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(54) SURFACE MATERIAL ATTENUATION OF RAREFACTION SHOCK WAVES TO ENHANCE SHAPED-CHARGES

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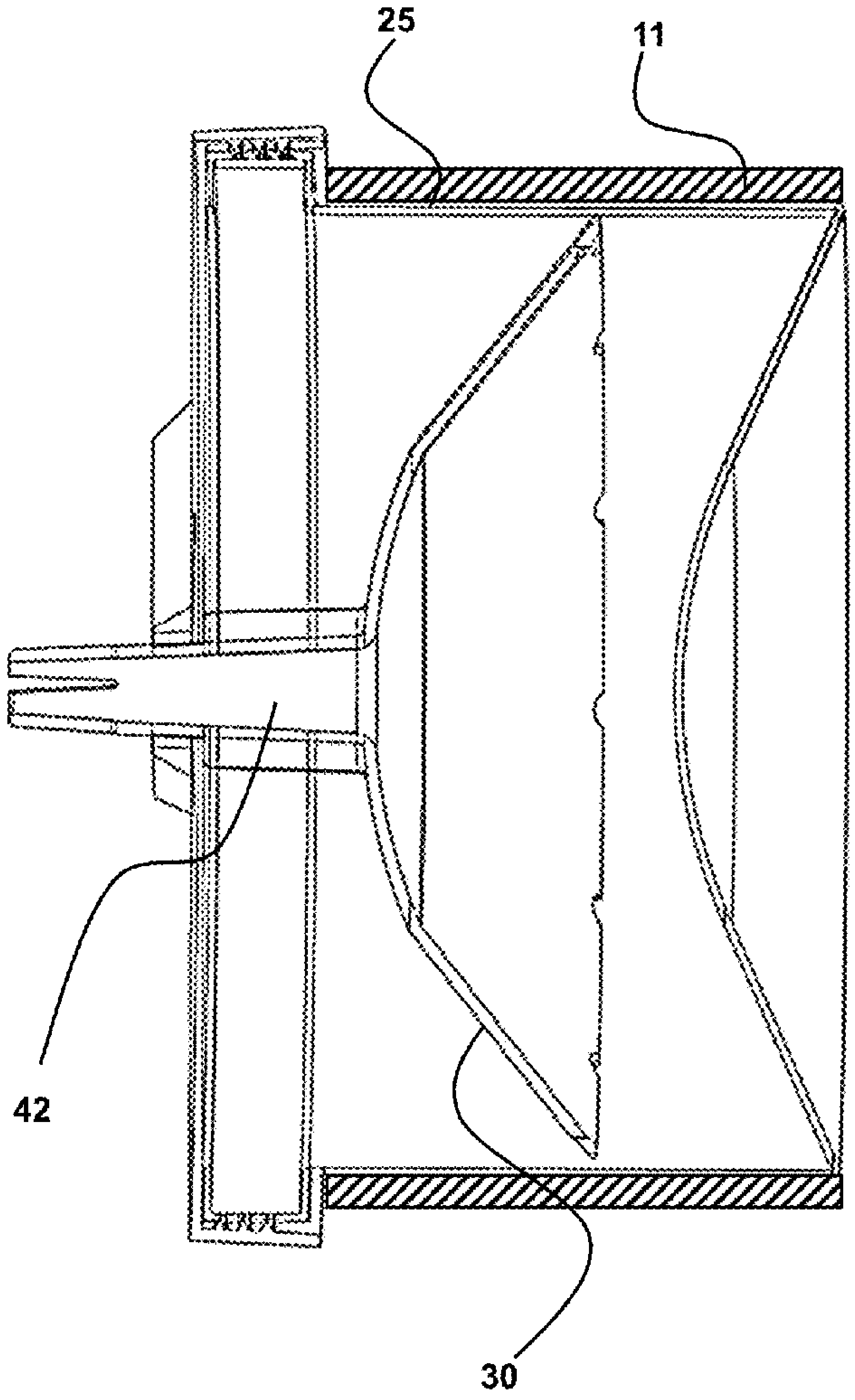
F42B 1/032	(2006.01)

(52) **U.S. Cl.**

CPC ***F41B 9/0046*** (2013.01); ***F42B 1/028*** (2013.01); ***F42B 1/032*** (2013.01)

(57) **ABSTRACT**

Provided herein are shaped-charges for focusing a filler, such as a fluid mass, and related methods of using the shaped-charges for disruption of an explosive target. The shaped-charge comprises an attenuating body positioned and configured to attenuate rarefaction waves to increase filler, including a fluid mass, explosively driven out of the container toward a target while also maintaining and enhancing fluid jet integrity. To further control impact and impulse forces on a target, additional layers may be used, including a foam layer and a jet-clipping layer positioned between the shaped-charge and the target surface. Also provided are propellant driven liquid disrupters having special attenuating bodies to improve liquid jet column characteristics.



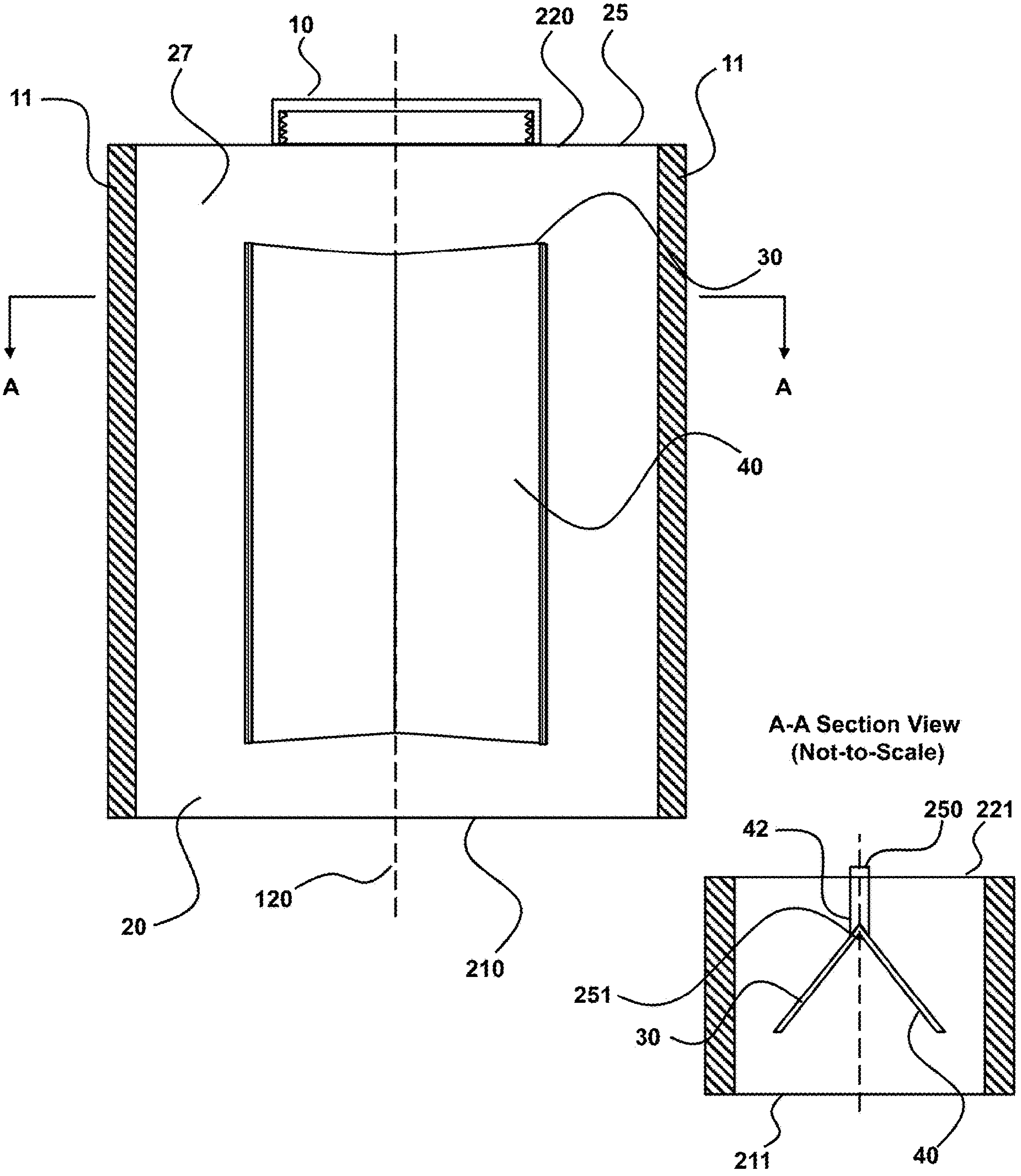
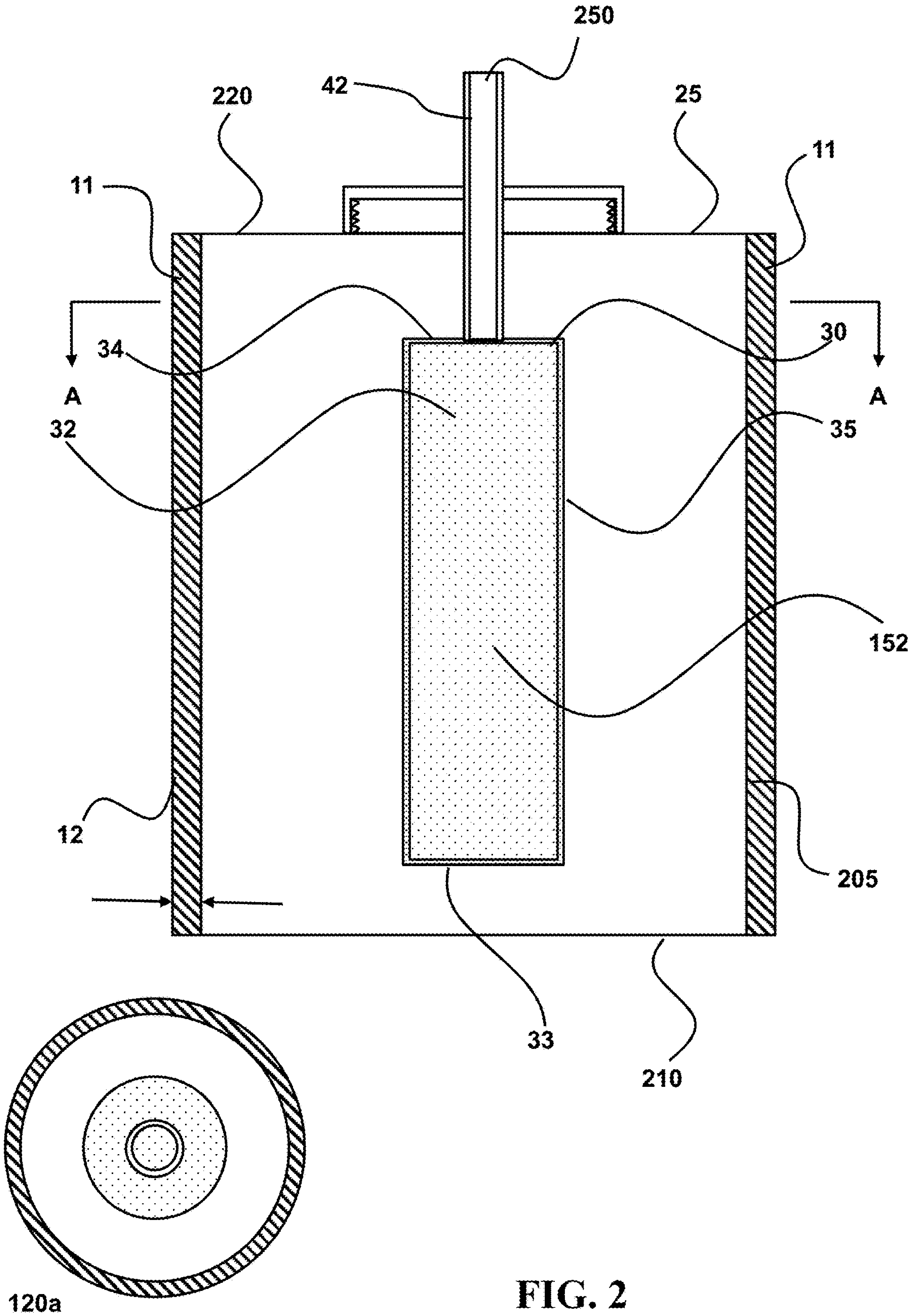

10
220
25
27
11
11
30
A
A
40
A-A Section View
(Not-to-Scale)
42
250
221
20
120
210
251
30
211
40

FIG. 1



120a
A-A Section View (Not-to-Scale)

FIG. 2

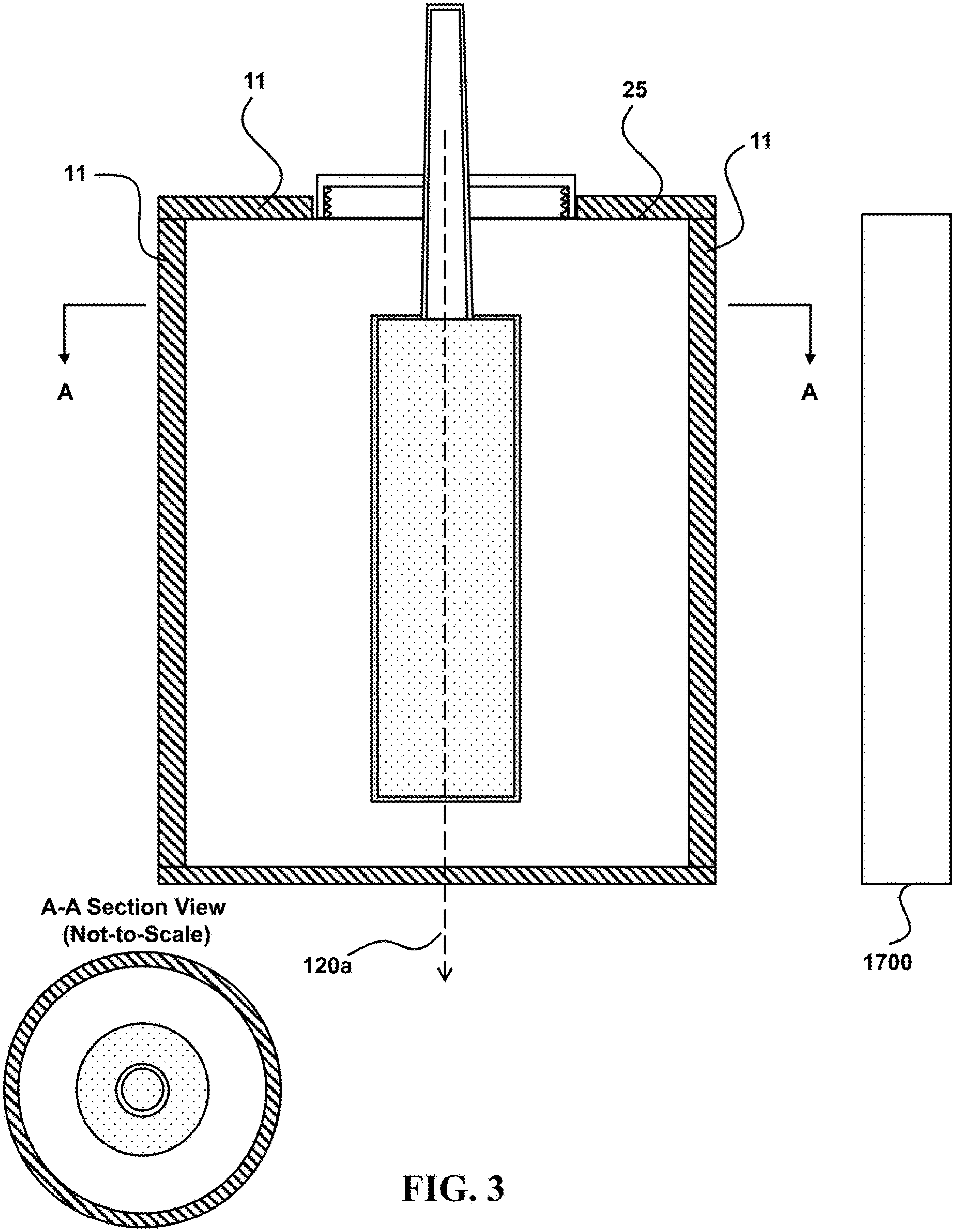


FIG. 3

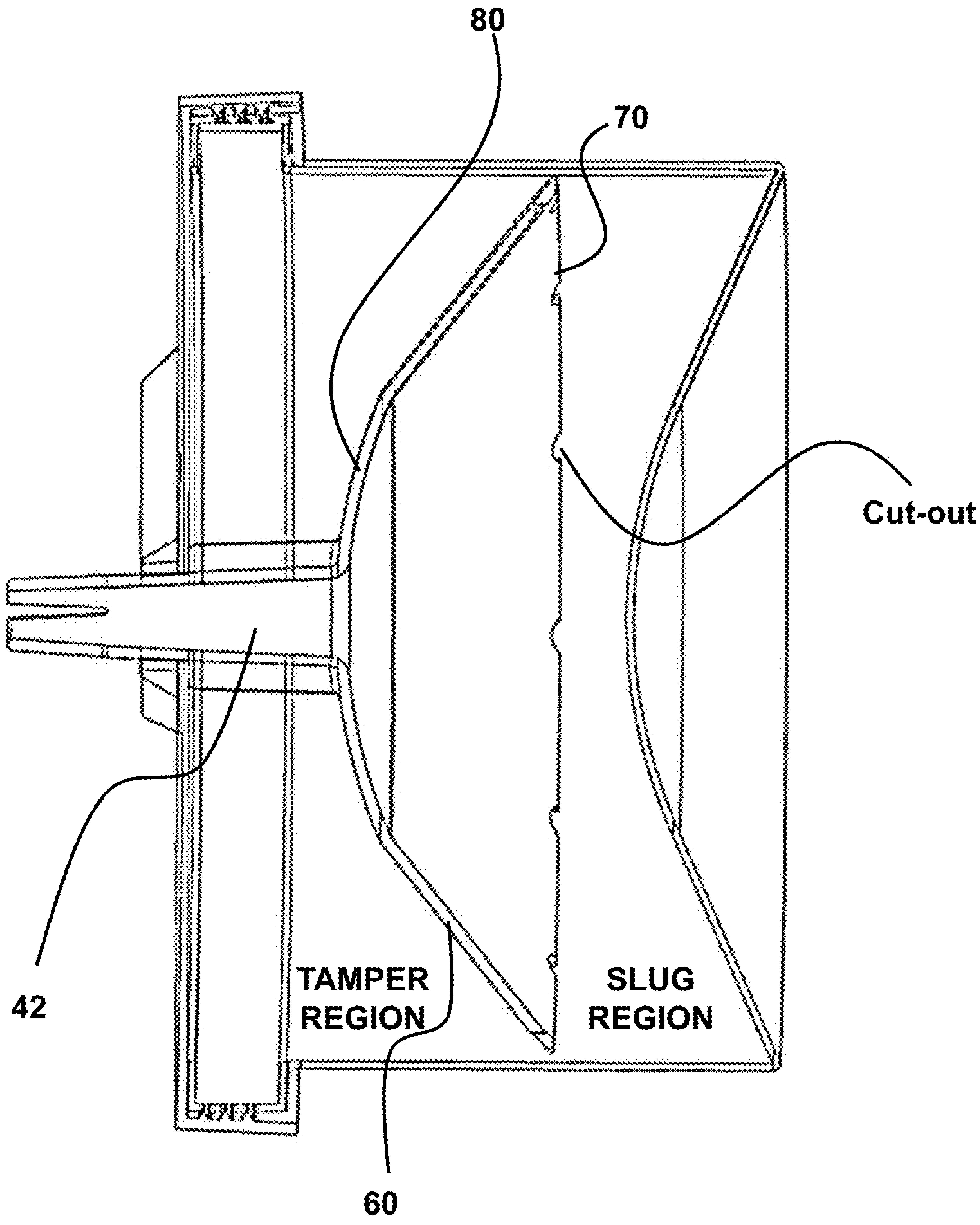


FIG. 4

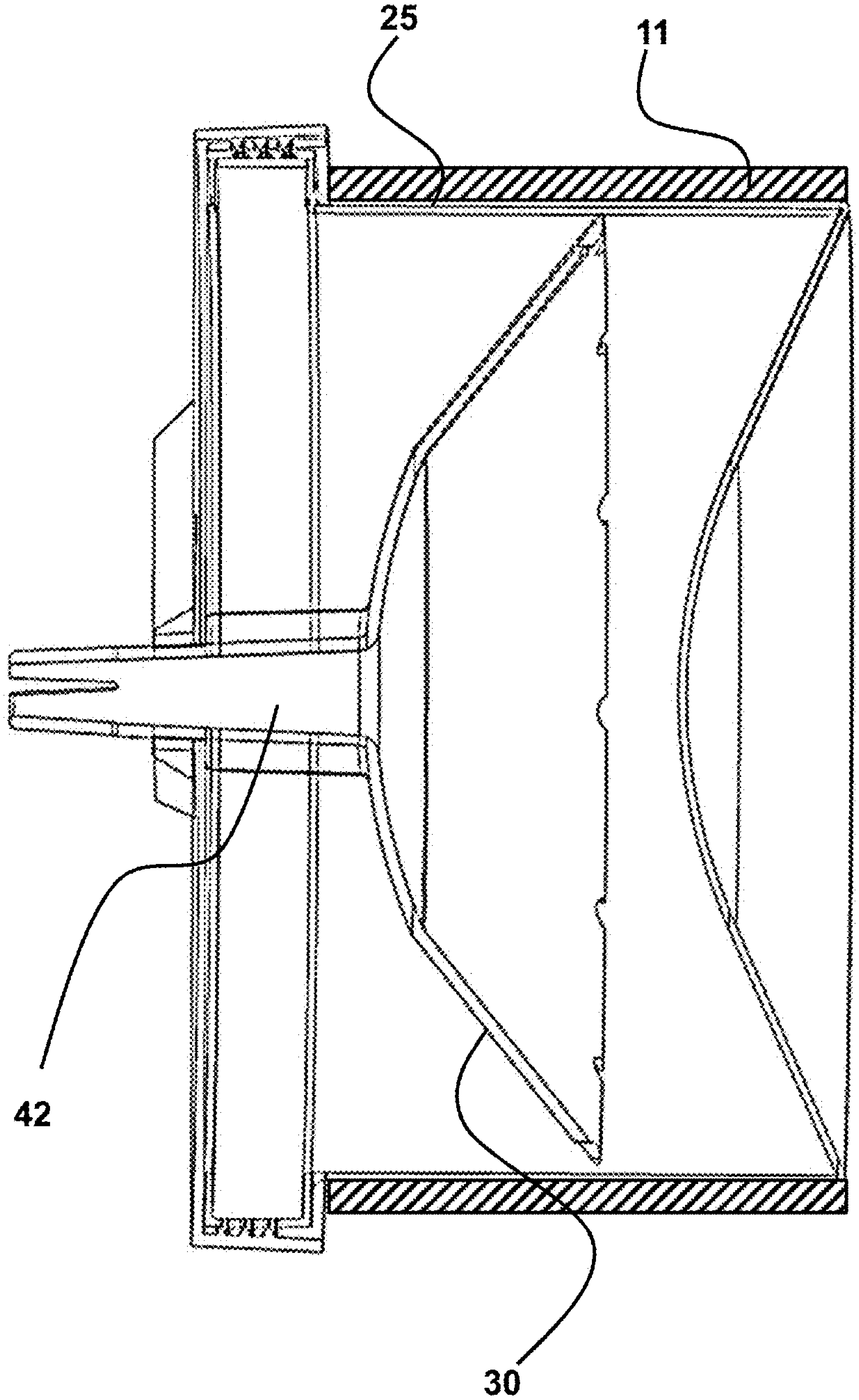


FIG. 5

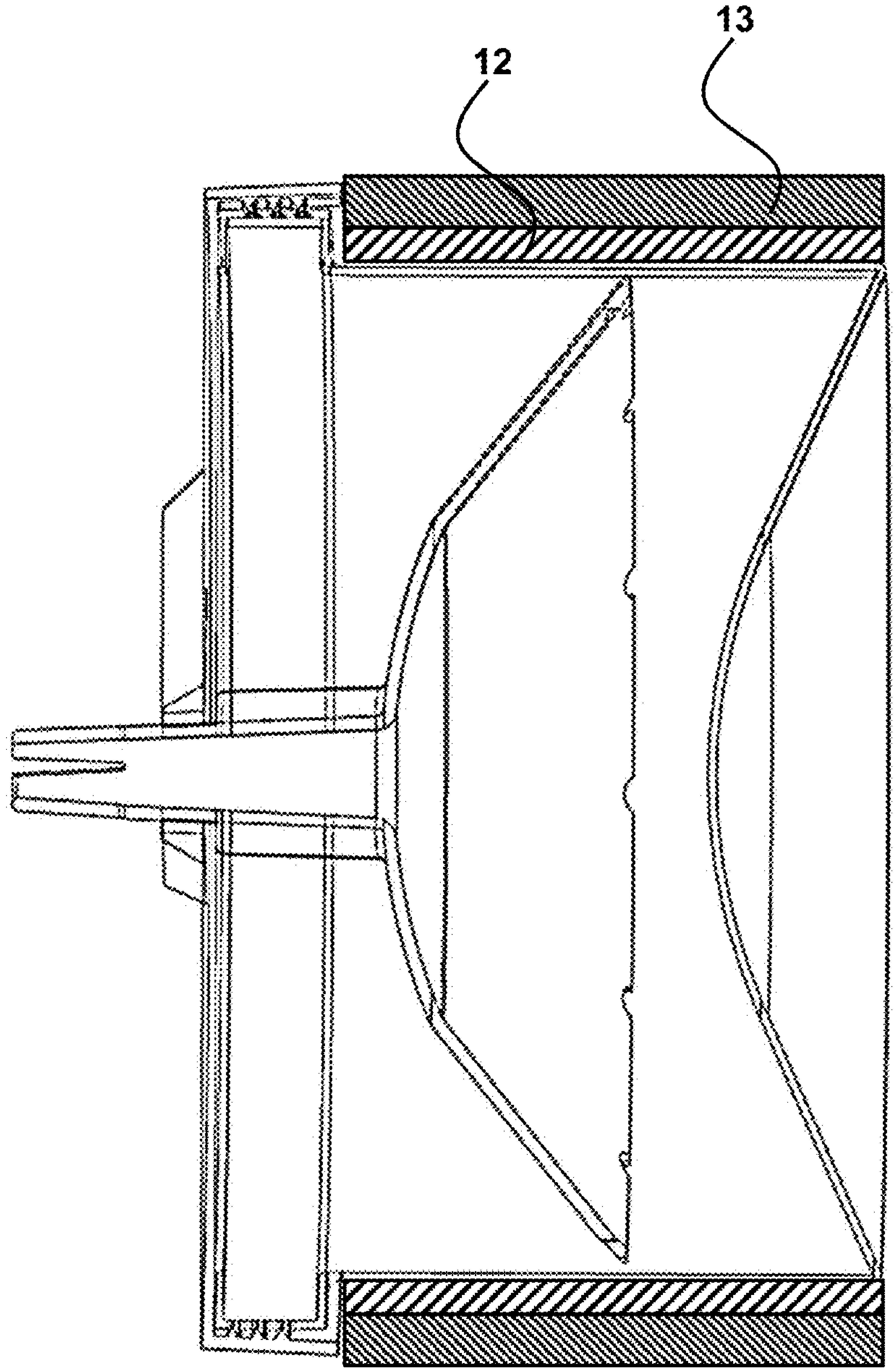


FIG. 6

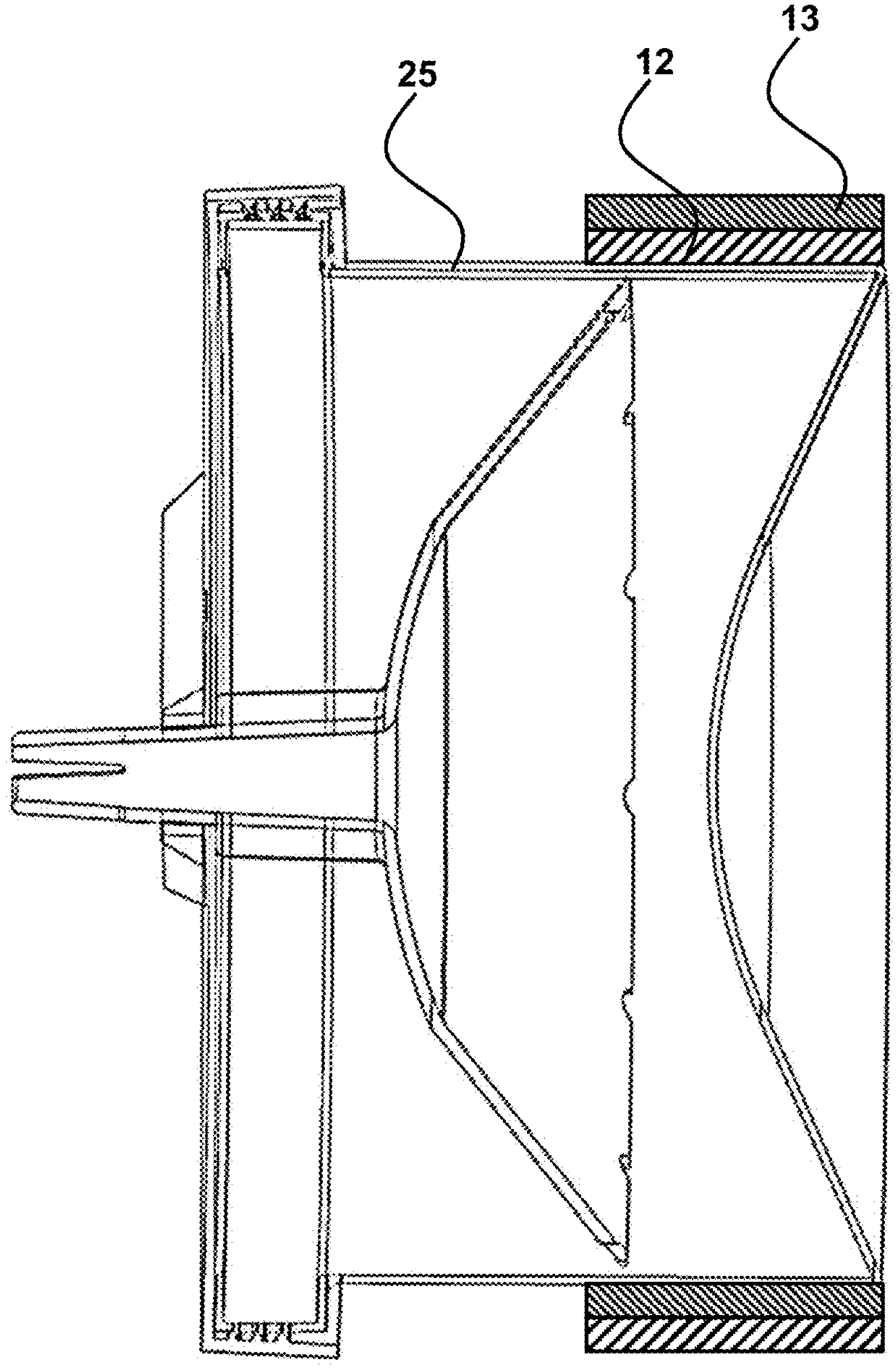


FIG. 7

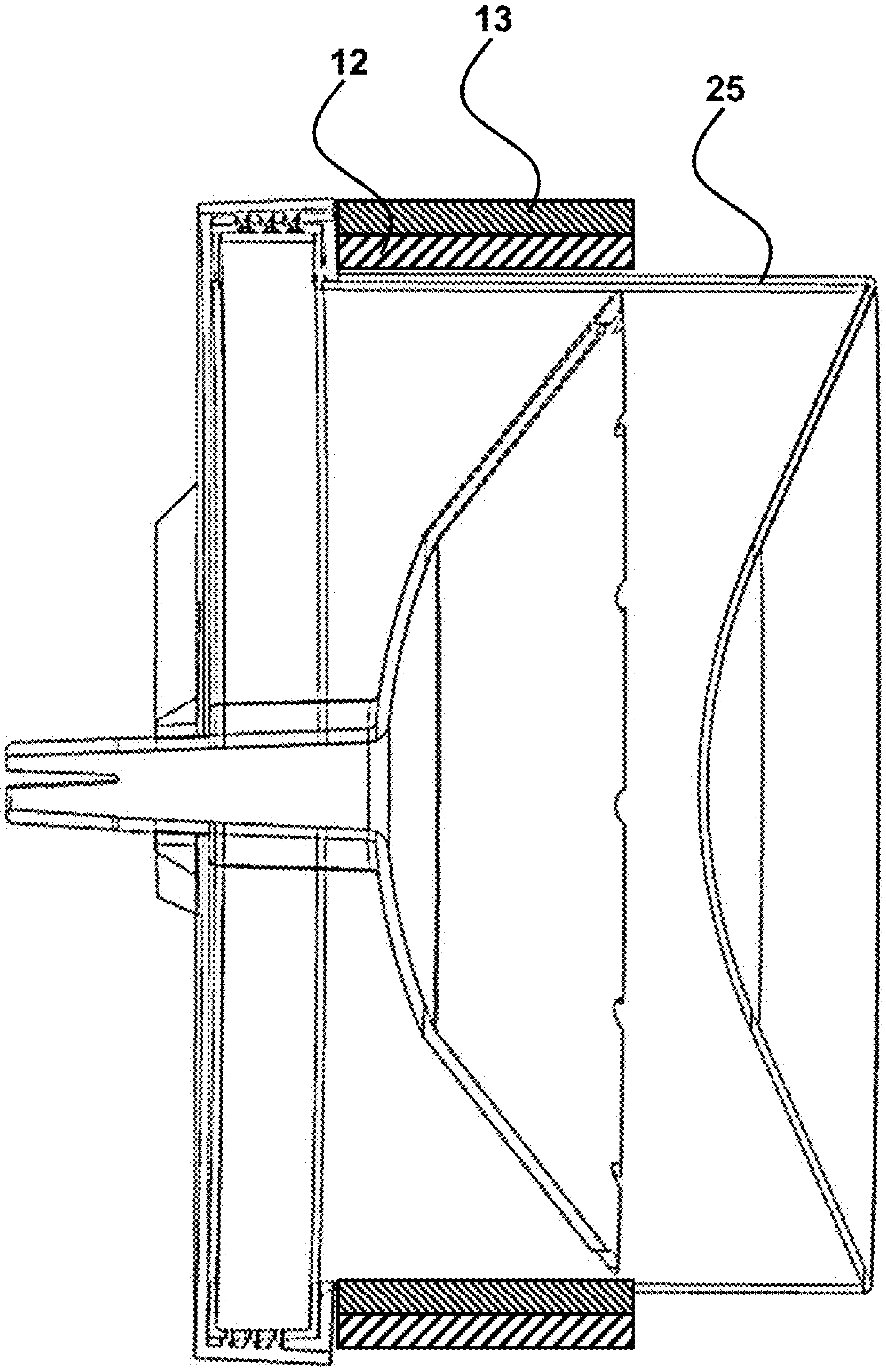


FIG. 8

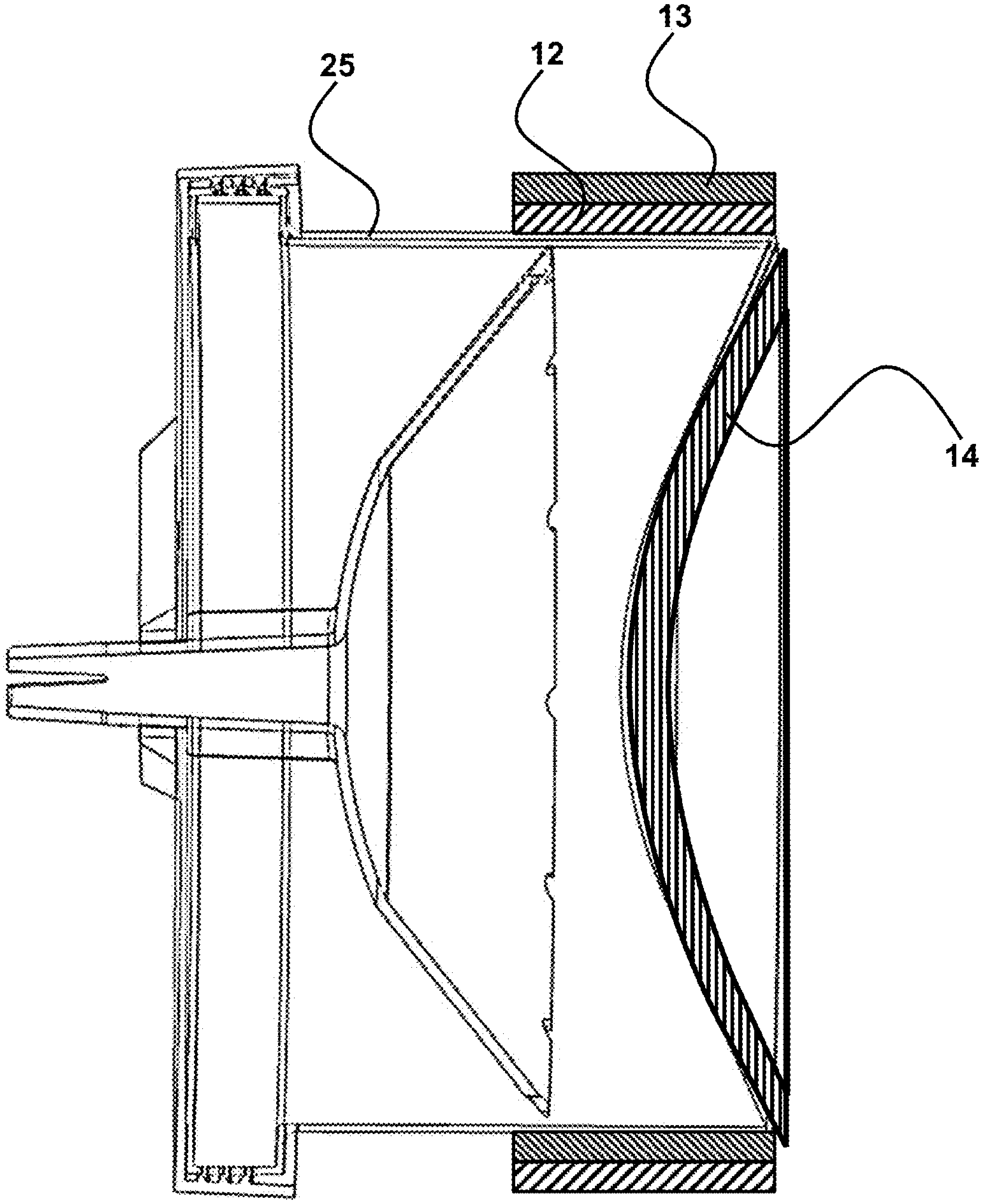


FIG. 9

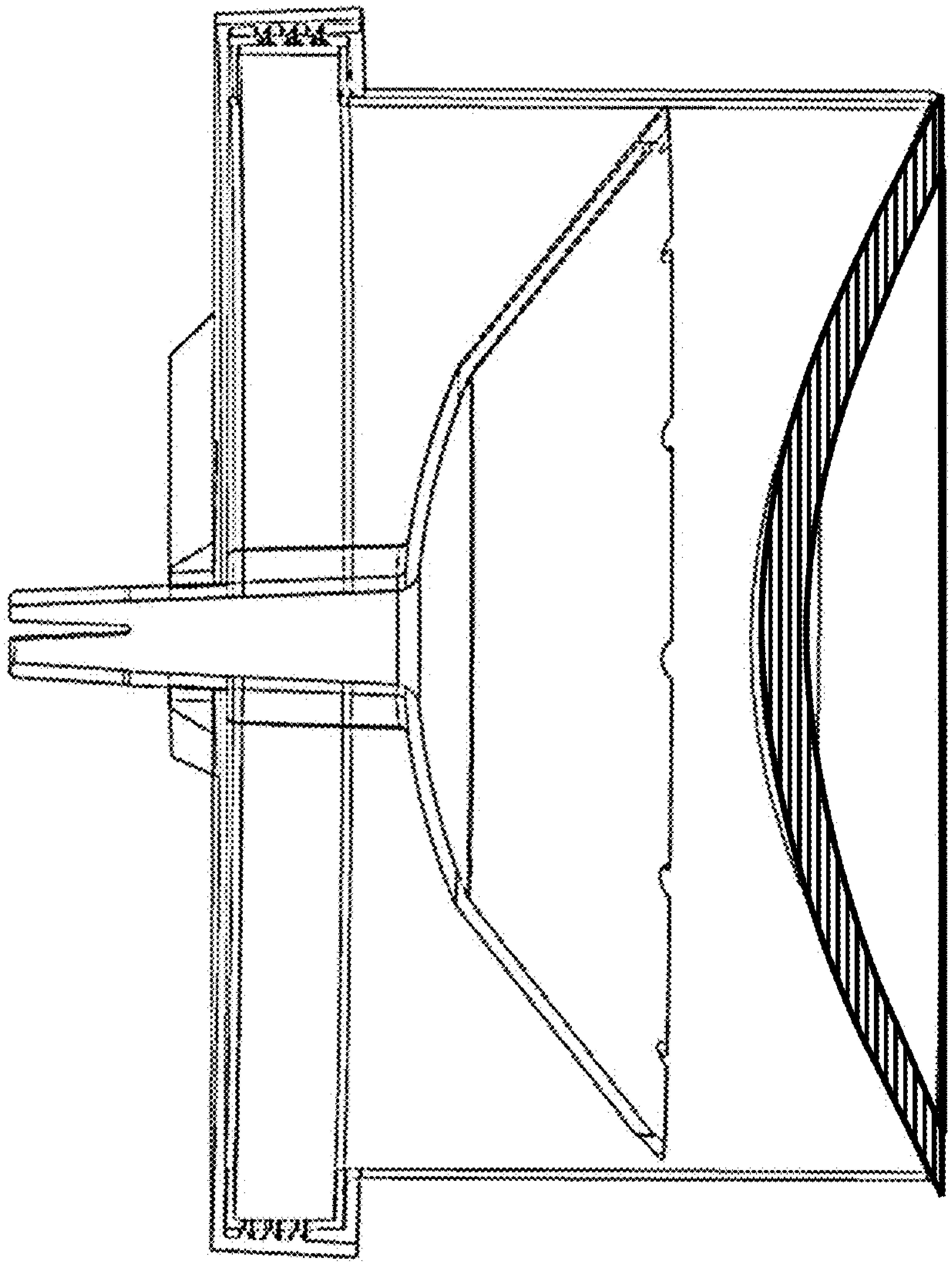


FIG. 10

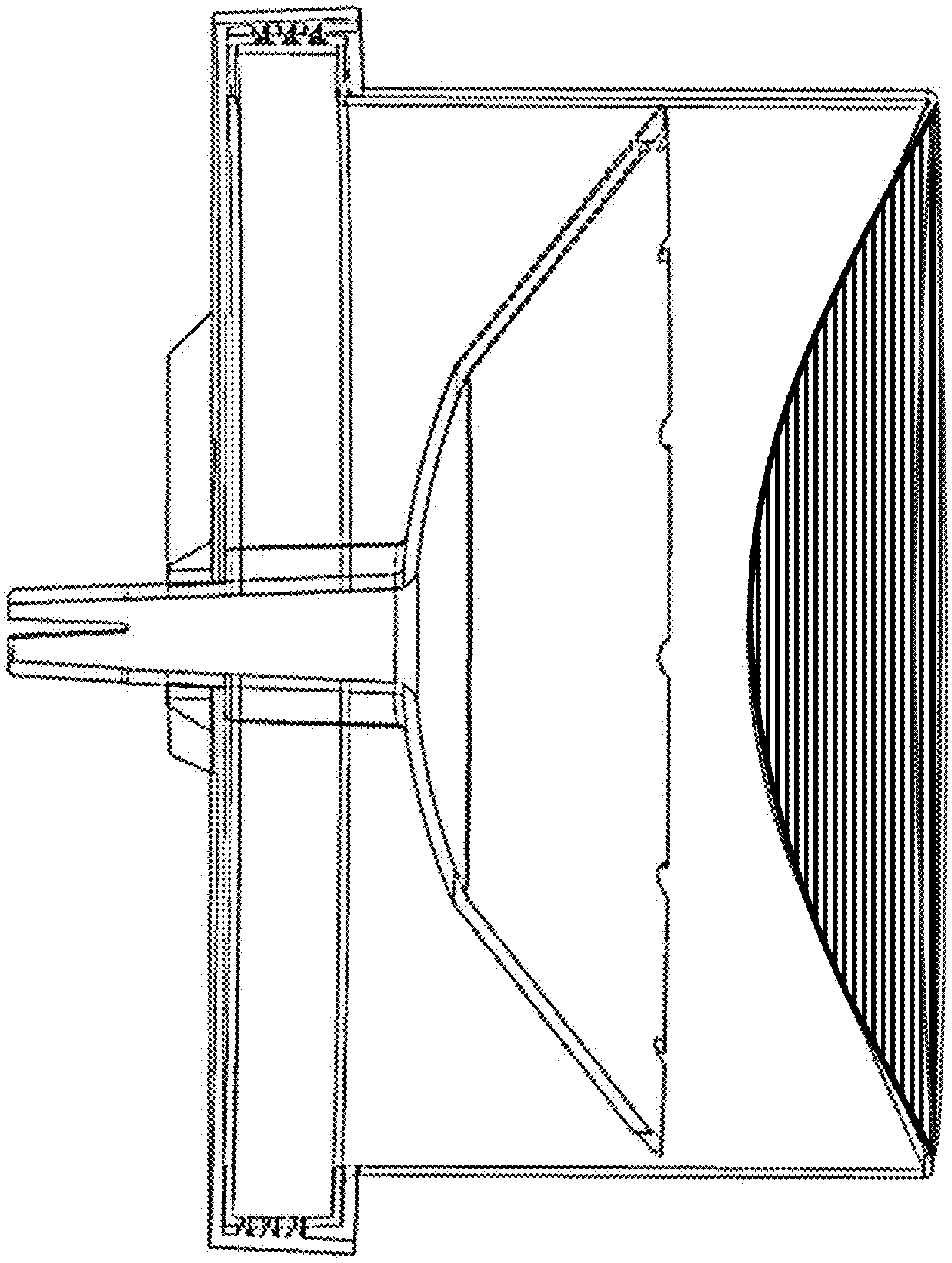


FIG. 11

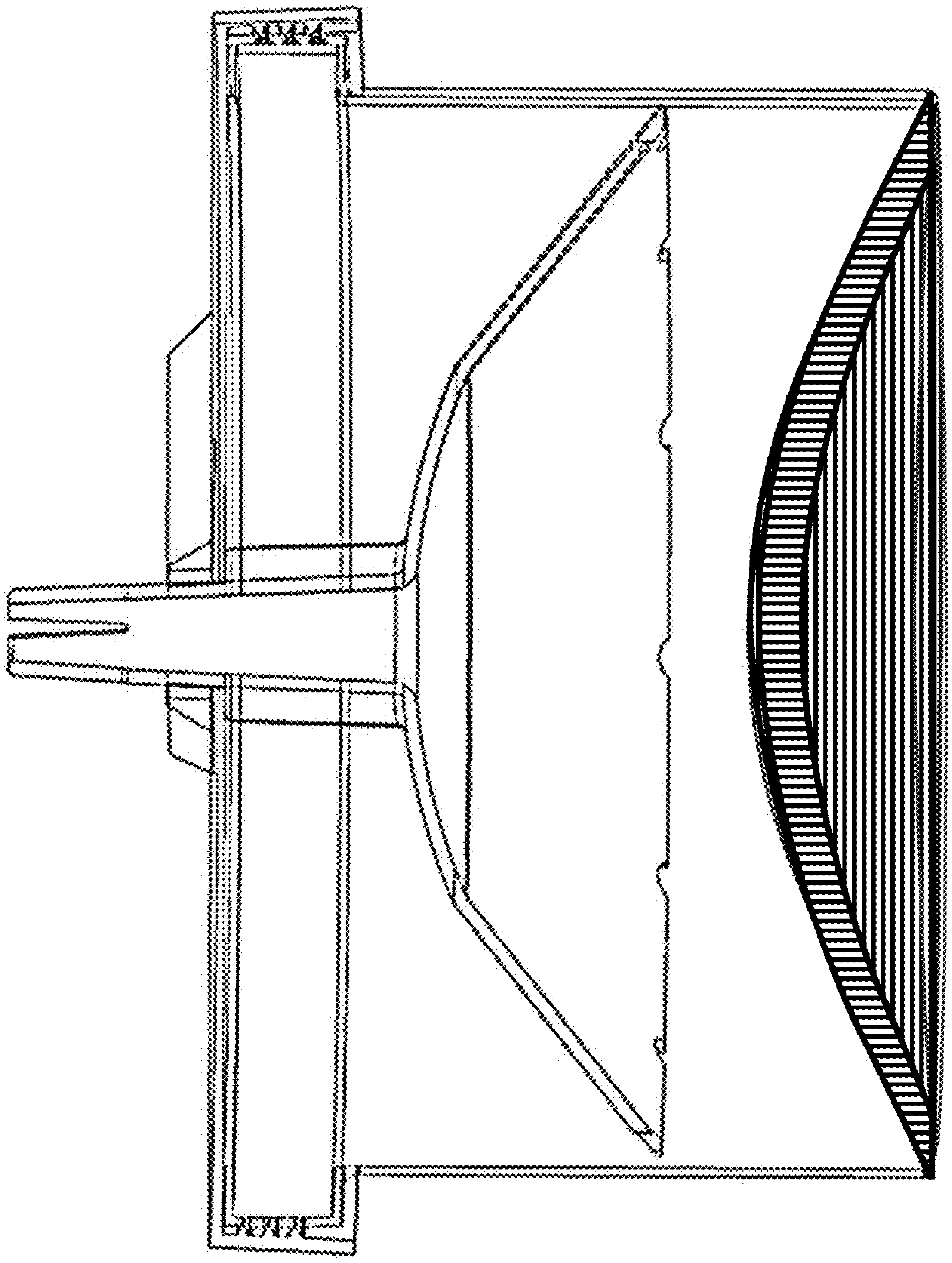


FIG. 12

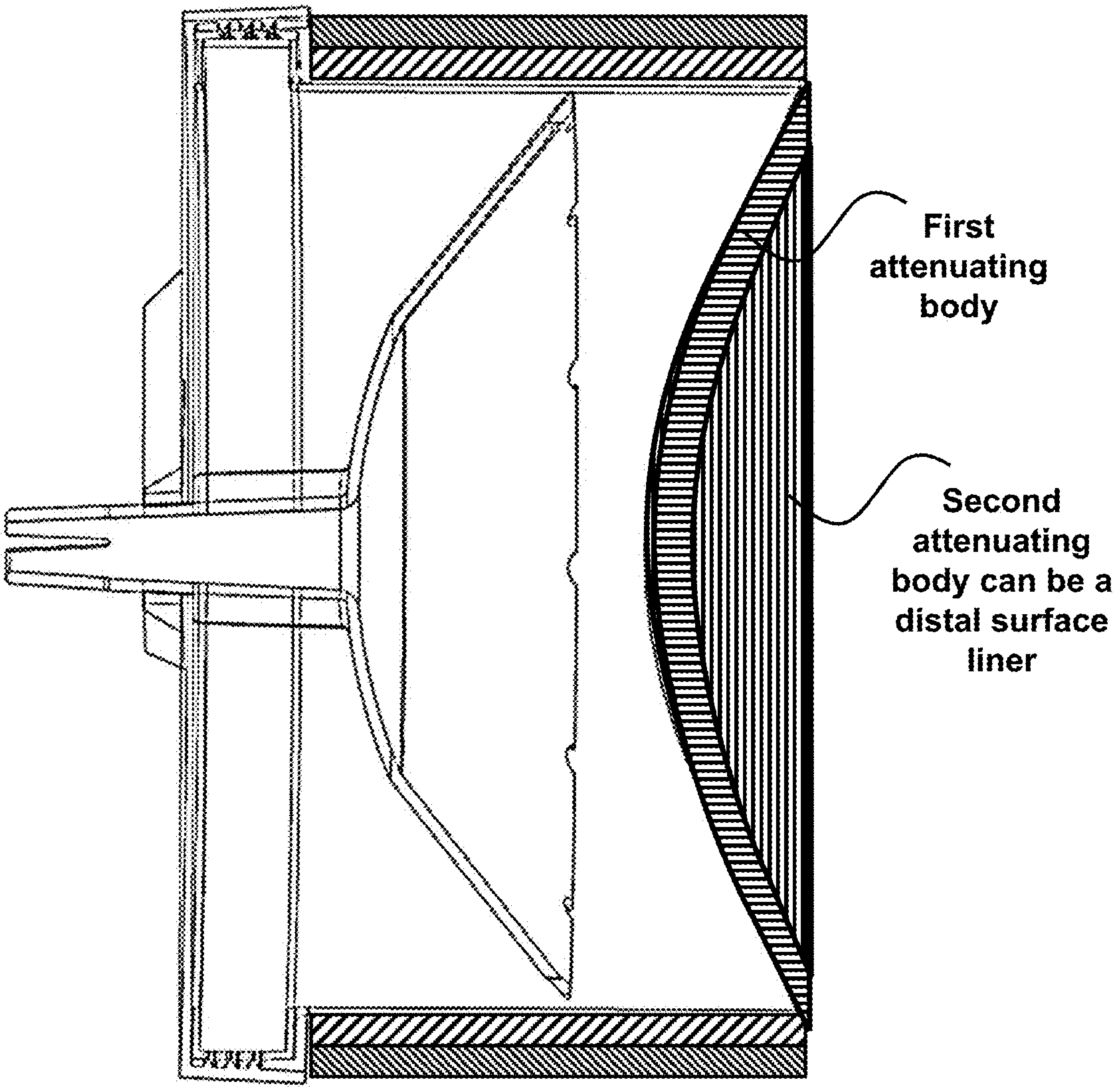

First attenuating body
Second attenuating body can be a distal surface liner

FIG. 13

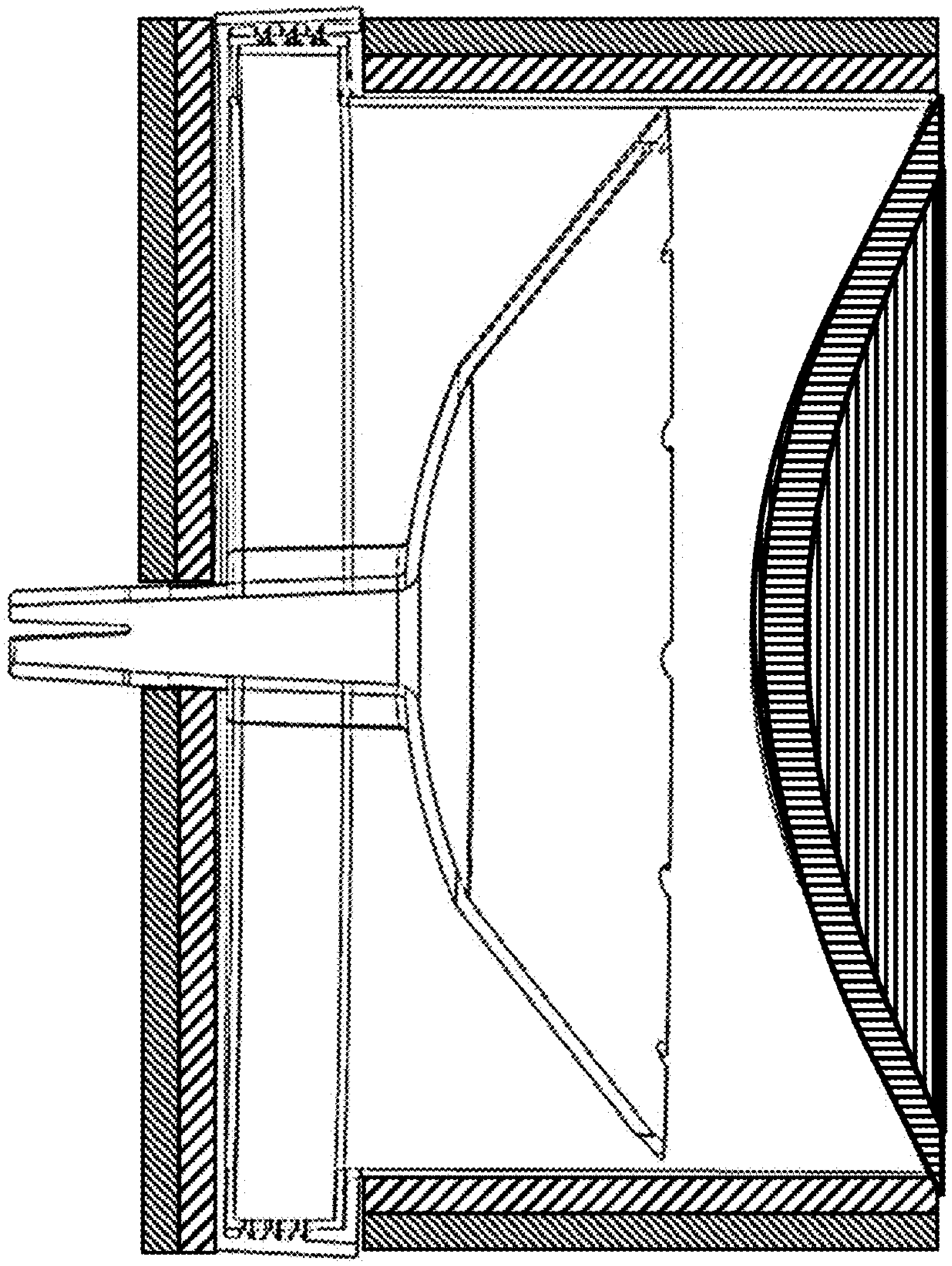


FIG. 14

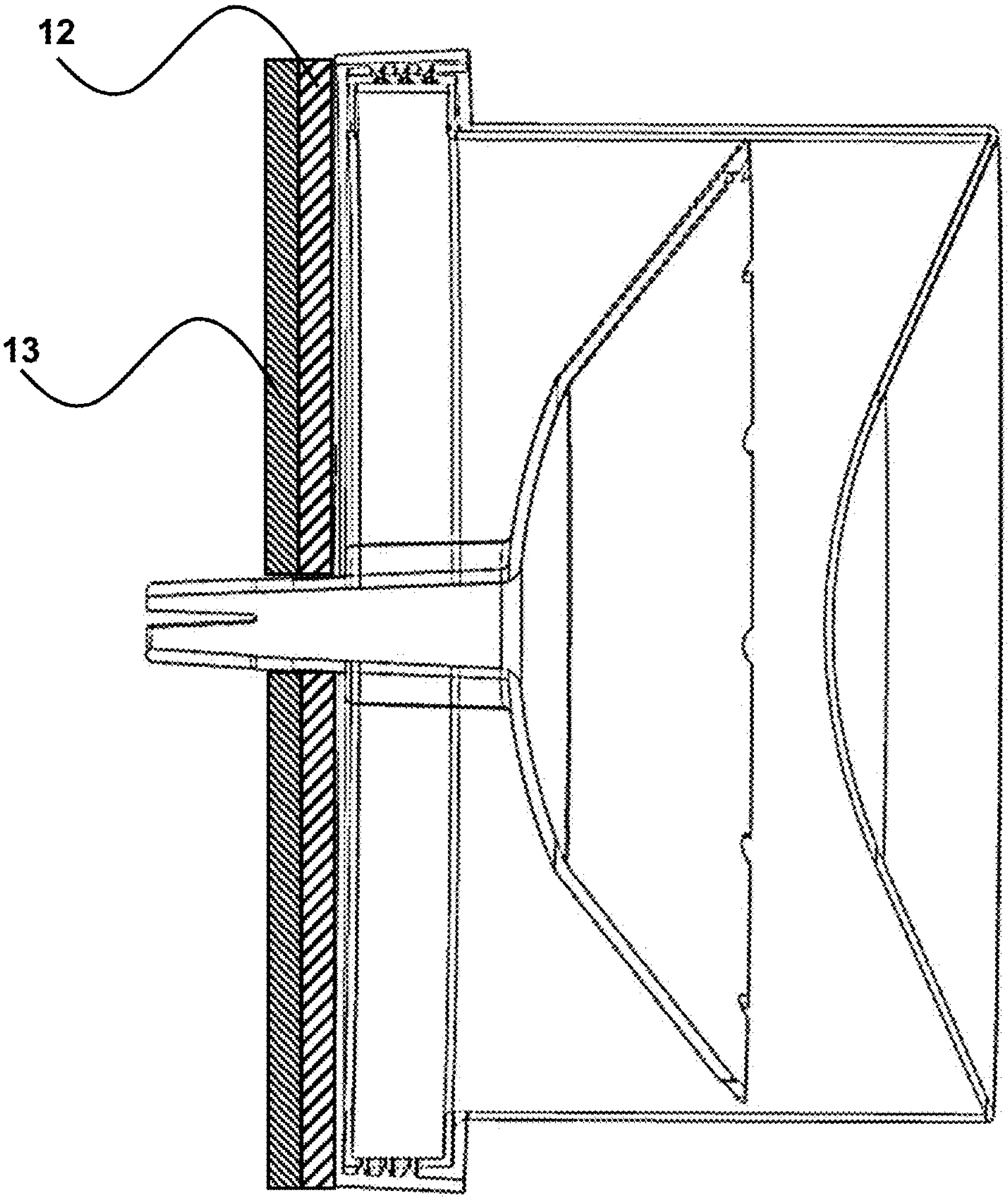
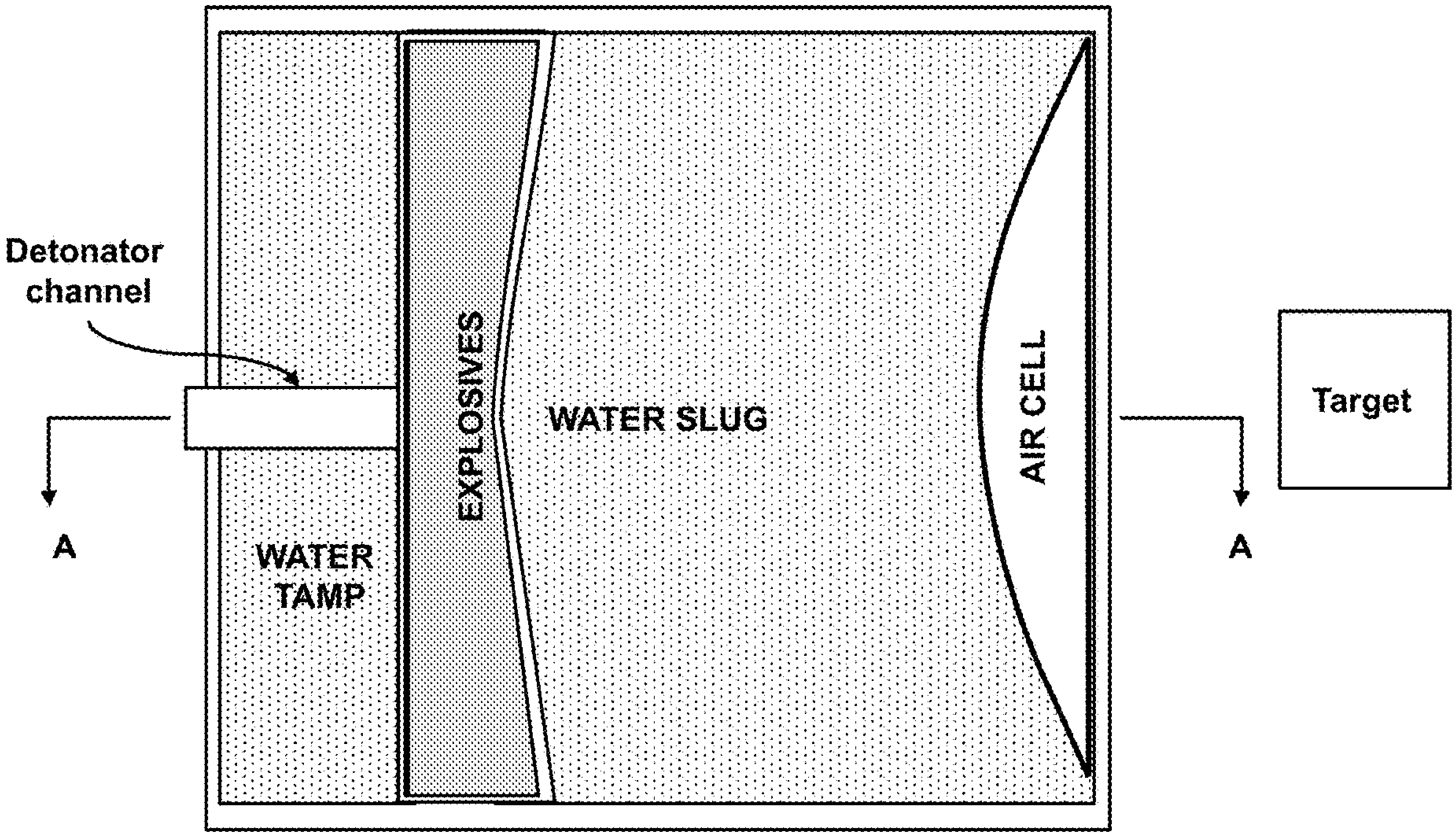


FIG. 15



A-A Sectioning

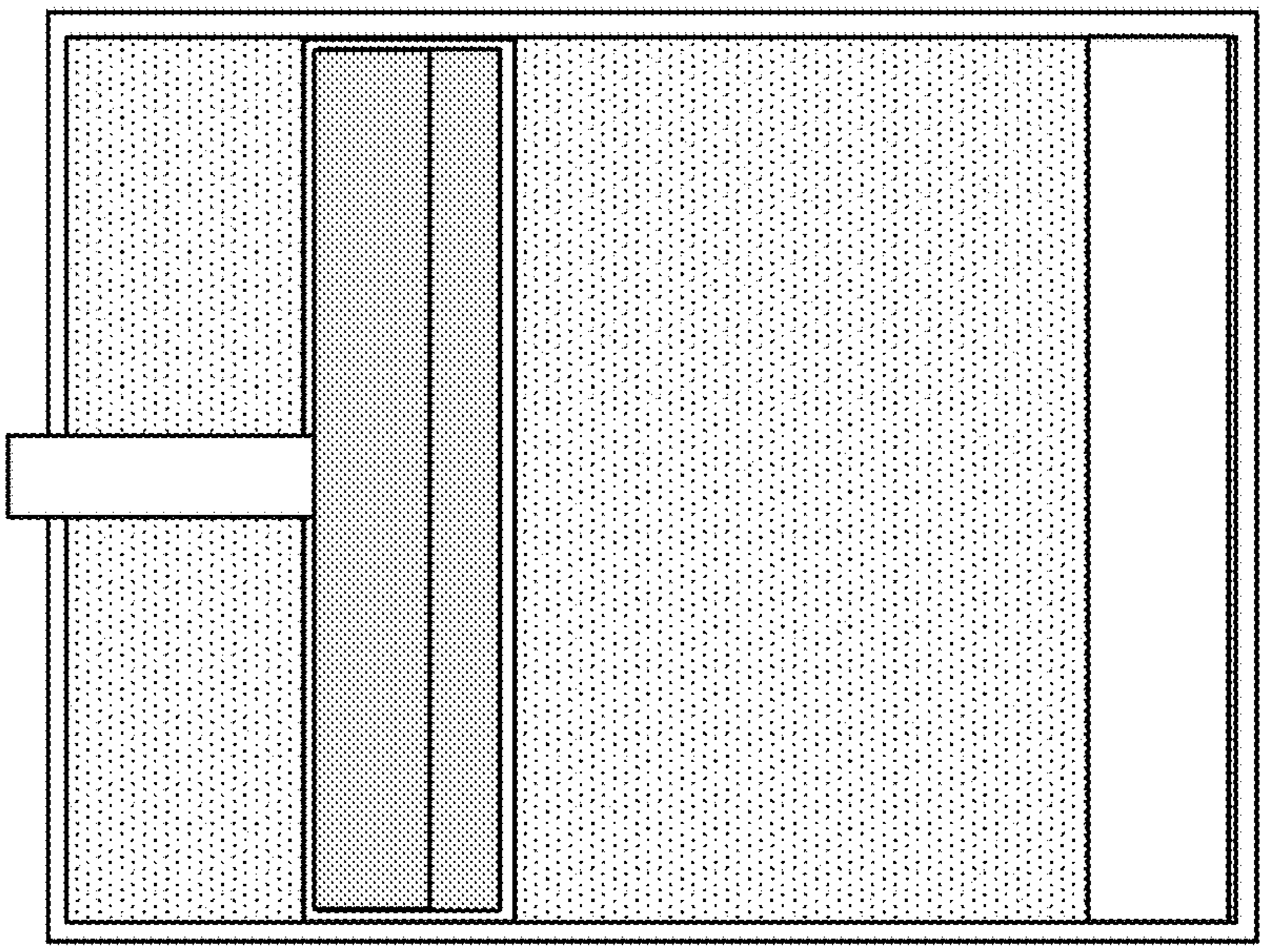


FIG. 16

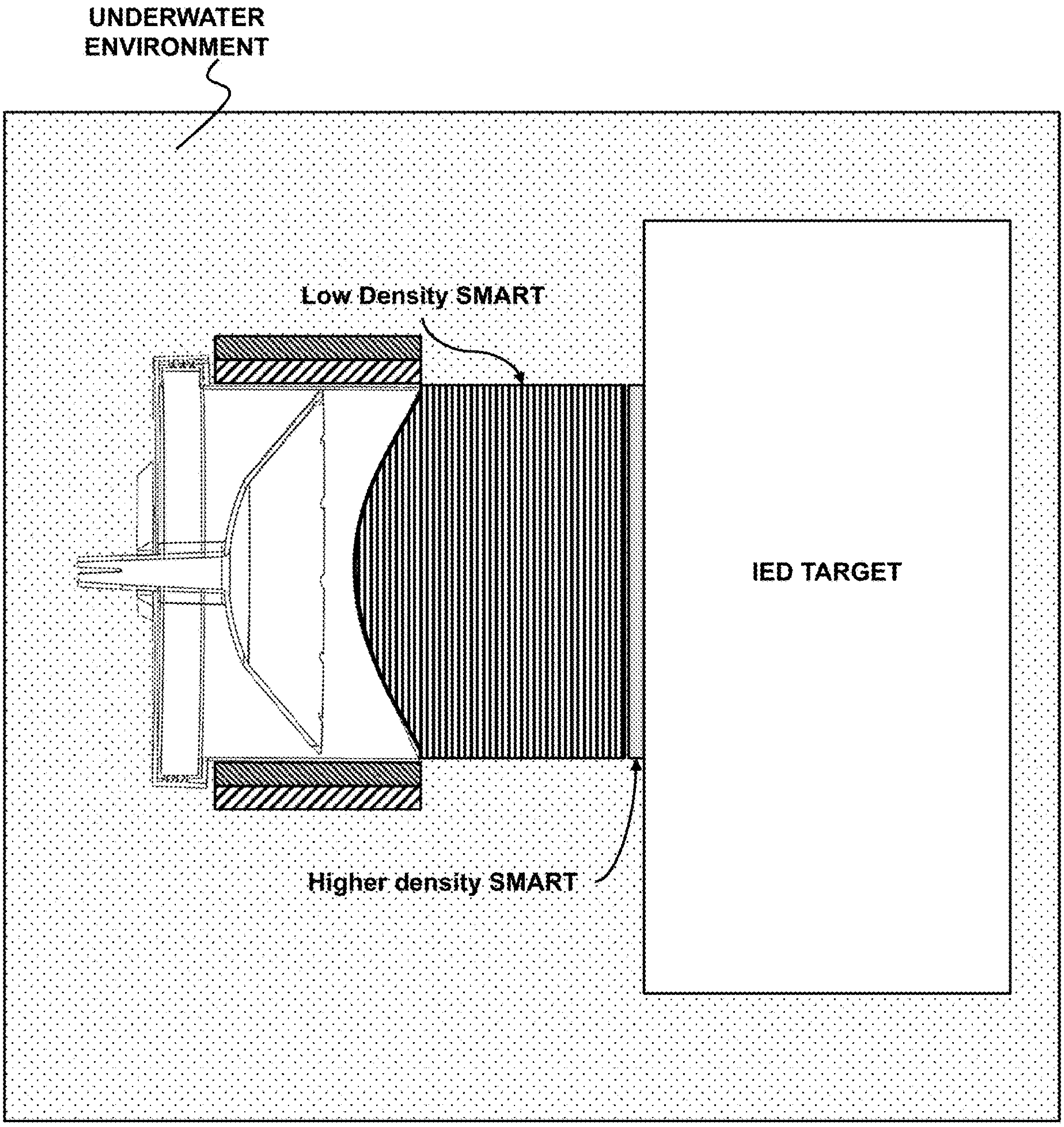

UNDERWATER ENVIRONMENT
Low Density SMART
IED TARGET
Higher density SMART

FIG. 17

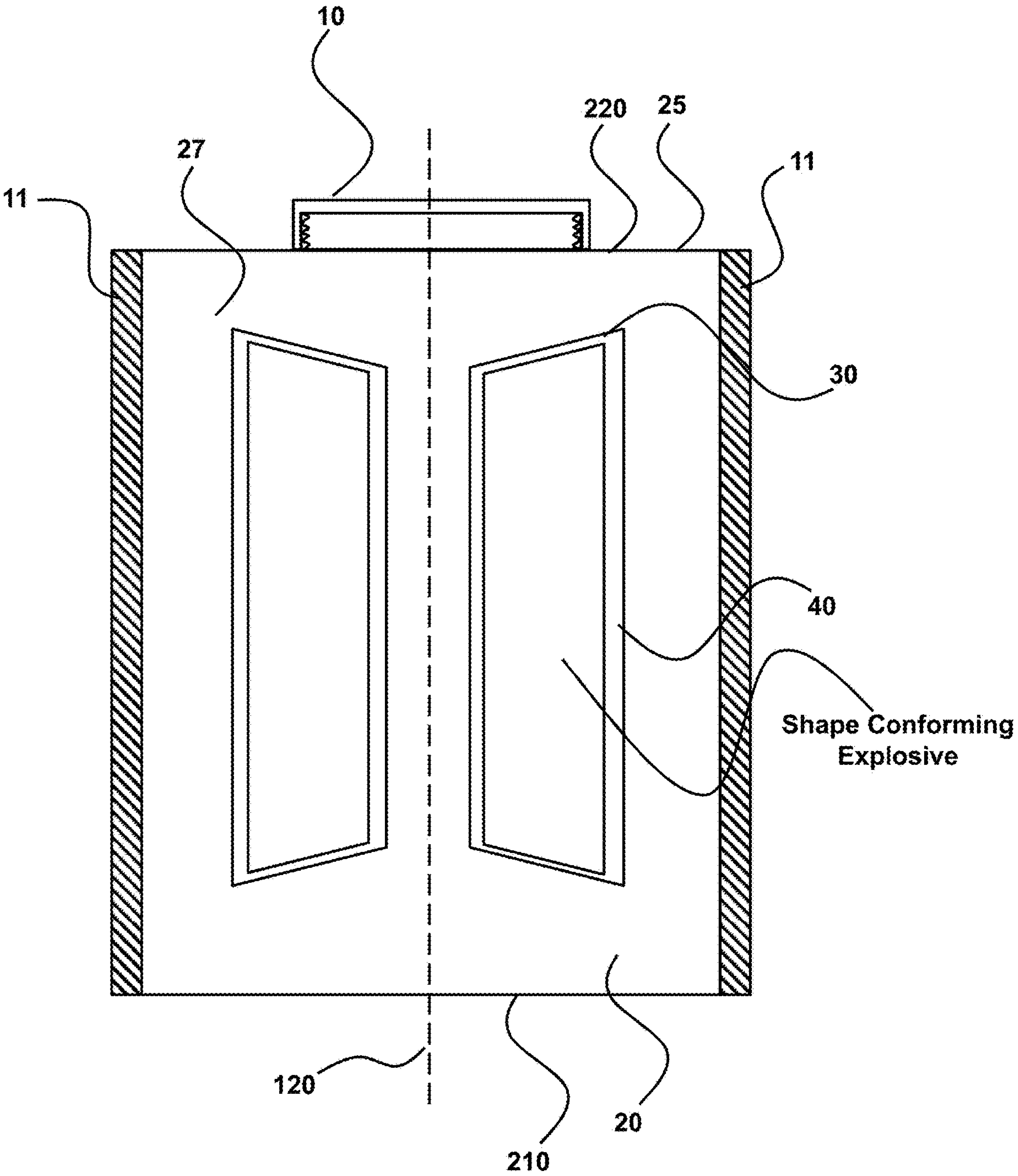


FIG. 18

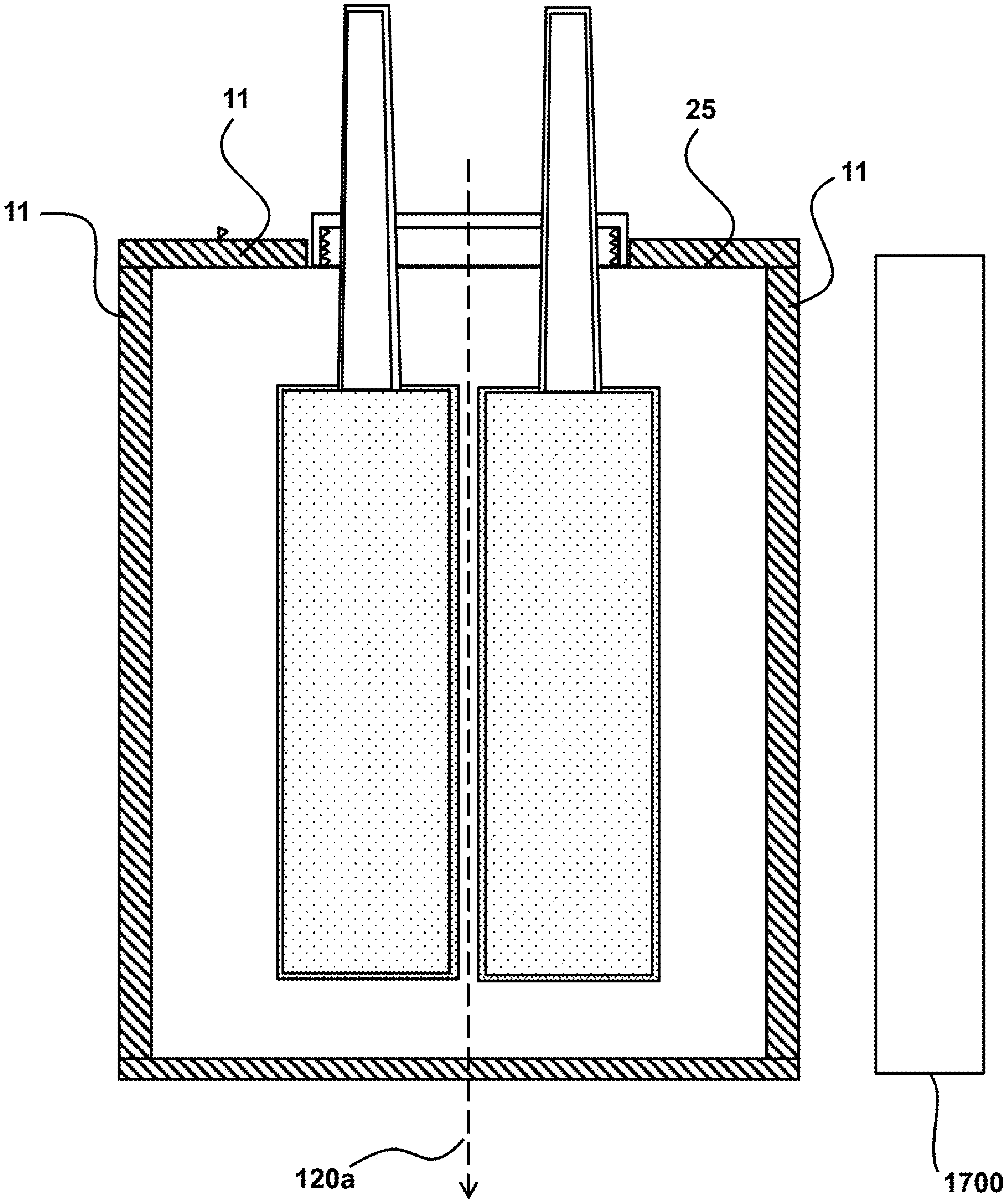
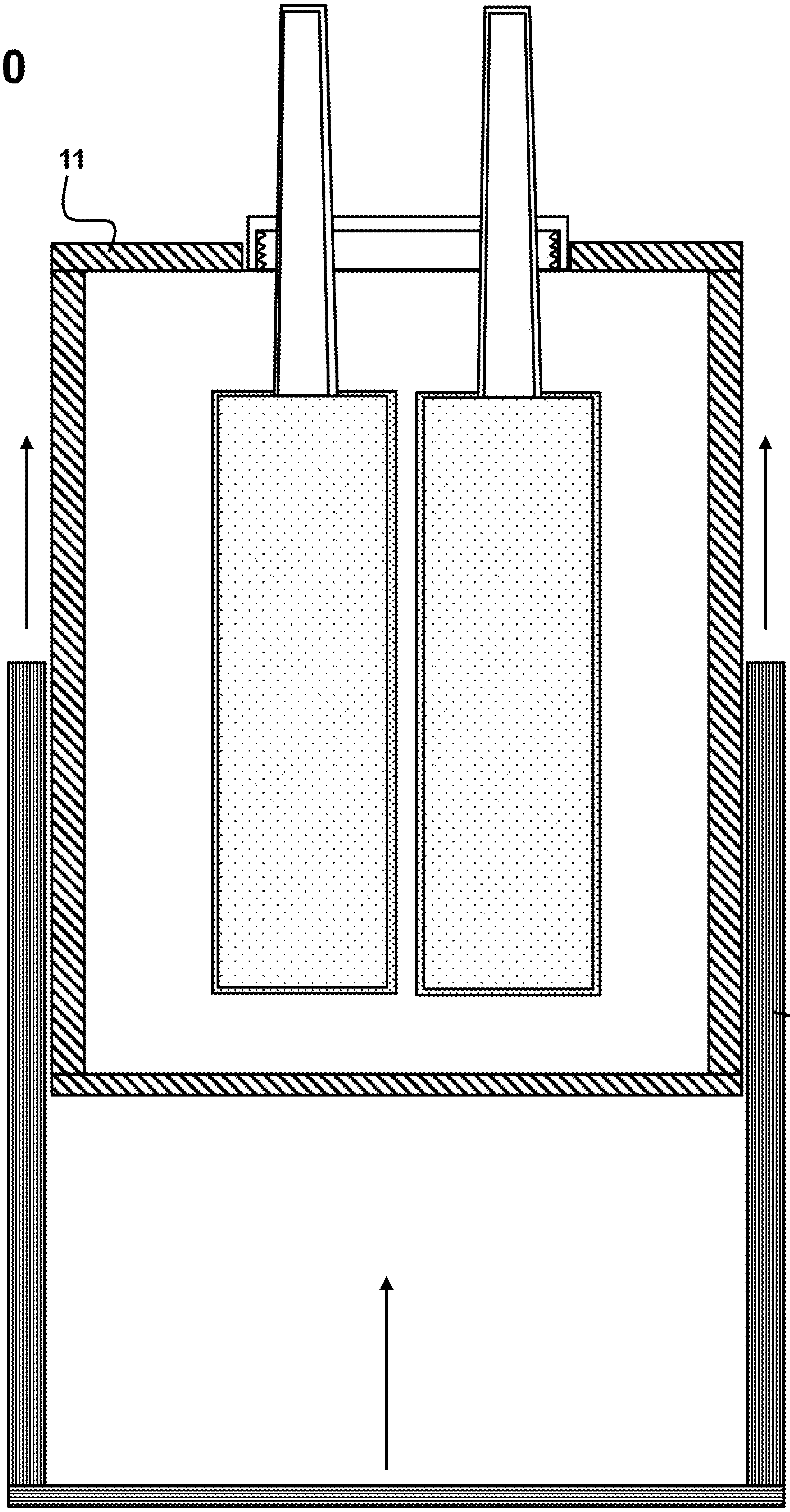


FIG. 19

FIG. 20



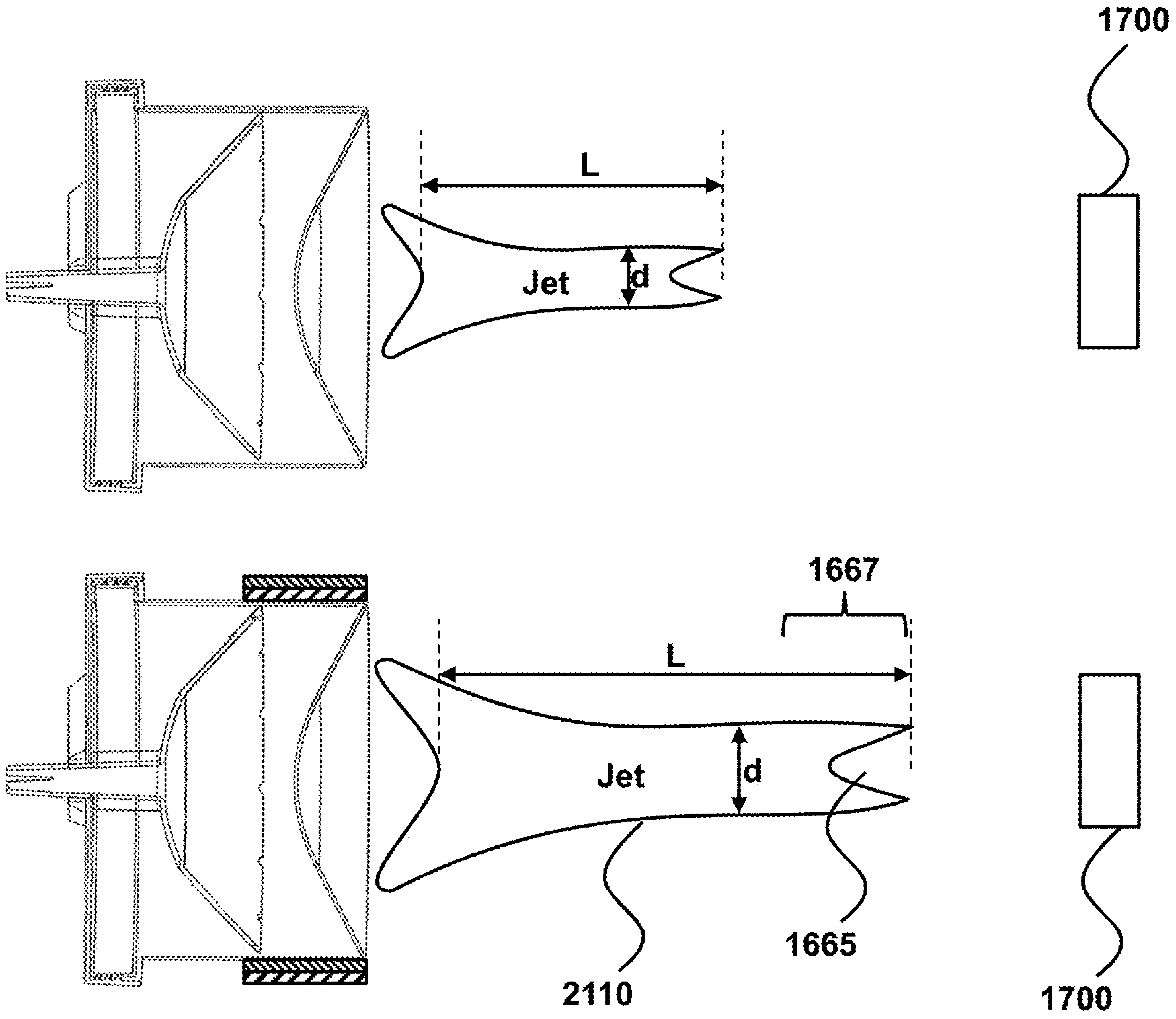
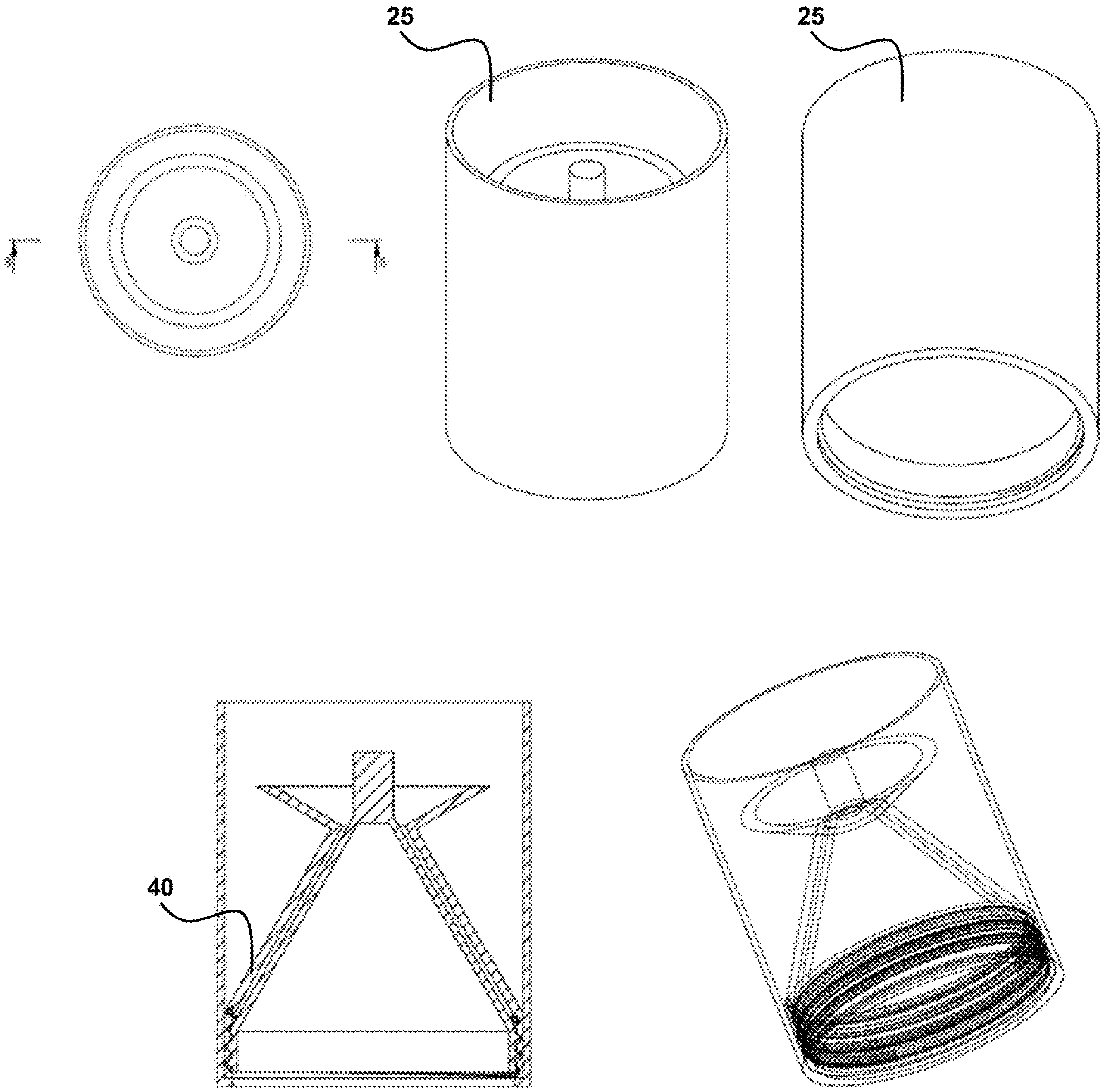


FIG. 21



SECTION B-B

FIG. 22

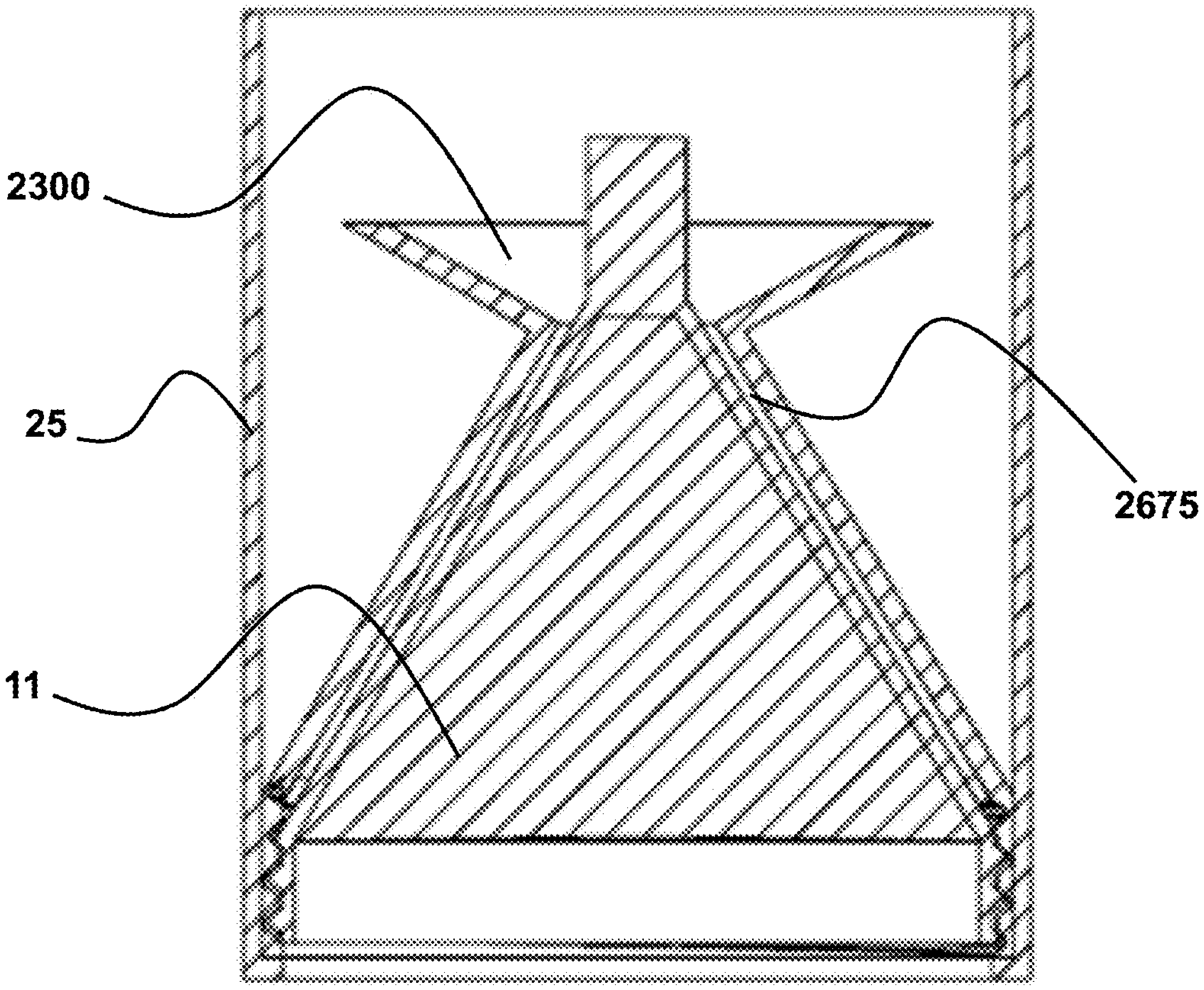
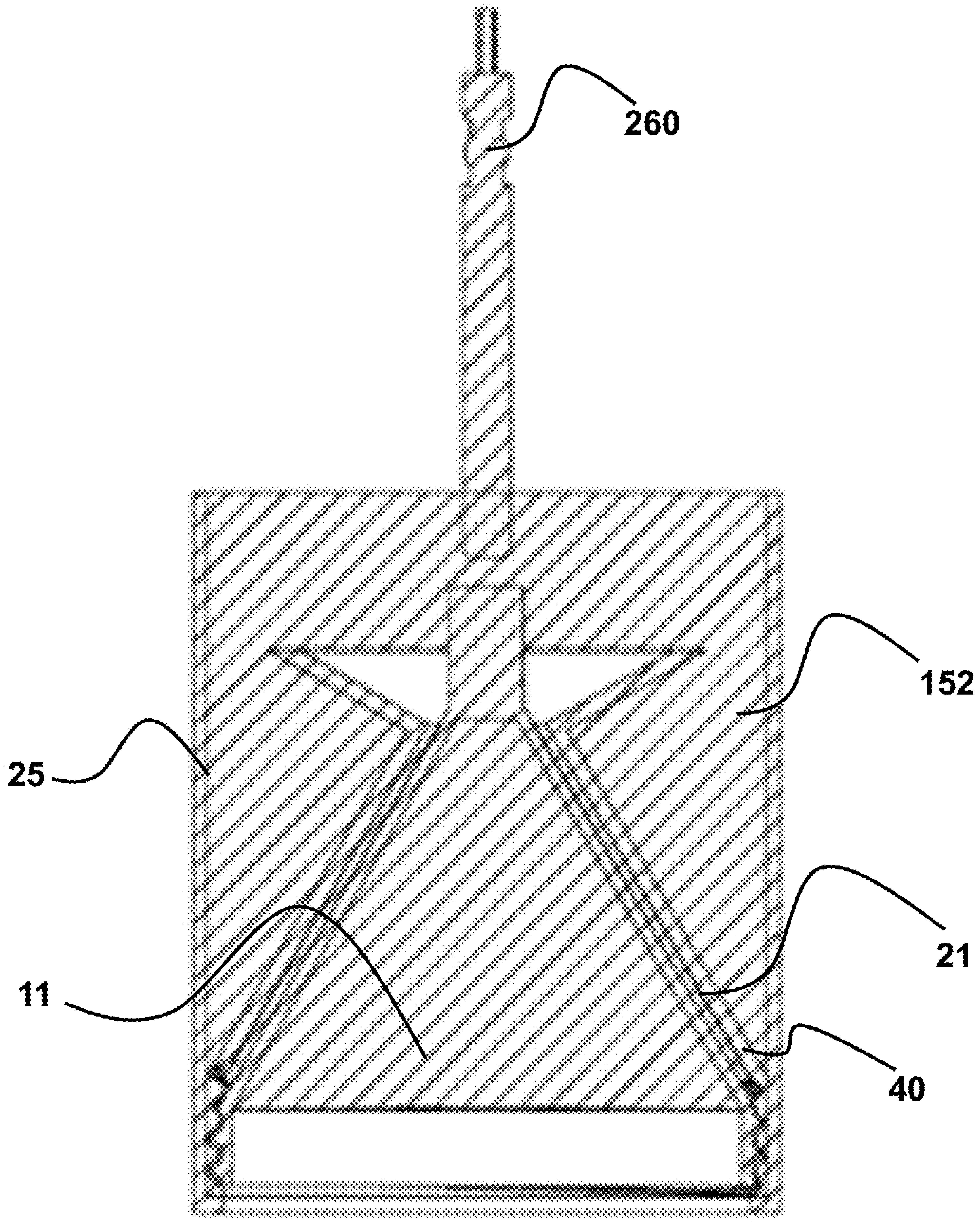


FIG. 23



SECTION B-B

FIG. 24

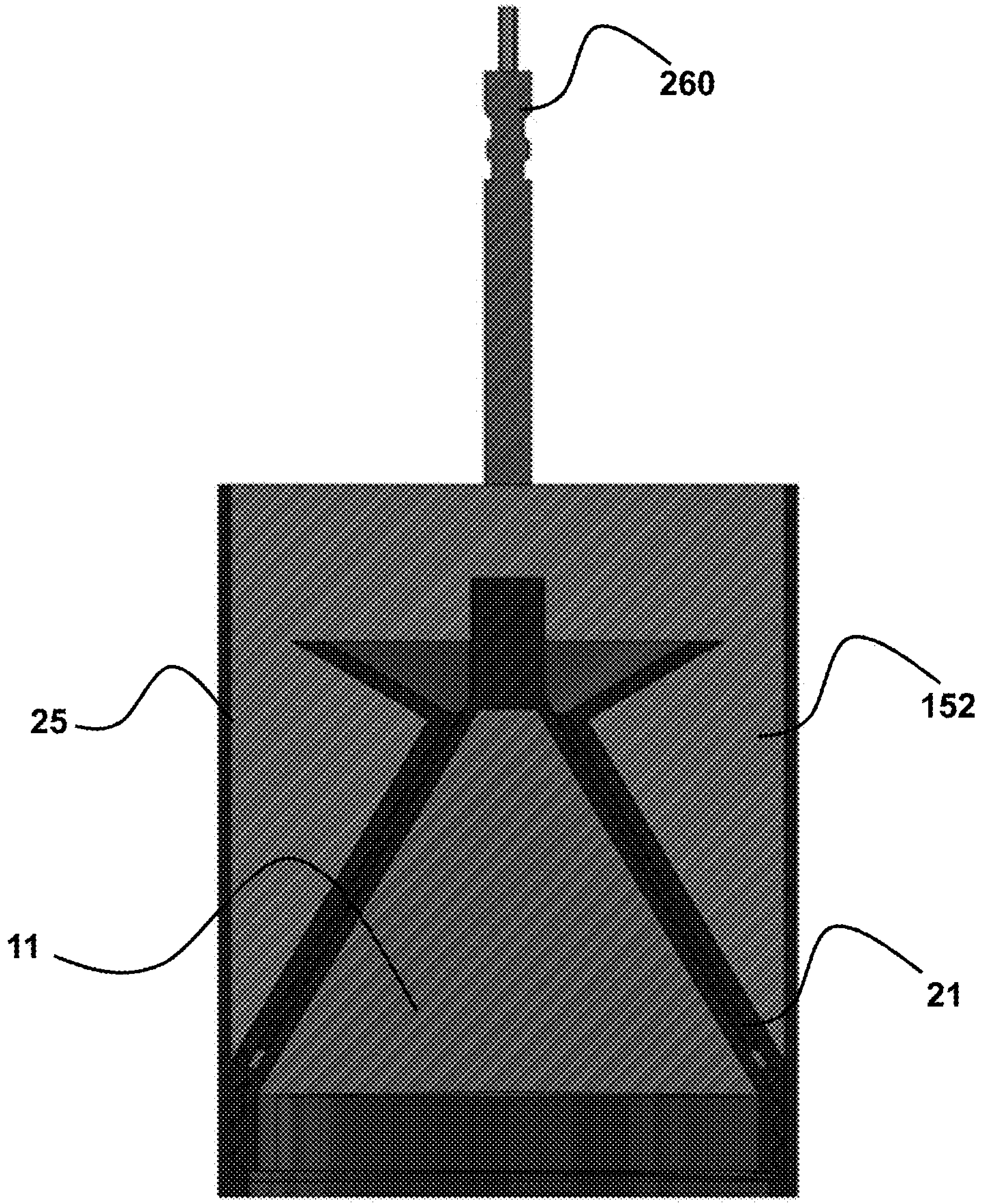


FIG. 25

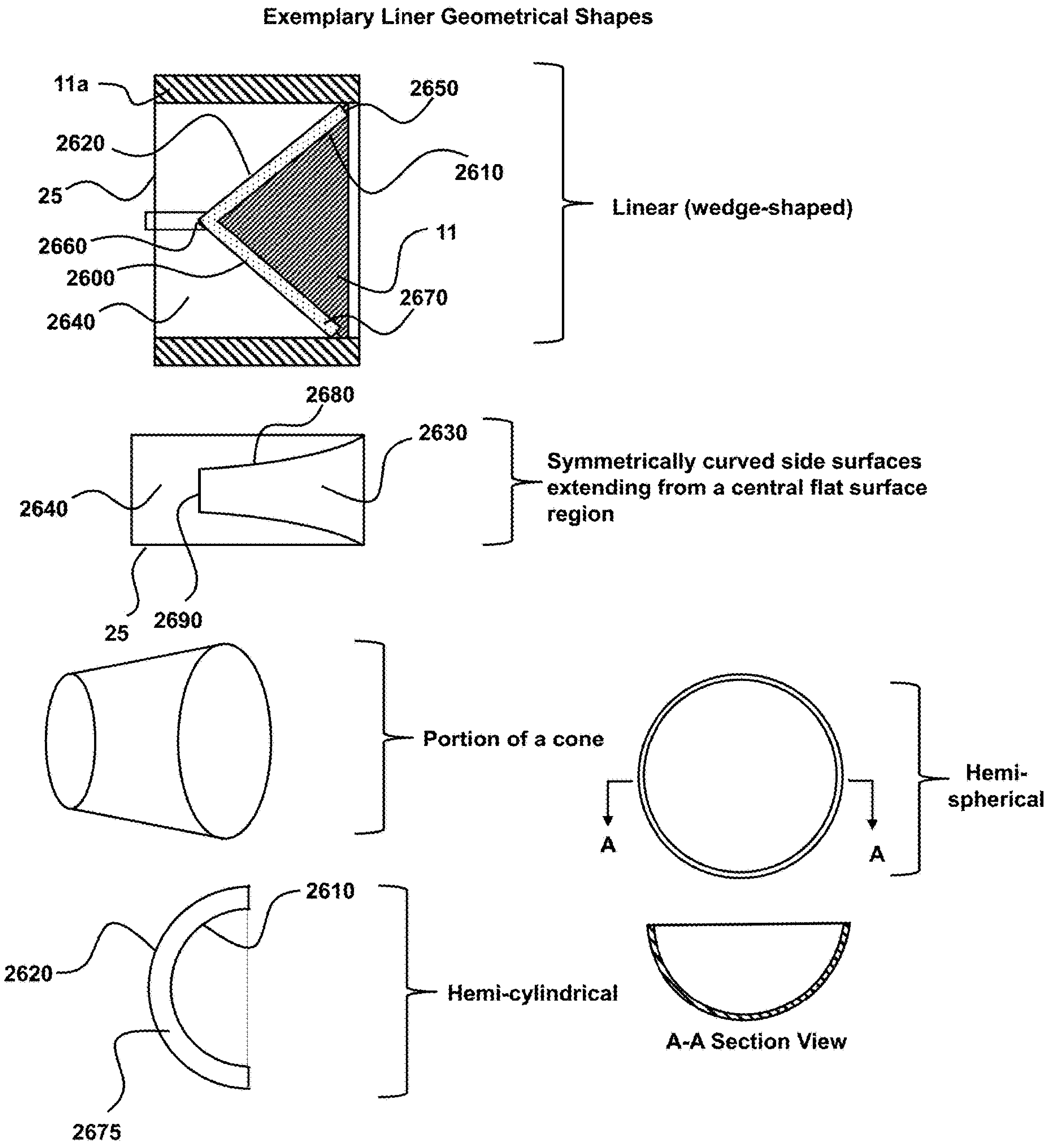

Exemplary Liner Geometrical Shapes
11a
2650
2620
2610
25
Linear (wedge-shaped)
2660
11
2600
2670
2640
2680
2630
2640
Symmetrically curved side surfaces extending from a central flat surface region
25
2690
Portion of a cone
Hemi-spherical
A
A
2610
2620
Hemi-cylindrical
A-A Section View
2675

FIG. 26

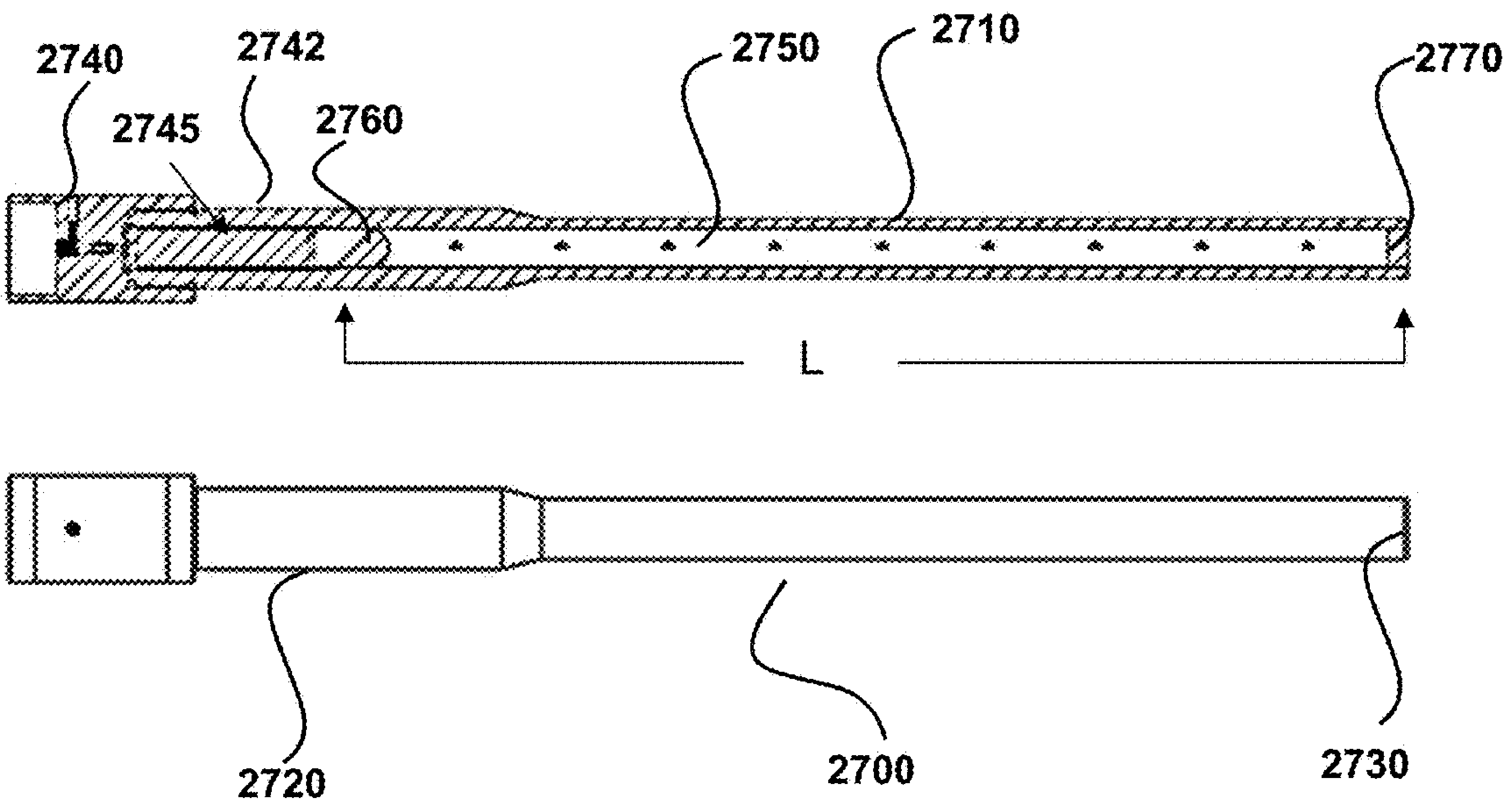


FIG. 27

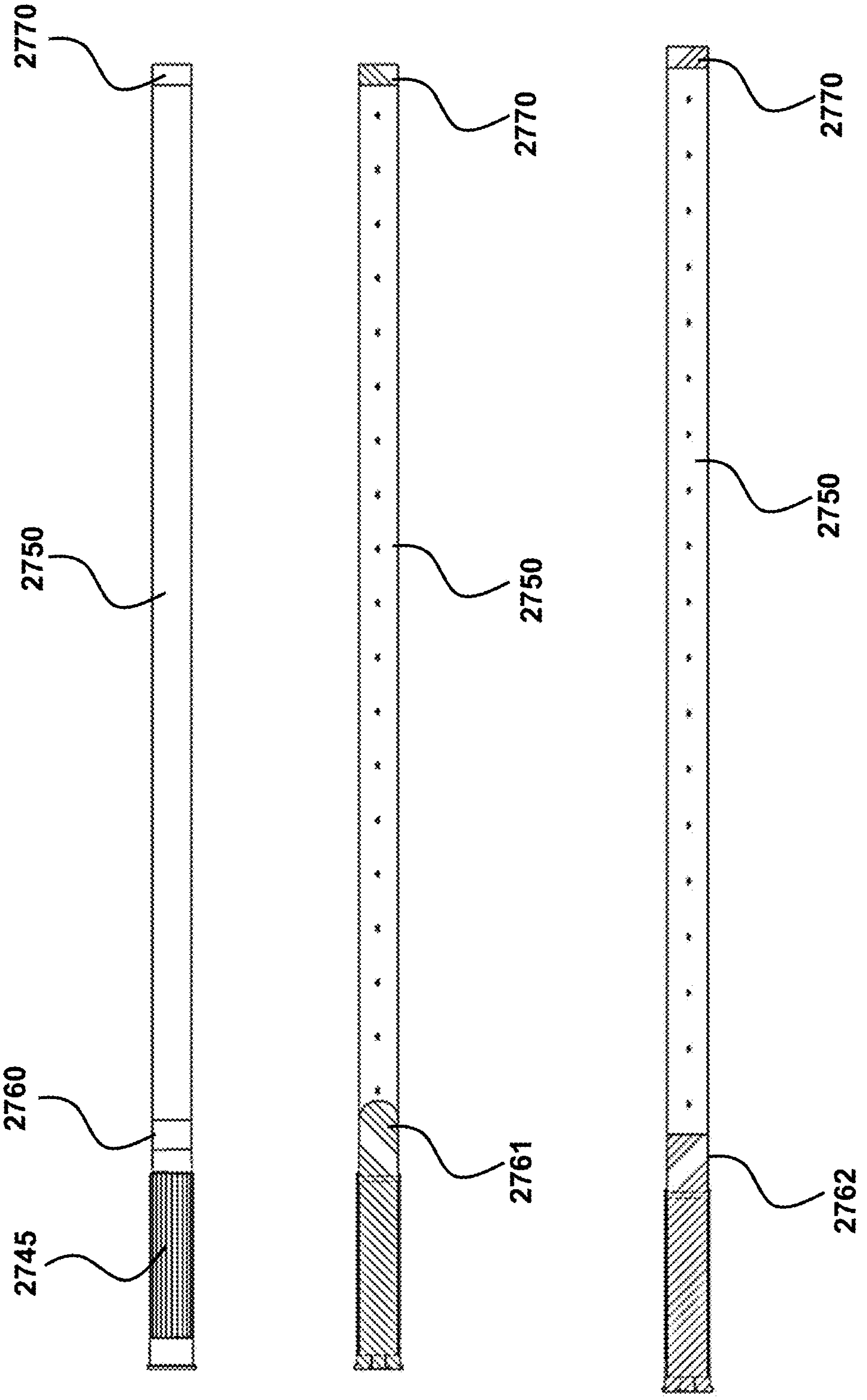


FIG. 28

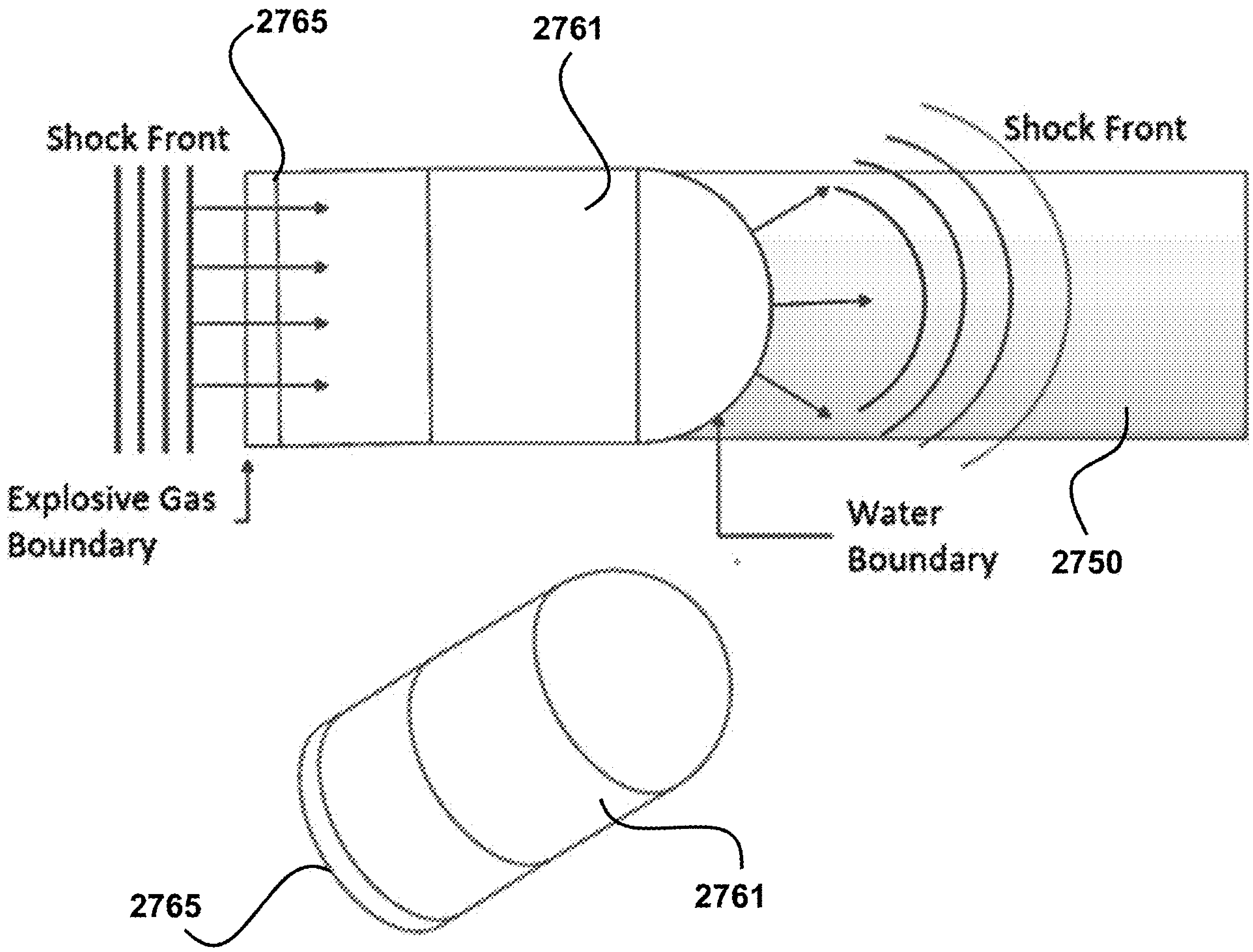

2765
2761
Shock Front
Shock Front
Explosive Gas Boundary
Water Boundary
2750
2765
2761

FIG. 29

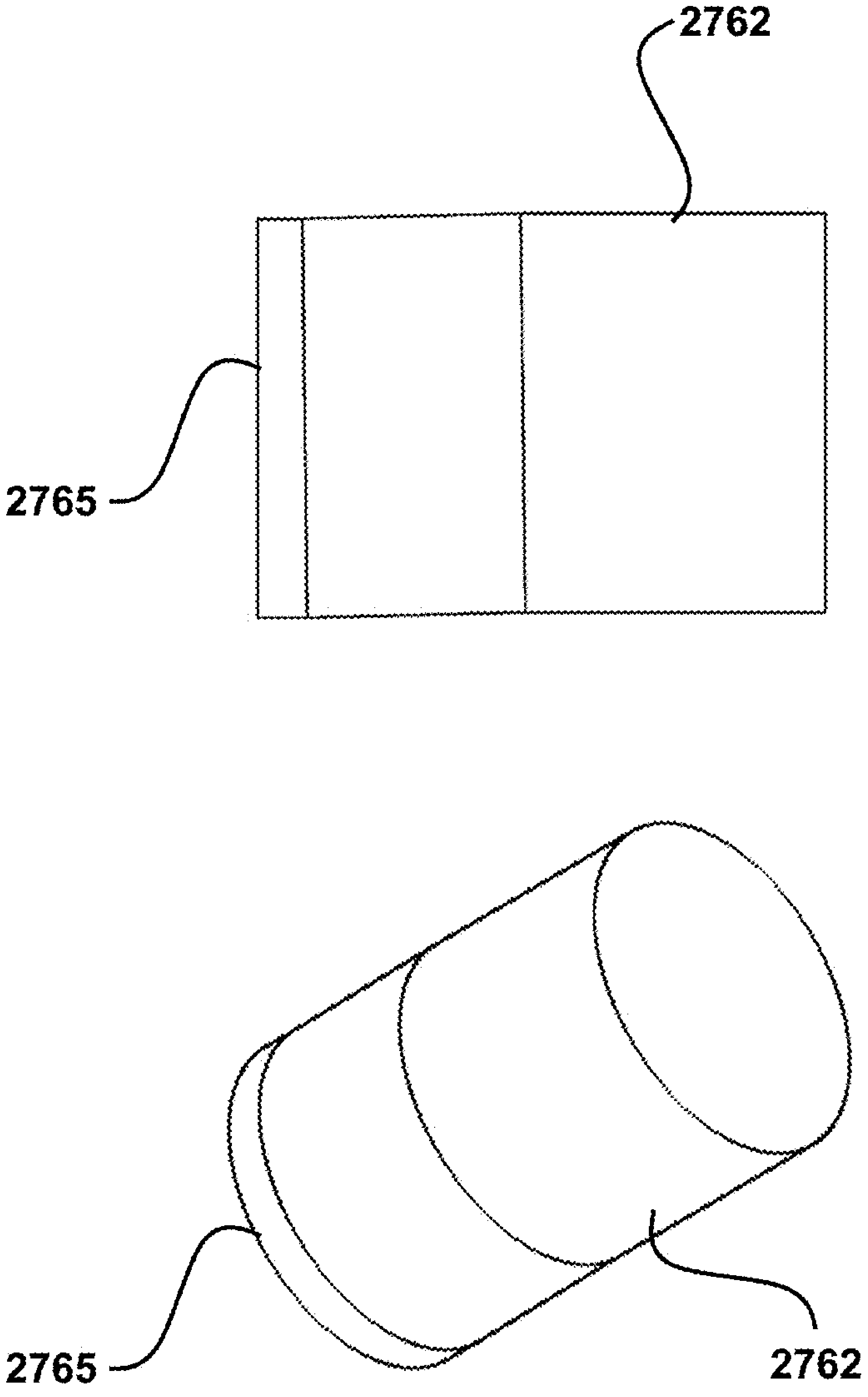


FIG. 30

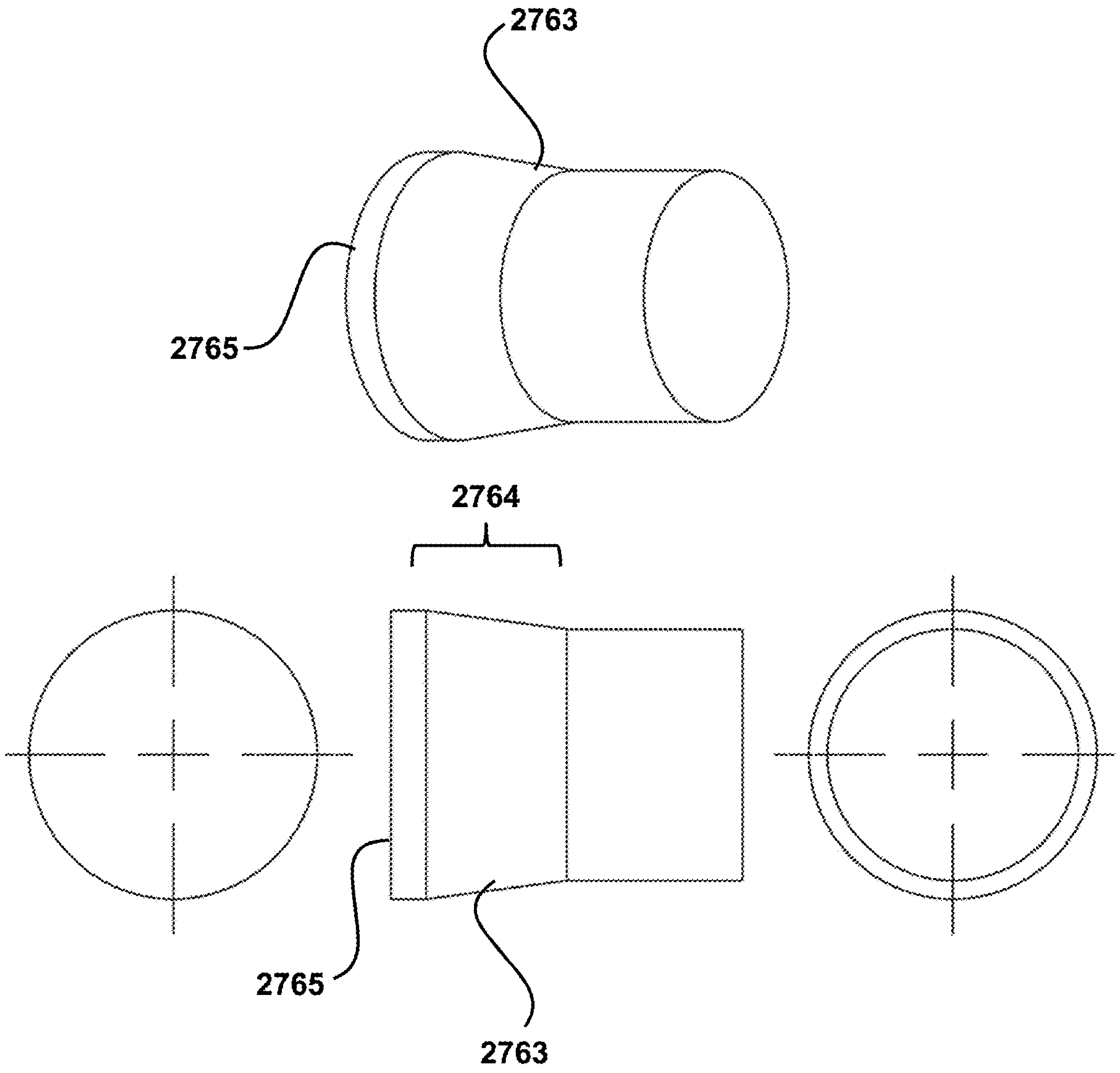


FIG. 31

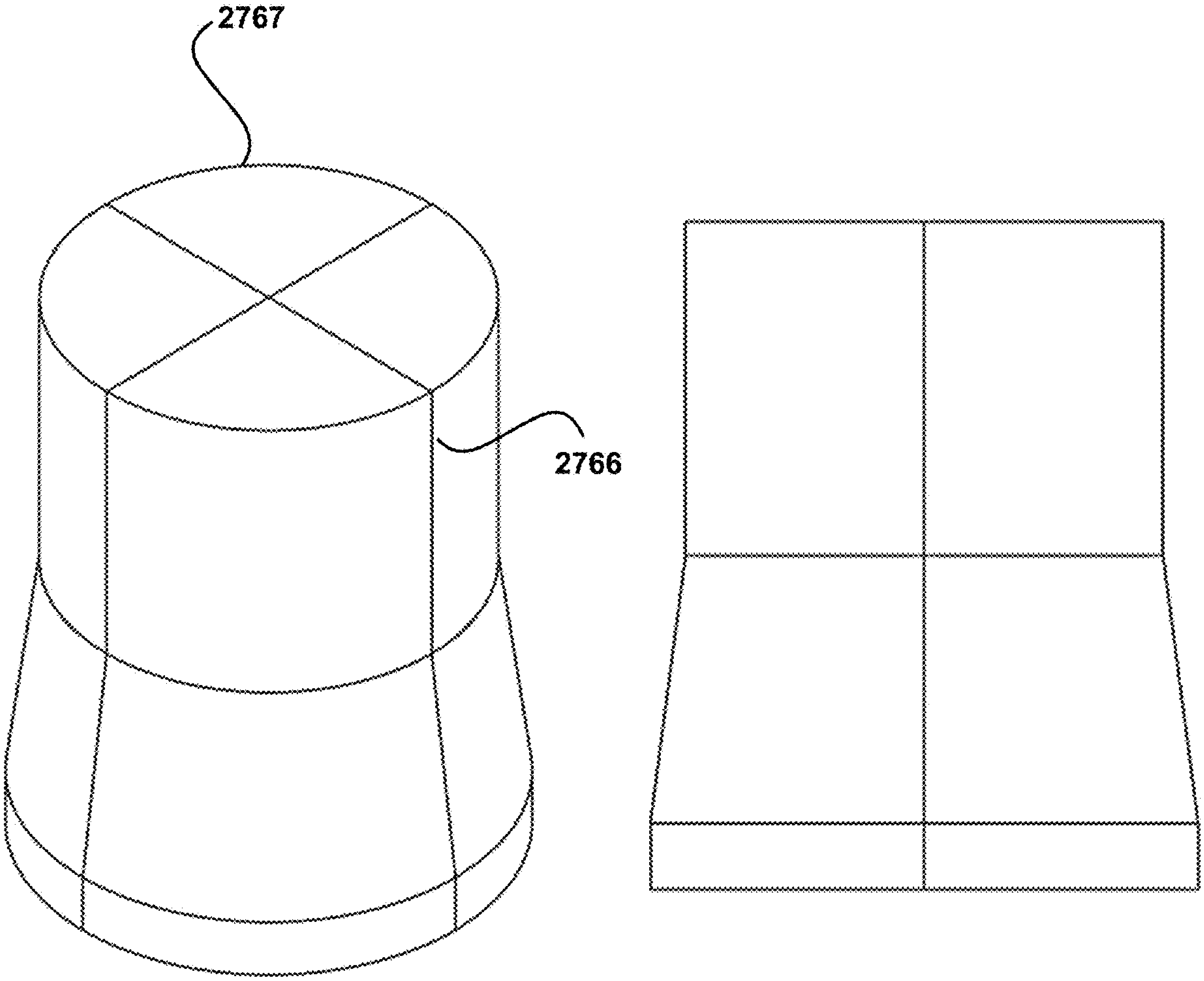


FIG. 32

SURFACE MATERIAL ATTENUATION OF RAREFACTION SHOCK WAVES TO ENHANCE SHAPED-CHARGES

STATEMENT OF GOVERNMENT INTEREST

[0001] The inventions described herein were invented by employees of the United States Government and thus, may be manufactured and used by or for the U.S. Government for governmental purposes without the payment of royalties.

CROSS REFERENCE TO RELATED APPLICATIONS

[0002] This application claims the benefit of priority to U.S. Pat. App. 63/295,347, filed Dec. 30, 2021, which is hereby incorporated by reference to the extent not inconsistent herewith.

BACKGROUND OF INVENTION

[0003] Explosively-propelled liquids are used to disrupt explosive devices, including improvised explosive devices (IEDs). One system relies on mass-focusing shaped-charges to propel a liquid fluid on target. See, for example, U.S. Pat. No. 10,921,089 (Atty. Ref. 338287: 15-20 US) and U.S. patent application Ser. No. 17/170,304 (Atty. Ref. 338710: 15-20A US) filed Feb. 8, 2021, each of which are incorporated by reference herein to the extent not inconsistent herewith.

[0004] There are several commercial and improvised shaped-charges that drive water and each have their strengths and weaknesses. A common method is to attach the explosives to a plastic former, which is either seated inside the fluid, sandwiched between fluid chambers, or is on the outside surface of the fluid container. Pressure fields are produced by shaping explosives into hemispherical, linear (wedge or hemi-cylindrical), rod and conical charge geometries. When the explosives are initiated, shocks form inside the water column and reflect off of the free field surfaces. Various parameters such as angles and corners within the container of fluid or on the explosive former define the pressure-time history of the gases and shocks acting on the water. There are regions of high and low pressure that will differentially accelerate the water to form a jet. High pressure regions are due to a Mach-stem effect which are formed by collisions of shocks, usually along a central axis or plane. A slug of water is the projectile, and water behind the explosives traps the gases, thus increasing the duration of pressure acting on the slug. Shocks can also reflect at the tamper boundaries and move back into the water, amplifying the pressure.

[0005] A common charge configuration of mass focusing shaped-charges driving a liquid fluid is linear and are symmetric along a bisecting plane. In the case of the Hydrajet™ disrupter (U.S. Pat. No. 6,269,725 by Cherry), a tall chevron profiled wedge former of explosives with an angle of 90 degrees is utilized and placed inside a rectangular shaped fluid-filled chamber. Cherry proposes an adjustable apex angle and a scalability in disrupter size. Another example of a linear charge is the mod series of disrupters (U.S. Pat. No. 6,584,908 by Alford). In that case, rather than a wedge, it is an arc section of a hemi-cylindrical shape. Alford uses two separate water chambers and sandwiches sheet explosives between them. The jet profile is similar to the Hydrajet™ disrupter. Linear high explosive charges that drive water form blade shaped water jets. A transverse cross sectioning of the jet would have the approximate profile of a narrow ellipse.

[0006] Omni-directional mass jetting high explosive disrupters are good at delivering high impulse to a target and use a rod-shaped explosive charge at the core of a cylindrically-shaped container. Those tools have axial symmetry. Omnidirectional tools produce low density jets because they rapidly particulate into droplets. Examples of these are the Mineral Water Bottle charge and the Bottler charge (U.S. Pat. No. 9,322,624). The bottler charge has three hemi-cylindrical indentations on the outer bottle surface that create a shock cavity effect and linear fluid jets at the center of each one.

[0007] Some water-based charges are more effective at perforating barriers such as liquid follow-through (LIFT) charges (U.S. Pat. No. 4,955,939). Conical LIFT charges have an air void. The explosives are rectangular prisms or right-angle cylinders and oriented so that the flat face of the cylinder it abutting the water. The detonator is positioned coaxially down the center of the charge. The explosive detonation wave shock couples at the water interface producing an approximate planar shock front that travels into the water surrounding the hollow cavity causing the water to collapse into the void and jet forward. The thin plastic liner collapses on itself and flows at the leading edge of the jetting fluid. Another example of conical LIFT charge is the Rocksmith Precision Closer™ disrupter (U.S. Pat. No. 8,677,902). The cone angles are approximately 45 to 60 degrees and the jets are moving at extremely high velocities, traveling in some cases in excess of Mach 10. An example of a linear LIFT charge is the Stingray™ disrupter (U.S. Pat. No. 8,091,479 B1). LIFT charges generally produce narrow fluid jets of low mass. They have high jet stretch rates and are good barrier penetrators but yield low bulk work on media and low impulse in our testing. As a result, they are relatively poor general disruption tools.

[0008] Water and other fluids can be driven explosively using shaped-charges to form liquid jets which move at relatively high velocity and can perform work on a target. Explosives are shaped and immersed in the water or placed on the outside of a water container. The explosives' detonation produces shock waves that move through the water. Typically, to create a jet, the charge is configured such that the shocks along a central axis or a bisecting plane converge and form a Mach stem. The pressure is higher in the center compared to the sides. A pressure gradient results in the water accelerating differentially as its position moves away from the center. The result is a jet that has a velocity profile with faster water at its front and the gradient is such that the water slows as one moves towards the explosive gas products. That velocity profile provides a number of challenges, including jet destabilization, gasification and atomization arising from shock waves in the fluid.

[0009] Provided herein are shaped-charges that stabilize the jet by the use of specially configured attenuating bodies that minimize or avoid the destabilizing effects associated with the shock waves moving through the fluid, while also ensuring that the generated liquid fluid jet has appropriate characteristics for reliable explosive target (e.g., IED's) disruption.

SUMMARY OF THE INVENTION

[0010] The filler focusing shaped-charges provided herein address the above-discussed problems by specially designed surfaces lined with one or more attenuating bodies to increase the efficiency of a jetted filler that is explosively propelled from a container volume. Conventional shaped-charges, in contrast, tend to have a uniform container thickness and, due to costs and plastic material molding processes, are very thin. For example, typical container wall thicknesses are between 0.01" and 0.08" and thus do not contribute much to the shock effects. The fluid-mass shaped-charges and related methods described herein utilize an attenuating body to improve fluid jet characteristics by controlled attenuation of the underlying shock and associated physical effects. For example, changing a plastic wall thickness of a container to between 0.25" and 0.5" by connecting an attenuating body to the sides of the container can be beneficial, including by attenuating body layer around the outer side surface of a container (e.g., a wrapping that wraps around the container or a sleeve the slides over the container sidewall, including a sidewall that has a circular circumference). The special layer, referred herein as an "attenuating body" (AB), increases relative work by the fluid jet and increases impulse and target penetration. Depending on the attenuating body position on the shaped-charge, attendant functional benefit of the attenuating body includes reduced fluid (e.g., water) gasification, an increase in inertial tamping, and increase in fluid jet velocity toward target. Positioning an attenuating body at various locations on the shaped-charge can dramatically increase the shaped-charge effectiveness at increased stand-off distance from a target, including by decreasing the rate of fluid jet stretch.

[0011] The shaped-charges and related methods are compatible with a range of explosives used to propel the liquid onto a target. For example, the explosive used to propel fluid liquid toward a target can be a shaped-conformable explosive that conforms to a shell surface. In another example, the explosive can be a volume-occupying explosive contained within a shell internal volume. The shell and explosive, whether in a surface or a container-supported configuration, are positioned in a container interior volume within a filler, including a fluid mass and/or solid particles. Both the explosive shell and the filler is contained within the container. As described herein, one or more attenuating bodies are connected to the container and/or the explosive shell to provide fluid jet characteristics by attenuating shock waves based, in part, on the application of interest.

[0012] Provided herein are shaped-charges for focusing a filler comprising a container having an interior volume to contain a shell laden with explosives and the filler. The filler can be a liquid such as water, HEET (see, e.g., U.S. Pat. No. 11,187,487, specifically incorporated by reference herein for HEET compositions and related disrupters), or other liquid that is explosively propelled to disrupt a target. The filler can be particulate solids, such as steel shot or other fine material, including garnet, sand and the like, that can form an explosively propelled jet. Filler is used broadly herein, with the devices and methods compatible with a combination of liquid and solid-containing fillers, so long as the solid particles are able to flow under an applied stress. The shell has a surface with a geometric shape configured to support a shape-conforming explosive or contain an explosive volume, wherein the geometric shape has a central longitudinal axis or a bisecting symmetry plane. The shell surface has a shell distal end, a shell proximal end that faces the distal end, and a shell sidewall that connects the distal end to the proximal end. For a shell that supports a shape-conforming explosive, the sidewall may correspond to the thickness of the shell, with a distal end shell surface that faces the target and the opposed proximal end shell surface that faces away from the target. For a shell that is a container to contain an explosive volume, there may be more distinct shell sidewalls that physically separate the shell distal and proximal end surfaces. An attenuating body, such as an AB layer, is connected to at least a portion of the container surface inner and/or outer-facing surfaces. Preferably, the attenuating body has an attenuating body thickness of between 0.03" and 2", such as between 0.03" and 1", that can be connected to one or more surfaces of a conventional shaped-charge container. In this manner, conventional shaped-charges can be retro-fitted with an attenuating layer to improve shaped-charge performance. The attenuating body thickness may spatially vary, including depending on the application of interest and the material composition of the attenuating body. For example, a distal surface (e.g., the depth of the shaper) on a CAT-shaped embodiment (see, e.g., U.S. Pat. No. 10,921,089, incorporated by reference herein for the CAT embodiments), may be filled with an attenuating body, such as between about 1" and 2", including about 1.8". This relatively thick attenuating body can fill the CAT distal surface shape that is, effectively, an indentation (concave shape). In this aspect, the attenuating body may have a maximum thickness along the central longitudinal axis where the indentation is greatest, tapering to a minimum at the edge of the distal surface that connects to a container sidewall.

[0013] The explosives forming surface shell or explosives filled shell (also referred herein more generally as "shell") is longitudinally aligned or centrally positioned relative to the attenuating body, and the corresponding container surface to which the attenuating body is connected. "Connected" is used broadly herein and can refer to a container surface that functionally is at least partially formed from the attenuating body or a more distinct component that is separately provided to the container surface. Depending on the shell configuration, explosives filled shell container or explosives shell support surface, their alignment or central positioning may be with respect to the shell longitudinal axis or the shell bisecting symmetry plane. This reflects that the shaped-charge can tolerate some off-center variance without unduly impacting the shock attenuation function of the attenuating body. The explosives shell or explosives body may be moved backward and forward, thereby impacting the relative length of the tamp and slug region. In an embodiment, the attenuating body, container surface, and explosives shell are all concentrically aligned with each other, with the longitudinal axes of each aligned and identically positioned. Furthermore, the shaped-charge can also accommodate an air gap in the container, for embodiments where fluid does not completely fill the container interior volume, to create a lift effect. Alternatively, the air gap may correspond to a bladder, in order to create a rarefaction wave shaper at the distal end of the CAT charge.

[0014] A channel can extend through the container surface and terminates or passes through the shell surface at a contact position coincident with the central longitudinal axis or the bisecting symmetry plane. The channel is configured to functionally provide the ability to reliably and safely detonate the explosives with an initiator. In other words, there is an initiator contact point connected to the shape conforming explosive or the explosive volume configured to initiate detonation of the shape conforming explosive or the explosive volume. The initiator may be an electric or non-electric detonator, detonation cord or sensitized detonation cord. The channel can terminate at the shell surface and then wire, shock tube and/or detonation cord can be fed along the channel out to the environment. A blasting machine can fire the stimulus, to initiate a detonator and controlled detonation of the explosive associated with the shell. In this manner, the fluid in the container is controllably expelled, with an improved jet characteristic provided by the attenuating body.

[0015] More specifically, the attenuating body has an attenuating body parameter configured to provide reflected shock wave attenuation after actuation of the initiator to detonate the explosives and explosively drive fluid from the interior volume of the container toward a target. The container may be formed from the attenuating body, in whole or in part. The attenuating body parameter may be any one or more of attenuating body thickness, material composition, bulk density, heterogeneity, geometry, location on the container surface, one of the shock Hugoniot parameters (e.g., bulk speed of sound or 's' number), and any combination thereof. "Heterogeneity" refers to different portions of the attenuating body having a different material property, such as gas spaces, porosity, material composition (solid, liquid, gas portions), void space fraction, composition fraction (e.g., percentage volumes occupied by a solid, liquid, or gas), and so are particularly relevant for foams and aerogels. For example, the percentage volume that is solid can vary from very low (approaching 5% or less) to very high (above 95% or greater). Of course, many applications of interest preferably have low density foams, so that the percentage of volume of solid is preferably less than 50%. The attenuating body parameter(s) are selected to provide, for the application of interest, a desired shock attenuation. The shock impedance, and shock velocity is defined by the equation of state. Hugoniot parameters include material density, bulk speed of sound, and 's' number. There is an approximately linear relationship between the shock velocity and particle velocity. The slope of the line is the 's' number. In this manner, we not only reduce the intensity of the reflected wave but at the corner of the container there is a timing mismatch so that the shock traveling in the AB is slower than that in the water at the air boundary. The colliding waves do not amplify at the corners like they would without the AB.

[0016] Exemplary AB densities include, but are not limited to, AB density on a distal container surface. Between about 0.015 g/cm^3-1 g/cm^3; for AB on container sidewalls between about 0.5 g/cm^3-2 g/cm^3 (including between 0.8 g/cm^3-1.5 g/cm^3). For a jet clipper (e.g., a second attenuating body), density may be between 0.5 g/cm^3-2 g/cm^3.

[0017] The attenuating body may be formed of a material selected from the group consisting of: plastic; foam; wood; clay; wax; natural or synthetic rubber; and combinations thereof, including in multilayers and/or composites. The container may itself correspond to the attenuating body, in whole or in part. For example, the container may be made of the attenuating body, including an attenuating body comprising one or more of a foam, rubber (natural or synthetic), plastic, metal, wood, clay, wax.

[0018] The invention provided herein is compatible with attenuating body/bodies connected at any of a variety of surfaces. The robust accommodation of attenuating body positions reflects the ability of the instant invention to accommodate a diverse range of applications. For example, shock wave behavior is dependent on any of a variety of application properties, including fluid composition, material composition of the components of the shaped-charge (e.g., type of explosive, detonator, container composition, shell composition), physical parameters (e.g., thicknesses, spatial dimensions, container volume) and target/bomb characteristics (stand-off distance, target surface property, environment such as in air or underwater). Any one or more of the application properties are used to inform attenuating body or bodies parameter, including location, layer thickness, use of multiple layers, contour, and the like. For underwater applications, low density foam is placed in front of the water slug and displaces the water between the target and the water slug. The water environment creates the tamp- no container needed when the shaped-charge is underwater. Because the extreme confinement created by a submerged water environment, the IED explosive may detonate on impact of the water jet. This issue is addressed by adding a denser layer of a surface material attenuation of rarefaction shock waves (SMART) at the end of the foam which is adjacent to the bomb. This clips the jet tip and attenuates the precursor shock wave going into the bomb.

[0019] Exemplary positions of the attenuating body include: In an embodiment, the attenuating body is connected to at least a portion of the container sidewall. In an embodiment, the attenuating body is connected to at least a portion of the container distal end and/or proximal end. In an embodiment, the attenuating body is connected to all surfaces of the container, thereby covering the container outer-facing or inner-facing surface. In an embodiment, the attenuating body is connected to at least a portion of the shell surface. In an embodiment, the attenuating body is connected to one or more of the shell sidewall, shell distal end, or the shell proximal end. In an embodiment, a first attenuating body is connected to at least a portion of the shell surface and a second attenuating body is connected to at least a portion of the container surface. The attenuating body may correspond to a sleeve that slide over at least a portion of the container side-wall outer surface. The sleeve may be open-ended so that the container distal end is not covered. Alternatively, the sleeve may be closed-ended so that the container distal end (along with at least a portion of the container sidewall) is covered. The AB may slide over an outer-facing sidewall surface of the container in a tight-fit configuration.

[0020] In an embodiment, the shaped-charge comprises a plurality of shells.

[0021] In an embodiment, the container and attenuating body are independently formed of a material having a low density, including a density of less than 1.1 g/cm^3, and the attenuating body is optionally contoured to increase an effective standoff distance compared to an equivalent shaped-charge without the attenuating body by lowering the rate of jet stretch.

[0022] In an embodiment, the explosives forming shell is formed of a plastic material. In an embodiment, the geometric shape of the shell, including a plastic shell, comprises: a truncated cone having an open distal end and a closed proximal end, the closed proximal end having a smoothly-curved concave shape; an outer circumference with a plurality of cut-outs radially spaced around the outer circumference; wherein the geometric shape is axially-symmetric about a central longitudinal axis. U.S. Pat. No. 10,921,089, which is specifically incorporated by reference herein for the "truncated cone" geometry.

[0023] In an embodiment, provided is a second attenuating body that is a distal surface layer in contact with the attenuating body that at least partially covers the container distal surface.

[0024] The AB may be an AB layer. The AB may comprise two AB materials, such as a at least one attenuating body corresponding to an AB layer having a layer thickness connected to an outer surface or an inner surface of the attenuating body, wherein the sum of the layer thickness and the attenuating body thickness is between 0.25" and 1.5". The layer may comprise: natural rubber; synthetic rubber, silicone, clay, Teflon™, neoprene, sorbothane, nitrile, PVC, or polyurethane. The AB layer may be a sleeve that slips over an outer-facing of the container sidewall.

[0025] The AB layer may have a density of between 0.015 g/cm^3 and 2.0 g/cm^3, or between 0.8 g/cm^3 and 1.8 g/cm^3.

[0026] Any of the attenuating bodies may comprise a multilayer comprising a plurality of distinct attenuating body layers. Each layer can be independently selected to have a thickness and material composition.

[0027] The attenuating body may be a layer that is prefabricated into the charge design (e.g., incorporated with a surface of the shell and/or container) or connected to the attenuating body sidewall inner or outer-facing surface. The connection may be by a tight-fit frictional force or may include an adhesive layer. The connection may be by an elastic force, wherein an AB is flexible, bendable and/or stretchable. The AB may be painted, sprayed, or otherwise applied onto a surface.

[0028] The shaped-charge may further comprise an AB layer configured to slip over an outer surface of the attenuating body (e.g., accessible) surface of the container. In this manner, there can be "on-site" retro-fitting of a layer over a standard shaped-charge. The AB layer may have a substantial thickness to for an AB body volume that is configured to be placed into the container volume, thereby occupying a fraction of the container volume, such as up to 30% of the container volume, for example.

[0029] The attenuating body thickness may spatially-vary. In this manner, additional jet characteristic control is achieved. For example, thicker attenuating body layer may correspond to regions where an increase in rarefaction wave dissipation is desired, including near corners.

[0030] The shaped-charge may further comprise an AB layer that: partially covers the sidewall; covers the container proximal end; covers the distal end of the container, or an attenuating body connected thereto, and the AB layer is contoured with a spatially-varying thickness; covers the distal end of the container, or an attenuating body connected thereto, and the AB layer is not contoured and instead has a spatially-constant thickness; covers the container sidewall and the distal end of the container; covers the entire container surface; covers the entire shell surface; or any combination thereof.

[0031] The shaped-charge may further comprise: a foam having a density less than 0.5 g/cm^3 positioned to fill a gap between the shaped-charge and a target, wherein the foam reduces water gasification and reduces a liquid jet forward velocity gradient; and a barrier layer adjacent or in contact with a target surface, wherein the barrier layer has a density of between 0.5 g/cm^3 to 2 g/cm^3.

[0032] In an embodiment, the explosives shell is concentrically aligned with respect to the container surface and the attenuating body is connected to at least a portion of the container surface.

[0033] Also provided herein are methods of explosively driving a filler, including a fluid and/or solid particles, to disrupt an explosive target using any the of the filler focusing shaped-charges provided herein. For example, the method may comprise the steps of: providing the shaped-charge with a fluid liquid positioned in the interior volume, wherein the shell is immersed in the liquid and aligning the mass focusing shaped-charge with an explosive target. The initiator is actuated to detonate the explosive in or on the shell surface and initiate a detonation wave that travels substantially parallel to the longitudinal axis, wherein the geometric shape and position of the shell and the attenuating body are configured to generate a tamp and timing of rarefaction waves to increase a pressure duration and amplitude to drive the liquid toward the explosive target and increase a bulk mass of a liquid jet. In particular, the increase in bulk mass is relative to an equivalent filler focusing shaped-charge without any of the attenuating body. The increase in bulk mass of the liquid jet may be characterized as a greater than 5%, greater than 10%, greater than 20%, or greater than 50% increase, such as up to between 50% to 60%, compared to a corresponding shaped-charge without any of the attenuating bodies. The generated liquid jet has a gaseous bubble in an interior or a void in the front portion of the liquid jet, such that upon target impact a shock impulse is reduced to minimize risk of target explosive shock initiation. Furthermore, the liquid jet tip may narrow in width or diameter, which also reduces the risk of target explosive shock initiation. In this manner, the target is disrupted while avoiding an uncontrolled explosion for a target that is an IED or the like.

[0034] The method may further comprise the step of adjusting a jet characteristic by adjusting an attenuating body characteristic without changing a shaped-charge geometry or liquid container geometry. Examples of attenuating body characteristic include a thickness of the attenuating body layer, attenuating body volume, density, Young's modulus, porosity, material uniformity, yield strength, and shock Hugoniot properties such as the bulk speed of sound and 's' number.

[0035] The attenuating body may be positioned on the shaped-charge at an incident site. Alternatively, the attenuating body may be pre-installed. For an attenuating body that is a separate component from the surface, an adhesive may be used to connect the attenuating body to a surface. The attenuating body may be an AB layer adhesively fixed to the surface, or may slip over the surface.

[0036] The method may further comprise the step of: applying a jet-clipper layer having a density of between 0.5 g/cm^3 to 2.0 g/cm^3 on a target surface of the explosive target; and/or applying a foam having a density less than 0.25 g/cm^3 to at least partially fill a gap between the container distal surface and the target surface. The jet-clipper layer results in the rapid erosion of the jet tip, thus reducing the velocity of the water impacting the target barrier and then impacting the explosives after the bomb's skin is perforated. The jet-clipper layer also attenuates precursor shock waves generated during target impact. Notably, the use of the intervening foam and/or jet-clipper layer is beneficial when the shaped-charge is submerged underwater for example against improvised ship mines.

[0037] The explosive forming shell may have a special geometry configured to support a shape-conforming explosive and ensure a fluid is appropriately propelled from the shaped-charge toward the target. In one embodiment, this is achieved by a special geometry that is generally described herein as a catenary paraboloid, specifically a plastic shell and facing distal end of the container (also referred herein as a plastic body, so that "container" and "plastic body" may be interchanged) in which the plastic shell is positioned. The fluid immerses the plastic shell and the fluid portion between the shell surface and the distal end of the plastic body is the projectile region corresponding to liquid that will be propelled toward a target upon detonation of the explosive supported by the plastic shell surface.

[0038] As described, the shaped-charges focus a filler, including a fluid mass. The shaped-charges are particularly suited for disrupting IEDs. The shaped-charges can comprise a plastic shell having a surface with a geometric shape configured to support a shape-conforming explosive. In this manner, the geometric shape is configured to provide desired explosive characteristics on the supported explosive to force a filler or a fluid mass toward a target. The geometric shape may comprise a truncated cone having an open distal end and a closed proximal end, the closed proximal end having a smoothly-curved concave shape, an outer circumference with a plurality of cut-outs radially spaced around the outer circumference. The geometric shape may be axially-symmetric about a central longitudinal axis. A cylindrical plastic body has an interior volume for containing a liquid and the plastic shell, the cylindrical plastic body having: a plastic body closed distal end having a geometric shape that is substantially matched to the concave shape of the plastic shell closed proximal end; a plastic body proximal end that faces the plastic body distal end; wherein the plastic shell is concentrically positioned to the cylindrical plastic body with respect to the central longitudinal axis. A channel extends through the cylindrical plastic body proximal end and terminates at the plastic shell surface at a contact position coincident with the central longitudinal axis, wherein the channel is configured to accommodate a detonator. In this manner, a detonator can be operably connected to the shape-conforming explosive at the central longitudinal axis for precise and well-controlled detonation.

[0039] The shaped-charge may further comprise the shape-conforming explosive mated to at least a portion of the plastic shell surface.

[0040] The plastic body proximal end may comprise an end cap that fluidically seals the liquid and plastic shell in the cylindrical plastic body interior volume.

[0041] The shaped-charge may further comprise a detonator in a press-fit configuration in the channel and, when present, the shape-conforming explosive, to fluidically seal the liquid in the interior volume.

[0042] The shaped-charge is compatible with a range of curvatures, including a concave shape that is a catenary paraboloid.

[0043] In use, the plastic shell is laterally positioned in the interior volume of the cylindrical plastic body to form a tamper region having a tamper length and a projectile region having a projectile length, wherein a ratio of the tamper length to the projectile length is between 1:1 to 2.5:1.

[0044] The cone angle can be selected from a range that is greater than or equal to 90° and less than or equal to 150°. This reflects that the invention is compatible with a range of geometries and filler (fluid mass) characteristics. For example, depending on the application of interest, including target characteristics such as barrier properties, stand-off distance, and desired fluid impact and post-impact characteristics, the cone angle, lengths, curvatures are varied. This can impact the surface area and, therefore, the amount of explosives supported by the surface.

[0045] The shaped-charge is compatible with a range of interior volumes, including between 32 and 7040 fluid ounces and/or an outer diameter of between 3 inches and 25 inches.

[0046] The shaped-charge may have a transition region on the plastic shell surface for smoothly transitioning from the truncated cone to the smoothly-curved concave shape. In this aspect, "smoothly transitioning" refers to a continuous slope such that there are not observable discontinuities or sharp edges on the surface.

[0047] In an embodiment, the plastic shell closed proximal end has a diameter that is between 30% and 80% of the diameter of the open end.

[0048] The shaped-charges described herein may further comprise a fluid positioned in the interior volume. In an embodiment, the fluid is a highly efficient energy transfer (HEET) fluid, including any of those described in U.S. Pat. No. 11,187,487 titled "DISRUPTER DRIVEN HIGHLY EFFICIENT ENERGY TRANSFER FLUID JETS" filed Aug. 18, 2017, which is specifically incorporated by reference herein for the HEET fluids described therein. Specific examples include a combination of liquid and solid particles, such that the HEET fluid combines the advantages of both water and solid projectiles as they have viscoelastic behavior and can have solid particles mixed into a fluid, including sand mixtures, and/or is a high viscosity fluid such as corn syrup, molasses or the like.

[0049] In an embodiment, the plastic body has a sidewall thickness and a front face thickness, wherein the sidewall thickness is between 2 and 4 times thicker than the front face thickness. The sidewall is optionally formed of a plastic material having a higher density than a plastic material of the front face. Examples include, but are not limited to, polyvinyl chloride (PVC), Polyterafluroethylene, Polyoxymethylene (POM) such as Delrin® plastic, phenolic Polyethylene terephthalate (PET), polyethylene terephthalate (PETE), Chlorinated Polyvinylchloride, Phenolic plastics. Similarly, sidewall relative to front face density may have a ratio up to 1.5. As described herein, the plastic body may correspond to the container to which an attenuating body is connected.

[0050] The shaped-charge may be further described in terms of one or more of: the truncated cone has a truncated cone angle of between 90° and 150°; the smoothly-curved concave shape corresponds to a paraboloid; and/or the truncated cone and paraboloid transition at a transition region, and the transition region is approximately tangential to both the truncated cone and the paraboloid.

[0051] The shaped-charge may have an explosive weight per unit area of between 1 g/in^2 and 6 g/in^2.

[0052] The shaped-charge may further comprise: a spherical projectile adjacent to the exterior distal surface of the plastic body and placed at the center of the concavity along the longitudinal axis. The spherical projectile is preferably a polyball formed of a polyurethane. The spherical projectile preferably has a spherical geometry and diameter that is between about 10% to 50% of the diameter of the plastic shell open distal end. In this configuration, the spherical projectile is physically separated from the fluid contained in the plastic body by the thickness of the wall of the plastic body distal surface.

[0053] The shaped-charge has a geometric shape configured to generate a liquid jet having an annular cross-section upon impact with a target, including specifically the plastic shell surface and cylindrical plastic body closed distal end. This annular cross-section (e.g., a ring of liquid having a cylindrical outer surface) is a unique jet-shape that reduces shock impulse and thus enables the shaped-charge to have twice the explosive load of comparable commercial disrupters without causing shock initiation of explosives on impact.

[0054] The shape conforming explosive is preferably a sheet explosive or a detonation cord explosive connected to a distal-facing surface of the plastic shell.

[0055] The shaped-charge has a geometry configured to reduce a forward velocity gradient of a generated fluid jet. In this manner, the liquid fluid jet maintains integrity after explosive detonation.

[0056] The outer surface of the plastic body distal end may comprise a plurality of scores to generate petal formation, prevent cylindrical plastic body impact on the target during use and minimize risk of unwanted shock initiation. The scores may be on the outer-facing and/or inner-facing surface of the plastic body distal end. The scores may be characterized as recess features in the surface having a penetration depth. Exemplary penetration depths correspond to between 10% and 90% wall thickness, such as about 30%-60%. The exact penetration depth is variable in that the purpose of the scores is to generate structural faults, such that upon explosive motion of the filler, including a liquid fluid mass, the distal end surface of the plastic body physically separates and falls apart to avoid impact force on a barrier target. Without such scoring, there is a risk of the distal end being carried along with the front face of the filler (particulate solids or liquid fluid) jet and making impact on the barrier target, with attendant potential uncontrolled path in the target interior. Scoring the front face to induce petal formation of the plastic and using low density and high ductility plastic (Polypropylene, polyethylene) prevents the shaped-charge body plastic from impacting at close stand-offs.

[0057] Also provided herein are methods of explosively driving a fluid to disrupt an explosive target using any of the shaped-charges described herein. The method may comprise the steps of: providing a shaped-charge of the instant invention with a liquid positioned in the interior volume, wherein the plastic shell is immersed in the liquid; aligning the mass focusing shaped-charge with an explosive target; initiating a detonation wave in the shape-conforming explosive that travels substantially parallel to the longitudinal axis, wherein the geometric shape and position of the plastic shell and the plastic body distal end are configured to generate a tamp and timing of rarefaction waves to increase a pressure duration and amplitude to drive the liquid toward the explosive target; and generating a liquid jet having an annular cross-section upon explosive target impact to reduce shock impulse and minimize risk of target explosive shock initiation. In this manner, the explosive target is disrupted. As described, the method may further comprise use of one or more attenuating bodies to provide further control of the impact of the rarefaction waves that otherwise adversely impact the liquid jet and/or minimize jet stretching, gasification or atomization.

[0058] Also provided herein are methods of making any of the shaped-charges described herein, such as by forming the shell, the container, and attenuating body, wherein the container can accommodate the shell in an interior volume, along with liquid, such that the shell (and explosive supported by the plastic shell) is immersed in the liquid with the attenuating body providing further improvement to the liquid fluid jet after detonation of the explosives associated with the shell.

[0059] Provided herein are shaped charges where the filler is a fluid mass. Also provided herein are shaped-charges where the filler comprises solid particles. For example, the shaped-charges may be generally similar to those where the filler is a liquid, but with a liner positioned in the container volume to separate a proximal explosive volume from a distal attenuating body volume. The liner itself has a liner volume configured to contain the solid particles. The liner may have any of a range of geometries, so long as upon explosive initiation, a jet formed from solid particles is controllably propelled on target. The solid particles may fuse under explosive pressures to form a unit mass that flows hydrodynamically. In this aspect, the shaped charges are more classical in nature, in that the filler is a more solid material that is crushed and flow in the form of a jet toward a target.

[0060] Also provided herein are propellant driven fluid disrupters comprising: a barrel having a bore with a barrel proximal end and a barrel distal end; a breech chamber operably connected to the barrel proximal end; a fluid at least partially filling the bore; an attenuating body breech plug positioned toward the barrel proximal end, such that the fluid extends from the attenuating body toward the barrel distal end; a blank cartridge positioned in the breech chamber and facing the attenuating body breech plug; an attenuating body muzzle plug positioned at the barrel distal end, wherein the attenuating body muzzle plug and the attenuating body breech plug fluidically seal the fluid in the barrel between the attenuating body muzzle plug and the attenuating body breech plug. The attenuating body breech plug has one or more attenuating body breech plug material properties configured to reduce primary shock and the attenuating body muzzle plug has one or more attenuating body muzzle plug material properties to reduce rarefaction waves upon detonation of explosives in the blank cartridge. The AB plug material properties include those describe above, such as AB thickness, material composition, bulk density, heterogeneity, geometry, a shock Hugoniot parameters such as bulk speed of sound or s-number, and any combination thereof. Shock impedance, and shock velocity is defined by the equation of state. Hugoniot parameters include material density, bulk speed of sound, and s-number. There is an approximately linear relationship between the shock velocity and particle velocity. The slope of the line is the s-number.

[0061] In an embodiment, the propellant driven fluid disrupter has at least one or both of: an AB body breech plug positioned toward the barrel proximal end, and/or an AB muzzle plug positioned at the barrel distal end. For example, one of the plugs may be a conventional-type plug. Although the invention is compatible with one of an AB plug, preferably, there is an AB body breech plug and an AB muzzle plug. In an embodiment, the muzzle plug may comprise a JSP.

[0062] The attenuating body of each of the muzzle plug and breech plug may have an independently selectable: density of between 1 lb/ft^3 and 6 lb/ft^3 and is a foam; crushable and pulverizable rigid closed cell foam; flexible compressible closed cell foam; material composition that is polyurethane foam, synthetic rubber, polyethylene foam, and/or neoprene. In this context, "crushable and pulverizable" refers to a material that breaks apart upon explosion, including by the explosives in a blank cartridge, so that what remains are microparticles having a micron-scaled sized particles (e.g., less than 1 mm, less than 500 μm, less than 100 μm, including average effective particle diameter).

[0063] The attenuating body breech plug may have a geometry that is a half-capsule or a right angle cylinder, or contoured to conform to the chamber, optional forcing cone and bore, each with a flat base that is adjacent to a distal end of the blank cartridge.

[0064] Without wishing to be bound by any particular theory, there may be discussion herein of beliefs or understandings of underlying principles relating to the devices and methods disclosed herein. It is recognized that regardless of the ultimate correctness of any mechanistic explanation or hypothesis, an embodiment of the invention can nonetheless be operative and useful.

BRIEF DESCRIPTION OF THE DRAWINGS

[0065] FIG. **1** is a front face sectional view of a shaped-charge having a shell surface with a geometric shape to support a shape-conforming explosive immersed in a fluid contained within a container. The shell surface provides support for shaping of explosives and focusing a filler, including a fluid mass, upon explosive detonation. An attenuating body is connected to a portion of the container surface.

[0066] FIG. **2** is a similar to FIG. **1**, except the shell has an interior shell volume in which explosives are contained.

[0067] FIG. **3** is similar to FIG. **2**, except the attenuating body forms the container.

[0068] FIG. **4** is an open side view of an assembled shaped-charge without the attenuating body.

[0069] FIG. **5** corresponds to FIG. **4** with the attenuating body illustrated as a single layer and material that covers the sidewalls of the container. Thickness can be varied depending on the application of interest.

[0070] FIG. **6** illustrates the embodiment of FIG. **5** with an attenuating body formed of a plurality of layers and plurality of material compositions. Each layer can independently vary in thickness and material composition. For example, the thickness may range between 0.125" to 0.5".

[0071] FIG. **7** illustrates the embodiment of FIG. **4** with an attenuating body formed of a plurality of layers that partially cover the container sidewalls, specifically a distal region of the container sidewalls. Each layer can independently vary in thickness and material composition.

[0072] FIG. **8** illustrates the embodiment of FIG. **4** with an attenuating body formed of a plurality of layers that partially cover the container sidewalls, specifically a proximal region of the container sidewalls. Each layer can independently vary in thickness and material composition.

[0073] FIG. **9** illustrates the embodiment of FIG. **4** with an attenuating body formed of a plurality of layers that covers a portion of the container sidewalls, specifically a distal region of the container sidewalls. An attenuating body, illustrated as one layer (but that may comprise one or more layers of the same or differing materials), also covers the distal surface of the container. Each layer can independently vary in thickness and material composition.

[0074] FIG. **10** illustrates the embodiment of FIG. **4** with an attenuating body connected to the distal surface of the container and is contoured to the surface. Attenuating body may comprise one or more layers of the same or differing materials. In this embodiment, no attenuating body is on the container sidewall.

[0075] FIG. **11** illustrates the embodiment of FIG. **4** with an attenuating body connected to the distal surface of the container to fill the void formed by the concave-shaped distal surface of the container. Attenuating body may comprise one or more layers of the same or differing materials. In this embodiment, no attenuating body is on the container sidewall.

[0076] FIG. **12** illustrates the embodiment of FIG. **4** with an attenuating body formed of a plurality of layers and materials connected to the distal surface of the container to fill the void formed by the concave-shaped distal surface of the container. Attenuating body may comprise one or more layers of the same or differing materials. In this embodiment, no attenuating body is on the container sidewall.

[0077] FIG. **13** illustrates the embodiment of FIG. **4** with an attenuating body formed of a plurality of layers and materials connected to the distal surface of the container to fill the void formed by the concave-shaped distal surface of the container and to cover the sidewalls of the container. Attenuating body may comprise one or more layers of the same or differing materials.

[0078] FIG. **14** illustrates the embodiment of FIG. **4** with an attenuating body formed of a plurality of layers and materials connected to the distal surface of the container to fill the void formed by the concave-shaped distal surface of the container and to cover the sidewalls and proximal surface of the container. Attenuating body may comprise one or more layers of the same or differing materials. In this manner, all container surfaces may be covered by attenuating layer(s).

[0079] FIG. **15** illustrates the embodiment of FIG. **4** with an attenuating body formed of a plurality of layers and materials connected to the proximal surface of the container.

[0080] FIG. **16** top panel is a top view of the container and shell, with a spatially-varying thickness of the shell. The bottom panel is a cross-section of the top panel A-A.

[0081] FIG. **17** illustrates an underwater application, where low density SMART (e.g., foam) and higher density SMART between the target and low density SMART.

[0082] FIG. **18** is an example of two shells that are each shape-conforming explosive.

[0083] FIG. **19** is an example of two shells that contain an explosive volume.

[0084] FIG. **20** illustrates a slip-on AB layer configuration. The arrows indicated the direction for slipping the AB layer onto the attenuating body.

[0085] FIG. **21** illustrates liquid jet propelled toward target without (top panel) and with (bottom panel) attenuating bodies. The attenuating body provides an improvement in both jet length and jet diameter.

[0086] FIG. **22** illustrates different views of a conical shaped charge configured for use with a SMART material and a filler that is formed of solid particles within a liner that functionally acts as a portion of a shell surface. The top panels depict a front, front-side and front-bottom view of the container of the shaped charge. The bottom panels illustrate internal components, with the bottom left panel a section B-B view as defined in the top left panel. The bottom right panel is a perspective view through the container. All views illustrate the container only, in which the filler, explosives and SMART material can be positioned.

[0087] FIG. **23** illustrates the container of FIG. **22** with the SMART material.

[0088] FIG. **24** illustrates the container and SMART material of FIG. **23** with explosives.

[0089] FIG. **25** is another view of conical shaped charge with SMART, filler, explosives and detonator.

[0090] FIG. **26** illustrates exemplary liner geometrical shapes, where the liner is configured to contain filler that are solid particles and to define an explosive volume on a liner proximal side and an attenuating body volume on a liner distal side. Illustrated embodiments include a linear or wedge shape (see, e.g., FIG. **1**); symmetrically curved side surfaces extending from a central flat surface region; portion of a cone; a hemi-spherical; and hemi-cylindrical. For ease of illustration, the bottom two panels do not illustrate the container.

[0091] FIG. **27** illustrates use of an attenuating body (AB) with a propellant driven disrupter, such as a water cannon. The top panel is a cross section and the bottom panel a view of the outer surface of the propellant driven disrupter, including barrel and breech portions.

[0092] FIG. **28** illustrates AB position in relating to water and blank cartridge for various AB breech plug geometry, including half-capsule (middle panel) and cylindrical (bottom panel).

[0093] FIG. **29** illustrates an AB half-capsule geometry to disperse primary shock produced by propellant explosion in the breech.

[0094] FIG. **30** illustrates an AB cylindrical shaped geometry.

[0095] FIG. **31** illustrates a contoured breech plug AB.

[0096] FIG. **32** illustrates scoring or notching to facilitate fracturing of the AB plug (e.g., frangible AB plug).

DETAILED DESCRIPTION

[0097] In the following description, numerous specific details of the devices, device components and methods of the present invention are set forth in order to provide a thorough explanation of the precise nature of the invention. It will be apparent, however, to those of skill in the art that the invention can be practiced without these specific details.

[0098] In general, the terms and phrases used herein have their art-recognized meaning, which can be found by reference to standard texts, journal references and contexts known to those skilled in the art. The following definitions are provided to clarify their specific use in the context of the invention.

[0099] "Filler" is used broadly herein to refer to a material that is able to fill the interior volume of the container or a layer that itself define explosive volume from an attenuating body volume, immersing a shell surface, and that is capable of being explosively driven in a jet geometry toward a target. The filler can be solid-based plurality of particles, liquid-based or a combination of solid(s) and liquid(s). "Fluid" refers to a liquid-based material that is contained in the interior volume of the container and that immerses the shell surface. "Particle" refers to fine solid particles configured to form a jet toward a target after explosive propulsion. The solid particles may fuse under explosive pressures to form a unit mass that flows hydrodynamically. The shaped-charges are compatible with any number of liquids, including water and high-density liquids, such as corn syrup. As described herein and at U.S. Pat. No. 11,187,487, the fluid may be a high energy efficient (HEET) fluid. The fluid may comprise solid particles suspended in a liquid medium.

[0100] "Attenuating body" refers to one or more layers of material that are connected to the shaped-charge to provide desired control of the fluid or solid jet generated upon detonation of the explosives associated with the shell or liner. That attenuating body is also referred herein as "SMART". The attenuating body may correspond to an AB layer that is configured to be positioned on another surface. In this aspect "connected" refers to an attenuating body that is connected to the shaped-charge in a manner that the functionality of the components of the shaped-charge is maintained. For example, an attenuating body connected to a container wall does not impact the ability of the wall to contain the liquid. The connection may be direct or indirect. For example, there may be an adhesive applied to adhesively connect the attenuating body to a surface. There may be an intervening attenuating body, such as an attenuating body layer, between a surface of the shaped-charge and an attenuating body. This is also described herein as an attenuating body multilayer configuration. One function of the attenuating body is to functionally adjust a wall surface thickness so as to impact reflected shock waves that are propagated in the contained liquid and interact with liquid/wall interfaces. The thickness of the attenuating body is selected to achieve the desired fluid jet outcome and, as explained, depends on various parameters. Exemplary thicknesses include ranges between 0.03" and 1". The thickness of an attenuating body may be spatially constant or spatially vary. A spatially-varying attenuating body thickness is also referred herein as a "contoured" attenuating body. The attenuating body may be conformable to a surface. In this manner, the attenuating body has a flexibility such that it can deform and conform to a surface, including a curved surface or a sharp-edged surface. The container material can be the attenuating body and thus the container thickness can be varied and contoured at various locations to provide improved jet characteristics. The container may also have a bisecting symmetry plane.

[0101] The attenuating body may correspond to a foam. "Foam" refers to a material that is formed by trapping pockets of gas in a liquid or a solid. A solid foam can be closed-cell or open-cell, depending on whether the pockets are completely surrounded by the solid material. In an open-cell foam, gas pockets connect to each other, including via pores. In a closed-cell, gas pockets are not connected to each other. The foam is polydisperse and is characterized as not uniform and stochastic. Foams efficiently attenuate shockwaves because of the heterogeneous structure in combination with low bulk density. In this manner, pressure waves are broken up and dispersed, thereby providing good shock tamping. Depending on the application of interest, which influences the desired liquid jet characteristics, the foam can be made from any of a range of materials, such as plastic, rubber (natural or synthetic), aluminum or other metals. For example, blasting cap protectors are made from aluminum foam because an aluminum foam absorbs the shock. The attenuating body may also be an aerogel. "Aerogel" refers to a synthetic porous material derived from a gel, where the liquid component has been replaced with a gas without significant collapse of the gel structure. Exemplary aerogels include, but are not limited to, solid smoke, solid air, solid cloud, blue smoke, silica aerogels, carbon aerogels, polymer-based aerogels, metal-oxide aerogels, and the like.

[0102] "AB layer" is used broadly to refer to an AB providing functional benefit of the shaped charge. The AB layer may be a layer of material affixed to and/or adjacent to another material. For example, the AB layer may be a shape-conforming material that is effectively wrapped around another surface. The AB layer may be a sleeve of material that slides over a container surface, such as container side-wall outer facing surface. The AB layer may be adhered to a surface by a layer of adhesive, such as an inner or outer-facing container surface. The AB layer may be provided with a substantial thickness so that the AB layer is effectively an AB volume that occupies a fraction of the container volume, such as up to 10%, up to 20% or up to 30% of the container volume. The AB layer may be adjacent to, in physical contact with, or connected to the distal surface of the container volume. In this manner, the AB platform described herein is versatile and can be used in a number of various configurations, depending on the application of interest. The AB layer may be a sheet of constant thickness that is contoured to the proximal container face or may be flexible and bendable such that it conforms to a contoured surface. An AB layer may be an air cell or a low density foam. The AB layer may be a volume of material that has curvature on its distal surface, and occupies a significant volume. This aspect is generally characterized as an AB layer having a substantial thickness that results in the AB layer being an AB body volume.

[0103] "Focusing" refers to the ability to force liquid in a desired direction with desired properties related to jet formation, stability, and impact pressure or force against a target, including post-barrier penetration.

[0104] The term "substantially matched" refers to two components that are similar. In the context of a geometric shape, it refers to a deviation from absolute correspondence that does not adversely impact functional properties associated with the fluid jet and target disruption. The term is intended to reflect that the shaped-charges provided herein are able to tolerate differences between surfaces (e.g., plastic shell surface and cylindrical plastic body distal end) without significant degradation in a liquid jet parameter. As desired, the term may be optionally quantitatively defined, such as curve parameters that differ by less than 10% from each other, such as curvature, distances, and any parameters associated with a corresponding curve fit, such as:

$$y = \frac{e^{ax} + e^{-ax}}{2a} = \frac{\cosh ax}{a}$$

where the parameter "a" is within 10% for each of the two best-fit curves (with surface then formed as a rotation of the function about the central longitudinal axis). In a similar manner, best-fitting of any of the curves or corresponding surfaces may be performed to define whether two surfaces are substantially matched.

[0105] Unless otherwise defined, "approximately" or "substantially" refers to a value that is within 10% of a desired or true value, and can correspondingly include identically matched.

[0106] "Proximal" and "distal" are relative to the detonator and target. A distal position is further from the detonator and closer to the target than a proximal position. In other words, distal is toward the direction of a target, and proximal more away from the target. The terms are useful in describing relative positions of components.

[0107] The terms "central longitudinal axis" and "bisecting symmetry plane" are used to refer to relative positions with respect to the shaped-charge and associated target. In general, a longitudinal axis corresponds to the notional line leading from the shaped-charge toward a target, and is relevant for shells that have a container volume for containing an explosive. A "bisecting symmetry plane" is generally relevant for a shell having a surface to support a surface-conforming explosive. For desired fluid jet characteristics, the surface has a plane of symmetry, referred herein as a bisecting symmetry plane, where the distal shell surface faces toward the target through the container distal end.

[0108] The invention can be further understood by the following non-limiting examples.

[0109] Referring to FIG. **1**, the shaped-charge **10** has a container **25** that defines interior volume **27** to contain a shell **30** having a shell surface **40** that defines a geometric shape **40** that can support a shape-conforming explosive (not shown). One example of a geometric shape is the CAT shape illustrated in FIGS. **4-15** (see also U.S. Pat. No. 10,921,089, including for the geometric surfaces of the shells, which are specifically incorporated by reference herein). Of course, the shaped-charges provided herein are compatible with other shells, including shells having a shell volume **32** configured to contain an explosive volume **152**, as illustrated in FIG. **2**. FIGS. **1-2** illustrate an attenuating body **11** connected to the container side walls. The attenuating body, depending on the application of interest, can connect to other locations of the container side walls, including most or all of the container surface, including all sides (FIG. **3**) and/or to at least a portion of the shell surface.

[0110] The shell **30** has a shell distal end **33**, a shell proximal end **34** and a shell sidewall **35** that connects the shell distal end surface with the shell proximal surface, with shell bisecting symmetry plane illustrated by **120** in FIG. **1** and central longitudinal axis **120***a* in FIG. **3** (longitudinal axis for shell container). Generally, the term "distal" refers to the surface that is nearest in the direction of the target, with proximal surface furthest from the target. Accordingly, the filler or the fluid mass is controllably expelled, including as a water jet, in a direction out of the shell distal end surface, whether the shell forms a surface shell shape **40** to support an explosive charge (e.g., FIG. **1**) or a shell interior volume **27** in which an explosive charge is positioned, so that there is effectively and explosive volume **152** (e.g., FIGS. **2-3**). For a liquid explosive, the explosive volume **152** may be equal to or less than the interior shell volume **32** formed by shell walls **33 34 35**, and selected depending on the application and target characteristics, with desired filler or fluid mass expulsion out of the container **25**. For example, FIG. **2** illustrates shell volume **32** equal to explosive volume **152** For a shape-conforming explosive, the mass of the explosive and surface area of the explosive are relevant parameters for controlled filler or fluid mass expulsion out of the container **25** toward a target.

[0111] As discussed herein, the attenuating body **11** is selected and positioned to provide desired filler or fluid mass expulsion characteristics by controllably manipulating reflected shock waves upon detonation of the explosives positioned in the container with attendant fluid shock wave/wall surface interaction. Particularly relevant attenuating body characteristics are material composition and body thickness **12**. Preferred thicknesses include a thickness between 0.03" and 1" or between 0.75 mm and 2.6 cm. The attenuating body may contact an outer and/or inner surface of container **25**. In some embodiments, attenuating body **11** may contact at least a portion of a surface of the shell **30**, including contacting both a container surface and a shell surface, or only one of a shell surface or a container surface. In a preferred embodiment, the contact is to an outer surface of the container **25**. The container **11** surfaces may include container distal **210**, proximal **220** and side surface **205**. A stem **42** may accommodate channel **250** through which an explosive initiator operably connects, such as an electrical line for an electronically-triggered explosive, with a fluid jet directed to a target **1700**. In this manner, there is an initiator contact point **251** configured to initiate detonation of the explosive (whether explosive volume or shape-conforming) to drive filler out the distal end of the container toward a target in the form of a filler jet **2110** (see, e.g., FIG. **21**).

[0112] FIGS. **4-15** illustrate an embodiment where the shell of the shaped-charge has a geometric shape corresponding to a truncated cone with an open distal end and a closed proximal end, referred to as a catenary advanced technology (CAT) disrupter. See, e.g., U.S. Pat. No. 10,921,089, including particularly for various figures illustrating the truncated cone geometry and their use in shaped-charges for focusing a filler or fluid mass. FIG. **4** illustrates the shaped-charge without an attenuating body, with FIGS. **5-15** illustrating different positions and configurations of the attenuating body **11**, including one or more layers, independent positioning of the attenuating body relative to distal, proximal and/or side-surfaces of the container and/or shell. Incorporation of the attenuating body provides another means for independently adjusting jet characteristics. In this manner, the shaped-charges and related methods of disrupting a target are readily tailored and controlled, including to the operational situation and circumstances, so as to achieve reliable fluid mass (e.g., water or HEET) or solid mass explosive propulsion toward the target.

Example 1: Methods to Reduce Water Gasification and Atomization in High Explosive Mass-Focusing Shaped-Charges

[0113] The shaped-charges and related methods of using an attenuation body, such as by lining the side-wall or the front-face of a jetting water high explosive shaped-charge with specific materials and thicknesses, increases the fluid jet efficiency. Side-wall lining with an attenuating body increases the measured relative work, impulse and penetration by up to 50%. Water gasification is reduced and a slight increase in inertial tamping increases the jet velocity. Alternatively, using an attenuating body on the front face has a different beneficial effect. Front-face attenuating body having a low density and optionally contoured material dramatically increases the charge's effectiveness at greater standoffs by lowering the rate of jet stretch.

[0114] Water and other fluids (e.g., HEET) can be driven explosively using shaped-charges to form liquid jets which move at relatively high velocity and can perform work on a target. Explosives are shaped and immersed in the fluid (e.g., water) or placed on the outside of a water container. The explosives' detonation produces shock waves that move through the water. Typically, to create a jet, the charge is configured such that the shocks along a central axis or a bisecting plane converge and form a Mach stem. The pressure is higher in the center compared to the sides. A pressure gradient results in the water accelerating differentially as its position moves away from the center. The result is a jet that has a velocity profile with faster water at its front and the gradient is such that the water slows as one moves towards the explosive gas products.

[0115] The attenuating body provided herein stabilizes the fluid and reduces gasification and atomization resulting from shock waves in the fluid. This maximizes the amount of liquid fluid propagating in the jet and increases the distance the jet will travel in air or inside a medium before it breaks apart. Most jets fail to propagate beyond a few feet in air. The work function and impulse are highly dependent on the velocity of the jetting liquid and the mass of fluid during impact with an object.

[0116] In the arts of improvised explosive device (IED) neutralization or ordnance disposal, jetting fluids can be used to break apart bombs. Containers are accessed, fuze components are destroyed, and explosives and components are expelled and separated. If the purpose of the jetting water is to neutralize IEDs, the fluid mass focusing shaped-charge is referred to as a high explosives disrupter. These tools can also be used to breech structures such as bomb casings, vehicle bodies or buildings.

[0117] When a shaped-charge is initiated, the detonation wave couples to the fluid and it generates shock waves inside of the fluid. These shocks are essential in creating a particle forward velocity gradient which macroscopically causes the formation of a fluid jet. Without the velocity gradient, the fluid tends to move as a unit mass and not jet. These jetting fluid can do work cutting through materials such as steel and low strength continuous media. Fluid jets, due to their relatively low density and high heat capacity, are preferred to access and disable IEDs. The relatively low impact pressures have a reduced risk of shock initiating explosives inside an IED or bomb. In addition, due to a fluid jet's resistance to compression, including for water, high mass, inviscid and inelastic nature, the duration of loading is very long, resulting in maximized momentum and energy transfer to impacted targets.

[0118] Unfortunately, the very same shock waves that are necessary to form the fluid jet ultimately result in its destruction. They cause the fluid to atomize and to gasify, thereby adversely impacting jet integrity and attendant energy transfer. Liquid fluids, including water, cannot withstand tensor or hoop stress and thus forms droplets as the jet expands radially and stretches apart from lengthening. Furthermore, at room temperature, water boils at relatively low pressures. For example, at 25° C., water boils when the atmospheric pressure above liquid water surface drops to below approximately 0.5 psi. After the explosion, because of the water's high heat capacity, the bulk of the water in the charge container remains at room temperature. As explained below, water vapor bubbles form inside the water projectile region and these bubbles progressively grow. Generally, a vapor bubble forms along the symmetry axis or plane of the water-filled charge and at the corners. The bubbles can destroy the jet early in its formation so that the bulk density of the jet is too low to perform work. The water is transformed into gas rather than forming a jetting liquid.

[0119] The water gasification results from the shock waves associated with detonation of the explosive that reflect at the container walls, and water-air boundaries. The shock wave unloads and the reflected wave is a rarefaction wave also known as a release wave. Unlike the primary compressive shock wave caused by the explosion, rarefaction waves are tensor waves and are negative pressure waves. At the front face, due to the intensity of the primary shock wave, the reflective wave can be at the critical pressure to induce water bubble formation. The tension is amplified when the rarefaction waves collide. The tensor stress causes a void in the water which then creates a surface for the water to boil at the interface with the void. This is the reason the explosive's distance from the container front-face and tamp-back wall is critical to allow the principle shock to attenuate. At the corners, the shocks reflected off the side and the front converge and amplify also causing gasification at the corner of the jet. Once a water vapor bubble forms there is a second water-gas boundary and now shock reflections occur at this interface. The process results in the continual growth of the gas bubble until the shocks dissipate.

[0120] The amplitude of the reflected shocks and the decompression of the fluid (e.g., water) is dependent on the shock impedance and the shock Hugoniot properties of the container, air, and fluid (e.g., water). Two well defined properties are the bulk speed of sound and the pre-shock density. Generally, the container shell thickness for most mass-focusing shaped-charges is uniform and very thin because of the cost and the plastic material molding process. Typical container wall thicknesses are between 0.01" and 0.08" and thus do not contribute much to the shock effects. However, we recently observed that changing the plastic wall thickness to between 0.25" and 0.5" on the sides of a container can be beneficial. However, increasing the front wall thickness can be highly detrimental for two main reasons. The first is the plastic fragments can be driven at high velocity and shock initiate explosives when they impact an IED. The second effect is not so obvious and that is the dramatic reduction of the forward velocity gradient. The fluid is projected forward as a low velocity slug rather than forming a jet. Understanding and accommodating these effects are important for the configuration, positioning and use of attenuating body to better control and improve fluid jets with attendant functional benefit of tailored impact to the target.

[0121] Experimentation and CTH hydrocode modeling further clarify the reason for the improved jetting properties of manipulating the high explosive disrupter container sidewall material and thickness. Using 0.25" thick ASA 3D printed plastic side wall to the CAT shaped-charge results in a 50% increase in cavitation and in penetration, and a 40% increase in impulse. 3D printed ASA material is considered a non-ideal material in that it is inhomogeneous in structure and density and as a result is similar to foams, which are known to attenuate shocks. Shock attenuation is also dependent on the speed of sound and the density. Generally, lower speed of sound materials and/or lower density materials will attenuate shocks more efficiently. The ASA has the approximate density of water and is a form of acrylic which has similar sound speed to water. There is not a significant inertial tamping benefit. The improvement in performance is believed to be due to the shocks on the side-wall attenuating through the plastic and also due to the timing mismatch of the release waves traveling back into the water compared to the front.

[0122] Experiments with an attenuating body corresponding to a 0.25" thick silicone rubber lining the side-wall has similar results to the ASA material. The silicone rubber has a measured density of 1.25 g/cm^3 and the ASA material is reported to have a density of approximately 1 g/cm^3. If density was a primary contributor due to increased inertial tamp then a 25% increase in density should show a measurable increase in performance, but it did not improve penetration in a multi-layered panel penetration test. The observed results are consistent with the theory of shock attenuation in the sidewall and reduction of the Mach stem effect at the front corner due to timing mismatch created by differing wall thickness at the front and side. The front corner region is predicted to be the most sensitive zone to add side-wall material. To validate this, a band of silicone rubber was placed only on the sides of the projectile region of the water and not the back tamp water in the container. In the multi-layered spaced panel test, the partially covered sidewall performed similarly to the completely lined sidewall.

[0123] To assess the benefits of inertial tamping and using a high strength material to further confine the water, CTH modeling was conducted for the CAT mass-focusing shaped-charge using a 0.25" thick steel sidewall liner. Steel is approximately 8 times the density of water. The result was poor jet formation and gasification of the water in the projectile region. The high speed of sound in steel, above 5,500 m/sec, and the impedance mismatch at the steel-water boundary, transitioning from a high Z to a low Z material resulted in amplification of the rarefaction wave effects. From this, we conclude that the preferred attenuating body material is a low Z material compared to water and a lower speed of sound material, non-ideal. Representative ranges of low Z values as comparing the acoustic impedance difference to water: silicone rubber −27%, polyethylene foam −22.6%, natural gum rubber −1%, LDPE 19%, polyurethane 20%, neoprene 31%, HDPE 55%, polypropylene 60%, and PVC 118%. In contrast, steel is a high Z material and its acoustic impedance difference compared to water is 2998%. The materials relative shock impedance difference to water is similar to their acoustic impedances. Shock impedance is more complex because it will change with the shock velocity, which depends on the quantity of explosives used.

[0124] High percent elongation materials would hold together longer as they stretch from the radial expansion after the explosion. The shocks are reflected repeatedly in the water and a material that stays in contact with the water for a longer duration would further improve their effectiveness. Natural gum rubber has a relatively low sound speed, 1,500 m/s, comparable to water at 1,480 m/s at room temperature. Rubbers are well known for very large percentage elongation, and natural rubber is reported to stretch to 500% without failure. A36 mild steel, in contrast, has an approximate percent elongation of 20%-40%.

[0125] Experiments are conducted by wrapping the axisymmetric CAT shaped-charge side wall with 0.25" and 0.5" thickness natural gum rubber sheet as the attenuating body. This performs slightly better than the silicone rubber sheet attenuating body but has a density of approximately 1 g/cm^3. In a multi-layered spaced panel test in which the layers were separated by a 3" spacing, the CAT shaped-charge covered with the 0.25" thickness sheet showed a 50% increase in penetration compared to the tool with no wrapping. The 0.5" thick natural rubber sheet showed a 30% increase in penetration compared to the control and the average hole diameter in the panels is slightly larger. Furthermore, only covering the water slug region of the CAT with the attenuating body has similar results compared to the sidewall completely lined with the attenuating body.

[0126] CTH in silico modeling experiments were completed on a linear mass focusing shaped-charge with an attenuating body made from various materials such as silicone, Teflon®, neoprene, PVC, and polyurethane. For polyurethane, the density was varied. The attenuating body thickness was 0.25" thick or 0.5" thick in the CTH simulations. In all cases, the experiments show a slight increase in jet tip velocity and a jet with reduced gasification compared the control simulation without an attenuating body. In addition, substituting an attenuating body with the equivalent volume of water did not improve the jet or reduce gasification.

[0127] The benefits of a sidewall attenuating body applies to all axisymmetric and linear mass-focusing shaped-charges. The lining that is the attenuating body does not measurably increase the weight or the dimensions of the charges. This makes the attenuating body a practical way to improve efficiency by optimizing the amount of fluid (e.g., water) contributing to penetration, cavitation and impulse for the same net explosive weight. The practical deployment of the high explosive disrupters is not adversely impacted and optionally the attenuating body can be added at the incident site simplifying deployment. For example, the attenuating body can be an AB layer that is positioned over an outer surface, and any portions thereof, of the shaped-charge container. Rapid application can be done by using a pre-applied high strength tape such as 3M VHB Transfer Tape. The cost of most rubbers and plastics such as PVC are reasonable making volume production of AB layers affordable. The velocity will not increase significantly which means there is no increase in the risk of shock initiation due to the jet impacting an IED in a region containing explosives. Several commercially available high explosive disrupters would receive immediate benefits from the attenuating bodies and related methods described herein.

[0128] Placing an attenuating body at the front (e.g., distal surface) of a high explosive mass focusing shaped-charge has a very different effect than placing an attenuating body on the container sidewall. CTH simulations of polyurethane foams placed on a charge face of varying density from 0.015 g/cm^3 to 1 g/cm^3 were examined. The thickness was one inch for all densities. The lowest density had no observable effect. At the 1 g/cm^3 density the jet did not form and the water moved as a unit mass and there was a reduction in gasification at the jet central plane. At 0.5 g/cm^3, gasification at the jet central plane was reduced and the jet stretch was significantly slowed. The forward velocity gradient was reduced. At the one charge diameter distance, the jet was wide and the length shortened. The CTH stimulations predict that the jet would produce large cavities but low penetration through medium at typical standoffs of one charge diameter. A reduced forward velocity gradient has the benefit that the rate of jet lengthening is slower and thus the high explosive disrupter produces jets that remained intact at significantly larger standoffs before the jet is stretched apart into droplets.

[0129] Experiments with GreatStuff™ foam, 0.016 g/cm^3, of approximately 1-inch thickness at the charge face did not show a loss in penetration in the multi-layered separated panel tests. These observations are consistent with CTH simulations.

[0130] Underwater tests indicate there is a dramatically reduced performance of commercially available mass-focusing shaped-charges. The effectively infinite medium of water at the front of the charge may have similar effects as the CTH modeled 1 g/cm^3 foam materials that are placed against the charge front face. The jet will not form and the water in the charge will move as a unit mass. In addition, the ideal penetration equation predicts that in a fluid-fluid interaction, water jet erosion pushing through water dramatically reduces the distance the jet will travel before being completely ablated. We have shown in underwater experiments that placing a foam, such as 0.15 g/cm^3 density Styrofoam®, between the charge face and the target results in jet formation and perforation of thin steel barriers. Furthermore, the jet penetrates through a medium of gun powder placed adjacent to the steel barrier. In one embodiment, we use a hemi-cylindrical mass-focusing linear shaped-charge.

[0131] Multiple layers of materials are beneficial in controlling the shock impact effects on explosives inside of IEDs, including at the disrupter distal surface that faces toward the IED. Accordingly, provided herein is an attenuating body formed from a plurality of attenuating body layers. We demonstrate the limits to the quantity of explosives that should be used to drive water to neutralize bombs. Water jets from disrupters can shock initiate common IED explosives after impacting the skin of a bomb. Disrupter standoff may need to be adjusted such that the jet tip erodes in flight. At the time of arrival, the velocity on impact is lower due to the forward velocity gradient for longer standoff distances. This results in the impact pressure, which is proportional to the square of the jet velocity, to be reduced below the critical pressure of initiation of the IED's explosives. Furthermore, jet stretch causes the fluid tip to narrow which also reduces the shock impulse. This increase in the distance to traverse to the target causes the jet to stretch and atomize and thus results in reduced performance such as lower target cavitation and impulse. Based on this, provided herein are shaped-charges and related methods that avoids the need to change the standoff by using an optional low-density foam to fill the gap between the shaped-charge distal surface and the target. The low-density foam is coupled with a layer of higher density material near or in contact with the bomb barrier. The higher density material can be a density of 0.5 g/cm^3 to 2 g/cm^3 and adjacent to the target. This material clips the jet and exploits the shock impedance of the materials and the process of shock attenuation to reduce the impact pressures and compressive heating of the IED explosives that are on the other side of the bomb barrier. We refer to this layer as a "jet clipper" layer and is further helpful in IED defeat. The jet clipper layer can be used with or without a low-density foam medium and has been experimentally shown to reduce the probability of shock initiation of IED explosives (see, e.g., FIG. **17**).

[0132] Using attenuating bodies greatly improves the efficiency of high explosive shaped-charges that drive a fluid, including water. For a given explosive weight the relative work and penetration is readily increased by 50% through the use of attenuating bodies compared to an equivalent fluid mass focusing shaped-charge without an attenuating body. The increase in the mass of the jet because of preservation of liquid water contributed to a 40% increase in impulse. Attenuating bodies, including AB layers, are cost effective and can be prefabricated into the charge design through molds or connected to the sidewalls by various connectors, such as clips, fasteners and/or adhesives. For axisymmetric charges, the attenuating body can be slipped onto the body, including on an outer surface of the container. Molds for plastics and synthetic rubbers such as polyurethane can be made such that the container sidewall is of an optimized thickness compared to the front. The front of the container (distal container surface) should be as thin as possible for maximum work, penetration and impulse. Also, the thin-walled distal container surface reduces plastic impacting the target. Foams at the jet front can be used to preserve liquid water by reducing water gasification and dramatically reduce the forward velocity gradient. Foaming the disrupter front by providing foam to the container distal surface, or anywhere between the target and container distal surface, improves the jet's effective working distance because the jet will form more slowly and thus be intact at greater standoff distances. Attenuating body materials, including an AB layer, are affordable and do not drastically increase the cost of the charge. The attenuating body may be an AB layer that is formed from distinct attenuating body layers. The total additional volume and weight does not greatly increase and so portability of the charge is not adversely affected. For the first time, a high explosive disrupter's jet characteristics can be modified without changing the charge geometry or the shaped-charge container that contains the fluid. Examples include, but are not limited to, wraps, sleeves, appliques such as spray or painted on materials, which can be provided on-site or ahead of time.

Example 2: Shaped-Charge Theory and Application

[0133] A Catenary Advanced Technology (CAT) disrupter is a mass focusing shaped-charge that explosively drives a large volume of water, or other liquid such as Highly Efficient Energy Transfer (HEET) fluid as described in any of U.S. patent application Ser. No. 15/731,874, U.S. Pat. No. 10,451,378, U.S. Pub. No. 2020/0025508, each to Vabnick et al. The liquids jet at relatively high velocity to disrupt improvised explosive devices (IEDs). The jet may perforate the barrier(s) of a bomb, destroy fusing components and cause separation of the firing train to include expulsion of the explosive main charge. The CAT disrupter has an axially symmetric geometry. The shell may be formed of a plastic material, that shapes the explosives (also referred herein as an HE former) is a hybridization of a truncated cone at the opening which transitions to a smooth-curved surface such as a parabola at the closed end. Sheet explosives are mated to the surface of the HE former. An enhanced water charge (EWC) was previously developed using a plastic bowl lined with sheet explosives or lined with overlapping wraps of detonation cord. As with all mass focusing shaped-charges, the CAT disrupter uses a Mach-stem effect to cause a higher pressure field along its axis of longitudinal symmetry. The water near the center is accelerated more than the water in the periphery. The CAT disrupter fluid jet tip can be explosively propelled in a range from transonic to supersonic velocities. The jet velocity can be controlled by the amount of explosives applied to the explosive former or by modifying disrupter geometric parameters to include cone angle and tamper mass-to-projectile mass ratio. Due to the HE former's parabolic base, the water is collimated and has a greatly reduced forward velocity gradient (FVG) compared to other mass focusing charges. This results in unprecedented penetration and effective working distance. The CAT shaped-charge can disrupt IEDs up to four times farther than other fluid mass focusing disrupters of comparable size. Modification of the cone angle can also be used to change the jet profile including the cross-sectional area at any point along its length.

[0134] One embodiment of the CAT disrupter has a container volume of approximately 64 ounces and drives a water slug that is 5 to 10 times the volume of the water projectile in a propellant-driven water cannon/dearmer such as the percussion actuated non-electric (PAN) disrupter (U.S. Pat. No. 4,957,027) or similar dearmer.

[0135] The CAT disrupter jet profile in cross section is similar to the jet formed by the PAN with the Reverse Velocity Jet Tamper (ReVJeT) disrupter enhancer adapter (U.S. Pat. No. 10,451,378). The CAT disrupter average jet cross sectional area is significantly larger and travels at higher velocity. Using the maximum explosive load tested, the velocity of the CAT disrupter jet tip averages five times faster than that of a PAN jet.

[0136] Several inefficiencies in mass focusing explosive shaped-charges are minimized in the design of the CAT disrupter. A dominant destructive hydrodynamic factor in all mass focusing high explosive tools is the FVG. The jet will break up into droplets or particles, thus losing the jet's effective density and its ability to transfer momentum and energy. The FVG can be explained qualitatively by dividing the jet into discrete elements. Proceeding from the rear of the jet to its front, each element is progressively faster. The rate of jet stretch increases with explosive load. The FVG can be complex and may not be linear. The jet stretches apart by this hydrodynamic stress. Atomization also occurs from the turbulence inside the jet and air drag along its front and sides. The CAT disrupter FVG is considerably reduced compared to other disrupter high explosive shaped-charges described herein. As described, further improvements are provided by attenuating body, including on the container distal surface, foam and a jet-clipper layer positioned toward the target, including adjacent the target surface.

[0137] The disrupter can also be used to drive HEET fluids (U.S. patent application Ser. No. 15/731,874 titled "High Energy Efficient Transfer Fluids" filed Aug. 18, 2017). There are experimentally demonstrated advantages which show that higher density liquids have improved penetration, notable increases in bulk work and momentum transfer and, due to their higher mass can lower jet velocities. The latter is important when impact sensitive explosives are present inside an IED. Due to the hydrodynamic characteristics of the jet, the impact pressures have a squared dependence with jet velocity. The shock Hugoniot properties of the HEET fluids also may contribute to the reduced risk of shock initiation of explosives inside an IED when they are impacted by a disrupter jet. In addition, experiments showed HEET-filled disrupters had increase performance with respect to stand off.

[0138] An initiator comprising a detonator can be coaxially seated in contact with charge apex and initiated. The resultant detonation wave shock couples into the water and shock waves move inside the fluid. Due to shock impedance at the water-container interface, the shock rarefaction waves reflect back into the water slug which can further contribute to water movement. In one embodiment of the CAT disrupter, the sidewalls of the fluid container were three times thicker than the front face and used higher density PVC compared to the front face which was made from ASA material. Tests of CAT disrupters constructed from uniformly thick ASA sidewalls and front were less efficient at penetration and impulse than the CAT disrupter embodiment using a thick PVC side wall. Provided is a method of using inertial confinement and shock impedance to increase the efficiency of the CAT disrupter. Thus, PETE plastic on the side wall can further improve the efficiency of the CAT disrupter given it is of higher density than PVC. PVC and PETE are 1.35 and 1.5 times the density of ASA, respectively. As described herein, and illustrated in FIGS. **5**-**15**, attenuating body **11**, including a plurality of attenuating body layers, such as **12 13 14**, provide for further manipulation and control of rarefaction waves.

[0139] We observed that thickening the wall on the front face of the charge and using a high strength, brittle plastic had negative effects on performance. High explosive disrupters whose front surface are made from low ultimate tensile strength and high tensile elongation plastics such as low-density polyethylene (LDPE), high density polyethylene (HDPE), or polypropylene (PP) should have better performance with respect to jet velocity, penetration and impulse. Wall thicknesses between 0.02 inches and 0.08 inches result in good performance. Brittle plastics that have similar densities to water fracture into particles that travel along with the jet and resulted in explosive initiation on impact with targets filled with common explosives. The attenuating bodies provided herein can address these issues.

[0140] Due to the normalized velocity profile of the CAT jet, a high strength, high durometer (80-95) polyurethane ball can be placed at the axial center of the shock wave dampener. The ball can be used as a jet stabilizing projectile (JSP) (U.S. Pat. Pub. No. 2021/0041205 (published Feb. 11, 2021; now U.S. Pat. No. 11,262,155, incorporated by reference herein) titled "Fluid Jet Stabilizing Projectile for Enhanced IED") and behaves similarly to the JSP used with the PAN disrupter and ReVJeT adapter. Such a ball is particularly useful for jet tip shapes that are annular, as such a shape promotes hydraulic trapping of the polyurethane ball. The polyball seats inside the hollow region of the jet and is trapped by the jet due to its flow properties. The ball causes a slip stream such that air drag is reduced around the jet tip and a low-pressure zone behind the ball will cause the water to flow forward around the rear surface of the ball creating hydraulic stabilization of its flight. The advantages of a JSP for bomb disablement is increased barrier limit thickness and the reduced surface area on impact which is known to lower shock impulse as previously described. Polyurethane has similar shock Hugoniot properties as water and thus reduces the risk of shock initiation of explosives due to shock impedance. The JSP should be 10% to 50% of the CAT container diameter to produce the air drag benefits. In comparison, Rock et al. (U.S. Pat. No. 8,677,902) propose using a small metallic bead in the apex of the hollow void (shock cavity) of their LIFT charge. They propose the small bead material to be copper, steel, lead or depleted uranium, which are at least nine times the density of water. The small bead is explosively driven forward, but does not ride the jet tip. There is an extreme forward velocity gradient in a conical LIFT and the metal bead would not behave like a JSP. The JSP can be encased in an attenuating body on the distal face of a high explosive disrupter. The attenuating body may have a recess to optionally seat a JSP. See also, U.S. Pat. No. 11,421,971 (incorporated by reference herein).

Example 3: Geometrical Configurations

[0141] In one embodiment, the shell is specially configured to have a desired geometric shape to achieve the desired functional benefits described herein with respect to a subsequently generated fluid projectile. The shaped-charges provided herein are compatible with a range of shell types and shapes. For example, more generic shapes are reflected in FIGS. **1**-**3**, with one embodiment intended to illustrate the shaped-charges can accommodate complex curvatures provided in FIGS. **4**-**15**.

[0142] In terms of geometrical shape having curvatures, FIG. **4** illustrates a truncated cone **60** geometric shape with an open distal end **70** a closed proximal end **80** having a smoothly-curved concave shape. FIGS. **5**-**15** are various embodiments to illustrate the ability to position attenuating body and/or alter material composition, including use of multilayers.

[0143] FIG. **1** further illustrates the shell can have a surface geometrical shape to provide support to a shape-conforming explosive. The devices provided herein are compatible with a range of shape-conforming explosives, including a sheet that conforms to the surface or a cord-type explosive that is laid along the shell surface. A cuboidal-shaped container **25**, for example can be the Hydrajet™ disrupter, and has a closed top **210** and a base **220**. The top **210** and base **220** face each other and are separated by a separation distance. The shell **30** is centrally positioned to the container **25** with respect to the central plane **120** and, as illustrated, can have a chevron/wedge profile which faces distally (toward a target). The distal **211** and proximal **221** container surfaces face each other (see A-A section) and are separated by a separation distance in a direction toward the target, with a stem **42** having a channel **250** operably connected to the shell **30** and, more specifically, shell surface **40**.

[0144] The position of the shell surface **40** along the central plane can be adjusted by changing the position of the shell stem **42** that accommodates channel **250** for the initiator detonator.

[0145] A channel **250** is configured to operably connect to an initiator detonator for detonating shape-confirming explosive that is at least partially mated to shell surface **40**.

[0146] The shell **30** has a specially configured surface to ensure appropriate forces on the filler (including a liquid fluid mass) **20** contained in the container interior volume **27** of the container **25** upon detonation of explosives supported by the shell surface. In an embodiment, the shell is a plastic shell. A shape-conforming explosive is positioned on the shell surface, wherein the plastic shell surface has the desired three-dimensional geometry. The plastic shell surface can be concave-shaped. The concave-shaped surface is a "catenary paraboloid", such as generally illustrated in FIG. **4**. The curve of the proximal end of the surface is superficially similar in appearance to a paraboloid, but is more accurately a smooth curve, including a portion of a spheroid or that is U-shaped and is described herein as catenary. It can be generally approximated as a surface formed from revolution of a portion of a hyperbolic cosine function. A distal portion of the shell surface **40** is a portion of a cone, referred herein as a "truncated cone".

[0147] As illustrated in FIG. **4**, the plastic shell is laterally positioned relative to the ends of the container to form a tamper length and a projectile length. The ratio of tamper length to projectile length is selected depending on the application of interest and attendant desired fluid jet characteristics, including with respect to type of target **1700**, filler or fluid mass properties, and stand-off distance **1710**.

[0148] Optionally, the shell distal end has one or more scores to facilitate, after detonation, well-controlled separation of the distal end to further reduce risk of unwanted detonation.

[0149] Various additional embodiments are illustrated in FIGS. **16-20**. FIG. **16** illustrates an embodiment where there is an air gap, illustrated as air cell, which may be a bladder filled with a gas, such as air, or a low density closed-cell foam. FIG. **17** illustrates the shaped-charges provided herein may be used in an underwater environment, with two different SMART materials positioned between the distal end of the container and the target surface (illustrated as low density SMART and high density SMART). The SMART materials may comprise foam of different densities.

[0150] FIGS. **18-19** illustrate multiple shell configurations, including for a shell to support a shape-conforming explosives (FIG. **18**) or to contain explosive volumes (FIG. **19**).

[0151] FIG. **20** illustrates use of an attenuating body layer **18** configuration to slip over a container, including a container that may also correspond to an attenuating body **11**. Of course, in certain applications the AB layer **18** may slip over a container **25** to impart desired attenuating body characteristics to a conventional container. As discussed, the layer **18** may also be used with an adhesive positioned between a container (or attenuating body) outer surface. In this manner the AB layer may not only be slipped over the surface, but may simply be brought into contact, such as by wrapping or placement of the layer(s) on the adhesive, with the adhesive positioned on desired locations of the container (or attenuating body). Layer **18** may be provided in a tight-fit configuration over the container outer surface, particularly the container sidewall(s). Layer **18** may be provided as a conformable wrap that wraps around the container sidewall.

Example 4: Fluid Jet Characteristics

[0152] FIG. **21** illustrates fluid jet **2110** (also referred herein as a filler jet) characteristics without (top panel) and with (bottom panel) attenuating body. The fluid jet (e.g., water, HEET, etc.) has improved characteristics, such as jet length (L) and jet diameter (d) by use of the attenuating body. The liquid jet can have a hollow void **1665** in the distal portion **1667** of the liquid jet or a hollow void in the interior of the liquid jet. The ability to control the jet characteristics with placement of attenuating body is an elegant platform to provide additional jet control, even for conventional shaped-charges that do not have the attenuating body. A user may position the attenuating body on a conventional shaped-charge container and obtain a significant benefit in jet performance. Of course, the attenuating body may be pre-positioned, including incorporated as part of the container wall.

Example 5: Solid Particle Filler

[0153] The devices and methods provided herein are compatible with a filler which comprises solid particles, such as solid particles that have fluid-like characteristics. The solid particles are sized and have characteristics such that they may flow under an applied shear. Accordingly, the filler may be described as being formed of fine particles. Fine refers to an average particle diameter that is sufficiently small such that the filler, as a whole, has fluid-like capabilities including flowing under an applied shear force and forming a jet from the shaped-charges described herein, and that can move in a manner so as to fill a desired volume. For example, the particles may have an average characteristic diameter that is less than or equal to 5 mm, 1 mm, 500 μm, or 40 μm. Exemplary materials from which particles may be formed include, but are not limited to, shot (e.g., S70 shot), glass, garnet, sand, ceramic, plastic, metal (e.g., copper, brass, or lead), hydrocarbons, sugar, and/or salt.

[0154] Any of the devices and methods may have a container with a built-in funnel so that solid particles may be poured into the container, including within a liner positioned in the container. The SMART devices and methods provided herein can be applied for a filler that comprises solid particles, including for liners having any of a variety of geometries that contain the solid particles, including conical-shaped, portion of a cone, linear (wedge-shaped), hemi-cylindrical; hemi-spherical; and symmetrically curved side surfaces that optionally extend from a central flat region that is a flat surface (trumpet-shaped). Because solid particles cannot withstand hoop stress or any tensor stress, and certainly not to the extent a filler that is liquid can, incorporating SMART is particularly beneficial in the context of a filler comprising fine solid particles to reduce those stresses and provide an improved jet comprising solid particles.

[0155] Provided herein are liner-based shaped charges wherein the fill comprises particles, including solid particles positioned within the liner, and/or a unitary and continuous material formed from a ductile material with a wall thickness of up to 0.25", with an attenuating body (SMART) material positioned adjacent to a distal liner surface. Use of such a SMART-liner configuration beneficially provides an increased efficiency of the shaped charges. This provides an important functional benefit of reducing the required quantity of explosives that would otherwise be needed and attendant dramatic decrease in costs. Applications include mining applications. In addition, in a breaching application, use of such a SMART-liner configuration has the added benefit of reducing or avoiding hazardous fragments from conventional breach tools that have metal skins.

[0156] FIGS. **22-25** illustrate a conical shaped charge configured for use with a filler corresponding to solid particles. FIG. **22** shows the container **25**, with the bottom panels the internal geometry of the shaped charge. The filler solid particles are positioned within a shell surface, such as corresponding to liner **2600** (FIG. **26**). As illustrated in FIGS. **23-25**, on the distal side of shell surface **40** (e.g., forming a conical volume), a SMART material attenuating body **11** is positioned. The attenuating body **11** fills the cavity that can be cone-shaped. As desired, the attenuating body may also form a seal between the shell surface (also referred in this embodiment as a shell "liner") **40** and an inner-facing surface of the container **25**. See, e.g., U.S. Pat. No. 10,683,735 (McCarthy et al.). On the proximal side of shell surface **40** an explosive material **152** is positioned, such as composition C-**4**. Filler may comprise solid particles **21** positioned within shell surface **40**. Detonator **260** provides a controlled detonation of explosive material **152**, with attenuating body **11** beneficially providing reduced tensile waves to solid particles **21** positioned in liner **40** (functionally equivalent to a shell surface as liner defines extent of explosives **152**). Detonation of explosives, in concert with SMART attenuation body **11** effectively drives filler solid particles **21** as a jet out of the distal-facing surface in a direction that is toward the bottom of the Figure.

[0157] FIG. **26** illustrates shaped charges having different liner **2600** geometries for focusing a filler comprising solid particles **2670** positioned in the liner and/or a unitary and continuous material formed from a ductile material. The liner **2600** has a distal surface **2610** that faces toward a target and a proximal surface **2620** that faces toward the proximal end of the container **25**. Liner distal surface **2610** along with container **25** surfaces define an attenuating body volume **2630** configured to contain an attenuating body **11**. In this example, the attenuating body may be a layer and/or a volume-occupying material, such as a foam, positioned adjacent to the liner distal surface **2610** and that occupies most, if not all, the attenuating body volume that is formed between the liner distal surface and the container **25** walls. Of course, as desired and depending on the application conditions and various material properties, less than all the attenuating body volume may be filled, with the remainder air-filled.

[0158] Adjacent to the liner proximal surface **2630**, explosives are positioned in the explosive volume **2640** defined by the liner proximal surface **2630** and container **25** walls. Liner distal end **2650** is sealingly connected to the container sidewall, including by attenuating body **11**, or a separate seal layer, such as a ring, positioned around the region between the liner distal end **2650** and container **25**. As desired, additional attenuating body **11***a* may be positioned adjacent to the container sidewall to further influence jet characteristics. Attenuating body **11***a* and **11** may be the same or may be a different material, such as a layer material **11***a* and a foam material for **11**. The geometry of the liner refers to the liner narrowing to a minimum distance **2660** at the proximal-most position of the liner corresponding to the minimum distance between liner and container **25** proximal end. Filler corresponding to particles **2670** are positioned in the liner, illustrated as liner volume **2675**, and may be filled via a funnel **2300** (see, e.g., FIG. **23**) connected to liner volume **2675**. Alternatively, the liner may correspond to a a unitary and continuous material formed from a ductile material, such as a metal, including but not limited to copper, steel or the like.

[0159] FIG. **26** is also intended to illustrate that this embodiment is compatible with any of variety of liner geometric shapes, including linear (top panel), symmetrically curved surfaces (second panel from top); portion of a cone (third panel from top); and hemi-cylindrical (bottom panel); hemi-spherical (bottom right panel). Of course, any of a variety of shapes may be used, with preference for a symmetric geometry, about either a symmetry line or a symmetry plane. For example, the side surface of the liner may be curved side surface(s) **2680** extending from a central region **2690** that is a flat surface.

[0160] Instead of comprising particles, the liner can alternatively comprise a unit mass of material, including a conventional classical shaped charge liner. Exemplary liners include, but are not limited to, a shaped sheet of a ductile materials, such as copper, steel, or the like, of defined wall thickness up to 0.25".

Example 6: Propellant Driven Disrupters with Attenuating Body Plug

[0161] An AB can be used as the breech (e.g., chamber) plug and as the muzzle plug of a gun disrupter, namely a propellant-driven liquid disrupter. In this manner, a plug formed of an AB material can be used as a shock decoupler between the water column in the barrel and the explosive cartridge, including a blank cartridge, used to propel water out of the barrel in a water jet. Such disrupter platforms generate waves that can adversely impact and even destroy the water jet, as confirmed by high-speed video and in flash X-ray. See, e.g., U.S. Pat. Nos. 10,451,378 and 10,760,872, describing a ReVJeT device useful in enhancing liquid jet parameters. Addressing and avoiding pressure waves are beneficial. When the pressure wave arrives at a water-air interface, it reflects back into the water column as a rarefaction wave (tensor wave). It has the same damaging effect, but to a lesser degree, than the high explosives generated rarefaction waves. Any time there is a transition of a high impedance material (water) to an extremely low impedance material (air) the reflected wave pressure amplitude changes sign. Thus, when the rarefaction wave arrives at the proximal (chamber side) of the water column, it reflects back into the water as a compressive wave. We see the effect as rings of water spraying radially because water cannot withstand hoop stress. The damaging pressure waves are even more pronounced in shorter barrels.

[0162] The AB (e.g., SMART material) attenuates the explosive wave at the proximal end of liquid in the disrupter barrel and then the AB positioned at the muzzle end of the disrupter barrel further attenuates the reflected wave at the distal side of the water column, in a manner similar to that explained in the earlier examples related to the high explosive shaped charges. The tensor wave amplitude is lower.

[0163] In conventional systems having a breech plug that is not an AB, the non-AB plug, due to the muzzle blast, appears to be driven up through the center of the water column of the water jet. It is similar to driving a nail through the middle of the water column, with the result being that the water column is hollowed out. In contrast, a plug formed of an AB, such as a foam material, will break up and atomize. This avoids the problem of a conventional non-AB plug that is driven up the center of the water column and thus degrades and even destroys it and adversely impacts a desired jet parameter useful for target disruption. This reflects the fact that a "tube" of water has much less penetration than a "rod" of water.

[0164] In addition, to the advantages of using an AB described for the above mass focusing shaped charges, specially configured and positioned AB provides important functional benefits for water cannons, described herein as a propellant driven disrupters that explosively drive a jet of liquid from a barrel to a target. Referring to FIGS. **27-32**, a propellant driven disrupter **2700** has a bore **2710**, bore proximal end **2720** and bore distal end **2730** (that faces toward a target), with a bore length of distance L separating the bore distal and proximal ends. Breech **2740** and breech chamber **2742** are operably connected to the barrel proximal end, such that a blank cartridge **2745** can be positioned in the breech chamber. More generally, there is an explosive driven means positioned toward the proximal end of the bore to explosively drive a fluid **2750** that at least partially fills the bore. Attenuating body (AB) breech plug **2760** and muzzle plug **2770** are positioned toward the proximal and distal ends of the barrel, respectively. For example, the plugs may be positioned at the distal and proximal ends of the barrel. Of course, the disrupter tolerates some variation in the exact positions, including, for example, up to 10% deviation from the ends (relative to barrel length, L).

[0165] Breech plug AB can have any of a variety of geometries, including but not limited to, a geometry that is a half-capsule **2761** (FIG. **29**), a right angle cylinder **2762** (FIG. **30**), or contoured **2763** (FIG. **31**) to conform to the chamber, optional forcing cone **2743** and bore, each with a flat base **2765** that is adjacent to a distal end **2746** of the blank cartridge. FIG. **32** illustrates scores or notches **2766** in the AB, to facilitate controlled breakage of the AB upon explosive ignition of blank cartridge. In this manner, the AB does not adversely impact jet formation or risk unwanted interaction with explosive target; instead, the AB can split apart from the jet, including in an outward radial direction relative to jet centerline. The scores or notches have a depth sufficient to ensure that after explosion of the cartridge to propel liquid out of the barrel, the plug breaks apart away from the liquid jet column to thereby ensure there is no adverse impact on liquid jet parameter, such as amount of liquid in the jet, jet length, jet velocity, penetration depth and the like. This controlled break-away and separation of the AB plug is generally described herein as a frangible plug **2767**. Similarly, a light weight, crushable/pulverizable AB plug may be used that will not be rammed up the center of the water column that is explosively driven out of the barrel muzzle end.

[0166] FIG. **27** illustrates an AB muzzle plug and breech plug between which water is contained. The AB muzzle plug reduces rarefaction waves and the AB breech plug reduces primary shock. Preferred AB material properties for the plug embodiments include a density between 1 lb/ft^3 and; 6 lb/ft^3 and a material that is foam; crushable and frangible rigid closed cell foam or flexible compressible closed cell foam; optional materials: rigid or flexible polyurethane foam, synthetic rubber, polyethylene foam, or neoprene.

[0167] FIG. **28** illustrates exemplary AB plug position in relation to water and blank cartridge, with breech plug geometries that is half-capsule **2761** and right-angle cylindrical **2762**. The AB's positioned at distal end (e.g., muzzle plug AB **2770**) and proximal end (e.g., breech plug **2760**) fluidically seal the bore and prevent leakage of liquid positioned in the bore **2710** barrel. For clarity, the top panel is a view with the barrel removed from view, and the middle and lower panels are sectioned view of the top panel.

[0168] FIG. **29** illustrates a functional benefit of the AB plug, including a half-capsule breech plug geometry **2761**, to disperse primary shock produced by propellant explosion. Arrows indicate planar shock front dispersed radially causing exponential drop with distance from the water **2750** AB **2761** boundary. Shock wave crests are represented as lines as the shock front approaches the explosive gas boundary.

[0169] A cylindrical **2762** (right-angle) AB plug is illustrated in FIG. **30**, including a proximal (face toward distal end of blank cartridge) end that is a flat base **2765** configured to be adjacent to the distal end of the blank cartridge. FIG. **31** is an example of a contoured geometry **2763** breech plug where the proximal portion **2764** of the AB is contoured to tightly seal forcing cone (optionally present) and bore. The flat base **2765** is adjacent to blank cartridge, with a taper in the forcing cone region that partially extends into the bore.

[0170] The invention is compatible with use of at least one of an AB muzzle plug and AB breech plug. For example, the AB muzzle plug could instead be a JSP, including any of the JSP's provided in U.S. Pat. No. 11,262,155, which is specifically incorporated by reference herein for the JSP geometry, compositions, and uses.

[0171] FIG. **32** illustrates a frangible plug **2767** having scores or notches **2766** to facilitate controlled fracturing of the AB after explosive detonation of explosives in the blank cartridge that drives a column of water out of the barrel. The controlled fracturing of frangible breech plug avoids or minimizes any impact of the breech plug on jet parameter and/or avoids or minimizes unwanted impact of plugs on a target. This is relevant because flash X-ray imagery shows a standard breech plug that is driven up the explosively propelled water jet column. The jet hollows and disperses radially from the rear as the breech plug progresses to the jet tip. The jet shrinks. A frangible AB plug **2767** that fractures is able to separate from the water jet column at the time of barrel exit, thereby avoiding adverse impact on the water jet column. In this aspect, a "score" or "notch" refers to a disturbance in the outer-facing surface of the AB plug, such as line(s) or removed material extending in a longitudinal direction between the proximal and distal ends of the AB, the distal surface and/or the proximal surface. The depth of the disturbance is dependent on the application of interest, including the AB material, the liquid composition and/or distance to target. In general, the deeper the score, the more readily the AB material breaks apart. This is, of course, balanced by ensuring the AB continues to provide sufficient functional benefit with respect to fluidic seal and primary shock dispersal. The frangible plug may comprise ceramic microbubbles, such as a hollow-plug having an interior volume filled with ceramic microbubbles. More generally, the interior volume of any of the plugs may contain microparticles (e.g., average diameter less than 1 mm, less than 500 μm, less than 100 μm, and less than 25 μm. An AB plug can provide an increase in up to 50% penetration compared to use of non-AB plugs.

STATEMENTS REGARDING INCORPORATION BY REFERENCE AND VARIATIONS

[0172] All references throughout this application, for example patent documents including issued or granted patents or equivalents; patent application publications; and non-patent literature documents or other source material; are hereby incorporated by reference herein in their entireties, as though individually incorporated by reference, to the extent each reference is at least partially not inconsistent with the disclosure in this application (for example, a reference that is partially inconsistent is incorporated by reference except for the partially inconsistent portion of the reference).

[0173] The terms and expressions which have been employed herein are used as terms of description and not of limitation, and there is no intention in the use of such terms and expressions of excluding any equivalents of the features shown and described or portions thereof, but it is recognized that various modifications are possible within the scope of the invention claimed. Thus, it should be understood that although the present invention has been specifically disclosed by preferred embodiments, exemplary embodiments and optional features, modification and variation of the concepts herein disclosed may be resorted to by those skilled in the art, and that such modifications and variations are considered to be within the scope of this invention as defined by the appended claims. The specific embodiments provided herein are examples of useful embodiments of the present invention and it will be apparent to one skilled in the art that the present invention may be carried out using a large number of variations of the devices, device components, methods steps set forth in the present description. As will be obvious to one of skill in the art, methods and devices useful for the present methods can include a large number of optional composition and processing elements and steps.

[0174] As used herein and in the appended claims, the singular forms "a", "an", and "the" include plural reference unless the context clearly dictates otherwise. Thus, for example, reference to "a cell" includes a plurality of such cells and equivalents thereof known to those skilled in the art. As well, the terms "a" (or "an"), "one or more" and "at least one" can be used interchangeably herein. It is also to be noted that the terms "comprising", "including", and "having" can be used interchangeably. The expression "of any of claims XX-YY" (wherein XX and YY refer to claim numbers) is intended to provide a multiple dependent claim in the alternative form, and in some embodiments is interchangeable with the expression "as in any one of claims XX-YY."

[0175] When a group of substituents is disclosed herein, it is understood that all individual members of that group and all subgroups, are disclosed separately. When a Markush group or other grouping is used herein, all individual members of the group and all combinations and subcombinations possible of the group are intended to be individually included in the disclosure.

[0176] Every device, system, formulation, combination of components, or method described or exemplified herein can be used to practice the invention, unless otherwise stated.

[0177] Whenever a range is given in the specification, for example, a temperature range, a time range, or a composition or concentration range, all intermediate ranges and subranges, as well as all individual values included in the ranges given are intended to be included in the disclosure. It will be understood that any subranges or individual values in a range or subrange that are included in the description herein can be excluded from the claims herein.

[0178] All patents and publications mentioned in the specification are indicative of the levels of skill of those skilled in the art to which the invention pertains. References cited herein are incorporated by reference herein in their entirety to indicate the state of the art as of their publication or filing date and it is intended that this information can be employed herein, if needed, to exclude specific embodiments that are in the prior art. For example, when composition of matter are claimed, it should be understood that compounds known and available in the art prior to Applicant's invention, including compounds for which an enabling disclosure is provided in the references cited herein, are not intended to be included in the composition of matter claims herein.

[0179] As used herein, "comprising" is synonymous with "including," "containing," or "characterized by," and is inclusive or open-ended and does not exclude additional, unrecited elements or method steps. As used herein, "consisting of" excludes any element, step, or ingredient not specified in the claim element. As used herein, "consisting essentially of" does not exclude materials or steps that do not materially affect the basic and novel characteristics of the claim. In each instance herein any of the terms "comprising", "consisting essentially of" and "consisting of" may be replaced with either of the other two terms. The invention illustratively described herein suitably may be practiced in the absence of any element or elements, limitation or limitations which is not specifically disclosed herein.

[0180] One of ordinary skill in the art will appreciate that starting materials, biological materials, reagents, synthetic methods, purification methods, analytical methods, assay methods, and biological methods other than those specifically exemplified can be employed in the practice of the invention without resort to undue experimentation. All art-known functional equivalents, of any such materials and methods are intended to be included in this invention. The terms and expressions which have been employed are used as terms of description and not of limitation, and there is no intention that in the use of such terms and expressions of excluding any equivalents of the features shown and described or portions thereof, but it is recognized that various modifications are possible within the scope of the invention claimed. Thus, it should be understood that although the present invention has been specifically disclosed by preferred embodiments and optional features, modification and variation of the concepts herein disclosed may be resorted to by those skilled in the art, and that such modifications and variations are considered to be within the scope of this invention as defined by the appended claims.

1. A shaped-charge for focusing a filler comprising:

a container having an interior volume formed from a container surface to contain a shell and the filler, the container surface having a container distal surface, a container proximal surface, and a container sidewall connecting the container distal surface and the container proximal surface;

a shell having a surface with a geometric shape configured to support a shape-conforming explosive or contain an explosive volume, wherein the geometric shape has a central longitudinal axis or a bisecting symmetry plane and the shell surface has:

a shell distal end;

a shell proximal end that faces the container distal end;

a shell sidewall that connects the shell distal end to the shell proximal end for the shell that contains the explosive volume;

an attenuating body connected to or forming at least a portion of the container surface, the attenuating body having an attenuating body thickness of between 0.03" and 2";

wherein the shell longitudinal axis or bisecting symmetry plane is longitudinally aligned or centrally positioned relative to the

attenuating body and the corresponding container surface;

an initiator contact point connected to the shape conforming explosive or the explosive volume configured to initiate detonation of the shape conforming explosive or the explosive volume;

wherein the attenuating body has an attenuating body parameter configured to provide reflected shock wave attenuation after detonation of the shape-conforming explosive or the explosive volume and explosively drive filler from the interior volume of the container toward a target as a filler jet.

2. The shaped-charge of claim **1**, wherein the filler comprises a fluid mass and/or a granular solid.

3. The shaped-charge of claim **1**, wherein the filler comprises water, metal shot, steel shot, copper shot, lead shot, ceramic particles, garnet, salt, hydrocarbon, glass, sand or a HEET fluid.

4. The shaped-charge of claim **1**, wherein the container is formed of the attenuating body.

5. The shaped-charge of claim **1**, wherein the attenuating body parameter is selected from the group consisting of attenuating body thickness, material composition, bulk density, heterogeneity, geometry, one of the shock Hugoniot parameters such as bulk speed of sound or 's' number, location on the container surface, and any combination thereof.

6. The shaped-charge of claim **1**, wherein the attenuating body is formed of a material selected from the group consisting of: plastic; foam; wood; clay; wax; rubber (natural or synthetic); aerogel; and any combination thereof.

7. The shaped-charge of claim **1**, wherein the attenuating body is connected to:

at least a portion of the container sidewall;

at least a portion of the container distal end;

at least a portion of the container proximal end; or

the container sidewall, the container distal end, and the container proximal end, to cover the container surface.

8. The shaped-charge of claim **1**, comprising a plurality of shells.

9. The shaped-charge of claim **1**, wherein the shell is formed of a plastic material and the geometric shape comprises:

a truncated cone having an open distal end and a closed proximal end,

the closed proximal end having a smoothly-curved concave shape;

wherein the geometric shape is axially-symmetric about a central longitudinal axis.

10. The shaped-charge of claim **1**, wherein the attenuating body comprises an AB layer that at least partially covers the container distal surface, including an inner-facing and/or an outer-facing surface of the container distal surface.

11. The shaped-charge of claim **1**, wherein the attenuating body is an AB layer positioned in the container volume and occupies a fraction of the container volume, wherein the AB layer is sealingly connected to the container.

12. The shaped-charge of claim **1**, further comprising a second attenuating body corresponding to an AB layer having an AB layer thickness connected to an outer surface or an inner surface of the attenuating body, including container sidewall, wherein the sum of the AB layer thickness and the attenuating body thickness is between 0.25" and 1.5".

13. The shaped-charge of claim **1**, wherein the attenuating comprises an AB layer formed from: natural rubber; silicone, Teflon™, neoprene, sorbothane, nitrile PVC, vinyl or polyurethane.

14. The shaped-charge of claim **1**, wherein the attenuating body comprises a multilayer.

15. The shaped-charge of claim **1**, wherein the attenuating body is configured to:

slip over an outer surface of the container;

adhere to an outer surface of the container with an adhesive layer positioned between the liner and the outer surface of the attenuating body; and/or

wrap around an outer surface of the container.

16. The shaped-charge of claim **1**, wherein the attenuating body thickness spatially-varies.

17. The shaped-charge of claim **1**, wherein the attenuating body:

at least partially covers the container sidewall;

at least partially covers the container proximal end;

at least partially covers the container distal end and has a spatially-varying thickness;

at least partially covers the container distal end and has a spatially-constant thickness;

at least partially covers the container sidewall and the container distal end;

covers the entire container surface;

covers the entire shell surface; or

any combination thereof.

18. The shaped-charge of claim **1**, further comprising:

a foam having a density less than 0.5 g/cm^3 positioned to fill a gap between the shaped-charge and a target, wherein the foam reduces water gasification and reduces a liquid jet forward velocity gradient; and/or

a jet clipper layer adjacent or in contact with a target surface, wherein the jet clipper layer has a density of between 0.5 g/cm^3 to 2 g/cm^3.

19. A method of explosively driving a filler to disrupt a target, the method comprising the steps of:

providing the shaped-charge of claim **1** with the filler positioned in the interior volume, wherein the shell and explosive is immersed in the filler;

aligning the shaped-charge with a target;

initiating detonation of the shape-conforming explosive or the explosives volume to initiate a detonation wave that travels substantially parallel to the longitudinal axis or bisecting plane, wherein the geometric shape and position of the shell and the attenuating body are configured to generate a tamp and timing of rarefaction waves to increase a pressure duration and amplitude to drive the filler as the filler jet toward the explosive target and increase a bulk mass of the filler jet;

thereby disrupting the target.

20. The method of claim **19**, further comprising the step of adjusting a jet characteristic of the filler jet by adjusting an attenuating body characteristic without changing a shaped-charge geometry or filler container geometry.

21. The method of claim **20**, further comprising the step of positioning the attenuating body on the shaped-charge at an incident site, wherein the positioning comprises slipping and/or adhering the attenuating body that is a liner to an outer surface of the container.

22. The method of claim **19**, further comprising the step of:

applying a jet-clipper layer having a density of between 0.5 g/cm^3 to 2.0 g/cm^3 on or adjacent to a barrier surface of the explosive target; and/or applying a foam having a density less than 0.25 g/cm^3 to at least partially fill a gap between the container distal surface and the explosive target.

23. A shaped-charge for focusing a filler comprising:

a container having an interior volume formed from a container surface to contain an explosive, the filler, and an attenuating body; the container surface having a container distal surface, a container proximal surface, and a container sidewall connecting the distal surface the proximal surface;

a liner positioned in the container volume, the liner having a distal surface and a proximal surface, wherein:

the distal surface defines an attenuating body volume configured to contain the attenuating body;

the proximal surface defines an explosive volume configured to contain the explosive;

the liner has a geometric shape that at a distal end is sealingly connected to the container sidewall and tapers to a minimum distance toward the container proximal surface:

the filler comprising: particles positioned in the liner between the liner distal surface and the liner proximal surface; and/or a unitary and continuous material formed from a ductile material;

wherein the attenuating body has an attenuating body parameter configured to provide reflected shock wave attenuation after detonation of the explosives to explosively drive the particles from the interior volume of the container.

24. (canceled)

25. A propellant driven fluid disrupter comprising:

a barrel having a bore with a barrel proximal end and a barrel distal end;

a breech chamber operably connected to the barrel proximal end

a fluid at least partially filling the bore;

at least one or both of :

an AB breech plug positioned toward the barrel proximal end, such that the fluid extends from the AB breech plug toward the barrel distal end;

an AB muzzle plug positioned at the barrel distal end, wherein the AB muzzle plug and the AB breech plug that are both present fluidically seal the fluid in the barrel between the AB muzzle plug and the AB breech plug;

a blank cartridge positioned in the breech chamber and facing the attenuating body breech plug when present;

wherein: the AB breech plug has one or more attenuating body breech plug material properties configured to reduce primary shock and the AB muzzle plug has one or more attenuating body muzzle plug material properties to reduce rarefaction waves upon detonation of explosives in the blank cartridge.

26. (canceled)

27. (canceled)

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