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Hampton et al.

[11] **3,782,128**

[45] **Jan. 1, 1974**

[54] **CRYOGENIC STORAGE VESSEL**

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[73] Assignee: **Lox Equipment Company,** Livermore, Calif.

[22] Filed: **June 1, 1970**

[21] Appl. No.: **42,052**

[52] **U.S. Cl.** ..... **62/51,** 62/52, 220/9 LG, 220/15

[51] **Int. Cl.** **F17c 7/02**

[58] **Field of Search** ..... 220/10, 9 LG, 15; 62/45, 51, 50

[56] **References Cited**

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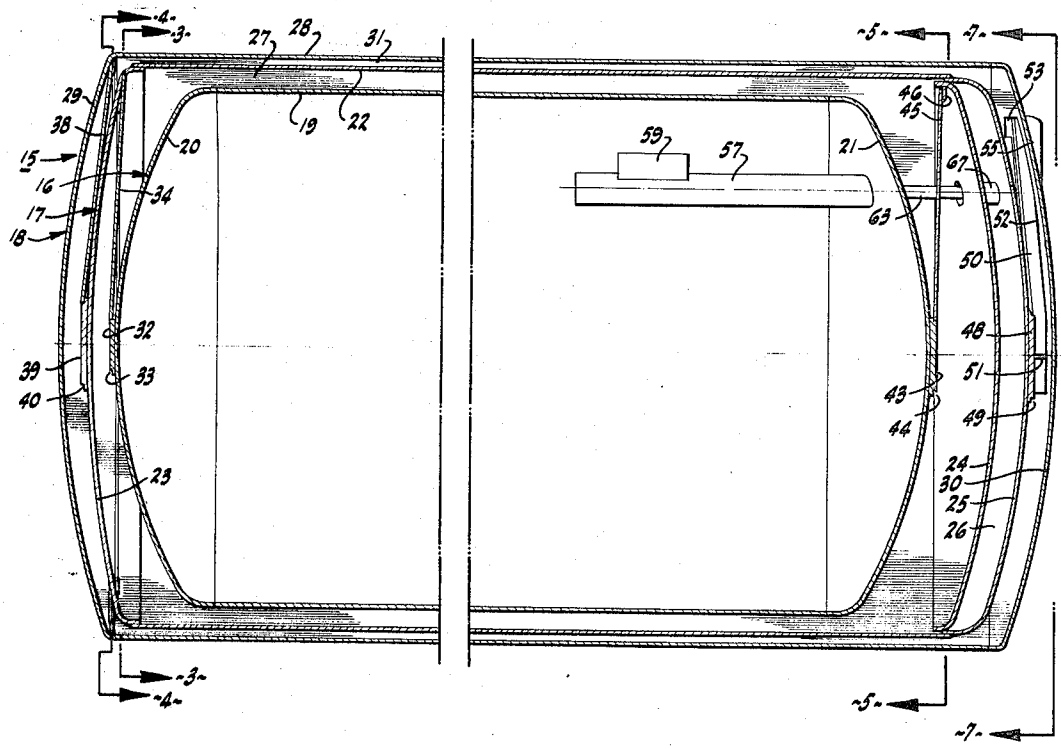
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[57] **ABSTRACT**

A vessel for storing and transporting cryogenic fluids such as liquid helium. The vessel comprises a plurality of elongated containers supported one within another in coaxial circumjacent relation in a manner minimizing heat transmission therebetween, and it further comprises a cooling system forming a temperature barrier that restricts inward migration of heat from the outer to the inner container. Respecting the support system, the inner fluid-receiving container is supported by an encapsulating intermediate heat shield container which in turn is supported by an outer jacket surrounding and enclosing the intermediate heat shield. The support means effecting such interrelationship includes both transverse support structure constraining the containers relative to each other against transverse or radial displacements and longitudinal support structure interconnecting the containers one with another and constraining the same against relative longitudinal displacements at least at one end of the vessel. The transverse support structure constitutes a plurality of structurally independent supports as respects the interconnection of the inner container with the intermediate heat shield and interconnection of the heat shield with the outer jacket; and all of the support structures define restricted thermal flow paths through which heat migration from the outer container to the inner container is sharply limited. Respecting the cooling system, two flow-separated cooling coils surround the heat shield container, one of which carries a coolant such as liquid nitrogen and the other of which connects both with the inner fluid-receiving container and with a delivery system through which fluid is withdrawn from the inner container.

24 Claims, 15 Drawing Figures



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SHEET 1 OF 8

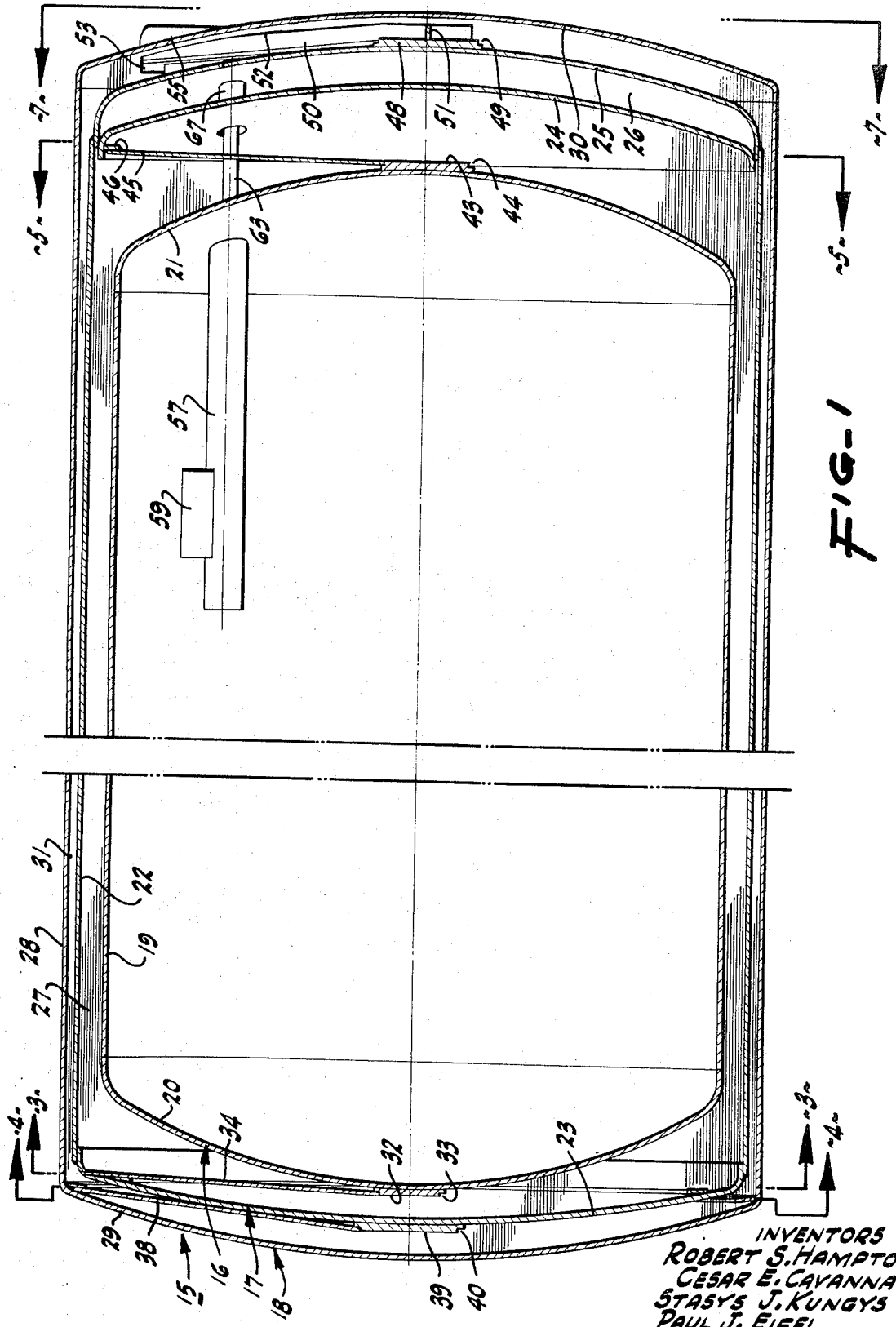


FIG-1

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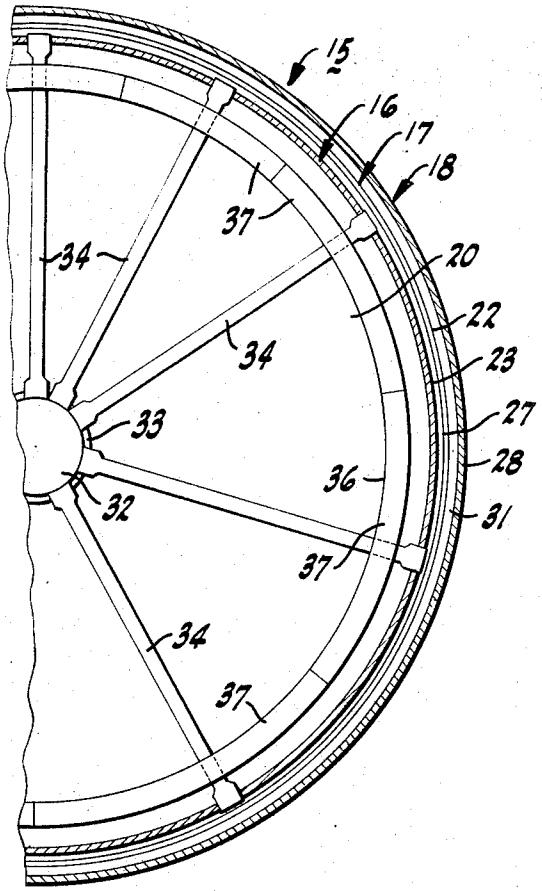


FIG-3

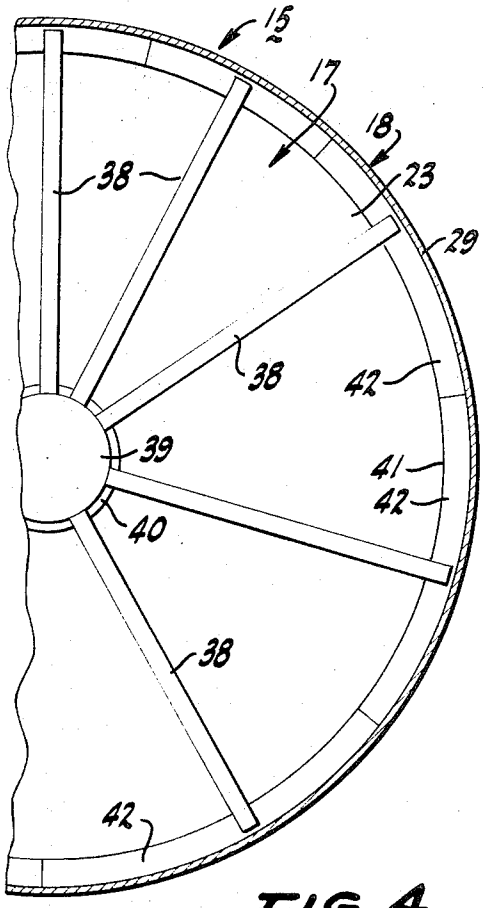


FIG-4

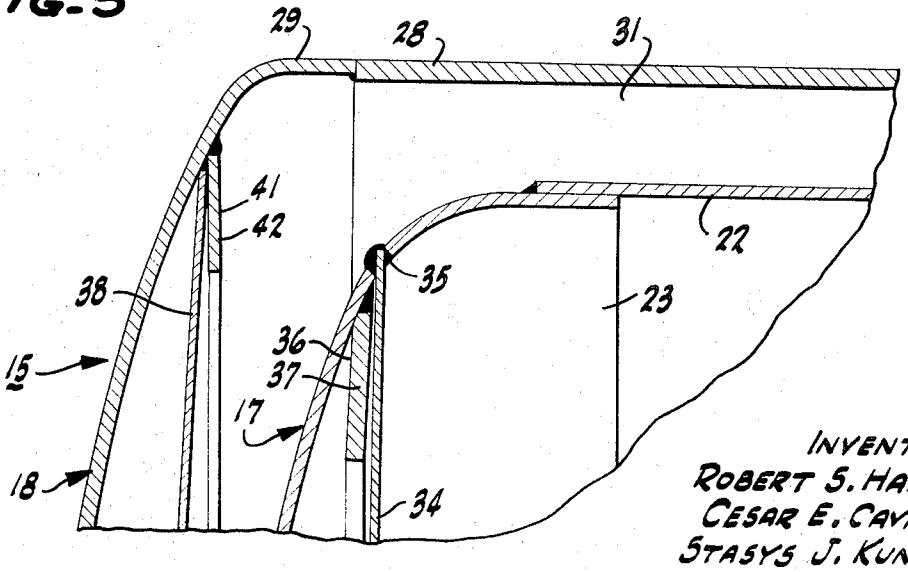


FIG-2

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FIG. 8

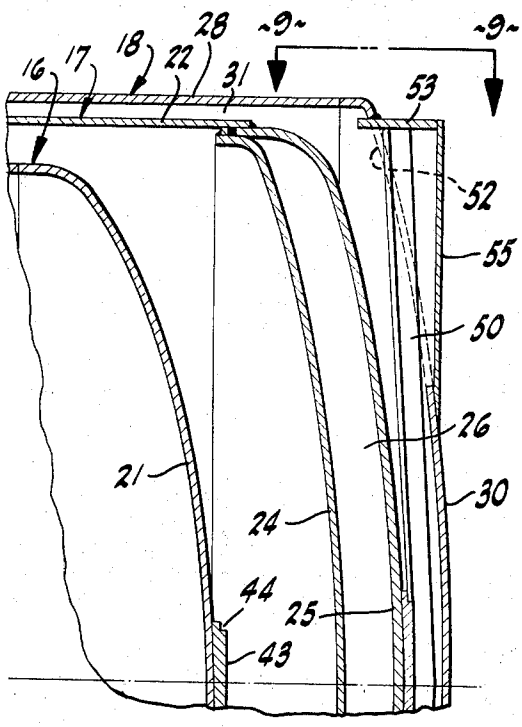
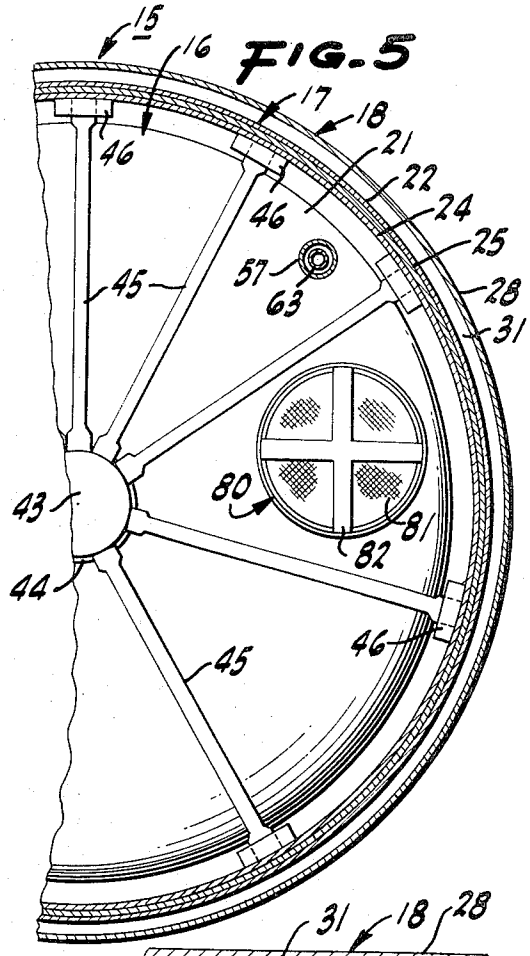


FIG. 5



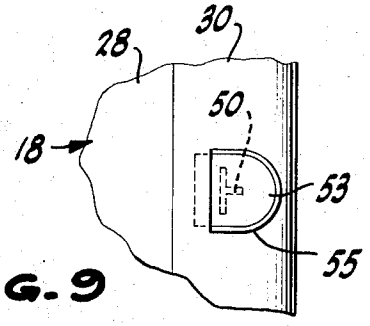


FIG. 9

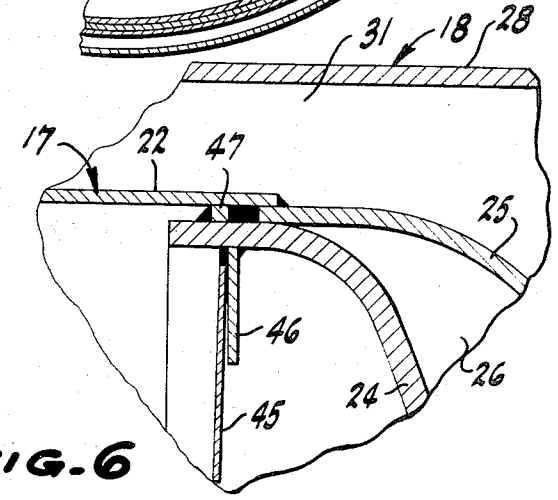
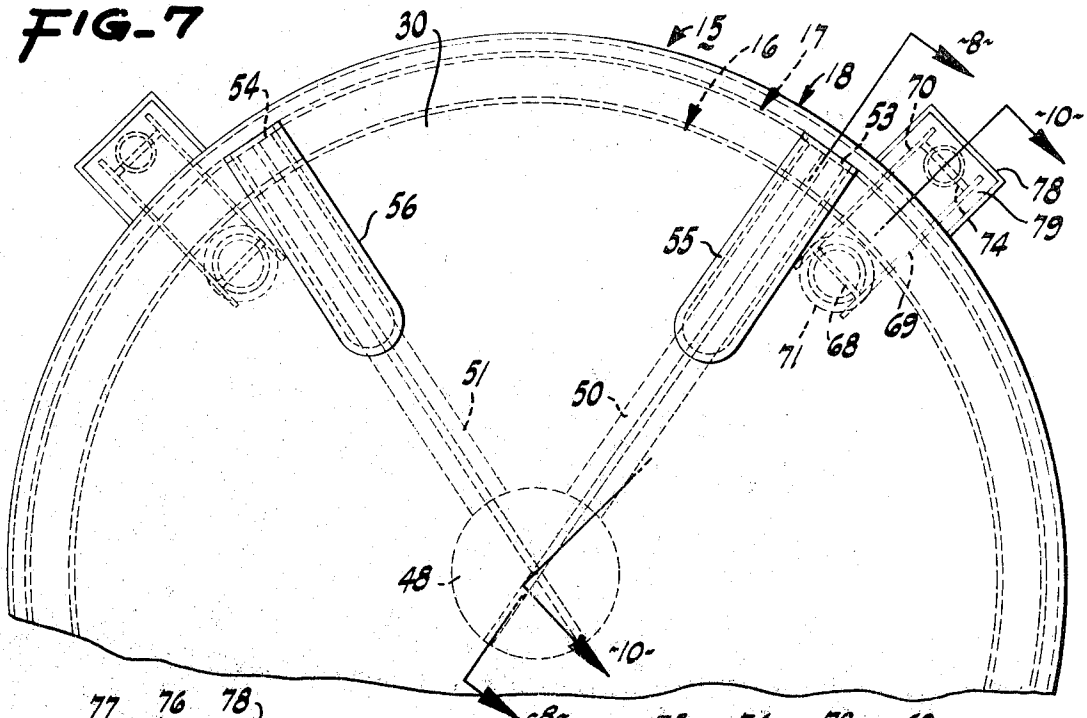


FIG. 6

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FIG-7



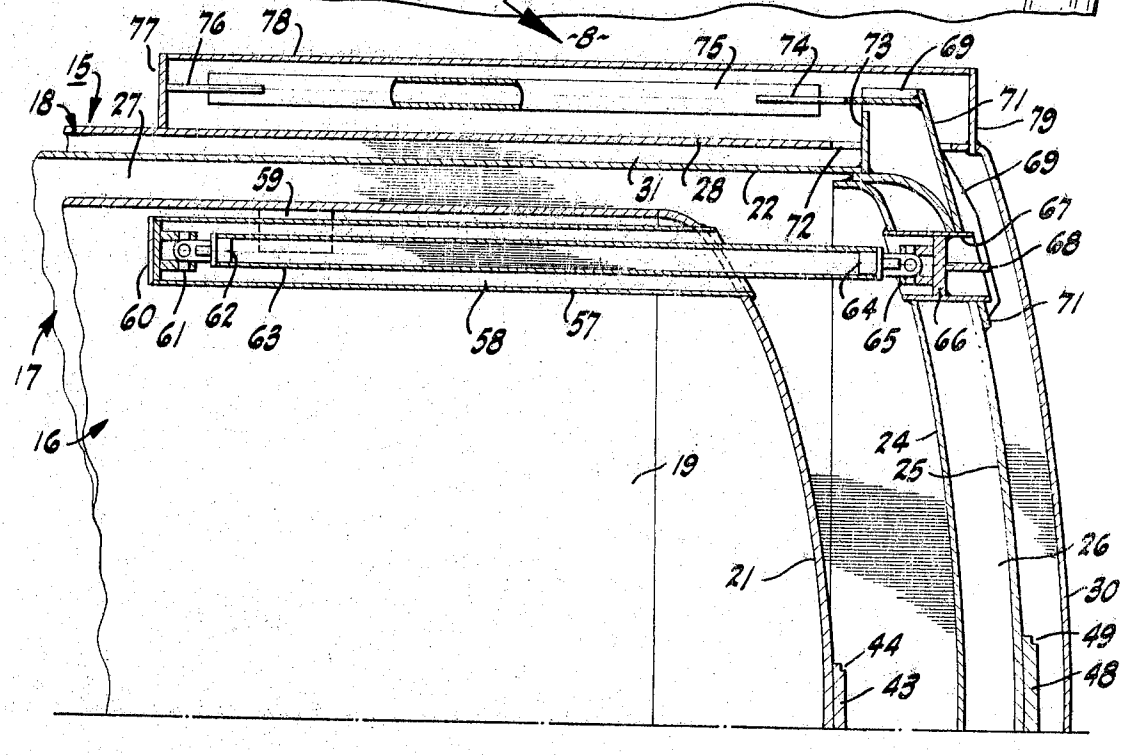


FIG-10

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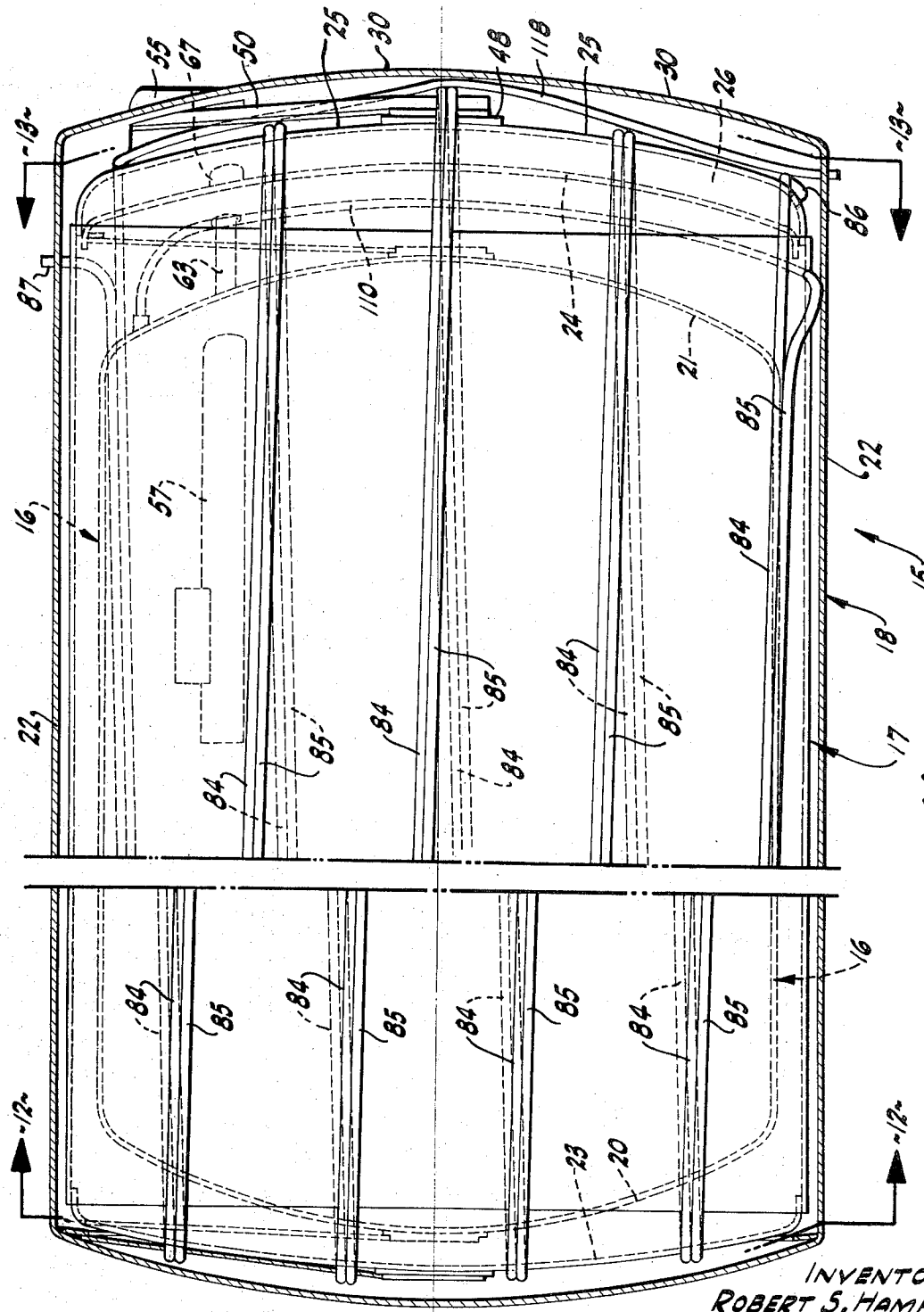


FIG. 11

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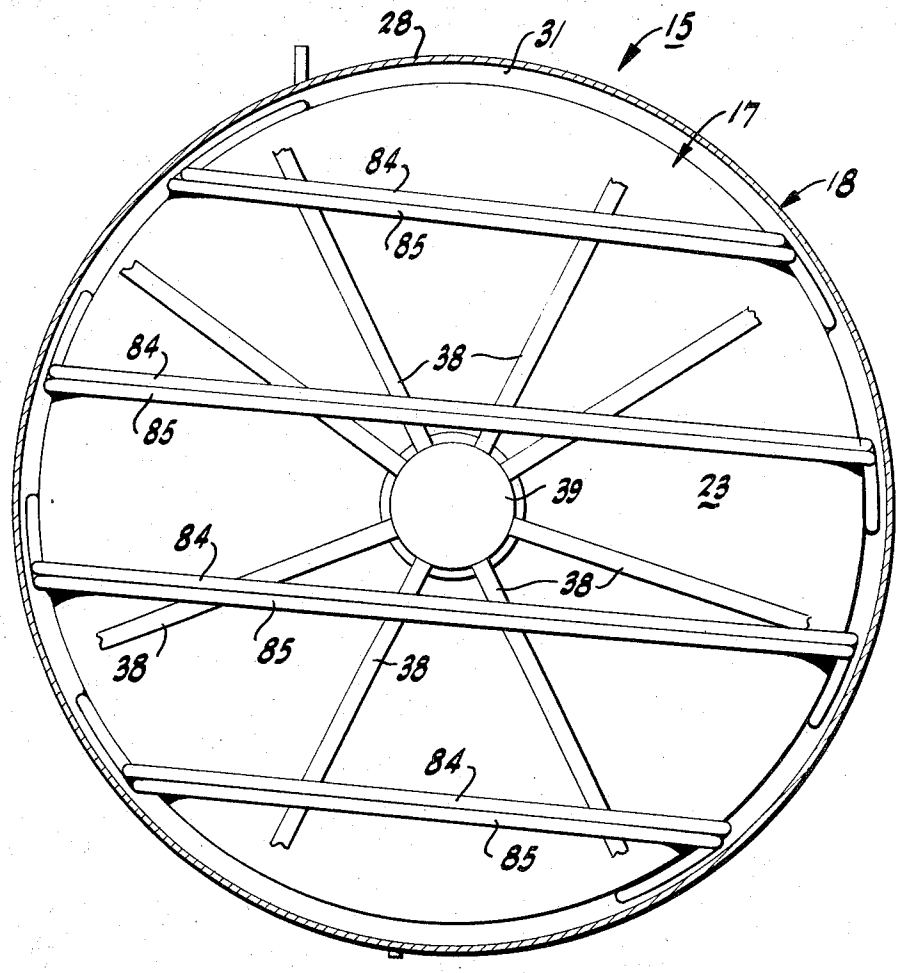


FIG. 12

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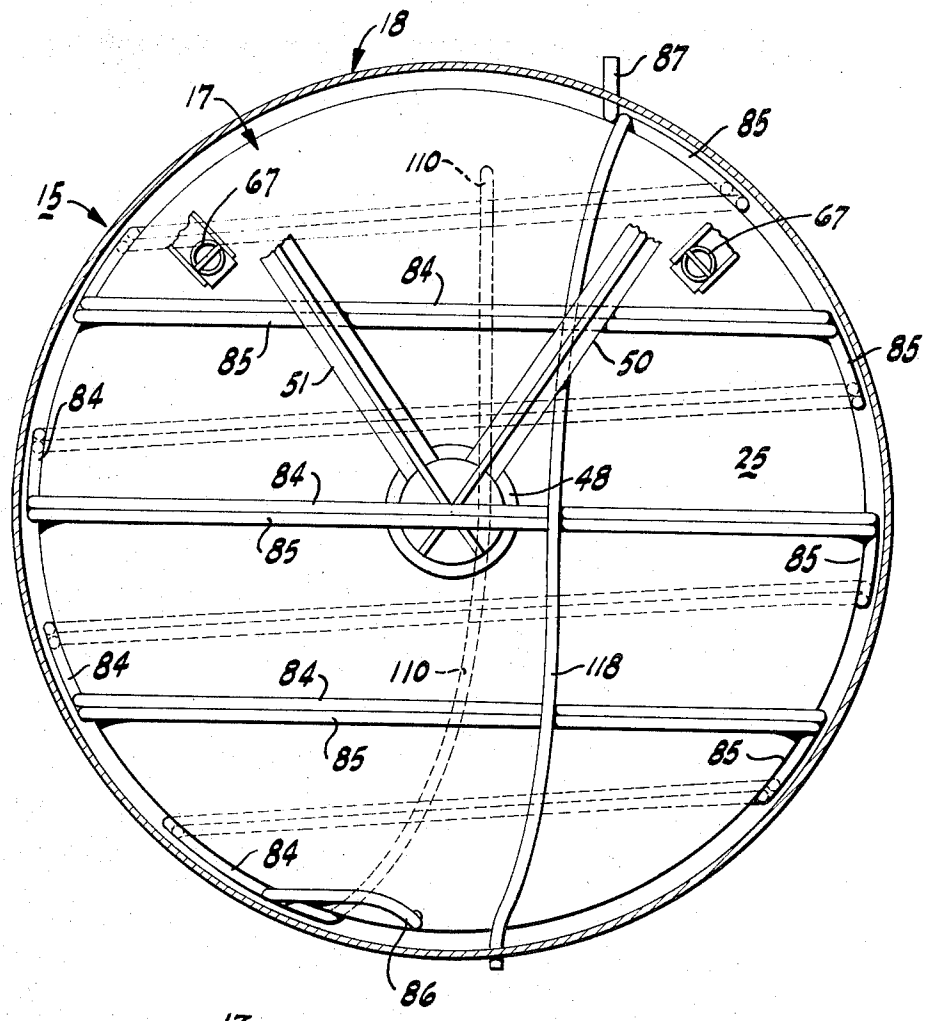


FIG-13

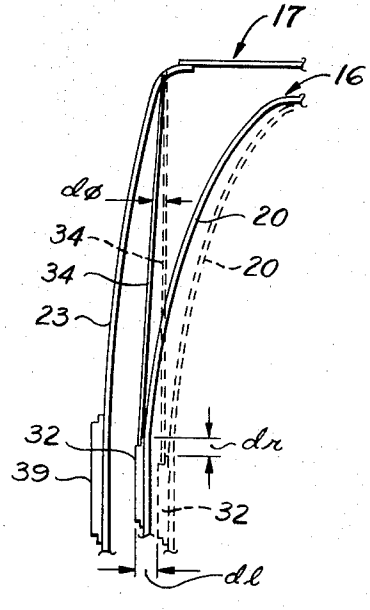
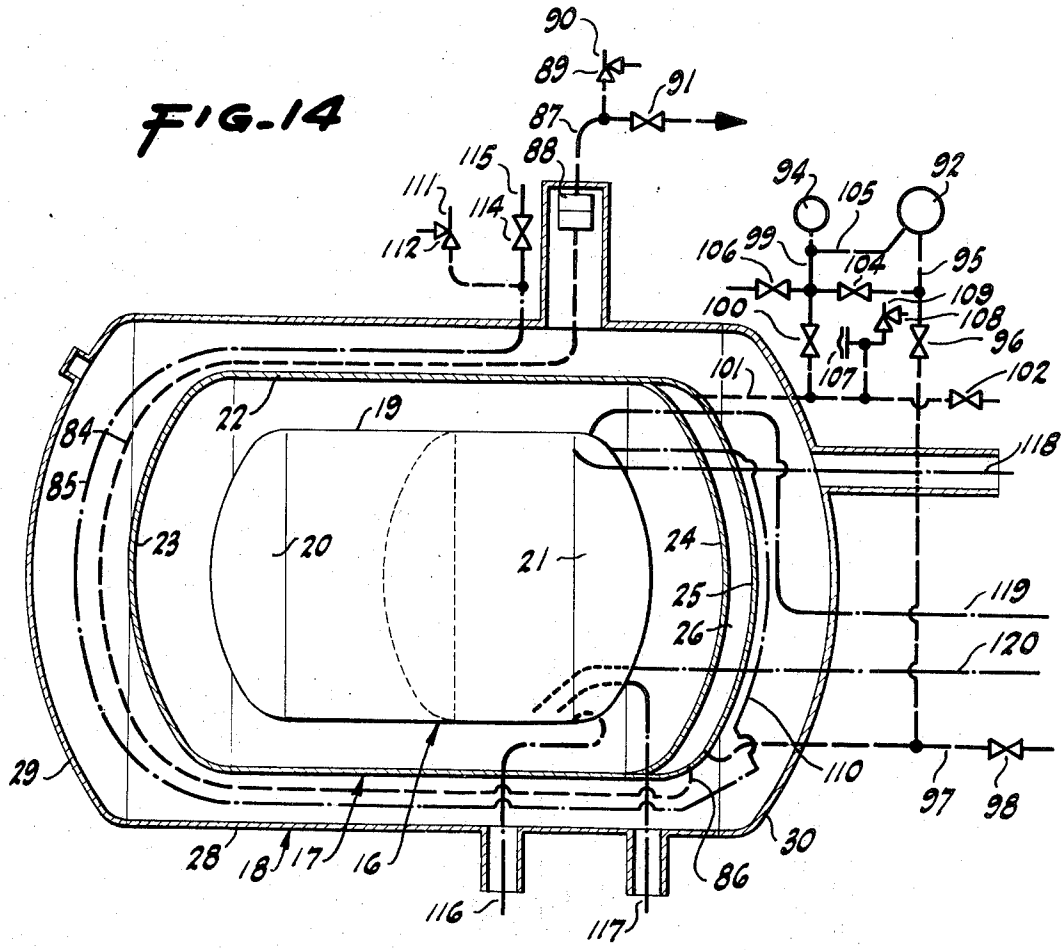


FIG-15

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FIG-14



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CRYOGENIC STORAGE VESSEL

This invention relates to a vessel for storing and transporting cryogenic fluids, such as helium and nitrogen, either in their liquid phase or as a cold gas so that large quantities of any such fluid can be handled economically and have maximum refrigerative properties when used.

With fluids of this type, it is most desirable to store and transport the same in their liquid phase, but maintenance of the liquid condition is not always possible because of the very low critical temperature values of such fluids (critical temperature usually being defined as the temperature above which liquefaction of a particular gas cannot occur). Considering helium as an example, the critical temperature thereof is slightly below −450°F at which temperature liquefaction can be effected at approximately 2.26 atmospheres. Evidently then, in order to store and transport liquid helium (and other similar fluids) as a single-phase fluid, special equipment and conditions must be provided, and equipment for this purpose has been developed and is presently in use. Stated generally, the vessels used for storing and transporting cryogenic fluids are large Dewar vessels which constitute an inner container for the fluid and an outer insulating shell or jacket enclosing the same.

In storing and transporting large quantities of a cryogenic fluid, vessels of considerable size and capacity are necessary, and in contrast to small vessels, the difficulty of supporting one vessel within another while at the same time minimizing the paths of heat migration through the support structure has been a considerable problem. In this reference, consider the case of a vessel intended to transport from 10,000 to 20,000 gallons of a fluid such as liquid helium, such a vessel would have a length that might be considerably greater than 40 feet, and it will be apparent that considerable support structure is required to adequately maintain or suspend the inner fluid-receiving vessel within the outer shell or jacket. If massive support elements are employed, they necessarily define substantial paths for heat transmission from the outer jacket (which is at ambient temperature substantially exceeding the low-temperature requirements of the cryogenic fluid) to the inner container, thereby tending to boil off the product or to elevate the temperature of the fluid confined therewithin.

An object of the present invention is to provide an improved vessel for storing and transporting cryogenic fluids such as liquid helium and the like.

Another object is in the provision of an improved cryogenic storage vessel that includes a plurality of containers supported one within another in substantially concentric relation, and in which improved support means are employed to support the containers in such relative circumjacent relation so as to readily accommodate the static and dynamic loads imparted thereto and at the same time minimize heat transmission via the support structure from the outer container or jacket to the inner container in which the cryogenic fluid is stored.

Still another object is that of providing an improved cryogenic vessel of the type described in which the support means employed accommodate, particularly at one end of the vessel, flexing of one container relative to another such as might be enforced thereon because of temperature changes and because of variation in the

static and dynamic loads to which the vessel may be subjected.

Yet another object is to provide a vessel of the character set forth in which the support means comprises transverse support structure effective to connect one container with another so as to prevent relative transverse displacements therebetween, and which also comprises longitudinal support structure connecting one vessel with another so as to constrain the same against relative longitudinal displacements.

A further object is in the provision of transverse support structure that includes a plurality of angularly spaced spokes adjacent each end of the vessel for supporting one container with respect to the container circumjacent thereto, and in which the aforementioned longitudinal support structure includes rod components located at one end of the vessel and arranged so as to change their direction in a manner such that certain of the longitudinal dimensions thereof are disposed in parallel to reduce the overall length thereof but in which the functional advantages are the equivalent of a rod arrangement in which such dimensions would be oriented in serial relation.

Still a further object is that of providing a vessel for cryogenic fluids and the like having a bipartite cooling system defining a temperature barrier restricting the inward migration of heat from an outer jacket container to an inner fluid-receiving container, the two cooling arrangements of such system being substantially independent in their operation.

Yet a further object is to provide a vessel of the type described in which one of the bipartite cooling systems in one mode of operation thereof utilizes the fluid withdrawn from the inner container to effect the temperature barrier, and in another mode of operation utilizes a separate and independent cooling media.

Additional objects and advantages of the invention, especially as concerns particular details and features thereof, will become apparent as the specification continues.

An embodiment of the invention is illustrated in the accompanying drawings in which:

FIG. 1 is a longitudinal sectional view of a cryogenic storage vessel embodying the invention;

FIG. 2 is an enlarged broken longitudinal sectional view of the upper left hand corner portion of the vessel as it is shown in FIG. 1;

FIG. 3 is a broken transverse sectional view taken generally along the line 3—3 of FIG. 1;

FIG. 4 is a broken transverse sectional view taken generally along the line 4—4 of FIG. 1;

FIG. 5 is a broken transverse sectional view taken along the line 5—5 of FIG. 1;

FIG. 6 is an enlarged, broken longitudinal sectional view of the upper right hand corner portion of the intermediate container of the vessel as it is shown in FIG. 1;

FIG. 7 is an enlarged, broken end view in elevation taken substantially along the line 7—7 of FIG. 1;

FIG. 8 is a broken longitudinal sectional view taken along the line 8—8 of FIG. 7;

FIG. 9 is a broken top plan view taken along the line 9—9 of FIG. 8;

FIG. 10 is a broken longitudinal sectional view taken along the line 10—10 of FIG. 7;

FIG. 11 is generally a side view in elevation of the intermediate heat shield container (the outer container

being broken away) showing the cooling coils in position thereabout;

FIG. 12 is a transverse sectional view taken along the line 12—12 of FIG. 11;

FIG. 13 is a transverse sectional view taken along the line 13—13 of FIG. 11;

FIG. 14 is a schematic diagram of the cooling system for the vessel; and

FIG. 15 is a broken longitudinal sectional view, somewhat diagramatic, of the upper left hand corner portion of the inner storage container and intermediate head shield, the former being shown by broken lines in a contracted position.

As indicated hereinbefore, the storage vessel is intended for use with cryogenic fluids that are necessarily stored and transported at very low temperatures in an effort to maintain the fluid in its liquid phase. By way of example, one of the cryogenic fluids commonly stored and transported is helium and the critical temperature-pressure values (i.e., the temperature-pressure conditions above which helium as a liquid cannot exist) thereof are 5.2° Kelvin (i.e., −267.96°C or −450.328°F) and 2.26 atmospheres. Therefore, as heretofore stated, if helium is being stored within the vessel, it is desirable to maintain the temperature-pressure conditions at or below the critical values for this fluid so that the fluid phase thereof can be preserved. However, it is very difficult to maintain these values, and often the helium will become a two phase system and finally change into the gaseous phase. Even when change to the gaseous phase occurs, with a vessel embodying the present invention a very substantial quantity (as much as 70 percent or more) of liquid helium can be reclaimed by depressurizing the vessel by venting the same through its gas phase line which cools the remaining helium, thereby causing the same to revert to its liquid phase. Nevertheless, it is necessary to minimize to negligible amounts any heat migration between the cryogenic fluid and the ambient environment in which it must be stored and transported.

The vessel illustrated most completely in FIG. 1 provides this desirable result, and it is designated in its entirety with the numeral **15.** The vessel **15** may be used either for stationary storage or for mobile storage and transport, and in the latter case it will be equipped with wheels (not shown) that enable it to be rollingly transported by any suitable truck tractor as disclosed in the copending patent application of Cesar E. Cavanna, Ser. No. 817,986, filed Apr. 21, 1969. Although the size and capacity of any particular vessel **15** may vary considerably, by way of indicating a general order of magnitude of typical vessels, the overall length of one wheel-equipped vessel intended to transport approximately 10,500 gallons of liquid helium is about 40 feet and the outer diameter thereof is about 8.0 feet.

The vessel **15** includes a plurality of axially elongated containers disposed one within another in substantially concentric relation, but it should be noted that exact coaxiality is not a requisite although in the usual case the containers will be coaxially related one to the others in radially spaced relation. As shown in FIG. **1,** such a plurality of containers includes a first or inner storage container **16,** a second or intermediate heat shield container **17,** and a third container or outer jacket **18** enclosing the intermediate heat shield **17** and, therefore, the first or inner storage container **16** which is adapted to receive and store the cryogenic fluid therewithin. For convenience of illustration and because it forms no part of the present invention, the filler and discharge systems for the container **16** have been omitted, but should details concerning such system be desired, reference may be made to the copending patent application of Robert S. Hampton, Ser. No. 808,765, filed Mar. 20, 1969 now U.S. Pat. No. 3,602,003.

The vessel **15** is generally similar from end to end thereof, but there is some departure therebetween as concerns the support means interconnecting the various containers **16, 17** and **18.** In this respect, a functional difference between the two ends exists, and the left end of the vessel as it is shown in FIG. **1** may be referred to as the "flexible end" and the right end as the "fixed end". Adjacent the ends of the vessel **15,** the hollow cylindrical sidewall **19** of the inner container **16** is respectively equipped with bulkheads **20** and **21** which are outwardly convex or dish shaped and are welded or otherwise rigidly and sealingly related to the sidewall **19.** A suitable material for fabrication of the inner container **16** is stainless steel, although many other materials can be used.

The intermediate container or heat shield **17** includes an elongated hollow cylindrical sleeve **22** of somewhat greater diameter than the sidewall **19** and of substantially greater length. Adjacent the flexible end of the vessel **15,** the sleeve **22** is close by a bulkhead **23** that is also outwardly convex closed dish shaped but has much less curvature than the bulkhead **20,** as shown in FIG. **1,** and telescopes into the end portion of the sleeve **22** to which it is welded or otherwise fixedly and sealingly related. Adjacent the fixed end of the vessel **15,** the sleeve **22** of the intermediate container **17** is equipped with a pair of bulk heads identifiable as an inner bulk head **24** and an outer bulkhead **25.**

The bulkheads **24** and **25** are spaced apart axially except at their circumferential edges so as to define a closed chamber **26** therebetween, and they are welded or otherwise rigidly and sealingly secured to each other and to the sleeve **22.** Inspection of FIG. **1** makes it evident that the heat shield container **17** is spaced from the inner container **16** both along the sidewalls and at each end, and the chamber defined therebetween is generally denoted with the numeral **27.** As with the inner container **16,** a suitable material for fabrication of the intermediate heat shield container **17** is stainless steel, although other materials can certainly be used.

The outer container or jacket **18** is also formed of an elongated hollow cylindrical sleeve **28** having a greater diameter than that of the sleeve **22** so as to be spaced radially outwardly therefrom, and it is also of greater length. Adjacent its opposite ends, the sleeve **28** is equipped with end closures or bulkheads **29** and **30** that are each outwardly convex or dish shaped and approximate the curvature of the respectively adjacent bulkheads **23** and **25** of the intermediate container **17.** The bulkheads **29** and **30** are welded or otherwise rigidly and sealingly connected to the sleeve **28,** and together therewith define a compartment **31** about the intermediate heat shield **17.** Various materials may be used to fabricate the outer jacket **18,** and a suitable material is ordinary carbon steel.

Evidently, the containers **16, 17** and **18** require support means interconnecting the same to enforce the spaced apart relationship shown and described, and such support means includes radial or transverse support structure so as to prevent transverse displacements

of one container relative to the others, and further includes longitudinal support structure to prevent bodily displacements of one container relative to the others in axial directions. Such support means will now be described with the transverse support structure being first considered, and the order of description thereof will proceed from the flexible or left end of the vessel to its fixed or right end because such order advantageously progresses from the more simple construction to that of greater complexity.

Referring in particular to FIGS. 1, 2 and 3 it will be noted that the bulkhead 20 at the flexible end of the inner container 16 is provided centrally with a hub or mounting plate 32 welded or otherwise rigidly anchored to the bulkhead along the outer surface thereof. The plate 32 has an offset step or annular recess 33 formed along the outer edge thereof and into which seat the inner ends of a plurality of spokes or arms 34. The spokes 34 are welded to the plate 32 and extend outwardly therefrom in angularly spaced relation that, in the particular configuration shown, are radially oriented with respect to the center of the plate 32 and to the longitudinal axis of the vessel 15. At their outer ends, each of the spokes 34 is fixedly secured to the bulkhead 23 of the intermediate head shield 17, and for this purpose, the heat shield is provided with a plurality of openings 35 (FIG. 2) formed therein and into which the spokes project.

Each spoke 34 is welded to the bulkhead 23 at the location of its projection therethrough, as shown in FIG. 2. The openings 35 may or may not be closed by the welds, for in any case the chambers 27 and 31 are otherwise in open communication for vacuumizing purposes. Adjacent the spokes 34 at the location of their connection with the bulkhead 23 is a reinforcing and stiffening ring 36 formed of a plurality of angular segments 37, as is most evident in FIG. 3. The segments 37 are disposed and welded together in end to end relation and define a substantially endless ring that is continuously welded to the bulkhead 23 so as to be fixed with respect thereto.

It will be observed in FIG. 3 that the arcuate segments 37 vary in angular length generally progressing in length from top to bottom of the vessel 15. In this connection, a segment 37 is associated with each of the spokes 34 which traverses its adjacent segment at about the midpoint thereof. Accordingly, a greater number of spokes 34 are disposed along the upper semicircular portion of the vessel 15 than along the lower portion thereof, and in the specific embodiment being considered, there are five spokes located above the horizontal center plane of the vessel and four spokes located therebelow. Although the spokes 34 constrain the inner and intermediate containers 16 and 17 against transverse or radial displacements with respect to each other, they accommodate some relative longitudinal displacements or flexing, as will be described hereinafter.

The transverse or radial support structure further includes at the flexible end of the vessel 15 a plurality of angularly spaced outer spokes or arms 38, as shown best in FIG. 4, that are radially oriented and extend outwardly from an inner plate or abutment 39 welded or otherwise rigidly secured to the bulkhead 23 of the heat shield 17, and which hub or plate 39 has a circumferential groove or recess 40 formed thereabout and into which the spokes 38 seat at their inner ends so as to be welded or otherwise rigidly secured to the plate 39. At their outer ends, each of the spokes is welded to the bulkheads 29, as shown best in FIG. 2, and all of the spokes 38 are reinforced and stiffened at their outer ends by a ring 41 comprised of a plurality or arcuate segments 42 connected by welding in end to end succession to define a continuous ring as shown in FIG. 4. The segments 42 are welded to the bulkhead 39 and are in substantially contiguous relation with the spokes 38 at their outer ends.

The segments 42 increase in angular length from top to bottom of the vessel 15, and each spoke 18 is disposed so as to traverse the associated segment at about the midpoint thereof. Accordingly, there are more spokes 38 throughout the upper section of the vessel 15 then along the bottom section thereof, and in the specific vessel being considered, there are five spokes angularly spaced from each other about the upper half of the vessel and four angularly spaced spokes of the bottom half thereof. The spokes 38 are effective to radially relate the intermediate container 17 and outer container 18 so as to prevent relative transverse displacements therebetween but they permit some longitudinal movement therebetween as will be considered hereinafter.

The radial support structure adjacent the fixed end of the vessel 15 will now be considered, and particular reference will be made first to FIGS. 1, 5 and 6 as concerns the interconnection of the inner and intermediate containers 16 and 17, and second to FIGS. 1, 7, 8 and 9 as concerns the transverse interconnection of the inermediate and outer containers 17 and 18.

The bulkhead 21 of the inner container 16 is equipped centrally with a plate or hub 43 that may be welded thereto and is provided along its outer edge with an annular groove or recess 44. Seated within the recess 44 are the inner ends of a plurality of angular spaced inner spokes or arms 45 that, in the form shown, are radially disposed and may be welded or otherwise rigidly secured to the plate 43. At their outer ends, each of the spokes 45 is welded to the inner bulkhead 24 of the intermediate container or heat shield 17, as shown best in FIG. 6. Each of the spokes 45 is reinforced or stiffened by a plurality of respectively associated plate elements or segments 46 that are welded to the inner bulkhead 24 in substantially contiguous relation with the respectively associated spokes 45 along the outer sides thereof, as shown in both FIGS. 5 and 6. Since the spokes 45 are radially disposed, they interrelate the inner container 16 and intermediate container 17 in a manner preventing relative transverse displacements therebetween.

As illustrated best in FIG. 6, the bulkheads 24 and 25 are welded to the cylindrical wall 22 of the heat shield container 17, and the bulkhead 24 projects inwardly to a greater extent than the bulkhead 25 so as to underlie the cylindrical wall 22 of this container. A generally square-shaped bar bent so as to conform to the outer circumference of the bulkhead 24 and of sufficient width to substantially engage the inner surface of the circumjacent wall 22 is interposed between the bulkhead and wall to form an endless ring 47 that is welded to the bulkhead as shown.

The outer bulkhead 25 has rigidly affixed thereto at a central location along the longitudinal axis of the vessel a plate or hub 48 provided with an outer annular groove or recess 49 cut therealong, as shown in FIGS.

1, 8 and 10. Extending radially outwardly from the hub or plate 48 are a pair of hanger or suspension spokes 50 and 51 which, as shown best in FIG. 9, are of T-shaped configuration. As is most evident in FIGS. 1 and 7, the flange of each of the hangers 50 and 51 seats within the recess 49 formed in the plate 48, but the webs of each hanger extend across the plate 48 in a lap joint.

The hangers 50 and 51 are angularly spaced from each other by about 70° (i.e., 35° from each side of a vertical plane through the center of the vessel) and along their outer end portions they respectively project through openings 52, FIG. 8, formed in the bulkhead 30 of the outer container 18. At their outer extremities, the hangers 50 and 51 are respectively welded to cover plates 53 and 54 that are welded to the bulkhead 30 and are also welded to arcuate enclosures 55 and 56, respectively, configurated to conform to the arcuate shape of the bulkhead 30 and are welded thereto. Accordingly, each of the openings 52 formed in the bulkhead 30 are sealingly closed by the respectively associated plates and covers 53, 55 and 54, 56 which also rigidly connect the hangers 50 and 51 to the outer container 18.

In contrast to all of the aforementioned spokes 45, 38, and 34 which are all relatively thin, generally planar components, the hangers 50 and 51 are T-shaped and therefore provide considerable resistance to flexure along the longitudinal axis of the vessel 15 because of the presence of the web of each hanger which is disposed at right angles to the flange thereof. Each of the hangers 50 and 51 also provides resistance to transverse flexure because in such direction, the flanges thereof lie in the planes of such tendency toward flexure and serve as beam webs to resist generally transverse flexure. Accordingly, it may be said that the hangers 50 and 51 and components associated therewith establish a relatively rigid interconnection of the outer container or jacket 18 with the intermediate container or shield 17 through the outer bulkhead 25 thereof.

The aforementioned support means, as indicated hereinbefore, also include longitudinal support structure interconnecting the various containers one with another adjacent the fixed end of the vessel 15 so as to constrain the containers against significant longitudinal or axial displacements relative to each other. Such longitudinal support structure will now be described with particular reference to FIGS. 1, 7 and 10.

Considering first the longitudinal interconnection of the inner container 16 with the intermediate container or heat shield 17, the bulkhead 21 of the inner container is provided at angularly spaced locations (respectively offset in opposte directions from the vertical center plane of the vessel by about 45°, as is most evident in FIG. 7) with an opening through which projects a cylindrical pipe or rod 57 defining an axially extending cylinder 58 therewithin. Adjacent one end, the pipe 57 is welded to the bulkhead 21 so as to be rigidly and sealingly related thereto, and it is supported adjacent its inner end by one or more straps 59 secured to the wall 19. The inner end of the pipe 57 is closed by an end wall 60 that is welded thereto and carries a universal joint 61 one component of which is fixedly attached to the closure wall and the other components of which is rigidly affixed by means of a closure plug 62 to a hollow cylindrical rod 63 of substantially greater length than the pipe 57 so as to project outwardly through the open end thereof toward the inner bulkhead 34 of the intermediate head shield 17, as shown in FIG. 10.

At its opposite end, the tubular rod 63 is closed by a plug 64 having attached thereto one component of a universal joint 65 the other component of which is rigidly attached to an end closure 66 located within and sealingly and rigidly related to a hollow cylindrical shell 67 in axial alignment with the pipe 57 and extending through openings provided therefore in the bulkheads 24 and 25. The shell 67 is welded to each of the bulkheads so as to be sealingly and fixedly secured thereto. It will be appreciated that the structure described rigidly interconnects the inner container 16 with the intermediate container 17 because at one end the rod 63 is fixed to the bulkhead 21 of the inner container through the hollow pipe 57 and intermediate components constituting the closure 60, universal joint 61 and plug 62 and at its other end it is fixed to the intermediate container 17 through the shell 67 and intermediate structure constituting the closure 66, universal joint 65 and plug 64.

The universal joints 61 and 65 are advantageous in that they permit easy assembly of the components in the event of dimensional discrepencies resulting from manufacturing tolerances, and they also accommodate any slight tendency toward transverse displacements of the inner container 16 relative to the intermediate container 17 such as may result from the weight or static load carried by the inner container and any road shocks or dynamic loads that might be transmitted to the vessel 15 during transport thereof. The effective length for thermal transmission purposes of the longitudinal support interconnecting the inner and intermediate containers is substantially equal to the longitudinal length of the rod 63 because of its being insulated from circumjacent pipe 57 and connected thereto only at one end via the universal joint 61. In a structural sense, the longitudinal support actually changes direction and while mechanically relating the individual lengths of the pipe 57 and rod 63 in parallel, functionally the relationship thereof is one of serial interconnection.

In the event of the inner container 16 tending to shift longitudinally to the right as viewed in FIG. 10 relative to the intermediate container 17, the rod 63 will be compressively stressed and the pipe 57 will be placed in tension. Conversely, any tendency for the inner container 16 to shift in the opposite direction will place the rod 63 in tension and enforce a compressive stress upon the pipe 57. The long effective length of the pipe 57 and rod 63 is advantageous in that these components function as very stiff springs accommodating limited axial displacements of the inner container relative to the intermediate container and, as is well known, the longer the length of any such spring, the lower is the fatigue thereof resulting from cyclically repetitive compression and elongation.

The longitudinal support structure further includes an arrangement for interconnecting the intermediate container 17 and outer container 18 and, as shown in FIG. 7 and 10, such means are respectively arranged with the two angularly spaced inner longitudinal support structures just described. In this respect, the outer support structure includes a flat plate-like web 68 rigidly related to the closure 66 and to the shell 67 so as to be anchored by the latter to the heat shield or intermediate container 17. The plate 68 extends outwardly

beyond the end of the shell 67 and is enlarged thereat, as shown in FIG. 7, and welded along such enlargement to brackets 69 and 70 that are welded to a ring plate 71 circumjacent the outer end of the shell 67 and which is welded both to the shell and to the bulkhead 25. Each of the members 69 and 70 is shaped to conform to the curved configuration of the bulkhead 25, as shown in FIG. 10, and the ring plate 71 extends upwardly for substantially the entire height of each of the members 69 and 70.

The members 69, 70 and 71 extend upwardly through an opening 72 provided therefor in the cylindrical shell or wall 28 of the outer container 18. Also extending upwardly through the opening 72 is a reinforcing member 73 that is disposed intermediate the brackets 69 and 70 and is welded thereto, as well as being welded to the cylindrical wall 22 and bulkhead 25 of the intermediate container 17. Located along the outer surface of the container wall 28 is a flat fin-like connector 74 that at one end is disposed intermediate the brackets 69 and 70 and is welded thereto and to the upper end of the ring plate 71.

The connector 74 extends longitudinally toward the flexible end of the vessel 15 and projects into a slot provided therefor at one end of a hollow tubular rod 75 and is welded to the rod so as to be firmly attached thereto. At its opposite end, the rod 75 is slotted and a similar fin-like connector 76 is seated therein and welded thereto. The connector 76 is welded to an end wall 77 of an enclosure 78 having an inverted generally U-shaped configuration, as shown in FIG. 7. At the opposite end of the enclosure 78 an end wall 79 is provided and such end wall 79 together with the end wall 77 and entire enclosure 78 are welded to the outer container 18 so as to be rigidly and sealingly related thereto and thereby form an hermetic enclosure about the opening 72.

As stated hereinbefore, it is necessary that the various containers be thermally insulated one from another so as to sharply restrict the rate of heat migration therebetween, and as will be explained hereinafter, the support means comprising the transverse support structure located at each end of the vessel 15 and the longitudinal support structure located at the fixed end thereof provide an arrangement for so minimizing transmission of heat between the inner and outer containers. In addition, the chambers 27 and 31 respectively surrounding the inner container 16 and intermediate container 17 are thermally insulated spaces, and cooling means within the chamber 31 cool the intermediate heat shield 16, as will be explained hereinafter. However, the insulation and insulating means form no part of the present invention and have been omitted for simplification and clarity, but for general information it may be mentioned that such spaces may be evacuated or vacumized and/or filled with one of the very effective modern insulations used extensively in the cryogenic field and sometimes referred to as "supper insulation".

In the vessel 15 shown, an evacuation valve and flow conduit system are arranged with the outer chamber 31 so as to vacuumize the same, and a plurality of getter structures 80 (FIG. 5), such as two at each end of the vessel, are carried by the bulkheads 20 and 21 of the inner container 16 so as to absorb fluid within the compartment 27, thereby reducing the fluid pressure therewithin. Each getter structure 80 may constitute a generally cylindrical hollow projection from the associated bulkhead of the inner container, and such projection is closed by a wire mesh screen 81 held in place by spring clips 82 and adapted to contain a predetermined quantity of activated charcoal and a getter molecular sieve material. Also, the cylindircal space within the shell 57 circumjacent the hollow rod 63, the space within the rod 63, the space within the housing 78 about the hollow rod 75, and the space within the hollow rod 75 may also be provided with an insulating material as, for example, aluminized Mylar sheeting wrapped about the rods or coiled within the space, as the case may be. As previously suggested, the vacuumizing system reduces the pressure in each of the interconnected chambers 27 and 31.

Since the steel materials used to construct the vessel 15 are relatively good thermal conductors, minimizing the rate of heat conductivity along the support means interconnecting the various containers 16, 17 and 18 is of major significance, and both the transverse support structure and longitudinal support structure accomplish such minimization by sharply restricting or limiting the magnitudes of the paths of heat migration. Thus, at both the fixed and flexible ends of the vessel 15, the inner container 16 is connected to the intermediate container or heat shield 17 only by the spokes 34 and 45 each of which is relatively narrow and mechanically contacts the inner container only at the arrow areas of engagement with the plates 32 and 43, which plates respectively define rather restricted areas of engagement with the bulkheads of the inner container.

At their outer ends, each of the spokes 34 and 45 also has a restricted area of engagement with the intermediate heat shield 17, and in this respect it should be observed (see FIGS. 2 and 6) that each of the reinforcing segments 37 at the flexible end of the vessel are spaced from the respectively associated spokes 34 and 45 because of their relative angular orientations, thereby further minimizing the areas of contact and paths for heat migration. Further, it should be observed that the markedly superior tensile strength of the steel materials forming the spokes 34 and 45 is used in supporting the inner container 16 and contents thereof relative to the circumjacent heat shield 17. That is to say, all of the spokes 34 and 45 may be quite narrow since the majority of the spokes in each case are under tension and a much smaller cross sectional area is required to enable a support to carry a weight in tension than is required for a support to carry the same weight in compression.

This same minimization or reduction in the paths of heat migration between the heat shield 17 and outer jacket 18 is defined by the spokes 38 adjacent the flexible end of the vessel and by the hangers 50 and 51 adjacent the fixed end thereof. Analogously, the paths of heat migration along the longitudinal support structures are quite restricted and constitute essentially only the restricted cross sectional solid or metal areas of the cylindrical pipe 57 and of the tubular rod 63 and the restricted areas of interconnection thereof with the intermediate heat shield. Continuing with the longitudinal support structure, the interconnection of the heat shield 17 with the outer jacket 18 is also defined through a restricted thermal flow path largely defined as to its heat-transmitting capacity by the restricted physical interconnection of the hollow tubular rod 75 at each end thereof with the connectors 74 and 76.

It may also be noted that the inner and outer radial or transverse support components are isolated from

each other so that no single continuous flow paths are defined radially outwardly through the support components from the inner container **16** to the outer jacket **18.** A somewhat similar discontinuity pertains as to the inner and outer longitudinal support structures although there is a restricted serial interconnection thereof established at the shell **67.**

The structural assembly described at the fixed or right end of the vessel **15** as it is shown in FIG. **1** largely prevents significant displacements of one container relative to the other. However, at the opposite or flexible end of the vessel, the radial spokes **34** and **38** which respectively connect the inner and intermediate containers and intermediate and outer containers permits relative displacements of all of the containers particularly in axial or longitudinal directions. Enabling such relative movement accommodates temperature differentials and changes, and displacements owing to static and dynamic loads that may be imparted to the vessel differentially as respects the various containers thereof.

The bipartite cooling system which provides a temperature barrier restricting the inward migration of heat from the outer container **18** to the inner container **16** is illustrated in FIGS. **11** through **14** to which particular reference will now be made. The cooling system constitutes two separate and substantially independent cooling arrangements, one of which utilizes withdrawal of the contents of the inner container **16** as a means for providing the temperature barrier and the other of which utilizes a separate cooling media confined within the reservoir **26.** The temperature barrier is associated with the intermediate heat shield container **17,** and it includes first and second flow conduits **84** and **85** respectively formed or configurated into coils that are wound about and are welded or otherwise fixedly secured to the heat shield container, as illustrated best in FIGS. **11, 12** and **13.**

The flow conduit **84** is connected at one end thereof via a conduit section **86** to the lower end of the reservoir **26,** and at its other end the conduit **84** is vented to atmosphere through an outlet section **87** having control and regulator elements located therealong as is shown diagrammatically in FIG. **14.** In this respect, the cooling fluid contained within the reservoir **26** and flowing through the conduit **84** is a low temperature cryogenic fluid such as nitrogen, and a trap **88** is interposed in the line **87** so as to retain liquid nitrogen in the conduit **84** and permit only gaseous nitrogen to be vented to atmosphere. A pressure relief valve **89** is disposed in the line which vents at **90** so as to establish the pressure at which venting occurs. A valve-equipped drain line **91** communicates with the line **87** at the juncture of the trap **88** and relief valve **89** to enable the line to be drained. Generally, the conduit **84** is filled with liquid nitrogen and as it absorbs heat tending to migrate through the heat shield container **17** toward the inner container **16,** the resultant expansion of parts of the liquid nitrogen and conversion thereof into the gaseous phase is followed by the escape of the heated gas to atmosphere, thereby forming a temperature barrier restricting the inward migration of heat from the outer container **18** to the inner container **16.**

A gage network is also associated with the reservoir **26,** as shown in FIG. **14,** and it includes a liquid level gage **92** and a pressure gage **94.** The liquid level gage **92** is connected to the bottom of the reservoir **26** via a conduit **95** which has a pressure equalizing valve **96** interposed therealong. At its lower end, the conduit **95** may communicate directly with a fill or supply line **97** which has a fill valve **98** disposed therealong. The pressure gage **94** is connected by a line **99** having a vapor-to-gage valve **100** located therealong to the upper end of the reservoir **26** through a branch conduit **101.** The branch conduit **101** has a vent valve **102** therein by means of which the reservoir **26** at its upper end is vented to atmosphere. The conduits **95** and **99** which respectively connect with the gages **92** and **94** are interconnected by a gage equalizing valve **104,** and the line **99** is also connected directly to the liquid level gage **92** by a line **105.** A liquid block valve **106** connects the line **99** intermediate to gage **94** and valve **100** to atmosphere. A bursting disc **107** and relief valve **108** vent the line **101** to atmosphere, as shown at **109.**

Thus, the portion of the bipartite cooling system that comprises the reservoir **26** and flow conduit **84** constitutes a complete and independent system flow-isolated from the interior of the fluid-receiving container **16** and flow system connected therewith. Liquid nitrogen or other comparable cooling media is supplied to the reservoir **26** through the valve **98** and supply line **97,** and since the flow conduit **84** is in open communication with the reservoir **26** adjacent the lower end thereof, the conduit and cooling coil defined thereby is ordinarily filled with the liquid fluid. As heat is absorbed by the liquid within the conduit **84** and portions of the liquid are thereby converted to the gaseous phase, the gaseous components are vented to atmosphere at **90** through the trap **88** and relief valve **89.** The liquid level and pressure within the reservoir **26** are made evident by tha gages **92** and **94,** and the pressure within the reservoir is prevented from exceeding some predetermined value by the relief valve **108** through which the reservoir is vented to atmosphere at **109.** In the event of malfunction of the valve **108,** the bursting disc **107** will rupture, if necessary, to limit the pressure of the fluid within the reservoir **26.** The various valve, regulator, gage, and safety components within the nitrogen cooling system are standard items well-known in the art, and for this reason no further description thereof is included.

The conduit **85** is connected at one end thereof to the interior of the fluid-receiving inner container **16,** and such connection is made adjacent the upper end of the container through a conduit section **110.** Adjacent its other end, the flow conduit **85** is vented to atmosphere at **111** through a pressure release valve **112** that defines the maximum permissible gaseous pressure within the conduit **85.** A cooling valve **114** is also connected to the line **85** and is manually operable and is used to permit sufficient escape of the gaseous fluid (i.e., helium) from the conduit **85** so as to cool the same and the heat shield container **17** about which it is coiled. The valve **114** vents to atmosphere at **115.** It should be observed that the vent **115** can be connected to a delivery system by means of which the helium gas otherwise venting to atmosphere can be conducted to a compressor or otherwise retained for use. It will be appreciated that a complete delivery and withdrawal system is associated with the inner container **16** which will also have a pressure gage, liquid level gage, safety devices, and vent means, but such details have been omitted because they are not germane to the present invention. Accordingly, in FIG. **14** only the general connections with the container **16** are shown and they include the fill and

drain line 116, vapor return line 117 which communicates with the vent line 118, and the lines 119 and 120 which respectively communicate with a liquid level gage and pressure gage neither of which is shown. For a complete disclosure concerning the details of an entire system associated with a cryogenic storage and transport vessel, reference may be made to the copending application of Robert S. Hampton, Ser. No. 808,765, filed Mar. 20, 1969now U.S. Pat. No. 3,602,003, and entitled Method of and Apparatus for Transporting Cryogenic Liquids.

The bipartite cooling system evidently constitutes a liquid nitrogen cooling arrangement that comprises the flow conduit 84 and a gaseous helium cooling arrangement that comprises the conduit 85. The coil defined by the conduit 84 is ordinarily filled with liquid nitrogen, but as the nitrogen absorbs heat migrating inwardly from the outer container 18 toward the intermediate heat shield 17, portions of the liquid nitrogen are converted into gas and bubble outwardly along the conduit to the vent 90. However, since the coil defined by the conduit 84 extends longitudinally about the heat shield container 17 there is a temperature differential as between the bulk head 23 at the flexible end of the vessel and the bulk head 25 at the fixed end thereof because of the reservoir 26 and storage therewithin of the low temperature nitrogen. Therefore, as gaseous nitrogen circulates along the conduit 84, it is reliquified each time it circulates through those portions of the conduit which are adjacent the reservoir 26. In any event, the liquid nitrogen cooling arrangement forms a temperature barrier tending to maintain the intermediate heat shield container 17 at a relatively uniform temperature which, for example, may be of the order of −300°F.

The temperature barrier defined by the liquid nitrogen cooling arrangement is very effective and absorbs substantially all of the heat migrating inwardly toward the heat shield container 17. It has been calculated that the shield is effective to absorb well over 90 percent of the heat migrating inwardly, and in many instances it is believed that the heat absorption may approach 99 percent of the total inward migration of heat. Thus, for example, the outer container 18 may have a temperature of about +70°F, the intermediate container 17 may be maintained at a temperature of about −300°F, and the inner container 16 will maintain a helium temperature of about −452°F.

As helium gas is admitted into the conduit 85, it may have a temperature of about −400°F, and as the helium gas emerges from the conduit 85 it will be at a much higher temperature which may approach that of the nitrogen say, for example, about 300°F. As explained hereinbefore, this helium gas can either be vented to atmosphere or, desirably, is carried by a delivery system to a compressor or other place of implant use. The helium gas admitted to the conduit 85 is the normal boil off gas from the container 16, and by admitting it into the conduit 85, it will reduce the evaporation rate within the container 16 because more heat is taken from the gas than would be normally vented. Consequently, by using the gaseous helium cooling arrangement, the boil off rate from the container 16 is markedly reduced. It might be mentioned that the liquid nitrogen cooling arrangement is advantageously used during transport of the cryogenic vessel, and that the gaseous helium cooling system is advantageously used when the vessel is located at a storage facility at a point of use, at which time the boil off helium can be effectively utilized in the plant facility. It would not be necessary at this time to use the nitrogen cooling system.

In one specific embodiment of the invention, the rate of helium boil off is limited to the order of 0.5 percent per day, and the support system has a maximum heat leak therethrough of about 2 BTUs per hour. The insulation provided between the spaced containers has a heat leak of about 22 BTUs per hour.

Although the heat conductivity of stainless steel is about 12 times less efficient than that of cooper, the arrangements heretofore described enable steel containers to be used throughout, thereby permitting the higher strength of steel to be used. For example, and referring to FIG. 1, the supports 34 at the flexible end of the vessel move toward the right, as viewed in FIG. 1, when the shield 17 first cools, and the difference in longitudinal movement of the shield 17 and inner vessel 16 results in a net longitudinal movement of the support 34. Thus, the supports 34 will tend to have a more nearly vertical orientation, but because the supports shrink owing to the difference in temperature between the liquid helium within the inner container and the temperature of the shield established by the liquid nitrogen, the two movements tend to compensate each other and the supports 34 operate effeciently with the stress level therein being due essentially to the load carried by the inner container 16. Since the supports 34 are of thin steel, they are highly flexible and any bending stresses are negligible.

More particularly, and referring to FIG. 15, stress of significance will develop in the supports 34 (in the absence of means to prevent the same) when there are substantial temperature differences between the containers such as the inner container 16 being cold and the heat shield 17 being warm, and vice versa. Considering the case of the inner container 16 becoming cold, it will shrink longitudinally through a distance $d1$, and correspondingly, each support 34 will necessarily swing through an angle $d0$ toward a more nearly vertical orientation.

As a result of the angular change $d0$, any support 34 will tend to displace the mounting plate 32 radially through a distance dr; but since the plate cannot be so displaced because it is constrained by all of the supports 34, each support will tend to be compressed. At the same time, however, the decreasing temperature of the container 16 which appears in gradient form along each support 34 will cause the same to shrinks, thereby tending to decrease the distance between the mounting plate 32 and outer welded end 35 of each support. Evidently, if the amount of the radial shrinkage can be made equal to the radial distance dr, no stress would be developed in the supports 34 as a consequence of the temperature change noted.

It is difficult to achieve the pure form of this desirable result, but proper selection of the angular disposition of each support 34 from the vertical (i.e., essentially the angle $d0$) will approximate the same such that each support has a limited tensile force therealong at substantially all times and is never stressed beyond about 70 percent of its yield strength including the load-induced stress when the inner container 16 is filled. As a specific example, is the aforementioned vessel for liquid helium in which the inner container 16 has a length of about 450 inches and is cooled to approximately

−452°F. and the slightly longer container **17** is cooled to about −320°F., supports **34** having a length of approximately 40 inches may have an angular disposition of 7°.

In such vessel, thermally induced relative longitudinal movement between the inner vessel **16** and heat shield **17** of 0.124 inches induced negligible stress; and in the same vessel such relative movement between the heat shield **17** and outer jacket **18** of 1.160 inches resulted in negligible stress in the supports **38** when the angular disposition thereof was about 1 ½°. Thus, the desired relationship is one in which thermally induced radial shrinkage of each radial support is effectively compensated by the radial decrease in the distance between the ends of the support resulting from the arc through which it swings as a consequence of thermally induced relative longitudinal shrinkage of the containers to which the support is attached.

Considering the supports **45** at the fixed end of the vessel, as the intermediate container **17** cools the supports **45** become shorter, but the diameter of the inner storage container **16** shrinks or decreases. Consequently, there is an increasing stress within the supports **45** as they tend to become shorter. However, because the two functions are generally concurrent, the stress is not materially increased and the supports are well able to withstand the load imparted thereto by the liquid helium within the inner container **16.** The angular spacing between the supports adjacent each end of the vessel affords a proper G-loading along their respective axes.

The attachment of the inner container **16** to the shield **17** and attachment of the shield **17** to the outer container **18** as heretofore described affords a double heat barrier length. The various supports operate effectively because of this length, and the intermediate points along the supports (i.e., at the intermediate container **17**) are at a substantially fixed temperature which is that of the intermediate container, and is about −300°F when the liquid nitrogen cooling system dominates and about −360°F when the gaseous helium system is effective.

The aforementioned bipartite cooling system comprising the two coils **84** and **85** could be converted into a single-coil system selectively connected to the nitrogen storage supply or to the inner helium container **16.** In such cases, it would be most convenient to provide a vacuum-jacketed valve and conduit (neither being shown) exteriorly of the outer container **18** to permit such selective interconnection of the coil. With an arrangement of this type, the cooling coil could be connected with the nitrogen storage chamber **26** and nitrogen circulated through the coil to cool the heat shield **17,** as heretofore described; and this same coil could then be evacuated and connected to the gaseous side of the helium container **16** to permit helium to circulate through the coil, as previously explained, to absorb heat and cool the shield.

The cooling function of the nitrogen system can be automatically controlled and regulated to a predetermined discharge temperature by means of a temperature-responsive solenoid-operated valve in the nitrogen line, and the valve **89** is such a valve. The trap **88** allows only gaseous nitrogen to be vented through the valve **89,** as set forth hereinbefore.

While in the foregoing specification an embodiment of the invention has been set forth in considerable detail for purposes of making a complete disclosure thereof, it will be apparent to those skilled in the art that numerous changes may be made in such details without departing from the spirit and principles of the invention.

What is claimed is:

1. A vessel for cryogenic fluids and the like, comprising: a plurality of longitudinally extending containers supported one within another in spaced apart relation, one of said containers being an inner storage container adapted to receive such fluid therein, a second thereof being an intermediate heat shield enclosing the inner container, and a third being an outer jacket enclosing all of said containers; and support means interconnecting said containers to maintain the same in spaced apart relation and at the same time minimize conductive heat migration through the support means between said outer and inner containers, said support means including transverse support structure providing adjacent each end of said vessel a plurality of relatively thin and narrow spaced apart inner transverse supports substantially confined within the space between said inner storage and intermediate heat shield containers and extending outwardly from the center portion of said inner container at each end thereof generally adjacent its longitudinal axis to the outer portions of said heat shield generally adjacent its cylindrical surface to interconnect the same adjacent the ends thereof, said transverse support structure further providing adjacent each end of said vessel a plurality of relatively thin and narrow spaced apart outer transverse supports substantially confined within the space between said intermediate heat shield and outer jacket containers and extending outwardly from the center portion of said heat shield at each end thereof generally adjacent its longitudinal axis to the outer portion of said outer jacket generally adjacent its cylindrical surface to interconnect the same adjacent the ends thereof, said inner and outer transverse supports disposed in structural parallelism and functional serialism and being relatively long with the length of the thermal path defined thereby between said inner container and outer jacket being materially greater than the transverse distance therebetween to define relatively long thermal paths restricted in cross sectional area and effective to reduce conductive heat migration therethrough.

2. The vessel according to claim **1** in which said inner transverse supports include a plurality of angularly spaced inner spokes adjacent each end of said inner container and being connected therewith and extending generally radially outwardly therefrom to areas of connection with said intermediate heat shield container to constrain said inner container against transverse displacements relative thereto, and in which said outer transverse supports include a plurality of angularly spaced outer spokes adjacent each end of said intermediate heat shield container and being connected therewith and extending generally radially outwardly therefrom to areas of connection with said outer jacket to constrain said intermediate heat shield container against transverse displacements relative thereto.

3. The vessel according to claim **2** in which said inner and outer spokes adjacent one end of said vessel are relatively flexible in longitudinal directions so as to accommodate limited relative longitudinal displacements of said containers, the relatively great lengths of said

flexible spokes being contributive to the longitudinal flexibility thereof.

4. The vessel according to claim 1 in which said inner and outer transverse supports are angularly disposed relative to a transverse plane normal to the longitudinal axis of said vessel so as to accommodate thermally induced relative changes in said containers without excessively stressing said supports.

5. The vessel according to claim 4 in which the angular orientation of said inner supports is selected to define the relationship in which any thermally induced change in the radial length of an inner support tends to be compensated by the radial change in the distance between the ends thereof as such support swings between its selected angle and a more nearly transverse disposition as a consequence of thermally induced relative longitudinal changes in the lengths of said containers.

6. A vessel for cryogenic fluids and the like, comprising: a plurality of longitudinally extending containers supported one within another in spaced apart relation, one of said containers being an inner storage container adapted to receive such fluid therein, a second thereof being an intermediate heat shield enclosing the inner container, and a third being an outer jacket enclosing all of said containers; and support means interconnecting said containers to maintain the same in spaced apart relation and at the same time minimize conductive heat migration through the support means between said outer and inner containers, said support means including transverse support structure providing adjacent each end of said vessel of plurality of spaced apart inner transverse supports substantially confined within the space between said inner storage and intermediate heat shield containers and extending outwardly from the center portion of said inner container at each end thereof to the outer portions of said heat shield to interconnect the same adjacent the ends thereof, said transverse support structure further providing adjacent each end of said vessel a plurality of spaced apart outer transverse supports substantially confined within the space between said intermediate heat shield and outer jacket containers and extending outwardly from the center portion of said heat shield at each end thereof to the outer portion of said outer jacket to interconnect the same adjacent the ends thereof, said transverse supports thereby being relatively long with the length of the thermal path defined thereby between said inner container and outer jacket being materially greater than the transverse distance therebetween to define relatively long thermal paths effective to reduce conductive heat migration therethrough, said support means further including longitudinal support structure providing inner longitudinal supports interconnecting said inner storage and intermediate heat shield containers, and also providing outer longitudinal supports interconnecting said intermediate heat shield and outer jacket containers, said longitudinal support structure being effective to resist relative bodily displacements between said containers in longitudinal directions.

7. The vessel according to claim 6 in which said inner and outer longitudinal supports are entirely located adjacent one end portion of said vessel.

8. The vessel according to claim 7 in which each of said inner and outer longitudinal supports comprises an elongated longitudinally extending rod interconnected one with another in a serial relationship so as to minimize conductive heat migration therethrough between said outer and inner containers as aforesaid.

9. The vessel according to claim 8 in which said longitudinal support structure further includes a pair of universal joints respectively located adjacent the ends of said inner rod and being connected therewith and with said inner and intermediate heat shield containers so as to accommodate limited transverse displacements therebetween.

10. The vessel according to claim 8 in which each of said rods is hollow so as to reduce the cross sectional area of the conductive heat path defined thereby.

11. The vessel according to claim 8 in which said inner and outer transverse supports are angularly disposed relative to a transverse plane normal to the longitudinal axis of said vessel so as to accommodate thermally induced relative changes in said containers without excessively stressing said supports.

12. The vessel according to claim 11 in which the angular orientation of said inner supports is selected to define the relationship in which any thermally induced change in the radial length of an inner support tends to be compensated by the radial change in the distance between the ends thereof as such support swings between its selected angle and a more nearly transverse disposition as a consequence of thermally induced relative longitudinal changes in the lengths of said containers.

13. The vessel according to claim 8 in which said inner transverse supports include a plurality of angularly spaced inner spokes adjacent each end of said inner container and being connected therewith and extending generally radially outwardly therefrom to areas of connection with said intermediate heat shield container to constrain said inner container against transverse displacement relative thereto, and in which said outer transverse supports include a plurality of angularly spaced outer spokes adjacent each end of said intermediate heat shield container and being connected therewith and extending generally radially outwardly therefrom to areas of connection with said outer jacket to constrain said intermediate heat shield against transverse displacements relative thereto; and in which said inner and outer spokes adjacent one end of said vessel are relatively flexible in longitudinal directions so as to accommodate limited relative longitudinal displacements of said containers, the relatively great lengths of said flexible spokes being contributive to the flexibility thereof.

14. The vessel according to claim 13 in which said inner and outer transverse supports are angularly disposed relative to a transverse plane normal to the longitudinal axis of said vessel so as to accommodate thermally induced relative changes in said containers without excessively stressing said supports.

15. A vessel for cryogenic fluids and the like, comprising: a plurality of containers supported one within another and including an inner storage container adapted to receive such fluid therein, an intermediate heat shield enclosing the inner storage container, and an outer jacket enclosing the latter; and a bipartite cooling system defining a temperature barrier restricting the inward migration of heat from said outer jacket to said inner container and including first and second flow conduits located intermediate said inner container and outer jacket and each being formed to define a cooling coil therebetween disposed in heat exchange

relation with said heat shield; a reservoir for a coolant such as liquid nitrogen or the like, the first of said flow conduits being connected adjacent one end thereof to said reservoir and adjacent its other end being vented to atmosphere to enable liquid coolant converted to the gaseous phase by absorbing heat to escape to atmosphere, and the second of said flow conduits being connected adjacent one end thereof to said inner storage container and adjacent its other end disabling cryogenic fluid to be released therefrom, heat migrating inwardly from said outer jacket toward said inner container being absorbed at least in part by any flow of coolant through the coil defined by said first flow conduit and any flow of cryogenic fluid through the coil defined by said second flow conduit and temperature-responsive valve means disposed in said first flow conduit and being operative to control the flow of such coolant therethrough in accordance with predetermined temperature values.

16. The vessel according to claim **15** and further comprising support means interconnecting said containers to maintain the same in spaced apart relation and at the same time minimize conductive heat migration through the support means between said outer and inner containers and including transverse support structure, the length of the thermal path defined between said inner container and outer jacket by said transverse support structure being materially greater than the transverse distance therebetween.

17. The vessel of claim **16** in which said transverse support structure includes inner transverse supports substantially confined within the space between said inner storage and intermediate heat shield containers and interconnecting the same adjacent the ends thereof, and further includes outer transverse supports substantially confined within the space between said intermediate heat shield and outer jacket containers and interconnecting the same adjacent the ends thereof; and in which said inner transverse supports extend outwardly from the center portion of said inner container at each end thereof to said heat shield, and said outer transverse supports extend outwardly from the center portion of said heat shield to said outer jacket, whereby said transverse supports are relatively long and define relatively long thermal paths so as to reduce conductive heat migration therethrough.

18. The vessel according to claim **17** in which said transverse support structure includes inner transverse supports extending from said inner storage container adjacent the center portion of an end thereof to said heat shield, and further includes outer transverse supports extending from said heat shield adjacent the center portion of an end thereof to said outer jacket, said inner and outer transverse supports being angularly disposed relative to a transverse plane normal to the longitudinal axis of said vessel so as to accommodate thermally induced relative changes in said containers without excessively stressing said supports, and in which the angular orientation of said inner supports is selected to define the relationship in which any thermally induced change in the radial length of an inner support tends to be compensated by the radial change in the distance between the ends thereof as such support swings between its selected angle and a more nearly transverse disposition as a consequence of thermally induced relative longitudinal changes in the lengths of said containers.

19. The vessel according to claim **17** in which said support means includes transverse support structure comprising inner transverse supports interconnecting said inner storage and intermediate heat shield containers, and further comprising outer transverse supports interconnecting said intermediate heat shield and outer jacket containers; and in which said longitudinal support structure includes inner longitudinal supports interconnecting said inner storage and intermediate heat shield containers, and further includes outer longitudinal supports interconnecting said intermediate heat shield and outer jacket containers.

20. The vessel according to claim **19** in which said inner transverse supports include a plurality of angularly spaced inner spokes adjacent each end of said inner container and being connected therewith and extending outwardly therefrom to areas of connection with said intermediate heat shield container to constrain said inner container against transverse displacements relative thereto, and in which said outer transverse supports include a plurality of angularly spaced outer spokes adjacent each end of said intermediate heat shield container and being connected therewith and extending outwardly therefrom to areas of connection with said outer jacket to constrain said intermediate heat shield against transverse displacements relative thereto; and in which said inner and outer spokes adjacent one end of said vessel are relatively flexible in longitudinal directions so as to accommodate limited relative longitudinal displacements of said containers.

21. A vessel for cryogenic fluids and the like, comprising: a plurality of longitudinally extending containers supported one within another in spaced apart relation, one of said containers being an inner storage container adapted to receive such fluid therein, a second thereof being an intermediate heat shield enclosing the inner container, and a third being an outer jacket enclosing all of said containers; and support means interconnecting said containers, said support means including longitudinal support structure interconnecting said containers so as to resist relative bodily displacements therebetween in longitudinal directions and providing inner longitudinal supports interconnecting said inner storage and intermediate heat shield containers and further providing outer longitudinal supports interconnecting said intermediate heat shield and outer jacket containers, each of said inner and outer longitudinal supports having an elongated longitudinally extending rod interconnected one with another in a serial relationship so that the length of the thermal path defined between said inner container and outer jacket by said longitudinal support structure is materially greater than the transverse distance therebetween so as to minimize conductive heat migration through the support means between said outer and inner containers, said support means further including transverse support structure interconnecting said containers so as to resist relative bodily displacements therebetween in transverse directions.

22. The vessel according to claim **21** in which said inner and outer longitudinal supports are entirely located adjacent one end portion of said vessel.

23. The vessel according to claim **22** in which said longitudinal support structure further includes a pair of universal joints respectively located adjacent the ends of said inner rod and being connected therewith and with said inner and intermediate heat shield containers so as to accommodate limited transverse displacements therebetween.

24. The vessel according to claim **22** in which each of said rods is hollow so as to reduce the cross sectional area of the conductive heat path defined thereby.

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