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America

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The Director

of the United States Patent and Trademark Office has received an application for a patent for a new and useful invention. The title and description of the invention are enclosed. The requirements of law have been complied with, and it has been determined that a patent on the invention shall be granted under the law.

Therefore, this United States

Patent

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DIRECTOR OF THE UNITED STATES PATENT AND TRADEMARK OFFICE

Maintenance Fee Notice

If the application for this patent was filed on or after December 12, 1980, maintenance fees are due three years and six months, seven years and six months, and eleven years and six months after the date of this grant, or within a grace period of six months thereafter upon payment of a surcharge as provided by law. The amount, number and timing of the maintenance fees required may be changed by law or regulation. Unless payment of the applicable maintenance fee is received in the United States Patent and Trademark Office on or before the date the fee is due or within a grace period of six months thereafter, the patent will expire as of the end of such grace period.

Patent Term Notice

If the application for this patent was filed on or after June 8, 1995, the term of this patent begins on the date on which this patent issues and ends twenty years from the filing date of the application or, if the application contains a specific reference to an earlier filed application or applications under 35 U.S.C. 120, 121, 365(c), or 386(c), twenty years from the filing date of the earliest such application ("the twenty-year term"), subject to the payment of maintenance fees as provided by 35 U.S.C. 41(b), and any extension as provided by 35 U.S.C. 154(b) or 156 or any disclaimer under 35 U.S.C. 253.

If this application was filed prior to June 8, 1995, the term of this patent begins on the date on which this patent issues and ends on the later of seventeen years from the date of the grant of this patent or the twenty-year term set forth above for patents resulting from applications filed on or after June 8, 1995, subject to the payment of maintenance fees as provided by 35 U.S.C. 41(b) and any extension as provided by 35 U.S.C. 156 or any disclaimer under 35 U.S.C. 253.

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(12) United States Patent
Singh

(10) **Patent No.: US 12,548,686 B2**
(45) **Date of Patent: Feb. 10, 2026**

(54) **SYSTEM FOR TRANSPORTING RADIOACTIVE MATERIALS**

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(73) Assignee: **HOLTEC INTERNATIONAL**

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 344 days.

(21) Appl. No.: **18/465,743**

(22) Filed: **Sep. 12, 2023**

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(51) **Int. Cl.**

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G21F 5/00	(2006.01)
G21F 5/008	(2006.01)
G21F 5/08	(2006.01)

(52) **U.S. Cl.**
CPC ***G21F 5/12*** (2013.01); ***G21F 5/008*** (2013.01); ***G21F 5/08*** (2013.01)

(58) **Field of Classification Search**
CPC G21F 5/12; G21F 5/008; G21F 5/08
See application file for complete search history.

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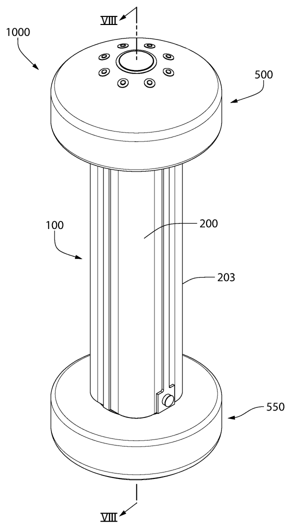
Primary Examiner — Nicole M Ippolito

(74) *Attorney, Agent, or Firm* — The Belles Group, P.C.

(57) **ABSTRACT**

A system for transporting radioactive materials which may include a containment vessel, a thermal shield, and an impact limiter. The containment vessel may include a vessel body having a storage cavity for receiving radioactive materials, a lid coupled to an upper portion of the vessel body to enclose a top end of the storage cavity, and a lid seal such as a gasket positioned between the lid and the upper portion of the vessel body. The thermal shield may be positioned over the lid. The first impact limiter may be positioned over the thermal shield. The thermal shield may be resistant to high temperatures and may help to protect the integrity of the lid seal when the system is subjected to high temperatures, such as during a fire condition.

20 Claims, 15 Drawing Sheets



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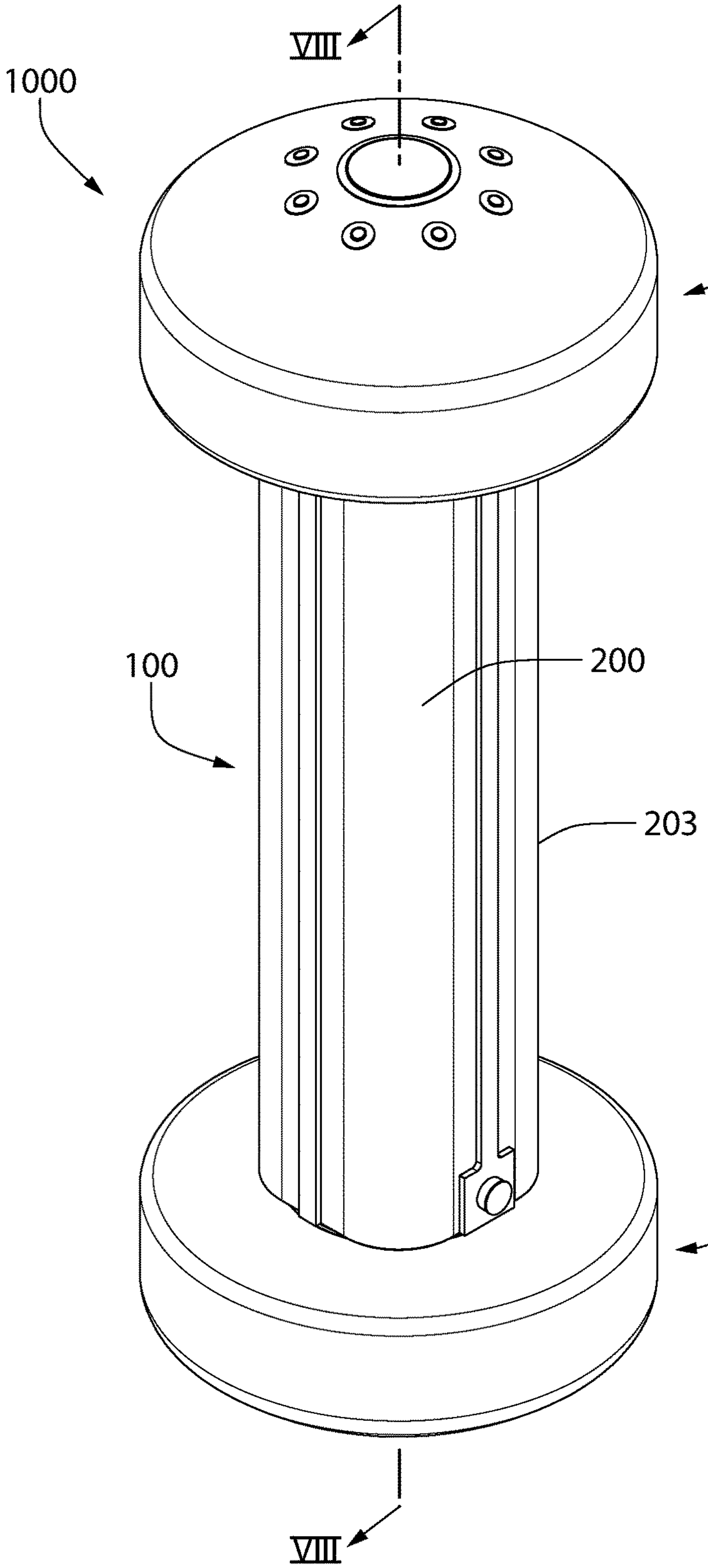


FIG. 1

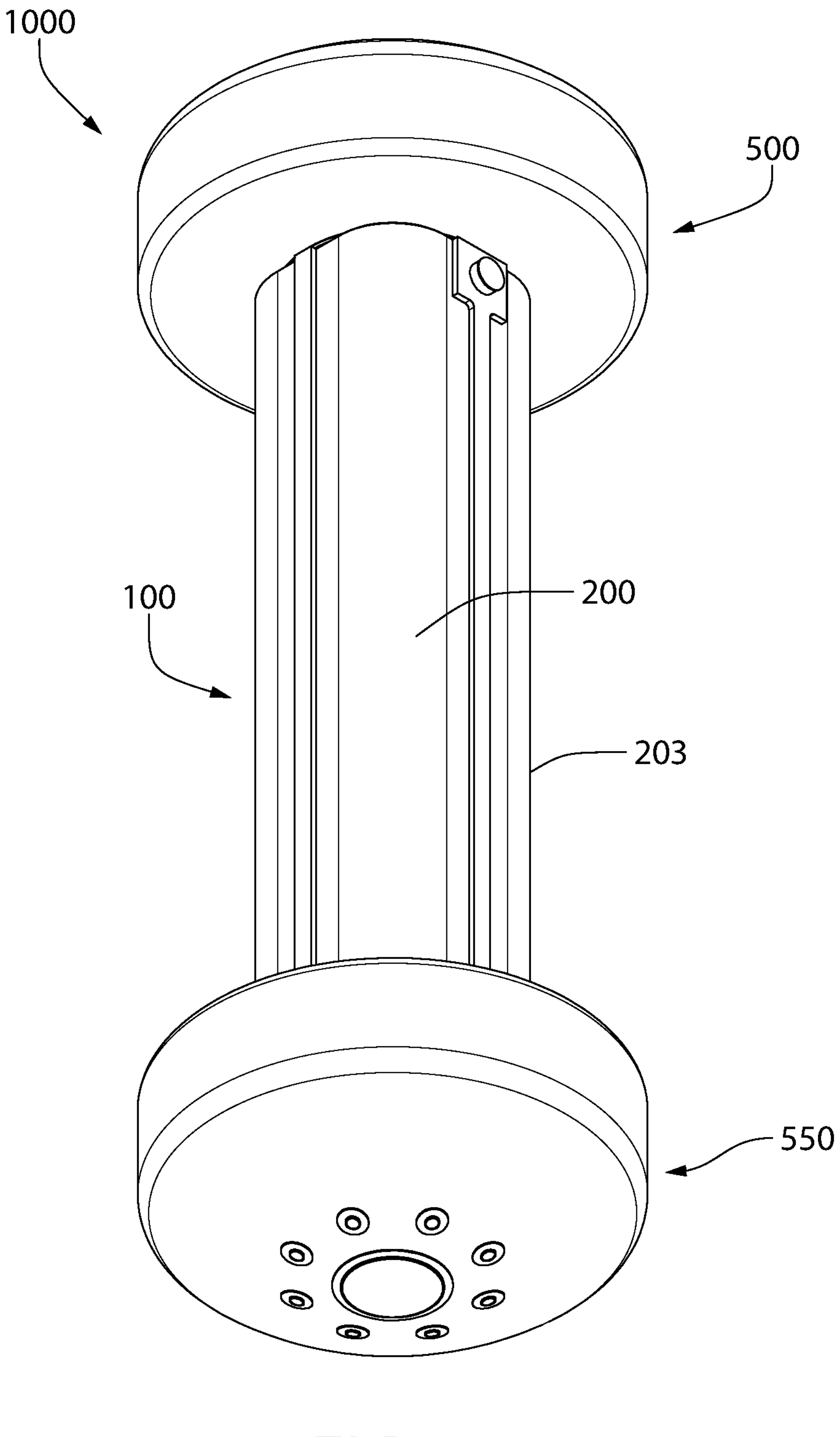


FIG. 2

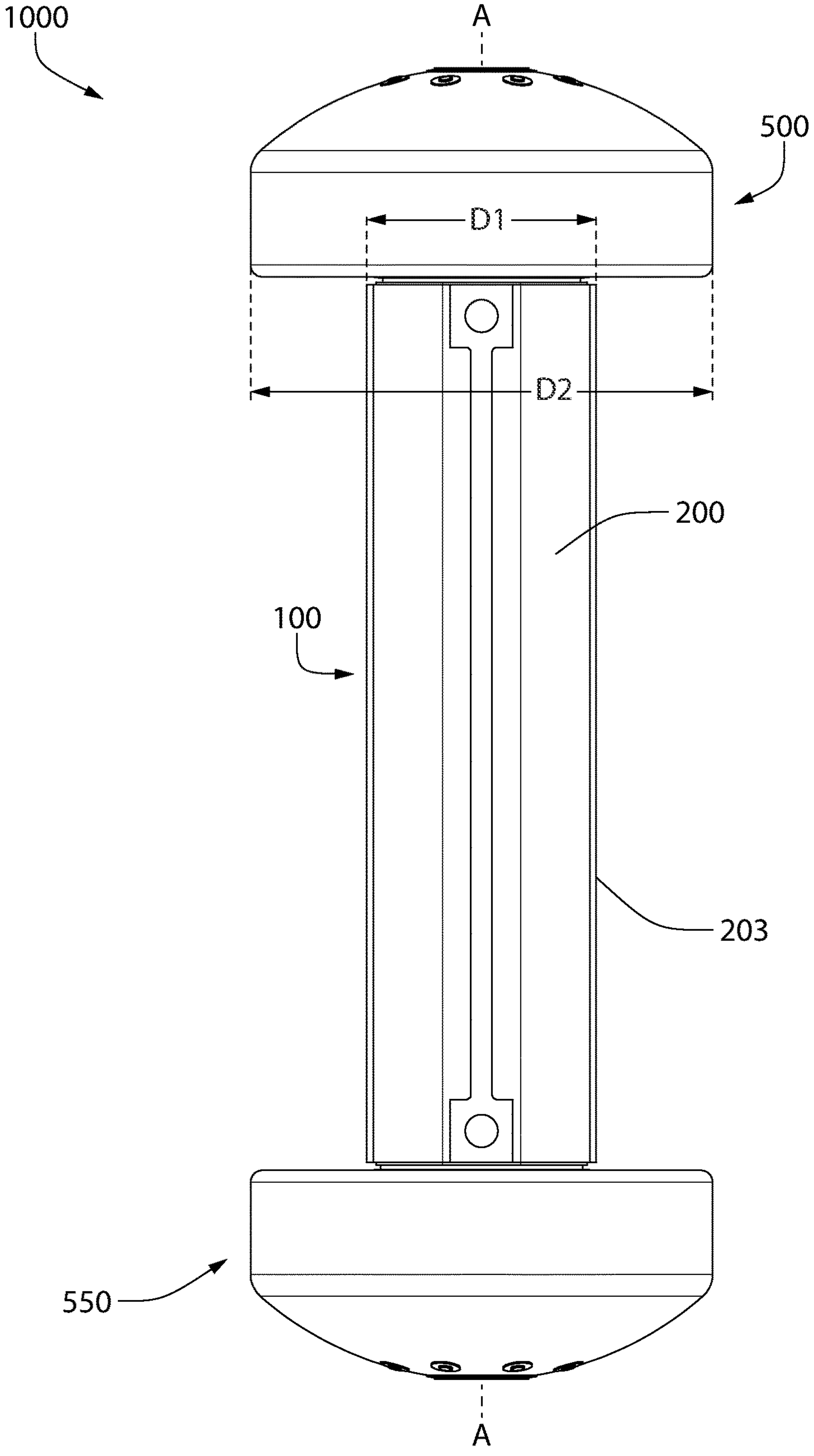


FIG. 3

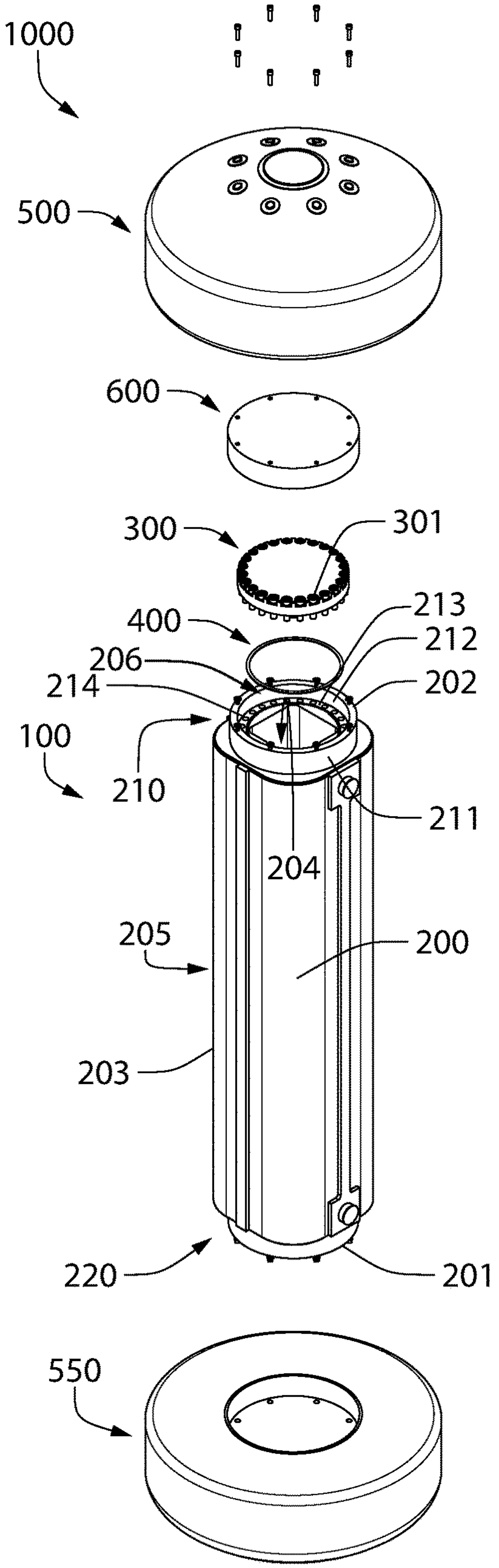
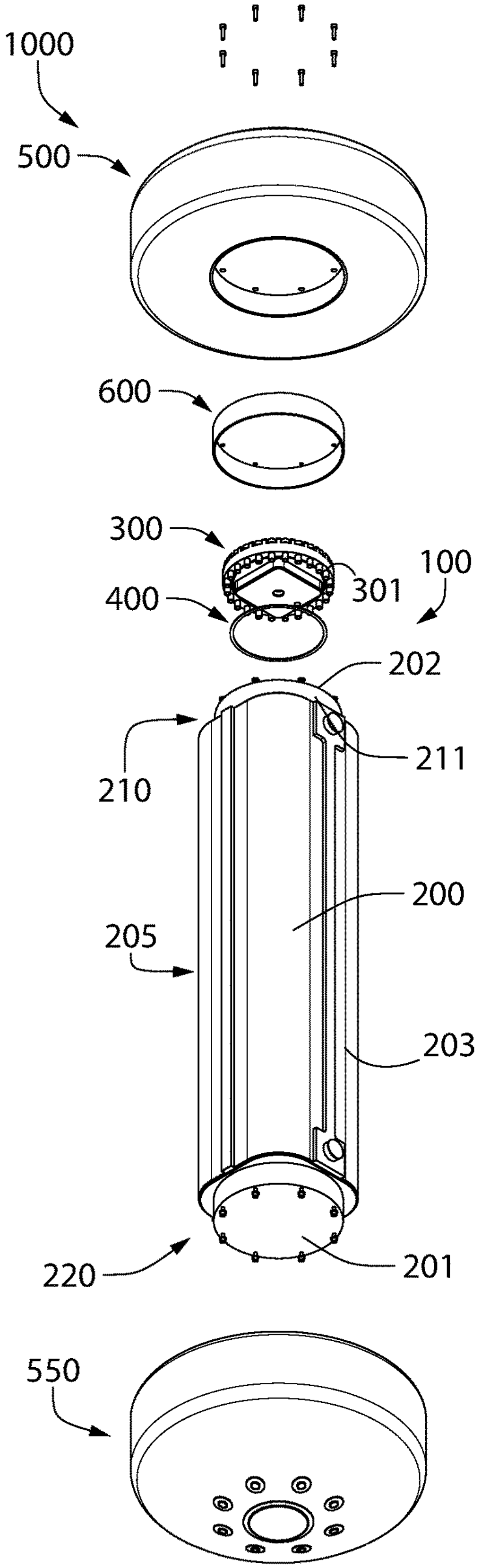

1000
500
600
300
301
400
213
212
206
202
214
100
210
211
204
205
200
203
220
201
550

FIG. 4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211
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220
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550

FIG. 5

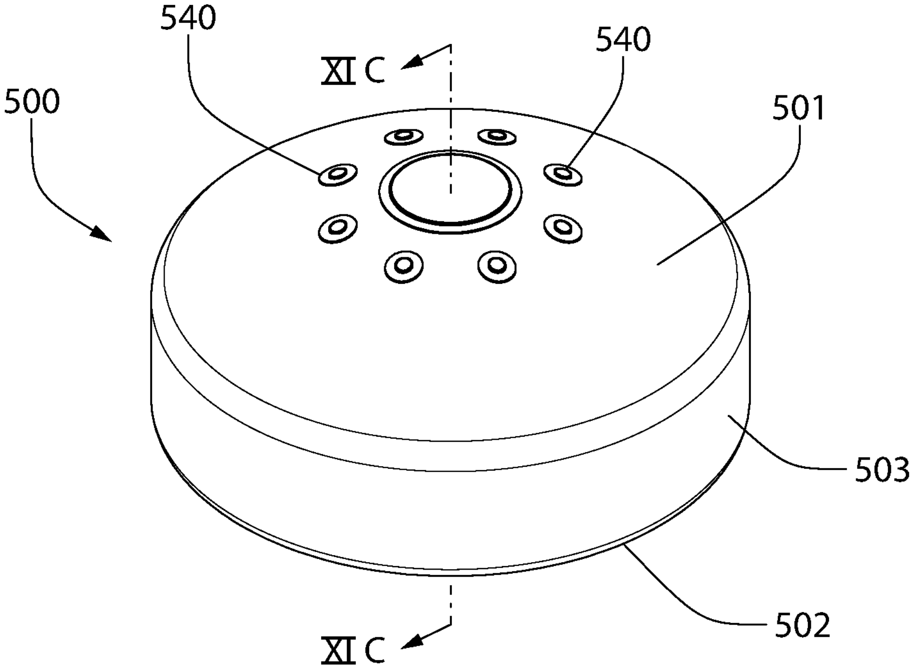


FIG. 6A

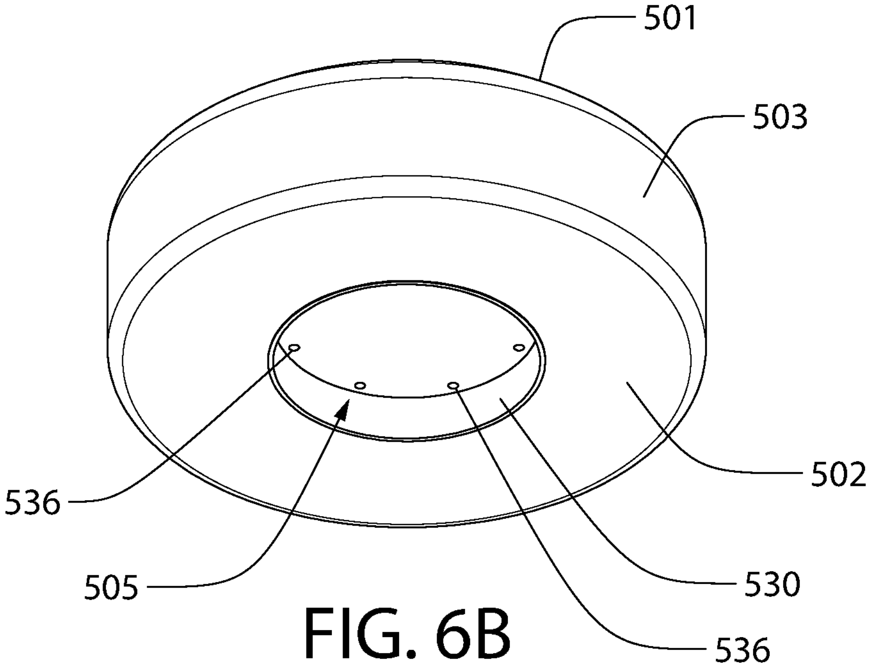
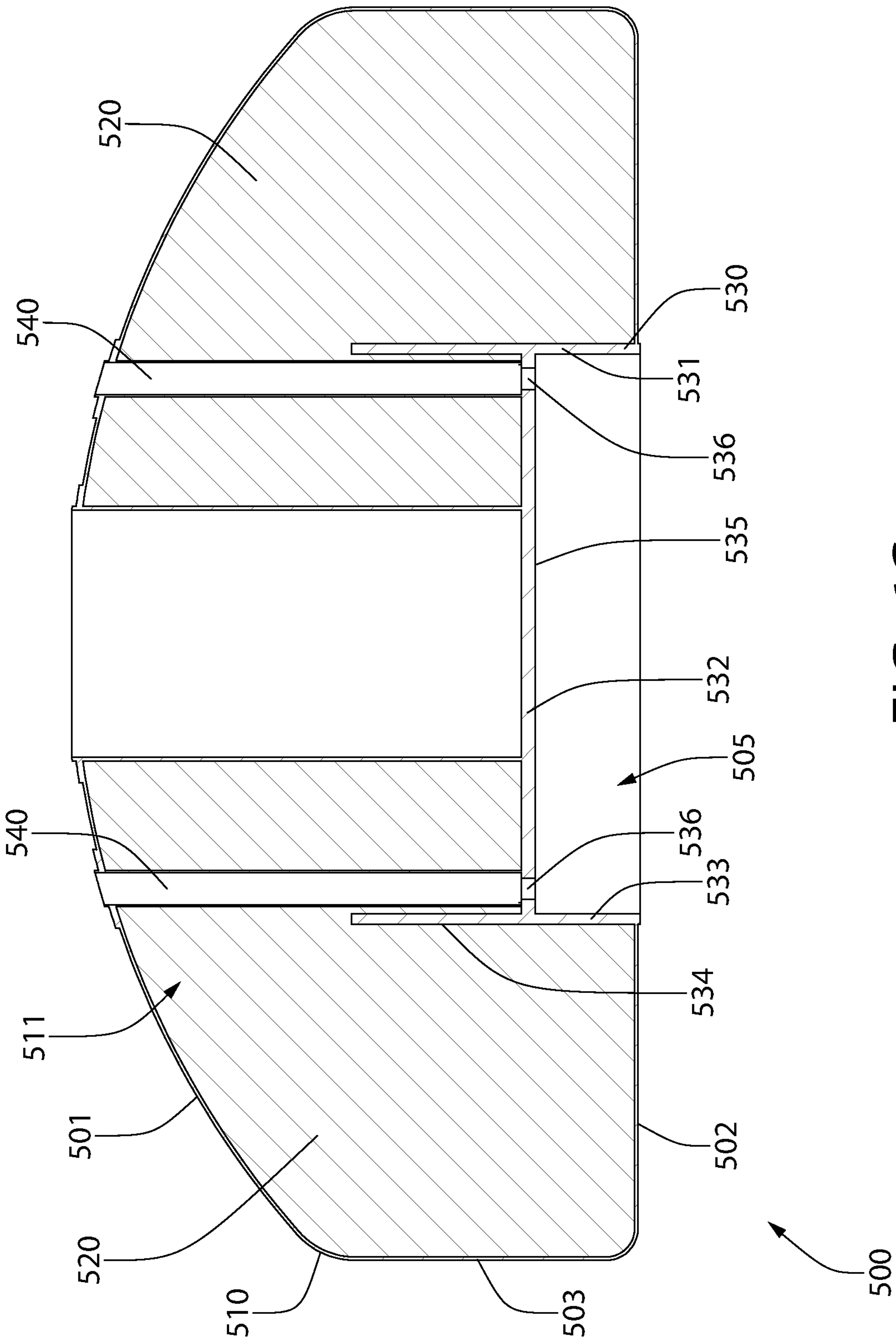


FIG. 6B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536
535
532
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540
536
533
534
511
501
502
520
510
503
500

FIG. 6C

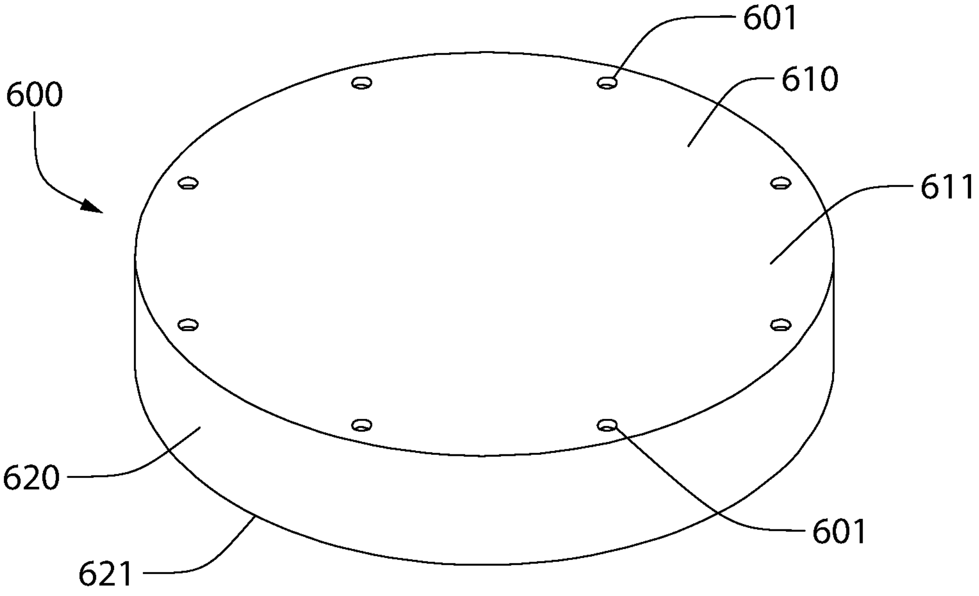


FIG. 7A

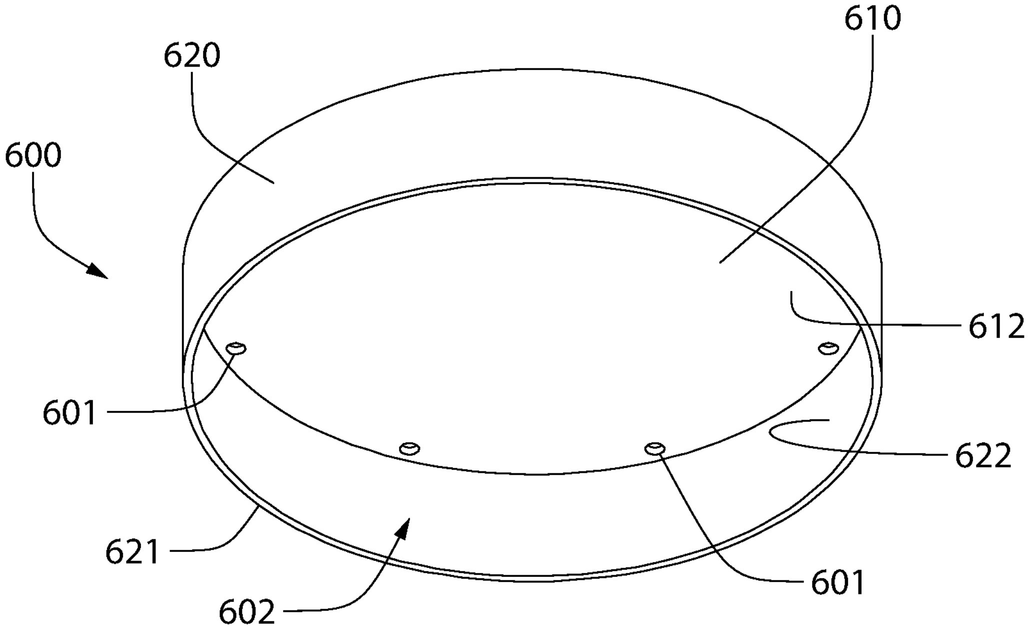
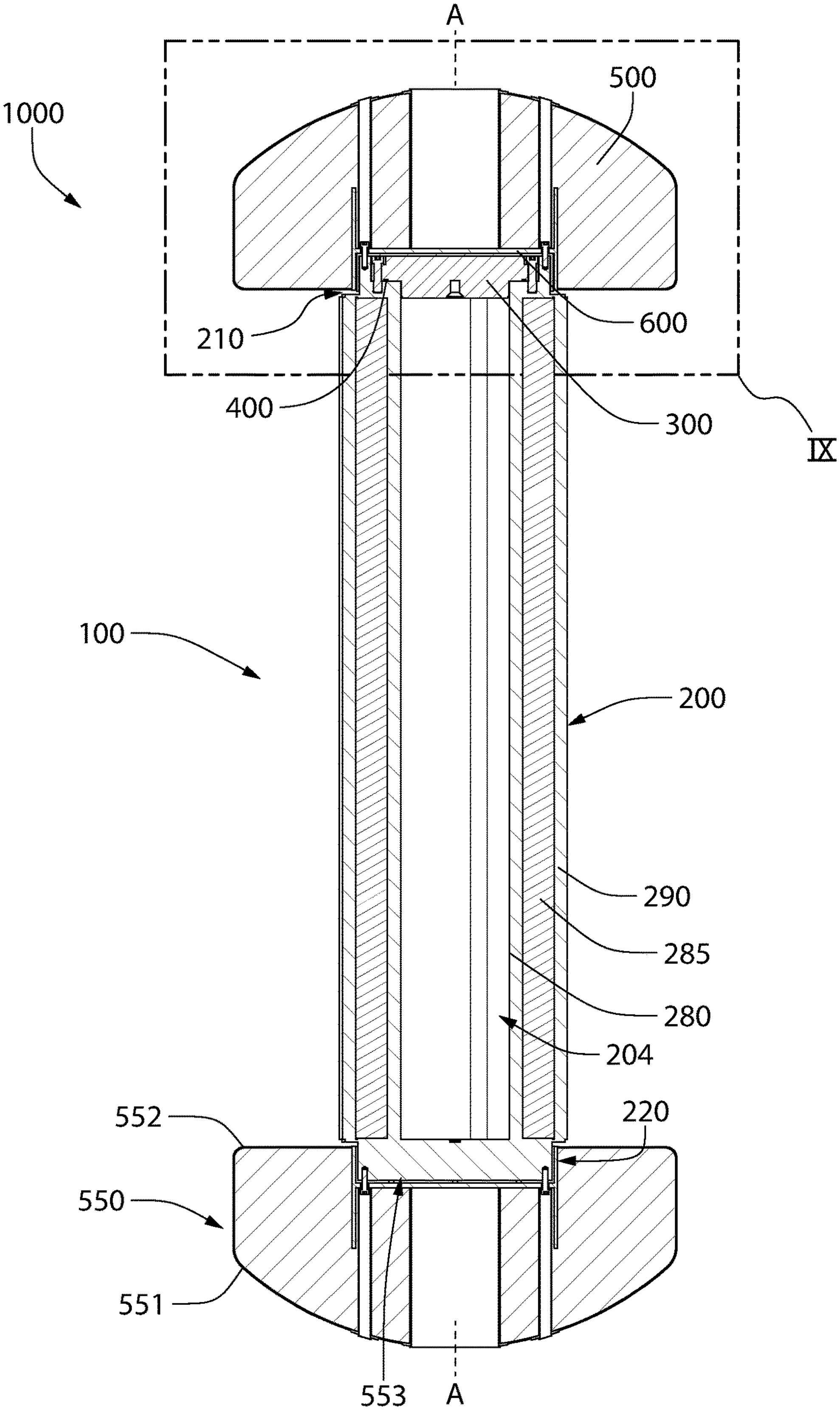


FIG. 7B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210
600
400
300
IX
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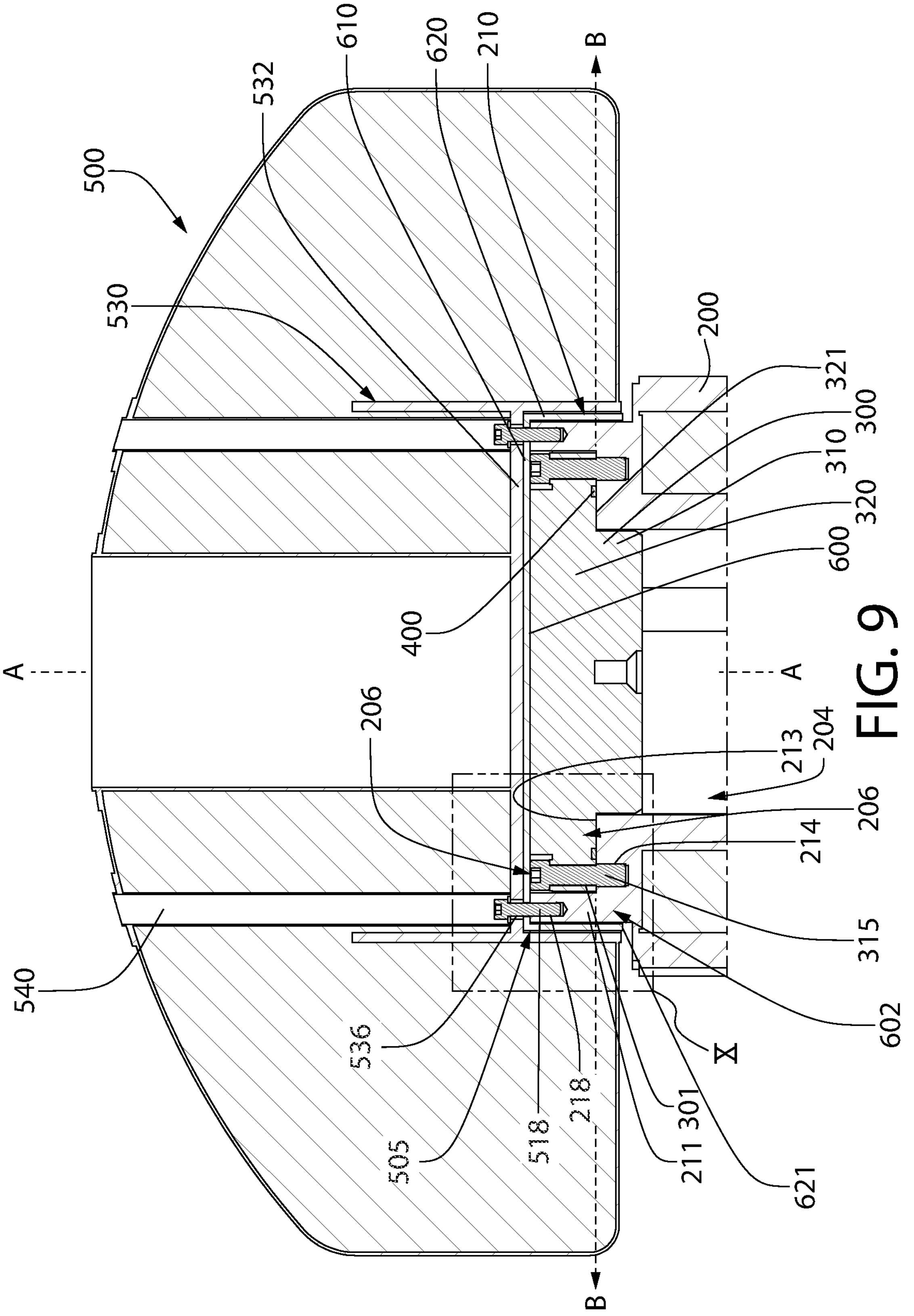
200
290
285
280
204
552
220
550
551
553
A

FIG. 8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530
532
610
620
210
B
B
200
321
300
310
320
600
400
A
A
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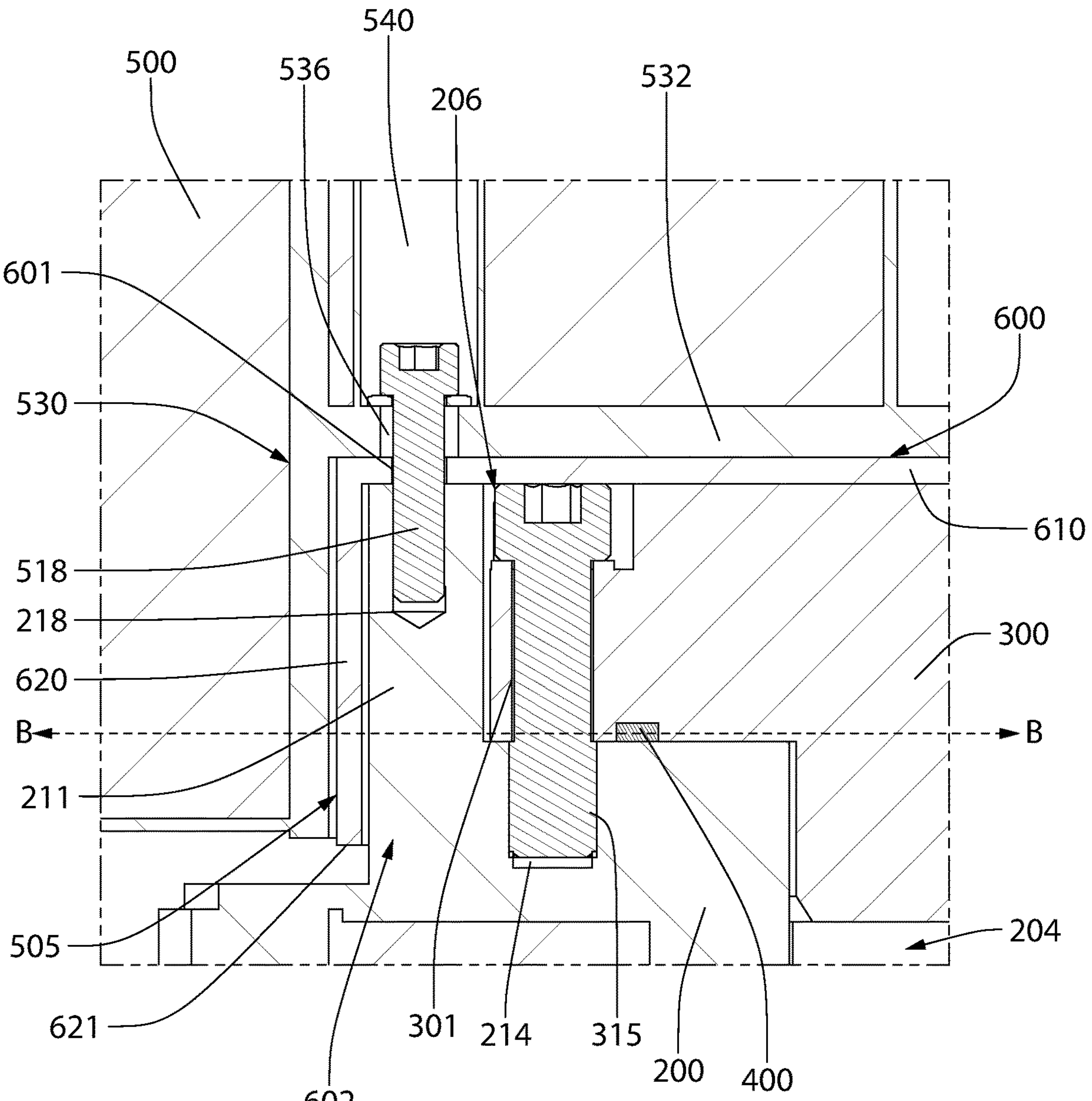
621
211
301
218
518
505
536
540

FIG. 9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536
540
206
532
601
600
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610
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218
300
620
B
B
211
505
204
621
301
214
315
200
400
602

FIG. 10

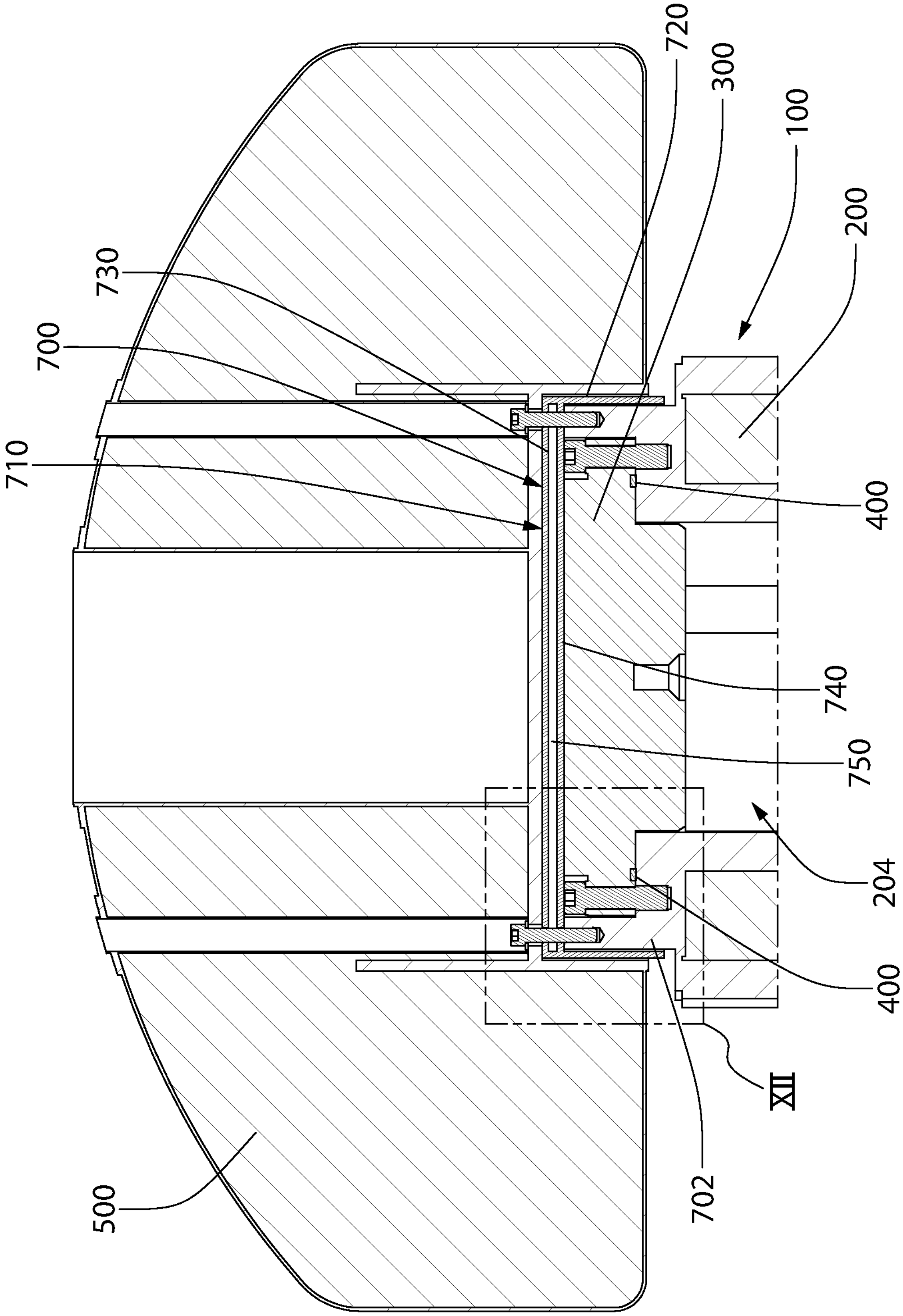
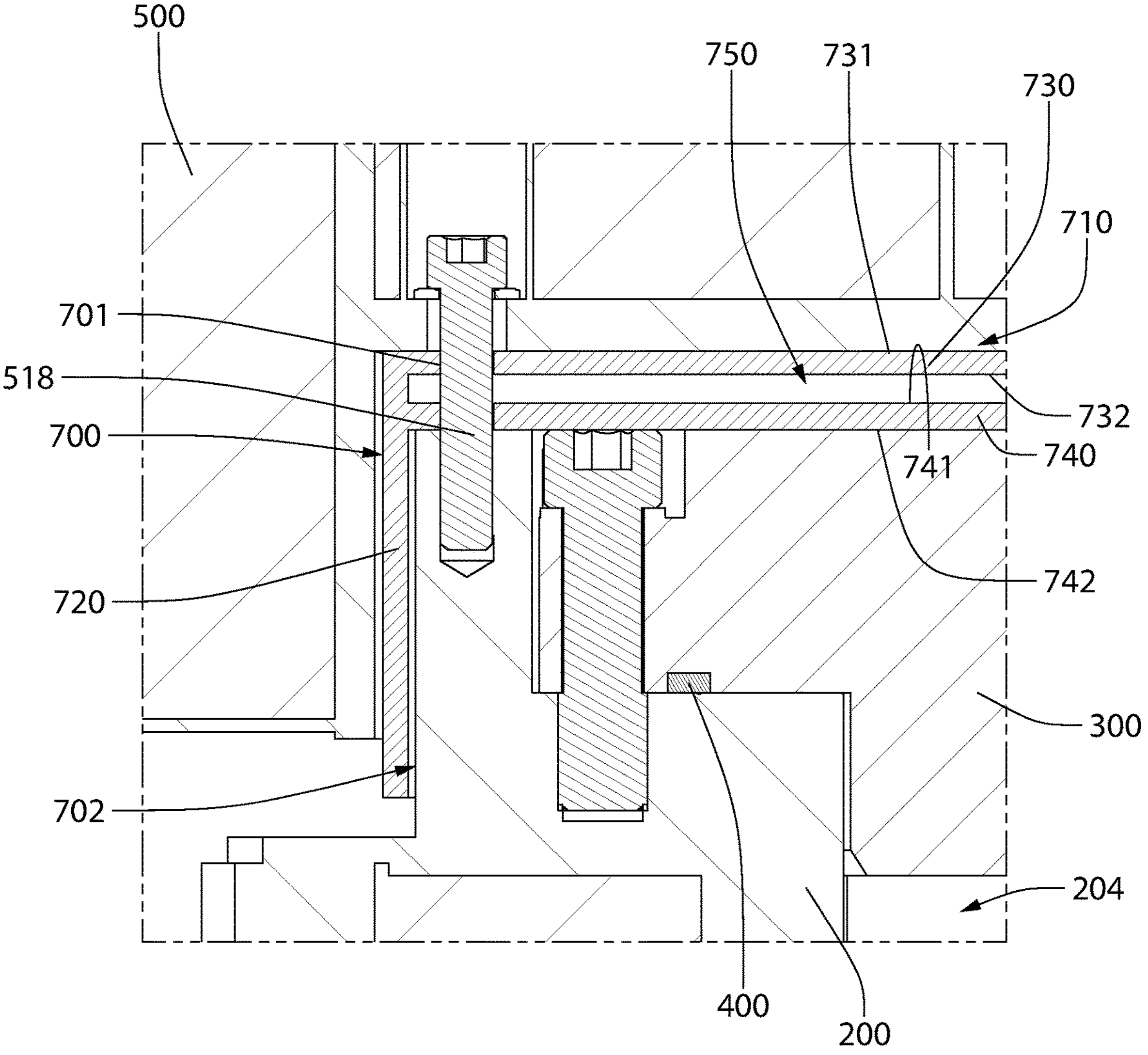


FIG. 11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750
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518
700
720
702
732
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740
742
300
204
400
200

FIG. 12

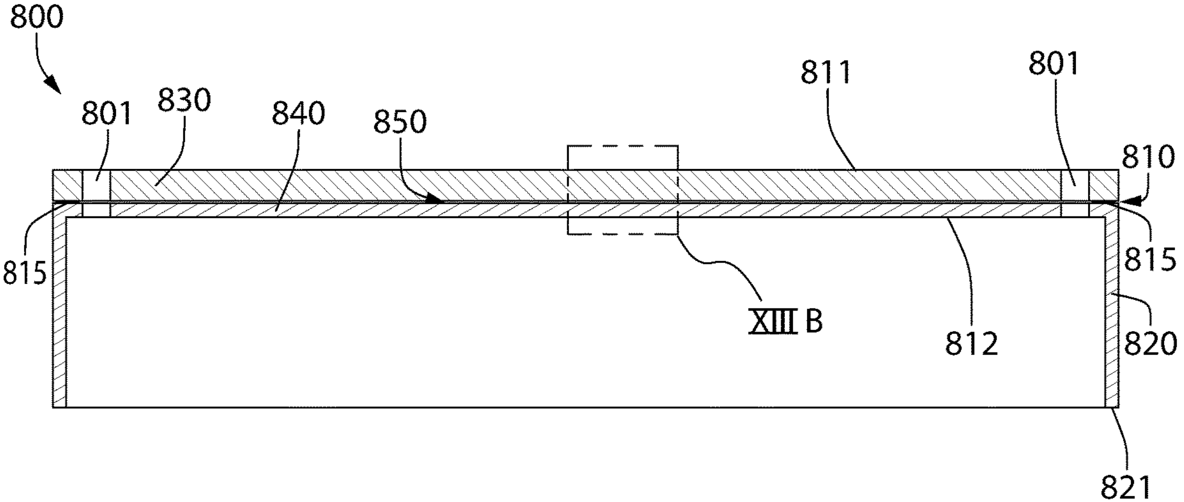


FIG. 13A

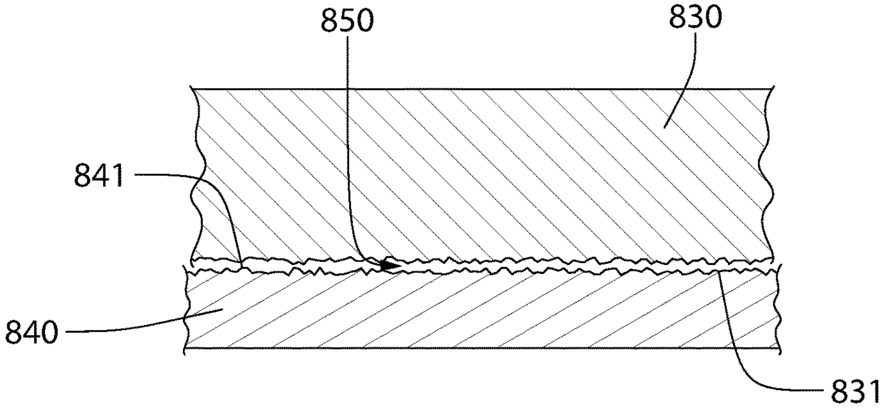
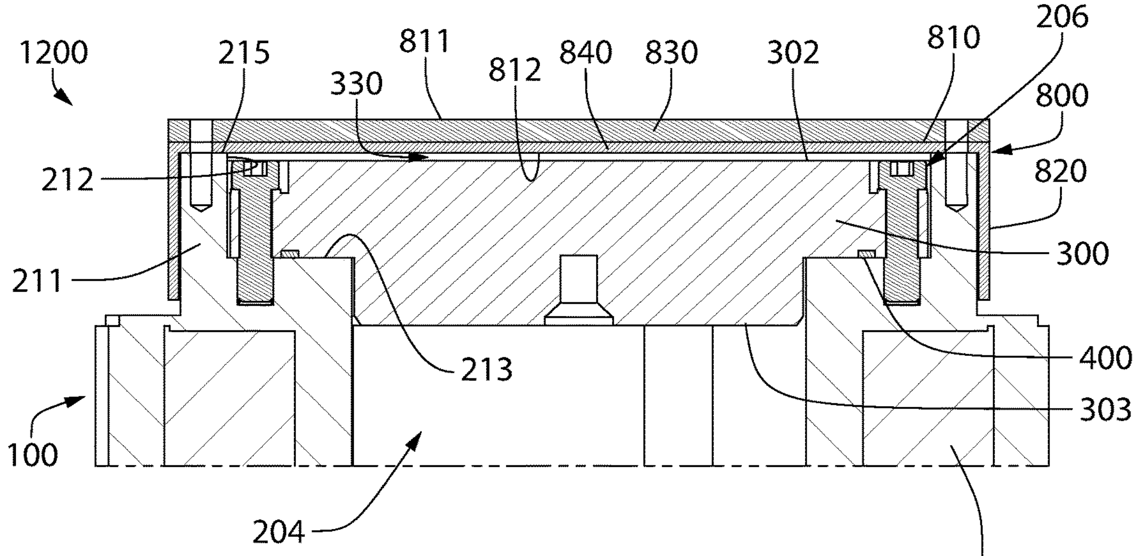


FIG. 13B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215
811
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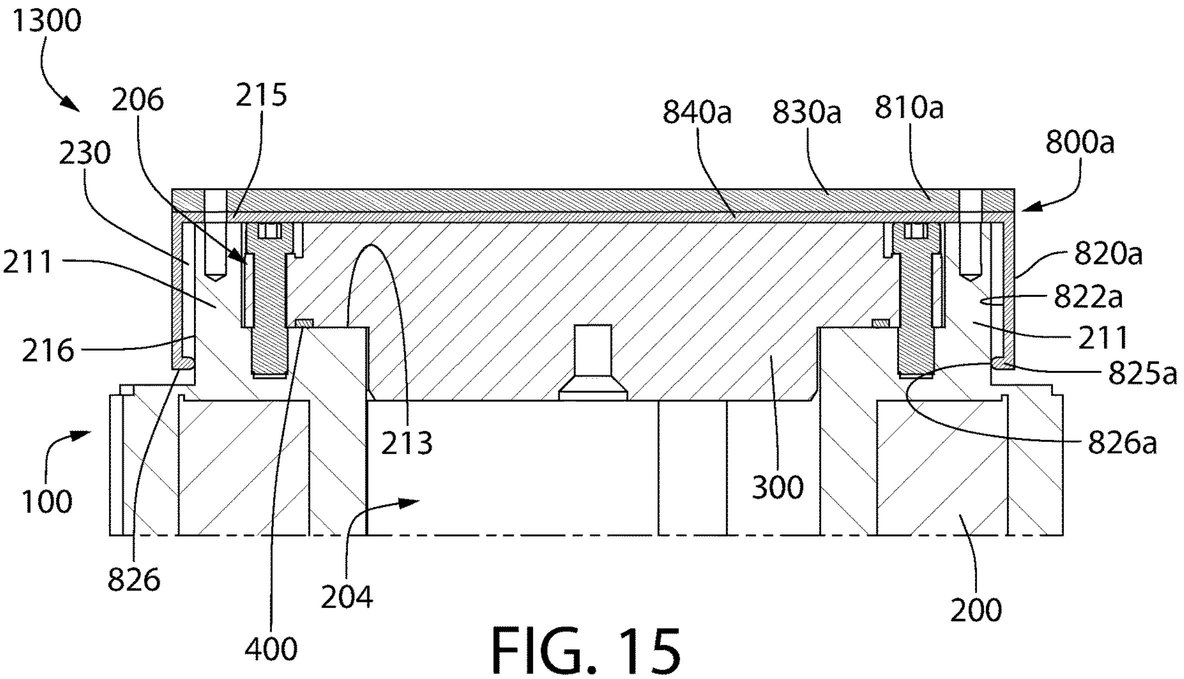
830
302
810
206
800
212
820
300
211
213
400
303
100
204
200

FIG. 14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840a
830a
810a
800a
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216
211
825a
213
826a
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826
204
200
400

FIG. 15

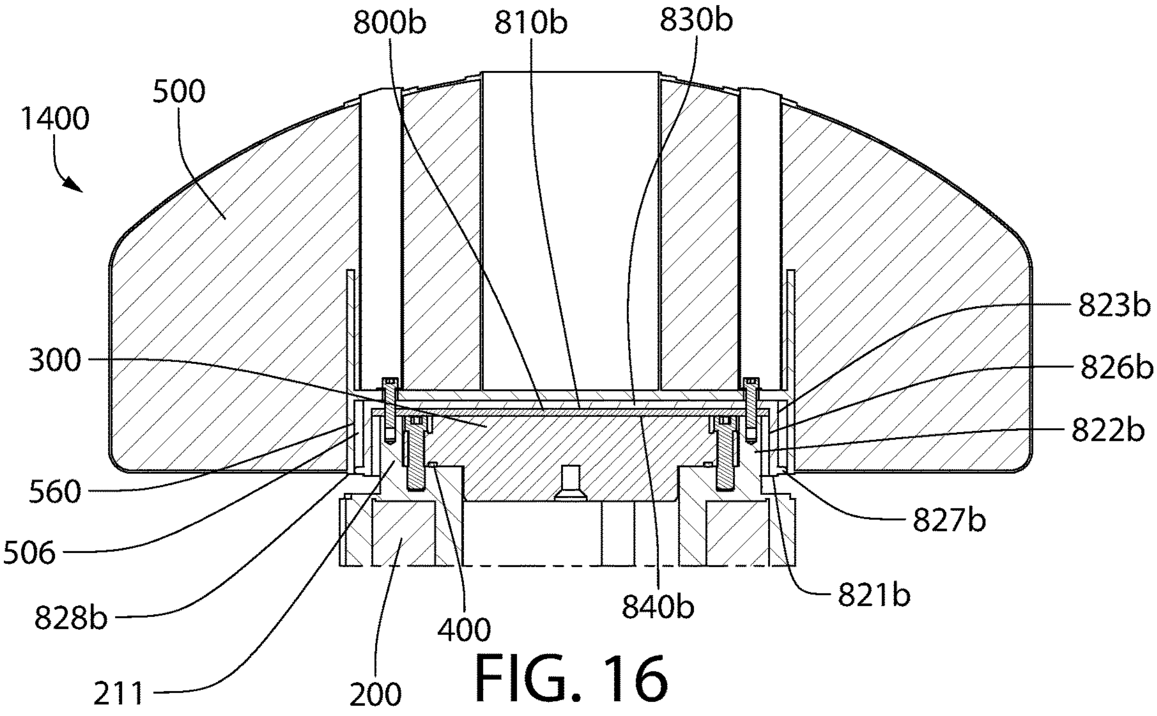

FIG. 16

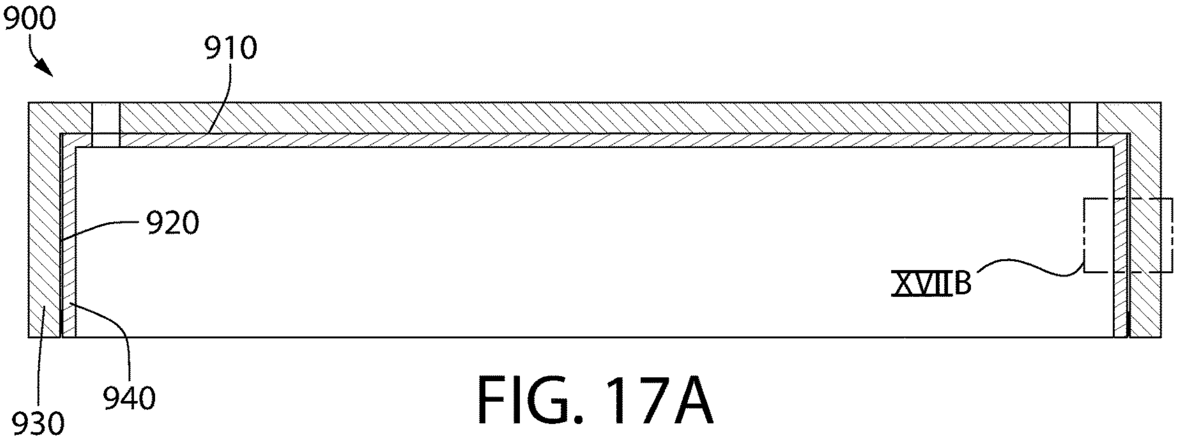

FIG. 17A

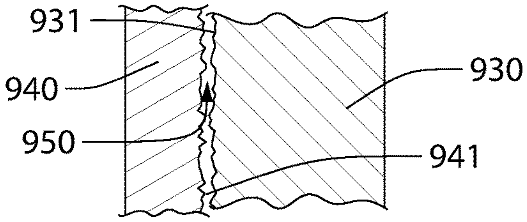

FIG. 17B

SYSTEM FOR TRANSPORTING RADIOACTIVE MATERIALS

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of U.S. Provisional Patent Application Ser. No. 63/405,967, filed Sep. 13, 2022, which is incorporated herein by reference in its entirety.

BACKGROUND

The present invention relates generally to systems and apparatuses for storing high level radioactive waste such as used or spent nuclear fuel. In the operation of nuclear reactors, the nuclear energy source is in the form of hollow zircaloy tubes filled with enriched uranium, collectively arranged in multiple assemblages referred to as fuel assemblies. When the energy in the fuel assembly has been depleted to a certain predetermined level, the used or "spent" nuclear fuel (SNF) assemblies are removed from the nuclear reactor and loaded into a canister while submerged in a spent fuel pool. The canisters have limited ability to block or attenuate the gamma and neutron radiation emitted by the decaying SNF other than borated water remaining in the canister from the spent fuel pool. Thus, when the nuclear waste is transferred from the spent fuel pool to an interim or long-term storage area, the canister is placed into a radiation-shielded outer ventilated overpack or cask. Casks of this type must meet strict requirements for accident conditions. There remains a need for improvements in systems for transporting radioactive materials to better account for different accident scenarios.

BRIEF SUMMARY

The present application discloses a system for transporting radioactive materials which may include a containment vessel, a thermal shield, and an impact limiter. The containment vessel may include a vessel body having a storage cavity for receiving radioactive materials, a lid coupled to an upper portion of the vessel body to enclose a top end of the storage cavity, and a lid seal such as a gasket positioned between the lid and the upper portion of the vessel body. The thermal shield may be positioned over the lid. The first impact limiter may be positioned over the thermal shield. The thermal shield may be resistant to high temperatures and may help to protect the integrity of the lid seal when the system is subjected to high temperatures, such as during a fire condition.

In one aspect, the invention may be a system for transporting radioactive materials, the system comprising: a containment vessel extending along a longitudinal axis from a top end to a bottom end, the containment vessel comprising: a vessel body having a storage cavity configured to receive radioactive materials; a lid coupled to an upper portion of the vessel body to enclose a top end of the storage cavity; and a lid seal positioned between the lid and the upper portion of the vessel body to hermetically seal the top end of the storage cavity; a thermal shield comprising a top plate and an annular skirt extending downward from the top plate to form a thermal shield cavity; a first impact limiter configured to absorb kinetic energy; and the first impact limiter and the thermal shield coupled to the containment vessel, the thermal shield located between the first impact limiter and the containment vessel so that the lid seal is located within the thermal shield cavity.

In another aspect, the invention may be a system for transporting radioactive materials, the system comprising: a containment vessel extending along a longitudinal axis from a top end to a bottom end, the containment vessel comprising: a vessel body having a storage cavity configured to receive radioactive materials; and a lid coupled to an upper portion the vessel body to enclose a top end of the storage cavity; a thermal shield comprising a top plate, the top plate being a multi-layer construct comprising a first layer and a second layer; a first impact limiter configured to absorb kinetic energy; and the first impact limiter and the thermal shield coupled to the containment vessel, the top plate of the thermal shield located between the first impact limiter and the lid of the containment vessel.

In yet another aspect, the invention may be a system for transporting radioactive materials, the system comprising: a containment vessel extending along a longitudinal axis from a top end to a bottom end, the containment vessel comprising: a vessel body having a storage cavity configured to receive radioactive materials; a lid coupled to an upper portion of the vessel body to enclose a top end of the storage cavity; and a lid seal positioned between the lid and the upper portion of the vessel body to hermetically seal the top end of the storage cavity; a thermal shield comprising a top plate having an effective thermal conductivity of 3 Watts/(Meter×Kelvin) or less; a first impact limiter configured to absorb kinetic energy; and the first impact limiter and the thermal shield coupled to the containment vessel, the top plate of the thermal shield located between the first impact limiter and the lid of the containment vessel.

Further areas of applicability of the present invention will become apparent from the detailed description provided hereinafter. It should be understood that the detailed description and specific examples, while indicating the preferred embodiment of the invention, are intended for purposes of illustration only and are not intended to limit the scope of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

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:

FIG. **1** is a top perspective view of a system for transporting radioactive materials in accordance with an embodiment of the present invention;

FIG. **2** is a bottom perspective view of the system of FIG. **1**;

FIG. **3** is a front view of the system of FIG. **1**;

FIG. **4** is an exploded top perspective view of the system of FIG. **1**;

FIG. **5** is an exploded bottom perspective view of the system of FIG. **1**;

FIG. **6**A is a top perspective view of an impact limiter of the system of FIG. **1** in accordance with an embodiment of the present invention;

FIG. **6**B is a bottom perspective view of the impact limiter of FIG. **6**A;

FIG. **6**C is a cross-sectional area taken along line VIC-VIC of FIG. **6**A

FIG. **7**A is a top perspective view of a thermal shield of the system of FIG. **1** in accordance with an embodiment of the present invention;

FIG. **7**B is a bottom perspective view of the thermal shield of FIG. **7**A;

FIG. **8** is a cross-sectional view taken along line VIII-VIII of FIG. **1**;

FIG. **9** is a close-up view of area IX of FIG. **8**;

FIG. **10** is a close-up view of area X of FIG. **9**;

FIG. **11** is a close-up view of area IX of FIG. **8** in accordance with an alternative embodiment of the present invention;

FIG. **12** is a close-up view of area XII of FIG. **11**;

FIG. **13**A is a cross-sectional view of a thermal shield in accordance with an alternative embodiment of the present invention;

FIG. **13**B is a close-up view of area XIIIB of FIG. **13**A;

FIG. **14** is a close-up view of area IX of FIG. **8** in accordance with another alternative embodiment of the present invention, whereby the impact limiter has been omitted;

FIG. **15** is a close-up view of area IX of FIG. **8** in accordance with yet another alternative embodiment of the present invention, whereby the impact limiter has been omitted;

FIG. **16** is a close-up view of area IX of FIG. **8** in accordance with still another alternative embodiment of the present invention;

FIG. **17**A is a cross-sectional view of a thermal shield in accordance with another alternative embodiment of the present invention; and

FIG. **17**B is a close-up view of area XVIIB of FIG. **17**A.

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

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.

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.

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.

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.

Referring first to FIGS. **1**-**5**, a system for transporting radioactive materials **1000** will be described in accordance with an embodiment of the present invention. The system **1000** generally comprises a containment vessel **100**, a first impact limiter **500** coupled to a first end (i.e., upper end) of the containment vessel **100**, a second impact limiter **550** coupled to a second end (i.e., lower end) of the containment vessel **100**, and a thermal shield **600**. The thermal shield **600** is visible only in FIGS. **4** and **5** among the set of FIGS. **1**-**5** because it is hidden from view in FIGS. **1**-**3** by the first impact limiter **500**.

The containment vessel **100** extends along a longitudinal axis A-A and generally comprises a vessel body **200**, a lid **300** that is coupled to an upper portion of the vessel body **200**, and a lid seal **400** that is positioned between the lid **300** and the upper portion of the of the vessel body **200**. The lid **300** and the lid seal **400** are only visible in FIGS. **4** and **5** among the set of FIGS. **1**-**5** because they are hidden from view in FIGS. **1**-**3** by the first impact limiter **500**. Some details about the containment vessel **100** and its constituent components will be described below. Additional details about the containment vessel **100** and/or its components may be described in U.S. Pat. No. 11,081,249, the entirety of which is incorporated herein by reference.

The vessel body **200** may be elongated between a first end **201** and a second end **202**. The vessel body **200** may comprise a sidewall **203** that extends between the first and second ends. The sidewall **203** may be cylindrical, although other shapes may be used in other embodiments. The vessel body **200** may define a storage cavity **204** that is configured to receive and hold radioactive materials, such as spent nuclear fuel or other forms of radioactive waste. The vessel body **200** may be constructed to provide radiation shielding to ameliorate the gamma and neutron radiation emitted by the decaying spent nuclear fuel or other high level radioactive waste held in the storage cavity **103**. The vessel body **200** may be any commercially-available storage and/or transport cask, such as for example without limitation HI-STAR or HI-STORM casks available from Holtec® International of Camden, New Jersey or other.

The vessel body **200** may be vertically elongated in the direction of the longitudinal axis A-A between the first and second ends **201**, **202**. The first end **201** may form a bottom end of the vessel body **200** and the second end **202** may form a top end of the vessel body **200**. The bottom end of the vessel body **200** may be closed (such as by a base plate or the like) and the top end of the vessel body **200** may be open, thereby forming a passageway into the storage cavity **204**. The vessel body **200** may be formed from metal. Radioactive materials, such as spent nuclear fuel assemblies or other nuclear waste, may be insertable into the storage cavity **204** through the open top end **202** of the vessel body **200** prior to securing the lid **300** thereon. The storage cavity **204** may extend for a full height of the vessel body **200** in one embodiment. The storage cavity **204** may be configured to hold only a single spent nuclear fuel canister in one embodiment. This may be ensured based on the shape of the vessel body **200** and the cross-sectional area of the storage cavity **204**, among other possible techniques.

The vessel body **200** may include an upper portion **210** and a lower portion **220**. The upper portion **210** may be an uppermost part of the vessel body **200** which includes the second end **202**. The lower portion **220** may be a lowermost part of the vessel body **200** which includes the first end **201**. Furthermore, the vessel body **200** may comprise a main body portion **205** that extends between the upper and lower portions **210**, **220**. The upper portion **210** of the vessel body **200** may comprise an annular collar **211** that extends upwardly from the main body portion **205** of the vessel body **200**. The annular collar **211** may comprise an inner surface **212** that defines an entry passageway **206** into the storage cavity **204**. The details of the upper portion **210** including the annular collar **211** are shown in FIGS. **8**-**10** and will be described in some additional detail with reference to those figures below.

The main body portion **205** may be formed by multiple vertically elongated cylindrical shells and radiation shielding materials. Alternatively, the main body portion **205** may be collectively formed by a plurality of axially aligned and vertically stacked cylindrical shell segments seal welded together at the joints therebetween to form an elongated shell assemblage. In one embodiment, the vessel body **200** may be a composite construction generally comprising a structural inner shell, an intermediate gamma shield, and an outer neutron shielding jacket. In such an embodiment, the shell, gamma shield, and jacket may be generally annular and cylindrical in shape, and may be concentrically aligned with each other and the longitudinal axis A-A. While the term "cylindrical" is used herein, it should be noted that the shape of the main body portion **205** is not limited to being cylindrical and other shapes, including those with square, triangular, hexagonal, octagonal, or other cross-sectional shapes, may be used.

With brief reference to FIG. **8**, in certain embodiments the vessel body **200** may include an inner shell **280**, an outer shell **290**, and an intermediate gamma shield **285** located in the space between the inner and outer shells **280**, **290**. The inner shell **280** may be formed of a structural metal such as steel (e.g. stainless steel or other) which forms the innermost part of the main body portion **205** and whose interior surface forms the storage cavity **204** of the vessel body **200** which holds the radioactive materials. The outer shell **290** may be integral with the inner shell **280** or a separate part that is coupled thereto. The outer shell **290** may be formed from the same material as the inner shell **280**.

The intermediate gamma shield **285** may be formed of a radiation shielding material, and more particularly a gamma shielding material effective for blocking gamma radiation emitted by the radioactive material stored in the storage cavity **204** of the vessel body **200**. The intermediate gamma shield **285** may be formed of lead of suitable thickness in some embodiments. However, other dense gamma blocking materials such as concrete, copper, suitably thick steel, etc. may alternatively be used as some non-limiting additional examples. The inner shell **280** and the intermediate gamma shield **285** may be in substantial conformal contact in some embodiments. Alternatively, the inner shell **280** and the intermediate gamma shield **285** may be radially spaced apart forming an annular gap therebetween. Both the inner shell **280** and the gamma shield **285** formed of dense steel and lead material types described above are each effective for gamma blocking applications. An outer neutron shielding jacket (not shown) may be positioned around the exterior of the vessel body **200**. The outer neutron shielding jacket may be formed from a boron-containing neutron shielding material such as Metamic® or Holtite™, although other neutron scattering/attenuating materials may be used.

Further details regarding the construction and structure of the main body portion **205** may be described in U.S. Pat. No. 11,081,249, which has been incorporated herein by reference.

The lid **300** may be a disc-shaped component that is configured to nest within the entry passageway **206** defined by the annular collar **211** when the lid **300** is coupled to the vessel body **200**. Of course, the lid **300** may take on other shapes designed to fit the shape of the opening in the top end (i.e., the second end **202**) of the vessel body **200** to close and hermetically seal the top end of the storage cavity **204**. The lid **300** may comprise a plurality of holes **301** through which fasteners such as bolts or the like may extend for purposes of coupling the lid **300** to the vessel body **200**.

The upper portion **210** of the vessel body **200** may comprise the annular collar **211** and a seal seat **213**. The annular collar **211** may comprise the seal seat **213**. The seal seat **213** may extend inwardly from the inner surface **212** of the annular collar **211** at a bottom end of the annular collar **211**. Stated another way, the annular collar **211** may extend upwardly from the seal seat **213** along an outer edge of the seal seat **213**. The seal seat **213** may form an upwardly facing surface or shoulder that is exposed when the lid **300** is not coupled to the vessel body **200**. The vessel body **200** may comprise a plurality of holes **214** formed into the seal seat **213**. The lid **300** may be positioned within the entry passageway **206** so that the holes **301** in the lid **300** align with the holes **214** in the seal seat **213**. Fasteners such as bolts, screws, or the like may be inserted through the holes **301** in the lid **300** and into the holes **214** in the seal seat **213** to secure the lid **300** to the vessel body **200**. The lid **300** may include a dual-lid assembly including inner and outer lids in some embodiments, such as described in U.S. Pat. No. 11,081,249 which was previously incorporated herein by reference. Alternatively, the lid **130** may be a single, monolithic structure. The lid **300** may be formed from metal such as steel, including without limitation stainless steel, and may have a sufficient thickness to effectively block gamma radiation emitted by radioactive materials stored in the storage cavity **204** of the vessel body **200**. It should be noted that the lid **300** may be formed from other metallic and non-metallic radiation blocking materials, such as lead, concrete, and the like.

The lid seal **400** may comprise a gasket or O-ring. The lid seal **400** may be formed from a polymeric material. The lid seal **400** may be formed from an elastomeric material or an elastomer type polymer, such as rubber, styrene-butadiene block copolymers, silicone elastomers, fluoroelastomers, polyurethane elastomers, or other thermoplastic elastomers, although the specific material used for the lid seal **400** is not to be limiting of the invention in all embodiments. The lid seal **400** may be a ring-shaped element that forms a closed-loop that surrounds an opening. The lid seal **400** is circular in the exemplified embodiment, although other shapes are possible and may be dictated by the shape of the lid **300** and the entry passageway **206**. The lid seal **400** may be positioned between a bottom surface of the lid **300** and the upper portion **210** of the vessel body **200** to hermetically seal the top end of the storage cavity **204** when the lid **300** is coupled thereto. More specifically, the lid seal **400** may be positioned between the bottom surface of the lid **300** and the seal seat **213** to achieve the appropriate hermetic sealing of the top end of the storage cavity **204**. The hermetic seal between the lid **300** and the vessel body **200** may be important to ensure that gamma and neutron radiation emitted by the radioactive materials stored in the storage cavity **204** do not pass into the atmosphere outside of the storage cavity **204**.

As noted above, the first impact limiter **500** is configured to be coupled to the upper portion **210** of the vessel body **200** and the second impact limiter **550** is configured to be coupled to the lower portion **220** of the vessel body **200**. The first and second impact limiters **500**, **550** may be configured to absorb kinetic energy, which may assist in protecting the vessel body **200** against damage during a drop scenario. The impact limiters **500**, **550** may provide protection to the containment vessel **100** and/or its contents during certain postulated accidents. The impact limiters **500**, **550** may protect the containment vessel **100** by ensuring that the impact limiters **500**, **550** are first to contact a hard surface during a drop scenario wherein the system **1000** is dropped onto a flat, essentially unyielding horizontal surface.

Referring to FIGS. **6**A-**6**C, the first impact limiter **500** will be described in detail. It should be appreciated that the second impact limiter **550** may be generally identical to the first impact limiter **500**, although some modifications may be required to effectuate the coupling of the second impact limiter **550** to the lower portion **220** of the vessel body **200**. Furthermore some modifications to the size of the second impact limiter **550** as compared to the first impact limiter **500** may be required to facilitate the fit of the second impact limiter **550** onto the lower portion **220** of the vessel body **200** and/or for functional reasons. In some embodiments, the size, structure, components, materials, and the like of the first and second impact limiters **500**, **500** may be the same.

The first impact limiter **500** may comprise a top surface **501**, a bottom surface **502**, and a side surface **503** extending between the top and bottom surfaces **501**, **502**. The bottom surface **502** may be flat/planar. The side surface **503** may be cylindrical. The top surface **501** may be domed or dome-shaped such that the top surface **503** may be curved and convex. In alternative embodiments, the top surface **501** may be flat/planar similarly to the bottom surface **502**. The first impact limiter **500** may comprise a depression **505** formed into the bottom surface **502** for receiving the annular collar **211** of the vessel body **200** when the first impact limiter **500** is coupled to the vessel body **200**.

The first impact limiter **500** may comprise a shell **510** that defines an internal cavity **511**. The internal cavity **511** may be filled, at least partially, with an energy absorbing material **520**. The energy absorbing material **520** may be a material that is crushable to dissipate external impact forces which might be caused by an end drop of the containment vessel **100** (i.e., a vertical drop on an end of the containment vessel **100** or at a slight oblique angle thereto). The energy absorbing material **520** may be a suitable preferably fire-resistant energy absorbing substance or structural assemblage. In one embodiment, the energy absorbing material **520** may comprise fire-resistant polyurethane or a similar pliable material with the ability to absorb large amounts of kinetic energy when undergoing large deformation. In another embodiment, the energy absorbing material **520** may be a crushable polymeric foam material of suitable density (e.g. polyethylene, etc.). In one embodiment, the energy absorbing material **520** may fill the internal cavity **511**.

The shell **510** of the first impact limiter **500** may be formed of a corrosion-resistant alloy. The corrosion-resistant alloy may be a suitable metal, such as for example without limitation stainless steel. Thus, the shell **510** may form a body portion of the impact limiter **500** that comprises a metal enclosure that is filled with the energy absorbing material **520**. Other metal materials including suitable gauge aluminum or other can be used. The shell **510** may provide a protective outer skin that encloses the energy absorbing material **520** at the outboard ends of the impact limiter **500** which shields the energy absorbing material **520** from minor damage, fire, and weather during transport and handling.

The first impact limiter **500** may comprise a bracket member **530**. The bracket member **530** may be integral with the shell **510** in some embodiments. In the exemplified embodiment, the bracket member **530** may be formed separately from the shell **510** and affixed thereto **510** such as via welding or the like. The bracket member **530** may have an H-shaped cross-sectional area, as shown in FIG. **6**C. The bracket member **530** may be formed from a rigid material, such as a metal. The bracket member **530** may comprise an annular sidewall **531** and a horizontal plate portion **532**. The annular sidewall **531** may comprise a lower sidewall portion **533** extending downwardly relative to the horizontal plate portion **532** and an upper sidewall portion **534** extending upwardly relative to the horizontal plate portion **532**. Thus, the horizontal plate portion **532** may divide the annular sidewall **531** into the upper and lower sidewall portions **533**, **534**. The lower sidewall portion **533** and a bottom surface **535** of the horizontal plate portion **532** may define the depression **505** in the bottom surface **502**. The upper sidewall portion **534** may extend into the internal cavity **511** of the shell **510**. The upper sidewall portion **534** may be in contact with the energy absorbing material **520** located within the internal cavity **511** of the shell **510**.

The lower sidewall portion **533** of the bracket member **530** and the horizontal plate portion **532** of the bracket member **530** may form a portion of a boundary of the internal cavity **511**. That is, the shell **510** may be open to the internal cavity **511** along the depression **505**. The lower sidewall portion **533** of the annular sidewall **531** and the horizontal plate portion **532** may collectively close the open portions of the shell **510** along the depression **505**. Thus, the internal cavity **511** may be filled with the energy absorbing material **520** via the opening formed along the depression **505**, and then the opening may be closed by welding or otherwise attaching the bracket member **530** to the shell **510**. In some embodiments, the shell **510** may extend along the sides of the depression **505** but not along the floor of the depression **505**. In such embodiments, the bracket member **530** may include the horizontal plate portion **532** to form the floor of the depression **505** and the upper sidewall portion **534**, but in such embodiments the lower sidewall portion **534** of the bracket member **530** may be omitted.

The horizontal plate portion **532** of the bracket member **530** may comprise a plurality of fastener holes **536** for receiving fasteners used to couple the impact limiter **500** to the containment vessel **100**. In the exemplified embodiment, the fastener holes **536** are arranged in a spaced apart manner along a ring. Each of the fastener holes **536** extends through the thickness of the horizontal plate portion **532** from the top surface thereof to the bottom surface **535** thereof.

The first impact limiter **500** may comprise a plurality of passageways or through-holes **540** that extend from the top surface **501** to the horizontal plate portion **532** of the bracket member **530**. Stated another way, each of the passageways **540** may extend from a top opening in the top surface **501** of the first impact limiter **500** to a bottom opening in the floor of the depression **505**. Each of the passageways **540** may be aligned with one of the fastener holes **536** in the horizontal plate portion **532** of the bracket member **530**. The first impact limiter **500** may be coupled to the containment vessel **100** by inserting a fastener (i.e., a bolt) through the passageway **540** and into and through one of the fastener holes **536**. The portion of the fastener that extends through the fastener hole **536** may then extend into a fastener receiving hole of the containment vessel **100**, as described in more detail below.

As best seen in FIG. **2**, when the impact limiters **500**, **550** are coupled to the containment vessel **100**, the impact limiters **500**, **550** have an outside diameter D**2** which is larger than an outside diameter D**1** of the containment vessel **100**. Accordingly, the impact limiters are configured to each protrude radially outward beyond the vessel body **200** to protect the vessel body **200** if dropped. The deformable impact limiters **500**, **550**, and not the containment vessel **100** (and specifically the vessel body **200** thereof), will first strike the impact surface (e.g. ground or concrete slab generally) to absorb and dissipate the impact force or kinetic energy of a fall.

The system **1000** described herein for transporting radioactive materials includes the containment vessel **100** formed from metal with two impact limiters **500**, **550** fastened to the upper and lower extremities of the containment vessel **100**. The containment vessel **100** may include the vessel body **200**, which may be thick-walled and may include an integral baseplate welded to the thick-walled cylinder which in turn is welded to a heavy flange. The lid **300** may be coupled to a top end of the vessel body **200** to close the top end of the storage cavity **204** of the containment vessel **200**. The only access to the storage cavity **204** of the containment vessel **200** may be through a bolted joint between a top flange of the containment vessel **200** and the lid **300**. The lid seal **400** may provide sequestration of radionuclides in the storage cavity **204**. The inner seal formed by the lid seal **400** may be referred to as the containment seal and the outer seal may be referred to as the test seal. To qualify under 10 CFR Part **71** regulations, a transport package (such as the system **1000** described herein) must be shown to maintain the integrity of the containment seal (lid seal **400** or gasket) which is essential to ensure complete isolation of the contents (radioactive gases and particulates) from the ambient under all normal and accident conditions. Possible accident conditions, recited in the governing USNRC regulations which can be found in 10 CFR 71.73, include the following four sequential events.

1. Free drop from a height of 30 feet on to an essentially rigid surface in the most vulnerable strike orientation.
2. Drop onto a 6-inch diameter mild steel bar resulting in a potential damage to the containment vessel's "containment boundary."
3. An all-enveloping fire around the transport package for a period of 30 minutes.
4. Complete submersion in a body of water.

The relevant verbiage from 10 CFR 71.73 on the hypothetical accidents is reproduced below for completeness (the tests refer to a scale model of the package):

1. Free Drop. A free drop of the specimen through a distance of 9 m (30 ft) onto a flat, essentially unyielding, horizontal surface, striking the surface in a position for which maximum damage is expected.
2. Puncture. A free drop of the specimen through a distance of 1 m (40 in) in a position for which maximum damage is expected, onto the upper end of a solid, vertical, cylindrical, mild steel bar mounted on an essentially unyielding, horizontal surface. The bar must be 15 cm (6 in) in diameter, with the top horizontal and its edge rounded to a radius of not more than 6 mm (0.25 in), and of a length as to cause maximum damage to the package, but not less than 20 cm (8 in) long. The long axis of the bar must be vertical.
3. Thermal. Exposure of the specimen fully engulfed, except for a simple support system, in a hydrocarbon fuel/air fire of sufficient extent, and in sufficiently quiescent ambient conditions, to provide an average emissivity coefficient of at least 0.9, with an average flame temperature of at least 800° C. (1475° F.) for a period of 30 minutes, or any other thermal test that provides the equivalent total heat input to the package and which provides a time averaged environmental temperature of 800° C. The fuel source must extend horizontally at least 1 m (40 in) but may not extend more than 3 m (10 ft), beyond any external surface of the specimen, and the specimen must be positioned 1 m (40 in) above the surface of the fuel source. For purposes of calculation, the surface absorptivity coefficient must be either that value which the package may be expected to possess if exposed to the fire specified or 0.8, whichever is greater; and the convective coefficient must be that value which may be demonstrated to exist if the package were exposed to the fire specified. Artificial cooling may not be applied after cessation of external heat input, and any combustion of materials of construction, must be allowed to proceed until it terminates naturally.
4. Immersion. For fissile material subject to § 71.55, in those cases where water in leakage has not been assumed for criticality analysis, immersion under a head of water of at least 0.9 m (3 ft) in the attitude for which maximum leakage is expected.

Accident scenarios corresponding to the four hypothetical accidents described above will now be described.

Accident #1: The first postulated accident in the series of the four listed above is the so-called "free drop" accident which posits a free fall of the loaded containment vessel from a height of 9 meters onto an essentially rigid surface. The structural requirement is to ensure that the cladding of the nuclear fuel (the tube that encloses the fuel pellets) stored inside the containment vessel will not rupture due to the high inertia loads produced by the impact. The function of the impact limiters is to ensure that the maximum g-load sustained by the impact is sufficiently low to keep the fuel cladding from rupturing.

Accident #2: Rupture from impact of a penetrant rod that also challenges the structural capacity of the containment vessel which must be sufficiently robust to remain un-breached by the penetrant rod.

Accident #3: Enveloping fire challenges the integrity of the seals that sequester the fuel inside the storage cavity. These seals (such as the lid seal **400**) are typically made of a polymeric material which are known to provide a reliable barrier to leakage of the containment vessel's contents unless their temperature is elevated beyond their rated temperature by a fire event.

Accident #4. The water submersion case seeks to ensure that the seals (such as the lid seal **400**) have remained effective after sustaining the previous accidents so that no intrusion of water in the fuel storage space would occur. (Water intrusion is unacceptable because it has the unsalutary effect of raising the reactivity of the stored fuel).

The invention described herein seeks to protect the seals, such as the lid seal **400**, from experiencing elevated temperatures beyond their rated range during or after a design basis fire event such as described above. Some design features of the impact limiters **500**, **550** used as part of the system for transporting radioactive materials **1000**, as described above, include the following.

A plate and shell type shell of revolution that forms the impact limiter enclosure is equipped with an integral skirt that fits over the barrel of the containment vessel at its two extremities. The material of the enclosure may be corrosion-resistant alloy such as stainless steel.

The external profile of the impact limiter **500**, **500** may be in the form of a dished (or domed) head as shown in the figures or cylindrical with a flat ends, or any other substantially axially symmetric shape.

The outer diameter of the impact limiter **500**, **550** is preferably set such that during a lateral drop event, the crush material locks up before the side wall of the containment vessel **100** impacts the target.

The inside space of the enclosure may be filled with a fire-resistant polyurethane or similar pliable material with the ability to absorb large amounts of kinetic energy when undergoing large deformation.

A number of bolts may be enclosed in the passageway **540**, as shown and described with reference to FIG. **6**C. The passageway **540** may be tubular. The bolts may provide the connection between the impact limiter **500**, **550** and the containment vessel **100**. The bolts may connect the impact limiter **500**, **550** to the vessel body **200** or to the lid **300** in different embodiments. The bolts may be tension-only members by virtue of their placement configuration and thus their function may be limited to keeping the impact limiter **500**, **550** from detaching itself from the containment vessel **100**.

The impact limiters **500**, **550** as described herein may conform with the above features and may be best configured to meet accident condition #1 described above. However, the puncture accident scenario may threaten the integrity of the thin skin (i.e., the shell **510**) of the impact limiter **500**, **550**, which may result in exposure of the crush material (i.e., the energy absorbing material **520**) during a possible subsequent fire event. With the crush material exposed, the fire event may threaten the crush material's physical integrity, including polyurethane crush material which can catch fire. Even aluminum honeycomb material, widely used in the industry, runs the risk of its glue or brazing being damaged from excessive exposure to heat. Another risk is that of overheating of the seals (such as the lid seal **400**) that lie right under the lid **300**. The lid seal **400**, while very effective in providing reliable containment in moderate temperatures, may become ineffective at elevated temperatures. This limitation of the lid seal **400** may be overcome by utilizing the thermal shield **600**, mentioned above and described in greater detail below.

Referring to FIGS. **7**A and **7**B, the thermal shield **600** will be described in accordance with an embodiment of the present invention. The thermal shield **600** generally comprises a top plate **610** having a top surface **611** and a bottom surface **612** and an annular skirt **620** extending downwardly from the bottom surface **612** of the top plate **610**. The annular skirt **620** extends downwardly from the bottom surface **612** of the top plate **610** along an outer edge of the top plate **610**. The annular skirt **620** terminates in an annular distal end **621**. The annular skirt **620** comprises an inner surface **622** and an outer surface **623** that is opposite the inner surface **622**. The inner surface **622** of the annular skirt **620** and the bottom surface **612** of the top plate **610** collectively define a thermal shield cavity **602**, whereby the inner surface **622** of the annular skirt **620** forms the sidewall boundary of the thermal shield cavity **602** and the bottom surface **612** of the top plate **610** forms the floor (or roof depending on orientation) of the thermal shield cavity **602**. Thus, the thermal shield **600** may be in the shape of an inverted cup.

The thermal shield **600** comprises a plurality of fastener holes **601** that extend through the top plate **610** from the top surface **611** to the bottom surface **612**. The fastener holes **601** are positioned in a spaced apart manner in a circular arrangement. The exact number, spacing, and positioning of the fastener holes **601** is not to be limiting of the invention in all embodiments. The fastener holes **601** may be configured to receive a fastener, such as a bolt, a screw, or the like, to facilitate the attachment of the thermal shield **600** to the containment vessel **100**, as described in more detail below. The fastener holes **601** may be spaced and positioned in the same manner as the fastener holes **536** of the first impact limiter **500** so that the same fastener/bolt may be used to couple the first impact limiter **500** and the thermal shield **600** to the containment vessel **100**, as described in more detail below with reference to FIGS. **8**-**10**.

The thermal shield **600** may be formed from any high temperature resistant, low heat conductivity and corrosion resistant alloy. In one embodiment, the thermal shield **600** may be formed from austenitic stainless steel. In one embodiment, the thermal shield **600** may comprise a polished surface, although this may not be required in all embodiments. Specifically, the outer surface of the thermal shield **600** may be a polished surface. Forming the thermal shield **600** with polished or shiny surfaces may minimize radiative heat through the thermal shield **600** and into the containment vessel **100**. The outer surface of the thermal shield **600**, which is formed by the outer surface **622** of the annular skirt **620** and the top surface **611** of the top plate **610**, may have an emissivity coefficient of 0.2 or less. In another embodiment, the outer surface of the thermal shield **600** may have an emissivity coefficient of 0.1 or less.

In some embodiments, the thermal shield is formed from a material having a thermal conductivity of about 30 Watts/(Meter×Kelvin), or less. In some embodiments, the thermal shield is formed from a material having a thermal conductivity of about 20 Watts/(Meter×Kelvin), or less. In some embodiments, the thermal shield may be formed from a material having a thermal conductivity of between about 10 Watts/(Meter×Kelvin) and about 40 Watts/(Meter×Kelvin), more specifically between about 10 Watts/(Meter×Kelvin) and about 30 Watts/(Meter×Kelvin), more specifically between about 12 Watts/(Meter×Kelvin) and about 25 Watts/(Meter×Kelvin), and still more specifically between about 15 Watts/(Meter×Kelvin) and about 21 Watts/(Meter×Kelvin). The term "about" as used herein allows for a variation of plus/minus 5%.

The thermal shield **600** may have an effective thermal conductivity. When the thermal shield **600** comprises a single layer, the effective thermal conductivity may be the thermal conductivity of that single layer. When the thermal shield **600** comprises multiple layers, the effective thermal conductivity may be a mean thermal value of all of the various layers. That is, if the thermal shield **600** is a laminate structure, the effective thermal conductivity may take into consideration the thermal conductivity of each of the layers. In some embodiments, when moving normally from an outer surface of the thermal shield **600** to an inner surface of the thermal shield **600**, the thermal shield **600** may have an effective thermal conductivity of about 3 Watts/(Meter×Kelvin), or less. In some embodiments, the thermal shield **600** may have an effective thermal conductivity of about 1 Watt/(Meter×Kelvin), or less. In some embodiments, the thermal shield **600** may have an effective thermal conductivity of about 0.75 Watts/(Meter×Kelvin), or less. The term "about" as used herein allows for a variation of plus/minus 5%. In some embodiments, it may be the top plate **610** of the thermal shield **600** that has the effective thermal conductivity within the ranges noted above.

In some embodiments the shell **510** of the impact limiter **500** and the thermal shield **600** may be formed from the same material, for example stainless steel material. However, this is not required in all embodiments. In some embodiments the shell **510** of the impact limiter **500** and the thermal shield **600** may both be formed from stainless steel, although they may have different surface finishes (for example, the thermal shield **600** may be polished and the shell **510** of the impact limiter **500** may not be polished).

Referring to FIGS. **8**-**10**, the system **1000** will be further described, with specific discussion of the relative positioning of the various components and parts of the system **1000** previously described. The vessel body **200** comprises the upper portion **210** which includes an second end or top end **202** of the vessel body **200** and the lower portion **220** which includes a first end or lower end **201** of the vessel body **200**. The second impact limiter **550** is coupled to the lower end **201** of the vessel body **200**. The second impact limiter **550** comprises a body portion **551** having a top surface **552** and a depression **553** formed into the top surface **552**. The lower end of the vessel body **200** may be located within the depression **553** of the second impact limiter **550** when the second impact limiter **550** is coupled to the vessel body **200**.

As noted previously but perhaps best shown in FIGS. **9** and **10**, the upper portion **210** of the vessel body **200** comprises the seal seat **213** and the annular collar **211** that collectively define the entry passageway **206** that forms a passageway into the storage cavity **204**. The lid **300** is positioned within the entry passageway **206**. The lid **300** may include a lower portion **310** that nests within the storage cavity **204** below the entry passageway **206** and an upper portion **320** that nests within the entry passageway **206**. The upper portion **320** may comprise a downwardly facing shoulder **321** that extends radially outwardly from the lower portion **310**. The downwardly facing shoulder **321** may be considered to form part of the bottom surface of the lid **300**. The downwardly facing shoulder **321** may rest atop of the seal seat **213** of the upper portion **210** of the vessel body **200** when the lid **300** is positioned within the entry passageway **206**.

The lid seal **400** may be located between the downwardly facing shoulder **321** and the seal seat **213** to hermetically seal the top end of the storage cavity **204**. The lid seal **400** may be compressed between the lid **300** and the seal seat **213** of the vessel body **200**. This compression of the lid seal **400** may be achieved solely due to the weight of the lid **300** as the lid **300** rests atop of the lid seal **400** and/or may be achieved when the lid **300** is coupled to the vessel body **200** with fasteners, as described below.

The lid **300** may be coupled to the vessel body **200** with fasteners **315** that extend into the holes **301** in the lid **300** and into the holes **214** in the seal seat **213**. The fasteners **315** may be bolts as previously described or other types of fasteners including screws, rivets, rods, threaded rods, or the like. The fasteners **315** and the holes **301** and the holes **214** may be located radially outward of the location of the lid seal **400** to prevent radiation from emitting from the storage cavity **204** and through the holes **301**, **214**.

The thermal shield **600** may be positioned atop of the lid **300**. Specifically, the thermal shield **600** may be positioned so that the top plate **610** of the thermal shield **600** covers the lid **300** and the annular skirt **620** of the thermal shield **600** extends downwardly along an outer surface of the annular collar **211** of the vessel body **200**. A small gap or space may exist between the annular skirt **620** of the thermal shield **600** and the outer surface of the annular collar **211** of the vessel body **200**, as best shown in FIG. **10**. In alternative embodiments, a tight fit may exist between the annular skirt **620** and the annular collar **211** so that the gap is reduced or eliminated.

The thermal shield **600** may fully cover the lid **300** so that no portion of the lid **300** is exposed when the thermal shield **600** is positioned thereon or when the thermal shield **600** is coupled to the vessel body **200**. In the embodiment shown in FIGS. **8**-**10**, the thermal shield **600** is positioned over the annular collar **211** of the vessel body **210** so that the top plate **610** of the thermal shield **600** is atop of the distal end of the annular collar **211** and the lid **300** and the annular skirt **620** circumscribes at least a portion of the annular collar **211**. The top plate **610** of the thermal shield **600** may overlie an entirety of the lid **300**. As used herein, the term overlie does not require direct contact between the top plate **610** of the thermal shield **600** and the lid **300**, but requires the top plate **610** of the thermal shield **600** to extend over and cover the lid **300**, which can be achieved regardless of whether the top plate **610** of the thermal shield **600** directly contacts the lid **300** or not.

The top plate **610** of the thermal shield **600** may be in direct contact with the top surface of the lid **300** in some embodiments, although there may be a gap between the top plate **610** of the thermal shield **600** and the top surface of the lid **300** in other embodiments, examples of which will be described herein below. Furthermore, while in the exemplified embodiment the inner surface **622** of the annular skirt **620** of the thermal shield **600** may be in contact with the outer surface of the annular collar **211** of the vessel body **200**, in other embodiments there may be a space or gap between the inner surface **622** of the annular skirt **620** and the outer surface of the annular collar **211**.

As noted above, the thermal shield **600** comprises the top plate **610** and the annular skirt **620** that collectively define the thermal shield cavity **602**. When the thermal shield **600** is positioned over the lid **300** and coupled to the containment vessel **100**, at least a portion of the annular collar **211** of the vessel body **200**, at least a portion of the lid **300**, and the lid seal **400** are located within the thermal shield cavity **602**. Thus, a plane B-B oriented perpendicular to the longitudinal axis A-A that intersects the lid seal **400** will also intersect the annular skirt **620** of the thermal shield **600**. The plane B-B also intersects the lid **300** and the annular collar **211** of the vessel body **200**. Stated another way, the thermal shield cavity **602** may be defined between the bottom surface **612** of the top plate **610** of the thermal shield **600** and a plane on which the distal end **621** of the annular skirt **620** lies. As shown in FIGS. **9** and **10**, the lid seal **400** is located within the thermal shield cavity **602** so defined. By positioning the lid seal **400** within the thermal shield cavity **602**, the thermal shield **600** is able to reduce the amount of heat that is able to reach the lid seal **400** from the exterior of the containment vessel **100** during a fire situation or a design basis fire event, such as described above. This can help to preserve the integrity of the lid seal **400** even when the system **1000** is fully engulfed in flames, which can prevent liquid from penetrating into the storage cavity **204** during a later water immersion event (or while trying to put out the flames of the fire) and also prevent radiation from being emitted from the storage cavity **204**.

The first impact limiter **500** is positioned over the thermal shield **600** and coupled to the containment vessel **100** so that the thermal shield **600** is located between the first impact limiter **500** and the containment vessel **100**. More specifically, the thermal shield **600** may be located between the first impact limiter **500** and the lid **300**. The top plate **610** of the thermal shield **600** may be located within the depression **505** of the first impact limiter **500**. Furthermore, at least a portion of the annular skirt **620** of the thermal shield **600** may be located within the depression **505** of the first impact limiter **500** when the first impact limiter **500** is coupled to the containment vessel **100**. In some embodiments, a distal portion of the annular skirt **620** may extend past the bottom surface **502** of the first impact limiter **500** so that the distal portion of the annular skirt **620** may not be located within the depression **550** of the first impact limiter **500**. In other embodiments the distal end **621** of the annular skirt **620** may be recessed within the depression **505** of the first impact limiter **500**.

The first impact limiter **500** may be coupled to the containment vessel **100** with fasteners **508**. The fasteners **508** may be inserted into the passageways **540** of the first impact limiter **500** until the heads of the fasteners **508** abut against the horizontal plate portion **532** of the bracket member **530**, thereby preventing the fasteners **508** from moving further axially in the direction of the containment vessel **100**. When so positioned, shank portions of the fasteners **508** extend into and through the fastener holes **536** in the horizontal plate portion **532** and into a fastener receiving hole **218** that is formed in the distal end of the annular collar **211** of the vessel body **200** to securely couple the first impact limiter **500** to the vessel body **200**. In the exemplified embodiment, the first impact limiter **500** is coupled directly to the vessel body **200** via the fasteners **518**. In other embodiments, the fasteners holes **536** may align with the lid **300** which may include the fastener receiving holes **218** so that the first impact limiter **500** may be coupled to the lid **300** with the fasteners **218**, with the lid **300** in turn being coupled to the vessel body **200** with the fasteners **315**.

As noted above, the thermal shield **600** is positioned between the first impact limiter **500** and the vessel body **200**. Furthermore, the thermal shield **600** includes the fasteners holes **601**, which are aligned with the fastener holes **536** in the bracket member **530** of the first impact limiter **500** and with the fastener receiving holes **218** in the containment vessel **100**. Thus, the fasteners **518** may extend through the fastener holes **536** in the bracket member **530**, through the fastener holes **601** in the thermal shield **600**, and into the fastener receiving holes **218**. As such, the same fasteners **518** may be used to couple the first impact limiter **500** and the thermal shield **600** to the containment vessel **100**.

Referring to FIGS. **11** and **12**, a portion of a system for transporting radioactive materials **1100** is illustrated in accordance with an alternative embodiment of the present invention. The system **1100** is identical to the system **1000** except for the differences specifically mentioned herein. In particular, the system **1100** comprises the containment vessel **100** which includes the vessel body **200**, the lid **300**, and the lid seal **400**, all of which are identical to those components as described above with reference to the system **1000**. Furthermore, the system **1100** includes a first impact limiter **500** and a second impact limiter **550**. Although the second impact limiter **550** is not shown in FIGS. **11** and **12**, it should be understood that the portion of the system **1100** which is not illustrated in FIGS. **11** and **12** is identical to the same portion of the system **1000** described above. Finally, the system **1100** includes a thermal shield **700**. The thermal shield **700** of the system **1100** differs somewhat from the thermal shield **400** of the system **1000**, as described in detail below. In this embodiment, the description of the components above with reference to FIGS. **1**-**10** is applicable except with regard to the specific modification to the thermal shield **700** described below. Description of the material of the thermal shield **600** may be applicable to the thermal shield **700**.

The thermal shield **700** comprises a top plate **710** and an annular skirt **720** extending downward from the top plate **710** to form a thermal shield cavity **702**. In this embodiment, the top plate **710** of the thermal shield **700** is a multi-layer construction. Specifically, the top plate **710** of the thermal shield **700** comprises a first layer **730** and a second layer **740**. The first layer **730** comprises a top surface **731** that forms a top surface of the top plate **710** and a bottom surface **732** opposite the top surface **731**. The second layer **740** comprises a top surface **741** and a bottom surface **742** opposite the top surface **741**, with the bottom surface **742** of the second layer **740** forming a bottom surface of the top plate **710**.

The bottom surface **732** of the first layer **730** is spaced apart from the top surface **741** of the second layer **740** by a gap **750**. In the exemplified embodiment the gap **750** has a width, measured from the bottom surface **732** of the first layer **730** to the top surface **741** of the second layer **740**, that is 5 mm or less. In some embodiments, the gap **750** may have a width that is no more than 4 mm, more specifically no more than 3 mm, more specifically no more than 2 mm, more specifically no more than 1 mm. In this embodiment, the gap **750** may have a constant and consistent width measured between the bottom surface **732** of the first layer **730** and the top surface **741** of the second layer **740**. However, the invention is not to be so limited in all embodiments and the width of the gap **750** may vary along a length of the gap **750**. In some embodiments, air may be located within the gap **750**. In other embodiments, the gap **750** may be evacuated of air to further block the ingress of heat from a fire towards the vessel body **200** and outwards the lid seal **400**. In still other embodiments, a substance or material that further reduces the ingress of heat towards the lid **300** and the lid seal **400** may be disposed within the gap **750**. For example, an insulation material may be disposed within the gap **750**. Such insulation materials may include fiberglass, wool, cotton, paper, wood cellulose, straw, foam, or the like.

As with the prior described embodiment, the containment vessel **100** includes the vessel body **200**, the lid **300** coupled to the upper portion of the vessel body **200**, and the lid seal **400** positioned between the lid **300** and the upper portion of the vessel body **200** to hermetically seal the top end of the storage cavity **204**. The first impact limiter **500** and the thermal shield **700** are coupled to the containment vessel **100** (with fasteners as previously described) so that the thermal shield **700** is located between the first impact limiter **500** and the containment vessel **100**. As such, the lid seal **400** is located within the thermal shield cavity **702**. The two layer arrangement of the top plate **710** of the thermal shield **700** may more effectively block the inflow of heat (such as from a fire) towards the lid **300** and the lid seal **400** as compared to the single layer arrangement of the top plate **610** of the thermal shield **700** previously described. The air gap **750**, whether evacuated or not, may further block the ingress of heat from a fire. This may serve to protect the integrity of the lid seal **400** to ensure radiation is contained within the storage cavity **204** of the vessel body **200**.

In another embodiment, the annular skirt **720** may also have a multi-layer arrangement similar to the top plate **710**. That is, the annular skirt **720** may also comprise first and second layers that are spaced apart by a gap which may be filled with air or evacuated of air or filled with some other substance, such as an insulation material as described above, that helps to prevent the ingress of heat towards the lid **300** and the lid seal **400**.

In the exemplified embodiment, the top plate **710** comprises holes **701** for receiving the fasteners **518** that are used to couple the first impact limiter **500** and the thermal shield **700** to the containment vessel **100**. In the exemplified embodiment, the holes **701** extend through the gap **750** between the first and second layers **730**, **740** of the top plate **710** of the thermal shield **700**. In other embodiments, the top plate **710** of the thermal shield **700** may include an outer portion that is positioned radially outward of the gap **750** and which does not include the gap **750**. That is, the outer portion (which may be annular or ring-shaped, although this is not required) may be a solid region where the gap is filled in by the material of the thermal shield **700**. In such embodiment, the holes **701** may be located along this outer portion of the top plate **710** so that the holes **701** are not in fluid communication with the gap **750**.

Referring to FIGS. **13**A and **13**B, a thermal shield **800** is illustrated in accordance with another embodiment of the present invention. In FIGS. **13**A and **13**B the thermal shield **800** is illustrated by itself. It should be appreciated that the thermal shield **800** can be used in place of the thermal shield **600** or the thermal shield **700** and is configured to be positioned in the same manner as the thermal shields **600**, **700** described above. Thus, the interaction between the thermal shield **800** and the containment vessel **100** and between the thermal shield **800** and the first impact limiter **500** is the same as that described above with reference to the thermal shields **600**, **700**.

The thermal shield **800** comprises a top plate **810** having a top surface **811** and a bottom surface **812** and an annular skirt **820** extending downwardly from the bottom surface **812** of the top plate **810** to a distal end **821** of the annular skirt **820**. The annular skirt **820** may extend from the top plate **810** along a peripheral edge of the top plate **810**. The top plate **810** may be a multi-layer construction. Specifically, the top plate **810** may comprise a first layer **830** and a second layer **840**, similar to the construction of the top plate **710** of the thermal shield **700**. The first layer **830** may have a bottom surface **831** and the second layer **840** may have a top surface **841**, with the top surface **841** of the second layer **840** being adjacent to the bottom surface **831** of the first layer **830**. The first and second layers **830**, **840** may be welded together by a weld joint **815**. The weld joint **815** may be an annular weld joint At least a portion of the bottom surface **831** of the first layer **830** may be spaced apart from at least a portion of the top surface **841** of the second layer **840** by a gap **850**.

While in this embodiment there exists the gap **850** between the first and second layers **830**, **840** similar to the thermal shield **700**, in this embodiment the gap **850** may not have a consistent or constant width measured between the bottom surface **831** of the first layer **830** of the top plate **810** and the top surface **841** of the second layer **840** of the top plate **810**. Rather, the width of the gap may vary. In this embodiment, the first and second layers **830**, **840** of the top plate **810** of the thermal shield **800** may not be in conformal surface contact, and this non-conformal surface contact may create the gap **850**.

The non-conformal surface contact between the first and second layers **830**, **840** may occur or be achieved in several ways. In one embodiment, the bottom surface **831** of the first layer **830** and/or the top surface **841** of the second layer **840** may not be perfectly planar. The first and second layers **830**, **840** may only be welded together along an annular peripheral portion thereof. As a result, the bottom surface **831** of the first layer **830** and the top surface **841** of the second layer **840** may contact one another in some regions but not in others, and in the regions where they do not contact the gap **850** will exist. In other embodiments, one or both of the bottom surface **831** of the first layer **830** and/or the top surface **841** of the second layer **840** may be roughened to create the gap **850** when the first and second layers **830**, **840** are coupled together. In other embodiments, one or both of the bottom surface **831** of the first layer **830** and/or the top surface **841** of the second layer **840** may be textured to create the gap **850** when the first and second layers **830**, **840** are coupled together. In still other embodiments, one or both of the bottom surface **831** of the first layer **830** and/or the top surface **841** of the second layer **840** may be dented so that when the first and second layers **830**, **840** are coupled together the gap **850** exists. Other techniques for making the bottom surface **831** of the first layer **830** non-conformal with the top surface **841** of the second layer **840** when the first and second layers **830**, **840** are coupled together may be used to form the gap **850** in other embodiments.

The gap **850** may be non-uniform and also discontinuous because there may be no gap in certain regions where the bottom surface **831** of the first layer **830** contacts the top surface **841** of the second layer **840**. The width of the gap **850** may be less than 5 mm, less than 4 mm, less than 3 mm, or more specifically less than 2 mm. The width of the gap **850** may be approximately 1 mm, with approximately including a tolerance of 5%. The gap **850** may be a practical air gap formed due to the non-conformal surface contact between the first and second layers **830**, **840** as described herein. The gap **850** may be an interstitial space that exists between the first and second layers **830**, **840**. The interstitial space or gap **850** may be evacuated of air. The interstitial space or gap **850** may have a negative pressure. An insulation material, some examples of which are provided above, may be located in the gap **850** in some embodiments.

As with the prior embodiments, the top plate **810** may comprise holes **801** for receiving fasteners that are used to couple the first impact limiter **500** and the thermal shield **800** to the containment vessel **100**. The holes **801** may extend from an opening in the top surface **811** of the top plate **810** to an opening in the bottom surface **812** of the top plate **810**. Thus, the holes **801** may extend through the first and second layers **830**, **840** of the top plate **810**.

Referring to FIGS. **14**, a portion of a system for transporting radioactive materials **1200** is illustrated in accordance with an alternative embodiment of the present invention. The system **1200** is identical to the systems **1000**, **1100** except for the differences specifically mentioned herein. In particular, the system **1200** comprises the containment vessel **100** which includes the vessel body **200**, the lid **300**, and the lid seal **400**, all of which are substantially identical to those components as described above with reference to the systems **1000**, **1100** (any modification/difference will be noted below). Furthermore, the system **1200** includes the first impact limiter **500** and the second impact limiter **550**, although those components are not depicted in FIG. **14** to avoid clutter. It should be understood that any component, structure, or portion of the system **1200** which is not illustrated in FIG. **14** is identical to the same component, structure, or portion of the system **1000** described above. Finally, the system **1200** includes the thermal shield **800** described above with reference to FIGS. **13**A and **13**B. Of course, any of the thermal shields **600**, **700**, **800** (or thermal shield embodiments described below) could be used in the system **1200**.

The upper portion of the vessel body **200** comprises the annular collar **211** which extends from the seal seat **213** to a distal end **215** of the annular collar **211**. The inner surface **212** of the annular collar **211** and the seal seat **213** collectively define the entry passageway **206**. The lid **300** is positioned within the entry passageway **206**. The lid **300** comprises a top surface **302** and a bottom surface **303** that is opposite the top surface **302**. The lid seal **400** is compressed between a portion of the bottom surface **303** of the lid **300** and the seal seat **213** (as discussed in more detail above).

The thermal shield **800** is positioned over the distal end **215** of the annular collar **211** and over the top surface **302** of the lid **300**. The annular skirt **820** of the thermal shield **800** may circumscribe a portion of the annular collar **211**. In the exemplified embodiment, the bottom surface **812** of the top plate **810** of the thermal shield **800** is spaced apart from the top surface **302** of the lid **300** by a gap **330**. That is, there is no contact between the bottom surface **812** of the top plate **810** of the thermal shield **800** and the top surface **302** of the lid **300**. In the exemplified embodiment, this gap **330** is formed by recessing the top surface **330** of the lid **300** relative to the distal end **215** of the annular collar **211** of the vessel body **200**. As seen in FIG. **14**, the lid **300** is recessed within the entryway passage **206** such that the top surface **302** of the lid **300** is located below a plane on which the distal end **215** of the annular collar **211** lies. In this embodiment, the gap **330** is defined by the top surface **302** of the lid **300**, the bottom surface **812** of the top plate **810** of the thermal shield **800**, and the inner surface **212** of the annular collar **211** of the vessel body **200**.

There are alternative ways that the gap **330** can be created. For example, there may be support members located on the distal end **215** of the annular collar **211** which protrude from the distal end **215** of the annular collar **211**. The thermal shield **800** may be positioned such that the bottom surface **812** of the top plate **810** is in contact with and supported by the support members. In this situation, even if the top surface **302** of the lid **300** is flush with the distal end **215** of the annular collar **211**, there will be a gap, such as the gap **330**, between the top surface **302** of the lid **300** and the bottom surface **812** of the thermal shield **800**. Another alternative would be to include protuberances that extend from the bottom surface **812** of the thermal shield **800** in a position such that the protuberances contact the distal end **215** of the annular collar **211** when the thermal shield **800** is positioned over the annular collar **211**. These are some of the non-limiting techniques that may be used to create/form the gap **330** described herein and depicted in FIG. **14**.

Referring to FIGS. **15**, a portion of a system for transporting radioactive materials **1300** is illustrated in accordance with another alternative embodiment of the present invention. The system **1300** is identical to the systems **1000**, **1100**, **1200** except for the differences specifically mentioned herein. In particular, the system **1300** comprises the containment vessel **100** which includes the vessel body **200**, the lid **300**, and the lid seal **400**, all of which are substantially identical to those components as described above with reference to the systems **1000**, **1100**, **1200** (any modification/difference will be noted below). Furthermore, the system **1300** includes the first impact limiter **500** and the second impact limiter **550**, although those components are not depicted in FIG. **15** to avoid clutter. It should be understood that any component, structure, or portion of the system **1300** which is not illustrated in FIG. **15** is identical to the same component, structure, or portion of the system **1000** described above. Finally, the system **1300** includes a thermal shield **800***a* which is similar to the thermal shield **800** described above, with a slight modification. It should be appreciated that any of the thermal shields **600**, **700**, **800** (or thermal shield embodiments described below) could be used in the system **1300**, with the modification noted below.

As with the prior embodiments, the lid **300** is positioned within the entry passageway **206** defined by the annular collar **211** and the seal seat **213**. In this embodiment, the top surface **302** of the lid **300** is even or flush with the distal end **215** of the annular collar **211**, although this is not required and the top surface **302** of the lid **300** may be recessed relative to the distal end **215** of the annular collar **211** similar to what is shown in FIG. **14**. The thermal shield **800***a* is positioned over the annular collar **211** so that the top plate **810***a* of the thermal shield **800***a* is atop of the distal end **215** of the annular collar **211** and the annular skirt **820***a* of the thermal shield **800***a* circumscribes at least a portion of the annular collar **211**.

In this embodiment, the thermal shield **800***a* comprises the top plate **810***a* and the annular skirt **820***a*, similar to the embodiment of the thermal shield **800***a* described above. The top plate **810***a* may be a multi-layer construction comprising the first layer **830***a* and the second layer **840***a*, although this is not required and the top plate **810***a* could be a single layer construction similar to the thermal shield **600**. Moreover, in this embodiment the thermal shield **800***a* comprises an annular lip or ridge or rib **825***a* that protrudes from the inner surface **822***a* of the annular skirt **820***a*. In the exemplified embodiment, the annular lip **825***a* is located adjacent to the distal end **821***a* of the annular skirt **820***a*, although the annular lip **825***a* could be located at other positions along the inner surface **822***a* of the annular skirt **820***a* in other embodiments.

When the thermal shield **800***a* is positioned over the annular collar **211** of the vessel body **200**, a distal end **826***a* of the annular lip **825***a* contacts an outer surface **216** of the annular collar **211** while a remainder of the inner surface **822***a* of the annular skirt **820***a* is spaced apart from the outer surface **216** of the annular collar **211** by a gap **230**. The gap **230** exits between the inner surface **822***a* of the annular skirt **820***a* of the thermal shield **800***a* and the outer surface **216** of the annular collar **211** of the vessel body **200**. The gap **230** may be an annular gap in some embodiments. In some embodiments, the features of FIG. **15** may be combined with the features of FIG. **14** to create the gap **330** and the gap **230** in the same embodiment. Such gaps **230**, **330**, when filled with air, evacuated to negative pressure, or filled with an insulating material, may assist in blocking the ingress of heat, such as from a fire, towards the storage cavity **204** to protect the integrity of the lid seal **400**, among other potential benefits.

Referring to FIGS. **16**, a portion of a system for transporting radioactive materials **1400** is illustrated in accordance with another alternative embodiment of the present invention. The system **1400** is identical to the systems **1000**, **1100**, **1200**, **1300** except for the differences specifically mentioned herein. In particular, the system **1400** comprises the containment vessel **100** which includes the vessel body **200**, the lid **300**, and the lid seal **400**, all of which are substantially identical to those components as described above with reference to the systems **1000**, **1100**, **1200**, **1300** (any modification/difference will be noted below). Furthermore, the system **1300** includes the first impact limiter **500** and the second impact limiter **550**, although only the first impact limiter **500** is depicted in FIG. **16**. It should be understood that any component, structure, or portion of the system **1400** which is not illustrated in FIG. **16** is identical to the same component, structure, or portion of the system **1000** described above. Finally, the system **1400** includes a thermal shield **800***b* which is similar to the thermal shield **800** described above, with a slight modification. It should be appreciated that any of the thermal shields **600**, **700**, **800** (or thermal shield embodiments described below) could be used in the system **1400**, with the modification noted below.

In this embodiment, the thermal shield **800***b* comprises the top plate **810***b* and the annular skirt **820***b*. The top plate **810***b* may comprise the first and second layers **830***b*, **840***b*, or may be a singular layer. The annular skirt **820***b* comprises a distal end **821***b*, an inner surface **822***b*, and an outer surface **823***b*. Furthermore, the annular skirt **820***b* comprises an annular lip, rib, or ridge **827***b* that protrudes from the outer surface **823***b* of the annular skirt **820***b*. In the exemplified embodiment, the annular lip **827***b* protrudes from the outer surface **823***b* of the annular skirt **820***b* adjacent to the distal end **821***b*, although the annular lip **827***b* could be located at other positions along the outer surface **823***b* in other embodiments. The annular lip **827***b* may terminate in a distal end **828***b*.

The lid **300** is positioned within the entry passageway **206** of the vessel body **200** and coupled to the vessel body **200**. The thermal shield **800***b* is positioned over the annular collar **211** of the vessel body **200** (and also over top of the lid **300**). The first impact limiter **500** is positioned over the thermal shield **800***b*. In this embodiment, the distal end **828***b* of the annular lip **827***b* is in contact with a sidewall **506** of the depression **505** of the first impact limiter **500**. As such, there is a gap **560** between the outer surface **823***b* of the annular skirt **820***b* and the sidewall **506** of the depression **505** of the first impact limiter **500**. There may also exist a gap between the inner surface **822***b* of the annular skirt **820***b* and the outer surface of the annular collar **211**, although in other embodiments the inner surface **822***b* of the annular skirt **820***b* may contact the outer surface of the annular collar **211**.

Referring to FIGS. **17**A and **17**B, a thermal shield **900** will be described in accordance with yet another embodiment of the present invention. The thermal shield **900** may be used in any of the systems **1000**, **1100**, **1200**, **1300**, **1400** described herein. That is, the thermal shield **900** may be used in place of any of the thermal shields **600**, **700**, **800**, **800***a*, **800***b*. In this embodiment, the thermal shield **900** comprises a top plate **910** and an annular skirt **920** extending downwardly from a bottom surface **911** of the top plate **910**. In this embodiment, the thermal shield **900** is a multi-layer structure including a first layer **930** and a second layer **940**. However, in some embodiments the annular skirt **920** may be a multi-layer structure and the top plate **910** may be a single layer structure.

With particular focus on the annular skirt **920**, the first layer **930** may comprise an inner surface **931** and the second layer **940** may comprise an inner surface **941** that faces the inner surface **931** of the first layer **930**. The first and second layers **930**, **940** of the annular skirt **920** of the thermal shield **900** may not be in conformal contact with one another, such that an interstitial space **950** may exist between the first and second layers **930**, **940**. The interstitial space **950** may form a gap between the inner surfaces **931**, **941** of the first and second layers **930**, **940**. The interstitial space **950** may be non-uniform in its width measured between the inner surfaces **931**, **941** of the first and second layers **930**, **940**. The interstitial space **950** may be non-continuous such that portions of the inner surfaces **931**, **941** of the first and second layers **930**, **940** may be in contact while other portions of the inner surfaces **931**, **941** of the first and second layers **930**, **940** are not in contact. Thus, the interstitial space **950** may form an air gap that helps to block the ingress of heat from a fire or other heat source towards the storage cavity **204** and towards the lid seal **400**, as has been described in detail herein.

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.

What is claimed is:

1. A system for transporting radioactive materials, the system comprising:

- a containment vessel extending along a longitudinal axis from a top end to a bottom end, the containment vessel comprising:
  - a vessel body having a storage cavity configured to receive radioactive materials;
  - a lid coupled to an upper portion of the vessel body to enclose a top end of the storage cavity; and
  - a lid seal positioned between the lid and the upper portion of the vessel body to hermetically seal the top end of the storage cavity;
- a thermal shield comprising a top plate and an annular skirt extending downward from the top plate to form a thermal shield cavity;
- a first impact limiter configured to absorb kinetic energy; and
- the first impact limiter and the thermal shield coupled to the containment vessel, the thermal shield located between the first impact limiter and the containment vessel so that the lid seal is located within the thermal shield cavity.

2. The system according to claim **1** wherein the first impact limiter comprises a body portion having a bottom surface and a first depression formed in the bottom surface, the top plate of the thermal shield located within the first depression of the first impact limiter, and wherein at least a portion of the annular skirt of the thermal shield is located within the first depression of the first impact limiter.

3. The system according to claim **1** further comprising:

- the upper portion of the vessel body comprising an annular collar extending upward from a main body portion of the vessel body, the annular collar forming an entry passageway into the storage cavity;

the lid positioned in the entry passageway of the annular collar; and

the thermal shield positioned over the annular collar so that the top plate of the thermal shield is atop the annular collar and the annular skirt circumscribes at least a portion of the annular collar.

4. The system according to claim **3** further comprising a first gap between a bottom surface of the top plate of the thermal shield and a top surface of the lid.

5. The system according to claim **3** wherein an annular gap exists between an inner surface of the annular skirt of the thermal shield and an outer surface of the annular collar of the vessel body.

6. The system according to claim **3** wherein the lid seal is compressed between the lid and a seal seat of the annular collar.

7. The system according to claim **1** wherein the top plate of the thermal shield is a multi-layer construction comprising a first layer and a second layer.

8. The system according to claim **7** wherein the first layer has a lower surface adjacent a top surface of the second layer, where in the lower surface of the first layer and the top surface of the second layer are not in conformal surface contact.

9. The system according to claim **8** wherein an interstitial space exists between the first and second layers.

10. The system according to claim **9** wherein the interstitial space has a negative pressure.

11. The system according to claim **1** wherein the top plate of the thermal shield overlies an entirety of the lid.

12. The system according to claim **1** wherein an outer surface of the thermal shield is a polished surface.

13. The system according to claim **1** wherein the thermal shield is formed of an austenitic stainless steel.

14. The system according to claim **1** wherein the first impact limiter comprises a body portion comprising a metal enclosure filled with a fire-resistant polyurethane.

15. A system for transporting radioactive materials, the system comprising:

a containment vessel extending along a longitudinal axis from a top end to a bottom end, the containment vessel comprising:

a vessel body having a storage cavity configured to receive radioactive materials; and

a lid coupled to an upper portion the vessel body to enclose a top end of the storage cavity;

a thermal shield comprising a top plate, the top plate being a multi-layer construct comprising a first layer and a second layer;

a first impact limiter configured to absorb kinetic energy; and

the first impact limiter and the thermal shield coupled to the containment vessel, the top plate of the thermal shield located between the first impact limiter and the lid of the containment vessel.

16. The system according to claim **15** wherein the first layer has a lower surface adjacent a top surface of the second layer, wherein the lower surface of the first layer and the top surface of the second layer are not in conformal surface contact.

17. The system according to claim **16** wherein an interstitial space exists between the first and second layers, wherein the interstitial space has a negative pressure.

18. The system according to claim **15** wherein the top plate of the thermal shield overlies an entirety of the lid.

19. The system according to claim **15** wherein an outer surface of the thermal shield is a polished surface.

20. A system for transporting radioactive materials, the system comprising:

a containment vessel extending along a longitudinal axis from a top end to a bottom end, the containment vessel comprising:

a vessel body having a storage cavity configured to receive radioactive materials;

a lid coupled to an upper portion of the vessel body to enclose a top end of the storage cavity; and

a lid seal positioned between the lid and the upper portion of the vessel body to hermetically seal the top end of the storage cavity;

a thermal shield comprising a top plate having an effective thermal conductivity of 3 Watts/(Meter×Kelvin) or less;

a first impact limiter configured to absorb kinetic energy; and

the first impact limiter and the thermal shield coupled to the containment vessel, the top plate of the thermal shield located between the first impact limiter and the lid of the containment vessel.

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