the objectives of the present invention is the design and manufacture of a series of maximum capacity, economically competitive dual-purpose containers that can hold PWR and BWR fuel, activated material of fuel additives, and equipped or having the possibility of being equipped with impact attenuators, having an improved location and better properties with respect to containers used today. Dual-purpose containers present optimal characteristics for removing the residual heat generated by the fuel elements.

[0008] The container object of the invention comprises:

- A single wall carbon steel vessel carrying out structural, confinement and shielding functions, primarily against gamma radiations. This vessel has a cylindrical configuration, is open at the top, formed from a cylindrical shell to which the base closing the vessel at the bottom is welded. A dual bolted lid system provides confinement and shielding. This system further allows easy recovery of the fuel elements under any normal or abnormal operating conditions, while at the same time it allows continuous monitoring of the pressure between lids to ensure and control any possible leak of the confinement barrier.
- Inside said steel vessel there is a frame built with stainless steel sheets that define a grate for housing therein boron-aluminium tubes inside of which the fuel elements are in turn inserted, which allows maintaining the sub-critical state and the thermal criteria which ensure the thermal limits of the cladding. In those circumstances where the criticality requirements are not high, the boron-aluminium tubes can be replaced with boron-aluminium sheets that would be an integral part of the grate forming the frame.
- Aluminium profiles located radially on the steel vessel forming the container are arranged to help dissipate in an entirely passive manner the residual heat generated by the fuel elements, being capable of removing the generated heat. Filler material is inserted in these profiles and carries out neutron radiation shielding functions. The outermost surface comprises a metal enclosure for said neutron shield-

ing.

[0009] At least two journals project from the inner vessel for lifting the container and two journals for moving the container. This configuration allows using the same container for storage either in ITSF (Individualized Temporary Storage Facility) at power plants or in a future CTSF (Centralised Temporary Storage Facility) and for intermodal transport (by road, rail or sea), without any need for refitting. For the transport operation, all that will be necessary is for two impact attenuators to be coupled to the container, bolted to the outer lid and to the bottom of the container, and a protective barrier as well as the transport cradle itself on which the container is placed.

[0010] The container has a completely autonomous design and does not require sharing any system or component with the nuclear power plant during storage (with the exception of the pressure transducer, which is installed in the outer lid and must be connected to a data sampling system so as to continuously monitor pressure in the inter-lid space).

[0011] The frame consists of a stainless steel structure (grate) formed by sheets between 5 and 10 mm thick which form cells, and inserted in these cells are tubes or sheets having a square cross section between 5 and 20 mm thick, manufactured in an aluminium and boron carbide (Al-B_4C) matrix metal composite of (MMC) which has neutron absorption capacity. The thickness of the MMC tubes or sheets is selected depending on the design of the spent fuel housed therein. The frame, in turn, is secured inside the cavity of the container by guides consisting of aluminium profiles screwed around the stainless steel structure of the frame, which guides transfer decay heat from the frame to the body of the container to facilitate removing said heat from the container.

[0012] The decay heat generated by the fuel elements housed in the container is removed by passive means. No type of coolant is used in the container, and only the inner cavity is pressurised with an inert helium gas atmosphere. Helium presents suitable thermal conductivity and favours removing decay heat from fuels housed in the frame.

[0013] The heat transmission mechanisms considered in the design of the container are described in detail below.

- Fuel elements are housed in the cells of the frame, said elements being the only heat source from the container under normal operating conditions. The heat is transmitted from the UO_2 pellets to the cladding of the element, and from there to the helium occupying the gaps in the inner cavity of the container. The remaining elements forming the fuel element (screens, nozzles, springs and guide tubes) also remove heat into the inert helium atmosphere.
- In addition to having good criticality control properties, MMC sheets or tubes exhibit excellent thermal conductivity due their high aluminium content.
- The stainless steel sheets of the frame also help dissipate the heat, transmitting it by conduction to the guides. Finally, the guides of the aluminium frame also help remove heat from inside the frame. The heat transfer from the set of components of the frame to the inner wall of the vessel occurs through conduction and radiation mechanisms.
- The heat reaching the inner surface of the vessel is transmitted by conduction through the thickness thereof, and then also by conduction through the aluminium profiles and the neutron absorber, even reaching the neutron shielding enclosure. This enclosure houses the neutron shielding material. The outer enclosure is the final conductive element before the final removal of heat in the radial direction. The arrangement of the heat-dissipating profiles, placed between the vessel and the outer shell, in an intermediate position between tangential and radial has been envisaged, forming an angle of about 45º with respect to the radius or the tangent at the contact point with the vessel or with the outer shell for optimal heat radiation.
- At the bottom of the container, heat is transmitted from the inner cavity to the outer surface by conduction through the bottom of the vessel and in the axial direction.
- Heat is propagated in the lids by conduction, convection and radiation from the fuel elements to the inner lid, also in the axial direction. The same heat transfer mechanisms are effective in the inter-lid space, also pressurised with helium.
- The heat generated by the fuel elements as well as the heat absorbed by solar radiation is transmitted from the outer surfaces of the container to the environment by means of convection and radiation mechanisms, and this heat is transmitted from the bottom of the container to the storage facility base slab by conduction.

Description of the figures

[0014] To complement the description that is being made and for the purpose of helping to understand the features of the invention, a set of drawings is attached to the present specification in which the following is depicted in an illustrative and non-limiting manner:

Figure 1 shows a general perspective view of a dual-purpose container according to the present invention, in which various partial sections have been made to observe all its components and their distribution.

Figure 2 depicts a perspective view of the vessel (1) showing a partial cross section, which vessel forms the structural part of the container.

Figure 3 depicts a perspective view of the frame (4) of a dual-purpose container with MMC tubes inserted in the grate structure of the frame formed by the stainless steel sheets, showing a partial cross section of said frame (4).

Figure 4 depicts a perspective view of the frame of a dual-purpose container, with MMC sheets assembled together with the stainless steel sheets, forming the grate structure of the frame, also showing a partial cross section of said frame (4).

Figure 5 is a cross section detail of a region of the frame (4) of the container, which shows two types of guides (43 and 44) forming an essential part of the system for removing heat from this container and the insertion of the MMC tubes (5) in the grate formed with the stainless steel sheets (41).

Figure 6 shows a cross section of a container according to a horizontal plane.

Preferred embodiment of the invention

[0015] As can be seen in the mentioned drawings, the vessel (1) of the container is primarily formed by set of slabs (11) forming the inner shell. The bottom (12), comprised of a circular planar slab, is welded to the inner shell at the lower part thereof.

[0016] Heat-dissipating aluminium profiles (2), the neutron shielding material (3), and, as the outermost surface, the enclosure (6) of the neutron shielding, are located radially on the inner shell.

[0017] To facilitate decontamination, the outer surfaces of the container have been designed and finished such that they do not have projecting parts, with the exception of the four lift journals (9) and rotation journals (10).

[0018] The design of the vessel (1) of the container with all the elements concerned is shown in Figure 2. All the components forming the vessel are described in detail below.

[0019] The inner shell (11), manufactured in carbon steel, provides structural resistance of the container and the main shielding component against gamma radiation. It can be one-piece or formed two parts welded to one another.

[0020] At the upper end of the shell two seating surfaces (13, 14) have been machined so as to receive an inner lid (7) and an outer lid (8) by means of a bolted connection. The sealing surfaces of the inner lid and outer lid are protected by means of a stainless steel cladding. The lift journals (9) and rotation journals (10) are located on the outside of the shell.

[0021] The neutron shielding material (3) is installed in the spaces in the set of heat-dissipating aluminium profiles (2), which are positioned by contact on the outer surface of the shell of the vessel (1).

[0022] The bottom (12) is comprised of a circular planar slab with a cylindrical heel to that it can be attached to the cylindrical enclosure by welding. The outer face contains several threaded holes for anchoring the bolts of the lower impact attenuator used during transport of the container to the CTSF, or to any other spent fuel storage location.

[0023] The neutron shielding material (3) used consists of a synthetic polymer that is solid when in service and based on an epoxy resin on which boron carbide is adhered. This material is located in the cells formed by the aluminium profiles.

[0024] The assembled heat-dissipating aluminium profiles (2) are preferably aluminium alloy cells between 2 and 10 mm thick located radially between the two cylindrical shells, inside which the material of the neutron shielding (3) is inserted. The skew between consecutive sheets is 10°, such that each of these heat-dissipating profiles is arranged forming an angle of about 45° with respect to the radius or tangent at the contact point with the vessel (1) or with the outer shell (6).

[0025] Finally, the shell (6) and enclosing rings form a cylindrical enclosure manufactured in rolled carbon steel sheet between 10 and 40 mm thick, with upper and lower closure bands (called rings). It confines and isolates the neutron shielding material (3) from the outside and from the set of heat-dissipating profiles (2). The relief valve, the purpose of which is to limit pressure inside the enclosure, is located on said enclosure.

[0026] The lift journals (9) are located in the upper part of the container. They are two solid high-strength steel journals, the purpose of which is to hoist and handle the container. Each of the lift journals is fixed by a series of bolts to machined cavities in the shell of the container, in two diametrically opposed positions. The rotation journals (10) are used during container turning manoeuvres in the transfer or transport cradle. They are similar to the lift journals (9). Both sets of journals may include a cavity in which there is located neutron shielding material (2) due to the high neutron source strength in the lower part of the active length of the fuel elements. Similarly to the lift journals, the rotation journals are bolted to the vessel (1). The journals to be used in the design of the dual-purpose container can be either "male" or "female" type journals, depending on the limitations imposed in the power plant or by transport requirements.

[0027] Once the load is housed in the inner cavity, it is isolated from the outside by two lids, an inner lid (7) and an outer lid (8), each of said lids being capable of keeping the inner cavity leaktight. Both lids are bolted to the vessel (1), leaving about 5 mm between both lids to pressurise this chamber with helium. The measurement of the pressure in the inter-lid space provides a warning in the hypothetical case of there being a leak in the confinement system within the container.

[0028] The inner lid (7) consists of a circular planar slab manufactured in low-alloy steel. On its periphery there is a series of through holes so that it can be attached to the body of the container by alloyed carbon steel bolts. The lower face of the lid (7) is closed on the seating surface (14) of the vessel (1) with a double metallic sealing joint (15) that is part of the confinement system, which prevents the possibility of any radioactive material leakage.

[0029] The outer lid (8) forms a second leaktight barrier of the container, a redundant barrier, which has the primary purpose of protecting the confinement system against impacts of any type. It consists of another circular planar slab or plate the lower face of which is closed on the seating surface (13) of the vessel (1) and is fixed to it with a group of alloyed carbon steel bolts. The lower face of the lid is closed on the seating surface of the vessel with a double metallic joint (15). Once they are closed and bolted, there is a minimum gap between the inner lid (7) and the outer lid (8) called inter-lid space.

[0030] On the outer face, lid (8) presents a series of threaded holes (81) for anchoring the bolts of the upper impact attenuator.

[0031] The design of the container includes three penetrations its closure lids: two in the inner lid (7) and one in the outer lid (8). The vent and drain penetrations are embedded in the inner lid, have direct access to the inner cavity of the container, and are, therefore, penetrations of the confinement system. The pressure control penetration in the outer lid allows detecting possible anomalies in the operation of the container. The drain and vent penetrations of the inner lid have respective quick disconnect valves; both penetrations are used for acing the inner cavity of the container after fuel is loaded.

[0032] In turn, the fuel frame (4) is comprised of three metallic subsets:

- A grate structure (42), formed by a set of austenitic stainless steel sheets (41), arranged longitudinally with respect to the generatrix of the vessel (1), connected to one another by means of slots (411) that allow fitting these sheets together, forming the cells where the fuel elements are housed. All the sheets (41) have vertical slots so as to enable fitting together, giving rise to square cells. Vertical plates made of the same material and having the same thickness which reinforce the set are spot welded on the outer surfaces of the cell mesh.
- The fuel elements occupy the inside of the cells of the grate (42) inserted in tubes (5), consisting of tubes having a square cross section manufactured in aluminium-boron carbide composite (Matrix Metal Composite, MMC) having neutron absorption capacity, which helps to maintain the inner cavity in a subcritical state.
- Finally, the guides of the frame (43, 44) are aluminium alloy profiles which secure the fuel cells (42) and constitute a fundamental part of the transition system between the polygonal periphery of the cells and the cylindrical interior of the vessel (1). Its cross section presents cells having a triangular shape (44) and a quadrangular shape (43), and the face close to the cylindrical enclosure of the vessel is always curved.

[0033] The guides of the frame (43, 44) are screwed to the vertical reinforcement plates, which are welded to the outer faces of the sheet grate structure (42) of the frame (4).

[0034] Having sufficiently described the nature of the invention as well as a preferred embodiment thereof, it is hereby stated for all intents and purposes that the materials, forma, shape and arrangement of the described elements may be modified, provided that this does not alter the essential features of the invention that are claimed below.

Claims

1. A container for storing and transporting spent nuclear fuel, of the type which comprises a body formed by a cylindrical steel vessel (1) closed at the bottom and provided with an upper bolted closure system equipped with leaktight sealing means, which provides structural resistance of the container and neutron shielding to the fuel, the vessel accommodating an inner frame (4) formed by a grate of stainless steel sheets (41) that define a plurality of cells (42), each one being suitable to contain a tube (5) having a cross section equivalent to that of the cells, suitable to contain therein a load of spent nuclear fuel, **characterised in that** the frame (4) has, arranged around the stainless steel structure (42), aluminium alloy guides (43, 44) having rectangular and triangular cross sections and curved outer faces, forming between said guides and the grate of cells (42) a cylindrical conformation which adapts to the cavity of the vessel (1), transferring heat decay from the frame (4) to the steel vessel (1), the outer surface of the vessel having a set of heat-dissipating aluminium profiles (2), a neutron shielding material (3) being contained in spaces between the profiles, externally protected by means of a cylindrical shell (6) which confines and isolates the neutron shielding material (3) and the set of heat-dissipating profiles (2) from the outside, which facilitates removing heat from the container.

2. The container according to claim 1, **characterised in that** the vessel (1) is made up of at least one shell (11), or several shells welded together forming a cylindrical body, with the bottom (12) being welded to the lower base, whereas there have been machined in the upper opening two seating surfaces (13, 14) which are suitable for an inner lid (7) and an outer lid (8) to be fixed in said surfaces by respective bolts; the bottom (12) and the outer lid (8) having a series of threaded holes (81) in which impact attenuators protecting the container during transport are fixed by respective bolts.

3. The container according to the preceding claims, **characterised in that** the an inner lid (7) and an outer lid (8) are bolted in the vessel (1), sandwiching in the junctions respective confining metallic joints (14, 15) which prevents any sealed radioactive ma-

terial leakage, the space or chamber between the inner lid (7) and the outer lid (8) being pressurised with helium so that the measurement of pressure in this space allows detecting any leakage in the confinement system within the container.

4. The container according to the preceding claims, **characterised in that** the heat-dissipating profiles (2) located between the vessel (1) and the outer shell (6) are in an intermediate position between tangential and radial, forming an angle of about 45° with respect to the radius or tangent at the contact point with the vessel (1) or with the outer shell (6), and they are not welded to the body of the container (1) but rather fixed by the outer shell (6) itself.

5. The container according to the preceding claims, **characterised in that** there are fixed on the outside of the vessel (1) respective pairs of diametrically opposed journals (9, 10), two lift journals (9) located in the upper part of the container and two rotation journals (10) used during container turning manoeuvres in the transfer or transport cradle.

6. The container according to the preceding claims, wherein the structure of the grate (42) forming the region of the frame (4) holding the fuel is made up of a set of austenitic stainless steel sheets (41) arranged longitudinally with respect to the generatrix of the vessel, **characterised in that** said sheets (41) are connected to one another by means of vertical slots (411) that allow fitting these sheets together by strictly mechanical means, giving rise to square cells in which the fuel tubes (5) are housed and manufactured from an aluminium-boron carbide composite with neutron absorption capacity, which helps to maintain the inner cavity in a sub-critical state.

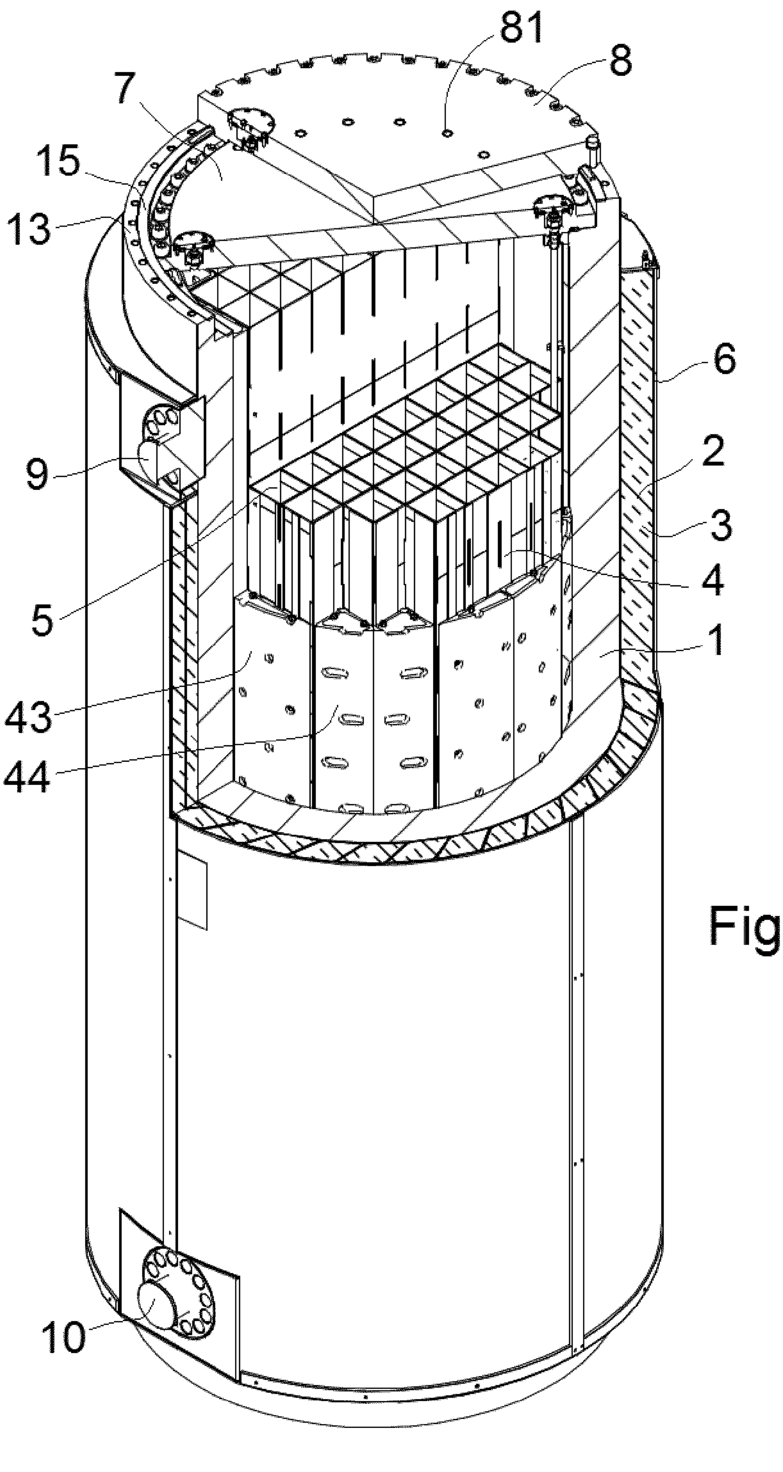
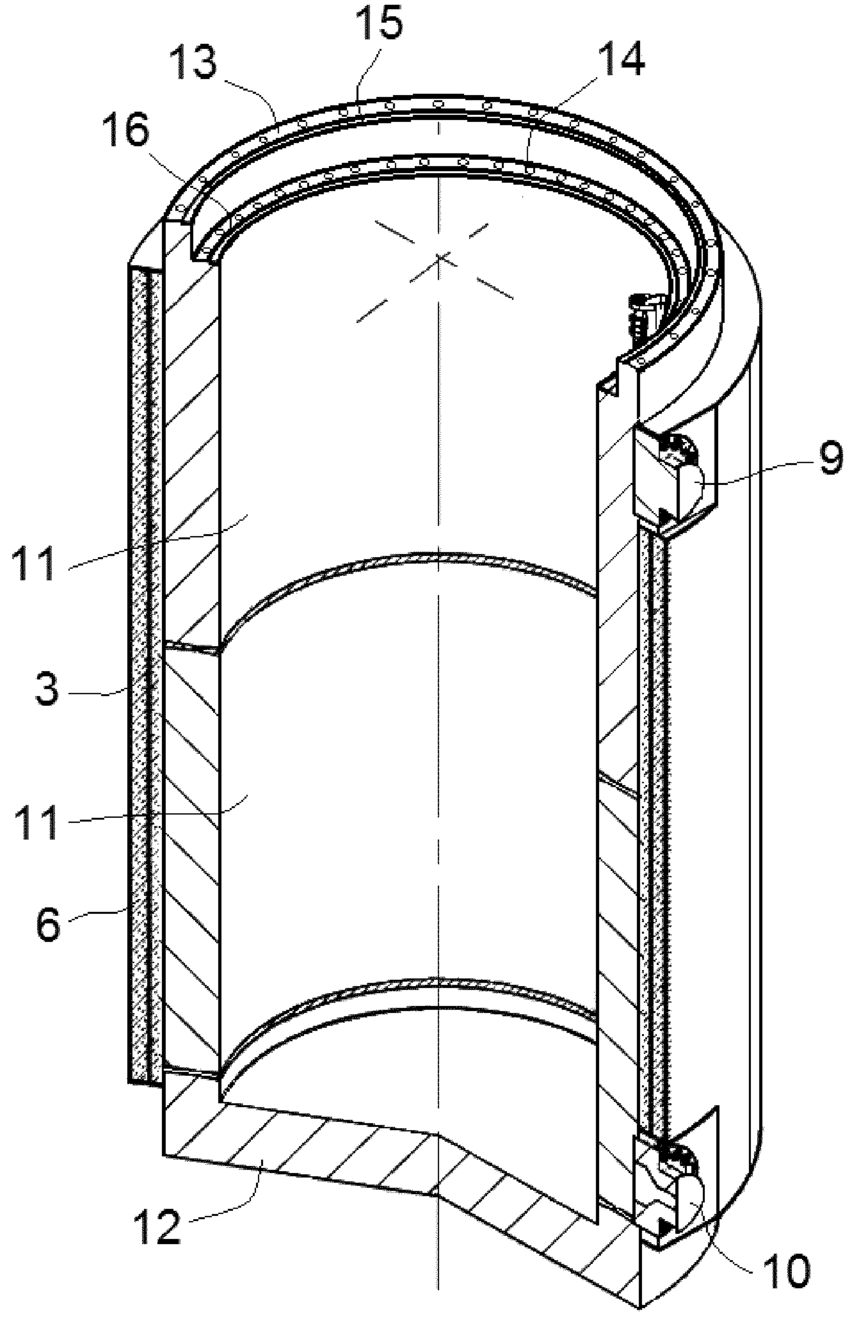


Fig. 1

Fig. 2



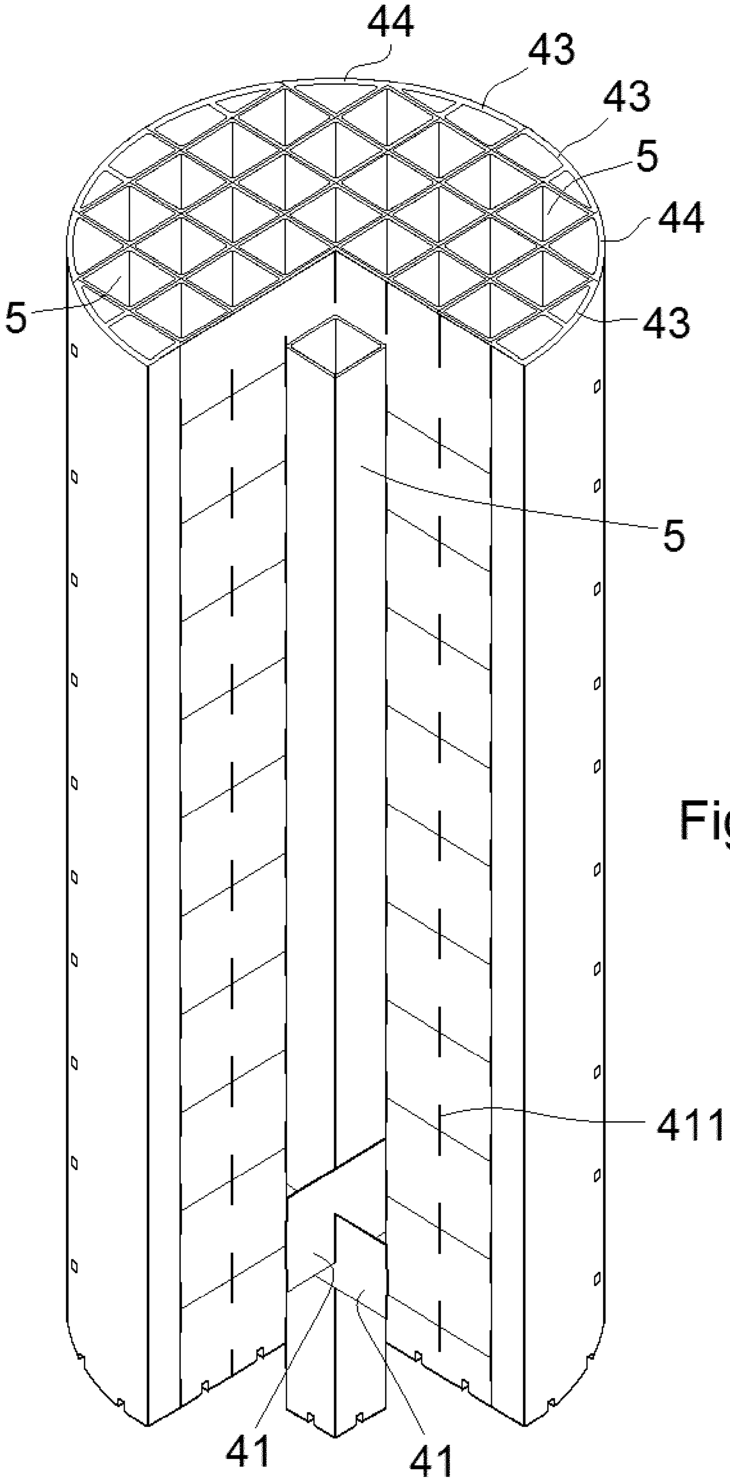


Fig. 3

Fig. 4

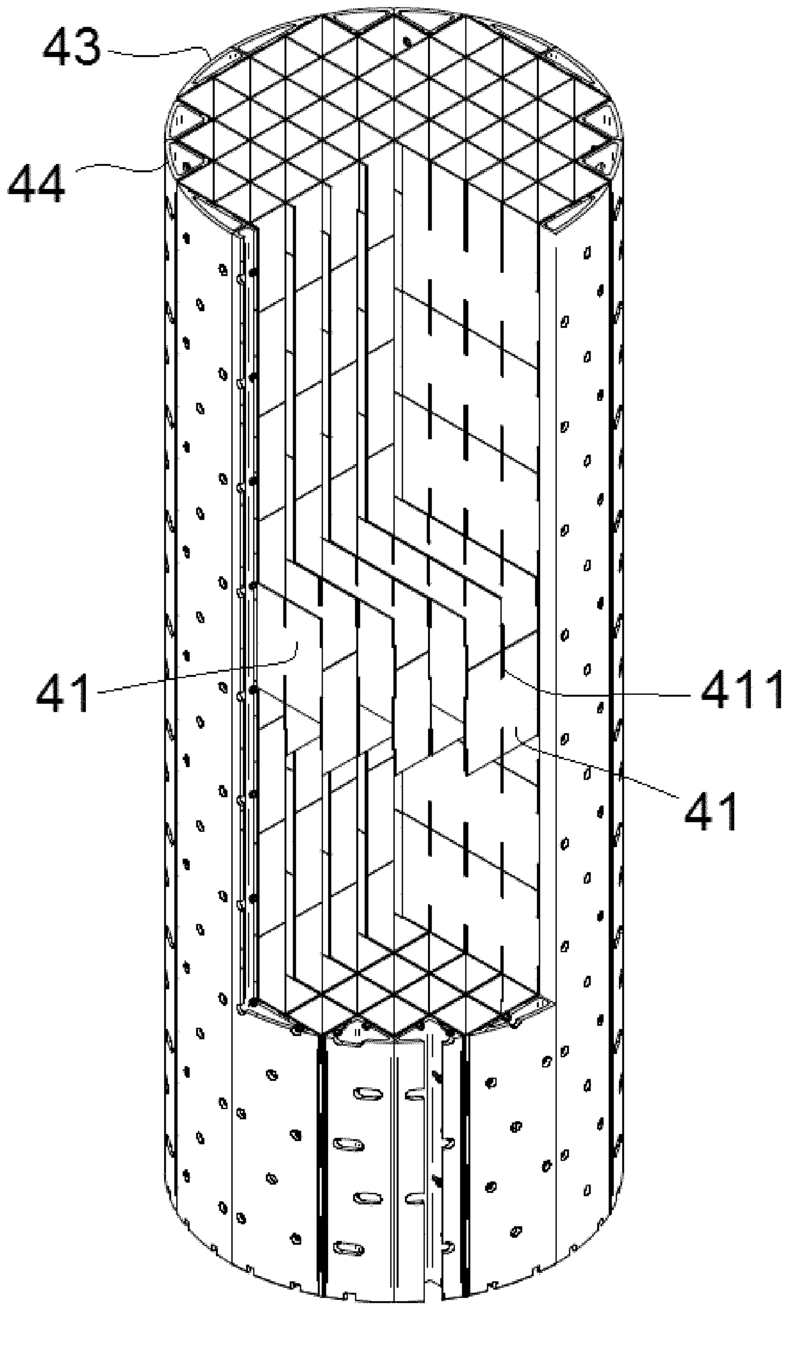
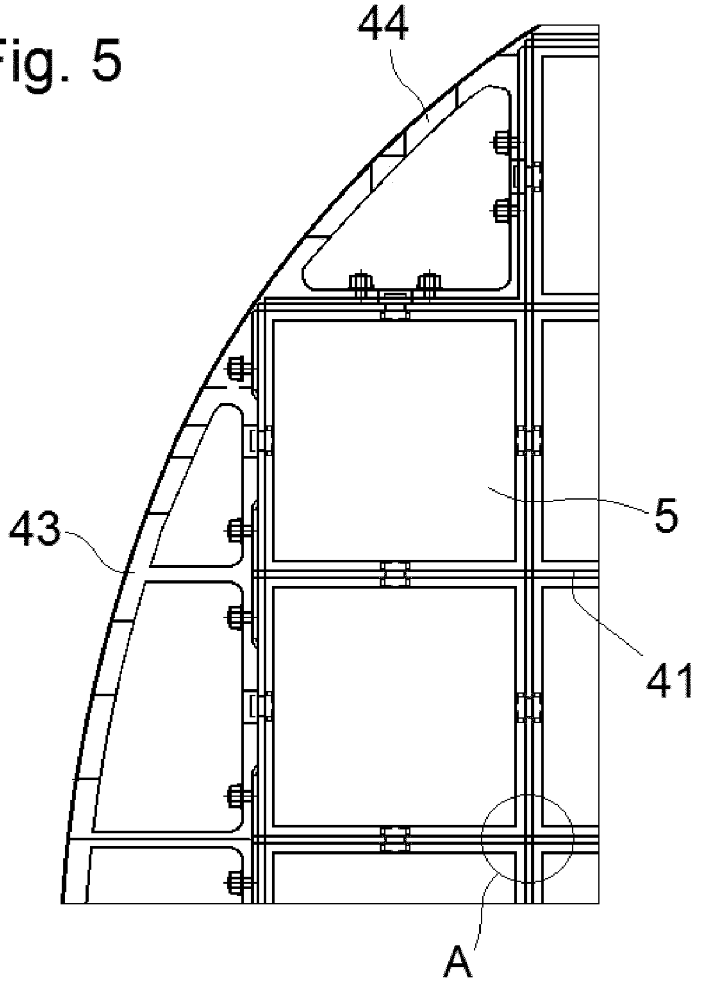


Fig. 5



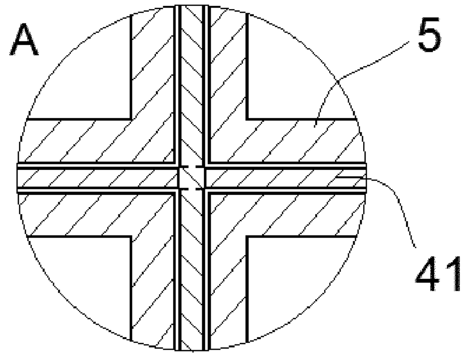
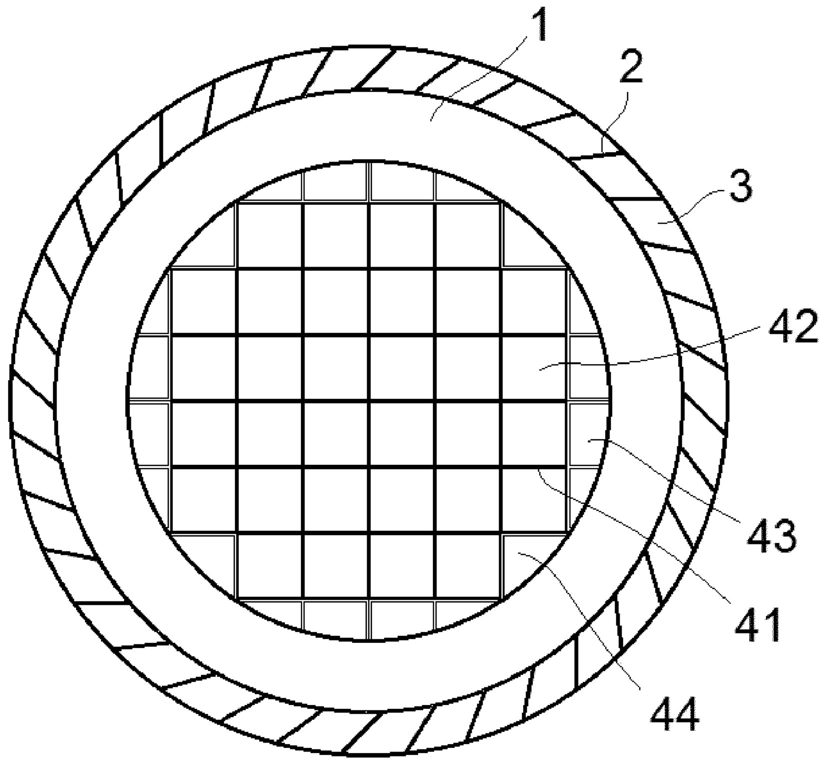


Fig. 6



INTERNATIONAL SEARCH REPORT

International application No.
PCT/ES2017/070130

A. CLASSIFICATION OF SUBJECT MATTER

G21F5/008 (2006.01)
G21F5/06 (2006.01)
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)
G21F

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)

EPODOC, INVENES

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	US 2014044227 A1 (MORRIS ET AL.) 13/02/2014, page 2, paragraphs [20 - 21]; figure 8,	1-6
A	US 6878952 B1 (OHSONO ET AL.) 12/04/2005, page 11, line 37 - page 13, line 35; page 15, line 1 – page 17, line 7; figures 1,2,17-20.	1-6
A	US 5898747 A (SINGH) 27/04/1999, column 7, line 33 - column 8, line 6; column 10, line 8 - column 11, line 14; figure 14,	1,2,6

☒ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:
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Date of the actual completion of the international search	Date of mailing of the international search report
24/11/2017	**(01/12/2017)**
Name and mailing address of the ISA/ OFICINA ESPAÑOLA DE PATENTES Y MARCAS Paseo de la Castellana, 75 - 28071 Madrid (España) Facsimile No.: 91 349 53 04	Authorized officer R. San Vicente Domingo Telephone No. 91 3498525

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/ES2017/070130

C (continuation).	DOCUMENTS CONSIDERED TO BE RELEVANT	
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Form PCT/ISA/210 (continuation of second sheet) (January 2015)

INTERNATIONAL SEARCH REPORT

Information on patent family members

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