Oct. 21, 1969 J. MULDER 3,473,341

COLD-GAS REFRIGERATION APPARATUS

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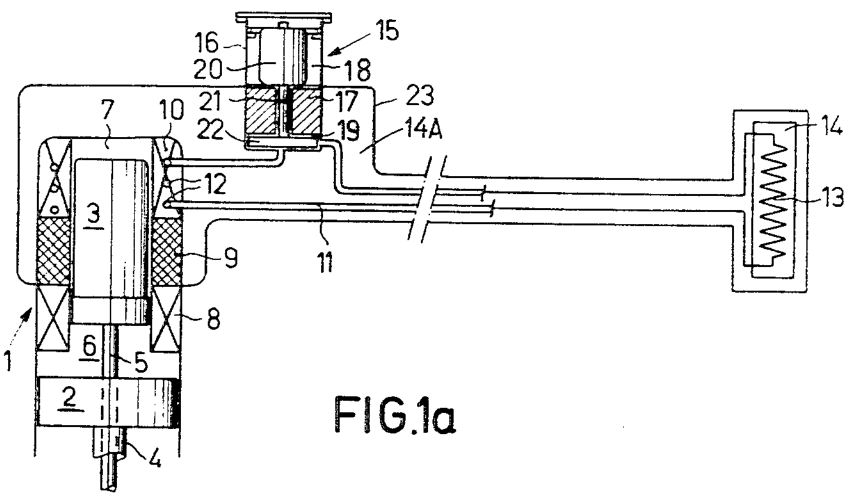

FIG.1a

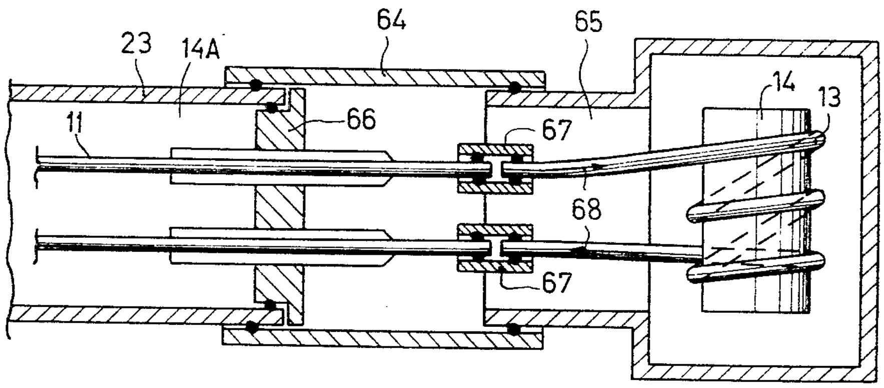

FIG.1b

INVENTOR.
JAN MULDER
BY
Frank R Jefferson
AGENT

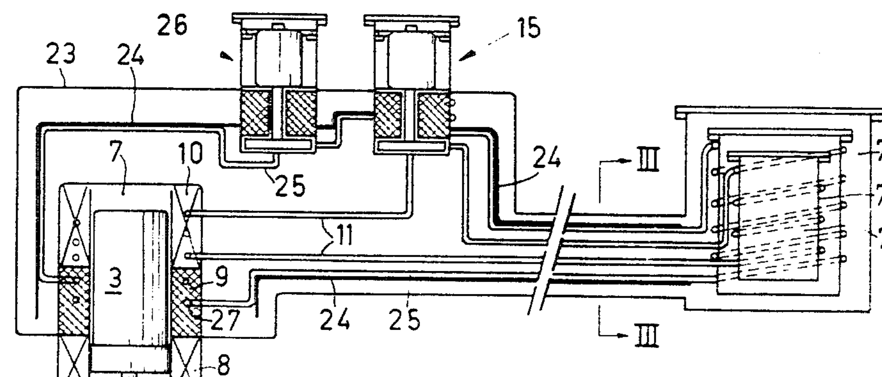

FIG. 2

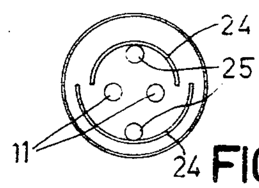

FIG. 3

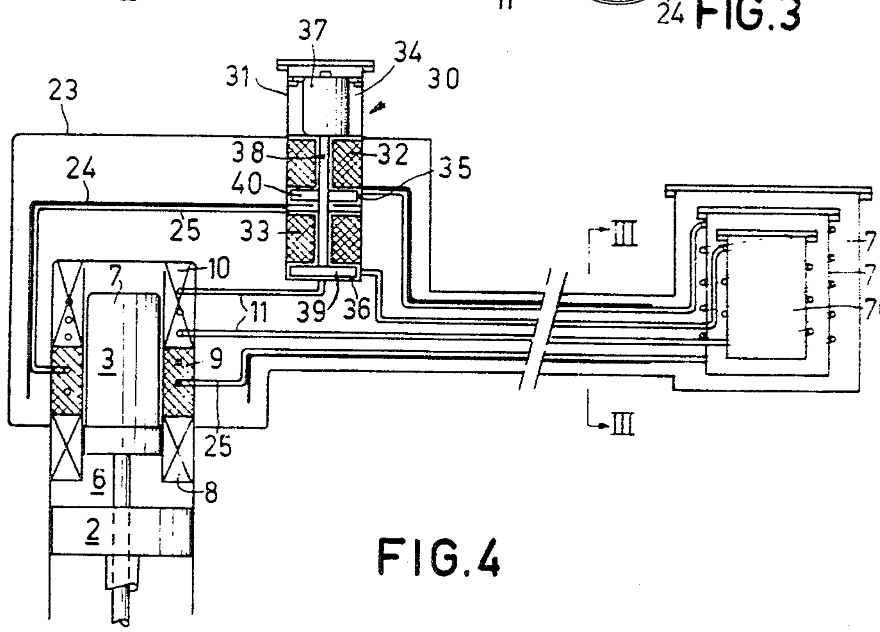

FIG. 4

JAN MULDER INVENTOR.

BY [signature]

AGENT

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COLD-GAS REFRIGERATION APPARATUS

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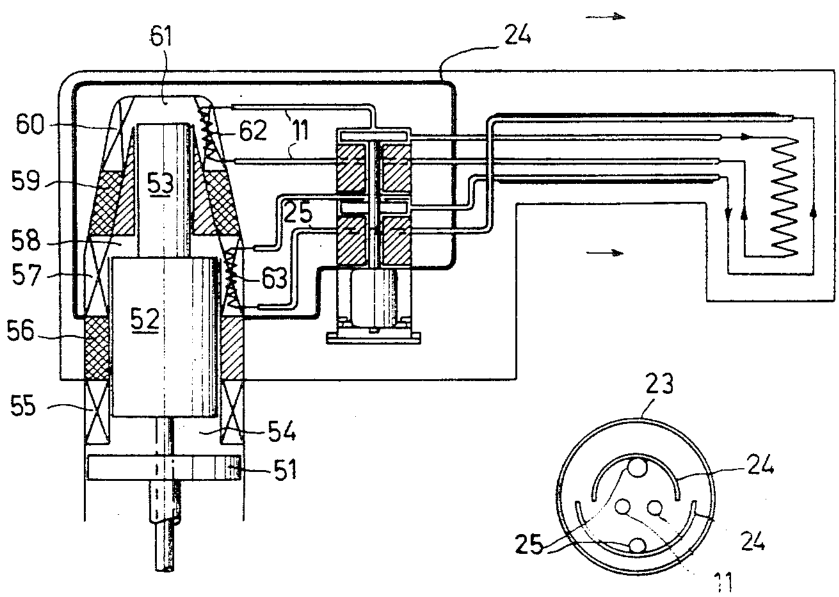

FIG.5

INVENTOR.
JAN MULDER
BY

AGENT

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COLD-GAS REFRIGERATION APPARATUS

Jan Mulder, Emmasingel, Eindhoven, Netherlands, assignor, by mesne assignments, to U.S. Philips Corporation, New York, N.Y., a corporation of Delaware

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Int. Cl. F25b 9/00
U.S. Cl. 62—6 8 Claims

ABSTRACT OF THE DISCLOSURE

A refrigeration apparatus including a cold-gas refrigerator with its freezer as a source of cold gaseous medium in combination with a cold-transport assembly for transporting the cold medium to an object to be cooled, the assembly including a vacuum-insulated housing about gas-transporting ducts and gas-circulating means.

This invention relates to a device for cooling comprising a cold-gas refrigerator, having at least one compression space of variable volume in which a higher average temperature prevails during operation, and at least one expansion space likewise of variable volume in which a lower average temperature prevails during operation, these spaces being connected together and a regenerator being situated in said connection. The device further comprises a cold transport device to transport cold supplied by the cold-gas refrigerator to the object to be cooled.

If objects such as electronic circuits and infrared equipment are to be maintained at a lower temperature then it will be necessary to supply cold to these objects to compensate for the developed and inleaking heat. This cold may be supplied by a cold-gas refrigerator; however, for spatial reasons and undesirable effects caused by vibration it is often impossible to bring the cold-gas refrigerator into direct contact with the object to be cooled. Consequently this means that the cold-gas refrigerator and the object must be arranged at a distance from each other, which implies then that a transport device is necessary for transporting the cold from the cold-gas refrigerator to the object to be cooled.

An object of the invention is to provide a device for cooling an object in which the cold-gas refrigerator and the object may be arranged at a distance from each other, and in which the cold from the cold-gas refrigerator is transported to the object to be cooled with a satisfactory thermal efficiency at greatly divergent temperatures and over a long distance.

To realize the envisaged object the device according to the invention is characterized in that the transport device is formed by a system of ducts which exchanges heat (a) with the space of the cold-gas refrigerator in which the lower average temperature prevails during operation, and (b) with the object to be cooled. This system of ducts contains a gaseous medium under a pressure which is higher than the atmospheric pressure, and further a pumping device for circulating the medium by continuous displacement thereof.

The device according to the invention has the advantage that the ducts of the system may have a comparatively small diameter by using a gaseous medium under pressure in the system, whereby a sufficient quantity of cold can be transported from the cold-gas refrigerator to the object to be cooled over a long distance with a relatively satisfactory thermal efficiency. A further advantage of the use of a gaseous medium is that cold can be transported at greatly divergent temperatures. In the device according to the invention there is a structurally great freedom in arranging the object to be cooled relative to the cold-gas refrigerator. The object to be cooled will experience no influence of possible vibrations caused by the cold-gas refrigerator.

The density of the medium in the system of ducts will increase, particularly at low temperatures. Since the device according to the invention comprises a pump of the type by which the medium is displaced continuously, difficulties caused by mass inertia forces which might indeed occur in pulsating pumping devices are not now experienced.

In a further embodiment of the device according to the invention the medium is helium. This means that cold can be transported from the refrigerator to the object to be cooled throughout the range of temperatures above 4° K. In another embodiment the pressure in the system of ducts is at least 10 atm. and at most 100 atm. In this range of pressures the most advantageous thermal efficiencies are achieved with small diameters of ducts.

A further advantageous embodiment of the device according to the invention is characterized in that the system of ducts and selectively also the space of the cold-gas refrigerator cooperating therewith and the object to be cooled are housed in a vacuum-insulated space in which at least part of the system of ducts, the space of the cold-gas refrigerator and the object to be cooled are surrounded by one or more radiation screens. Each screen consists of one or more portions for shielding the relevant part of the system of ducts, refrigerator and object to be cooled from the wall of the vacuum space, each screen being in heat contact with a cold source which supplies cold at a higher temperature than that in the space of the cold-gas refrigerator which exchanges heat with the said system of ducts. In this device radiating heat is absorbed in a very advantageous manner by radiation screens surrounding the system of ducts, refrigerator and object to be cooled, said radiated heat being compensated for by cold from a cold source which supplies its cold at a higher temperature. Said cold supplied at a higher temperature can be produced at a higher efficiency so that the total efficiency of the device is improved considerably. If, for example, the cold-gas refrigerator supplies its cold at approximately 20° K., the further cold source may be formed by a vessel containing liquid nitrogen, the radiating heat then being compensated for at the temperature of liquid nitrogen.

In a further advantageous embodiment the radiation screens are in heat contact with the regenerator of the cold-gas refrigerator. Then the regeneration loss occurring in the regenerator is thus used at least in part for cooling the radiation screens, which results in an extremely simple device operating with very low losses.

In a further embodiment of the invention, in which the refrigerator includes at least two expansion spaces of different temperatures, the radiation screens are in heat contact with the expansion space of the higher average temperature while the system of ducts exchanges heat with the expansion space of the lower temperature on the one hand and with the object to be cooled on the other hand.

In another embodiment the heat contact between the radiation screens and the further cold source, regenerator and expansion space having a higher average temperature, is formed by a second system of ducts which also contain a gaseous medium under pressure. The radiation screens are secured in a heat conductive manner to the ducts of said second system of ducts, resulting in an extremely advantageous transport of cold from the further cold-source, the regenerator and the second expansion space to the radiation screens.

In a further embodiment of the invention, each system of ducts includes a pumping device formed by a housing which is divided in two parts by an insulating wall, the first part housing an electric motor which is connected via a shaft passing with clearance through the partition to one or more fans present in the second part, the relevant system of ducts being connected to said second part. The device is constructed in such manner that the same medium as in the system of ducts is present in the entire housing and that also the same pressure as in this system of ducts prevails in the entire housing. In this manner a very satisfactory seal of the system of ducts and the housing is achieved, and it has been found that the gaseous medium surrounding the electric motor has a sufficiently strong thermal conductivity to dissipate the heat of the electric motor. According to the invention, the part of the housing accommodating the electric motor may then be arranged outside the vacuum-insulated space so that the heat of the electric motor is directly dissipated to the surroundings. Another possibility is to arrange the electric motor also in the vacuum space, a part of the cold from the cold source then being used as cooling for the electric motor. In this case it is also possible to provide a heat-conductive connection between the motor casing and the outer wall of the vacuum space along which the heat of the electric motor is dissipated to the outer wall.

In order to obviate losses of cold from the part of the pump housing accommodating the fans to the part of the housing accommodating the electric motor, another embodiment of the invention has the part of the housing of the pumping device situated between the fans and the electric motor in heat contact with a cold source which supplies cold at a higher temperature than that at which the cold-gas refrigerator cooperating with the relevant system of ducts supplies its cold. Said cold source may be the same as that with which the radiation screens are in heat contact, and in this manner heat leaking towards the system of ducts is again absorbed at an intermediate temperature level which is of course advantageous.

In a device according to the invention in which two systems of ducts are present, where one system cooperates with the space of the cold-gas refrigerator which supplies its cold at the temperature at which the object must be cooled, and the other system of ducts cooperates with a cold source, the regenerator and a space of the cold-gas refrigerator which supplies its cold at a higher temperature a pumping device is formed by a housing which is divided in three parts by two insulating walls. The first part houses an electric motor which is connected via a shaft passing with clearance through the two partitions to one or more fans rotatable within the second part of the housing and to one or more fans rotatable within the third part of the housing. The system of ducts is connected to the second part of the housing which is located between the electric motor and the third part of the housing, said system cooperating with the cold source, regenerator and an expansion space of the cold-gas refrigerator in which a higher average temperature prevails, while the system of ducts transporting cold from the space of the cold-gas refrigerator having the lowest average temperature to the object to be cooled is connected to the third part of the housing. This results not only in a more compact construction, but also the part of the pump housing cooperating with the system of ducts having the lowest temperature is automatically insulated from the part of the pump housing accommodating the electric motor.

In a further advantageous embodiment the electric motor of the pumping device is suitable to rotate at a high speed with the fan then having a small diameter and the connection shaft is then made of a poorly heat-conductive material. The housing accommodating the electric motor and fans may also have a small diameter so that losses of cold through the wall of the housing will be small. In this case the electric motor and the bearing of the shaft may be at room temperature, the housing on the side of the fans being closed and on the side of the motor being provided with a cover which permits mounting or dismantling of the pump. In this manner a pump is obtained in which the seal and bearing are at room temperature which is very advantageous.

In another embodiment the object to be cooled is formed by at least part of a wall of a high-vacuum space which is surrounded by a further vacuum space in which a radiation screen surrounding the high-vacuum space is arranged, said radiation screen being in heat contact with the second system of ducts cooperating with the further cold source, regenerator and expansion space of higher average temperature. In this manner a device is obtained in which a high vacuum can very quickly be created in a high-vacuum space by cooling of the walls, further heat losses due to radiation occurring at the lowest temperature being very small because the radiating heat is compensated for at a higher temperature level.

In order that the invention may be readily carried into effect, it will now be described in detail, by way of example, with reference to the accompanying diagrammatic drawings, in which:

FIGS. *1a* and *1b* show a cooling device comprising a cold-gas refrigerator and a system of ducts including a pumping device for transporting cold produced by the refrigerator to the object.

FIGURE 2 shows a device similar to that of FIGURE 1, but which comprises a second system of ducts including a pumping device, in which a medium circulates and which system exchanges heat with the regenerator of the cold-gas refrigerator, said system of ducts further being in heat contact with radiation screens, shielding the cold parts of the device from the wall of a vacuum space surrounding them.

FIGURE 3 shows a section of the device of FIGURE 2 taken on the line III—III.

FIGURE 4 shows a device similar to that of FIGURE 2, which includes only one pumping device for circulating the medium in the two systems of ducts.

FIGURE 5 shows a device for cooling an object, comprising a multi-stage cold-gas refrigerator.

In FIGURE 1 a cold-gas refrigerator **1** includes a piston **2** and a displacer **3**. The piston and displacer are connected to a driving mechanism (not shown) by a piston rod **4** and a displacer rod **5**, respectively, the driving mechanism being able to move the piston and displacer with a mutual phase difference. During movement of the piston its upper side varies the volume of a compression space **6**, while the upper side of the displacer **3** varies the volume of an expansion space **7**. These spaces communicate with each other through a cooler **8**, a regenerator **9** and a freezer **10**. The device also includes a system of ducts **11** which on the one hand exchanges heat, at **12** with the freezer **10**, and on the other hand exchanges heat, at **13**, with the object **14** to be cooled, shown diagrammatically. A pumping device **15** is included in the system of ducts **11** which contains gaseous helium under a pressure of 20 atm. circulated by the pumping device. This pumping device consists of a housing **16** which is divided in two parts **18** and **19** by a partition **17**. The part **18** houses an electric motor **20** which is connected via a shaft **21** passing with clearance through the partition **17** to a fan **22** which is accommodated in the part **19**. The system of ducts **11** is connected to the part **19**. A wall **23** surrounds those parts which will assume a low temperature during operation, it being possible to evacuate the space inside the wall **23**.

The operation of said device is as follows: During operation the cold-gas refrigerator will produce cold in the expansion space **7**, for example, at a temperature of 30° K. The pumping device **15** circulates the helium which is present in the system of ducts **11** under a pressure of 20 atm. and is cooled in a heat exchanger **12** up to the temperature prevailing in the expansion space **7** after which it flows through the system of ducts **11** to the object **14** to be cooled where it absorbs heat in the heat exchanger **13**, thus cooling the object **14**. The object **14** may be, for example, an electronic circuit, infrared equipment or a vacuum installation. The electric motor **20** including the bearing for the shaft **21** is always at room temperature which is advantageous especially for the bearing because ordinary ball-bearings can then be used. The electric motor can rotate at a high speed so that the fan **22** may have a small diameter. This also results in a small diameter of the housing **16** so that the loss of cold through the wall will be limited.

The object **14** to be cooled may either be arranged outside the vacuum space **14A** or inside it, and as is shown on an enlarged scale in FIGURE 1*b* it is also possible to incorporate the object **14** to be cooled together with the ducts exchanging heat therewith in a separate vacuum space **65**. The space **14A** is then connected through a detachable connection sleeve **64** to the space **65**. The space **14A** is closed by a cover **66**. The ducts of the system of ducts **11** then pass through this cover and are connected through the detachable connection sleeves **67** to the ducts exchanging heat with the object **14** to be cooled. In this manner the object to be cooled can easily be detached and replaced by another object to be cooled.

Although in the device of FIGURE 1 the parts of the device which are at a low temperature are separated from their surroundings by a vacuum insulation, a slight loss may still occur due to heat radiation from the wall of the vacuum space to the parts which are at a low temperature. In order to limit these losses in FIGURE 2 which shows a device similar to that of FIGURES 1, the parts which are at a low temperature are shielded from the cold wall **23** of the vacuum space by radiation screens. The radiation screens are shown diagrammatically and indicated by the reference numerals **24**. The radiation screens **24** are in heat-conductive contact with a second system of ducts **25** which also contains helium under a pressure of 20 atm. and which includes a pumping device **26** of a construction similar to that of the pumping device **15** included in the system of ducts **11**.

The system of ducts **25** exchanges heat with the regenerator **9**, at **27**. Consequently, the medium which is circulated in the system of ducts **25** will be cooled, at **27**, after which said medium gives off its cold to the radiation screens **24** which are in heat-conductive contact with the system of ducts **25**. In this device the system of ducts **11** (which exchanges heat with the freezer **10**, at **12**,) will have a temperature lower than that of the system of ducts **25** and the radiation screens **24** which are in heat-conductive contact therewith. This means that the system of ducts **11** and the object to be cooled are screened from the wall **23** of the vacuum space which will substantially be at room temperature, by radiation screens **24** of a higher temperature. As a result the heat radiating from the wall **23** to the interior will be absorbed by the radiation screens **24**, said radiated heat being compensated for by the cold which is derived from the regenerator, at **27**. In this device the radiated heat is thus compensated for by at least part of the regeneration loss which normally occurs in the regenerator **9**. The efficiency of the cold-gas refrigerator is thus not decreased, while the efficiency of the entire device is improved because the radiated heat is compensated for at a higher temperature. In this manner a device is obtained with which the cold from the cold-gas refrigerator can be transported to the object to be cooled over a long distance and with very low loss.

In this device the object to be cooled is formed by a high-vacuum space **70**. The system of ducts **11** is in heat contact with the wall of space **70** so that said wall will have substantially the temperature which prevails in expansion space **7**.

This low temperature will reduce the vapour tension of gases in space **70** to a very low value so that a high vacuum can be created. Surrounding the space **70** is a further vacuum space **71** in which a radiation screen **72** is arranged which is in heat contact with the system of ducts **25**. The coupling between the refrigerator including a cold transport device and the vacuum installation may again be constructed in the manner as shown in FIGURE 1*b*.

FIGURE 4 shows a device which in broad outline corresponds to the device of FIGURE 2 but in which now only one pumping device **30** is present, which comprises a housing **31** subdivided in three parts **34**, **35**, and **36** by insulating partitions **32** and **33**. The electric motor **37** is arranged in the part **34** which motor is connected via shaft **38** passing with clearance through the partitions **32** and **33** to a fan **40** disposed in the part **35** and a fan **39** disposed in the part **36**. The system of ducts **11** is connected to the part **36** while the system of ducts **25** is connected to the part **35**. In this manner not only a simple construction is obtained but also the part **36** which forms part of the system of ducts **25** containing the medium of a low temperature is again insulated from the electric motor **37**.

FIGURE 5 shows a device similar to that of FIGURE 4 but in which now the cold-gas refrigerator is designed as a two-stage cold-gas refrigerator. Said cold-gas refrigerator comprises a piston **51** and a displacer consisting of two portions **52** and **53** of different diameters. A compression space **54** is located above the piston **51** which space communicates with an intermediate expansion space **58** through a cooler **55**, a first regenerator **56** and a first freezer **57**. The intermediate expansion space **58** communicates with the final expansion space **61** through a second regenerator **59** and a second freezer **60**. Said cold-gas refrigerator supplies cold in the expansion space **58** at a temperature of approximately 70° K., while cold is supplied in the extension space **61** at a temperature of approximately 20° K. The system of ducts **11** exchanges heat, at **62**, with the freezer **60**, while the system of ducts **25** exchanges heat, at **63**, with freezer **57**. The further operation and construction of this device is fully identical with that of the FIGURES 2 and 4.

After the foregoing it will be evident that the invention provides an extremely simple device for cooling an object in which the cold-gas refrigerator and the object are arranged at a distance from each other and with which cold can be transported over a long distance from the refrigerator to the object to be cooled with an extremely satisfactory thermal efficiency and at a very low temperature.

What is claimed is:

1. A refrigeration apparatus comprising a cold-gas refrigerator having at least one compression space and one expansion space connected through a regenerator, the spaces being of variable volume and operable at respectively higher and lower average temperatures, with the expansion space being a primary source of cold gaseous refrigerating medium, in combination with a cold-transport assembly including:

(a) a primary duct system extending between the cold source and the object to be cooled,

(b) a primary device for circulating the medium through the duct system, the device including (1) a pump for continuously displacing the medium with the pressure thereof being higher than atmospheric pressure through the duct system, (2) drive means for operating the pump; and (3) a casing having first and second parts and an insulating partition therebetween for enclosing the pump and drive means respectively,

(c) a vacuum-insulated housing disposed about said first casing part including the pump and at least a major part of the duct system, providing space therein insulated from environmental heat, with the pump's drive means being disposed outside the vacuum-insulated housing and being operable at environmental temperature.

2. Apparatus as defined in claim **1** wherein the compression space froms a second cold source having at temperature higher than the primary cold source, and at least one radiation screen disposed between at least parts of the primary duct system and an interior wall of the vacuum-insulated housing, the second cold source being connected to the screen for supplying cold thereto.

3. Apparatus as defined in claim **2** further comprising a second duct system extending between the second cold source and each screen, and a second device similar to the primary device for circulating the second medium through said second duct system.

4. Apparatus as defined in claim **3** wherein said first and second devices comprise first and second pumps and a single drive means for both pumps.

5. Apparatus as defined in claim **1** wherein said gaseous medium is maintained at between 10 and 100 atm. pressure.

6. Apparatus as defined in claim **1** wherein said gaseous medium is helium.

7. Apparatus as defined in claim **1** wherein said drive means is an electric motor disposed with its bearings outside said insulated housing and including a shaft extending through the housing to the pump.

8. Apparatus as defined in claim **7** wherein the motor shaft has poor heat-conductivity.

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WILLIAM J. WYE, Primary Examiner