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(54) **Title:** REACTOR VESSEL WELL FOR SUPPORTING A NUCLEAR REACTOR IN A SUBTERRANEAN CAVITY

(57) **Abstract:** A system for supporting and housing a nuclear reactor in a subterranean vault comprises a concrete base mat and sidewall defining a subterranean cavity. A reactor pressure vessel (RPV) containing the fuel core is disposed in the subterranean cavity and includes radially-extending support trunnions coupled to the RPV shell. Each trunnion is received in a corresponding support recess in the sidewall interior surface to support the RPV in a vertically cantilevered suspended manner. A seismic stabilizer anchored in the base mat is positioned to engage the bottom head of the RPV during a seismic event to arrest lateral movement of the RPV. A metal liner system for the subterranean cavity includes inner and outer liners that cover the concrete base mat and sidewall. Thermal insulation interposed between the liners reduces heat transmission to the concrete from the RPV when operating to maintain safe concrete temperatures.

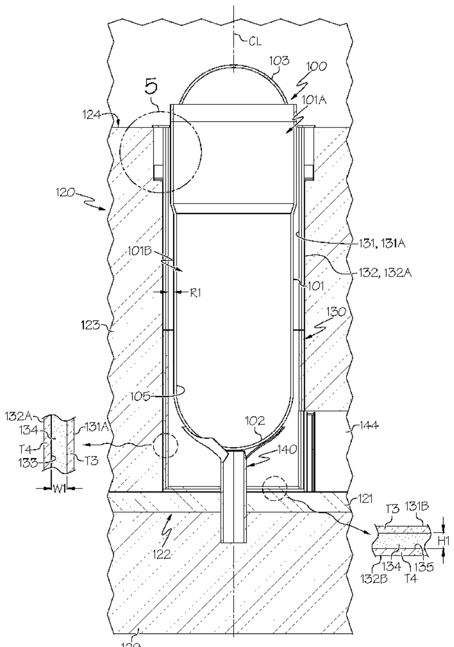

FIG. 1

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REACTOR VESSEL WELL FOR SUPPORTING A NUCLEAR REACTOR IN A SUBTERRANEAN CAVITY

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Application No. 63/615,872 filed December 29, 2023, which is incorporated herein by reference in its entirety.

BACKGROUND

[0002] The present invention relates generally to a nuclear small modular reactor (SMR), and more particularly to reactor vessel well for supporting an SMR in a subterranean cavity.

[0003] Nuclear reactor pressure vessels (RPVs) for SMRs are vertically elongated pressure vessels formed of a cylindrical thick steel shell in which the radioactive nuclear fuel core is housed to heat primary coolant. Such a vessel may be located substantially below grade for a majority of its height in a deep subterranean cavity known as a reactor vessel well (RVW). Some RPVs are hung in a suspended manner in the RVW from the reactor deck of a nuclear generation plant via reactor support structure (RSS) mounted to the RPV. There are numerous design considerations pertinent to mounting and supporting such a vessel in the RVW. For example, the width of the annulus between the RPV and the RVW should be as small as possible so that the bending moment exerted on the RPV, and the RSS is minimized. The placement of the RSS on the RPV needs to be optimized to minimize thermal stresses in the hot and cold leg primary coolant outlet and inlet nozzles on the RPV. Another important design imperative is to protect any concrete proximate to the RPV from reaching excessively high temperatures under long term conditions which, as noted by the American Concrete Institute (ACI-349) and US NRC (NUREG/CR-6900), should not exceed 150 Deg. F (degrees Fahrenheit). The surface temperature of the RPV in some SMRs under full power conditions may reach approximately 500 Deg. F. The hot RPV can heat the reinforced concrete of the floor or base mat of the RVW to temperatures above the maximum limit as well as the concrete preferably cylindrical sidewall of the RVW. The contact interface between the RSS and the concrete bearing surfaces is also a pathway to heat the latter which must be blocked to the maximum extent. To the above two requirements is added a universal design imperative for an SMR plant or any industrial or commercial scale building project which envisages minimizing the field construction work effort.

[0004] Improvements in supporting a RPV in an RVW is desired.

BRIEF SUMMARY

[0005] The present application discloses a system for supporting and housing a reactor pressure vessel (RPV) of a small modular reactor (SMR) substantially below grade in a deep subterranean reactor vessel well (RVW) which overcomes the foregoing structural and thermal challenges.

[0006] In one aspect, a nuclear reactor well for supporting a reactor substantially below grade comprises: a concrete base mat; a concrete sidewall extending vertically upwards from the base mat and defining a subterranean cavity configured for housing a reactor pressure vessel; a liner assembly disposed in the subterranean cavity, the liner assembly comprising an outer liner having portions disposed adjacent to the sidewall and the base mat, and an inner liner spaced inwards from the outer liner in the subterranean cavity; and thermal insulation disposed between the outer and inner liners.

[0007] In another aspect, a system for supporting and housing a nuclear reactor in a subterranean vault comprises: a concrete base mat; a concrete sidewall extending vertically upwards from the base mat and defining a subterranean cavity; a reactor pressure vessel disposed in the subterranean cavity and defining a vertical centerline axis, the reactor pressure vessel comprising a bottom head, a removable top head, and a cylindrical shell extending between the heads defining an internal cavity which holds a nuclear fuel core; the reactor pressure vessel further comprising a plurality of radial support trunnions coupled to the shell, each support trunnion received in a saddle disposed in a support recess formed in an interior surface of the sidewall to support the reactor pressure vessel in a vertically cantilevered suspended manner inside the subterranean cavity; a seismic stabilizer fixedly anchored in the base mat at a position below the bottom head of the reactor pressure vessel; wherein the seismic stabilizer is configured and operable to engage the bottom head of the reactor pressure vessel during a seismic event to arrest lateral movement of the reactor pressure vessel.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] The present invention will become more fully understood from the detailed description and the accompanying drawings, wherein like elements are labeled similarly and in which:

[0009] FIG. 1 is a partially rotated side view of reactor vessel well (RVW) defining a deep subterranean cavity configured for holding reactor pressure vessel (RPV) shown positioned therein in accordance with an embodiment of the present invention;

[0010] FIG. 2 is a side view thereof;

[0011] FIG. 3 is a perspective view of a seismic stabilizer of the RVW of FIG. 1 which is disposed at the bottom of the RVW to selectively engage the bottom head of the RPV during a seismic event;

[0012] FIG. 4 is a top view of the RPV of FIG. 1 showing a plurality of radial support trunnions and primary coolant inlets and outlets of the RPV;

[0013] FIG. 5 is an enlarged view taken from FIG. 1 showing a trunnion support recess formed proximate to the top of the concrete sidewall of the RVW and one of the trunnions (in dashed lines) supported from a support saddle disposed in the recess;

[0014] FIG. 6 is a side view of the support saddle;

[0015] FIG. 7 is a perspective view thereof;

[0016] FIG. 8 is a top view of the RVW with annular seal plate removed to reveal support recess locations in the RVW and trunnions of the RPV positioned therein on the support saddles; and

[0017] FIG. 9 is a perspective view of the RVW with its concrete sidewall and base mat thereof seated on a concrete foundation slab.

[0018] All drawings are schematic and not necessarily to scale. Features shown numbered in certain figures which may appear un-numbered in other figures are the same features unless noted otherwise herein.

DETAILED DESCRIPTION

[0019] The features and benefits of the invention are illustrated and described herein by reference to non-limiting exemplary embodiments. This description of exemplary embodiments is intended to be read in connection with the accompanying drawings, which are to be considered part of the entire written description. Accordingly, the disclosure expressly should not be limited to such exemplary embodiments illustrating some possible non-limiting combination of features that may exist alone or in other combinations of features.

[0020] In the description of embodiments disclosed herein, any reference to direction or orientation is merely intended for convenience of description and is not intended in any way to limit the scope of the present invention. Relative terms such as "lower," "upper," "horizontal," "vertical,", "above," "below," "up," "down," "top" and "bottom" as well as derivatives thereof (e.g., "horizontally," "downwardly," "upwardly," etc.) should be construed to refer to the orientation as then described or as shown in the drawing under discussion. These relative terms are for convenience of description only and do not require that the apparatus be constructed or operated in a particular orientation. Terms such as "attached," "affixed," "connected," "coupled," "interconnected," and similar refer to a relationship wherein structures are secured or attached to one another either directly or indirectly through intervening structures, as well as both movable or rigid attachments or relationships, unless expressly described otherwise.

[0021] As used throughout, any ranges disclosed herein are used as shorthand for describing each and every value that is within the range. Any value within the range can be selected as the terminus of the range. In addition, any references cited herein are hereby incorporated by reference in their entireties. In the event of a conflict in a definition in the present disclosure and that of a cited reference, the present disclosure controls.

[0022] As used herein, the terms "seal weld or welding" shall be construed according to its conventional meaning in the art to be a continuous weld which forms a gas-tight joint between the parts joined by the weld.

[0023] FIGS. 1-9 depict one embodiment of a reactor vessel well (RVW) 120 and various details thereof formed of reinforced concrete defining a subterranean cavity 127 configured for housing and supporting a nuclear reactor pressure vessel (RPV) 100 therein according to the present disclosure.

[0024] RPV 100 is an elongated steel vessel including a cylindrical hollow vertical shell 101 defining sides of the RPV, dish-shaped bottom head 102 coupled to the bottom end of the shell, and a removable top head 103 detachably coupled to the annular top end of the shell which closes the otherwise open top end of the vessel. The upper portion 101A of shell 101 where various piping penetrations into the internal cavity 105 of RPV 100 are made through RPV shell 101 may have a greater wall thickness T1 and concomitantly larger outside diameter D1 than the lower portions 101B of the shell below the upper portion having a thickness T2 and outside diameter D2. Thickness T1 may be 2 times or greater than thickness T2. As one non-limiting example T1 may be 12 inches and T2 may be 6 inches. Other suitable thicknesses may be used. The radial reactor support protrusions or trunnions 150 from which the RPV is hung in a suspended manner may also be coupled to the thicker upper portion 101A of the RPV shell 101 for strength. Because all penetrations in the RPV are located in the thicker upper portion of shell 101, the necessity for reinforcing the shell around these penetrations is obviated.

[0025] A plurality of head bolts (not shown) may be used to detachably and removably couple top head 103 to the shell 101 in a manner well known in the art. The bottom head 102 may be permanently coupled to the bottom end of the shell via a full continuous circumferential seal weld suitable for forming a pressure vessel. The shell, top head, and bottom head collectively define an internal cavity 105 configured for holding the nuclear fuel core 106 (represented schematically by dashed box in FIG. 2) and related appurtenances for heating the primary coolant held in the RPV 100. The removable top head 103 allows the fuel core to be inserted into the internal cavity of the RPV after which the top head is bolted closed onto the vessel. The shell, top head, and bottom head of the RPV are formed of thick steel such as carbon steel or stainless steel in one embodiment for corrosion resistance.

[0026] RPV 100 is fluidly coupled to a steam generator (not shown) which receives heated primary coolant from the RPV and returns cooled primary coolant to the RPV in a manner well known in the art. Accordingly, RPV 100 further includes the usual primary coolant outlet piping 111 defining "hot legs" which conveys the heated primary coolant to the steam generator and primary coolant inlet piping 112 defining "cold legs" which receives cooled primary coolant back from the steam generator.

[0027] With continuing reference to FIGS. 1-9 as applicable, the RVW 120 defines a below grade concrete vault 128 buried in and surrounded on at least some sides by soil for enclosing and shielding the RPV 100. The RVW may extend from the concrete operating deck 126 of the plant downward a suitable distance as needed so that the subterranean cavity 127 has a height sufficient to accommodate a majority of the length of the RPV. In one non-limiting embodiment, the bottom head 102 of the RPV 100 and at least a majority of the RPV shell 101 (e.g., 85% or more) including the lower portion that contains the fuel core 106 may be located within the RVW subterranean cavity 127 being surrounded by concrete for protection of the RPV against potential postulated projectile impacts and for radiation mitigation. The top head 103 of the RPV remains exposed above the operating deck to allow access to the head bolting and control rod/instrumentation penetrations in the head. The top end and adjoining uppermost portion of the RPV shell 101 adjacent head 103 may also remain exposed for a short distance above the concrete operating deck of the plant, which is defined by the top surface of sidewall 123 and extends 360 degrees around the subterranean cavity 127 and RPV 100.

[0028] The RVW 120 structure includes a flat concrete floor or base mat 121 defining a closed bottom end 122 of the RVW and a concrete sidewall 123 extending upwards from the base mat to define an open top end 124 of the RVW for inserting the RPV 100 into the well. The sidewall 123 defines the subterranean cavity 127 of the RVW configured for holding and supporting the RPV 100 therein substantially below grade in the vault 128 for a majority of its length. Sidewall 123 may be any suitable shape in cross-section. In the non-limiting illustrated embodiment, the inside surface 123A of the sidewall which defines the subterranean cavity 127 is cylindrical defining a circular shape in cross-section. The outside surface(s) 123B of sidewall 123 may be cylindrical or another suitable shape such as polygonal (e.g., rectilinear) as shown. The cylindrical inside surface 123A accommodates the cylindrical metal RVW liner assembly 130 further described herein which is concentrically and coaxially aligned with the inside surface of the sidewall. The outer surfaces 123B of the RVW 120 are embedded in soil or engineered fill and therefore may have any shape unrestricted by the RVW liner system.

[0029] Base mat 121 of RVW 120 is formed and seated on a flat reinforced concrete foundation slab 129 having a substantially greater thickness than the base mat. Slab 129 is the primary load bearing structure resting on the soil or engineered fill which may be at grade, or preferably located deep within a pit formed in the ground so that a majority of the RPV 100 when positioned in RVW 110 is below grade within subterranean cavity 127 of the well. Accordingly, the dead weight load of the concrete RVW 120 and RPV 100 are transferred downwards to the massive foundation slab 129 by the RVW sidewall and base mat.

[0030] In one embodiment, the RVW 110 is lined with a cylindrical double-walled RVW liner assembly 130 comprising an inner liner 131 and outer liner 132. Inner liner 131 comprises a vertical cylindrical inner shell 131A fixedly coupled at its perimeter to a circular flat bottom plate 131B via seal welding. Similarly, outer liner 132 comprises a vertical cylindrical outer shell 132A and a circular flat bottom plate 132B. Each bottom plate 131B, 132B is coupled to the bottom end of its respective shell 131A, 132A via seal welding to form a leak-resistant joint therebetween. Inner liner 131 is nested inside outer liner 132 in a concentric relationship. Bottom plate 132B of the outer liner 132 is seated atop the base mat 121 of RVW 110 when installed. The bottom plates 131B, 132B may have a greater thickness than the shells 131A, 132A since the bottom plates carry the weight load of the shells down to the base mat 121. Typical thicknesses which may be used as some non-limiting examples are a shell thickness of about 1/2 inch for inner and outer shells 131A, 132A and bottom plate 131B, 132B thickness of about 1 inch (double the shell wall thickness). The exterior cylindrical side surface of the outer liner 132 may be used as a “mold” for convenience in some embodiments for pouring concrete outside of and around it after seated on the base mat 121 to construct the sidewall 123 of the RVW. In such a case, the inside surface 123A of the concrete sidewall 123 takes on the cylindrical shape of and is in conformal contact with the vertical shell 132A of outer liner 132 with no real measurable space therebetween. The RVW liners 131, 132 may be formed of steel such as stainless steel or epoxy-coated carbon steel for corrosion resistance. Other metallic materials could be used.

[0031] According to one aspect of the invention, the RVW liner 130 is configured to prevent overheating the concrete of the RVW 120. As previously described herein, it is important that the concrete temperature of the RVW 120 not exceed the prescribed 150 Deg. F (degrees Fahrenheit) temperature limit to avoid deterioration and damage. To meet these concrete temperature restrictions, inner shell 131A of the inner liner 131 may be spaced radially apart from outer shell 132A of outer liner 132 by an annular space 133. The annular space extends from the liner assembly bottom plates 131B, 132B vertically upwards to the top ends of the shells 131A, 132A. Annular space 133 in the RVW liner system is filled with thermal insulation such as in one non-limiting embodiment a high efficiency radiation resistant non-organic insulation 134 (RRNI) that extends for the full height of the RVW 120 to the extent practicable. Suitable commercially-available insulating materials of this type include ceramic fiber insulations such as K-Wool and others. The double wall construction of the RVW liner 130 ensures that the RRNI remains encapsulated, protected, and has no direct contact with the RPV.

[0032] Annular space 133 may have any suitable width W1 in dimension measured between inner and outer shells 131A, 132A of the liner assembly 130. In one embodiment, W1 is preferably is substantially greater than the thickness of either the inner shell or outer shell alone or in combination. A non-limiting example width W1 is about 6 inches or more in some embodiments to be able to pack the necessary amount of thermal insulation 134 in the annular space. The inner and outer shells 131A, 132A in this example by contrast may have a thickness T3, T4 respectively of only about 1/2 inch each. Accordingly, W1 may be equal to or greater than 10 times either thickness T3 or T4 alone in some embodiments.

[0033] The relatively large annular space 133 between the inner and outer liner shells 131A, 132A allows a sufficient amount of thermal insulation 134 to be packed into the annular space 133 to minimize flow of heat radially outward from the RPV emitted by the nuclear fuel core to the concrete sidewall 123. Both the size of the annular space and type of insulation used is selected to prevent overheating the concrete of the RVW 120 which can degrade the concrete and its strength over time when exposed to high temperatures as noted in the foregoing Background section of this written description. The annular space dimensions and insulation are therefore preferably selected so that heat transmission is decreased to the point where the concrete is heated to a temperature that does not exceed the prescribed 150 Deg. F (degrees Fahrenheit).

[0034] In a similar vane to protect the concrete base mat 121 of RVW 120 from degradation caused by excessive heat over time, the bottom plate 131B of inner shell is spaced vertically apart from bottom plate 132B of the outer shell 132 by a vertical gap 135 which is filled with insulation 134 (e.g., RRNI). Vertical gap 135 may similarly have a height H1 of about 6 inches or more in some embodiments as needed to pack enough insulation so that the temperature of the base mat 121 does not exceed the prescribed 150 Deg. F. The bottom plates 131B, 132B may have the same thickness T3, T4 as the inner and outer liner shells 131A, 132A respectively of only about 1/2 inch each. Accordingly, W1 may be greater than 10 times the thickness T3 or T4 alone in some embodiments.

[0035] Other annular space 133 and vertical gap 135 dimensions and types of insulation may be used in combination to maintain the temperature of the concrete of the RVW 120 at a level that does not exceed 150 Deg. F. The invention is not limited to the dimensions or type of insulation provided herein as non-limiting examples. The thickness of insulation 134 (e.g., RRNI) is chosen to advantageously eliminate the need for active cooling or forced air circulation via a blower between the inner and outer liners 131, 132 which would otherwise be needed to maintain acceptable concrete temperatures of the RVW 120. The insulation therefore minimizes design complexity and capital, operating, and maintenance costs associated with provision of a blower forced air system.

[0036] It bears noting that the insulation 134 helps compensate for the relatively small radial air gap R1 provided between the vertical shell 101 of RPV 100 and inner shell 131A of RVW liner 130 which may be less than 3 inches in some embodiments. Although the internal cavity 105 of the RPV is filled with primary coolant (including radial gap R1), the amount of heat radiated outwards from the fuel core is substantial which is countered by the insulation 134 between the inner and outer liners 131, 132. The air gap is minimized to conserve valuable space within the reactor containment building.

[0037] The small radial gap R1 maintained between the inside surface of the RVW inner liner shell 131A and the outside surface of the RPV 100 allows for remote visual inspections of the RPV via commercially-available video inspection devices such as video recorders, cameras, or other techniques. The small gap R1 also advantageously allows for the cavity or well (RVW) inside the RVW liner assembly 130 between the RPV and liner to be filled with water for cooling in the event of a postulated beyond design basis loss-of-coolant accident (LOCA).

[0038] A ring-shaped flat annular seal plate 136 sequesters the RVW space (i.e. subterranean cavity 127) from intrusion of any foreign material or debris into the top of the RVW and cavity. Seal plate 136 is formed of metal and extends circumferentially around the exposed uppermost top end portion of the RPV shell 101 and RPV top head 103 which are elevated above the flat concrete operating deck 126 of the nuclear plant formed in part by the top surface of the RVW sidewall 123 (see, e.g., FIGS. 2 and 8-9).

[0039] In one embodiment, the RPV 100 may be supported in a vertically cantilevered manner within the RVW 120 via a plurality of radial support protrusions or trunnions 150 coupled to the exterior surface of the RPV. The trunnions are cylindrical and in one embodiment may be threaded into oversized tapped holes in the RPV upper portion 101A of the shell 101 for strength which is at least two times as thick as the lower portion 101B of shell as previously described herein. The threaded trunnion mounting connection substantially minimizes the on-site welding operation on trunnions enhancing both modularity and transportability of the RPV (i.e. trunnions may be removed for transport). In other possible embodiments, however, the trunnions may be welded to the RPV shell 101 if necessary. In one embodiment, two pairs of diametrically opposed trunnions 150 may be provided as shown. The trunnions 150 in each pair are circumferentially spaced apart, and each pair is circumferentially spaced apart from the other pair of trunnions. By providing two pairs of trunnions 150 on each side the RPV 100 (i.e. four circumferentially spaced apart support locations), the RPV is vertically locked in position to avoid excessive lateral swaying of the vessel side-to-side during a postulated seismic event is prevented. If a single trunnion were provided on each side, the RPV could swing back and forth in the event of an earthquake using the two trunnions as a pivot axis.

[0040] Each trunnion 150 of the RPV 100 is seated on and disposed inside a corresponding arcuately curved U-shaped saddle 155 supported from a flat horizontal support surface 151 defined by the concrete sidewall 123 of RVW 120. Saddles 155 define upwardly open cavities 155A for receiving the trunnions therein from above to supports the RPV. The support surfaces 151 are each defined and formed at the bottom of inwardly open support recesses 152 which are disposed on the inside surface 123A and upper portion of the RVW sidewall 123. Each recess 152 is vertically elongated. Openings may be formed in the inner and outer liners 131, 132 at circumferential locations corresponding in RVW sidewall 123 to each of the recesses 152 to accommodate the trunnions 150 for insertion into the recesses. Recesses 152 are both inwardly open towards the RPV 100 and upwardly open towards and penetrate the top end of the RVW sidewall 123 as shown to allow the trunnions to enter the recesses and access the saddles 155 from above when the RPV is first lowered and inserted into the RVW 120 by a crane or other hoist apparatus. It bears noting that use of trunnions 150 for the RPV support allows for access into the subterranean cavity 127 from the top of RVW.

[0041] Saddles 155 may each be fixedly mounted via welding to a metallic horizontal flat saddle support plate 156, which in turn is bolted to the concrete support surface 151 in the support recess 152. A thermal insulating gasket material 154 may be interposed between the saddle support plate 156 and support surfaces 151 within support recesses 152 to prevent transmission of heat from the RPV 100 through the trunnions to the RVW sidewall 123 within the recesses thereby preventing the concrete from overheating at the RPV support locations in the sidewall 123.

[0042] The RVW 120 further includes a seismic restraint feature to selectively engage and prevent excessive lateral movement of RPV 100 during a seismic event. Because the RPV is suspended from trunnions 150 located in the upper portion of the vessel, the lower portion and bottom head of the vessel are susceptible to a degree of swaying and lateral/radial movement induced by vibrations stemming from a seismic event. In one embodiment, the seismic restraint feature is a rigid metallic seismic stabilizer 140 comprising a rigid vertically oriented pedestal 141 fixedly anchored in the base mat 121 at the bottom of RVW 120 and a restraint head 142 fixedly coupled to the top end 141A of the pedestal (see, e.g., FIGS. 1-2 and 3). Pedestal 141 may be cylindrical in a preferred but non-limiting embodiments. In one embodiment, restraint head 142 may comprise a centrally-located mounting hole 142C which receives top end 141A of pedestal 141 therethrough for welding to the restraint head.

[0043] The bottom end 141B of the pedestal 141 is preferably deeply embedded for a length in the thick concrete foundation slab 129 of the reactor facility below and adjacent to base mat 121 of the RVW 120 (see, e.g., FIGS. 1-2). In one embodiment, pedestal 141 may extend completely through base mat 121 for embedment in slab 129 for maximum lateral stability and resistance to lateral vibration-induced bending loads imposed on the pedestal by the RPV 100 during a seismic event. An upper portion of the pedestal 141 projects upwards into the subterranean cavity 127 above the base mat 121 to which the restraint head 142 is attached inside the cavity. The pedestal 141 may be formed by a relatively large diameter round bar or preferably a pipe embedded in the concrete base mat 121 and slab 129 in one embodiment. As one non-limiting example, a heavy-walled schedule 160 section of steel pipe (e.g., 28 inch diameter NPS (nominal pipe size or another size)) typically used for high pressure fluid applications may be used for pedestal 141. In some possible embodiments when formed of a pipe section, the pedestal 141 may optionally be filled with concrete for added structural strength and stiffening. In other embodiments, a suitable short vertical structural member section such as an I-beam could be used for the pedestal. As shown in FIG. 1, pedestal 141 is coaxially aligned with vertical centerline axis CL of the RPV 100 when installed in the reactor well (i.e. RVW 120) to that the restraint head 142 of the seismic stabilizer is horizontally/laterally aligned with the center of the RPV bottom head 102 as further described below. It bears noting that the vertical centerline of the cylindrical subterranean cavity 127 is coaxially aligned with the centerline axis CL of the RPV when positioned in the cavity.

[0044] Pedestal 141 projects vertically upwards from the base mat 121 through bottom plates 131B, 132B of RVW liner assembly 130 where it is terminated at top by the seismic restraint head 142 as previously described herein. The restraint head is a predominantly flanged and arcuately curved dished head which is welded to the top end of the pedestal and is diametrically enlarged relative to the diameter of the pedestal 141. Restraint head 142 is positioned at the bottom of the subterranean cavity 127 such that it is laterally engageable with the convexly and arcuately curved dished bottom head 102 of RPV 100 during a seismic event.

[0045] Restraint head 142 of the seismic stabilizer is circular in top view and defines an upwardly open concavity142A which receives the RPV bottom head at least partially therein as shown. The restraint head has a diameter D3 larger than diameter D4 of the pedestal 141 which may be about nominally 28 inches for a 29 inch NPS pipe. As one non-limiting example, the restraint head may have an outside diameter D1 of about 80 inches and a wall thickness of 1.5 inches. Other suitable dimensions may be used commensurate with the diameter and curvature of the RPV bottom head 102 so long as the restraint head is able to receive the bottom head 102 of RPV 100 at least partially therein. Accordingly, restraint head 142 may be considered cup-shaped in structure and is configured to extend partially upwards along the sides of the RPV bottom head 102 when received in concavity 142A and completely encircles the RPV bottom head. Restraint head 142

[0046] When the RPV 100 is installed in the RVW 120, a small clearance gap G1 is provided between the RPV bottom head 102 and the seismic stabilizer restraint head 142 and pedestal top end 141A within its concavity 142A to permit free thermal expansion of the RPV 100 when heated under normal operating conditions by the fuel core. Preferably, gap G1 is maintained at all times during normal operation of the RPV 100 when a seismic event is not occurring such that there is no contact between the bottom head 102 and restraint head 142. Gap G1 may be about 1 inch for example in some embodiments; however, any suitable gap may be used depending on how much the RPV 100 grows vertically when heated to avoid contact with the restraint head 142 of the seismic stabilizer. Gap G1 allows for a small relative lateral movement before engagement between the RPV bottom head and restraint head in the event of a Design Basis Earthquake (DBE). The side portions of the RPV bottom head 102 laterally engage the restraint head 142 during the event. There is typically no contact between the bottom of the RPV bottom head and the restraint head 142 even during a seismic event as contact occurs along the sides of the restraint head. The seismic stabilizer 140 ensures that the RPV is supported by more than just the trunnions 150 of the reactor support structure at top of the RPV and not left as an entirely freely hanging suspended vertical cantilever during a DBE. Accordingly, the seismic stabilizer 140 advantageously engages and arrests lateral movement particularly of the lower portion of the RPV 100 during the DBE so that the vessel does not impact the RVW liner assembly 130 adjacent to the side shell 101 of the RPV to prevent damage to the vessel and liners.

[0047] Remote access to the bottom head 102 of RPV 100 for remote visual inspection may be provided via one or preferably more inspection holes 142B provided through the dished restraint head 142 of seismic stabilizer 140 and a laterally-extending manway 144 in concrete sidewall 123 of the RVW 120 (see, e.g., FIG. 3). Manway 144 is formed through the bottom portion of concrete sidewall 123 adjacent to and above the base mat 121 to gain access into the RVW subterranean cavity 123. A plurality of circumferentially spaced apart inspection holes 142B may be provided to allow access to all parts of the RPV bottom head 102 for remote visual inspection. Inspection holes 142B may be circular or other suitable shapes.

[0048] The RPV 100 may be optionally coated with a high temperature-tolerant glossy paint to minimize the emissivity of its external surfaces within the RVW 120. Alternatively, an alloy thermal spray may be used with the added advantage of protection against corrosion.

[0049] As previously described herein, the RVW liner assembly 130 exterior cylindrical side surface of the outer liner 132 may be used as a concrete form or "mold" for convenience in some embodiments for forming the sidewall 123 of the RVW 120.

[0050] A process or method for constructing the RVW in one embodiment may including the following steps: pouring the flat concrete base mat 121 in a void below grade; seating the RVW liner assembly 130 on the base mat, the liner assembly including an inner liner 131, an outer liner 132, and thermal insulation interposed between the inner and outer liners; pouring concrete around an exterior of the outer liner to a height to form a concrete sidewall 123, wherein the sidewall is in conformal contact with the outer liner. The sidewall may have a height coextensive with a height of the liner assembly.

[0051] Example Embodiments

[0052] 1. A nuclear reactor well for supporting a reactor substantially below grade comprising:

a concrete base mat;

a concrete sidewall extending vertically upwards from the base mat and defining a subterranean cavity configured for housing a reactor pressure vessel;

a liner assembly disposed in the subterranean cavity, the liner assembly comprising an outer liner having portions disposed adjacent to the sidewall and the base mat, and an inner liner spaced inwards from the outer liner in the subterranean cavity; and

thermal insulation disposed between the outer and inner liners.

[0053] 2. The nuclear reactor well according to example 1, wherein the sidewall of the nuclear reactor well is cylindrical.

[0054] 3. The nuclear reactor well according to examples 1 or 2, wherein the thermal insulation is operable to prevent heat emitted by the reactor pressure vessel when positioned in the subterranean cavity from overheating the concrete sidewall and base mat.

[0055] 4. The nuclear reactor well according to example 3, wherein the thermal insulation is a radiation resistant non-organic insulation selected and configured so that a temperature of the concrete of the base mat and sidewall does not exceed 150 degrees Fahrenheit.

[0056] 5. The nuclear reactor well according to example 2, wherein the inner and outer liners are formed of metal.

[0057] 6. The nuclear reactor well according to example 5, wherein:

the outer liner comprises a cylindrical first shell adjacent to the sidewall of the nuclear reactor well and a flat first bottom plate welded to the first shell, the first bottom plate seated on the base mat;

the inner liner comprises a cylindrical second shell concentrically aligned with the first shell, and a flat second bottom plate welded to the second shell.

[0058] 7. The nuclear reactor well according to example 6, wherein the first and second shells are spaced radially apart by an annular space filled with the thermal insulation, and the first and second base plates are spaced apart by a vertical gap filled with the thermal insulation.

[0059] 8. The nuclear reactor well according to example 7, wherein each of first and second bottom plates has a greater thickness than their respective first and second shells.

[0060] 9. The nuclear reactor well according to any one of examples 1-8, further comprising a seismic stabilizer fixedly anchored in the base mat at a position below a bottom head of the reactor pressure vessel when present in the subterranean cavity.

[0061] 10. The nuclear reactor well according to example 9, wherein the seismic stabilizer comprises a rigid vertically elongated pedestal having a lower portion embedded in the base mat and an upper portion projecting upwards into the subterranean cavity above the base mat, and a radially enlarged dish-shaped restraint head fixedly coupled to a top end of the pedestal.

[0062] 11. The nuclear reactor well according to example 10, wherein the restraint head defines an upwardly open concavity configured to receive the bottom head of the reactor pressure vessel at least partially therein.

[0063] 12. The nuclear reactor well according to example 11, wherein a clearance gap is provided within the concavity between the restraint head and bottom head of the reactor pressure vessel when present in the subterranean cavity so that there is no contact therebetween in the absence of a seismic event.

[0064] 13. The nuclear reactor well according to example 12, wherein the restraint head is configured and operable to laterally engage the bottom head of reactor pressure vessel during a seismic event to arrest lateral movement of the reactor pressure vessel.

[0065] 14. The nuclear reactor well according to examples 12 or 13, wherein the restraint head includes one or more inspection holes to access the bottom head of the reactor pressure vessel when present in the subterranean cavity for remote visual inspection.

[0066] 15. The nuclear reactor well according any one of examples 10-14, wherein the pedestal is coaxially aligned with a vertical centerline axis of the reactor pressure vessel when present in the subterranean cavity.

[0067] 16. The nuclear reactor well according to any one of examples 1-15, wherein the sidewall of the nuclear reactor well includes a plurality of vertically elongated support recesses formed in an interior surface thereof, each of the support recesses including an arcuately curved saddle configured to receive one of a plurality of radial support trunnions fixedly coupled to an exterior surface of the reactor pressure vessel when inserted into the subterranean cavity.

[0068] 17. The nuclear reactor well according to example 16, wherein the support recesses are inwardly and upwardly open such that the support recesses penetrate and extend downward from a top end of the sidewall.

[0069] 18. The nuclear reactor well according to examples 16 or 17, wherein each saddle includes a flat saddle support plate at bottom bolted to a horizontal support surface located at a bottom of each support recess.

[0070] 19. The nuclear reactor well according to example 18, further comprising thermal insulating gasket material interposed between each saddle support plate and its respective support surface in each support recess.

[0071] 20. The nuclear reactor well according to any one of examples 1-19, wherein the subterranean cavity has a height so that a majority of the reactor pressure vessel is received in the subterranean cavity when emplaced therein.

[0072] 21. The nuclear reactor well according to example 1, further comprising a manway extending through the sidewall adjacent to the base mat for accessing the subterranean cavity.

[0073] 22. A system for supporting and housing a nuclear reactor in a subterranean vault comprising:

a concrete base mat;

a concrete sidewall extending vertically upwards from the base mat and defining a subterranean cavity;

a reactor pressure vessel disposed in the subterranean cavity and defining a vertical centerline axis, the reactor pressure vessel comprising a bottom head, a removable top head, and a cylindrical shell extending between the heads defining an internal cavity which holds a nuclear fuel core;

the reactor pressure vessel further comprising a plurality of radial support trunnions coupled to the shell, each support trunnion received in a saddle disposed in a support recess formed in an interior surface of the sidewall to support the reactor pressure vessel in a vertically cantilevered suspended manner inside the subterranean cavity;

a seismic stabilizer fixedly anchored in the base mat at a position below the bottom head of the reactor pressure vessel;

wherein the seismic stabilizer is configured and operable to engage the bottom head of the reactor pressure vessel during a seismic event to arrest lateral movement of the reactor pressure vessel.

[0074] 23. The system according to example 22, wherein the trunnions are threadably coupled to an upper portion of the shell having a greater wall thickness and a lower portion of the shell.

[0075] 24. The system according to example 23, wherein two diametrically opposed pairs of trunnions are coupled to the shell.

[0076] 25. The system according to example 22, wherein the seismic stabilizer comprises a rigid vertically elongated pedestal having a lower portion embedded in the base mat and an upper portion projecting upwards into the subterranean cavity above the base mat, and a diametrically enlarged dish-shaped restraint head fixedly coupled to a top end of the pedestal.

[0077] 26. The system according to example 25, wherein the restraint head defines an upwardly open concavity configured to receive the bottom head of the reactor pressure vessel at least partially therein.

[0078] 27. The system according to example 26, wherein a clearance gap is provided within the concavity between the restraint head and bottom head of the reactor pressure vessel when present in the subterranean cavity so that there is no contact therebetween in the absence of a seismic event.

[0079] 28. The system according to example 27, wherein the restraint head is configured and operable to laterally engage the bottom head of reactor pressure vessel during a seismic event to arrest lateral movement of the reactor pressure vessel.

[0080] 29. The system according to example 26, wherein the restraint head includes one or more inspection holes to access the bottom head of the reactor pressure vessel when present in the subterranean cavity for remote visual inspection.

[0081] 30. The system according any one of examples 25-29, wherein the pedestal is coaxially aligned with the vertical centerline axis of the reactor pressure vessel.

[0082] 31. The system according to example 22, wherein the support recesses are inwardly and upwardly open such that the support recesses penetrate and extend downward from a top end of the sidewall.

[0083] 32. The system according to example 31, wherein the saddles are arcuately curved and the trunnions are cylindrical.

[0084] 33. The system according to example 32, wherein each saddle includes a flat saddle support plate at bottom bolted to a horizontal support surface located at a bottom of each support recess.

[0085] 34. The system according to example 33, further comprising thermal insulating gasket material interposed between each saddle support plate and its respective support surface in each support recess.

[0086] 35. The system according to any one of examples 22-34, wherein the subterranean cavity has a height so that a majority of the reactor pressure vessel is received in the subterranean cavity.

[0087] 36. The system according to any one of examples 22-35, wherein the concrete sidewall has a cylindrical configuration.

[0088] 37. The system according to example 36, further comprising a liner system including:

a metal outer liner comprising a cylindrical first shell adjacent to the sidewall and a flat first bottom plate welded to the first shell, the first bottom plate seated on the base mat;

a metal inner liner comprising a cylindrical second shell concentrically aligned with the first shell, and a flat second bottom plate welded to the second shell.

[0089] 38. The system according to example 37, wherein the first and second shells are spaced radially apart by an annular space filled with thermal insulation, and the first and second base plates are spaced apart by a vertical gap filled with radiation resistant thermal insulation.

[0090] 39. The system according to examples 37 or 38, wherein each of first and second bottom plates have a greater thickness than their respective first and second shells.

[0091] 40. The system according to examples 38 or 39, wherein the annular space has a width greater than a thickness of the first shell or the second shell, and the vertical gap has a height greater than a thickness of the first bottom plate or the second bottom plate.

[0092] While the foregoing description and drawings represent some example systems, it will be understood that various additions, modifications and substitutions may be made therein without departing from the spirit and scope and range of equivalents of the accompanying claims. In particular, it will be clear to those skilled in the art that the present invention may be embodied in other forms, structures, arrangements, proportions, sizes, and with other elements, materials, and components, without departing from the spirit or essential characteristics thereof. In addition, numerous variations in the methods/processes described herein may be made. One skilled in the art will further appreciate that the invention may be used with many modifications of structure, arrangement, proportions, sizes, materials, and components and otherwise, used in the practice of the invention, which are particularly adapted to specific environments and operative requirements without departing from the principles of the present invention. The presently disclosed embodiments are therefore to be considered in all respects as illustrative and not restrictive, the scope of the invention being defined by the appended claims and equivalents thereof, and not limited to the foregoing description or embodiments. Rather, the appended claims should be construed broadly, to include other variants and embodiments of the invention, which may be made by those skilled in the art without departing from the scope and range of equivalents of the invention.

CLAIMS

What is claimed is:

1. A nuclear reactor well for supporting a reactor substantially below grade comprising:

a concrete base mat;

a concrete sidewall extending vertically upwards from the base mat and defining a subterranean cavity configured for housing a reactor pressure vessel;

a liner assembly disposed in the subterranean cavity, the liner assembly comprising an outer liner having portions disposed adjacent to the sidewall and the base mat, and an inner liner spaced inwards from the outer liner in the subterranean cavity; and

thermal insulation disposed between the outer and inner liners.

2. The nuclear reactor well according to claim 1, wherein the sidewall of the nuclear reactor well is cylindrical.

3. The nuclear reactor well according to claims 1 or 2, wherein the thermal insulation is operable to prevent heat emitted by the reactor pressure vessel when positioned in the subterranean cavity from overheating the concrete sidewall and base mat.

4. The nuclear reactor well according to claim 3, wherein the thermal insulation is a radiation resistant non-organic insulation selected and configured so that a temperature of the concrete of the base mat and sidewall does not exceed 150 degrees Fahrenheit.

5. The nuclear reactor well according to claim 2, wherein the inner and outer liners are formed of metal.

6. The nuclear reactor well according to claim 5, wherein:

the outer liner comprises a cylindrical first shell adjacent to the sidewall of the nuclear reactor well and a flat first bottom plate welded to the first shell, the first bottom plate seated on the base mat;

the inner liner comprises a cylindrical second shell concentrically aligned with the first shell, and a flat second bottom plate welded to the second shell.

7. The nuclear reactor well according to claim 6, wherein the first and second shells are spaced radially apart by an annular space filled with the thermal insulation, and the first and second base plates are spaced apart by a vertical gap filled with the thermal insulation.

8. The nuclear reactor well according to claim 7, wherein each of first and second bottom plates has a greater thickness than their respective first and second shells.

9. The nuclear reactor well according to any one of claims 1-8, further comprising a seismic stabilizer fixedly anchored in the base mat at a position below a bottom head of the reactor pressure vessel when present in the subterranean cavity.

10. The nuclear reactor well according to claim 9, wherein the seismic stabilizer comprises a rigid vertically elongated pedestal having a lower portion embedded in the base mat and an upper portion projecting upwards into the subterranean cavity above the base mat, and a radially enlarged dish-shaped restraint head fixedly coupled to a top end of the pedestal.

11. The nuclear reactor well according to claim 10, wherein the restraint head defines an upwardly open concavity configured to receive the bottom head of the reactor pressure vessel at least partially therein.

12. The nuclear reactor well according to claim 11, wherein a clearance gap is provided within the concavity between the restraint head and bottom head of the reactor pressure vessel when present in the subterranean cavity so that there is no contact therebetween in the absence of a seismic event.

13. The nuclear reactor well according to claim 12, wherein the restraint head is configured and operable to laterally engage the bottom head of reactor pressure vessel during a seismic event to arrest lateral movement of the reactor pressure vessel.

14. The nuclear reactor well according to claims 12 or 13, wherein the restraint head includes one or more inspection holes to access the bottom head of the reactor pressure vessel when present in the subterranean cavity for remote visual inspection.

15. The nuclear reactor well according any one of claims 10-14, wherein the pedestal is coaxially aligned with a vertical centerline axis of the reactor pressure vessel when present in the subterranean cavity.

16. The nuclear reactor well according to any one of claims 1-15, wherein the sidewall of the nuclear reactor well includes a plurality of vertically elongated support recesses formed in an interior surface thereof, each of the support recesses including an arcuately curved saddle configured to receive one of a plurality of radial support trunnions fixedly coupled to an exterior surface of the reactor pressure vessel when inserted into the subterranean cavity.

17. The nuclear reactor well according to claim 16, wherein the support recesses are inwardly and upwardly open such that the support recesses penetrate and extend downward from a top end of the sidewall.

18. The nuclear reactor well according to claims 16 or 17, wherein each saddle includes a flat saddle support plate at bottom bolted to a horizontal support surface located at a bottom of each support recess.

19. The nuclear reactor well according to claim 18, further comprising thermal insulating gasket material interposed between each saddle support plate and its respective support surface in each support recess.

20. The nuclear reactor well according to any one of claims 1-19, wherein the subterranean cavity has a height so that a majority of the reactor pressure vessel is received in the subterranean cavity when emplaced therein.

21. The nuclear reactor well according to claim 1, further comprising a manway extending through the sidewall adjacent to the base mat for accessing the subterranean cavity.

22. A system for supporting and housing a nuclear reactor in a subterranean vault comprising:

a concrete base mat;

a concrete sidewall extending vertically upwards from the base mat and defining a subterranean cavity;

a reactor pressure vessel disposed in the subterranean cavity and defining a vertical centerline axis, the reactor pressure vessel comprising a bottom head, a removable top head, and a cylindrical shell extending between the heads defining an internal cavity which holds a nuclear fuel core;

the reactor pressure vessel further comprising a plurality of radial support trunnions coupled to the shell, each support trunnion received in a saddle disposed in a support recess formed in an interior surface of the sidewall to support the reactor pressure vessel in a vertically cantilevered suspended manner inside the subterranean cavity;

a seismic stabilizer fixedly anchored in the base mat at a position below the bottom head of the reactor pressure vessel;

wherein the seismic stabilizer is configured and operable to engage the bottom head of the reactor pressure vessel during a seismic event to arrest lateral movement of the reactor pressure vessel.

23. The system according to claim 22, wherein the trunnions are threadably coupled to an upper portion of the shell having a greater wall thickness and a lower portion of the shell.

24. The system according to claim 23, wherein two diametrically opposed pairs of trunnions are coupled to the shell.

25. The system according to claim 22, wherein the seismic stabilizer comprises a rigid vertically elongated pedestal having a lower portion embedded in the base mat and an upper portion projecting upwards into the subterranean cavity above the base mat, and a diametrically enlarged dish-shaped restraint head fixedly coupled to a top end of the pedestal.

26. The system according to claim 25, wherein the restraint head defines an upwardly open concavity configured to receive the bottom head of the reactor pressure vessel at least partially therein.

27. The system according to claim 26, wherein a clearance gap is provided within the concavity between the restraint head and bottom head of the reactor pressure vessel when present in the subterranean cavity so that there is no contact therebetween in the absence of a seismic event.

28. The system according to claim 27, wherein the restraint head is configured and operable to laterally engage the bottom head of reactor pressure vessel during a seismic event to arrest lateral movement of the reactor pressure vessel.

29. The system according to claim 26, wherein the restraint head includes one or more inspection holes to access the bottom head of the reactor pressure vessel when present in the subterranean cavity for remote visual inspection.

30. The system according any one of claims 25-29, wherein the pedestal is coaxially aligned with the vertical centerline axis of the reactor pressure vessel.

31. The system according to claim 22, wherein the support recesses are inwardly and upwardly open such that the support recesses penetrate and extend downward from a top end of the sidewall.

32. The system according to claim 31, wherein the saddles are arcuately curved and the trunnions are cylindrical.

33. The system according to claim 32, wherein each saddle includes a flat saddle support plate at bottom bolted to a horizontal support surface located at a bottom of each support recess.

34. The system according to claim 33, further comprising thermal insulating gasket material interposed between each saddle support plate and its respective support surface in each support recess.

35. The system according to any one of claims 22-34, wherein the subterranean cavity has a height so that a majority of the reactor pressure vessel is received in the subterranean cavity.

36. The system according to any one of claims 22-35, wherein the concrete sidewall has a cylindrical configuration.

37. The system according to claim 36, further comprising a liner system including:

a metal outer liner comprising a cylindrical first shell adjacent to the sidewall and a flat first bottom plate welded to the first shell, the first bottom plate seated on the base mat;

a metal inner liner comprising a cylindrical second shell concentrically aligned with the first shell, and a flat second bottom plate welded to the second shell.

38. The system according to claim 37, wherein the first and second shells are spaced radially apart by an annular space filled with thermal insulation, and the first and second base plates are spaced apart by a vertical gap filled with radiation resistant thermal insulation.

39. The system according to claims 37 or 38, wherein each of first and second bottom plates have a greater thickness than their respective first and second shells.

40. The system according to claims 38 or 39, wherein the annular space has a width greater than a thickness of the first shell or the second shell, and the vertical gap has a height greater than a thickness of the first bottom plate or the second bottom plate.

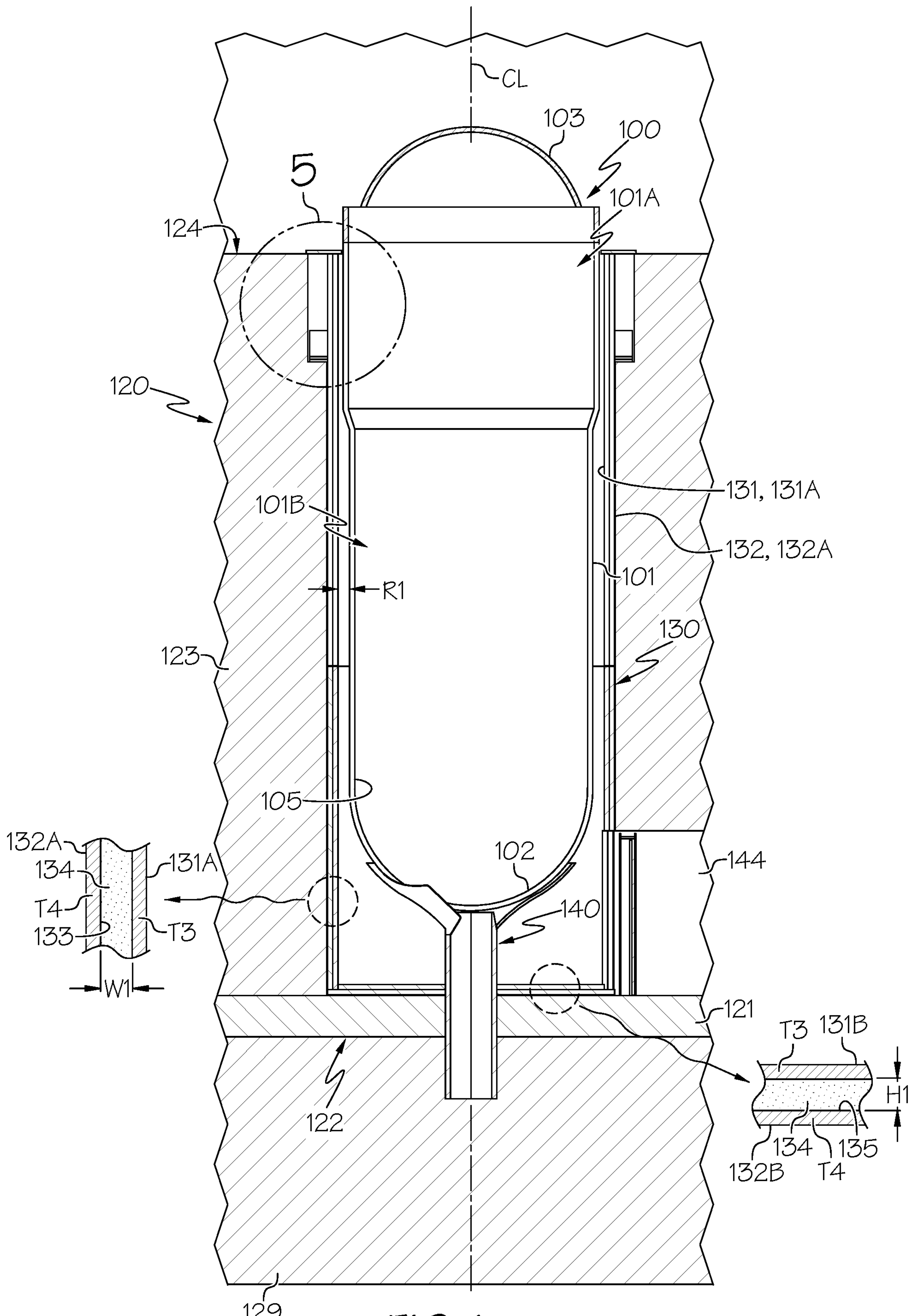
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FIG. 1

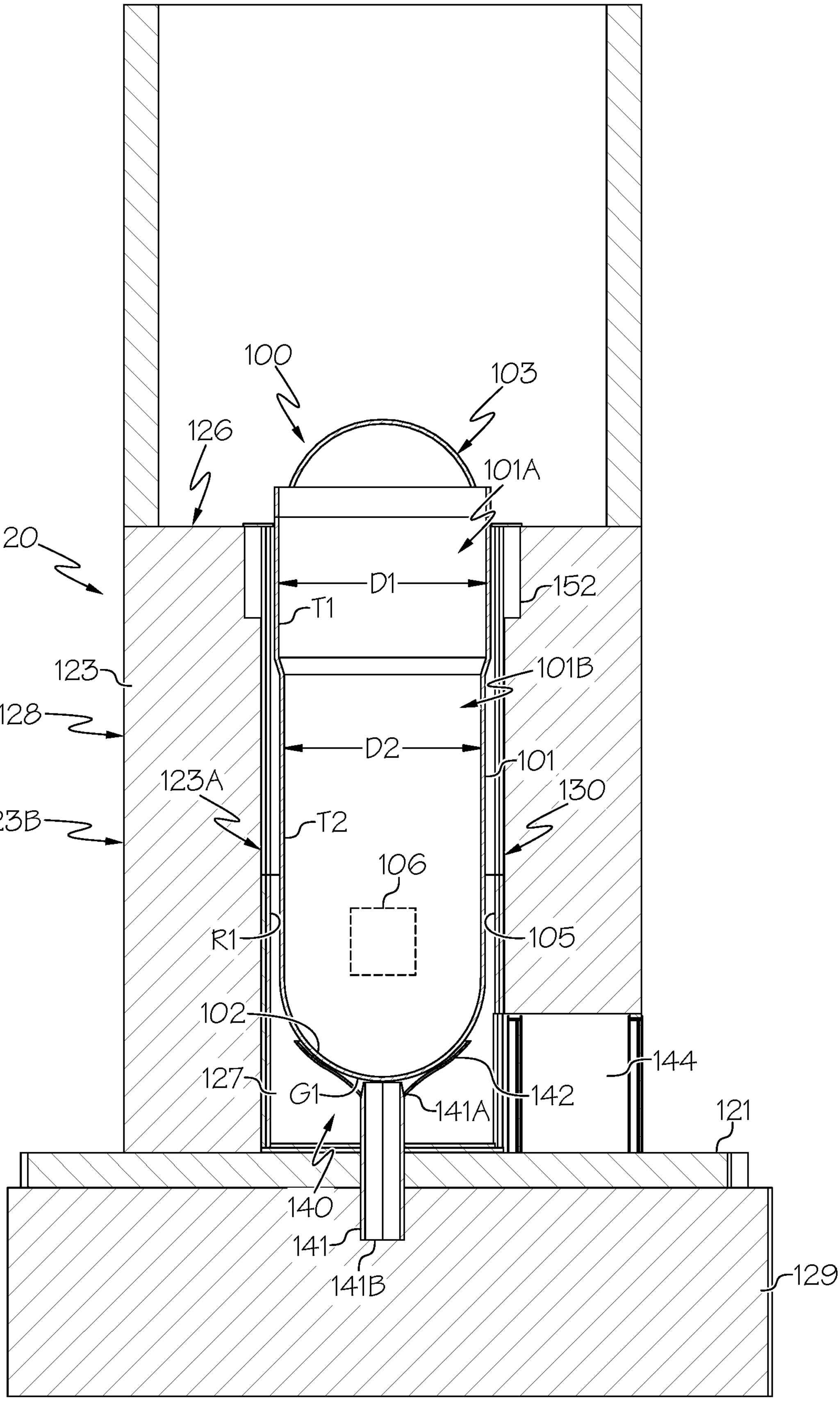
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FIG. 2

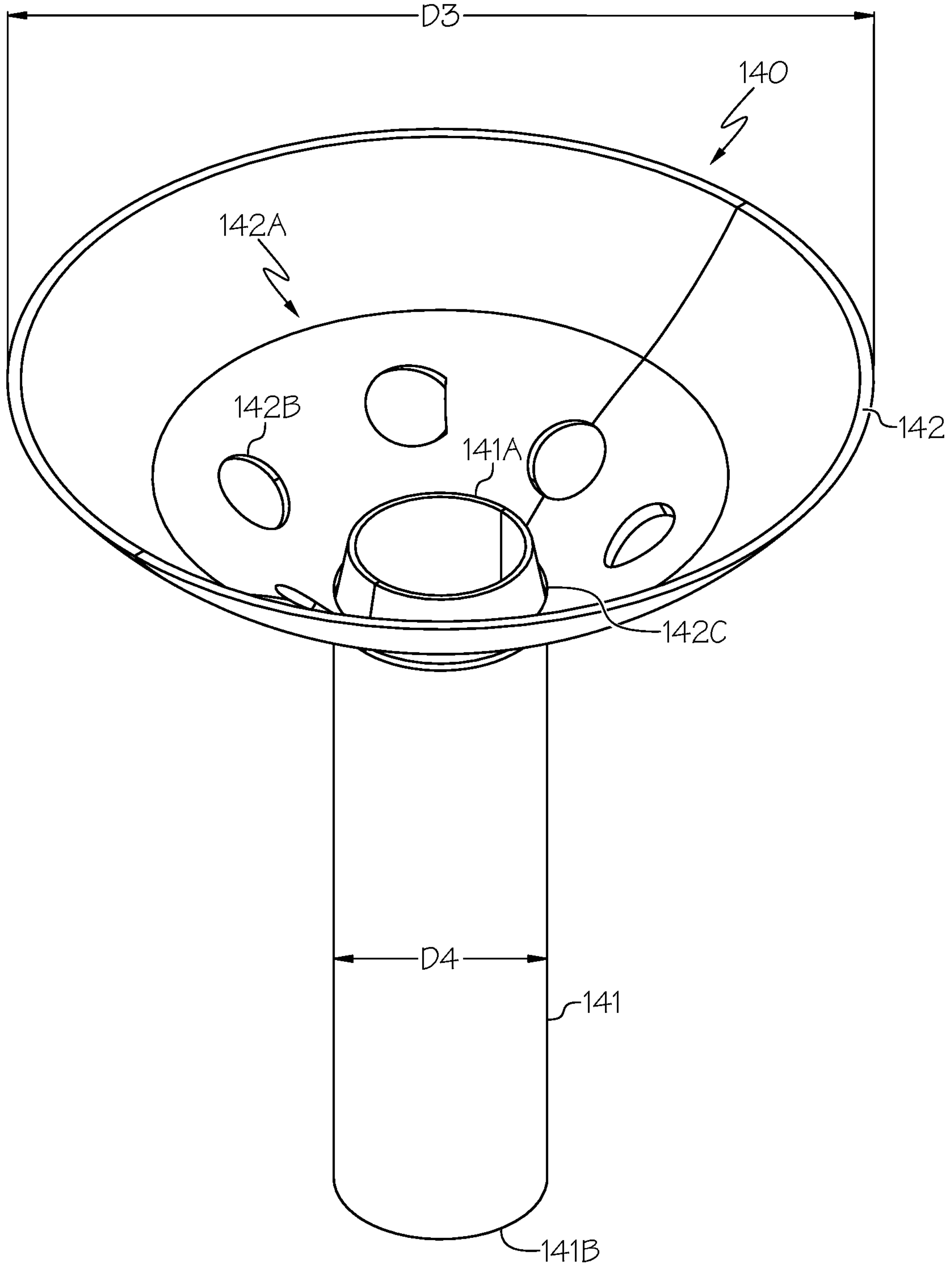

FIG. 3

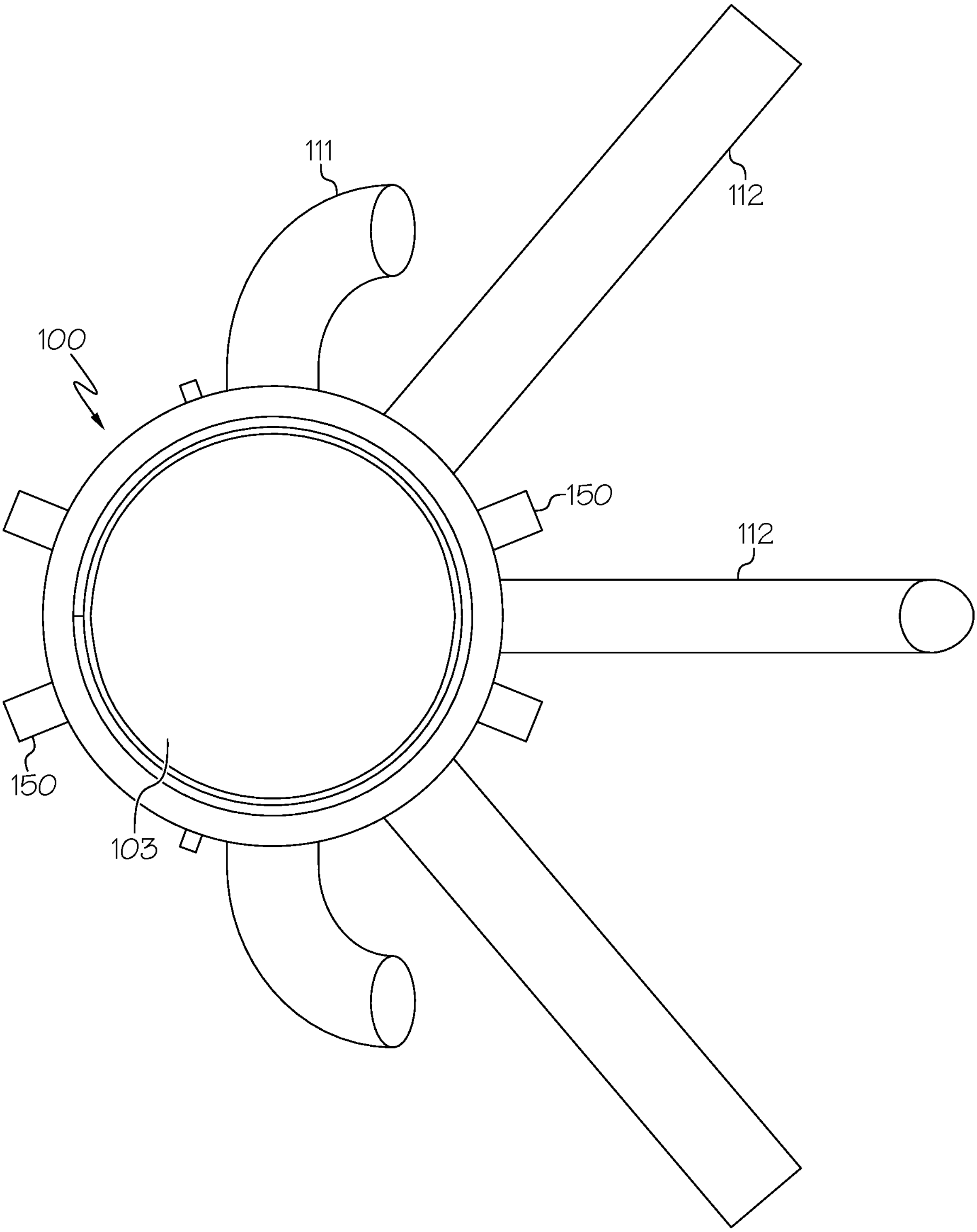

FIG. 4

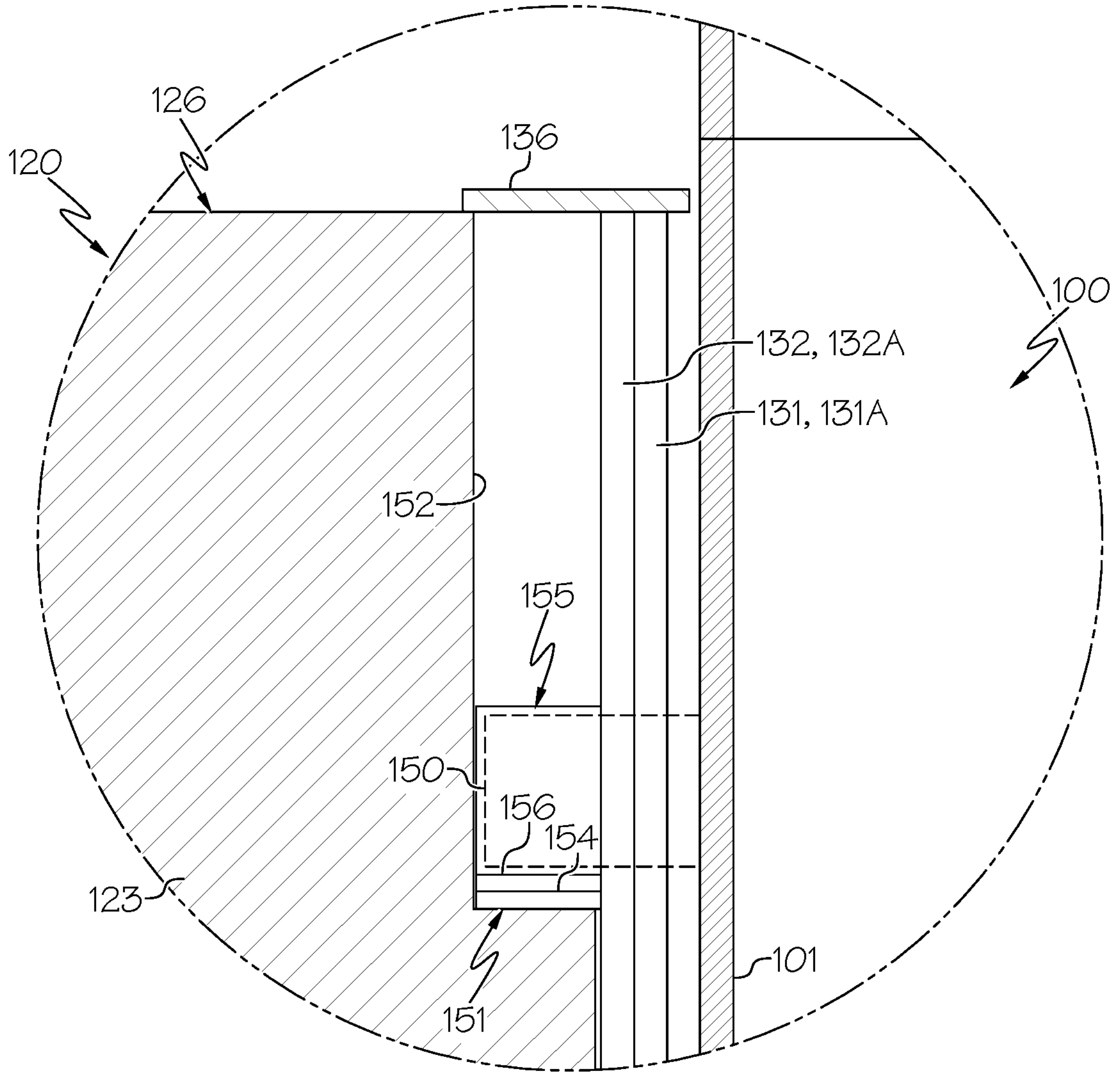
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FIG. 5

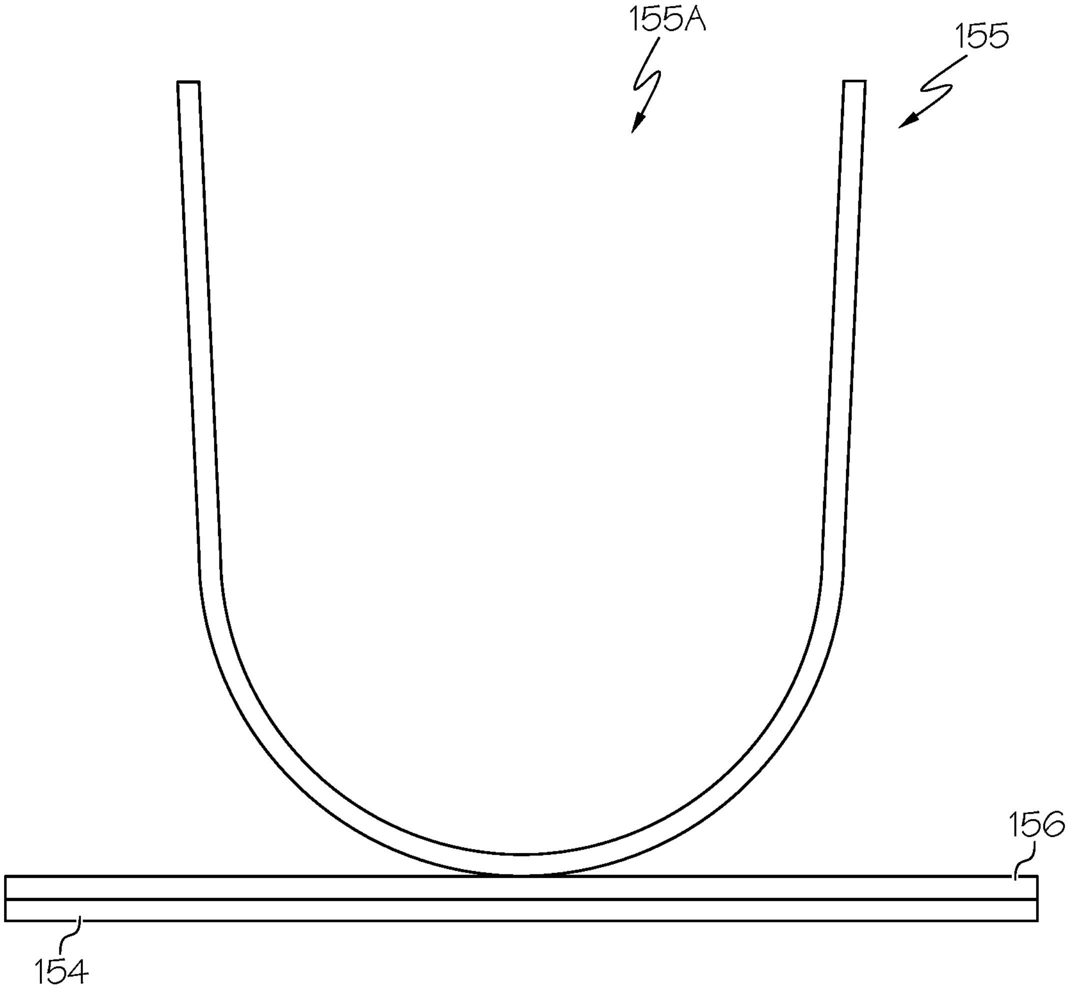

FIG. 6

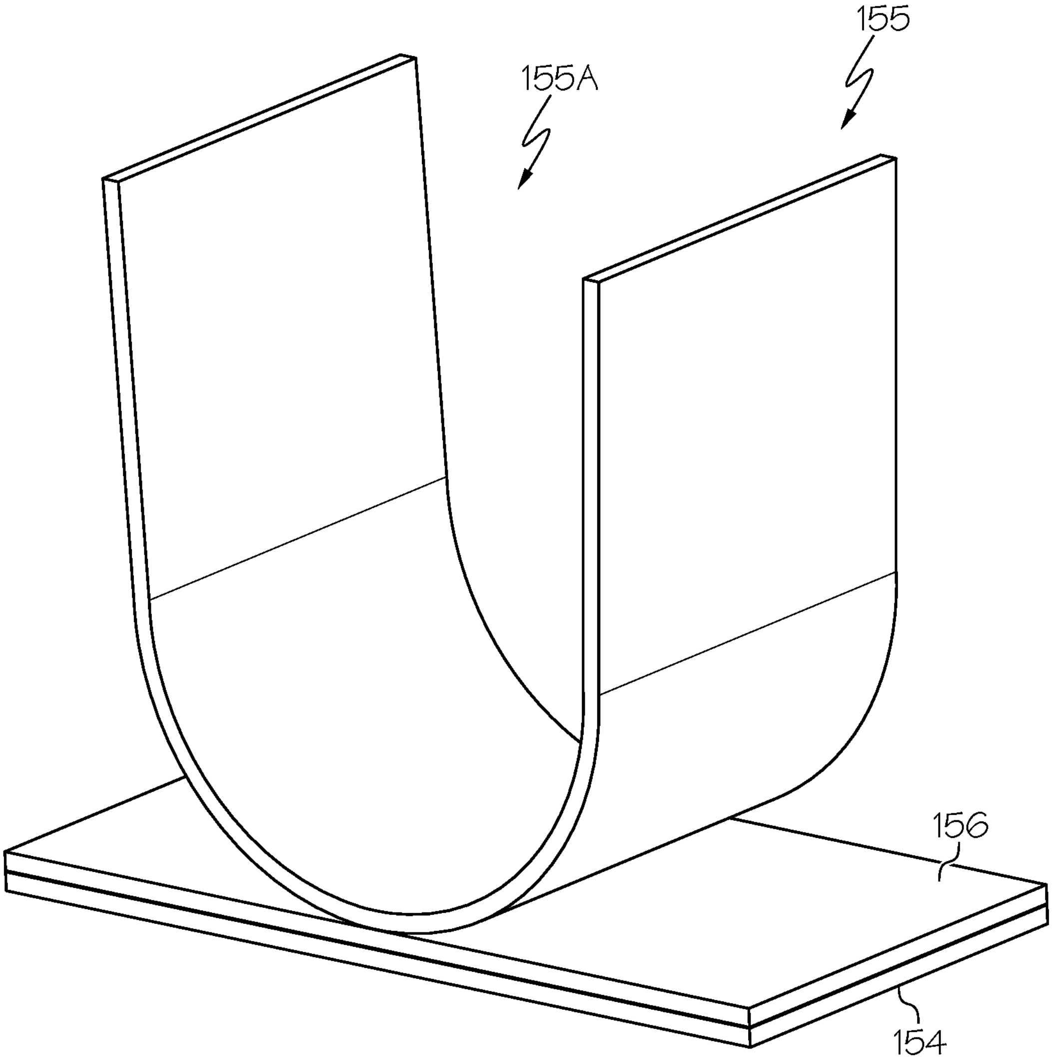

FIG. 7

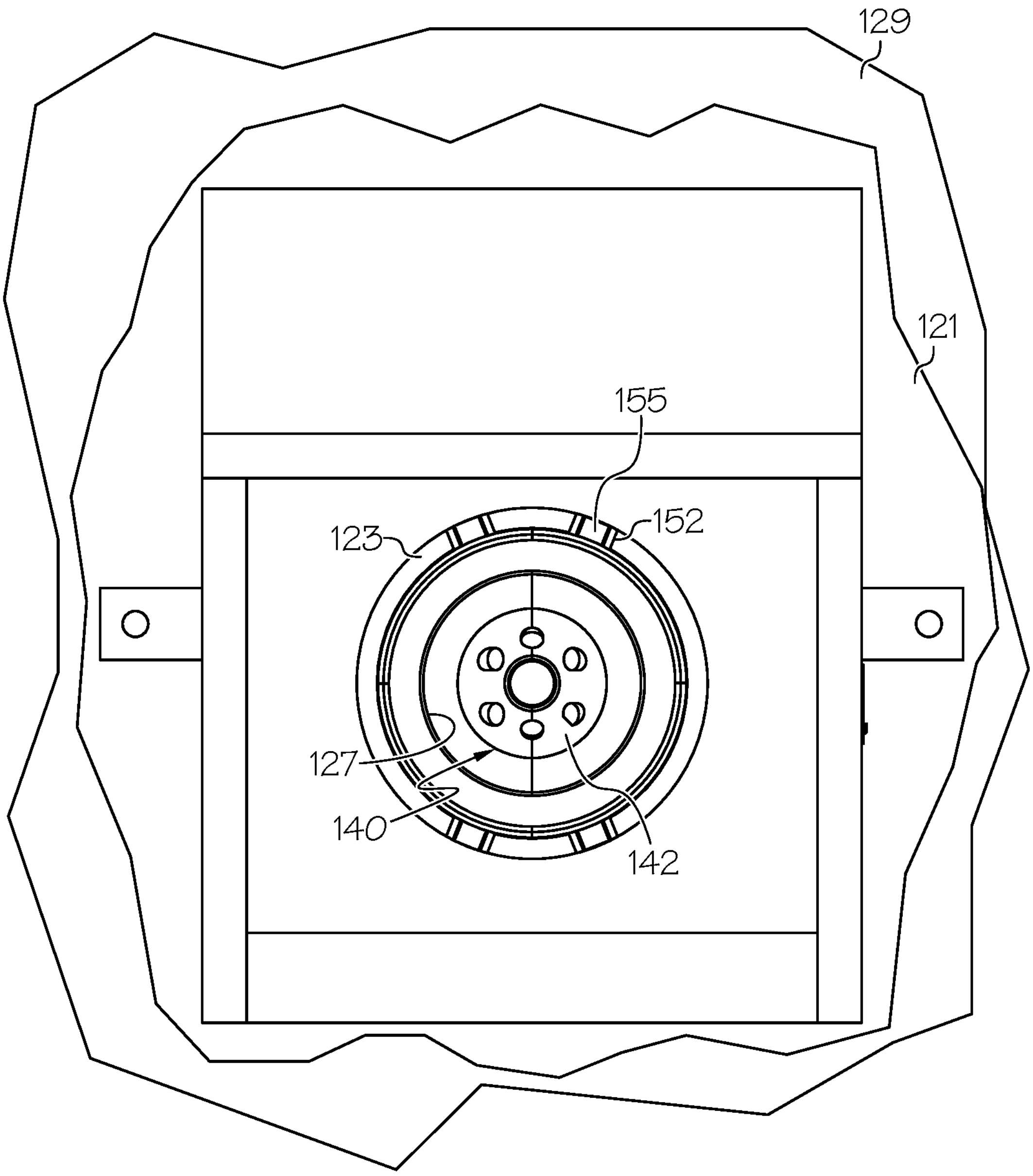

FIG. 8

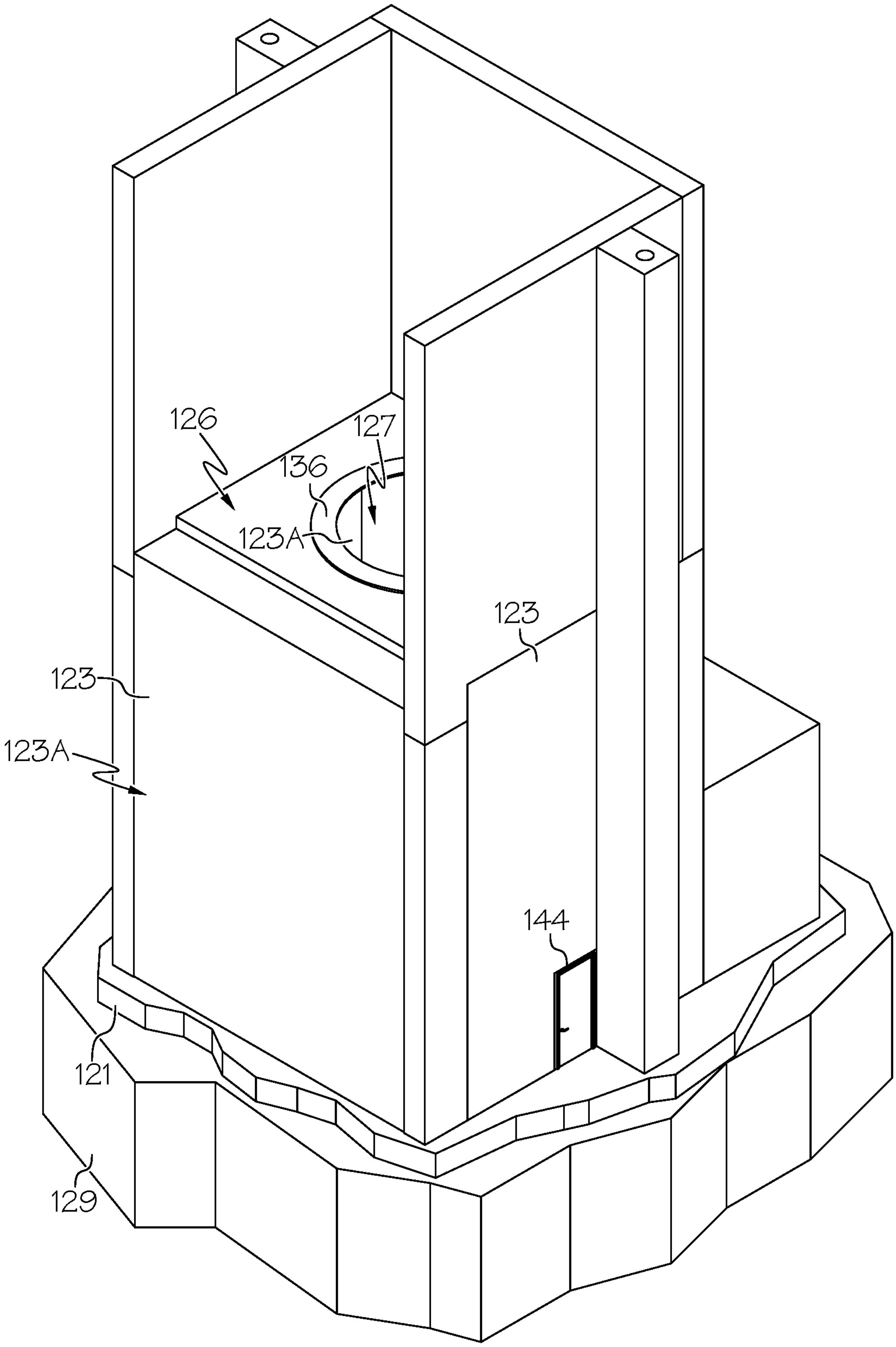

FIG. 9

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2024/061849

A. CLASSIFICATION OF SUBJECT MATTER

IPC: ***G21C 9/04*** (2025.01); ***G21C 11/08*** (2025.01); ***G21C 13/02*** (2025.01); *G21C 13/10* (2025.01); *G21C 17/007* (2025.01)
CPC: ***G21C 9/04; G21C 11/086; G21C 13/02;*** *G21C 13/10; G21C 17/007*

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)

See Search History Document

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

See Search History Document

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

See Search History Document

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
	US 5,406,602 A (HUNSBEDT et al.) 11 April 1995 (11.04.1995)	
X	Fig 1-5; col 1, ln 29-35; col 2, ln 31-34; col 3, ln 67-68; col 4, ln 1-11, 16-25; col 5, ln 18-23	1-5
Y	Fig 1-5; col 1, ln 29-35; col 2, ln 31-34; col 3, ln 67-68; col 4, ln 1-11, 16-25	6-8, 21
	US 5,307,388 A (INKESTER et al.) 26 April 1994 (26.04.1994)	
Y	Fig 1-2; col 2, ln 31-34, 45-52, 58-65	6-8
	US 3,930,943 A (MICHEL et al.) 06 January 1976 (06.01.1976)	
Y	Fig 1, 3; col 3, ln 45-65; col 5, ln 15-20	21
	US 11,636,956 B2 (COMMISSARIAT A L'ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES) 25 April 2023 (25.04.2023)	
A	entire document	1-8, 21
	US 10,147,506 B2 (BWXT MPOWER, INC.) 04 December 2018 (04.12.2018)	
A	entire document	1-8, 21

☑ 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
"D" document cited by the applicant in the international application
"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	Date of mailing of the international search report
19 February 2025 (19.02.2025)	**21 April 2025 (21.04.2025)**
Name and mailing address of the ISA/US **COMMISSIONER FOR PATENTS** **MAIL STOP PCT, ATTN: ISA/US** **P.O. Box 1450** **Alexandria, VA 22313-1450** **UNITED STATES OF AMERICA** Facsimile No. **571-273-8300**	Authorized officer **KARI RODRIQUEZ** Telephone No. **PCT Help Desk: 571-272-4300**

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 6,757,351 B1 (GOU et al.) 29 June 2004 (29.06.2004) entire document	1-8, 21
L	Article entitled “Research and development of radiation resistant beryllium grades for nuclear fusion applications”; Journal of Nuclear Materials 233-237; Kupriyanov et al. (1996) entire document	4

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2024/061849

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☑ Claims Nos.: **9-20 and 35-40**
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

This application contains the following inventions or groups of inventions which are not so linked as to form a single general inventive concept under PCT Rule 13.1.

Group I: Claims 1-8 and 21, directed to a nuclear reactor well for supporting a reactor substantially below grade.

Group II: Claims 22-34, directed to a system for supporting and housing a nuclear reactor in a subterranean vault.

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☑ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.: **1-8, 21**

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.