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COUPLING ARRANGEMENT BETWEEN CRYOGENIC REFRIGERATOR AND HEAT LOAD

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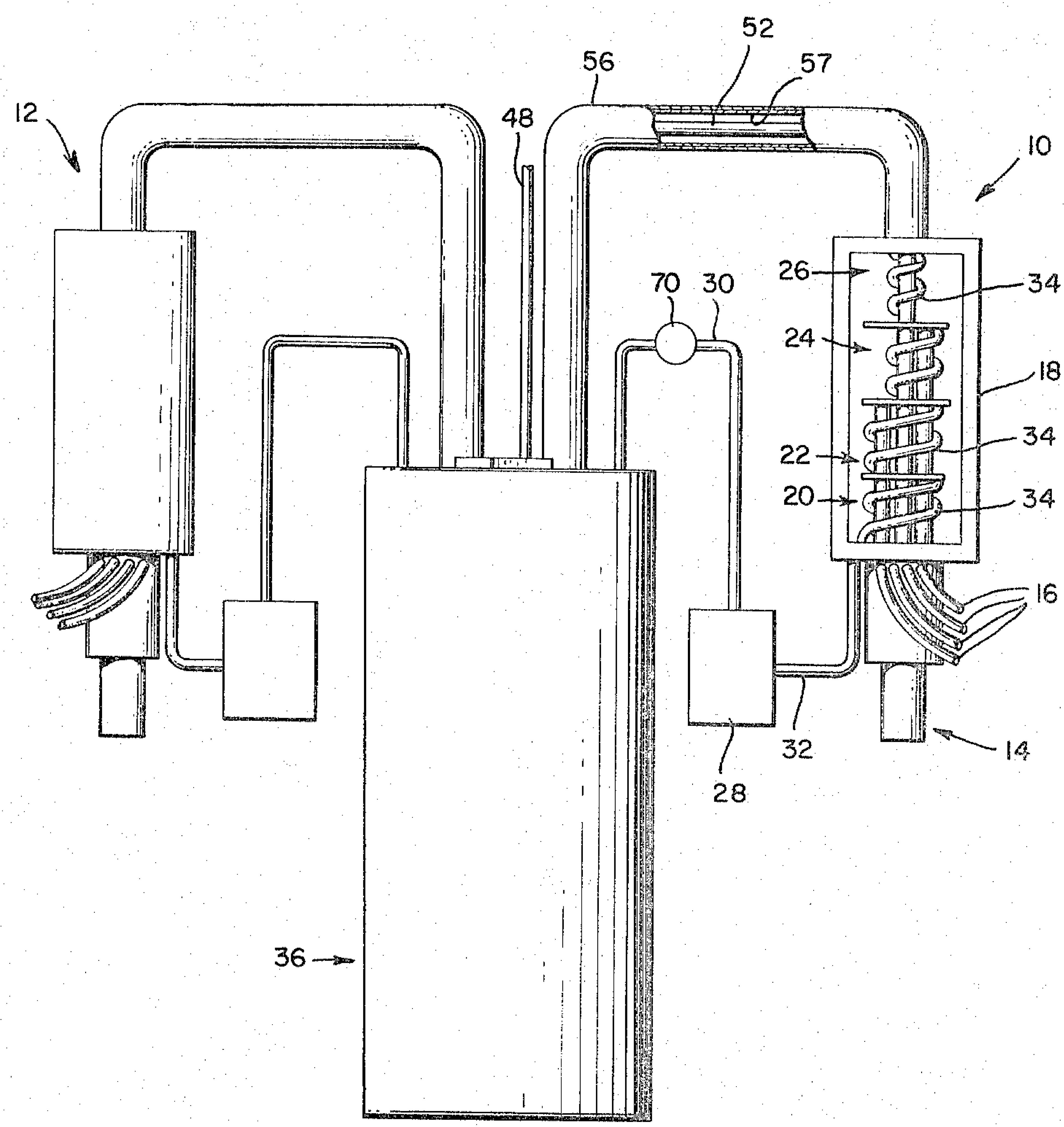

Fig. 1.

Kenneth W. Cowans,
INVENTOR.
BY [signature]
ATTORNEY.

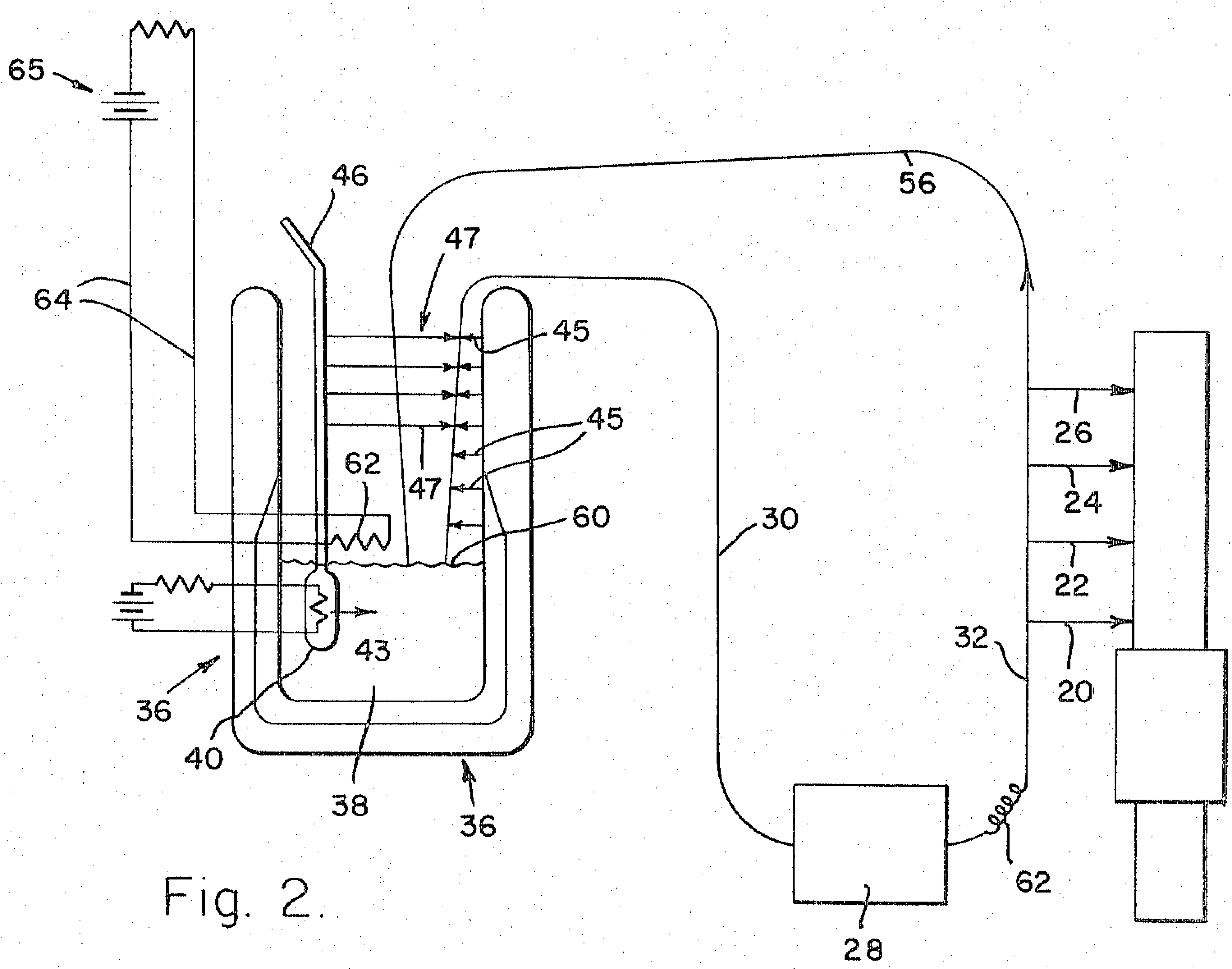

Fig. 2.

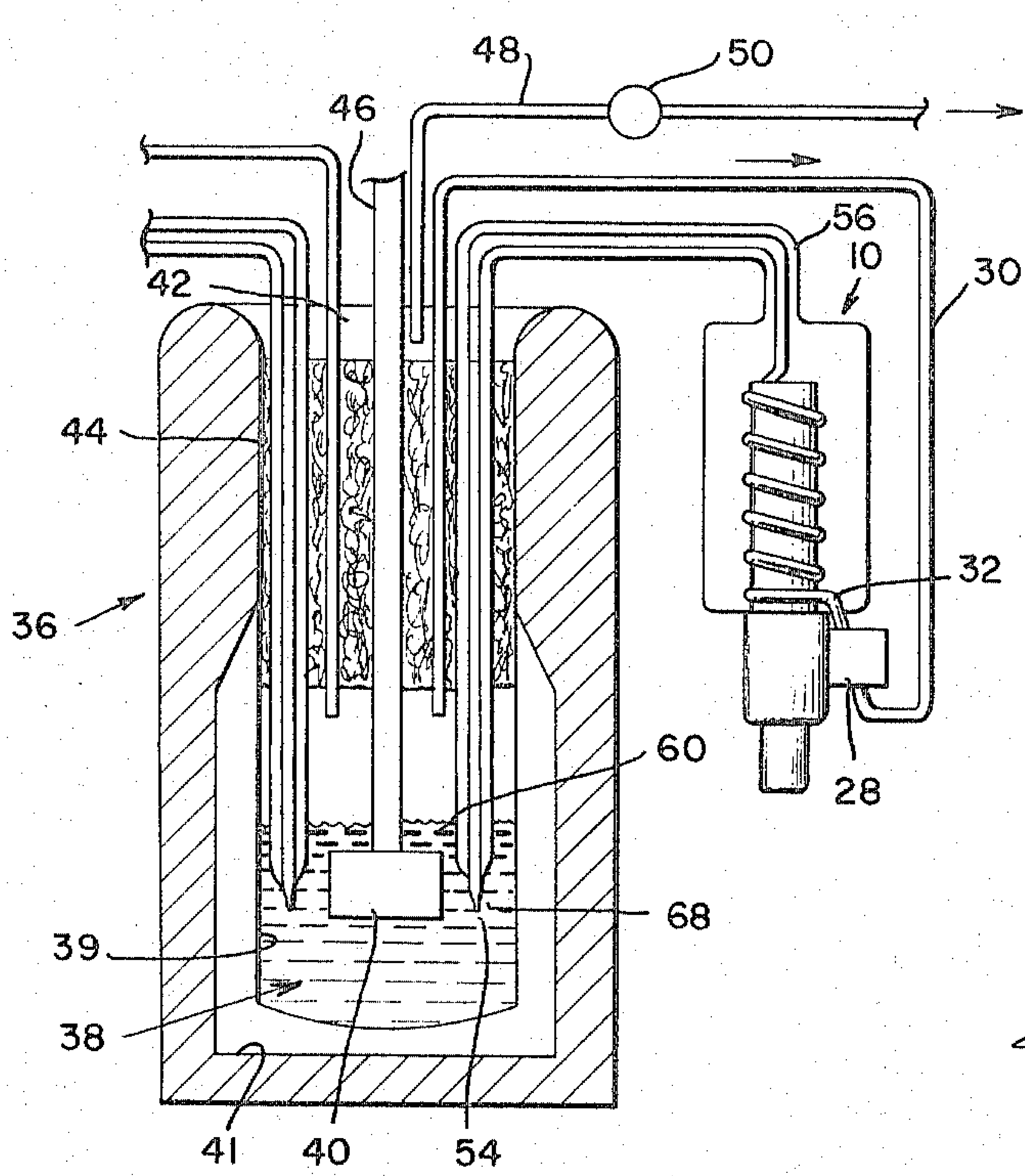

Fig. 3.

Kenneth W. Cowans,
INVENTOR.
BY.
ATTORNEY.

United States Patent Office

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COUPLING ARRANGEMENT BETWEEN CRYOGENIC REFRIGERATOR AND HEAT LOAD

Kenneth W. Cowans, Los Angeles, Calif., assignor to Hughes Aircraft Company, Culver City, Calif., a corporation of Delaware

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3 Claims. (Cl. 62—49)

The invention relates to a coupling arrangement between a cryogenic refrigerating source and a remote low temperature heat load and is particularly adapted to the maintenance of a steady-state temperature condition at the heat load over long periods of operation with a high degree of operating efficiency

In the reception, transmission and amplification of various signals, for example, the reception and amplification of radio signals between ground and air stations, it is essential, for satisfactory operation, that the amplifier arrangement be maintained in a steady-state low temperature ambient condition over extended periods of time. It is therefore a first purpose of the invention to provide a cryogenic fluid transfer arrangement that will provide such steady-state ambient condition over a reasonably long period of time. Additionally, the arrangement disclosed is readily adapted to the incorporation of a redundant or secondary power system which further enhances service time operation in the event of accidental primary power system shutdown.

A major problem presented in the design of systems of the type hereunder consideration involves the effective utilization of refrigerating capacity from the standpoint of cryogenic efficiency and work output and the resulting in service, economical operation. Secondarily, of course, economical system manufacture is of major importance.

A major problem with regard to such systems has been the design of components that, when integrated within the over-all system, accomplishes maximum refrigeration with a minimum of work input and within practical parameters. The problem of an efficient system is magnified, where, the ultimate refrigerating effect requires temperature reductions from an ambient in the range of 320° K. to an operating temperature in the range of 4° K.

With this in mind, the disclosed invention incorporates a cryogenic refrigerator and a coupling or transfer circuit combined with a heat load encapsulating Dewar in a combination adapted to produce the intended result in a highly efficient manner. The circuit employs a transfer pump which draws a cryogenic material from a load Dewar at essentially ambient temperature. The cryogenic gas from the Dewar is then circulated to a refrigerator where liquefaction is accomplished. The transfer circuit at the cryoengine is isolated from ambient by an evacuated or vacuum vessel, heat transfer being accomplished by direct conduction, that is, the circuit tubing physically contacting the refrigerator cooling sector. Preferably, the engine or refrigerator is multistaged. The transfer tube emanating from the cryoengine is the cold side of the circuit and carries the liquefied cryogenic material. The cold-side tube is again isolated from ambient by disposition thereof within a radiation shielded and evacuated (vacuum) transfer tube container. In the preferred embodiment the vacuum vessel and the vacuum tube container are unitary and the insulating vacuum is common thereto. The cold-side tube and tube container are received within the Dewar and the cold-side tube arranged to deposit the liquid cryogen at the load site. As a result of this structure, heat transfer in relation to the cold-side tube is negligible and may be practically discounted with reference to the heat balance required to maintain the desired steady-state temperature

condition at the load site. To achieve operational efficiency, it is important that structural dimensional integrity employed be accurately maintained during operation. Accordingly, it is desirable that the surface level of the liquid cryogen within the load Dewar be accurately maintained. To accomplish this result the system disclosed incorporates a regulating arrangement which is physically positioned within the Dewar at the desired level of liquid-vapor interface. The regulator is operative to dissipate heat to the Dewar in response to the degree of physical contact between the regulator and liquid cryogen. Specifically, the regulator comprises a resistance element with a constant current applied thereto, the resistance of said element varying in response to physical contact between the element and the cryogenic liquid. Specifically, as the temperature of the regulator is reduced by surface contact with the liquid cryogen, the resistance of the regulator increases and heat dissipation is increased. The dissipated heat stimulates the boiling and vaporization of the liquid cryogen. As a result the liquid interface is maintained at approximately the desired level. The attainment of an accurate located of liquid-vapor interface is an important feature of the invention. The heat load, of course, is continually bathed in the liquid cryogen thus maintaining its optimum operating temperature and an effective thermal balance may be achieved in the vapor aspect of the Dewar as will hereinafter be discussed.

The particular arrangement disclosed has been found to be highly effective in cooling an electronic device such as a preamplifier to an operating range at the approximate temperature of liquid helium. The particular Dewar that will encapsulate the preamplifier requires waveguide structure for signal transmission to and from the preamplifier. The waveguide structure enters the Dewar from an ambient atmosphere and etxends therein to engage the preamplifier. Heat conduction via the structure of the waveguide occurs. Additionally, the cold chamber of the Dewar will be subject to heat ingress by conduction along the Dewar walls and radiation shield and heat radiation from the Dewar walls. The most efficient operation of the system, with a minimum of waste refrigeration, requires that the vaporized cryogen leave the Dewar at approximately ambient temperature. This is most efficiently accomplished by the absorption of the noted heat load via warming of the vaporized cryogen by absorbing much of this heat ingress as it is moved to the egress port of the Dewar. Employing the disclosed arrangement, the waveguide structure is cooled continuously along its length to preamplifier operating temperature at the point of juncture therewith which avoids excessive heat impact at the preamplifier.

Thus, through vaporization and warming of the cryogen, a heat balance results assuring that the preamplifier is continuously bathed in liquid cryogen and maintained at its optimum operating temperature.

These and other objects and purposes of the disclosed invention will become apparent in the course of the following description and from an examination of the related drawings, wherein:

FIGURE 1 is a partially schematic, fragmentary perspective view of a typical system employing the invention;

FIG. 2 is a schematic illustration of the system employed and illustrates the invention in essentially flow diagram form; and

FIG. 3 is a fragmentary, partially schematic, vertical, sectional view of the load Dewar arrangement.

Describing the invention in detail and directing attention to the drawings, it will be understood that FIG. 1 discloses a coupling arrangement utilizing an active or primary system indicated generally at **10** and a standby or secondary system indicated generally at **12**. The standby or secondary system, of course, is only employed in the event of accidental failure of the primary system or when the primary system requires purposeful shutdown for service.

The systems **10** and **12** are identical in structure and operation and, accordingly, only the primary system will herein be discussed in detail.

To provide cooling and liquefaction of the cryogen within the transfer circuit, a cryogenic refrigerator indicated generally at **14** is provided. A typical refrigerator that will efficiently meet service requirement when the cryogen employed is helium may be a Solvay engine in operative series with a Joule-Thomson liquefier although other refrigerators may be employed. Specifically, a four-stage arrangement has been found satisfactory when the final heat load ambient temperature is in a range between 4° and 5° Kelvin. A plurality of leads **16, 16** are operatively associated with the refrigerator **14** and in communication with an appropriate compressor (not shown) in the conventional manner. An encasing vessel **18** surrounds the cooling stages **20, 22, 24** and **26**, of the refrigerator **14**, and vacuum insulates said stages from ambient.

A transfer circuit pump **28** is provided and has a vapor intake line **30** and a vapor outlet line **32**. The pump operates to circulate the cryogen as will hereinafter be described. In order to maximize heat transfer between the refrigerator **14** and the rtansfer line **32** within vacuum vessel **18**, the line **32** is arranged to physically contact (bonded to) the respective cooling stages so that efficient heat transfer therebetween may be achieved by direct conduction. This arrangement is illustrated at **34, 34** of FIG. 1.

The load containing Dewar is indicated generally at **36** in FIGS. 1 and 3. It comprises a chamber **38** at the lower aspect thereof housing the heat load such as an electronic preamplifier **40**. The chamber **38** is partially defined by Dewar wall **39** which is surrounded by radiation shield **41**. The intervening space is evacuated to offer appropriate vacuum insulation. The upper aspect of the Dewar **36** is closed by cap **42** and contains a cylinder of insulating material **44** such as fiberglass wool therebelow. Means **46** are provided for transmitting an energy signal to the preamplifier **40** and will hereinafter be referred to as the waveguide tubing. The waveguide tubing extends into the Dewar and is operatively associated with preamplifier **40** in chamber **38**. The vapor intake line **30** also communicates with chamber **38**. It is also desirable to provide a cryogen regenerating supply line **48** in communication with chamber **38**. The line **48** may be in communication with a helium supply (not shown) and may have a regulating valve **50** therein so that additional cryogen may be supplied to the circuit in the event pressure therein falls below a predetermined level.

A cold side liquid helium transfer line or tube **52** emanates from the refrigerator **14** and is in communication with the chamber **38** as at **54**. A particular feature of the transfer line **52** is that it is axially disposed within an elongated radiation shielded vacuum container **56**. The container **56**, being evacuated and closed, insulates the tube **52** from ambient temperature. An additional tube **57**, disposed between container **56** and tube **52** and made of copper or like material, may be incorporated and thus provide an effective insulating radiation shield. The container **56** also extends into chamber **38**, insulating the cold side tube **52** from heat transfer relation with the Dewar **36**. In the disclosed arrangement it has been found desirable that the container **56** physically communicate with the vessel **18** so that the vacuum existent in the vessel and the vacuum existent in the container **56** are identical. With this structure, heat transfer with the cold side tube **52** is negligible and may be disregarded in determining the physical structure required to maintain a steady-state heat balance within the Dewar **36**.

Considering system heat balance, attention will first

be directed to the Dewar **36**. Noting FIG. 2, it will be seen that heat dissipation into the Dewar **36** may be considered to emanate from the operating device or preamplifier **40** (arrow **43**), and from the Dewar walls (arrows **45, 45**), the latter resulting from wall radiation and conductive heat down container **56** and down the Dewar walls from ambient. The waveguide tubing or structure also dissipates heat to the internal aspect of the Dewar (arrows **47, 47**). Assuming that the surface **60** of the liquid cryogen is maintained in an approximately fixed location, it is desirable that vaporized cryogen leave the Dewar **36** and enter pump intake line **30** at about ambient temperature. Thus, the vaporized cryogen that is boiled off in cooling the preamplifier **40** is warmed to ambient by absorption of the heat dissipated to the Dewar as described above.

To accurately locate the surface or liquid-gas interface **60**, the invention provides a regulating device **62** (FIG. 2) which may be a carbon type resistor having associated therewith electrical leads **64, 64**. The leads **64, 64** are connected to an electrical power source **65**, which applies a constant current to the regulator **62**. Regulators of this type have a resistance inversely related to temperature. That is to say, as the temperature level of the carbon resistor is lowered the resistance thereof increases and the heat dissipation thereof increases. Consequently, in the operating system disclosed, as the surface of the carbon resistor **62** is contacted by the liquid helium and cooled, heat dissipation increases in proportion to the degree of surface contact with the liquid helium. The increased heat dissipation has the effect of increasing the boiling or vaporization rate of the liquid helium with the result that the liquid-gaseous interface **60** is accurately maintained at the appropriate level within the Dewar **36**.

It is desirable, to avoid heat balance disturbance via convection or acoustic resonance, that the flow of liquid helium to chamber **38** be continuous. To accomplish this result, a small liquid impedance or constriction is provided in the line **52** at the Dewar terminus thereof as at **68**. This fluid impedance has the effect of maintaining the line **52** in liquid-full condition. The fiberglass wool **44** in the upper aspect of the Dewar patently inhibits heat balance disturbance due to convection.

In operation, the engine **14** provides the refrigerating effect and acts as a heat sink to cool the helium in the transfer circuit. The preamplifier **40**, the system's primary load, offers optimum operation in an ambient condition of approximately 4° K., the temperature at which helium liquefies. The engine **14** may be of any conventional type having the capacity to liquefy helium. For example, a three-stage Solvay engine combined with a Joule-Thomson liquefier is effective to create the temperature levels needed. It will be understood that the cryogenic refrigerator or engine **14** employs helium gas to achieve this extremely low temperature but the gas utilized in the engine is independent of the cryogen in the transfer circuit.

Referring to FIG. 2, the transfer pump **28** removes helium gas from the Dewar **36** via line **30** at approximately ambient temperature of 320° K. and at atmospheric pressure. Heat above ambient added to the helium by the work of pump **28** will be dissipated to atmosphere at coil **62**. The gas is then pumped via line **32** to stages **20, 22** and **24** of the engine where the temperature of the gas is staged-lowered to 150° K., 50° K. and 15° K., respectively. At stage **26**, the Joule-Thomson liquefier, the temperature of the helium in the transfer circuit is lowered to 4° K. and liquefaction results.

The liquid helium is then transferred via line **52** and is deposited in the Dewar chamber **38** at port **54**. Within chamber **38** the helium boils as a result of heat absorption and the boiling effect cools the preamplifier as the liquid helium changes to its gaseous stage. The helium gas moves through the Dewar **36** to line **30** and is warmed to approximately ambient temperature as it enters line

30. In warming to ambient temperature in Dewar 36, the helium absorbs the heat load transmitted from ambient to the cold portion of the Dewar 36 by conduction via the Dewar walls, and the waveguide structure and radiation transmitted to the inner portions of the Dewar.

The line 52, being contained in vacuum transfer tube 56, delivers liquid helium to the heat load of the Dewar chamber 38 with negligible effect on the heat balance of the Dewar. The regulator 62 maintains the liquid-vapor interface of the helium at the proper level within the Dewar chamber so that a steady-state condition at the amplifier 40 is assured.

In the event the primary power source 10 fails, the liquid helium within the Dewar 36 continues to vaporize and the pressure within the transfer circuit will rise beyond the predetermined control level. This pressure rise within the Dewar vessel actuates relief valve 70. A conventional alarm (not shown) may be triggered by relief valve actuation and the redundant power source 12 may be activated to maintain the steady-state condition within the Dewar 36. Cool-down of redundant or stand-by system 12 occurs before the reservoir of liquid helium in chamber 38 is dissipated. During normal operation of the primary system 10, the redundant system 12 is static.

Means to regenerate the total volume of helium within the transfer circuit are provided. When pressure within the circuit falls below a determined level, the constant pressure valve 50 opens and helium gas is injected into Dewar 36 from a supply source (not shown) via line 48.

It will thus be apparent that the invention discloses a unique refrigerant transfer and coupling arrangement adapted to efficiently maintain a steady-state temperature condition at the heat load situs. The design is such that it is readily adapted to the incorporation of a redundant system and thus provides fail-safe operation over extended periods of time.

The invention as disclosed is by way of illustration and not limitation and may be modified in various particulars and yet fall within the scope of the appended claims.

What is claimed is:

1. In a refrigerant transporting arrangement for moving a cryogenic refrigerant from a refrigerating device to a remotely located heat load, the combination of,
- a casing of the Dewar type internally defining a chamber insulated to resist thermal transfer between the chamber and ambient atmosphere,
- said heat load being disposed within said chamber,
- a closed circuit refrigerant transport line having a cold segment terminating in an egress port communicating with the chamber,
- said transport line including a return segment communicating with the chamber,
- housing means encasing said device and said cold segment,

- said housing means being sealed from ambient atmosphere and evacuated to vacuum insulate said device and said cold segment from said ambient atmosphere,
- said transport line including a refrigerating segment disposed within said housing means and in heat conductive engagement with said refrigerating device,
- said refrigerating device being operative to reduce the temperature of said refrigerant in said last mentioned segment and to liquefy same,
- said housing means thermally insulating said cold segment from heat conductive relation with said casing,
- pump means to continually convey said refrigerant through said closed circuit line,
- said egress port being arranged to deposit liquid refrigerant within the chamber to bathe the heat load therein,
- and liquid level control means within the chamber operative to variably dissipate heat therein in response to the variation in surface contact between the control means and said liquid refrigerant to variably induce the boiling and vaporization of said liquid refrigerant and thereby control the level of the liquid refrigerant within the chamber,
- the vaporization and warming of said refrigerant being operative to absorb heat impinging on said chamber from said load and from ambient atmosphere,
- said return segment conveying vaporized refrigerant from the chamber to the refrigerating device at approximately ambient temperature.

2. An arrangement according to claim 1,
- wherein said refrigerating device comprises a refrigerator having a plurality of cold stages,
- said housing means enclosing said cold stages,
- the latter being disposed in a vacuum,
- said refrigerating segment being series-bonded to the respective cold stages of the refrigerator,
- said egress port being constricted to assure a liquid full condition in said cold segment.

3. An arrangement according to claim 2 and including passage means establishing communication between a supply source of cryogenic refrigerant and said chamber, and constant pressure valve regulating means within said passage means to accommodate regeneration of said cryogenic refrigerant when the pressure within the chamber falls below a determined level.

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LLOYD L. KING, *Primary Examiner.*