

US 20130235968A1

(19) **United States**(12) **Patent Application Publication**
Young et al.(10) **Pub. No.: US 2013/0235968 A1**(43) **Pub. Date: Sep. 12, 2013**(54) **REACTOR VESSEL COOLANT DEFLECTOR SHIELD****Publication Classification**(75) Inventors: **Eric Paul Young**, Corvallis, OR (US);
John T. Groome, Corvallis, OR (US);
Jose N. Reyes, JR., Corvallis, OR (US)(51) **Int. Cl.**
G21C 15/24 (2006.01)(52) **U.S. Cl.**
USPC **376/395**(73) Assignee: **NuScale Power, LLC**, Portland, OR
(US)(21) Appl. No.: **13/448,488**(22) Filed: **Apr. 17, 2012****Related U.S. Application Data**(62) Division of application No. 12/393,577, filed on Feb.
26, 2009.(60) Provisional application No. 61/115,614, filed on Nov.
18, 2008.(57) **ABSTRACT**

A power module includes a reactor vessel containing a coolant and a reactor core located near a bottom end of the reactor vessel. A riser section is located above the reactor core, wherein the coolant circulates past the reactor core and up through the riser section. In one embodiment, a coolant deflector shield includes flow-optimized surfaces, wherein the flow-optimized surfaces direct the coolant towards the bottom end of the reactor vessel. In another embodiment, the reactor housing includes an inward facing portion that varies a flow pressure of the coolant and promotes a circulation of the coolant past a baffle assembly and towards the bottom end of the reactor vessel.

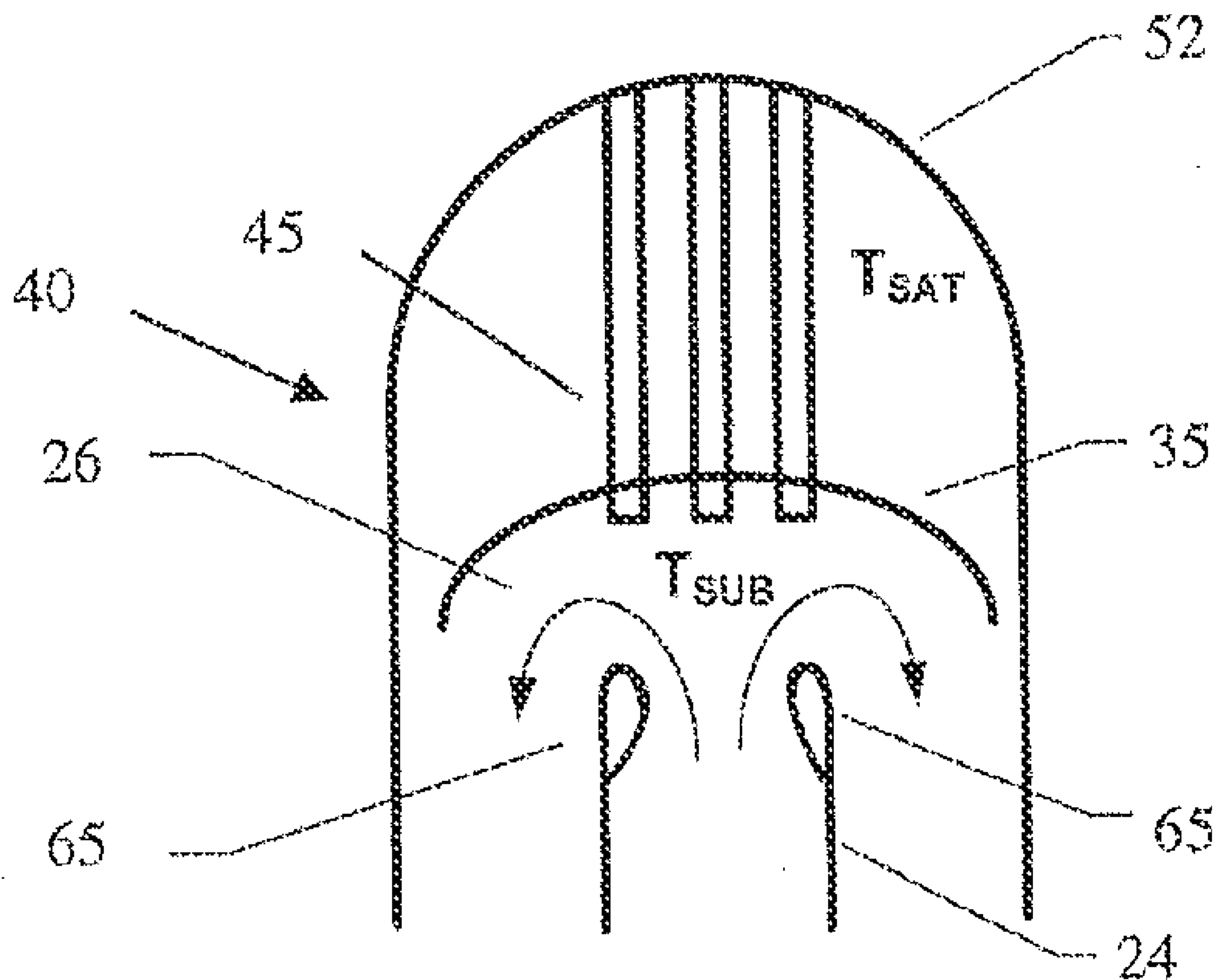


FIG. 1

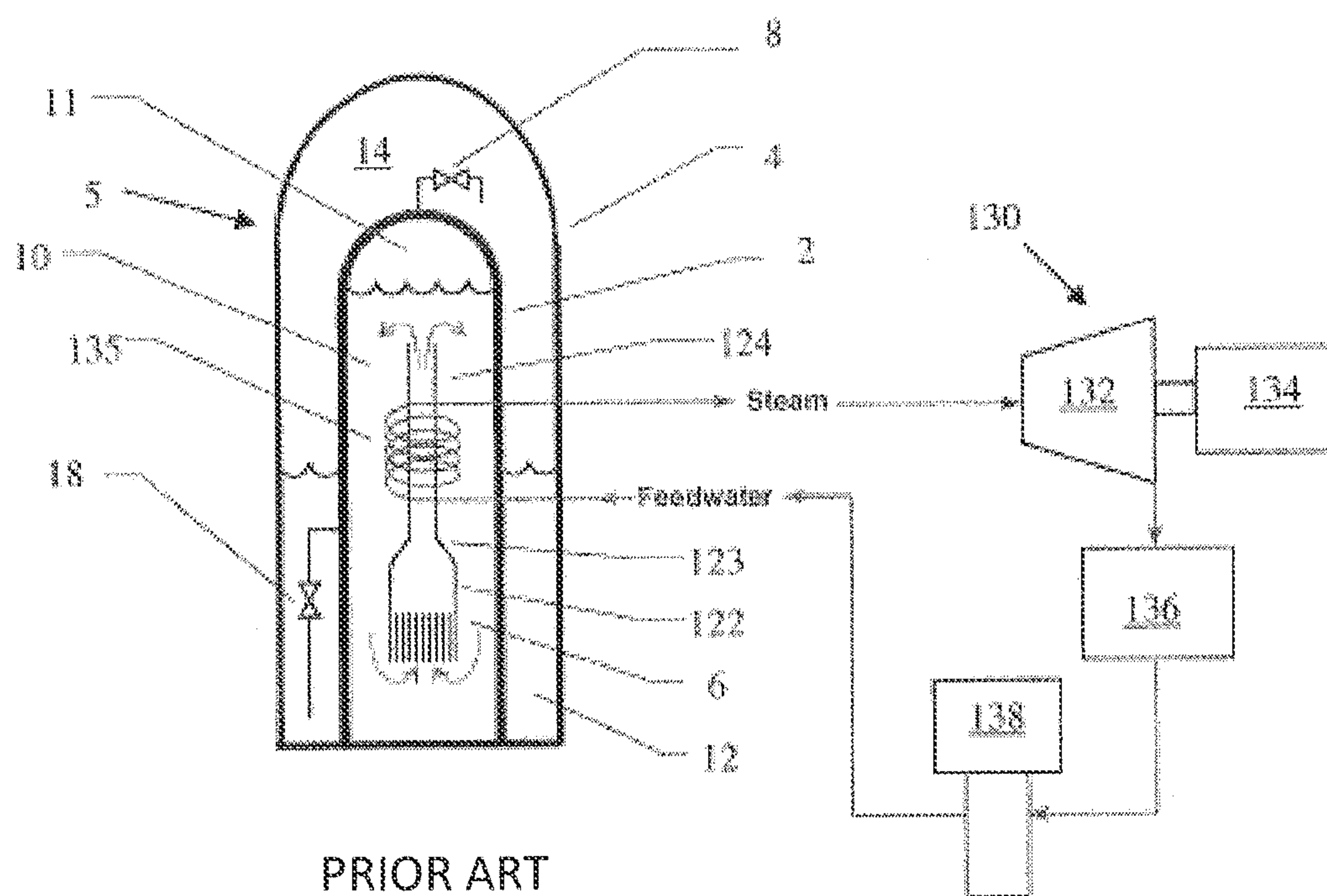
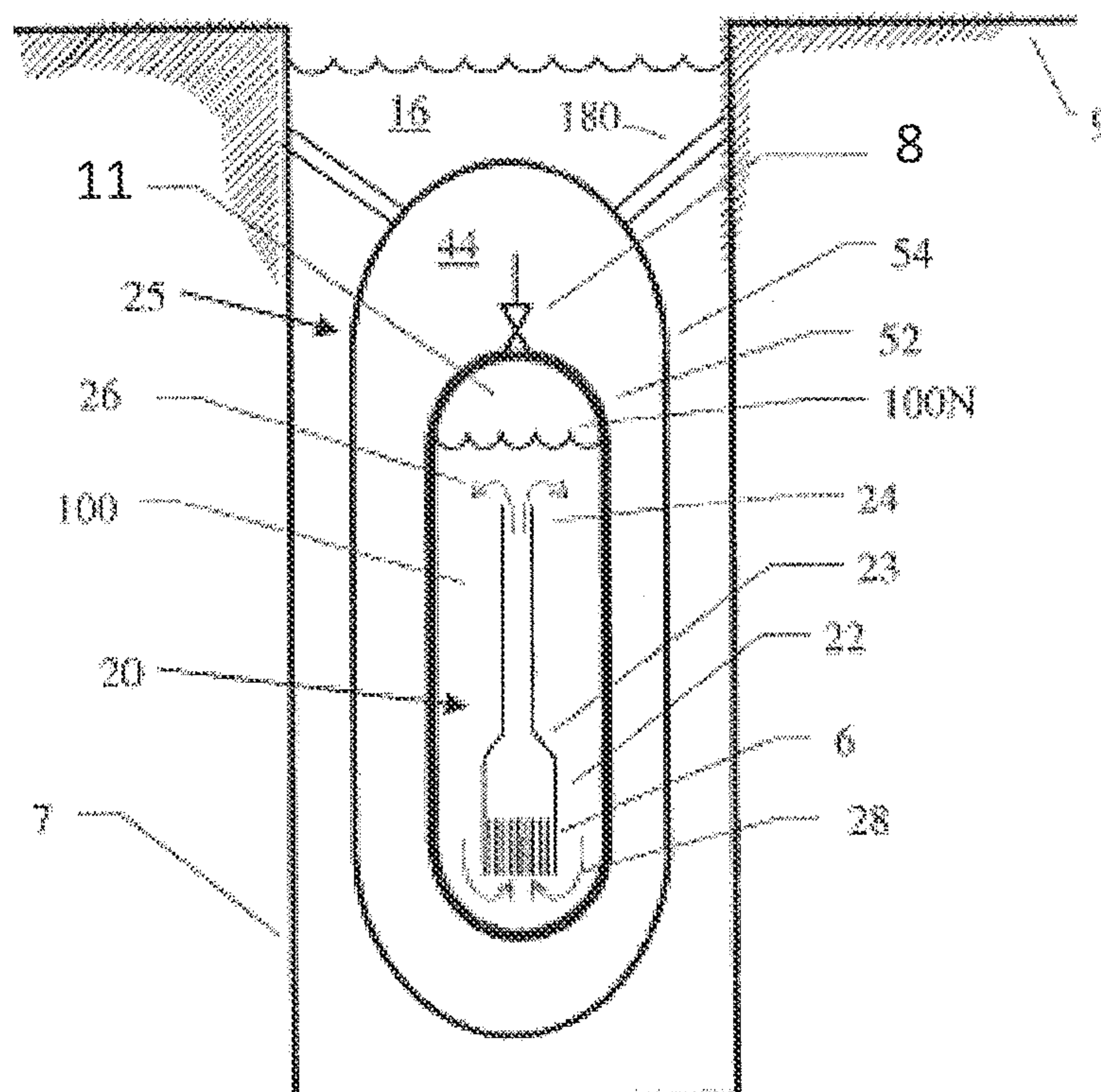


FIG. 2



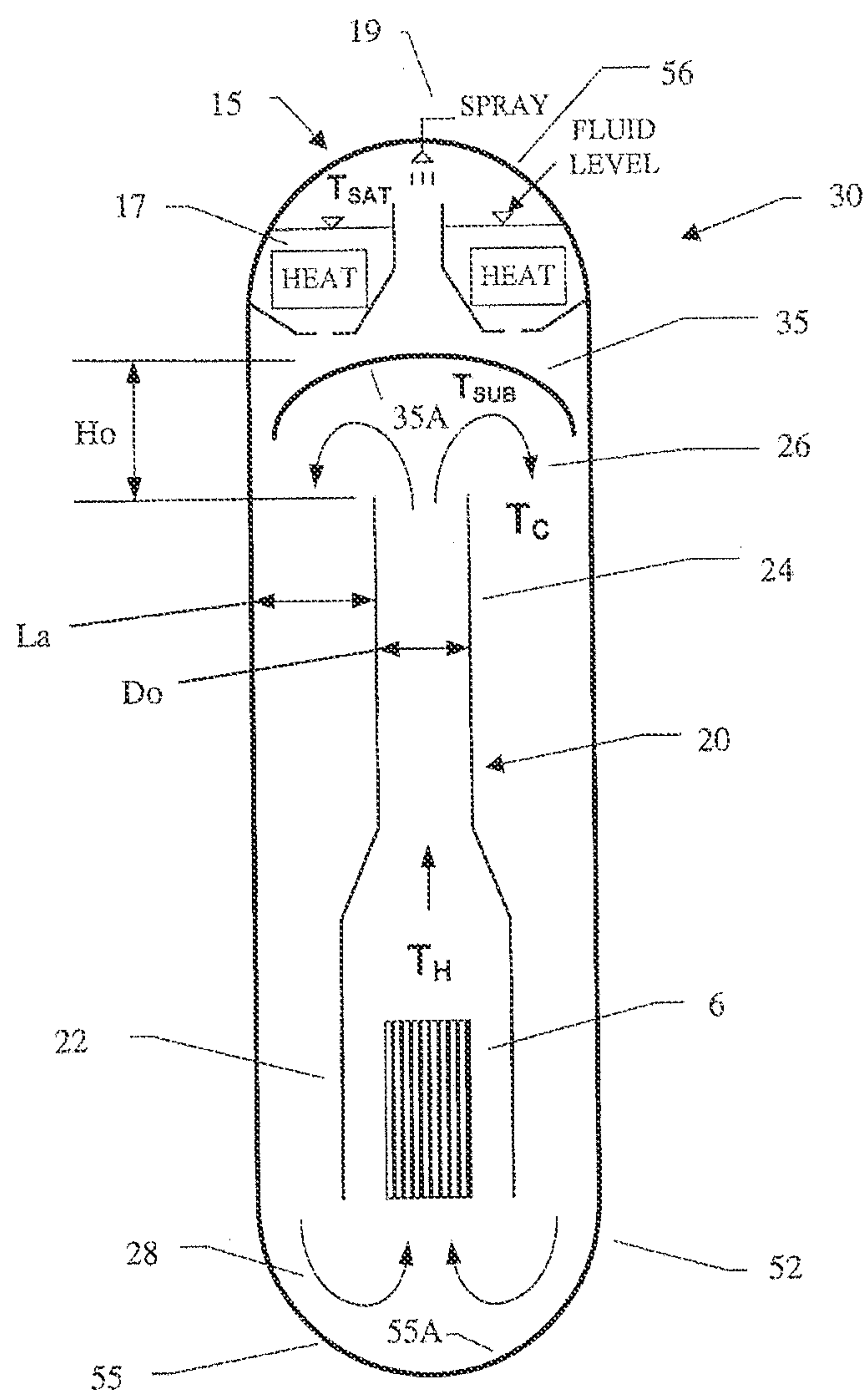


FIG. 3

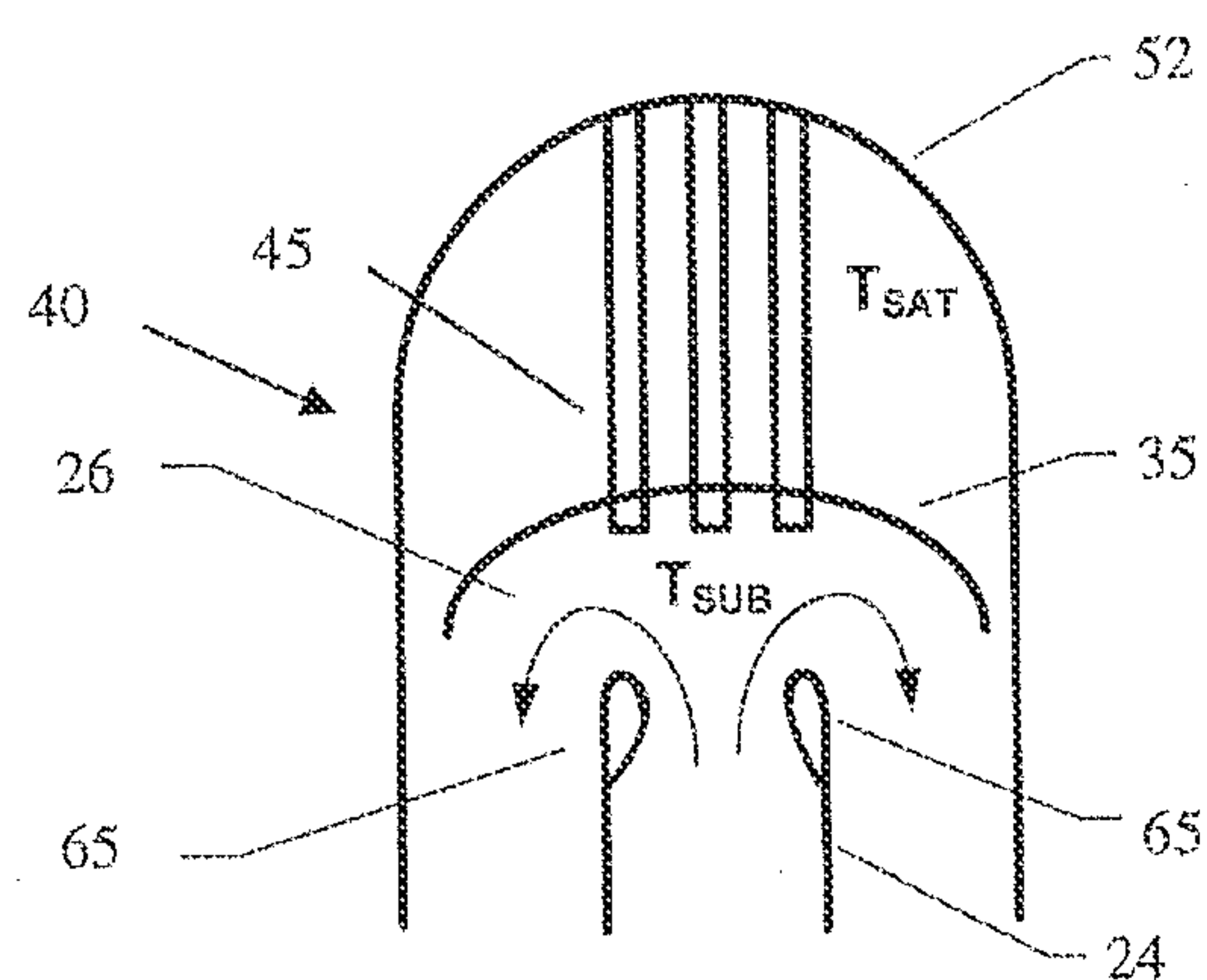


FIG. 4

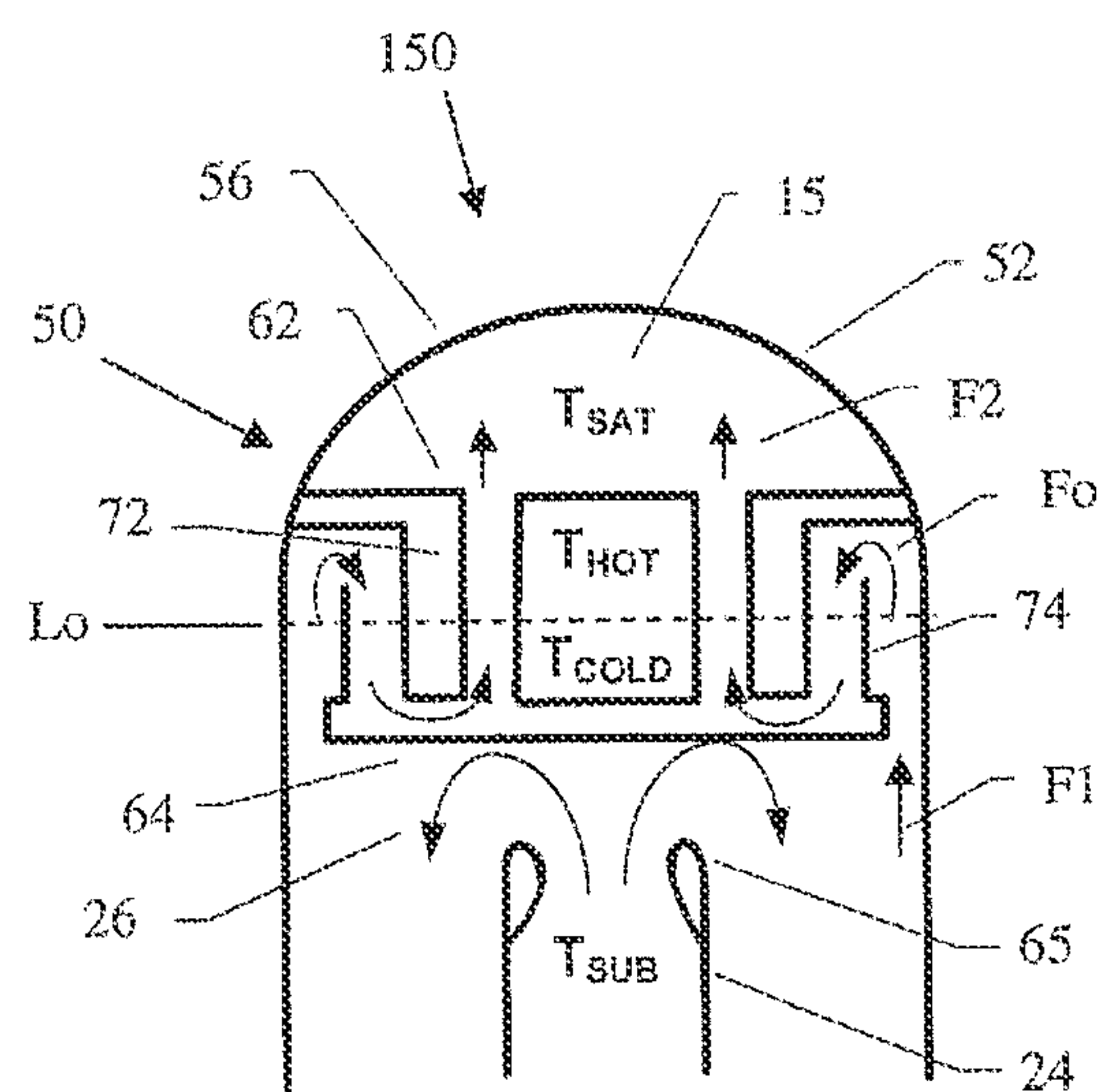


FIG. 5

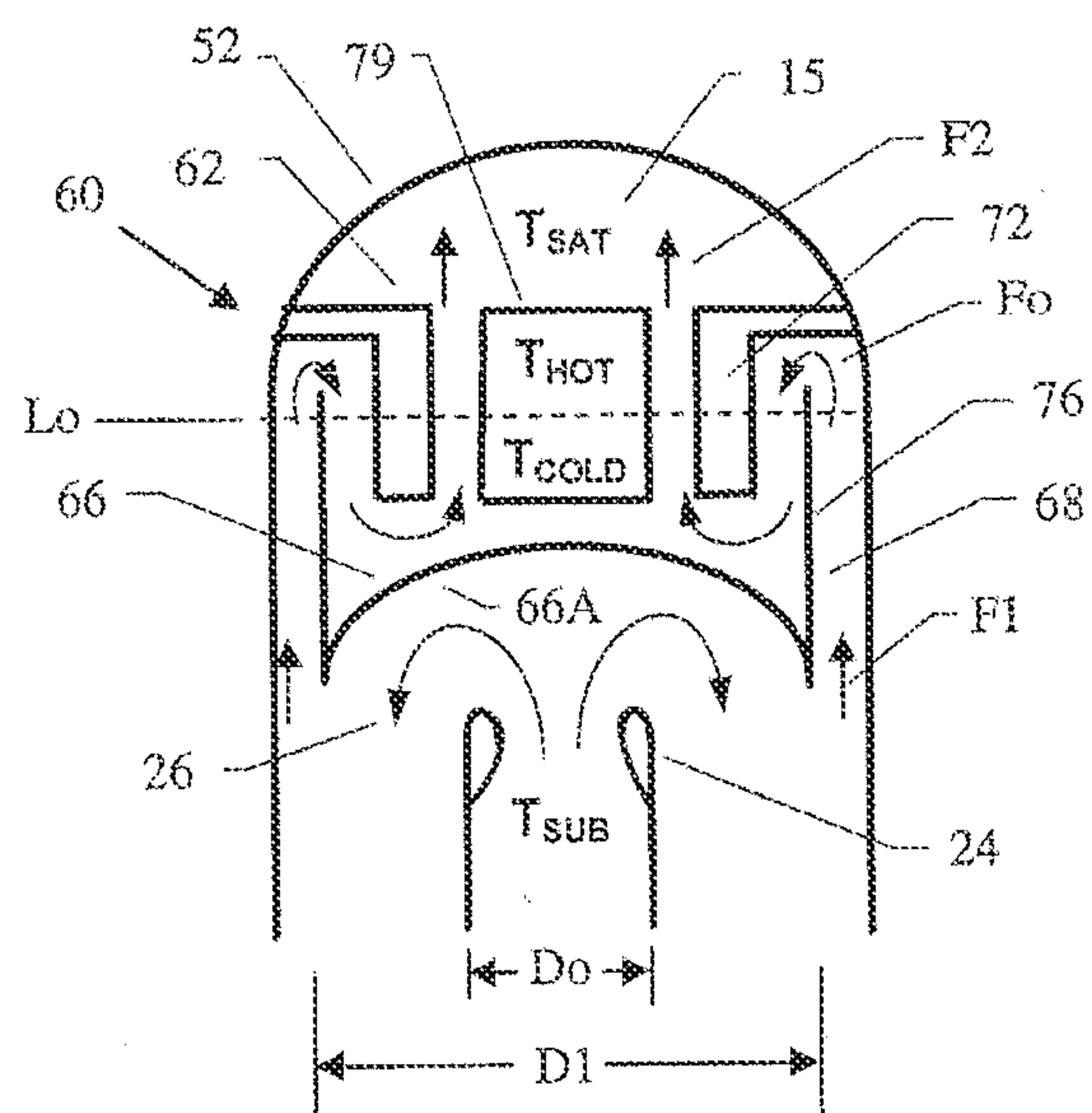


FIG. 6

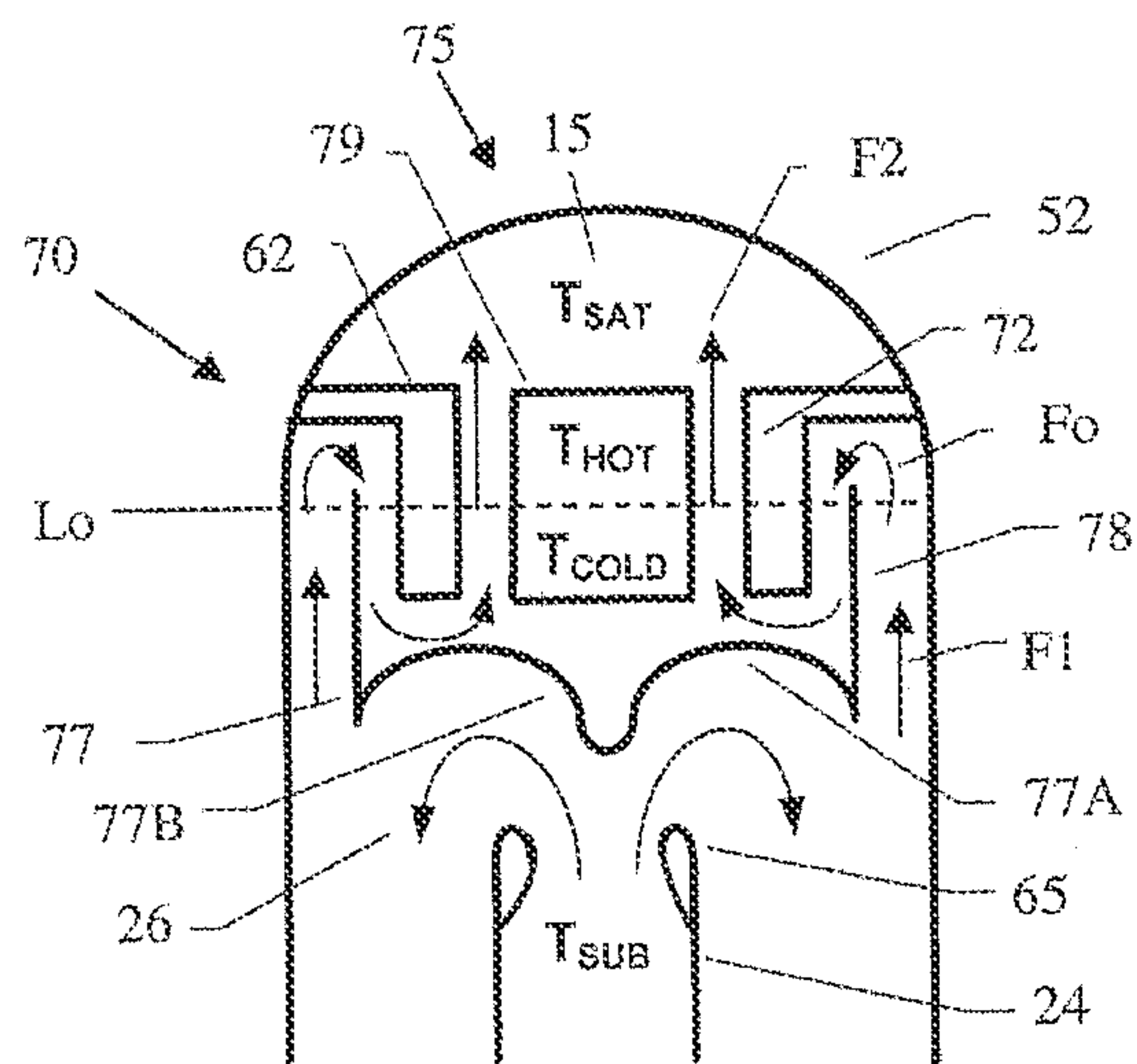


FIG. 7

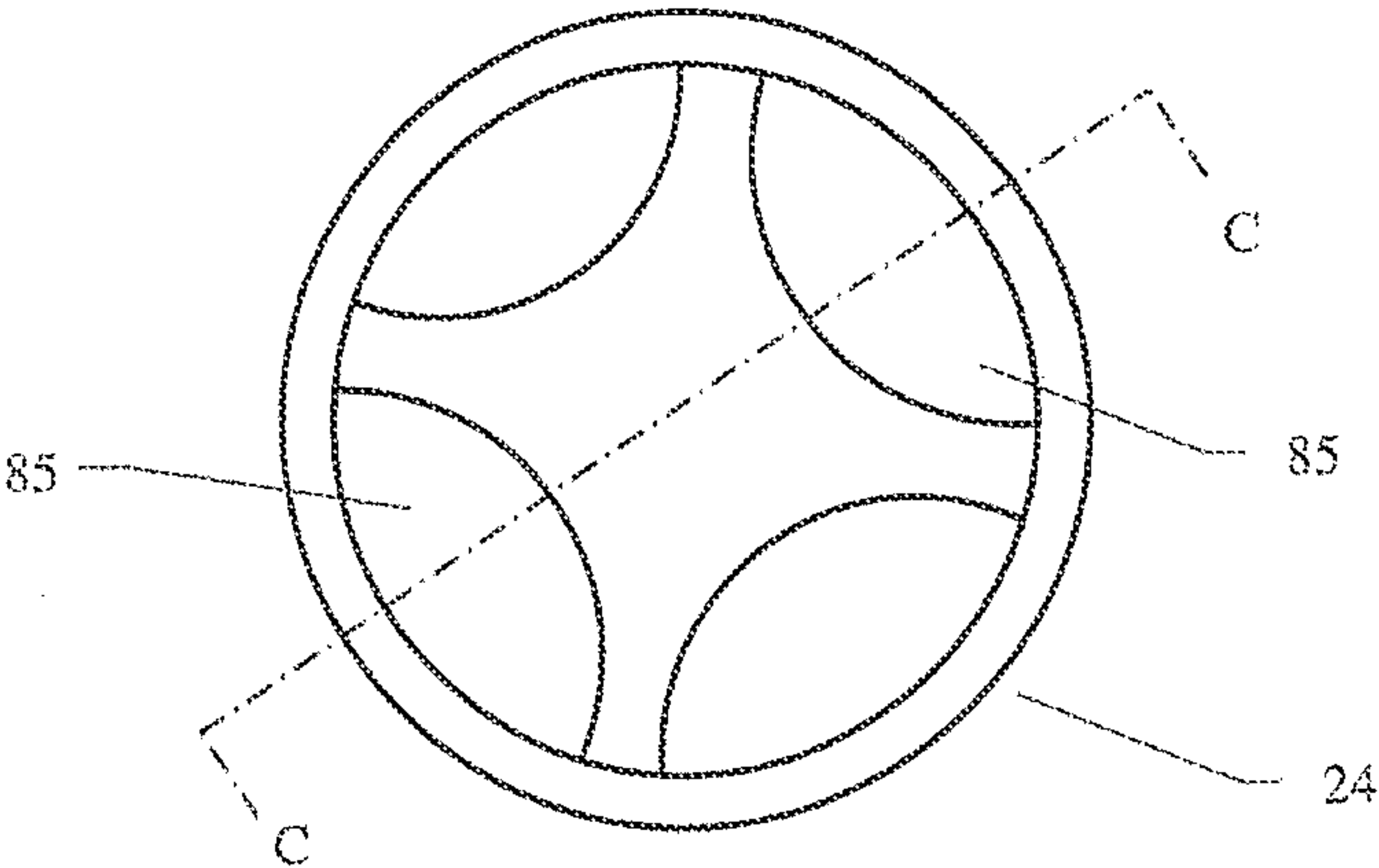


FIG. 8

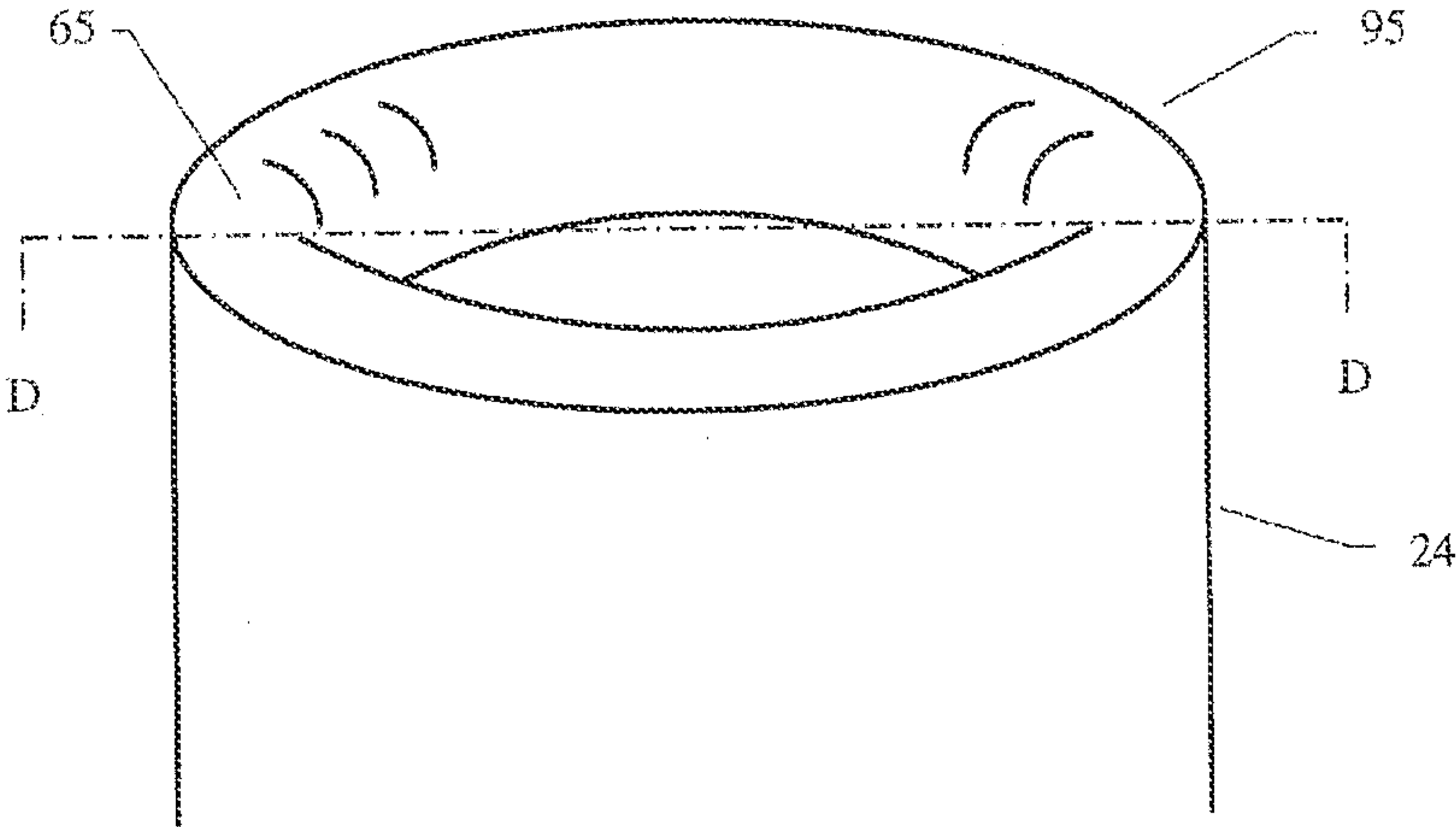


FIG. 9

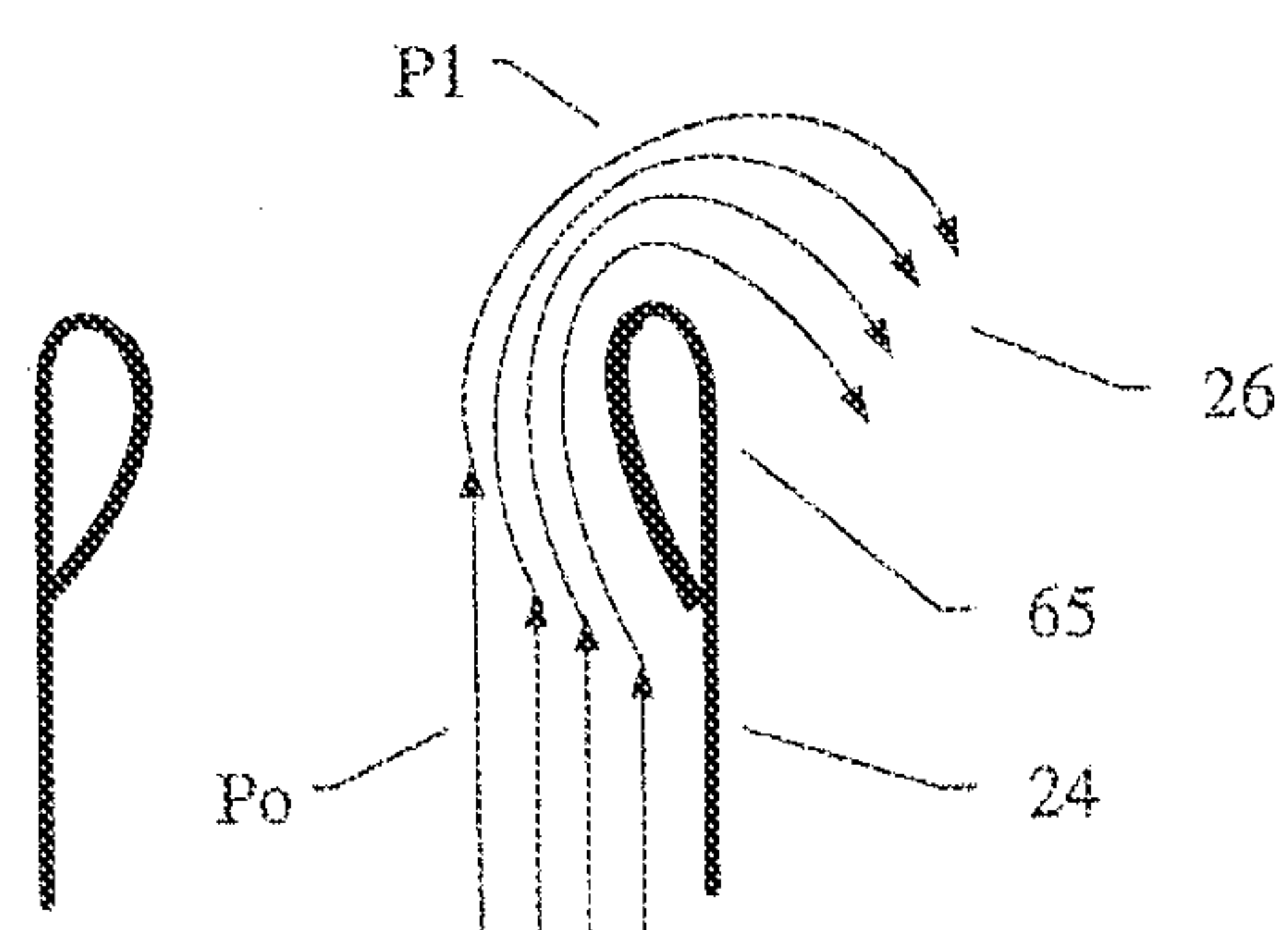
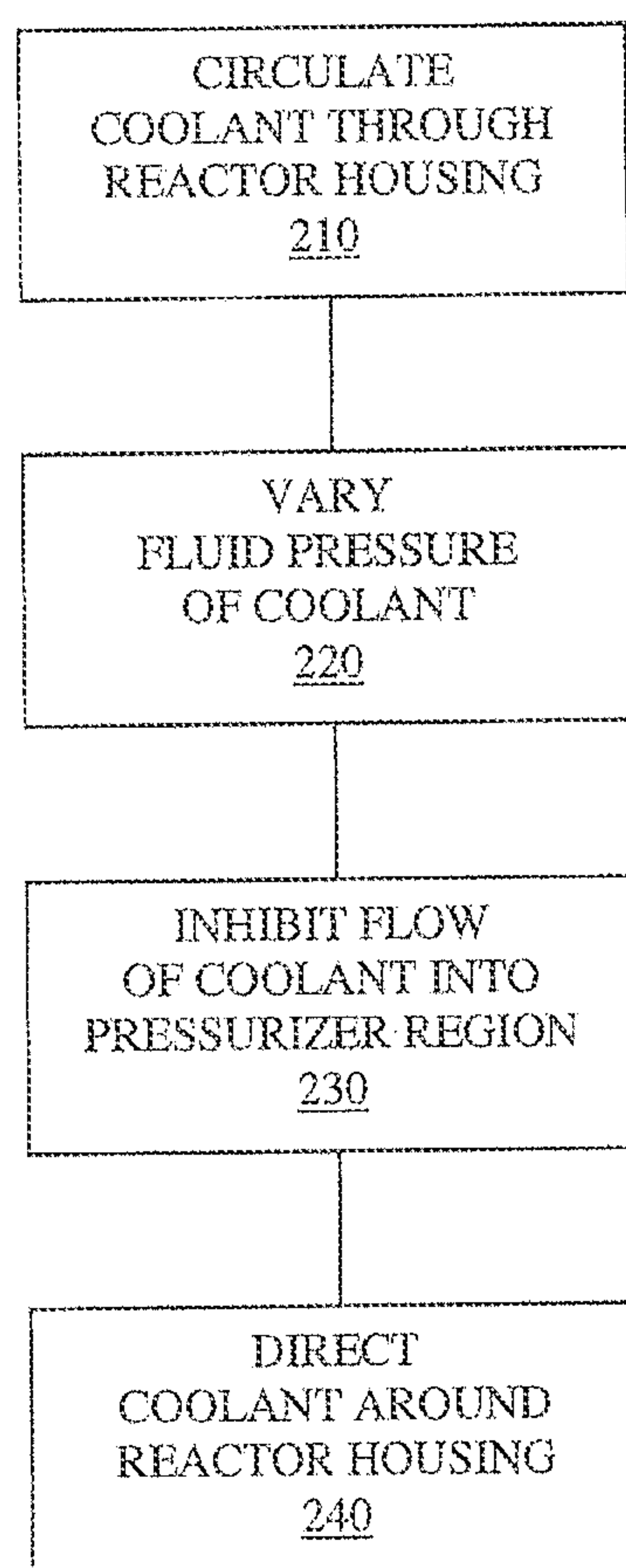


FIG. 10

FIG. 11



REACTOR VESSEL COOLANT DEFLECTOR SHIELD

[0001] This application claims priority to U.S. Provisional Patent Application Ser. No. 61/115,614, filed on Nov. 18, 2008 which is incorporated by reference in its entirety.

TECHNICAL FIELD

[0002] The invention relates to the field of nuclear power generation, including systems designed to cool a reactor core.

BACKGROUND

[0003] In nuclear reactors designed with passive operating systems, the laws of physics are employed to ensure that safe operation of the nuclear reactor is maintained during normal operation or even in an emergency condition without operator intervention or supervision, at least for some predefined period of time. A nuclear reactor **5** includes a reactor core **6** surrounded by a reactor vessel **2**. Water **10** in the reactor vessel **2** surrounds the reactor core **6**. The reactor core **6** is further located in a shroud **122** which surrounds the reactor core **6** about its sides. When the water **10** is heated by the reactor core **6** as a result of fission events, the water **10** is directed from the shroud **122** and out of a riser **124**. This results in further water **10** being drawn into and heated by the reactor core **6** which draws yet more water **10** into the shroud **122**. The water **10** that emerges from the riser **124** is cooled down and directed towards the annulus **123** and then returns to the bottom of the reactor vessel **2** through natural circulation. Pressurized steam **11** is produced in the reactor vessel **2** as the water **10** is heated.

[0004] A heat exchanger **135** circulates feedwater and steam in a secondary cooling system **130** in order to generate electricity with a turbine **132** and generator **134**. The feedwater passes through the heat exchanger **135** and becomes super heated steam. The secondary cooling system **130** includes a condenser **136** and feedwater pump **138**. The steam and feedwater in the secondary cooling system **130** are isolated from the water **10** in the reactor vessel **2**, such that they are not allowed to mix or come into direct contact with each other.

[0005] The reactor vessel **2** is surrounded by a containment vessel **4**. The containment vessel **4** is designed so that water or steam from the reactor vessel **2** is not allowed to escape into the surrounding environment. A steam valve **8** is provided to vent steam **11** from the reactor vessel **2** into an upper half **14** of the containment vessel **4**. A submerged blowdown valve **18** is provided to release the water **10** into suppression pool **12** containing sub-cooled water.

[0006] Water **10** circulates through the reactor vessel **2** as a result of temperature and pressure differentials that develop as a result of heat generation through reactor operation and through heat exchange with the secondary cooling system **130**. Accordingly, the efficiency of the circulation depends on the thermal properties of the reactor module **5** as well as its physical design and geometry. Conventional nuclear reactors include certain design features that tend to provide less than optimal coolant circulation, and must therefore rely on increased coolant volume or redundant components to ensure sufficient performance. The present invention addresses these and other problems.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] FIG. 1 illustrates a nuclear power system.

[0008] FIG. 2 illustrates a power module assembly comprising an internally dry containment vessel.

[0009] FIG. 3 illustrates a cross sectional view of an embodiment of a power module assembly comprising a reactor vessel deflector shield.

[0010] FIG. 4 illustrates a partial view of an example power module assembly comprising a reactor vessel deflector shield supported by one or more control rod guide tubes.

[0011] FIG. 5 illustrates a partial view of an example power module assembly comprising a baffle assembly and a coolant flow augmentation mechanism.

[0012] FIG. 6 illustrates an example baffle assembly comprising a reactor vessel deflector shield.

[0013] FIG. 7 illustrates a partial view of an example power module assembly comprising a reactor vessel deflector shield and coolant flow augmentation mechanism.

[0014] FIG. 8 illustrates a plan view of an embodiment of the coolant flow augmentation mechanism comprising a plurality of inward facing portions.

[0015] FIG. 9 illustrates an elevated side view of an embodiment of the coolant flow augmentation mechanism comprising a continuous inward facing portion.

[0016] FIG. 10 illustrates coolant flow around a coolant flow augmentation mechanism.

[0017] FIG. 11 illustrates a novel method of cooling a reactor core using a reactor vessel deflector shield.

SUMMARY OF THE INVENTION

[0018] A power module is herein disclosed as comprising a reactor vessel containing a coolant, and a reactor core located near a bottom end of the reactor vessel. A riser section is located above the reactor core, wherein the coolant circulates past the reactor core and up through the riser section. The power module further comprises a coolant deflector shield including an ellipsoidal or other flow-optimized surface, wherein the flow-optimized surface directs the coolant towards the bottom end of the reactor vessel.

[0019] A nuclear reactor module is herein disclosed as comprising a reactor vessel including an upper end and a lower end, a pressurizer located near the upper end of the reactor vessel, and a reactor core located near the bottom end of the reactor vessel. The nuclear reactor module further comprises a baffle assembly located between the reactor core and the pressurizer, and a reactor housing that directs coolant flow through the reactor core. The reactor housing comprises an inward facing portion that varies a flow pressure of the coolant and promotes a circulation of the coolant past the baffle assembly and towards the bottom end of the reactor vessel.

[0020] A method of cooling a reactor core is herein disclosed as comprising circulating a primary coolant through a reactor housing comprising an upper riser, and directing a flow of the coolant down a reactor vessel and around the reactor housing, wherein an ellipsoidal shaped lower end of the reactor vessel promotes coolant flow through the reactor core. An ellipsoidal or flow-optimized surface shaped deflector shield located above the upper riser promotes coolant flow around the reactor housing.

[0021] The invention will become more readily apparent from the following detailed description of a preferred embodiment of the invention which proceeds with reference to the accompanying drawings.

DESCRIPTION OF EXAMPLE EMBODIMENTS

[0022] Various embodiments disclosed or referred to herein may be operated consistent, or in conjunction, with features found in co-pending U.S. application Ser. No. 11/941,024 which is herein incorporated by reference in its entirety.

[0023] FIG. 2 illustrates a power module assembly 25 comprising an internally dry containment vessel 54. The containment vessel 54 is cylindrical in shape, and has ellipsoidal, domed, concave or hemispherical upper and lower ends. The entire power module assembly 25 may be submerged in a pool of water 16 which serves as an effective heat sink. The pool of water 16 and the containment vessel 54 may further be located below ground 9 in a reactor bay 7. The containment vessel 54 may be welded or otherwise sealed to the environment, such that liquids and gas do not escape from, or enter, the power module assembly 25. The containment vessel 54 may be supported at any external surface.

[0024] In one embodiment, the containment vessel 54 is suspended in the pool of water 16 by one or more mounting connections 180. A reactor vessel 52 is located or mounted inside the containment vessel 54. An inner surface of the reactor vessel 52 may be exposed to a wet environment including a coolant 100 or liquid, such as water, and an outer surface may be exposed to a dry environment such as air. The reactor vessel 52 may be made of stainless steel or carbon steel, may include cladding, and may be supported within the containment vessel 54.

[0025] The power module assembly 25 may be sized so that it can be transported on a rail car. For example, the containment vessel 54 may be constructed to be approximately 4.3 meters in diameter and approximately 17.7 meters in height (length). Refueling of the reactor core 6 may be performed by transporting the entire power module assembly 50 by rail car or overseas, for example, and replacing it with a new or refurbished power module assembly which has a fresh supply of fuel rods.

[0026] The containment vessel 54 encapsulates and, in some conditions, cools the reactor core 6. It is relatively small, has a high strength and may be capable of withstanding six or seven times the pressure of conventional containment designs in part due to its smaller overall dimensions. Given a break in the primary cooling system of the power module assembly 25 no fission products are released into the environment. Decay heat may be removed from the power module assembly 25 under emergency conditions. The reactor core 6 is illustrated as being submerged or immersed in a primary coolant 100, such as water. The reactor vessel 52 houses the coolant 100 and the reactor core 6. A reactor housing 20 comprises a shroud 22 in a lower portion and a riser 24 in an upper portion of the reactor housing 20. The riser 24 may be substantially cylindrical in shape. The shroud 22 surrounds the reactor core 6 about its sides and serves to direct the coolant 100 (shown as coolant flow 26, 28) up through the center of the riser 24 located in the upper half of the reactor vessel 52, then back down the annulus 23, as a result of natural circulation of the coolant 100. In one embodiment, the reactor vessel 52 is approximately 2.7 meters in diameter and includes an overall height (length) of approximately 13.7 meters. The reactor vessel 52 may include a predominately cylindrical shape with ellipsoidal, domed, concave, or hemispherical upper and lower ends. The reactor vessel 52 is normally at operating pressure and temperature. The containment vessel 54 is internally dry and may operate at atmo-

spheric pressure with wall temperatures at or near the temperature of the pool of water 16.

[0027] The containment vessel 54 substantially surrounds the reactor vessel 52 and may provide a dry, voided, or gaseous environment identified as containment region 44. Containment region 44 may comprise an amount of air or other fill gas such as Argonne. The containment vessel 54 includes an inner surface or inner wall which is adjacent to the containment region 44. The containment region 44 may include a gas or gases instead of or in addition to air. In one embodiment, the containment region 44 is maintained at or below atmospheric pressure, for example as a partial vacuum. Gas or gasses in the containment vessel may be removed such that the reactor vessel 52 is located in a complete or partial vacuum in the containment region 44.

[0028] During normal operation, thermal energy from the fission events in the reactor core 6 causes the coolant 100 to heat. As the coolant 100 heats up, it becomes less dense and tends to rise up through the riser 24. As the coolant 100 temperature reduces, it becomes relatively denser than the heated coolant and is circulated around the outside of the annulus 23, down to the bottom of the reactor vessel 52 and up through the shroud 22 to once again be heated by the reactor core 6. This natural circulation causes the coolant 100 (shown as coolant flow 26, 28) to cycle through the heat exchanger 135, transferring heat to a secondary coolant, such as the secondary cooling system 130 of FIG. 1, to generate electricity.

[0029] FIG. 3 illustrates a cross sectional view of an embodiment of a power module assembly 30 comprising a reactor vessel deflector shield 35. Reactor vessel 52 contains a reactor core 6 located near a bottom end 55 of the reactor vessel 52. A riser section 24 is located above the reactor core 6, wherein coolant circulates past the reactor core 6 to become high-temperature coolant T_H and then continues up through the riser section 24 where it is directed back down the annulus and cooled off by a heat exchanger 135 (FIG. 1) to become low-temperature coolant T_C .

[0030] The reactor vessel deflector shield 35 comprises a flow-optimized ellipsoidal, domed, concave, or hemispherical shaped portion 35A, wherein the flow-optimized portion 35A directs the coolant (shown as coolant flow 26) towards the bottom end 55 of the reactor vessel 52. The ellipsoidal portion 35A may come into direct contact with and deflect the coolant that exits the riser section 24. The ellipsoidal portion 35A operates to reduce a flow resistance or turning loss of the coolant flow 26, as compared to an interaction of the coolant with a flat, or irregular surface, or plenum region without a solid interface. In one embodiment, the reduction in turning loss is by a factor of four or five compared to systems without a deflector shield. The reactor vessel deflector shield 35 may be made of stainless steel or other materials which may be formed into an ellipsoidal or optimized shaped surface.

[0031] In one embodiment, the bottom end 55 of the reactor vessel 52 comprises a second flow-optimized ellipsoidal, domed, concave, or hemispherical portion 55A, wherein the second ellipsoidal portion 55A directs the coolant (shown as coolant flow 28) towards the reactor core 6. The ellipsoidal portion 35A and second ellipsoidal portion 55A increase flow rate and promote natural circulation of the coolant through the reactor core 6.

[0032] An optimization of the coolant flow 26 may be obtained according to a ratio of the distance H_o between the top of the riser section 24 and the center of the reactor vessel

deflector shield **35** and the relative distance Do between the walls of the riser section **24**, wherein the dimension La represents the distance between the outside of the riser **24** and the inside surface of the reactor vessel **52**. In one embodiment, the distance Do equals the diameter of the riser section **24**. The flow area inside the riser is Ao , the flow area inside the annulus is Aa . The optimized coolant flow ratios may be represented as Ho/Do and Aa/Ao .

[0033] In one embodiment, the optimized coolant flow ratio Ho/Do comprises a value 0.1 and 2.0, and the flow ration and Ao/Aa comprises a value between/approximately 1 and 10. Further optimization of the coolant flow **26** may be obtained by modifying the radius of curvature of the surface of ellipsoidal portion **35A** to eliminate/minimize boundary layer separation and stagnation regions.

[0034] The reactor vessel deflector shield **35** is illustrated as being located between the top of the riser section **24** and a pressurizer region **15**. The pressurizer region **15** is shown as comprising one or more heaters **17** and a spray nozzle **19** configured to control a pressure, or maintain a steam dome, within an upper end **56** of the reactor vessel **52**. Coolant located below the reactor vessel deflector shield **35** may comprise relatively sub-cooled coolant T_{SUB} , whereas coolant in the pressurizer region **15** in the upper end **56** of the reactor vessel **52** may comprise substantially saturated coolant T_{SAT} . A fluid level of the coolant is shown as being above the reactor vessel deflector shield **35**, and within the pressurizer region **15**, such that the entire volume between the reactor vessel deflector shield **35** and the bottom **55** of the reactor vessel **52** is full of coolant during normal operation of the power module assembly **30**.

[0035] FIG. 4 illustrates a partial view of an example power module assembly **40** comprising a reactor vessel deflector shield **35** supported by one or more control rod guide tubes or instrumentation structures **45**. The one or more control rod guide tubes or instrumentation structures **45** may be attached to an upper end of the reactor vessel **52**, and serve to guide control rods that are inserted into, or removed from, the reactor core **6**, or provide support for instrumentation devices located inside the reactor vessel **52**. By attaching or suspending the reactor vessel deflector shield **35** from the one or more control rod guide tubes or instrumentation structures **45**, the reactor vessel deflector shield **35** may be free from contacting the sides of the reactor vessel **52**. By isolating the reactor vessel deflector shield **35** from the reactor vessel walls **52**, the reactor vessel deflector shield **35** is protected from changes in rates of thermal expansion of the different materials and structures of the power module assembly **40**, or from any movement of components that might otherwise damage the reactor vessel deflector shield **35** or the reactor vessel **52**. The riser section **24** is illustrated as comprising an inward facing portion **65** that varies a flow pressure of the coolant to reduce a turning loss of the coolant **26** circulating by the reactor vessel deflector shield **35**.

[0036] In one embodiment, the cross section of the inward facing portion **65** approximates a cross section of an airplane wing in shape, but with a smaller cross sectional area, for example. The cross-section blunt end of the inward facing portion **65** may face the top of the vessel or the bottom, or be blunt on both ends. The inward facing portion **65** may be continuously located around a perimeter of an upper end of the reactor housing **20** or riser section **24** (e.g. FIG. 9). The inward facing portion **65** may effect a change in pressure and accompanying loss of turning resistance of the coolant **26**

about the entire perimeter of the riser section **24**. In one embodiment, the inward facing portion **65** comprises multiple portions (e.g. FIG. 8) located around a perimeter of the upper end of the reactor housing **20** or riser section **24**. The inward facing portion **65** may be understood to affect the coolant flow **26** or fluid pressure similar to the aerodynamics of an airplane wing, in that the flow is preferentially directed to minimize regions of separation and the related losses.

[0037] FIG. 5 illustrates a partial view of an example power module assembly **150** comprising a baffle assembly **50** and a coolant flow augmentation mechanism comprised of inward facing portion **65**. The reactor vessel **52** includes an upper end **56** and a lower end **55** (FIG. 3). Pressurizer region **15** is located near the upper end **56** of the reactor vessel **52**, whereas the reactor core **6** is located near the bottom end **55** of the reactor vessel **52**. Baffle assembly **50** is shown illustrated as being located between the reactor core **6** and the pressurizer region **15**. The reactor housing **20** (FIG. 3) directs coolant flow **28** through the reactor core **6**, wherein the reactor housing **20** comprises inward facing portion **65** that varies a flow pressure of the coolant and promotes a circulation of the coolant (illustrated as coolant flow **26**) to by-pass the baffle assembly **50** and towards the bottom end **55** of the reactor vessel **52**.

[0038] The baffle assembly **50** comprises an upper baffle plate **62** and a lower baffle plate **64**. A hot/cold liquid interface Lo due to stratification in the baffle region may exist between the upper and lower baffle plates **62**, **64** separating the sub-cooled coolant T_{SUB} from the saturated coolant T_{SAT} . The liquid interface Lo provides a medium in which the first fluid entering the pressurizer region when flow is into the pressurizer, is hot fluid, and afterwards the subcooled coolant T_{SUB} entering the pressurizer heats up (or mixes together with saturated coolant T_{SAT}) before entering the pressurizer region **15**. The baffle assembly **50** operates to impede a flow of the subcooled coolant T_{SUB} from entering the pressurizer region **15**, comprising substantially saturated coolant T_{SAT} . The baffle assembly **50** helps maintain or create a thermal trap between the upper and lower baffle plates **62**, **64**. A steam dome may be maintained in pressurizer region **15**, or the upper end **56** of the reactor vessel **52**. If the subcooled coolant T_{SUB} is allowed to enter the pressurizer region **15** too quickly, it may result in a loss of reactor vessel pressure or collapse of the steam dome.

[0039] The baffle assembly **50** effectively increases a flow path length from the subcooled coolant T_{SUB} on a first side of the baffle assembly **50** to the saturated coolant T_{SAT} on a second side of the baffle assembly **50**. Coolant flow (illustrated as $F1$) entering the baffle assembly **50** is allowed to flow around or by the lower baffle plate **64**. The coolant flow (illustrated as Fo) next maneuvers around one or more internal baffles **72**, **74** before exiting into the pressurizer region **15** as coolant flow $F2$, through or by the upper baffle plate **62**. The flow path made by the baffles directs the flow $F1$ past the structure of the baffle assembly **50** that is heated from the pressurizer region **15**. Directing of the flow $F1$ past the relatively hot structure heats this fluid, and additionally mixes the fluid with the T_{sat} region, effectively heating it previous to it entering the pressurizer region **15**.

[0040] FIG. 6 illustrates an example baffle assembly **60** comprising a reactor vessel deflector shield **66**. The reactor vessel deflector shield **66** comprises a flow-optimized ellipsoidal region or concave portion **66A** having a diameter $D1$ or width that is larger than a distance Do between the inward

facing portions **65** of the reactor housing **20** or riser section **24**. In one embodiment, the diameter **D1** of the lower baffle plate **66** is approximately equal to the width or diameter of the reactor vessel **52**.

[0041] The pressurizer region **15** is located at the upper end of the reactor vessel **52**. The baffle assembly **60** is located between the pressurizer region **15** and the riser section **24**. The baffle assembly **60** comprises one or more baffles **72**, **76** located between an upper baffle plate **62** and the reactor vessel deflector shield **66**. The one or more baffles **72**, **76** impede a flow of the sub-cooled coolant T_{SUB} into the pressurizer region **15**. The baffle assembly **60** may be understood to operate similarly as a pressurizer surge line of a typical pressurized water reactor design. The baffle assembly **60** may prevent an insurge of coolant from the reactor vessel **52** from entering the pressurizer region **15** too suddenly or at too low of a temperature. In one embodiment, the baffle assembly **60** operates to control a rate of insurge of the coolant into the pressurizer region **15**, and increases the temperature of the insurge flow by structure heat addition and mixing with hot fluids.

[0042] The baffle assembly **60** includes an upper portion which comprises the upper baffle plate **62**. The upper baffle plate **62** may include, or be attached to, one or more baffles **72**. The baffle assembly **60** further includes a lower portion which comprises the reactor vessel deflector shield **66**. The reactor vessel deflector shield **66** may include, or be attached to, one or more baffles **76**.

[0043] The baffle assembly **60** may comprise one or more heaters **79**. The one or more heaters **79** may be provided intermediate the upper and lower baffle plates **62**, **66**. In one embodiment, the one or more heaters **79** are provided within the upper baffle plate **62** to warm the coolant. In another embodiment the one or more heaters **79** are provided in the liquid interface **Lo**. Coolant that passes through the baffle assembly **70** may become heated to at, or near, saturation temperatures T_{SAT} while being transferred into the pressurizer region **15**. The baffle assembly **60** may be understood to both isolate the pressurizer region **15** from the subcooled coolant T_{SUB} , as well as promote increased flow rate of the coolant (illustrated as flow **26**) in the reactor vessel **52**.

[0044] In one embodiment, a width or diameter of the reactor vessel deflector shield **66** is less than a width or diameter of the reactor vessel **52** forming a pathway or channel **68** about the perimeter of the reactor vessel deflector shield **66**. The channel **68** provides a path for the coolant flow (illustrated as **F1**) to pass by or through the reactor vessel deflector shield **66**. Coolant continues to flow (illustrated as **Fo**) around the one or more baffles **72**, **76** before exiting by or through the upper baffle plate **62** as coolant flow **F2**. Coolant that passes through the baffle assembly **60** may become heated to at, or near, saturation temperatures T_{SAT} while being transferred through the pathway or channel **68** and being heated by the upper baffles **72**. FIG. 7 illustrates a partial view of an example power module assembly **75** comprising a baffle assembly **70** and coolant flow augmentation mechanism comprised of inward facing portion **65**. The baffle assembly **70** comprises an upper baffle plate **62** and a lower baffle plate **77** including one or more flow-optimized ellipsoidal, domed, hemispherical or concave surfaces **77A** and a divider **77B**. The flow-optimized concave surface **77A** of the lower baffle plate **77** directs the coolant **26** down around the riser section **24** of the housing **20** to the bottom of the reactor vessel **52**. The flow-optimized concave surface **77A** of the lower baffle

plate **77** may be understood to operate the same or similar to the flow-optimized ellipsoidal region or concave portion **66A** of the reactor vessel deflector shield **66** of FIG. 6. Divider **77B** further facilitates coolant **26** to flow in an outward direction from the center of the baffle plate **77**. Divider **77B** may be shaped similar to a bullet tip. Baffle plate **77** minimizes pressure loss of coolant flow based on an optimized position and geometry above the exit of the riser section **24**.

[0045] The baffle assembly **70** is located between the pressurizer region **15** and the riser section **24**. The baffle assembly **70** comprises one or more baffles **72**, **78** located between the upper baffle plate **62** and the lower baffle plate **77**. The one or more baffles **72**, **78** impede a flow of the sub-cooled coolant T_{SUB} into the pressurizer region **15**.

[0046] An upper portion of the baffle assembly **70** comprises the upper baffle plate **62**. The upper baffle plate **62** may include, or be attached to, one or more baffles **72**. A lower portion of the baffle assembly **70** comprises the lower baffle plate **77**. The lower baffle plate **77** may include, or be attached to, one or more baffles **78**. A pathway or channel may be formed through one or all of the baffles **72**, **78**. The channel provides a path for the coolant flow (illustrated as **F1**) to pass by or through the lower baffle plate **77**. Coolant continues to flow (illustrated as **Fo**) through the one or more baffles **72**, **78** before exiting by or through the upper baffle plate **62** as coolant flow **F2**.

[0047] The baffle assembly **70** may comprise one or more heaters **79**. The one or more heaters **79** may be provided intermediate the upper and lower baffle plates **62**, **77**. In one embodiment, the one or more heaters **79** are provided within the upper baffle plate **62** to warm the coolant entering the pressurizer region during an insurge. In another embodiment the one or more heaters **79** are provided in the temperature variation layer proximate to the liquid interface **Lo**. Coolant that passes through the baffle assembly **70** may become heated to at, or near, saturation temperatures T_{SAT} while being transferred into the pressurizer region **15**. The baffle assembly **70** may be understood to both isolate the pressurizer region **15** from the subcooled coolant T_{SUB} , as well promote increased flow rate of the coolant (illustrated as flow **26**) in the reactor vessel **52**.

[0048] In one embodiment, the inward facing portion **65** has a cross section which approximates an inverted teardrop. The inward facing portion **65** has a cross section which generally increases in thickness towards an upper end of the riser region **24**. The upper end of the reactor housing **20**, or riser section **24**, comprises a perimeter characterized by a rounded rim of the inverted teardrop.

[0049] FIG. 8 illustrates a plan view of an embodiment of the coolant flow augmentation mechanism **65** comprising a plurality of inward facing portions **85**. The coolant flow augmentation mechanism **65** is illustrated as comprising four inward facing portions **85** located about the perimeter of the top of the riser **24**, however it is understood that different numbers and types of inward facing portions **65** may be provided for. Partial views of the riser **24** and inward facing portion **65** illustrated in FIGS. 4, 5, and 7 may be understood as comprising a cross sectional view C-C of the coolant flow augmentation mechanism **85**.

[0050] FIG. 9 illustrates an elevated side view of an embodiment of the coolant flow augmentation mechanism **65** comprising a continuous inward facing portion **95**. The inward facing portions **95** is illustrated as being located about the perimeter of the top of the riser **24**. Partial views of the

riser 24 and inward facing portion 65 illustrated in FIGS. 4, 5, and 7 may be understood as comprising a cross sectional view D-D of the coolant flow augmentation mechanism 65.

[0051] FIG. 10 illustrates coolant flow 26 around a coolant flow augmentation mechanism 65. A fluid pressure P_0 of the coolant flow 26 exiting the riser 24 is varied as fluid pressure P_1 when it passes around the coolant flow augmentation mechanism 65. Coolant flow augmentation mechanism 65 increases an effective path of the coolant flow 26, which results in the varied fluid pressure P_1 , as the velocity of the coolant flow 26 varies. Varying the fluid pressure of the coolant operates to reduce a flow resistance or turning loss of the coolant flow 26 by preventing or minimizing boundary layer separation of the flow 26 from the riser 24. This is accomplished by providing a smooth transition for the flow exiting the riser section 24 and entering into the annulus flowing back towards the bottom of the reactor vessel 52.

[0052] FIG. 11 illustrates a novel method of cooling a reactor core using a reactor vessel deflector shield. The method may be understood to operate with, but not limited by, various embodiments illustrated herein as FIGS. 1-10.

[0053] At operation 210, a primary coolant is circulated through a reactor housing comprising an upper riser.

[0054] At operation 220, a fluid pressure of the coolant in the reactor housing is varied by directing a coolant flow around an inward facing portion of the upper riser.

[0055] At operation 230, a flow-optimized ellipsoidal, domed, concave or hemispherical shaped deflector shield forms a lower portion of a baffle system that inhibits the flow of coolant into a pressurizer region. In one embodiment, the flow-optimized ellipsoidal deflector shield is located between the upper riser and the pressurizer region, wherein the pressurizer region is located in an upper end of reactor vessel.

[0056] At operation 240, a flow of the coolant is directed down the reactor vessel and around the reactor housing. A flow-optimized ellipsoidal, domed, concave or hemispherical shaped lower end of the reactor vessel promotes coolant flow through the reactor core, and the flow-optimized ellipsoidal deflector shield located above the upper riser promotes coolant flow around the reactor housing.

[0057] Although the embodiments provided herein have primarily described a pressurized water reactor, it should be apparent to one skilled in the art that the embodiments may be applied to other types of nuclear power systems as described or with some obvious modification. For example, the embodiments or variations thereof may also be made operable with a boiling water reactor.

[0058] The rate of fluid flow about the reactor housing, the rate of insurge and outsurge flows within the baffle assemblies, and the variation in pressure of the fluid moving about flow augmentation devices, as well as other rates and values described herein are provided by way of example only. Other rates and values may be determined through experimentation such as by construction of full scale or scaled models of a nuclear reactor fluid system.

[0059] Having described and illustrated the principles of the invention in a preferred embodiment thereof, it should be apparent that the invention may be modified in arrangement and detail without departing from such principles. We claim all modifications and variation coming within the spirit and scope of the following claims.

1-21. (canceled)

22. A nuclear reactor module, comprising:

a reactor vessel;

a pressurizer located at an upper portion of the reactor vessel;

a reactor core located at a lower portion of the reactor vessel;

a baffle assembly located between the reactor core and the pressurizer; and

a reactor housing having an inward-facing portion and a flow path through the reactor housing that fluidly couples the reactor core to a lower portion of the baffle assembly, the inward-facing portion comprising a curvature for reducing turning loss of a coolant flowing past the inward-facing portion, the inward-facing portion of the reactor housing comprising multiple wing-shaped extensions located about a perimeter of an upper portion of the reactor housing.

23. The nuclear reactor module of claim 22, wherein a cross section of the inward-facing portion comprises an airfoil.

24. The nuclear reactor module of claim 23, wherein the inward-facing portion of the reactor housing is disposed about a perimeter of an upper portion of the reactor housing.

25. (canceled)

26. The nuclear reactor module of claim 22, wherein the baffle assembly comprises a lower baffle plate including an ellipsoidal surface having a perimeter that is larger than the inward-facing portion of the reactor housing.

27. The nuclear reactor module according to claim 26, wherein the ellipsoidal surface of the lower baffle plate directs the coolant towards the lower portion of the reactor vessel.

28. The nuclear reactor module according to claim 22, wherein the inward-facing portion of the reactor housing includes a cross section that approximates an inverted tear-drop.

29. The nuclear reactor module according to claim 22, wherein the inward-facing portion of the reactor housing includes a cross section that increases in thickness towards an upper portion of the reactor housing.

30. The nuclear reactor module according to claim 29, wherein the upper end of the reactor housing comprises a perimeter that includes a rounded rim.

31. A baffle assembly for use in a nuclear reactor module, comprising:

an upper baffle plate exposed to a pressurized volume of saturated coolant; and

a lower baffle plate exposed to subcooled coolant, the subcooled coolant in fluid communication between a location proximate to a portion of the lower baffle plate and a location proximate with the upper baffle plate, wherein one or more of the upper baffle plate and the lower baffle plate are heated by the saturated coolant.

32. The baffle assembly of claim 31, wherein a flow path created by a separation of the upper baffle plate and the lower baffle plate is of sufficient length to prevent an insurge of coolant from a volume proximate with the lower baffle plate.

33. The baffle assembly of claim 31, wherein the upper baffle plate is heated by the pressurized volume of saturated coolant.

34. The baffle assembly of claim 31, wherein the peripheral portion of the lower baffle plate curves in a direction towards a lower portion of the nuclear reactor module.

35. The baffle assembly of claim 31, wherein the lower baffle plate comprises a bullet-shaped tip at a central portion.

36. The baffle assembly of claim 35, wherein the lower baffle plate curves downward at a peripheral portion.

37. An upper portion of a nuclear reactor module, comprising:

- a pressurizer region; and
- a baffle assembly below the pressurizer region, the baffle assembly comprising:
 - an upper baffle plate proximate with the lower portion of the pressurizer region; and
 - a lower baffle plate below the upper baffle plate, wherein the lower baffle plate comprises a surface that curves downward toward a peripheral region of the lower baffle plate.

38. The upper portion of the nuclear reactor module of claim **37**, further comprising an upper portion of a riser having a curved inward-facing portion for reducing turning loss of coolant circulating from a lower portion of the nuclear reactor module.

39. The upper portion of the nuclear reactor module of claim **38**, wherein the curved inward-facing portion of the riser extends continuously about a perimeter of the upper portion of the riser.

40. The upper portion of the nuclear reactor module of claim **37**, further comprising a divider for directing coolant in an outward direction from a center of the lower baffle plate.

41. The upper portion of the nuclear reactor module of claim **37**, wherein the lower baffle plate is defined by a shape selected from the group consisting of an ellipsoid, a dome, a hemisphere, and a concave surface.

* * * * *