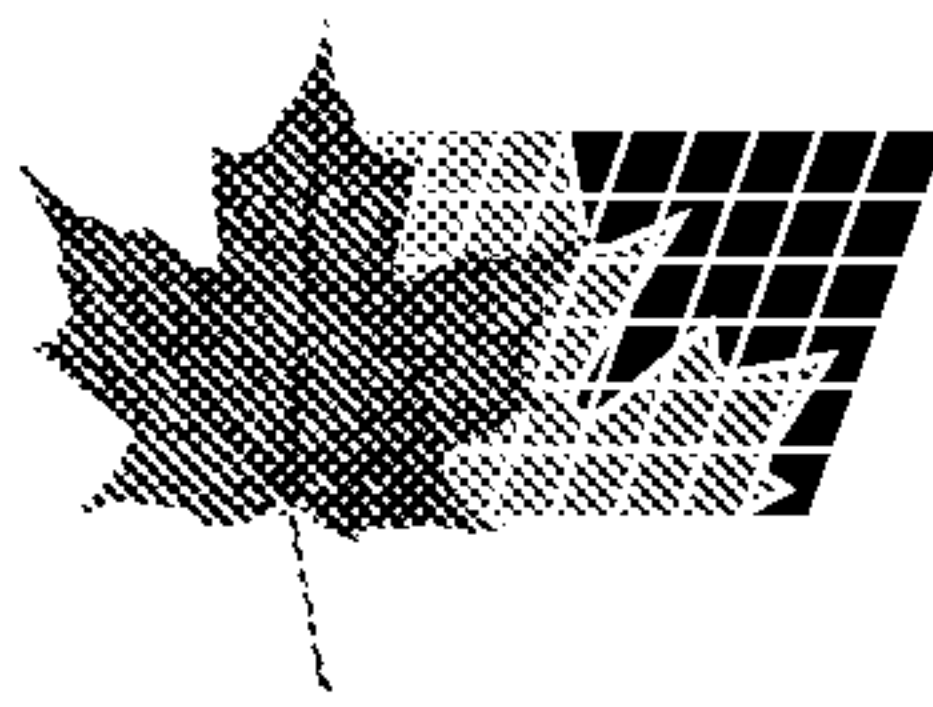




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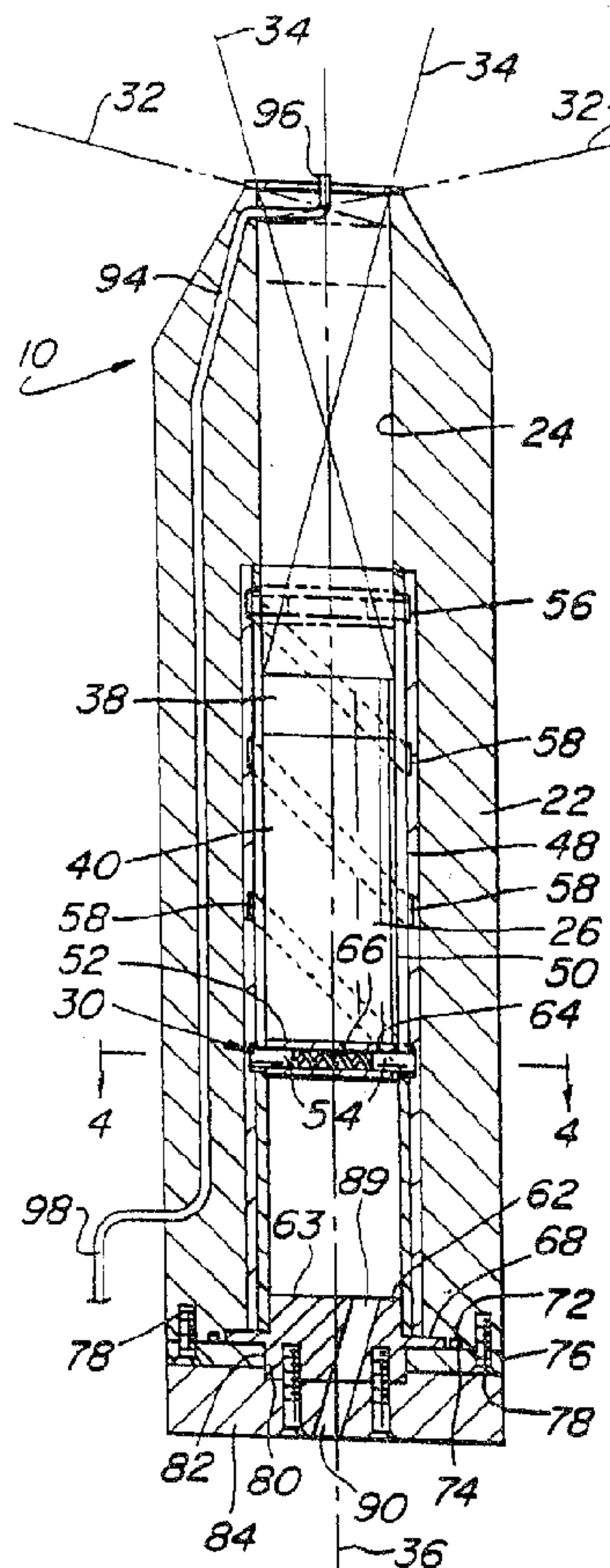
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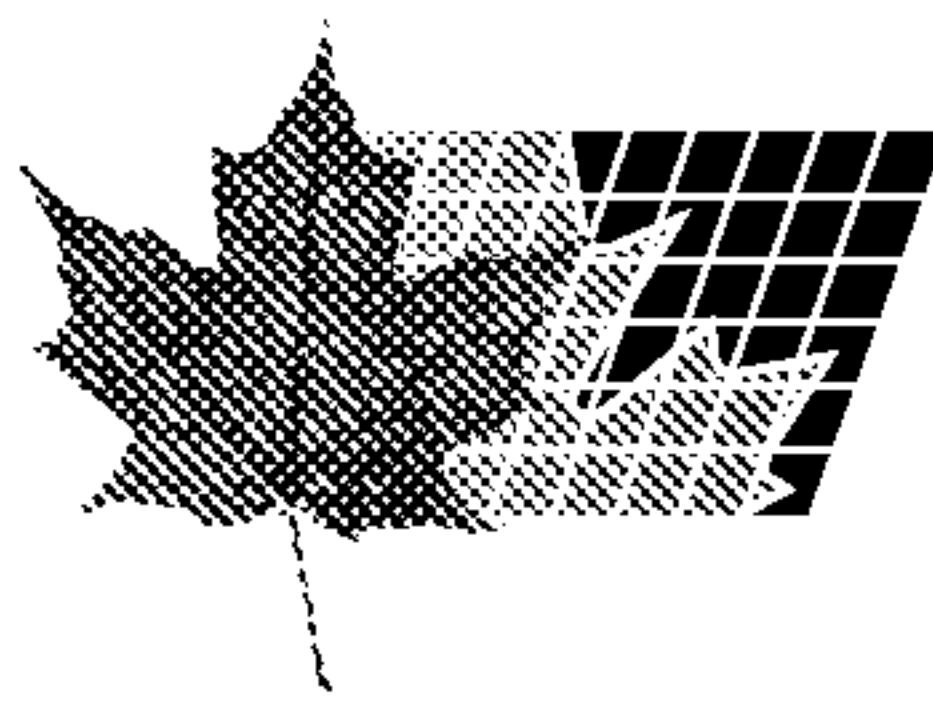
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(54) **APPAREIL POUR LA DETECTION, LA LOCALISATION ET LA
VISUALISATION DU RAYONNEMENT DANS LES SYSTEMES
BIOLOGIQUES**

(54) **APPARATUS FOR DETECTING, LOCALIZING, AND IMAGING
OF RADIATION IN BIOLOGICAL SYSTEMS**





(11) (21) (C) **2,060,307**
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(57) Des sondes collimatrices (10, 20, 100, 200, 300, 400 et 500) et des sondes (720 et 1100) associées à des collimateurs (800, 900 et 1000) servent à détecter, à localiser et à tracer ou mettre en images des rayonnements émanant d'une source cachée, par exemple située dans le corps d'un être vivant. Une sonde collimatrice ajustable en continu (10) comprend un détecteur de rayonnements (26) et un mécanisme d'ajustement en continu (30) de l'angle solide que les rayonnements peuvent traverser jusqu'au détecteur. Un récipient (600) soutient un spécimen sur la sonde. Des sondes non ajustables (720 et 1100) sont utilisées avec des collimateurs (800, 900 et 1000) séparés faciles à assujettir. Lorsque l'on utilise un tel collimateur avec la sonde, on peut ajuster l'angle solide d'acceptation de la sonde d'au moins un incrément discret.

(57) Collimating probes (10, 20, 100, 200, 300, 400, and 500) and probes (720 and 1100) and associated collimators (800, 900 and 1000) for detecting, localizing, and mapping or imaging radiation emanating from a hidden source, such as within the body of a living being. One continuously adjustable collimating probe (10) comprises a radiation detector (26) and an adjustment mechanism (30) for continuously adjusting the solid angle which radiation may pass to the detector. A receptacle (600) is also provided to hold a specimen on that probe. Non-adjustable probes (720 and 1100) adapted to be used with separate, readily securable, collimators (800, 900 and 1000) are also provided. When any such collimator is used on the probe it enables the adjustment of the probe's solid angle of acceptance in at least one discrete increment.

APPARATUS FOR DETECTING, LOCALIZING, AND
IMAGING OF RADIATION IN BIOLOGICAL SYSTEMS

ABSTRACT

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Collimating probes (10, 20, 100, 200, 300, 400, and 500) and probes (720 and 1100) and associated collimators (800, 900 and 1000) for detecting, localizing, and mapping or imaging radiation emanating from a hidden source, such as within the body of a living being. One continuously adjustable collimating probe (10) comprises a radiation detector (26) and an adjustment mechanism (30) for continuously adjusting the solid angle which radiation may pass to the detector. A receptacle (600) is also provided to hold a specimen on that probe. Non-adjustable probes (720 and 1100) adapted to be used with separate, readily securable, collimators (800, 900 and 1000) are also provided. When any such collimator is used on the probe it enables the adjustment of the probe's solid angle of acceptance in at least one discrete increment.

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APPARATUS FOR DETECTING, LOCALIZING, AND
IMAGING OF RADIATION IN BIOLOGICAL SYSTEMS

BACKGROUND ART

This invention relates generally to apparatus for detecting radiation, and more particularly to collimating probes for detecting, localizing, and imaging or mapping of radiation in biological systems or other systems.

It is now becoming an established modality in the diagnosis and/or treatment of certain diseases, e.g., cancer, to introduce monoclonal antibodies tagged with a radioactive isotope (e.g., Iodine 125) into the body of the patient. Such monoclonal antibodies tend to seek out particular tissue, such as the cancerous tissue, so that the gamma radiation emitted by the isotope can be detected by some apparatus, e.g., a CAT scanner, to provide information and/or an image of the radiation emitting tissue.

Hand-held radiation detecting probes have been used in the operating room to assist the surgeon in detecting and localizing the presence of radioactively tagged tissue within the body of the patient. Such a probe is disposed or held adjacent portion of the patient's body where the cancerous tissue is suspected to be in order to detect if any radiation is emanating from that site, thereby indicating that cancerous tissue is likely to be found there. In order to expeditiously localize the source of radiation detected by the probe collimators have been used to adjust, e.g., reduce, the solid angle (cone) in which radiation can be received or accepted by the probe's detector. Such probes/collimators do not provide optimum performance since they do not permit continuous varying of the solid angle of acceptance of the radiation. In some cases continuous adjustment of the probe's solid angle of acceptance is not required.

OBJECTS OF THE INVENTION

It is a general object of this invention to provide a collimating probe and methods of use which overcome the disadvantages of the prior art.

It is a further object of this invention to provide a collimating probe whose solid angle of acceptance can be varied continuously throughout a range defined by maximum and minimum predetermined angles.

It is still a further object of this invention to provide a continuously adjustable collimating probe which is easy to use.

It is yet a further object of this invention to provide a continuously adjustable collimating probe which is simple in construction.

It is yet a further object of this invention to provide methods of use of a continuously adjustable collimating probe for effecting the detection, localization, mapping or imaging of a hidden source of radiation in biological or other applications.

It is a further object of this invention to provide a probe and an associated collimator which may be readily secured thereto to establish at least one predetermined, lesser solid angle of acceptance of radiation from a source being examined than if no such collimator were utilized.

It is still a further object of this invention to provide a collimator which may be readily secured to a conventional radiation detecting probe to establish at least one predetermined, lesser solid angle of acceptance of radiation from a source being examined than if no such collimator were utilized.

It is yet a further object of this invention to provide a collimator which includes simple, yet efficient and reliable means for enabling it to be readily secured to a radiation detecting probe to establish at least one predetermined, lesser solid angle of acceptance of radiation from a source being examined than if no such collimator were utilized.

SUMMARY OF THE INVENTION

These and other objects of this invention are achieved by providing a collimating probe for detecting,

localizing, mapping or imaging radiation emanating from a hidden source, e.g., within the body of a living being.

The collimating probe comprises a small probe body formed of a radiation blocking material and arranged to be held adjacent the hidden source, radiation detecting means located within the probe body, window means confronting the detecting means through which radiation may pass, and adjustment means for adjusting the solid angle which radiation may pass through the window means to the detecting means. The solid angle is continuously variable between a predetermined maximum angle and a predetermined minimum angle and vice versa, whereupon the only radiation reaching the detecting means is that which is within the solid angle.

In accordance with one method the probe is disposed so that the window means is generally adjacent the hidden source to enable the detection of any radiation within the solid angle. The probe is moved until the detector detects such radiation. The adjustment means is adjusted to reduce the solid angle and the probe again moved until the detector detects such radiation. That process is repeated until the adjustment means is at or close to the minimum solid angle, whereupon the probe is located confronting the source of radiation, thereby precisely identifying its location.

In accordance with another aspect of this invention there is provided a probe having a body formed of a radiation blocking material, radiation detecting means located within the probe body, and a first radiation transparent, closed window located at the distal end of the probe body and confronting the detecting means through which radiation may pass in a first solid angle of acceptance.

A collimator is provided and is arranged when releasably mounted on the probe to decrease the first solid angle of acceptance of radiation through the window to the detecting means. The collimator comprises a cylindrical member formed of a radiation blocking material having a cylindrical bore extending therethrough and into which the distal end of the probe body is arranged to be inserted. The bore includes

an air vent communicating with the ambient atmosphere, at least one holding means (e.g., an annular recess extending about the inner periphery of the bore), and a resilient locking member (e.g., O-ring) located at the holding means. The bore also has a distal end at which a second radiation transparent, closed window is located.

The probe includes a recess extending about its outer periphery closely adjacent the distal end of the body for receipt of the resilient locking member to releasably secure the collimator to the probe when the distal end of the probe body is inserted into the bore in the collimator. The air vent enables air trapped between the distal end of the probe body and the collimator to vent to the ambient atmosphere.

BRIEF DESCRIPTION OF THE DRAWINGS

Other objects and many attendant features of this invention will become readily appreciated as the same becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawings wherein:

Fig. 1 is a plan view of one embodiment of a collimating probe utilizing one type of collimating technique constructed in accordance with this invention;

Fig. 2 is an enlarged sectional view taken along line 2-2 of Fig. 1;

Fig. 3 is an exploded perspective view of the probe shown in Fig. 2;

Fig. 4 is a sectional view taken along line 4-4 of Fig. 2;

Fig. 5 is a sectional view, similar to that of Fig. 2, but showing an alternative embodiment of the collimating probe of Fig. 1;

Figs. 6A and 6B are sectional views, at different collimation settings, of another alternative embodiment of a collimating probe utilizing a second collimating technique constructed in accordance with this invention;

Fig. 7 is a sectional view, similar to that of Fig. 2, but showing yet another alternative embodiment of a

collimating probe utilizing that second collimating technique constructed in accordance with this invention;

Fig. 8 is a sectional view of a portion of the embodiment shown in Fig. 7 but at a different collimation setting than that of Fig. 7;

Fig. 9 is a sectional view taken along line 9-9 of Fig. 7;

Fig. 10 is a sectional view, similar to that of Fig. 2, but showing still a further alternative embodiment of a collimating probe utilizing the second collimating technique constructed in accordance with this invention;

Fig. 11 is a sectional view of a portion of the embodiment shown in Fig. 10 but at a different collimation setting than that of Fig. 10;

Fig. 12 is a sectional view, similar to that of Fig. 2, but showing still a further alternative embodiment of a collimating probe utilizing a third collimation technique constructed in accordance with this invention;

Fig. 13 is a sectional view of a portion of the embodiment shown in Fig. 12 but at a different collimation setting than that of Fig. 12;

Fig. 14 is a sectional view taken along line 14-14 of Fig. 12;

Fig. 15 is a sectional view taken along line 15-15 of Fig. 13;

Fig. 16 is an enlarged perspective view of one portion of the probe of Fig. 12 shown in the condition as it is arranged in Fig. 12;

Fig. 17 is an enlarged perspective view of the portion of the probe shown in Fig. 16 but in the condition as it is arranged in Fig. 13;

Fig. 18 is a sectional view, similar to that of Fig. 2, but showing still a further alternative embodiment of a collimating probe utilizing the third collimation technique constructed in accordance with this invention;

Fig. 19 is a sectional view taken along line 19-19 of Fig. 18;

Fig. 20 is an enlarged plan view, partially in section, of an accessory for use with any of the collimating probes of this invention shown releasably secured to one such probe;

Fig. 20A is a perspective view of a specimen cup insert for use with the accessory shown in Fig. 20.

Fig. 21 is sectional view of another radiation detecting probe and an associated collimator constructed in accordance with the teachings of this invention;

Fig. 22 is a sectional view taken along line 22-22 of Fig. 21;

Fig. 23 is a partial sectional view of another embodiment of a probe and collimator constructed in accordance with the teachings of this invention; and

Fig. 24 is a view similar to that of Fig. 23 but showing yet another embodiment of a probe and collimator constructed in accordance with this invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to various figures of the drawing where like reference numerals refer to like parts there is shown at 10 in FIG.1 one embodiment of a collimating probe constructed in accordance with this invention. That probe, like all the other probes to be described herein, is arranged to detect the presence of radiation emanating from a hidden source (not shown), such as tissue tagged with a radioactive isotope, and to provide electrical output signals indicative thereof via a cable or wiring harness 12 to a conventional analyzer 14 or other conventional monitoring or imaging apparatus (not shown).

As will be described in considerable detail later the collimating probe 10 includes a radiation detector, of any suitable conventional type, and collimating means to establish the field of view of the probe, i.e., the solid angle of acceptance of the probe's radiation detector. In accordance with one aspect of this invention the collimating means is continuously adjustable to enable the user to readily establish any solid angle of acceptance between a maximum predetermined

angle and a minimum predetermined angle that radiation can be accepted by the probe's radiation detector.

Moreover, all of the probes of this invention provide significant shielding for radiation from all directions other than that within the solid angle of acceptance by virtue of the materials used and the shape and organization of the probe's components. Thus, the probes of this invention can be used with high energy radioisotopes, such as Indium 111.

The probe 10 shown in Figs. 1-4 basically comprises a probe body 22 of a generally cylindrical shape and size to be readily held in one's hand. The body 22, as well as other portions of the probe, to be described later, are formed of any suitable radiation blocking material, such as a tungsten alloy sold under the designation MIL-T-210140D by Teledyne Powder Alloys of Clifton, NJ 07012. The probe's body 22 includes a central passageway or internal bore 24 in which a conventional radiation detector 26 is located. The distal or free end of the probe's body 22 which is contiguous with the bore 24 defines a window 28 through which radiation is received when the probe is aimed at the suspected source of radiation. In the interests of preventing moisture or debris from gaining ingress into the bore and the detector located therein the window 28 is in the form of a very thin (0.025 mm) sheet of any suitable radiation transmissive material, e.g., beryllium. If desired, however, the window 28 may be open.

Also located within the probe body 22 is an adjustment assembly 30 for extending and retracting the detector 26 within the bore 24 toward and away from the window 28. In the extended position shown by the phantom lines of Fig. 2 the detector is positioned to detect radiation entering the window 28 within the maximum solid angle of acceptance shown by the phantom lines 32. When the detector 26 is retracted from the window to the position shown by the solid lines it can only receive radiation entering the window within the minimum solid angle of acceptance (shown by the solid lines designated as 34 in Fig. 2). The movement of the detector 26 within the probe body by the adjustment means 30 is along the

central longitudinal axis 36 of the bore and is effected by the rotation of a knob portion of the probe with respect to the probe body 22 about axis 36, as will be described later. The adjustment means 30 is constructed and arranged to move the detector to any longitudinal position along the axis 36 between the fully retracted position and the fully extended position described heretofore.

In accordance with one, exemplary, preferred embodiment of the invention the ratio of the angle of acceptance between the minimum and maximum is 4 to 1. Accordingly, the distal or window end of the probe is located approximately 25 mm from a source of radiation and the adjustment means has moved the detector within the internal bore 24 to the extended position, radiation can be received from any source within the circle A (Fig. 1) centered about the axis 36 and which circle has an area of approximately 1400 sq. mm. When the adjustment means is adjusted to move the detector the retracted position the area of the circle B (Fig. 1) from which radiation can be accepted is approximately 350 sq. mm.

It should be appreciated that when the collimating probe is set for its maximum angle of acceptance, the device is in its maximum sensitivity mode. Thus, in the exemplary embodiment described heretofore at the widest collimation setting the probe is four times as sensitive as when the collimation setting is at its narrowest solid angle of acceptance. The ability to continuously adjust the collimation, and hence the sensitivity, within this relatively large range enables the probe to be used effectively at any time during a relatively long period of time after the isotope is injected or introduced into the patient.

The detector 26 can take various forms. One preferred embodiment comprises a radiation detecting crystal 38, such as a cadmium telluride, and an associated solid state preamplifier 40, such as that sold by Amptek Corporation of Bedford, MA 01730, under the model designation A-225. Alternatively, as shown in Fig. 5, the detector 26 may comprise

a scintillation crystal 42 of any suitable material, e.g., sodium iodide, cesium iodide, bismuth germanate, etc., an associated photomultiplier means such as a silicon photodiode or avalanche photodiode or conventional photomultiplier tube 44, and when needed a preamplifier 46. All other details of the probe of Fig. 5 (designated by the reference numeral 20) are the same as that of the probe shown in Figs. 1-4 and will not be separately described.

The adjustment means 30 for moving the detector 26 of the embodiments of the probe shown in Figs. 1-5 is best seen in Figs. 2 and 3 and basically comprises a tracked sleeve 48, a slotted sleeve 50, a follower base 52 and follower pins 54. The tracked sleeve, as can be seen in Fig. 3, is a tubular cylindrical member of thin wall construction. The sleeve 48 is fixedly secured within an annular recess 56 in the internal bore 29 of the probe body 22. The sleeve 48 includes a helical recess or track 58 extending about axis 36 in the inner surface of the sleeve. The slotted sleeve 50 basically comprises a thin walled, cylindrical tubular member whose outside diameter is just slightly less than the inside diameter of the tracked sleeve 48. The slotted sleeve 50 includes a pair of longitudinally extending, pin location slots 60 disposed diametrically opposed to each other and parallel to the axis 36. A mounting plate 62 having a central upwardly projecting hub 63 extends into the bottom of the slotted sleeve 50 and is fixedly secured thereto (see Figs. 2 and 5).

The detector/preamplifier assembly 26 is disposed within the central passageway extending through the slotted sleeve 50 and is supported on the follower base 52. The follower base 52 is a disk-like member which is disposed for longitudinal movement within the slotted sleeve 50. To that end the outer diameter of the follower base is just slightly smaller than the inner diameter of the slotted sleeve 50. The follower base includes a passageway 64 extending diametrically therethrough perpendicular to the axis 36 and in which is located the follower pins 54. A helical biasing spring 66 is disposed within the follower base's passageway between the

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follower pins 54. This spring biases the follower pins radially outward so that the free end of each pin extends out of the follower base and through an associated slot 60 in the slotted sleeve 50 and into the portion of the helical track 58 contiguous therewith.

As shown clearly in Figs. 3 and 5 the mounting plate 62 includes an outwardly flanged portion 68 which is disposed within a correspondingly shaped annular recess within the end wall 70 of the probe body 22. An annular recess 72 is also located within the end wall 70 and extending about the annular recess holding flange portion 68. The recess 72 serves to hold an O-ring 74 therein. A base plate 76, in the form of a circular disk, is secured via conventional threaded screws 78 to the end wall 70 of the probe body 22, with the O-ring 74 interposed therebetween. The mounting plate includes a downwardly extending cylindrical hub portion 80 which extends through a central opening 82 in the base plate (see Fig. 3).

With the components secured together as just described, the mounting plate 62 and the slotted sleeve 50 fixedly secured thereto may be rotated about axis 36 with respect to the probe body 22 (and the base plate 76 to which it is fixedly secured). Such rotation moves the detector/preamplifier assembly 26 toward and away from the window 28 (depending upon the direction of rotation) and is effected by the user (e.g., surgeon) rotating an adjustment knob 84 located at the proximal end of the probe. Thus, as can be seen in Figs. 1-2 and 4-5, the knob is a circular disk-like member which is fixedly secured to the downwardly extending hub portion 80 of the mounting plate. The knob includes a central annular recess 86 in which that hub portion is disposed. The knob 84 is fixedly secured to the mounting plate 62 via plural threaded fasteners (screws) 88. In order to facilitate the grasping (twisting) of the knob with respect to the probe body 22, the outer surface of the knob may be knurled or include flattened portions.

As should be appreciated from the foregoing when the probe body 22 is gripped in the palm of the user and the knob

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84 is grasped and rotated (twisted) about axis 36 with respect to the probe body, the tracked sleeve 48 rotates with respect to the slotted sleeve 50. Accordingly, the free end of each of the extending follower pins 54 slides along respective portions of the helical track 58 in the sleeve 48. The longitudinally extending slots 60 in the sleeve 50 prevent the follower base from rotating and hence translate the twisting motion into an up/down motion of the follower base within the sleeve 50, with the direction of such motion depending upon the direction of rotation of the knob 84.

As can be seen in Fig. 2 a the mounting plate 62 includes an angled passageway 89 extending therethrough. A similar and coaxial angled passageway 90 extends through the knob 84. The two passageways 89 and 90 are contiguous and form the opening for a cable or wiring harness 12 carrying electrical current between the detector 26 and the analyzer 14. The follower base includes at least one hole (not shown) through which the cable or wiring harness from the detector 26 passes. Means, not shown, are provided to seal the passageways 88 and 90 from the ingress of moisture into the interior of the probe. The O-ring 74 also serves to prevent the ingress of moisture into the interior of the probe via the interface between the end wall 70 of the probe body 22 and the contiguous surface of the base plate 76.

In order to ensure that the only radiation received by the detector is that entering through the orifice adjacent window 28, the side wall of the probe body 22 is substantially thick, e.g., 5 to 9 mm of tungsten for shielding Iodine 131 and Indium 111, and 2 to 4 mm of tungsten for shielding Technetium 99m. Moreover, the knob 84 and the base plate are each formed of a radiation blocking material, such as the tungsten alloy making up the probe body 22. The follower base 52 is also formed of tungsten alloy or other radiation shielding material.

It should be pointed out that the conductors connected between the cadmium telluride crystal and the preamplifier of the embodiment shown in Figs. 1-4 or between

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CsI scintillation crystal, the photomultiplier and the preamplifier of the embodiment of Fig. 5 are not shown herein in the interest of drawing simplicity.

In order to expedite the aiming of the probe so its distal tip (window) is directed to whatever portion of the body the user wishes to examine, the probe 10 includes a light beam aiming system. That system basically comprises a light source such as an LED 92 (Fig. 3) disposed outside of the probe body 22, and an associated fiber optic or light pipe 94 extending down the length of the body and radially inward into the bore 24 close to the window 28. The free end of the light pipe 96 is disposed on the axis 36 and extends through a central opening in the window 28 on axis 36. The light source 92 is provided via an associated fiber optic light conductor 98, extending from outside the probe body to minimize electrical current in the probe.

As will thus be appreciated when the probe is positioned adjacent a patient and the light source energized a beam of light will exit from free end 96 of the light pipe coincident with the probe's central axis 36. This beam of light can then be directed at whatever portion of the patient's body is to be centered within the probes' angle of acceptance.

It must be pointed out at this juncture that the light aiming system just described is merely exemplary. Hence, other light generating systems to facilitate aiming of the probe may be incorporated in probe 10 or in any other probe constructed in accordance with this invention.

Operation of the probe 10 is as follows: The probe is adjusted to the maximum solid angle of acceptance and is then brought adjacent the portion of the patient's body to be examined. With the probe at this setting its sensitivity is maximum so that the general location of this emanated radiation can be readily found. The probe's solid angle of acceptance of the probe is reduced to whichever intermediate setting is desired by the user while monitoring the radiation detected and moving the probe in response to that detected radiation to center the probe over the source. This operation continues

until the probe is at its narrowest solid angle of acceptance and still receiving radiation. At this point the user can be sure that the source of that radiation is directly opposite the probe's window.

Referring now to Figs. 6A and B, another alternative embodiment of a probe 100 constructed in accordance with this invention is shown. In that embodiment the detector 26 is held stationary and a portion of the probe body having the entrance aperture and window 28 therein is moved with respect to it, to thereby continuously adjust the solid angle of acceptance. Components of the probe 100 which are common to the probes described heretofore are given the same reference numbers. Thus, as can be seen the probe 100 includes a cylindrical tubular probe body 102 formed of a radiation blocking material, such as tungsten alloy, having a central bore 104 in which is fixedly secured the radiation detector 26. In the embodiment shown in Figs. 6A and B the components forming the detector 26 are interconnected together via wires (not shown). The free end of the bore 104, is open at 106. The outer surface of the probe at the free end is tapered at 108.

A movable restrictor sleeve 110 in the form of a tube is disposed about probe body 102. The restrictor sleeve 110 has an central bore 112 whose internal diameter is just slightly larger than the external diameter of the probe body 102. The central bore 112 includes a tapered portion 113 adjacent its free end and which is complementary in shape with the conical surface 108 of the probe body 102. The free end 114 of the central bore 112 is of constant diameter extending about axis 36 to form an outlet or opening over which the window 28 is secured.

Adjustment means 116 are provided for moving the restrictor sleeve 110 and hence the entrance aperture and window 28 toward and away from the detector 26 between the solid line position 32 and the phantom line position 34, and vice versa, as shown in Figs. 6A and B. In particular, the adjustment means 116 basically comprises a helical groove or track 118 extending about the outer periphery of the probe body

102 about axis 36. A pair of follower or guide pins 120 extend into said track from diametrically opposed sides of the probe body 102. The pins 120 are located in respective ones of a pair of diametrically opposed bores 122 extending through the wall of the restrictor sleeve 110. Each follower pin 120 is secured in place within its bore via a respective threaded set screw 124 threadedly engaged at the end of the bore. A helical compression spring 126 is located in each bore between the associated follower pin and set screw to bias the pin radially inward and thus hold the pin's free end within the helical track 118.

The proximal (lower) end of the probe body 102 is fixedly secured within an annular recess 128 in a disk-like adjusting knob 130. The adjusting knob 130 includes a central passageway 132 extending therethrough which serves as the means for enabling the wire harness or cable 12 from the detector assembly 26 to pass out of the probe to the analyzer 14 or any other suitable means, e.g., computer, plotter, etc. Moisture sealing means (not shown) are provided to prevent the ingress of moisture through the passageway 132.

As will be appreciated by those skilled in the art when the probe sleeve 110 is held in the user's hand and the adjustment knob 130 is rotated or twisted about axis 36, the sleeve and the window 28 mounted thereon will be moved relative to the probe body, i.e., either brought toward or moved away from the detector assembly 26 fixedly secured within the probe body's bore 104, thereby adjusting the solid angle of acceptance of the radiation received through the aperture bounded by the window 28 to the detector assembly. Thus, the probe 100 may be used in the same manner as probes 10 and 20.

In Fig. 7 there is shown an alternative embodiment of a probe utilizing a movable restrictor to effect the continuous variation of the probe's solid angle of acceptance of radiation. That embodiment makes use of a movable restrictor sleeve of a generally thin walled construction and a probe body of generally thick walled construction. Thus, the combined outer diameter of the probe is still sufficiently

small that the probe can be comfortably held in the users palm. In that embodiment, when the restrictor of the probe is extended for maximum collimation there will be thick side wall portions of the probe's body to block the ingress of radiation therethrough to the detector. However, since the restrictor sleeve is of thin walled construction, additional radiation blocking means are mounted within the probe's restrictor to prevent the ingress of radiation to the detector through the side walls of the restrictor. As with the other embodiments described heretofore, the components which are common to other probe(s) described heretofore will be given the same reference numerals.

The body 202 of probe 200 is of a generally cylindrical construction having a central bore 204 therein. The bore extends from the free end 206 of the body 202 to an intermediate location 208. The remainder of the body is solid and forms an adjustment knob 210. The free end portion of the bore is closed off by a radiation transmissive window 212 constructed similarly to window 28 described heretofore. The outer surface 214 of the probe body 202 contiguous with the window 206 is tapered. The detector 26 is fixedly secured at the bottom of the bore 204. A passageway 216 extends down at an angle to the central axis of the probe and communicates with the outside of the probe. The passageway 216 serves to carry the wiring harness or cable 12 from the detector 26 to the analyzer 14 or other suitable means, e.g., computer, plotter, etc. Means (not shown) are provided within passageway 216 to serve as a moisture seal to preclude the ingress of moisture into the bore 204.

The restrictor sleeve of the probe is designated by the reference numeral 218 and basically comprises a tubular member of generally thin walled construction and having an internal bore 220 whose inside diameter is just slightly larger than the outside diameter of the probe body 202. The free end of the restrictor sleeve 218 includes a tapered wall portion 222 whose wall thickness is greater than that of the cylindrical portion of the sleeve. A constant diameter central

passageway 224 extends through the free end of the restrictor sleeve 218 to form an aperture over which a radiation transmissive window 28 is mounted.

The restrictor sleeve 218 is arranged to be moved toward and away from the detector 26 located within the probe body 202 by an adjustment assembly 226. That adjustment assembly basically comprises a helical track 228 in the periphery of the probe body 202 and extending about axis 36. A pair of follower or guide pins 230 extend through respective diametrically opposed threaded bores 232 in the side wall of restrictor sleeve 218. The pins 230 include external threads thereon to mate with internal threads in the bores 232. Each pin includes a free end which projects inward beyond the inner periphery of the restrictor sleeve 218 and into the helical track 228 portion contiguous therewith.

As will thus be appreciated by those skilled in the art if the handle or knob portion 210 is rotated while the restrictor sleeve 218 is held stationary, depending upon the direction of rotation the sleeve 220 will be either retracted to or extended with respect to the probe body 204, thereby moving the window 28 either toward or away from the detector 26. Thus, when the restrictor sleeve 218 is in the extended position shown in Fig. 7 the radiation reaching the detector 26 will be located within the minimum solid angle of acceptance denoted by the reference numeral 34. Conversely, when the restrictor sleeve 218 is in the retracted position, such as shown in Fig. 8, the radiation reaching the detector will be within the maximum solid angle of acceptance designated by the reference numeral 32.

Inasmuch as the free end portion 214 of the probe body 202 is tapered and the side wall of restrictor sleeve 218 is relatively thin, additional radiation shielding means is provided interposed therebetween to prevent stray radiation from reaching the probe's detector through the tapered side wall of the probe's body. Such means basically comprises a shield in the form of a truncated hollow cone 234 formed of a radiation blocking material, such as tungsten alloy. The

shield 234 includes an open upper end 236 and an open lower end 238. The shield 234 is held at an intermediate position between the tapered free end 214 of the probe body 202 and side wall and free end of the restrictor sleeve 218 via a pair of compression springs 240 and 242. Thus, one compression spring 240 is interposed between the inner surface of the shield and the conical outer surface 214 of the probe body 202. The conical spring 242 is interposed between the inner surface of the tapered wall portion 222 of the restrictor sleeve 218 and the outer surface of the shield 234.

As should be appreciated by those skilled in the art the conical shield will always be located approximately midway between the free end of the restrictor sleeve and the free end of the probe body, thereby substantially reducing the magnitude of stray radiation that may reach the detector through the side wall of the restrictor sleeve and the tapered side wall portion of the probe body.

In Figs. 10 and 11 there is shown yet another alternative embodiment of a probe 300 having a movable restrictor for continuously adjusting the solid angle of acceptance. The probe 300 is similar in construction to probe 200 shown in Figs. 7-9 except that probe 300 includes a plurality of conical shields instead of a single shield. This embodiment provides even more shielding for stray radiation than the embodiment of Fig. 7.

As before, common components and function of the probes shown in Figs. 7-9 and Figs. 10 and 11 are given the same reference numerals herein and their description and operation will not be reiterated. Thus, as can be seen in Fig. 10 the probe 300 includes three conical shields 234 which are mounted within the movable restrictor sleeve 218 between the tapered free end portion 214 of the probe body 202 and the tapered portion 222 of the free end of the sleeve 218. The shields 242 are generally equidistantly spaced, via respective helical springs 302, 304, 306, and 308. In particular, one helical spring 302 is interposed between the conical surface 214 of the probe body 202 and the inner surface of the lower

most of the conical shields 234. The second helical spring 304 is interposed between the outer surface of the lower most of the shields 234 and the inner surface of the intermediate shield 234. The third helical spring 306 is interposed between the outer surface of the intermediate shield 234 and the inner surface of the upper shield 234. Lastly, the fourth helical spring 308 is interposed between the outer surface of the upper shield 234 and the tapered inner conical surface of the free end of the restrictor sleeve 218.

In accordance with yet another aspect of this invention the continuous variation of the solid angle of acceptance of the probe's detector can be achieved by the use of an adjustable size entrance aperture. In such an arrangement the entrance aperture through which the radiation will reach the detector is continuously variable in area. One such probe is shown and designated by the reference numeral 400 in Figs. 12-17. In Figs. 18-20 there will be shown and described another such embodiment 500. It must be pointed out that those two embodiments are also merely exemplary, and other embodiments utilizing that concept are also encompassed by this invention.

Like the probe embodiments described heretofore, all common components of the probe 400 and any of the other probes described heretofore are given the same reference numerals and their construction and operation will not be reiterated. Thus, as can be seen in Figs. 12-17 the probe 400 basically comprises a probe body 402 of cylindrical construction and having a central cavity or bore 404 located therein. The detector 26 is located within the bore 404. The free end of the bore 404, also known as the aperture, is closed off by a radiation transmissive window 28, which like that described heretofore serves to prevent the ingress of moisture to the detector while enabling radiation to pass therethrough. The opposite end of the probe body 402 forms a knob 406 which may be knurled at its outer surface or include flattened portions to facilitate the grasping thereof. A central passageway 408 extends through the portion 406 and communicating with the bore 404. The

passageway 408 serves as the means for carrying the wiring harness or cable to the detector. Sealing means are provided within that opening to prevent the ingress of moisture to the interior of the cavity 404.

A tubular sleeve 410 is threadedly mounted on the probe body 402 at the free end thereof. The sleeve 410 includes internal threads 412 mating with external threads 414 on the outer periphery of the tube body 402. The free end of the sleeve 410 includes a conical outer surface 416 and a conical inner surface 418. The opening of the inner conical surface 418 at the free end of the sleeve 410 is closed off by a window 420. The window 420 is formed of a radiation transparent material, such as beryllium, aluminum, carbon, or other low atomic number solid material. Interposed between the free end 422 of the probe body 402 and the inner surface 418 of the sleeve 410 is an adjustable diameter collar assembly 424. That assembly basically comprises four collar segments 426 (see Figs. 16 and 17). Each segment includes a conical outer surface 434 which is arranged to cooperate with the inner conical surface 418 of the sleeve 410 as will be described later. Each collar segment 426-432 comprises a pair of projections 436 (Fig. 16) extending from one side thereof and a pair of correspondingly shaped recesses 438 (Fig. 16) extending into the other side thereof. Thus, the recesses 438 of one segment of the collar are adapted to receive the projections 436 of the immediately adjacent segment. In so doing the collar is arranged to be expanded from the closed position shown in Figs. 13, 15, and 17 to the open position shown in Figs. 12, 14, and 16, and vice versa.

The inner surface 440 of each segment is a circular arc of approximately 90°. Accordingly, when the segments are closed so that the collar is in the position shown in Figs. 13, 15, and 17 a central aperture of a predetermined diameter is formed by the conjoining arc segments 440. This central aperture forms the limiting orifice through which radiation may pass to the detector 26. The segments 426-432 of the collar are each formed of a radiation blocking material, such as

tungsten alloy. Accordingly, when the collar 424 is in the closed position its small diameter aperture restricts the radiation which may reach the detector assembly 26, thereby establishing the minimum solid angle of acceptance. This angle is shown schematically by the lines denoted by the reference numeral 34. Conversely when the segments are fully open, that is separated from one another by the maximum distance, their arcuate surfaces 440 define an aperture, which while not completely circular, nevertheless, approximates a circle of enlarged diameter (see Fig.14). The diameter of the aperture when the collar is in the fully open setting is such that the radiation entering through windows 420 and 28 to the detector are at the maximum solid angle of acceptance and just as if no sleeve 410 and no collar 424 was on the probe.

The means for effecting the continuous adjustment of the collar between the closed and open position and vice versa comprises a compressible circular spring split ring 442 which provides an outward bias force to the segments 426. In particular the ring 442 is disposed within the collar segments 426-432, with the ring engaging the inner conical surface 444 of each such segment. The bias force the ring applies to the segments causes them to move radially outward from axis 36. Thus, the ring tends to hold the collar in the open position shown in Figs. 12, 14 and 16. When the sleeve 410 is rotated about axis 36 in one direction it is retracted with respect to the probe body, thereby causing the sleeve's conical inner surface 418 to engage the conical outer surface 434 of each of the segments 426-432. The continued rotation in that direction applies an radially inward biasing force to the segments against the outward bias force provided by the ring 442, whereupon the segments move closer together. When the sleeve is rotated to the fully retracted position the collar is closed like shown in Figs. 13, 15 and 17. Conversely, when the sleeve 410 is rotated in the opposite rotational direction to move the sleeve to the fully extended position the collar segments are no longer constrained so that the outward bias force of ring 442 moves the collar segments to the fully opened position

shown in Figs. 12, 14, and 16, whereupon the probe is at the maximum solid angle of acceptance setting.

In Figs. 18 and 19 there is shown an alternative embodiment of a variable diameter aperture collimating probe. That probe is designated by the reference numeral 500. Again, common components with that of the previous described probes are identified by the same reference numerals.

The probe 500 includes a probe body 502 which is a cylindrical member having a central cavity or bore 504. The bore 504 contains the detector 26. The upper or free end of the bore 504 is closed by a radiation transmissive window 28. An angled passageway 506 extends through the body of the probe 502 into the bore 504 for carrying the wiring harness or cable 12 from the detector to the analyzer 14 or other means, as described heretofore. Sealing means are also located in that opening 506.

A tubular sleeve 508 of thin walled construction and having an internal diameter just slightly greater than the outer diameter of the probe body 502 is mounted on the probe body. The sleeve 508 includes an opening 510 which is of substantially larger diameter than the internal diameter of the cavity 504. The opening 510 is closed by a radiation transparent, moisture impervious window 512 like windows 28 described heretofore. Interposed between the sleeve 508 and the free end 514 of the body portion 502 is adjustment means in the form of an adjustable collar assembly 516.

The collar assembly 516 is arranged to vary the solid angle of acceptance of radiation passing from window 512 to window 28 and to the detector 26 located within the cavity 504. To that end the assembly 516 comprises a plurality of iris like segments 518. The segments conjoin with one another to form a tube-like member. The upper end 520 of each of the segments 518 extends at an angle to the remaining portion of the segment and terminates in an arcuate edge 522. These edges conjoin with one another to form a circular aperture. The aperture is of variable diameter and forms the adjustable window establishing the solid angle of acceptance of the probe.

To achieve such adjustability the upper end of each of the segments is arranged to be pivoted with respect to its lower end against the bias of a spring (to be described later) from the solid line position shown in Fig. 18 to the phantom line position shown therein. When the segments are in the solid line position shown in Fig. 18 the aperture formed by arcuate edges 522 is at a maximum diameter, thereby establishing the maximum solid angle of acceptance of gamma rays to the probe 500. When the segments 518 are at the pivoted or phantom line position shown in Fig. 18 the aperture is of considerably reduced diameter as shown schematically by the phantom lines in Fig. 19. Accordingly, when the segments 518 are in the phantom line position shown in Figs. 18 and 19 the probe is set to establish the minimum solid angle of acceptance (shown schematically by the solid lines 32).

To achieve the pivoting action just described the lower end of each of the segments 518 is flanged and forms a pivot 524 about which the segment may be rotated radially inward or outward. Each segment's pivot 524 is held within an annular recess 526 at the free end 514 of the probe's body portion 502. A second annular recess 528 is provided in the free end portion 514 of the probe's body 502. A helical compression spring 530 is interposed between the tapered surface and the top portion of each of the segments 518 and the bottom of the annular recess 528. The pivoting of the segments from the solid line position shown in Fig. 18 to the phantom line position shown therein, and vice versa, is effected by the rotation (twisting) of the sleeve 508 with respect to the body portion 502. To that end the body portion 502 includes a helical track 532 in its outer periphery. A pair of set screw follower pins 230 extend through diametrically opposed threaded bores 232 in the sleeve 508. The free end of each pin is located within the track 232.

The lower portion 534 of the probe's body 502 forms a knob or handle portion which is arranged to be grasped by the user. Thus, its surface may be knurled or include flatted portions to assist the grasping of it. The sleeve 508 may then

be rotated with respect to the probe's body 502 to extend or retract the sleeve thereon (depending on the direction of rotation). When the sleeve is rotated to the fully extended position the spring 528 is at its maximum expanded height (shown by the solid lines in Fig. 18). This causes the periphery of the top of the spring to engage the inner surface of the angularly extending portion 520 of each segment 518 to pivot the segments outward until the outer surface of the angularly extending portion engages the periphery of the opening 510. In this position the probe is set at the maximum solid angle of acceptance.

Rotation of the sleeve 508 with respect to body portion 502 in the opposite direction retracts the sleeve, whereupon the periphery of the sleeve's opening 510 slides across the tapered outer surface portion 522 of each segment 518. This action causes those segments to pivot about their pivot end 524 in a radially inward direction (towards the central axis 36 of the probe), thereby reducing the diameter of the aperture formed by edges 522. Continued rotation of the sleeve 508 in that direction causes further inward pivoting of the each of the segments 518, thereby further reducing the diameter of the aperture until the sleeve is fully retracted, whereupon the diameter of the aperture at its minimum. In this position the spring is fully compressed.

In order to verify that the tissue identified by the use of the probes of this invention indeed has radioactivity the probes are arranged to be used with an accessory specimen receptacle 600 which is constructed in accordance with another aspect of this invention and shown in Fig. 20. The receptacle is arranged to mate for use with any of the probes of this invention. Thus, the accessory receptacle 600 basically comprises a tubular member, formed of a radiation blocking material, such as tungsten alloy, and having a central recess 602. The central recess includes a bottom portion designated by the reference numeral 604 and an upper portion designated by the reference numeral 606. The bottom portion 604 of the recess is configured to accept the free (distal) end of any

probe constructed in accordance with this invention or otherwise.

In the embodiment shown in Fig. 20 the probe is designated by the reference numeral 10. In order to hold the receptacle 600 in place on the probe tip a conical ring-shaped gripping member 608 (i.e., an O-ring or split ring) is provided and extends into the bore portion 604 to fictionally engage the matching groove in the outer surface of the probe 10. When the receptacle 600 is mounted on the probe 10 as just described the hollow recess portion 606 is located directly over the probe's window 28. The portion 606 serves as a cavity or chamber for holding a specimen 612 to be tested. Disposable accessory specimen cups 620 (Fig. 20A) are provided for insertion into chamber 602 to prevent contamination of the chamber's surface by radioactivity from serial samples being assayed.

In order to prevent the specimen 612 from falling out and to block any stray radiation from entering the receptacle (and hence gaining egress to the probe's window) a cap 610, also formed of a radiation blocking material, e.g., tungsten alloy, is provided. The cap may be fictionally fit or threaded so that it does not slip off when it is used. Since the receptacle 600 and its cap are formed of a radiation blocking material stray radiation will be precluded from entering the probe's window. To further that end, the angle of the inner surface of the chamber 608 is approximately that of the probe's maximum solid acceptance (so that the probe is also at its maximum sensitivity). Accordingly, the probe can detect minute amounts of radiation from the specimen notwithstanding the fact that the probe may be located adjacent the source of radiation which is many orders of magnitude greater.

If the probe does detect radiation from the specimen the surgeon can feel some degree of assurance that the material which he excised is in fact the material which he desires to remove. The receptacle 600 can then be removed from the probe and the probe again used to detect if there is any other radiation emanating from the site of the excised tissue or

other site(s). Once such other tissue has been located it too can be removed or otherwise treated.

It must also be pointed out at this juncture that while the continuously adjustable collimating probes of this invention have particular utility for medical applications, that is to detect, localize, image and/or map radiation within the body of a living being, e.g., to facilitate cancer surgery, they can also be utilized for non-biological applications. In fact, the subject probe can be utilized for any application wherein detection, localization, imaging and/or mapping of hidden radiation is desired.

Referring now to Figures 21-24 of the drawing wherein like reference numerals refer to like parts there is shown at 720 in Fig. 21 one embodiment of a probe and one embodiment of a collimator constructed in accordance with another aspect of this invention. Unlike the probes of Figs. 1-20 the probe 720 of Figs. 21 (as well as the other probes of Figs. 22-24) is arranged to be used with a separate collimators (to be described hereinafter) constructed in accordance with another aspect of this invention. Those collimators, are arranged to be releasably secured, e.g., snap-fit, onto the probes of Figs. 21-24 to establish at least one discrete reduced solid angle of acceptance for the probe on which they are secured.

The collimating probe 720 includes radiation detecting means (to be described later) and is arranged to be used by itself or with a collimator constructed in accordance with this invention. One such collimator is designated by the reference numeral 800 and is shown in Fig. 21 mounted on probe 720. Two other types of collimators constructed in accordance with this invention are designated by the reference numerals 900 and 1000 and are shown in Figs. 23 and 24, respectively.

Any of the collimators 800, 900 or 1000, when secured to the probe 720, as will be described in detail later, serve to reduce the normal field of view of the probe, i.e., the solid angle of acceptance of the probe's radiation detector, to some lesser angle. Depending upon the construction of the collimator it may be used to reduce the normal field of view of

the probe to only a single predetermined angle (as in the case of Fig. 21) or may reduce it to one of several predetermined angles (as in the case of Figs. 23 and 24).

The probe 720 of this invention, with any associated collimator constructed in accordance with this invention, provides significant shielding for radiation from all directions other than that within the solid angle of acceptance by virtue of the materials used and the shape and organization of the probe and the collimator. Thus, the probe 720 with or without any of the collimators 800, 900, or 1000 can be used with high energy radioisotopes, such as Indium 111.

The probe 720 shown in Fig. 21 basically comprises a probe body 722 having a proximal portion 724A of a generally cylindrical shape and size to be readily held in one's hand. The body portion 24A terminates in a distal portion or tip 724B extending at an acute angle, e.g., 60 degrees, to the longitudinal axis of the body portion 724A. The angular orientation of the tip 724B with respect to the hand grip portion 724A of the probe's body 722 facilitates operator comfort and ease of aiming.

The probe body 722 and the collimators 800, 900 and 1000 are all formed of any suitable radiation blocking material like that described heretofore.

The probe body 722 includes a central passageway or internal bore 726 extending therethrough in which the various components which make up the radiation, optical and electrical components of the probe. The bore 726 is made up of four, longitudinally disposed sections, namely, 726A, 726B, 726C, and 726D, each of which is of a respective, different inside diameter. For example, the first section 726A is of 0.416 inch (10.6 mm) inside diameter. The second section 726B is of 0.375 inch (9.52 mm) inside diameter. The third section 726C is of 0.470 inch (11.9 mm) inside diameter. The fourth section 726D is of 0.750 inch (19 mm) inside diameter.

The free end of the probe's tip 724B contiguous with the bore section 726A defines a window 730 through which radiation is received by the probe's detecting means 728 when

the probe is aimed at the suspected source of radiation. The details of the radiation detecting means 728 will be described in detail later. Suffice it for now to state that such means comprises a scintillation crystal and associated components. The crystal is located within the second bore section 726B so that it confronts the window 730, whereupon the radiation blocking material of the probe's body contiguous with the window blocks the ingress of radiation so that the only radiation that reaches the crystal is that radiation within the probe's normal solid angle of acceptance (field of view). However, as noted earlier, when any of the collimators 800, 900 or 1000 is mounted on the probe tip 24B the normal solid angle of acceptance of the probe itself is reduced by portions of the collimator, as will be described later.

In the interests of preventing moisture or debris from gaining ingress into the probe's bore and the crystal of the detecting means 728 located therein the window 730 includes a very thin (0.025 mm) cover sheet 732 of a radiation transmissive material, e.g., stainless steel. The cover sheet is adhesively secured, e.g., by epoxy, on a ledge at the free end of bore section 726A.

Referring now back to Fig. 21 the details of the probe's radiation detecting means 728 will now be described. To that end The detecting means 728 can take various forms. One preferred embodiment comprises a scintillation crystal 736, a photomultiplier tube 738, and voltage divider 740. The crystal 736 may be of any suitable material, e.g., sodium iodide, mercuric iodide, bismuth germinate, etc. In the embodiment shown in Fig. 1 the crystal is a cylindrical body having a planar distal end face 742 disposed perpendicularly to the longitudinal axis of the crystal, and a planar proximal end face 744 disposed at an acute angle to the longitudinal axis. The outside diameter of the crystal is just slightly less than the inside diameter of the bore portion 726B in the probe's tip, so that it can readily fit therein. A thin sealing disk 746 is disposed on the ledge 48 formed by the interface of bore sections 726A and 726B and is adhesively secured, such as by

means of epoxy, thereon. The disk 746 provides an additional barrier against the ingress of moisture, thereby protecting the hygroscopic crystal 736, while also serving as a retaining member for the crystal. The disk 746 is preferably formed of stainless steel or a suitable plastic.

The photomultiplier tube 738 may be of any suitable type and basically comprises a cylindrical member, whose outside diameter is just slightly less than the inside diameter of the bore portion 726C, and has a an opposed pair of planar end faces 750 and 752, each of which is disposed perpendicularly to the longitudinal axis of the photomultiplier. The photomultiplier tube 738 is mounted within the bore portion 726C contiguous with the interface to the bore portion 726B, so that its distal end face 50 is located at that interface.

The angle of the end face 744 of the crystal 736 is the same as the angle of bore section 726B of the tip 724B to the probe body portion bore 726C, e.g., 60 degrees, so that when the crystal is in position within the bore it's angled end face 44 is located at the interface of the tip 724B and hand grip portion 724A of the probe's body, and with that end face being perpendicular to the longitudinal axis of portion 724A. Accordingly, the end face 744 of the crystal is parallel to and closely adjacent the end face 750 of the photomultiplier tube 738.

A very thin disk 754 is disposed on the ledge formed by the interface of bore sections 726B and 726C. This disk serves to retain the crystal 736 in place and prevents the ingress of moisture to the crystal from the proximal end of the probe. The disk 754 is formed of an optically transparent and index matched material, e.g., plastic, so that it can convey the light which is produced by the crystal 736 when it detects radiation to the photomultiplier tube 738. To achieve that end the disk 754 also abuts the distal end of the photomultiplier tube located in bore section 726C. If desired, the disk 754 may be formed of an optically index matched, mechanically shock absorbing material, such as an optical silicone elastomer.

In order to expedite the transmission of light between the components, the disk 754 may also be secured in place by a suitable index-matched grease or adhesive (not shown) so that it forms a good light transmissive joint with the crystal and with the end face 750 of the photomultiplier tube 738.

In Fig. 23 there is shown an alternative probe 1100. The probe 1100 is in most respects similar to probe 720 except for its radiation detecting means and its means for mounting a collimator onto its tip. Thus, the same reference numerals will be used to identify common features of probes 720 and 1100.

As can be seen in Fig. 23, probe 1100 uses an alternative detecting means to that shown in Fig. 21. In particular the alternative detecting means shown in Fig. 23 is similar in most respects to that of Fig. 21 except that does not require the crystal to have an angled proximal end for engagement with the proximal end of the photomultiplier tube 738. Thus, in the embodiment of Fig. 23 the crystal is designated by the reference numeral 756 and may be of conventional construction, i.e., include a pair of opposed planar end faces 758 and 760, each of which is perpendicular to the longitudinal axis of the crystal's body. One particularly useful crystal is that sold by Englehard Corporation of Solon, Ohio under the trademark HARSHAW POLYSCINT.

The crystal 756 is mounted within the bore section 726B of the tip 724B in the same manner as described heretofore. Since the proximal end face 760 of the crystal 756 is planar and perpendicular to the longitudinal axis of the crystal (and hence to the longitudinal axis of the bore section 726B in the tip 724B) it is not disposed parallel to the distal end face 750 of the photomultiplier tube 738 (which is located in bore section 726C). Thus, in order to convey the light from the crystal 756 to the photomultiplier tube 738 a light transmissive member or light pipe 762 is interposed between the proximal end face 760 of the crystal 756 and the sealing disk

754 located on the ledge formed at the interface of bore sections 726B and 726C.

The light pipe 760 basically comprises a cylindrical member, formed of a good light transmissive material, e.g., plastic or glass, and includes a distal end face 764 and proximal end face 766. The distal end face 764 is planar and is oriented perpendicularly to the longitudinal axis of the light pipe. The proximal end face 766 is also planar, but is disposed at the same acute angle, e.g., 60 degrees, as the bore section 726B is to the bore section 726C. Accordingly, when the light pipe 762 is in position its proximal end face 66 abuts sealing disk 754 in a good light transmissive joint. The distal end face 750 of the photomultiplier tube is also in a good light transmissive joint with the disk 754 as described heretofore. Moreover, the distal end face 764 of the light pipe abuts the proximal end face 760 of the crystal 756 in a good light transmissive joint, via another very thin, optically transparent, index-matched sealing disk 770. The disk 770, like disk 754, may be formed of a mechanical shock absorbing optically index matched material. In order to expedite the light transmission between all of the foregoing joints an index-matched grease or adhesive (not shown) may be provided at the abutting faces.

In either embodiment of Figs. 21 or 23 the voltage divider 740 circuit is located within the bore section 726C distally of the photomultiplier tube's proximal end face 752. The voltage divider circuit itself is disposed within a cylindrical housing whose outside diameter is just slightly less than the inside diameter of the bore section 726C and is held in place by a biasing spring (not shown). An electrical cable 772 (Fig. 21) extends from the voltage divider through bore section 726D. As can be seen in Fig. 21 the proximal end of the bore section 726D include an internally threaded throat 774 which is adapted to receive a mating end cap (not shown). The cable 772 extends through a opening in the end cap for connection to suitable monitoring apparatus (not shown).

As can be seen clearly in Fig. 21 a groove or recess 734 extends about the periphery of the tip 724B immediately adjacent the free end thereof at which the window 730 is located. This groove forms one portion of the means for enabling the releasable securement of the collimator 800 to the probe tip 724B. The other components making up the releasable securement means form a portion of the collimator itself and will be described later.

As can be seen in Figs. 21 and 22 the collimator 800 basically comprises a cylindrical shell having a sidewall section 802 defining an internal bore 804. The internal diameter of the bore is just slightly larger than the external diameter of the probe tip 724B to enable the probe tip to be closely received therein. The distal end of the collimator includes a conical wall section 806 having a central bore 808 therein. The bore 808 forms the window of the collimator. Like probe 720 the window 808 of the collimator 800 includes a very thin (0.025 mm) cover sheet 810 of any suitable radiation transmissive material, e.g., stainless steel, thereover.

An annular recess or groove 812 is located within the bore 804 of the collimator 800 and located closely adjacent the interface of the conical wall section 806 with cylindrical wall section 802. This recess 812 is arranged to receive and retain a resilient locking member 814 therein. The resilient member 814 preferably comprises an O-ring and serves as another component of the means for releasably securing the collimator 800 to the probe 720. The ring may be formed of any suitable material, such as neoprene rubber, nylon, steel or some other suitable metal (in the case where the material making up the ring is not resilient, e.g., is a metal, the ring is preferably split so that it can be readily inserted within the recess 812). In order to ensure that the ring 814 is trapped within the recess 812, that recess is of a greater depth than the groove 734 in the probe tip 724B. Moreover, the recess 812 includes square corners to ensure that the ring is retained permanently within it.

The collimator 800 is mounted on the probe tip 724B in the following manner. The probe tip 724B is inserted into the open end 816 of the bore 804 of the collimator and slid through the bore fully into the collimator, at which time the collimator's locking ring 814 reaches the probe's recess 734. Owing to the resiliency of the ring 814 and the shallow rounded corner nature of the recess 734 the ring 814 snap-fits into the recess easily, thereby releasably securing the collimator to the probe tip at that longitudinal position. Removal of the collimator 800 can be readily effected by merely pulling the collimator away from the probe tip, whereupon the ring 814 moves out of the recess 734 in the probe tip (the deep square cornered recess 812 serving to ensure that the ring 814 remains in that recess).

As can be seen clearly in Fig. 22 the collimator 800 includes venting means 818 in communication with its interior and also with the ambient atmosphere, so that when it is secured to the probe tip 724B any air that would be trapped within the collimator between the interior surface of its bore 804, the exterior surface of the probe tip 724B and the O-ring 814 will quickly vent to the ambient atmosphere. This feature ensures that air within the collimator 800 will not interfere with the rapid and reliable mounting of the collimator onto the probe tip. Moreover, the fact that the ring 814 is located at the interface of collimator wall sections 802 and 806, and hence very close to the free end of the probe tip when the collimator is in place, ensures that the air space within the collimator is kept to an absolute minimum, thereby further ensuring that any air within the collimator will not impede the mounting of the collimator onto the probe.

The venting means 818 may take any suitable form. In the preferred embodiments of this invention such means comprises a vent hole 818 extending radially out through the sidewall 802 and in communication with the internal bore 804 and the ambient atmosphere.

It must be pointed out at this juncture that the collimator 800 may take many forms and configurations. Thus,

other collimators 800 having different dimensions, wall thicknesses, etc. may be constructed for use with probe 720, so that each collimator establishes a different solid angle of acceptance of radiation. Accordingly, the person using the probe 720 can establish the desired field of view by the selection and mounting of the appropriately configured collimator 800 onto the probe 720.

As should be appreciated by those skilled in the art other types of resilient locking means may be used in lieu of the heretofore described ring 814. Thus, spring loaded ball bearing pressure retainers (not shown) could be inset within the collimator wall 802 (with such an embodiment the need for the ring holding recess 812 is obviated). So too, a ring (not shown) composed of various configurations of spring metal protuberances may be incorporated into the collimator to mate with the groove 734 in the probe's tip.

In Fig. 23 the probe 1100 is shown. As can be the probe tip 724B of probe 1100 is modified to include a plurality of spaced apart peripheral recesses 734. This arrangement enables a collimator 900 to be mounted on the probe at any of those recesses, thereby enabling the collimator 900 to establish different, respective fields of view for the probe 1100. As can be seen in Fig. 23 the collimator 900 is similar to that of collimator 800 shown in Fig. 1 (thus common elements are designated by the same reference numerals) except that the recess 812 and ring 814 located therein is located further proximally. Thus, with such an arrangement all that is necessary to change the field of view of the probe is to move the collimator to the desired longitudinal position on the probe tip between the solid and phantom line positions shown in Fig. 23.

In Fig. 24 there is shown the collimator 1000 mounted on probe 1100. This collimator is also arranged to provide different respective fields of view for the probe. The collimator 1000 is similar in most respects to the collimator 900 except for the releasable securement means utilized. Thus, in the interest of brevity the structural features which are

common to both collimators 900 and 1000 will be given the same reference numerals and those features will not be described at length hereinafter.

The means for releasably mounting the collimator 1000 onto the probe tip 724B of probe 1100 basically comprises holding means in the form of a plurality of recesses 1102, 1104, and 1106 which extend about the periphery of the bore 804 of collimator 1000. Each recess 1102-1106 is constructed similarly to the sharp cornered recess 812 of the collimators 800 and 900 in order to permanently receive and retain a respective one of plural locking rings 814 therein.

The collimator 1000 is mounted on the probe's tip 724B by inserting that tip within the collimator's bore 804 so that the ring 814 in a desired one of the grooves 1100-1106 is located opposite to one of the recesses 734 in the probe's tip at the desired longitudinal position for the collimator. Accordingly, the ring 814 will snap-fit into that recess 734, in a similar manner as described heretofore, thereby holding the collimator 1000 in place at that particular longitudinal position along the tip. This action establishes a particular reduced field of view for the probe. It must be pointed out at this juncture that only one recess 734 need be provided in the probe's tip 724B to accomodate any of the rings 814. In fact, such an arrangement may be preferrable since the elimination of each recess 734 means there is more shielding material, e.g., tungsten alloy, to provide additional shielding for the crystal from radiation through the sidewall of the tip portion 724B.

Like collimator 900, collimator 1000 when mounted on probe tip 724B of a probe 1100 can establish three respective fields of view for the probe. Thus, recess 1102 establishes the largest of the reduced fields of view of the probe 1100 when the collimator 1000 is mounted thereon, while the recess 1104 establishes an intermediate field of view, and recess 1106 establishes the narrowest field of view.

The recesses 1102-1106 may be equidistantly spaced from one another or may be spaced apart by predetermined differing distances so that any discrete desired field of view

between maximum (which is shown in phantom lines) and a minimum (which is shown in solid lines) may be established.

In order to change the field of view of the probe 1100 from that established by the then existing setting (location) of the collimator 900 or 1000 on the probe tip 724B all that is required is to pull or push the collimator along the tip to the desired longitudinal position. The releasable securement means of the probe and collimator of this invention enables such action to be accomplished readily, reliably and with accuracy and precision. In this regard when the collimator is pulled or pushed longitudinally from any set position on the probe's tip the ring 814 in the recess 734 exits that recess. Continued pulling or pushing on the collimator moves the collimator with respect to the probe's tip until a ring 814 is located opposite to desired recess 734 in probe's tip, whereupon the ring snap fits into that recess to hold the collimator in that position, and thus establishes the new field of view of the probe.

Without further elaboration the foregoing will so fully illustrate our invention that others may, by applying current or future knowledge, adopt the same for use under various conditions of service.

What is claimed as the invention is:

1. A probe (10, 20, 100, 200, 300, 400, 500) for detecting radiation emanating from a hidden source, said probe comprising a small probe body (22, 102, 202, 402, 502) formed of a radiation blocking material, radiation detecting means (26) located within said probe body (22, 102), window means (28) confronting said detecting means for enabling radiation to pass therethrough, and adjustable collimating means (30, 116, 226, 424, 516) for adjusting the solid angle (32,34) at which said radiation may pass through said window means to said detecting means (26), said solid angle being continuously variable between a predetermined maximum angle (32) and a predetermined minimum angle (34) and vice versa, said probe being characterized in that said probe body (22, 102, 202, 402, 502) is small and arranged to be held in one's hand for positioning said window means (28) adjacent said hidden source of radiation, said probe body being constructed to block radiation to said detecting means (26) from all directions except through said window means (28), whereupon the only radiation which may reach said detecting means (26) is that which is within said solid angle (32,34).

2. The probe (10, 20) of Claim 1 characterized in that said collimating means (30) moves said detecting means (26) within said probe body (22) with respect to said window means (28).

3. The probe (10, 20) of Claim 2 wherein said probe body (22) includes a longitudinal axis (36) and wherein said collimating means (30) is characterized in that it can be moved with respect to said axis to move said detecting means (26) within said probe body along said axis.

4. The probe (10, 20) of Claim 3 characterized in that said collimating means (30) comprises a portion (84) of said probe body and coupling means (48, 50, 52 and 54) connected to said detecting means (26), said portion (84) of said probe body and said coupling means cooperating with each other to move said detecting means within said probe body when

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said probe body portion (84) is moved.

5. The probe (10, 20) of Claim 4 characterized in that said probe body portion (84) is arranged to be rotated about said axis.

6. The probe (10, 20, 100) of Claim 1 characterized in that it additionally comprises light source means (92, 94, and 96) for directing a beam of light out of said probe body (22) adjacent said window means (28) to facilitate the location of said probe adjacent said source of radiation.

7. The probe (100, 200, 300, 400, 500) of Claim 1 characterized in that collimating means (100) includes sleeve means (110, 218, 410, 508) comprising a thin walled portion extending about said probe body portion (102, 202, 402, 502), said probe body portion being thicker walled than said sleeve means (110, 218, 410, 528).

8. The probe (200, 300) of Claim 7 characterized in that said free end of said sleeve means (218) is in the form of an inwardly directed annular flange (222), with said window means (28) being located within the interior of said flange, said sleeve means additionally comprising radiation blocking means (234) located therein and interposed between said inlet (212) of said probe body (202) and said annular flange (222) of said sleeve means (218).

9. The probe (200, 300) of Claim 8 characterized in that said radiation blocking means (234) comprises at least one conical member.

10. The probe (200, 300) of Claim 9 characterized in that said conical member (234) is mounted by positioning means (240, 242, 302, 304, 306, 308) substantially centered between said flange (222) of said sleeve means (218) and said inlet of said probe body.

11. The probe (400, 500) of Claim 1 wherein said probe body (402, 502) includes a longitudinal axis (36) and wherein said collimating means comprises collar means (424, 516) having a radiation transmissive passageway extending therethrough forming said window means, said collar means being characterized in that it is located within said probe body and moveable with respect to said axis.

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12. The probe (400, 500) of Claim 1 wherein said detecting means (26) is fixedly positioned within said probe body (402, 502) and wherein said window means comprises a radiation transmissive window (424, 516), said window being characterized in that it is adjustable in size and through which said radiation may pass unblocked, said collimating means serving to change the size of said window.

13. The probe (400, 500) of Claim 12 characterized in that said window means comprises a plurality of arcuate members (426, 428, 430, 432, 522) coupled to one another and forming an opening of adjustable internal diameter, said opening defining said window.

14. The probe (10, 20, 100, 200, 300, 400, 500) of Claim 1 characterized in that it additionally comprises receptacle means (600) arranged for releasable securement to said probe body (22, 102, 202, 402, 502) at said window means (28).

15. The probe (10, 20, 100, 200, 300, 400, 500) of Claim 14 characterized in that said receptacle means (600) is formed of a radiation blocking material and comprises a cavity (606), and wherein said cavity confronts said window means when said receptacle means is secured to said probe, whereupon radiation emanated from a specimen (612) located within said cavity (606) may pass through said window means (28) to said detector while said receptacle means blocks any stray radiation from entering said window.

16. A probe (720, 1100) having a collimator (800, 900, 1000) releasably mounted thereon, said probe being arranged for detecting radiation emanating from a hidden source when held adjacent said hidden source, said probe comprising a probe body (722) formed of a radiation blocking material, radiation detecting means (728) located within said probe body, and a first radiation transparent, closed window (732) located at the distal end of said probe body and confronting said detecting means through which radiation may pass in a first solid angle of acceptance, said collimator (800, 900, 1000) serving to decrease said first solid angle of acceptance of radiation through said first window (732) to said detecting means when

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said collimator is mounted on said probe body, said collimator (800, 900, 1000) comprising a cylindrical member (802) formed of a radiation blocking material having a cylindrical bore (804) extending therethrough and into which said distal end of said probe body is arranged to be inserted, characterized in that said collimator (800, 900, 1000) comprises an air vent (818) in communication with the ambient atmosphere, at least one holding means (812) located at a fixed position in the inner periphery of said bore, and a resilient locking member (814) held by said holding means thereat, said bore also having a distal end (808) at which a second radiation transparent, closed window is located, said probe body (722) blocking radiation to said detecting means (728) from all directions except through said window and including at least one recess (734) extending about the outer periphery thereof adjacent the distal end thereof for receipt of said locking member (814) to releasably secure said collimator to said probe body when said distal end of said probe body is inserted into said bore in said collimator, with said air vent enabling air trapped between said distal end of the probe body and said collimator to vent to the ambient atmosphere.

17. The probe (720, 1100) of Claim 16 characterized in that said holding means comprises an annular recess (812) extending about the periphery of said bore (804) of said collimator and wherein said resilient locking member comprises a ring (814).

18. The probe (720, 1100) of Claim 16 characterized in that said recess (734) in said probe body is located closely adjacent the distal end of said probe body and wherein said resilient locking member (814) of said collimator (800, 900, 1000) is located closely adjacent the window of said collimator to minimize the volume of air space enclosed between the outer surface of the probe, and the inner surface of the collimator's bore located distally of the locking member.

19. The probe (720, 1100) of Claim 18 characterized in that said holding means comprises an annular recess (812) extending about the periphery of said bore of said collimator (800, 900, 1000) and wherein said resilient locking member

comprises a ring (814).

20. The probe (720, 1100) of and collimator of Claim 16 characterized in that said holding means comprises an annular recess extending about the periphery of said bore (804) and which is deeper than said recess (734) in said probe body (722) to ensure that said locking member (814) remains seated within the recess in said collimator.

21. The probe (720, 1100) of Claim 20 characterized in that said resilient locking member comprises a ring (814).

22. The probe (1100) of Claim 16 characterized in that said probe includes plural recesses (734) extending about the outer periphery thereof and wherein said collimator comprises a plurality of spaced-apart locking members (814), each of said locking members being located at respective longitudinal positions in the periphery of said bore (804), each of said locking members (814) being arranged to cooperate with a selected one of said recesses (734) in said probe when said collimator is mounted on said probe to reduce said predetermined solid angle of acceptance of radiation to respective lesser value.

23. The probe (1100) of Claim 22 characterized in that said holding means comprises a plurality of spaced apart annular recesses (812) in the periphery of said bore of said collimator and wherein each of said resilient locking members comprises a ring (814).

24. The probe (720, 1100) of Claim 16 characterized in that said probe body includes an elongated linear hand grip portion (724A) and a linear tip (724B) portion extending at an acute angle thereto, said probe body including a first bore (726A) extending through said tip portion and a second bore (726C) extending through said hand grip portion, said bores extending at said acute angle to each other and communicating with each other, said radiation detecting means comprising a photomultiplier tube (738) located in said second bore (726C) and a scintillation crystal (736, 756) located within said first bore (726A), said crystal and said bore being in good light communication with each other via a light transmissive interface (754, 762).

25. The probe (1100) of Claim 24 characterized in that said crystal has a longitudinal axis parallel to the longitudinal axis of said first bore, and said photomultiplier tube has a longitudinal axis parallel to the longitudinal axis of said second bore, and wherein said light transmissive interface is formed by a planar proximal end face (760) of said crystal (756) and a planar end face (750) of said photomultiplier tube (738), said end face of said crystal extending at said acute angle to the longitudinal axis of said crystal, said end face of said photomultiplier tube extending perpendicularly to the longitudinal axis of said photomultiplier tube.

26. The probe (1100) of Claim 25 characterized in that it additionally comprises a light transmissive material (762) interposed between said planar end face (760) of said crystal (756) and said planar end face (750) of said photomultiplier tube (738).

27. The probe of Claim 26 characterized in that said material is a mechanical shock absorbing material.

28. The probe (1100) of Claim 24 characterized in that said light transmissive interface comprises a cylindrical member (762) formed of an optically transmissive material located within one of said first and second bores between said crystal (756) and said photomultiplier tube (738), said cylindrical member (762) having a longitudinal axis parallel to the longitudinal axis of said bore, a planar distal end face (764), and a planar proximal end face (766), said crystal having a planar proximal end face (760) disposed perpendicularly to the longitudinal axis of said first bore and arranged to abut said distal end face (764) of said cylindrical member in a good light tight joint, said photomultiplier tube having a planar distal end face (750) disposed perpendicularly to the longitudinal axis of said second bore and arranged to abut said proximal end face (766) of said cylindrical member in a good light transmissive joint.

29. The probe (720, 1100) of Claim 24 characterized in that it additionally comprises a light transmissive material (754, and 770) interposed between said planar end faces making

up said joints.

30. The probe (720, 1100) of Claim 29 characterized in that said material is a mechanical shock absorbing material.

31. The probe (1100) of Claim 28 characterized in that said cylindrical member (762) is located within said first bore, and wherein said distal end face (764) of said cylindrical member extends perpendicularly to the longitudinal axis of said first bore, said proximal end face (766) of said cylindrical member extending at said acute angle to said longitudinal axis of said first bore.

32. The probe (1100) of Claim 31 characterized in that it additionally comprises a light transmissive material (754, and 770) interposed between said planar end faces making up said joints.

33. The probe (1100) of Claim 32 characterized in that said material is a mechanical shock absorbing material.



FIG. 4

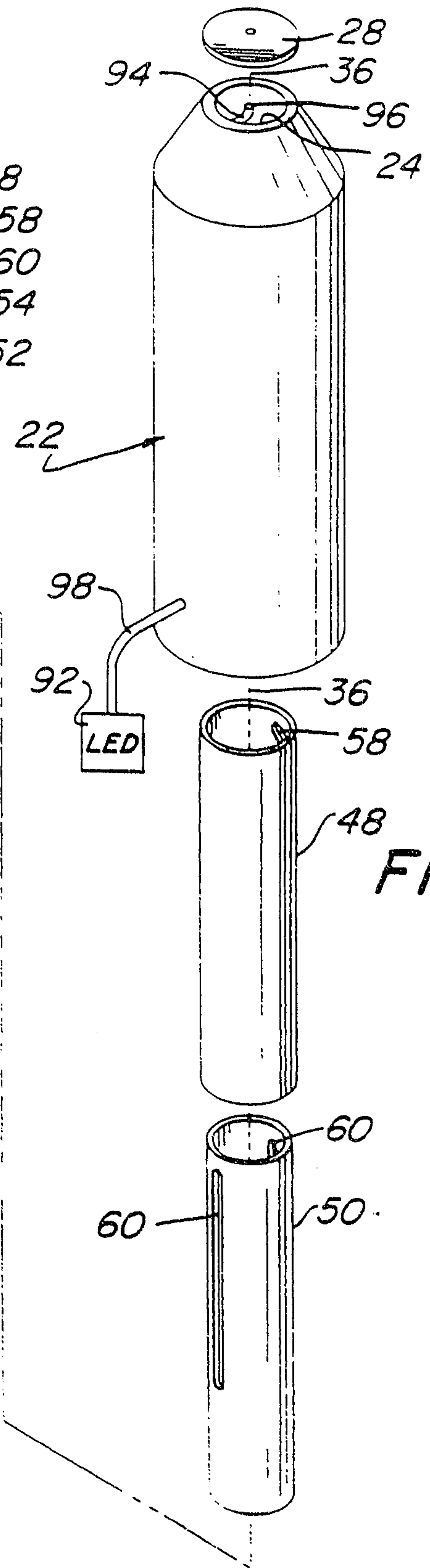
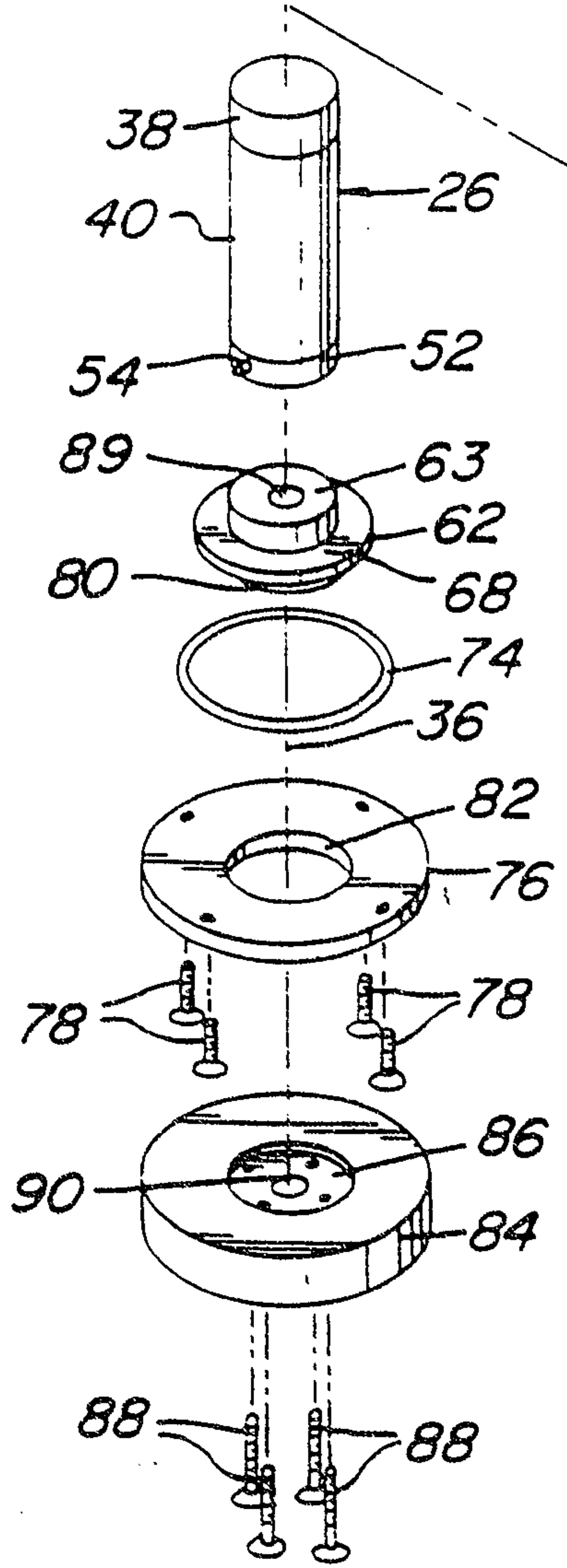
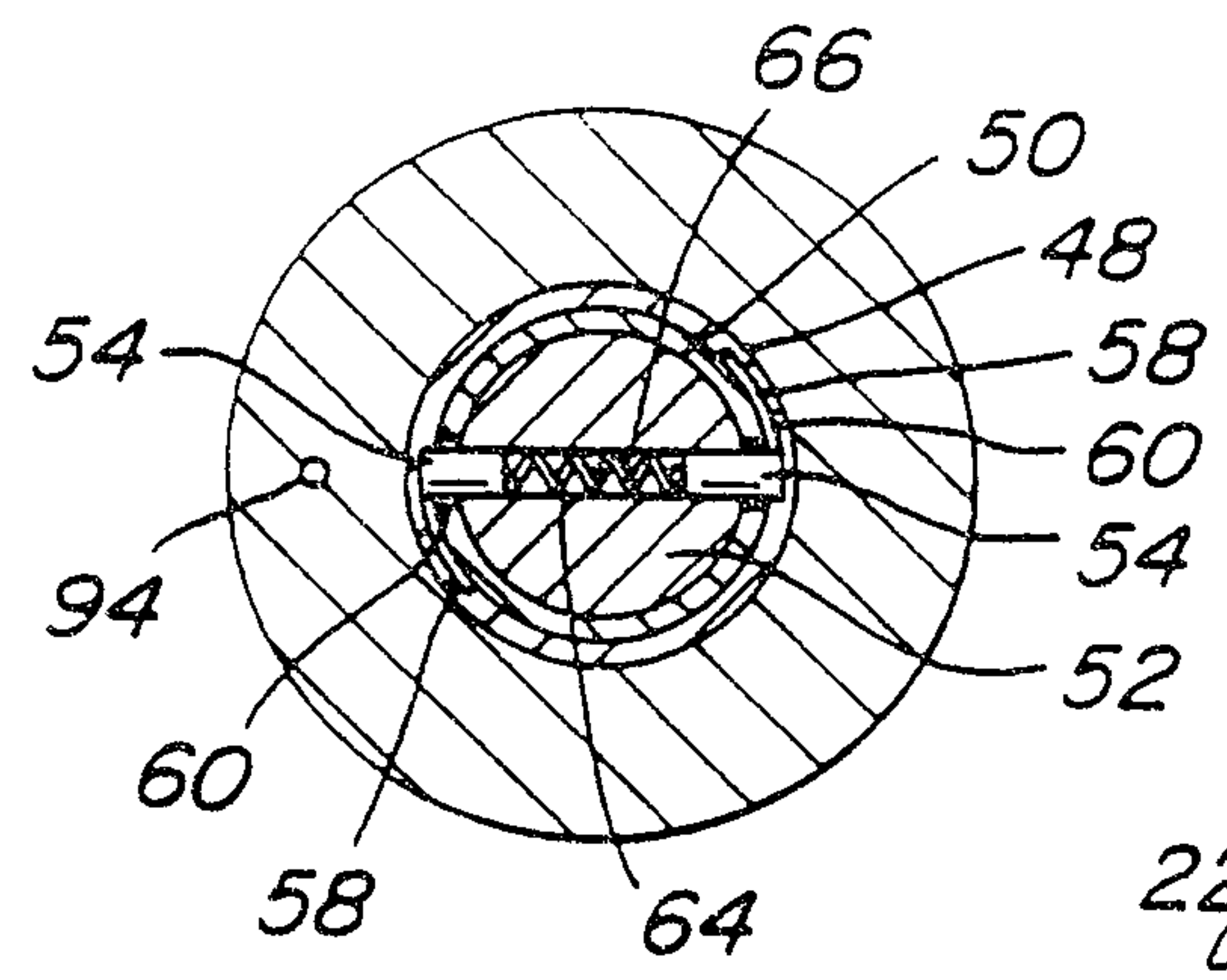


FIG. 3

FIG. 5

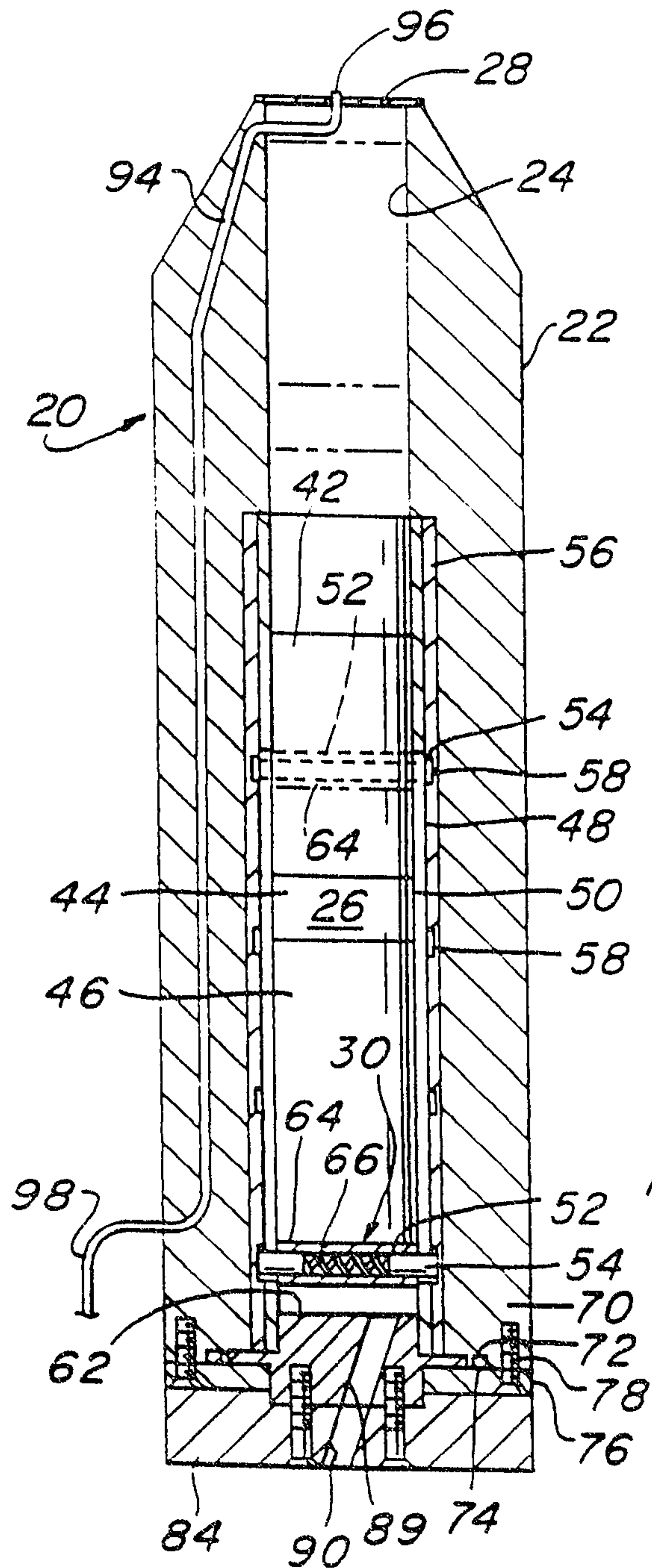
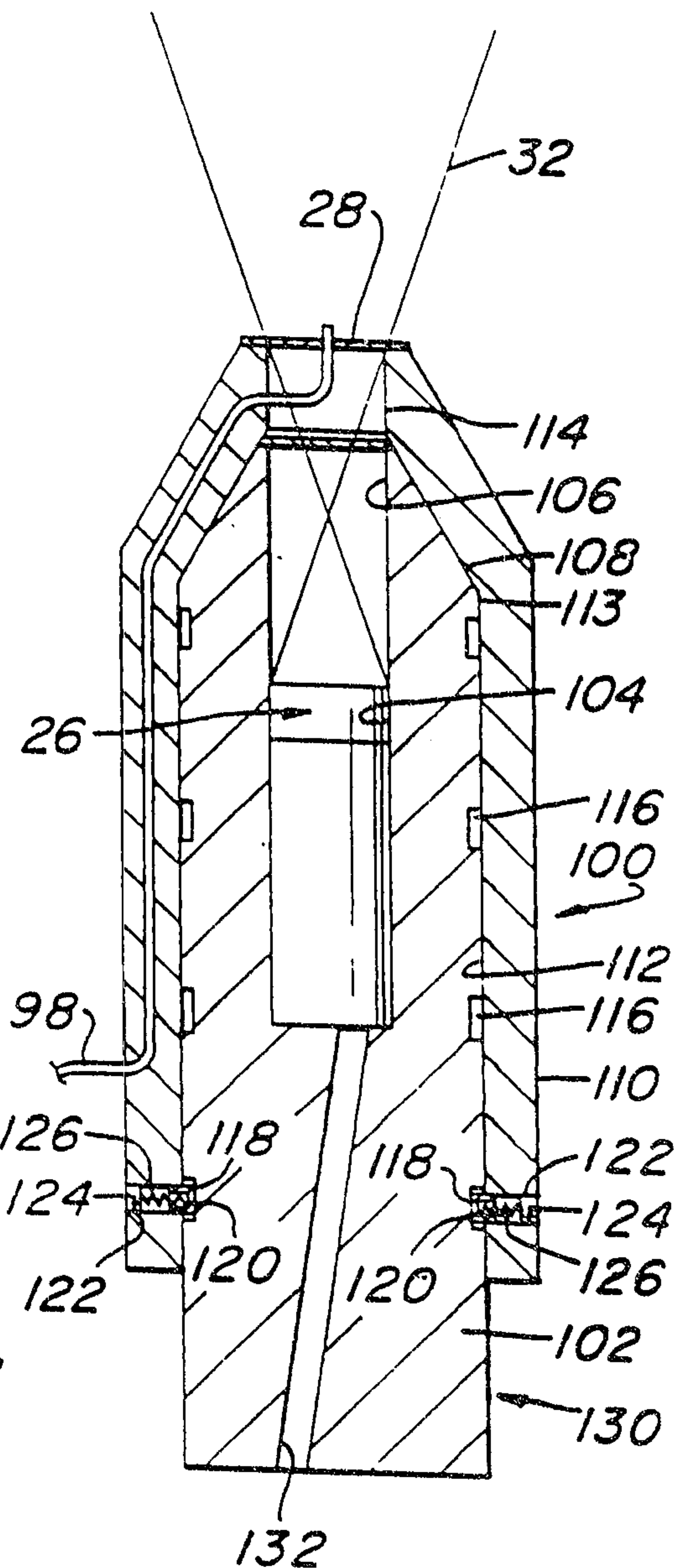


FIG. 6B



SUBSTITUTE SHEET

FIG. 20A

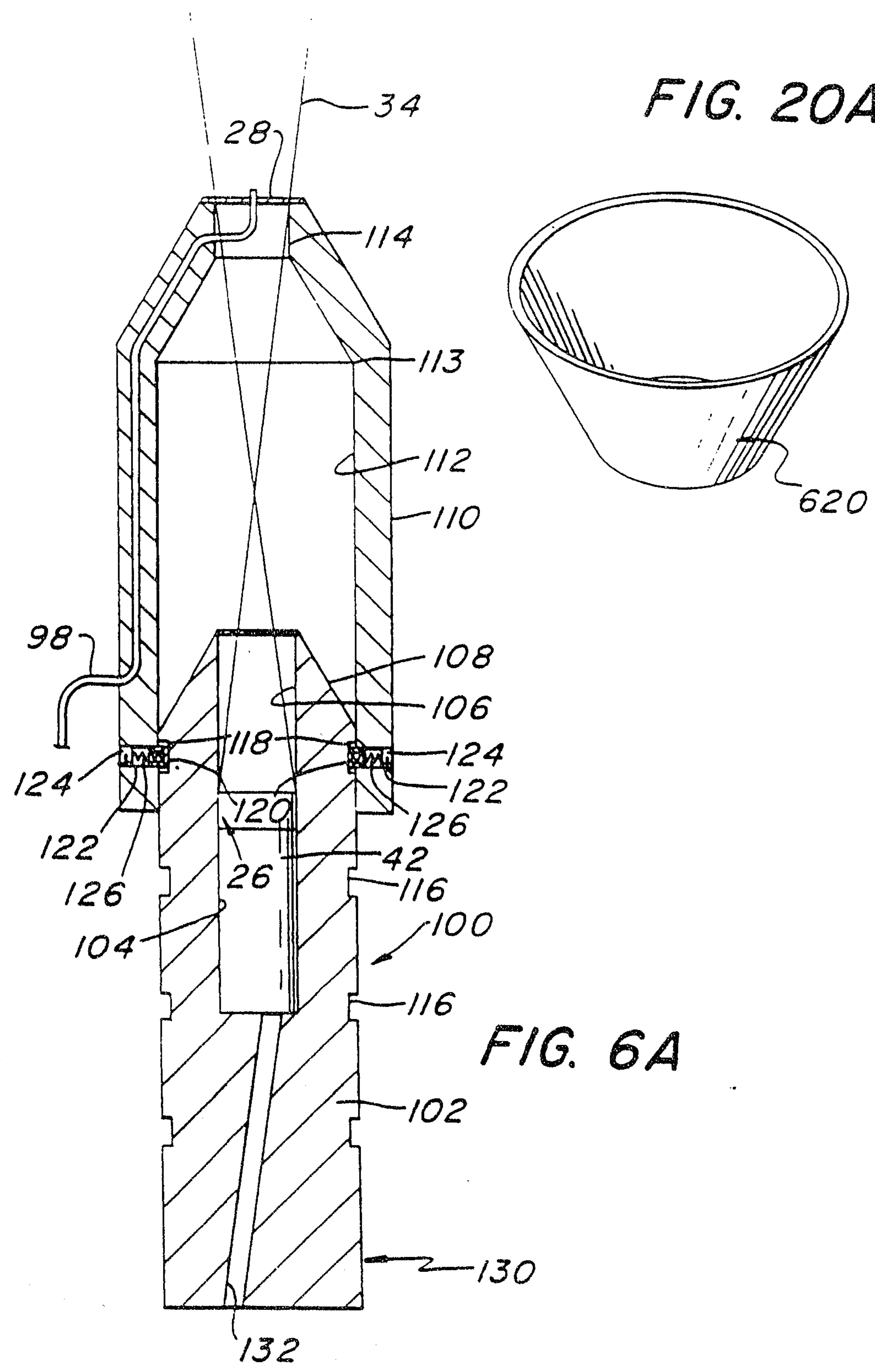
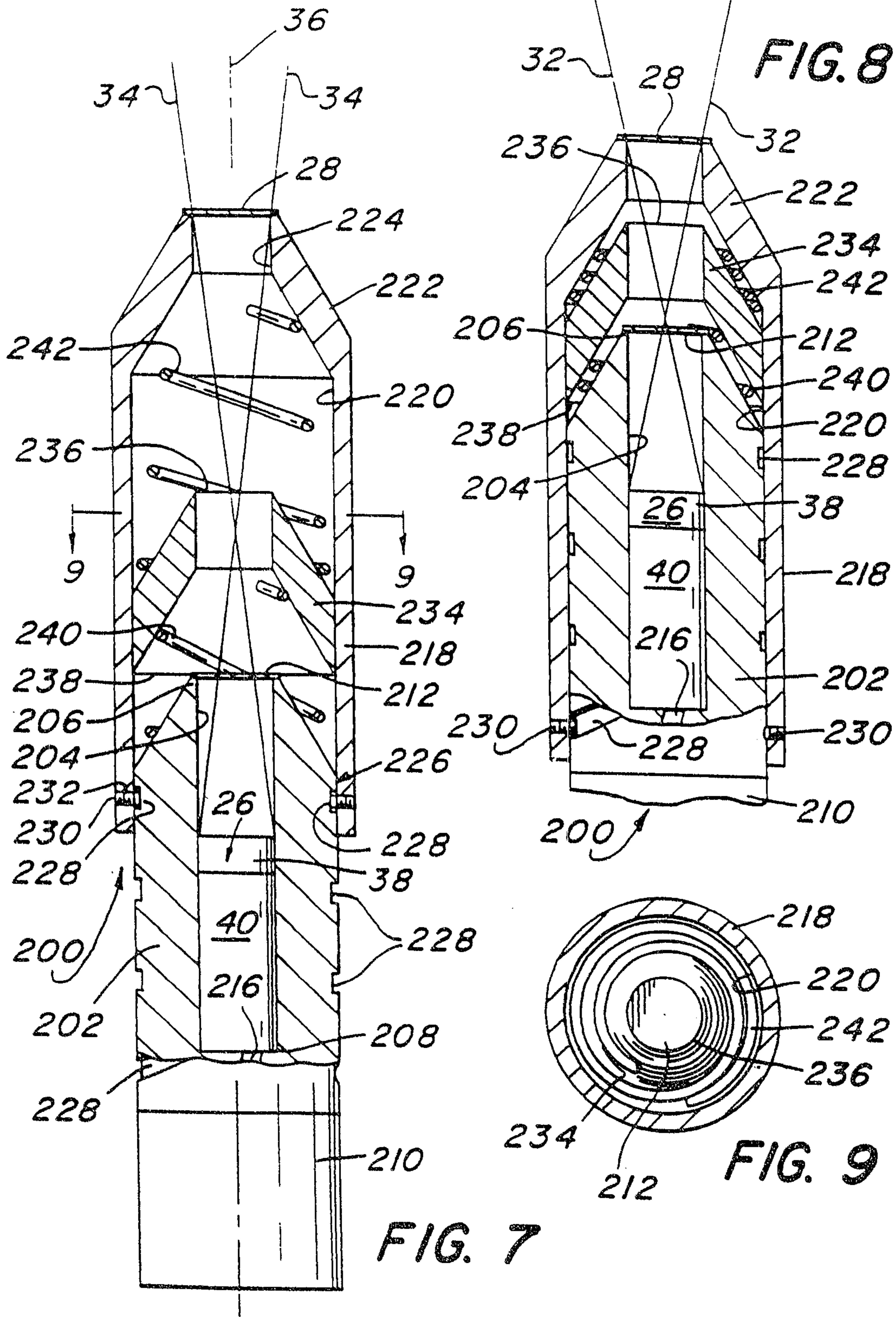


FIG. 6A



SUBSTITUTE SHEET

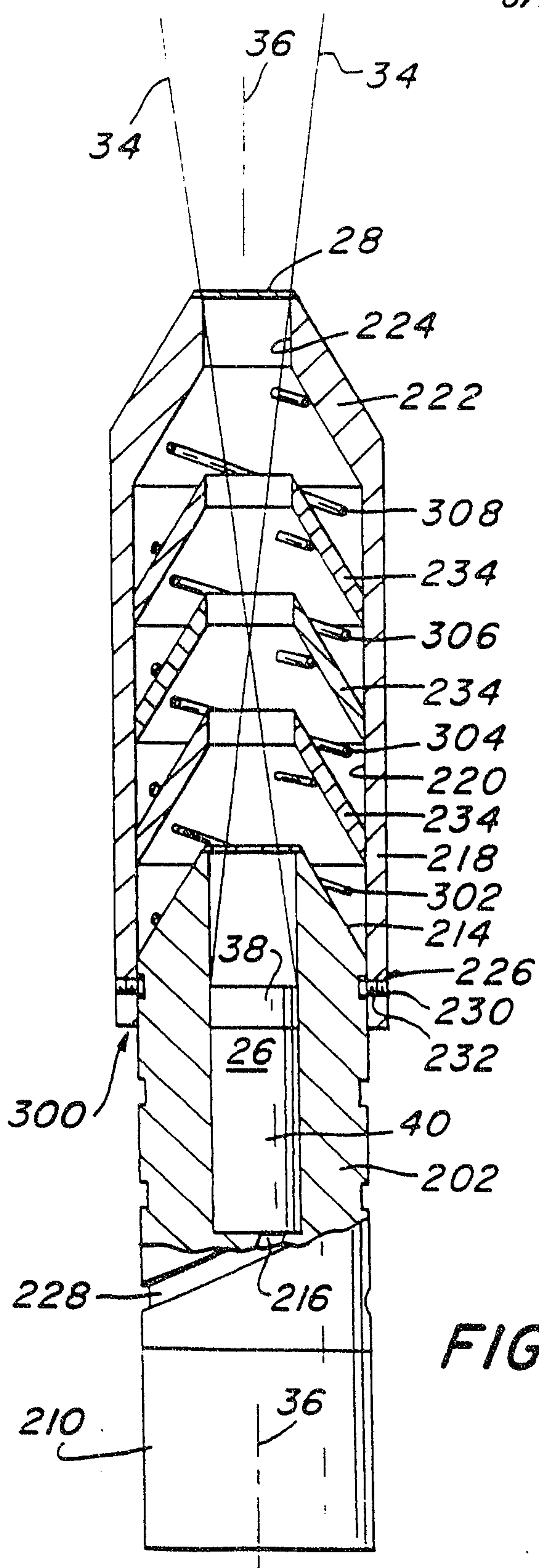


FIG. 10

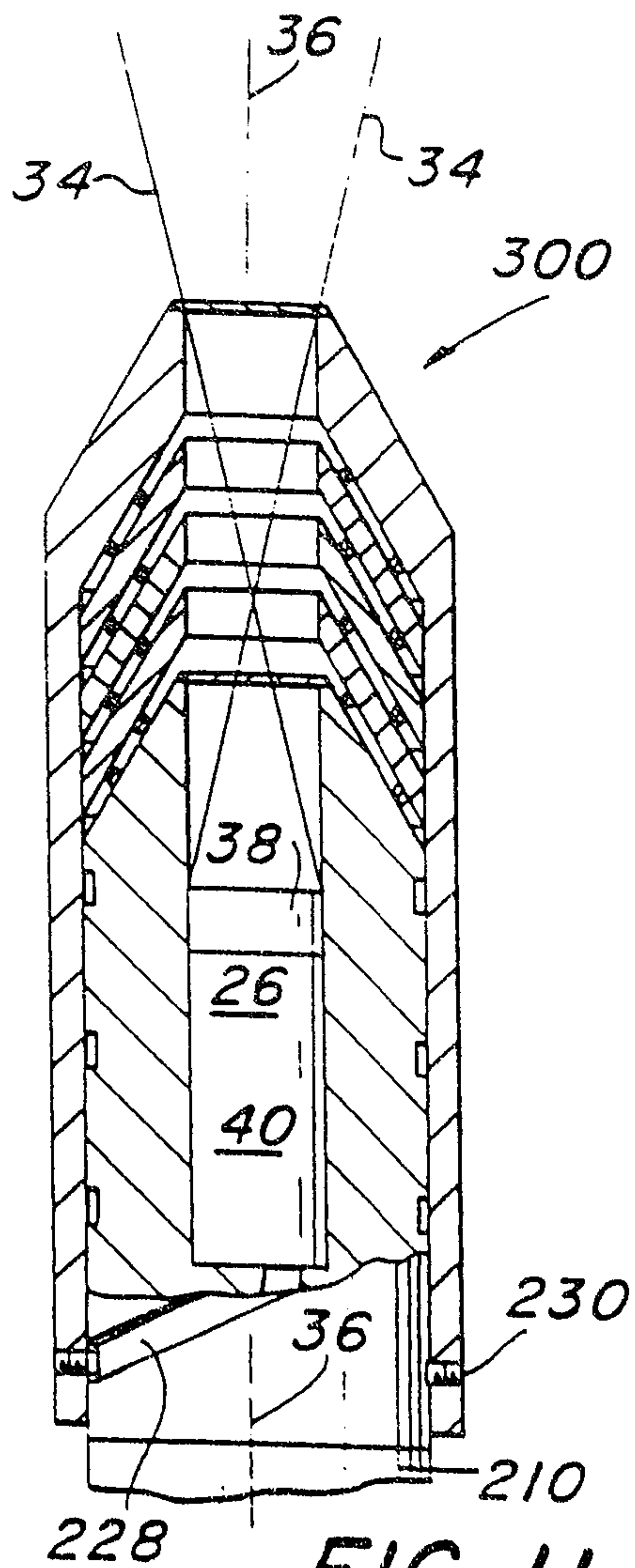


FIG. 11

SUBSTITUTE SHEET

FIG. 17

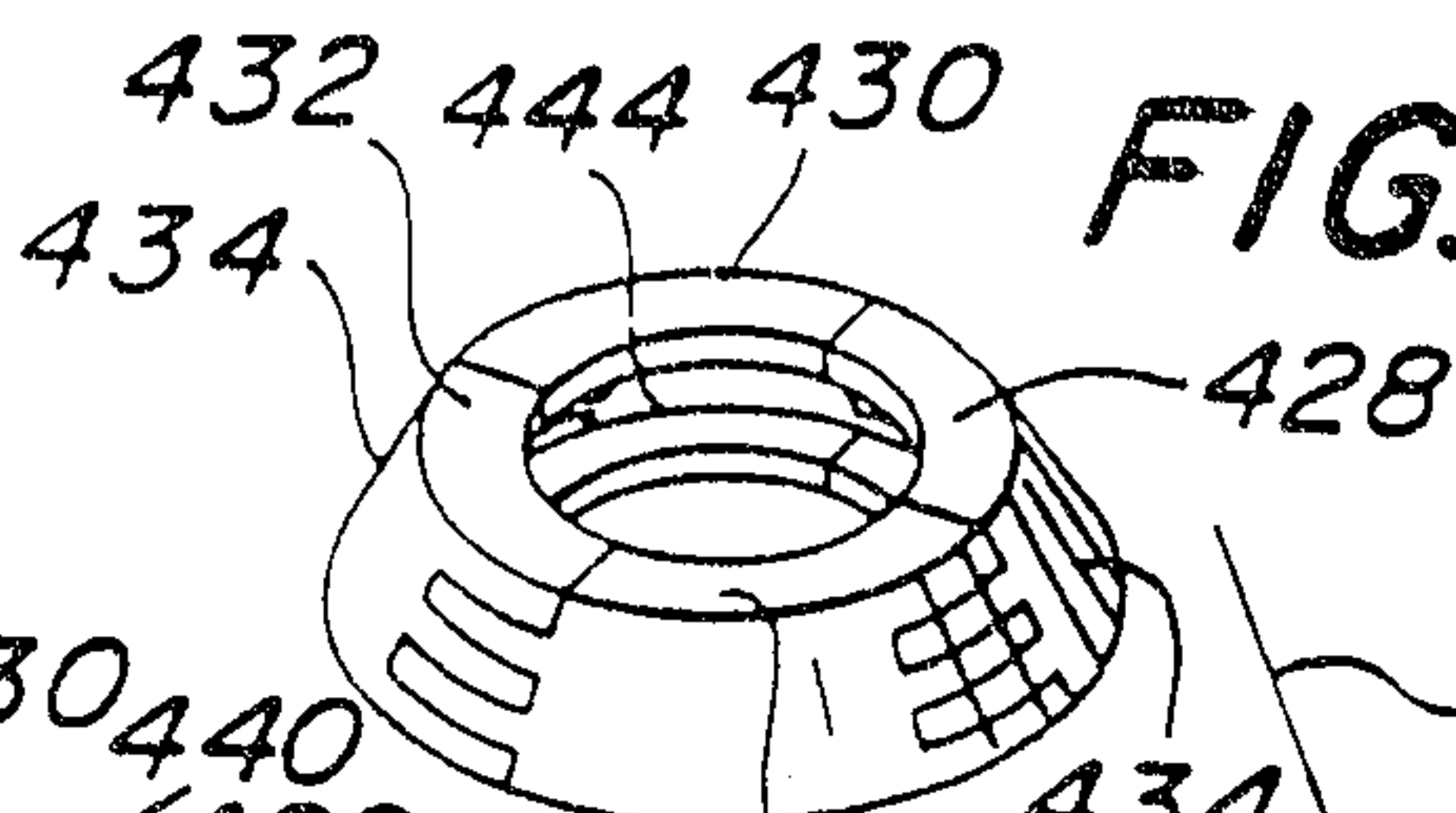


FIG. 16

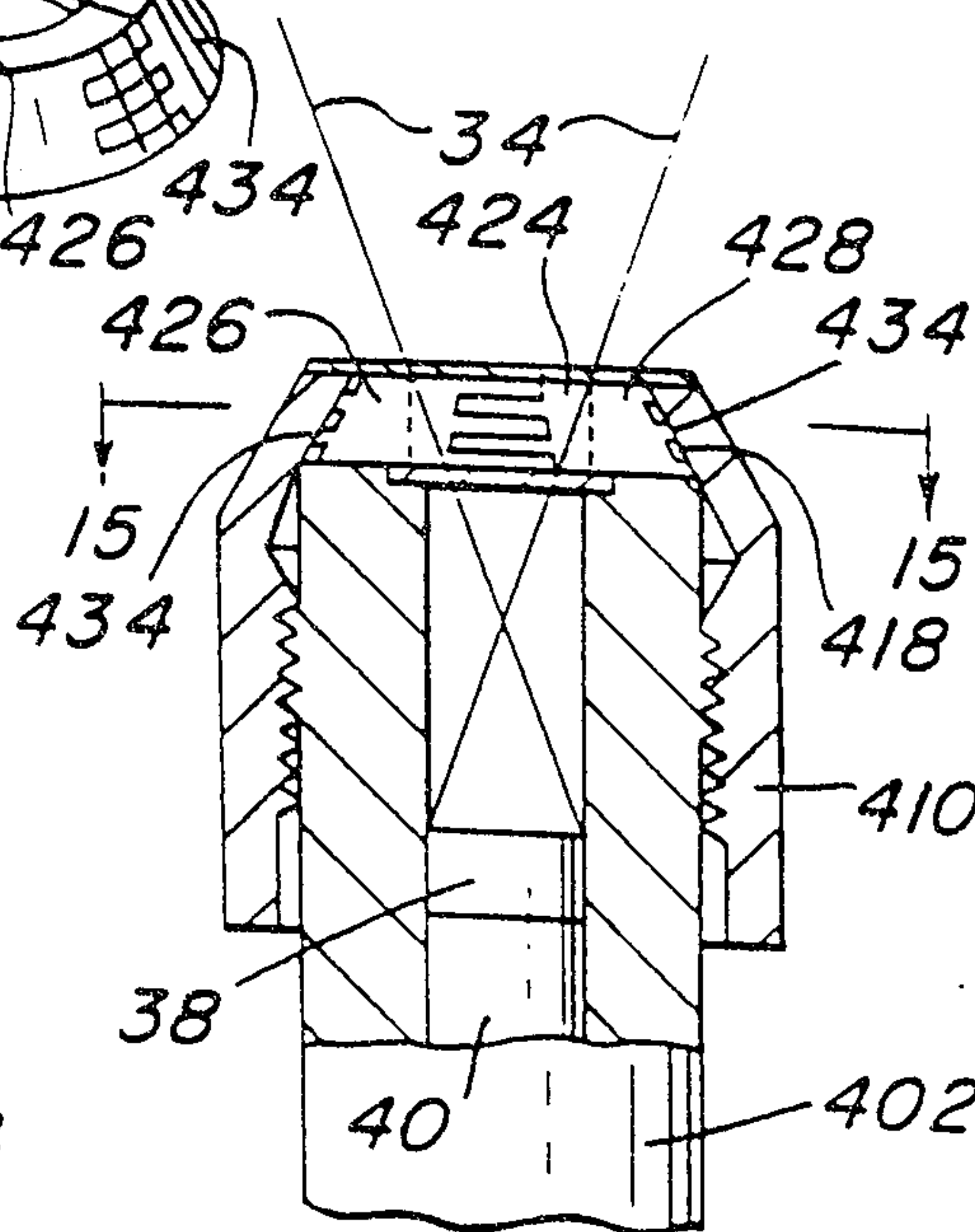
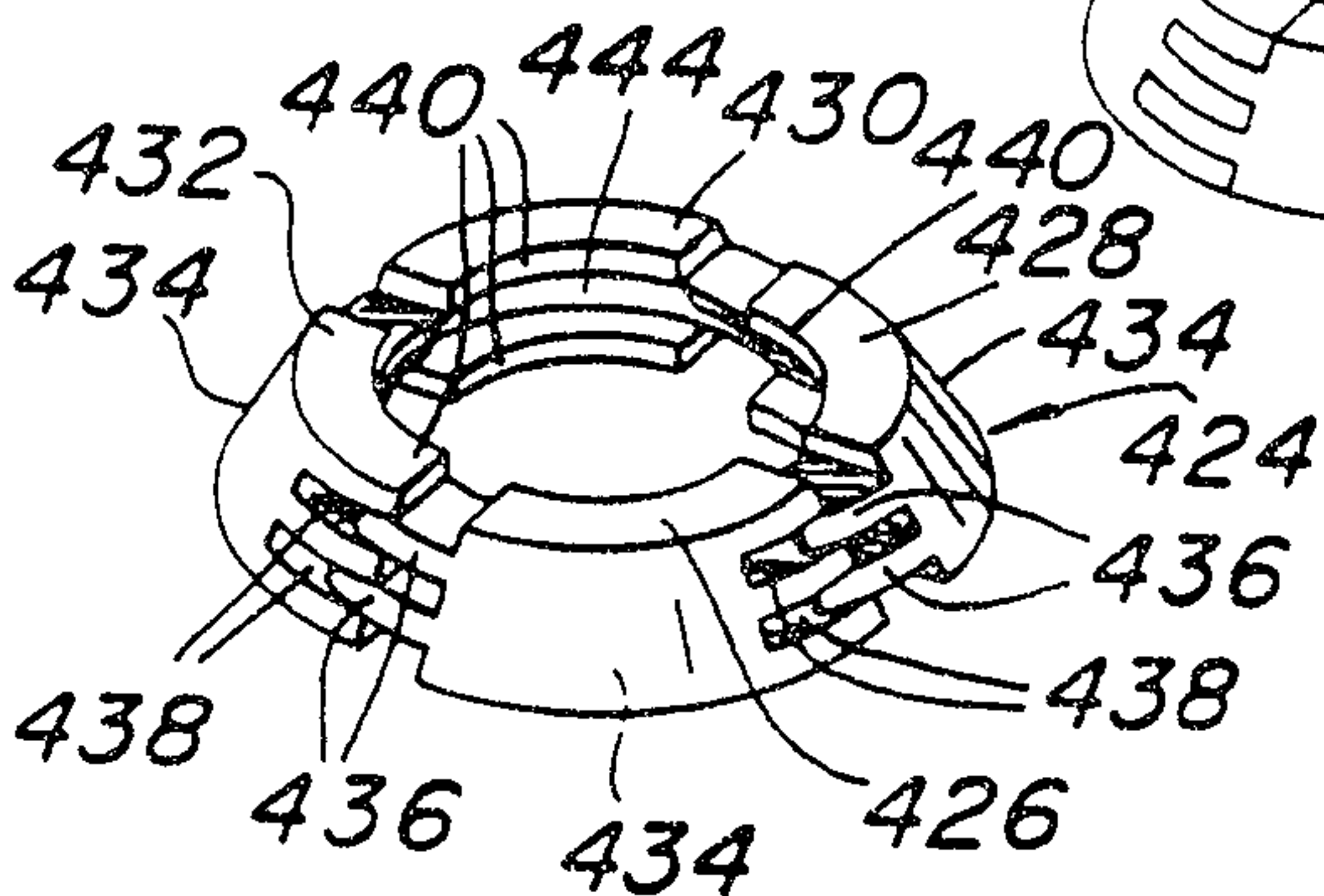


FIG. 13

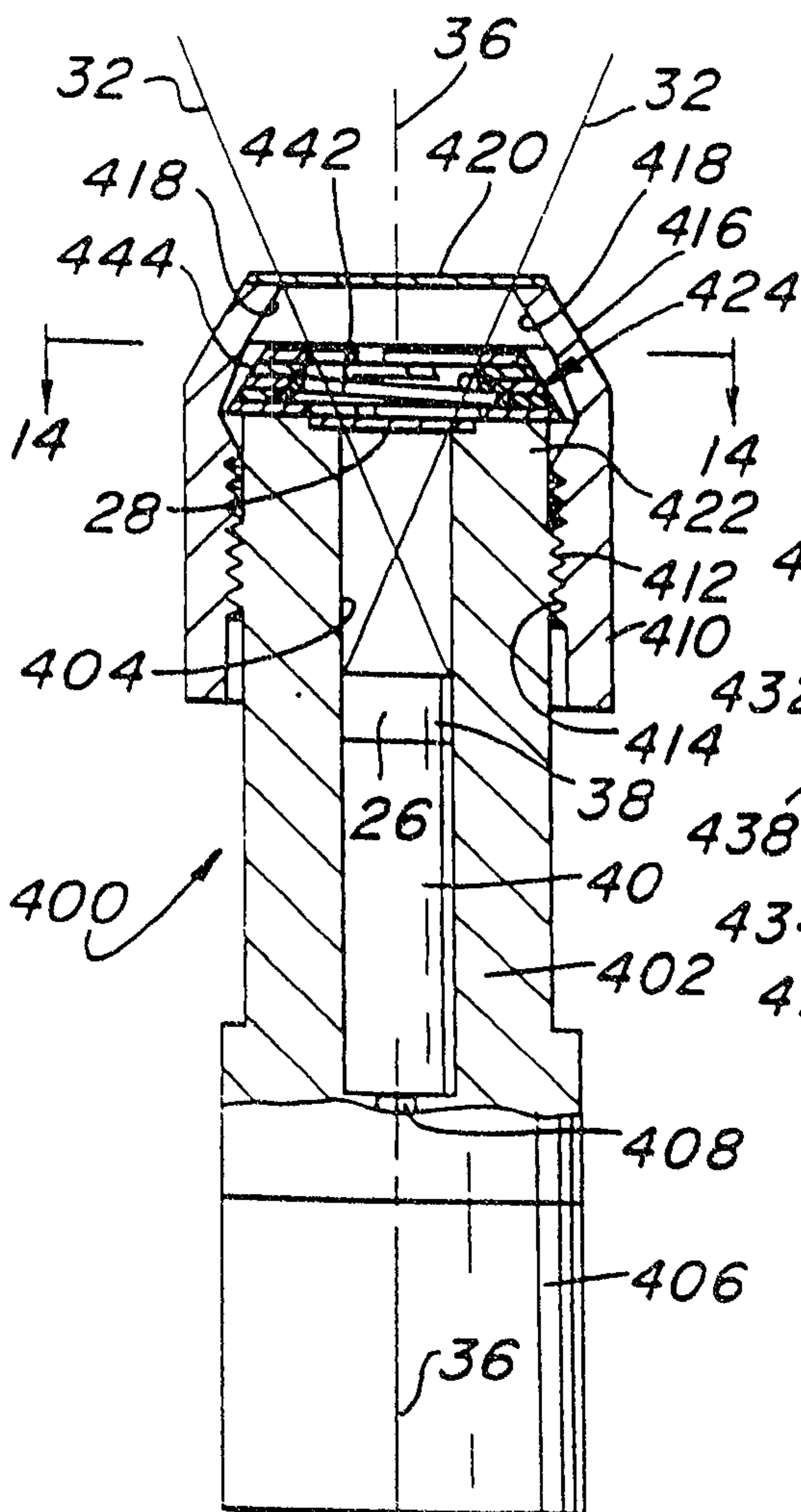


FIG. 12

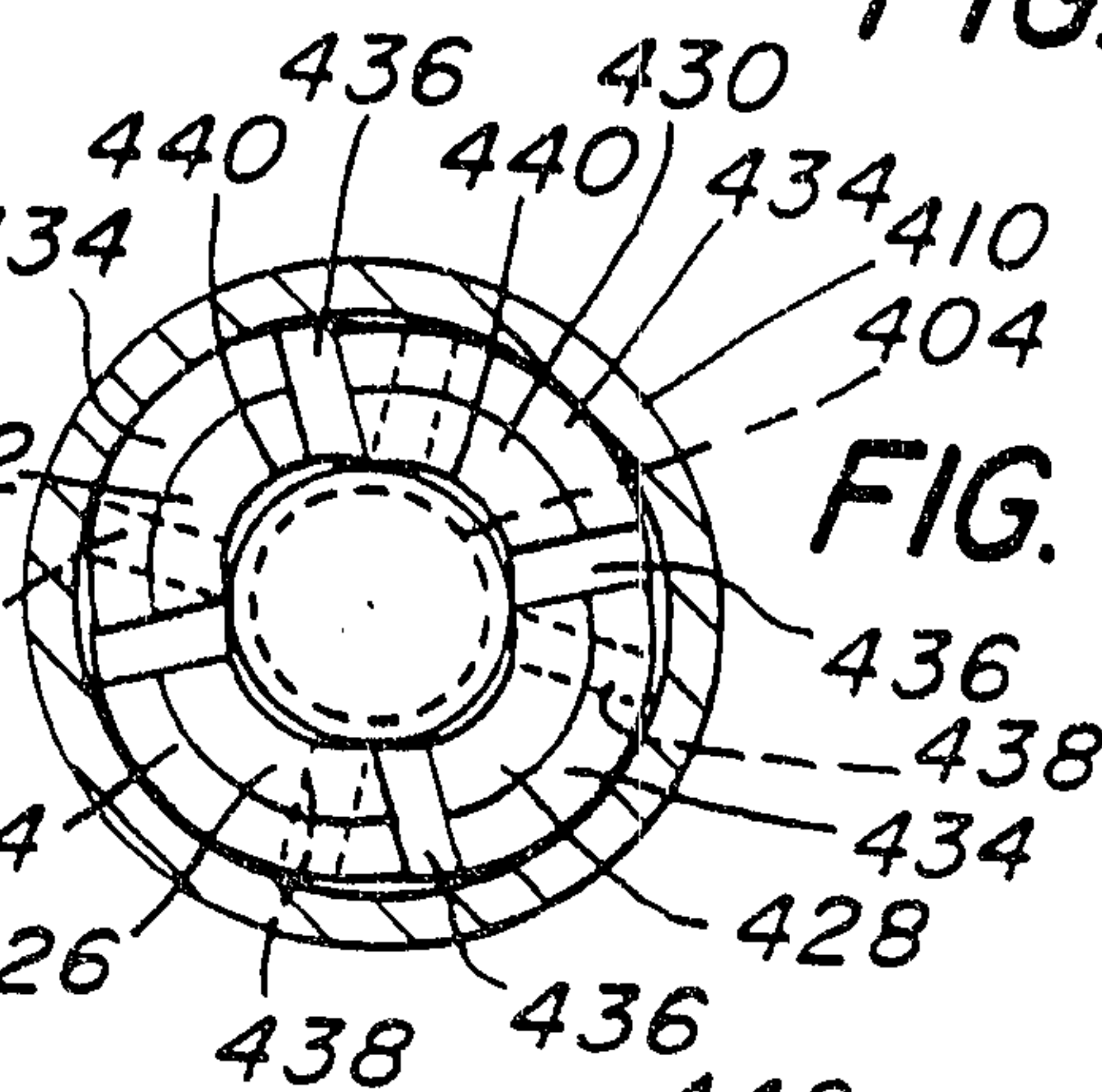


FIG. 14

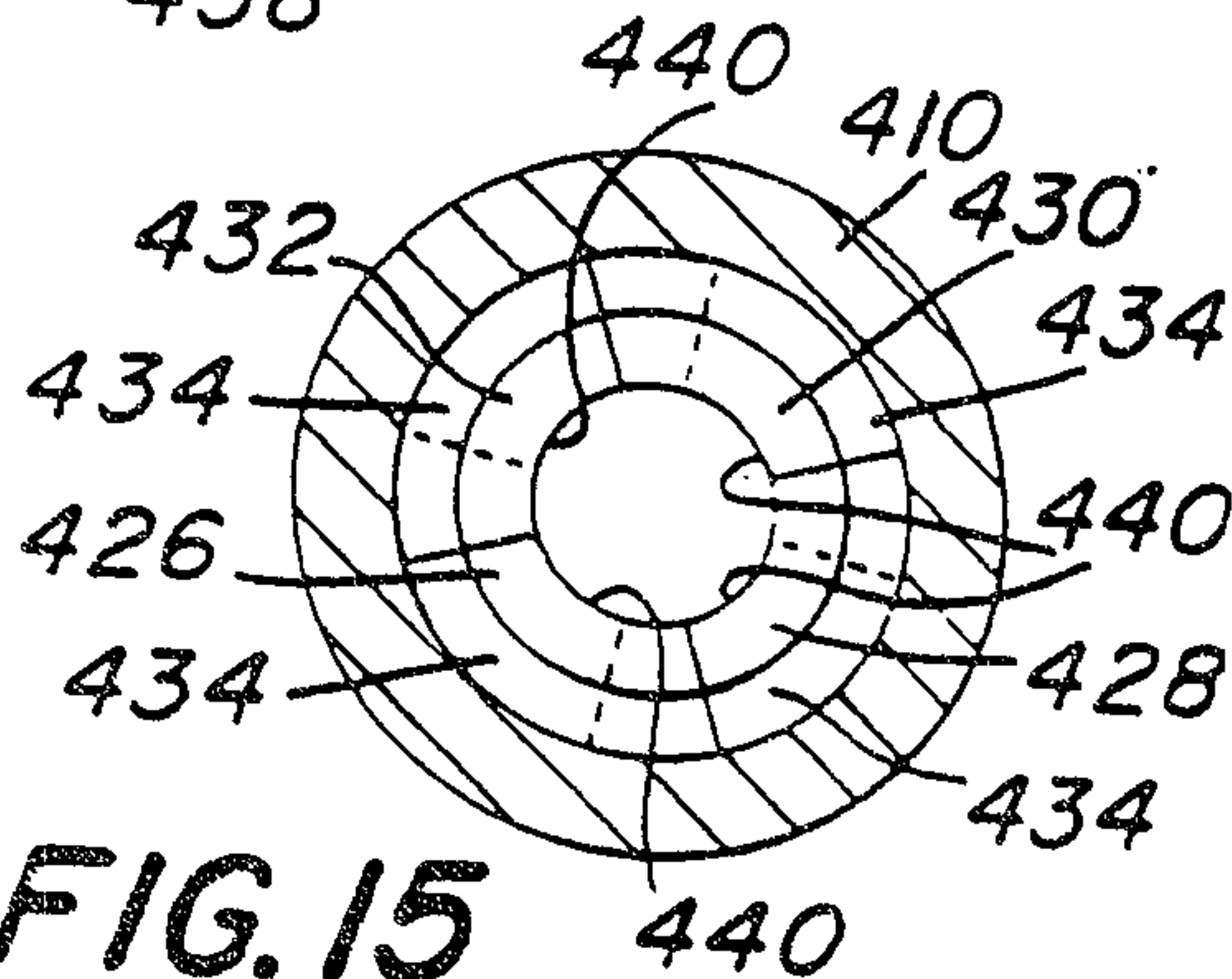


FIG. 15

CONFIDENTIAL SHEET

FIG. 19

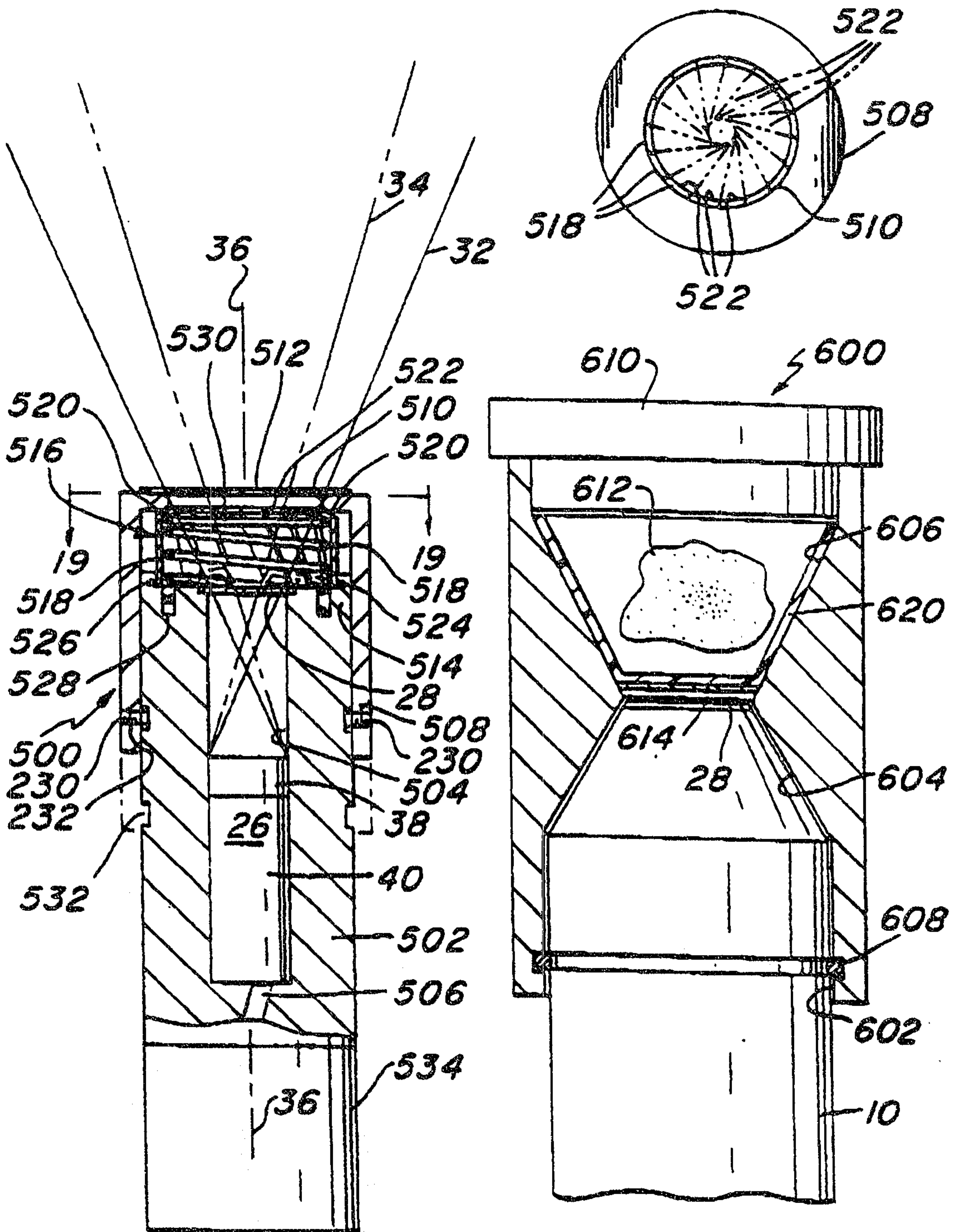


FIG. 18

FIG. 20

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SUBSTITUTE SHEET

FIG. 23

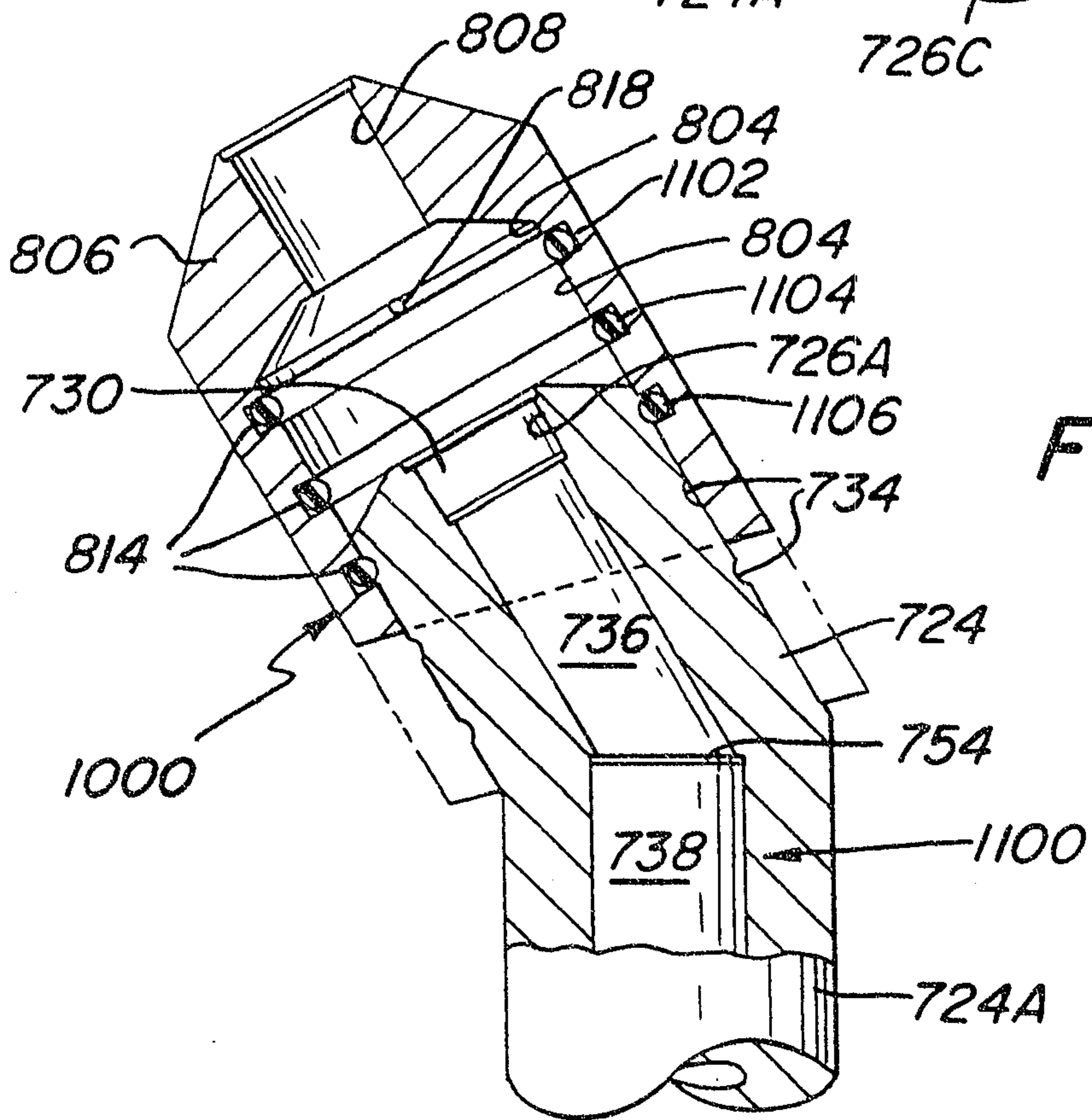
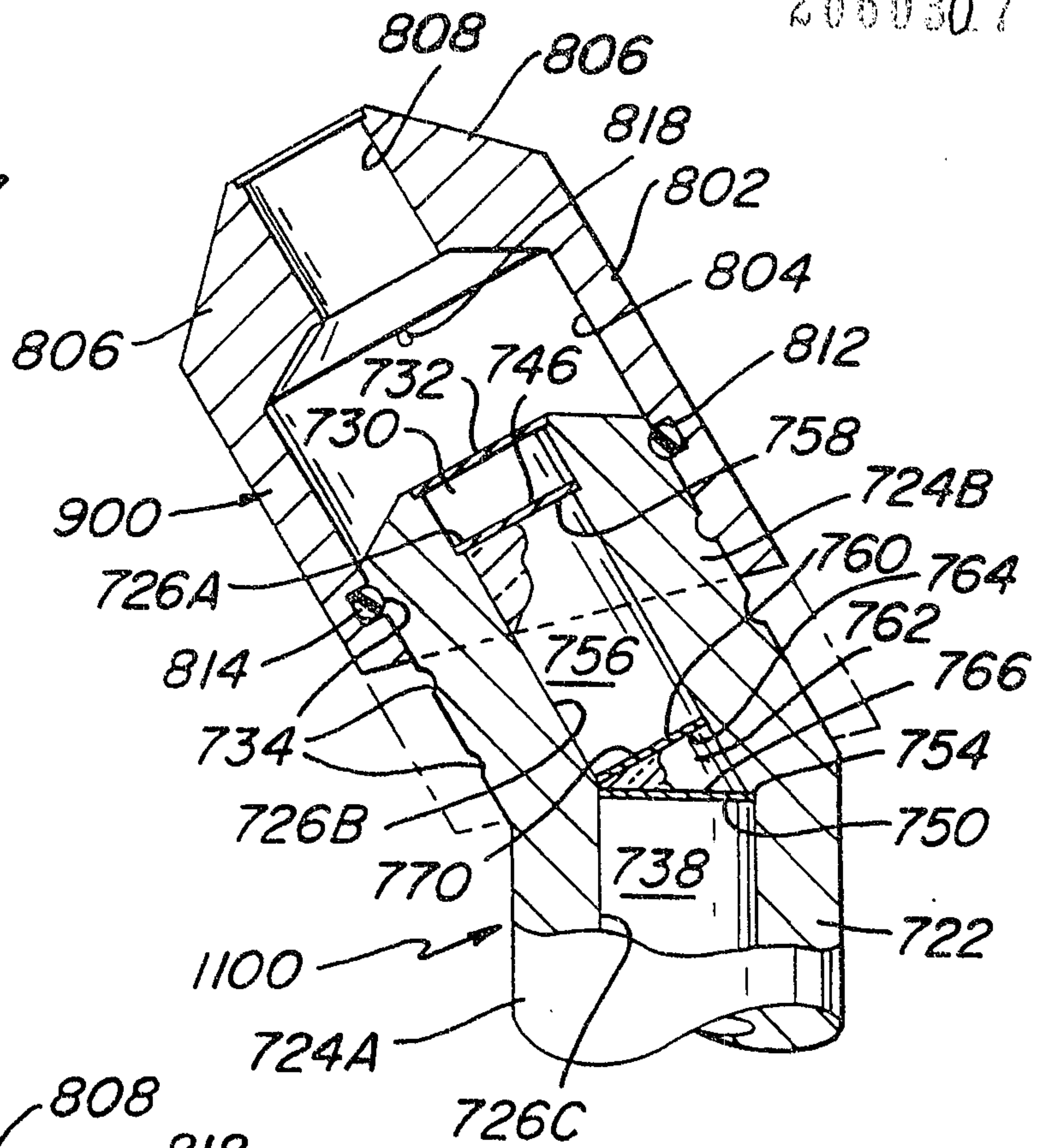


FIG. 24

