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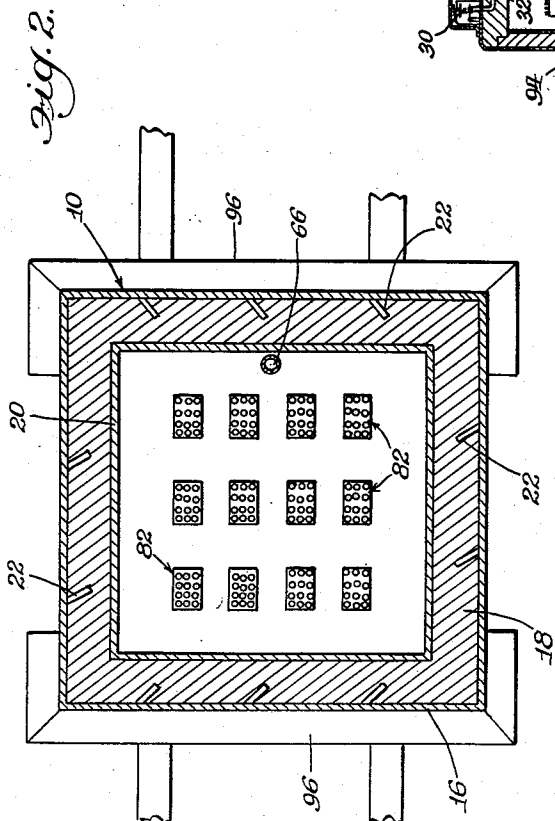
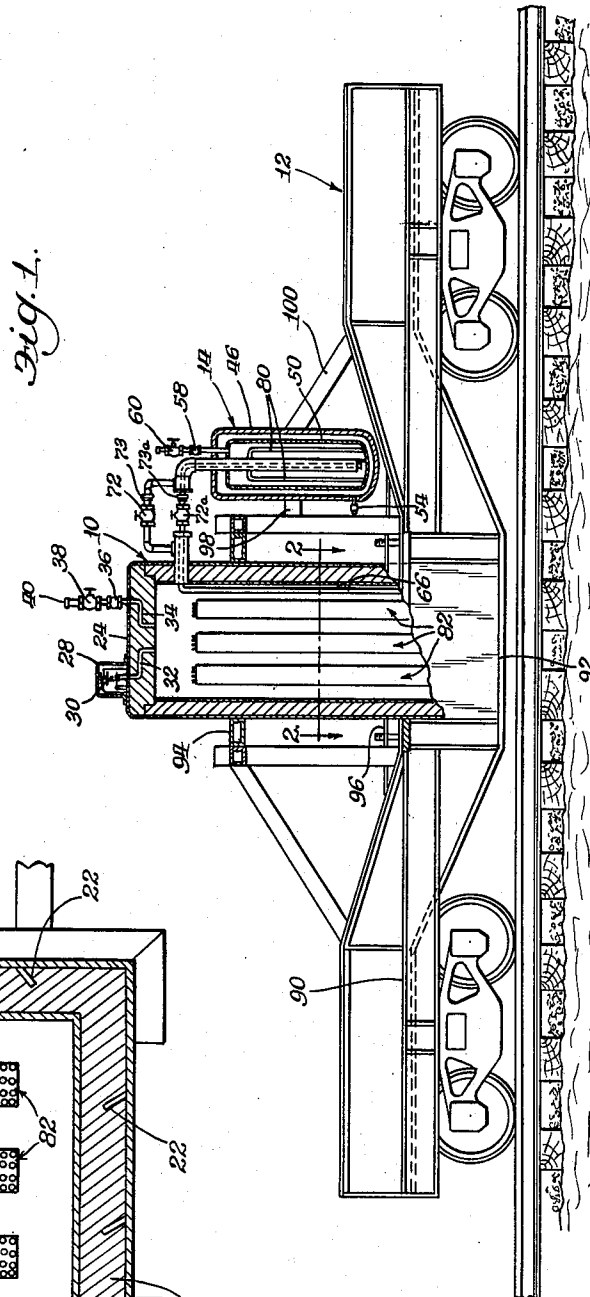
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3,133,197

APPARATUS UTILIZING LIQUID METAL COOLANT FOR TRANSPORTING
THERMALLY HOT INTENSELY RADIOACTIVE MATERIAL

Filed June 16, 1960

2 Sheets-Sheet 1



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Fig. 4.

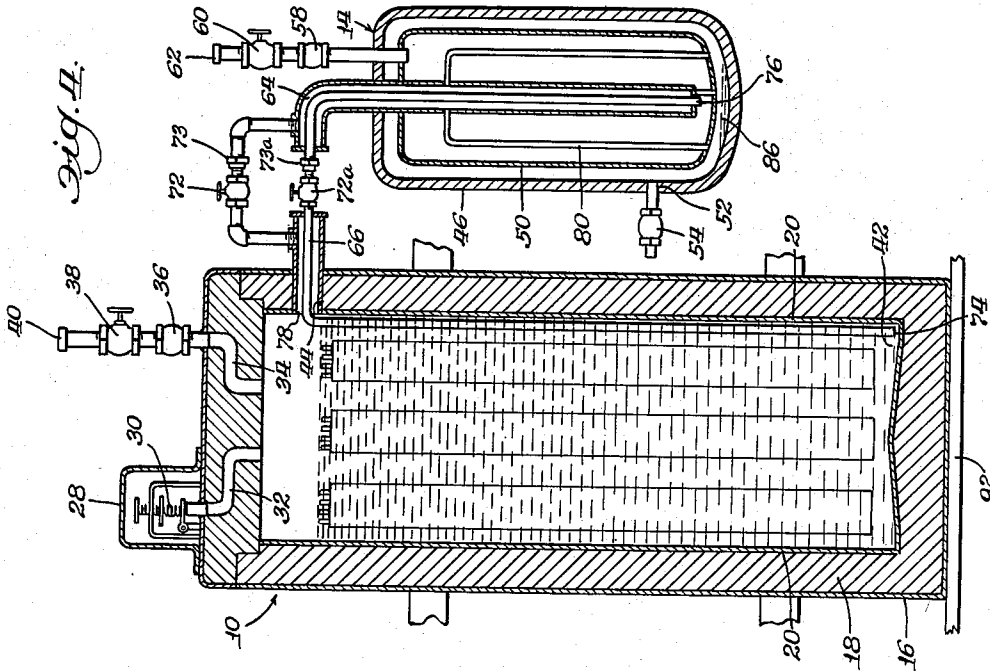
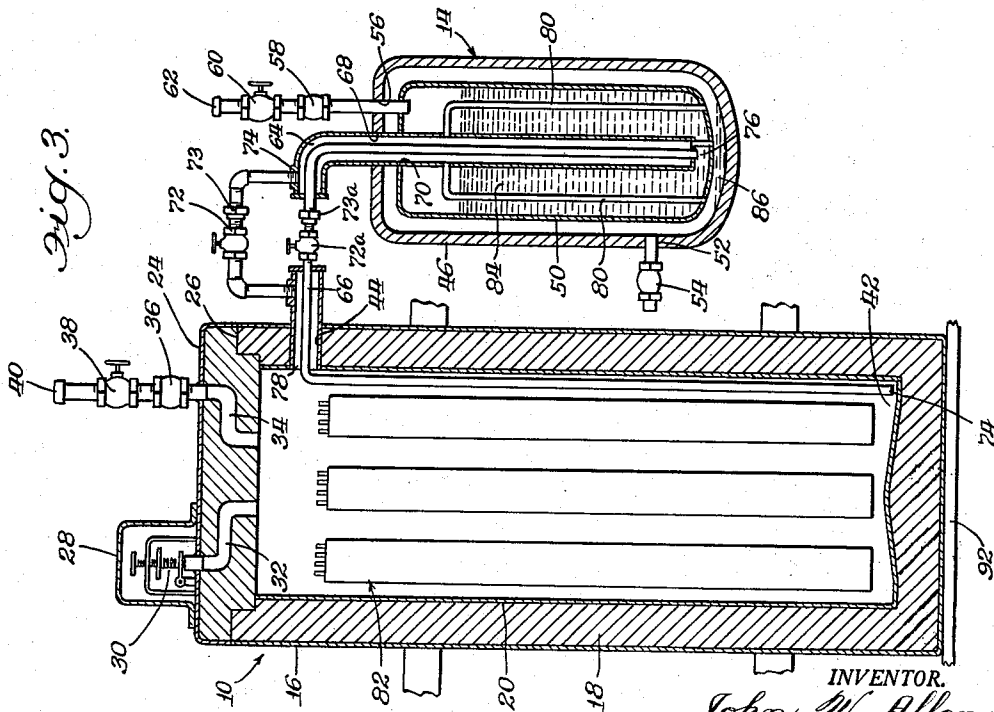


Fig. 3.



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1

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APPARATUS UTILIZING LIQUID METAL COOLANT FOR TRANSPORTING THERMALLY HOT INTENSELY RADIOACTIVE MATERIAL

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8 Claims. (Cl. 250-106)

This invention relates to apparatus for transporting radioactive and thermally hot materials, more particularly it relates to such apparatus employing liquid metal coolants.

There is a need for containers suitable for the shipment of intensely radioactive materials which may be exothermal and even under favorable cooling conditions may reach temperatures of several hundred degrees Fahrenheit. Such materials are, for instance, encountered as waste products in the form of spent nuclear reactor fuel elements. One specific example of the high exothermal character of radioactive waste in spent reactor fuel rods is indicated by the fact that approximately 100,000 B.t.u. per hour are emitted by a bundle of only thirty-two such fuel rods. A container in which to carry these rods must therefore dissipate this much thermal energy to maintain temperature equilibrium. Such an amount of heat compares with the heat capacity of a household furnace. Failure to dissipate the evolved thermal energy will cause an abrupt rise in temperature of the container and its contents and ultimately structural failure of the cask or the fuel rods.

It is necessary to transport intensely radioactive and highly exothermal nuclear reactor waste products over common carrier transportation lines such as truck and rail routes. These materials are carried into and through populated areas and are not infrequently left standing on sidings and in traffic where the general public could be exposed to the hazards of radiation and thermal heat burns excepting for the protection afforded by the container or shipping cask in which the dangerous material is being carried. Accordingly, the structural integrity, the completeness of the radiation shielding about the radioactive material, and the efficient dissipation of the evolved heat through such a shipping cask are urgent requirements.

The superior gamma ray shielding materials are very dense, lead and metal loaded concrete being examples of preferred shielding materials. Unfortunately these materials do not possess optimum high strength structural properties nor good heat conductivity, and in the case of lead is subject to relatively low melting temperature. Steel and stainless steels are good heat conductors but less efficient gamma ray attenuator materials from the dimensional point of view; and are subject to large dimensional changes when heated. This latter property in a thick walled structure such as a heavy shipping cask can lead to cracking and structural failure of a cask if, for example, it is heated unevenly by a large heat source contained within it. Despite these disadvantages in the available materials an adequate and safe shipping cask for radioactive exothermal materials may be fabricated from a composite of strong structural materials such as stainless steel lined with an efficient gamma ray attenuating material such as lead, provided however, means are present to effectively carry the excessive quantities of heat evolved by the radioactive material to the exposed surfaces of the cask where it may be safely radiated from the outer cask surfaces.

The present invention, among other objectives, provides means for accomplishing the necessary heat transfer between the radioactive material and, for example, the cask walls.

Nuclear reactor fuel rods are commonly encased in a

2

stainless steel or zirconium alloy sheath or clad. The integrity of the sheath or clad may be disrupted by overheating of the fuel rod from inadequate conduction of heat away from the rod by circulation of a coolant about its outer surface. Spent reactor fuel rods, even after removal from a reactor and temporary storage during a "cooling period," still may evolve sufficient heat to melt their sheaths when placed in an environment which confines the heat evolving from the rod. Numerous highly toxic and radioactive substances are present in irradiated fuel rods in the form of particulate matter and gases, which upon rupture of the fuel rod sheath are easily scattered. Such dispersions of radioactive materials constitute a most serious health hazard to any person coming in contact with them. In view of the sensitivity of the fuel rod sheath to localized high temperature, and the increased health hazards which result from sheath rupture of spent fuel rods, it is most important that effective means for transporting heat from the fuel rod surfaces to structures through which it can be removed and dissipated be provided during storage and shipping of spent fuel rods.

Fluid coolants circulated by convective flow about a heat source have long been utilized. Liquid metals or alloys possessing a relatively low freezing point and relatively high boiling point are adaptable to serve as a coolant in a shipping cask. It is, however, desirable to economize both weight and space in a shipping container for purposes of ease of handling as well as reduced transport costs. If the liquid metal coolant is selected to provide both efficient heat conduction and efficient radiation shielding a substantial reduction in both weight and dimension of the shipping cask may be achieved. Such a liquid metal alloy, that is both an effective and safe coolant and an effective radiation shield material is, for example, lead bismuth alloy.

It is therefore an object of this invention to provide an apparatus for safely shipping and storing exothermal radioactive material.

It is another object of this invention to provide a means of efficiently cooling radioactive exothermal materials during long distance transport of these materials.

It is still another object of this invention to provide an efficient safe method for conducting substantial quantities of heat from a radioactive heat source within a shipping cask to the exposed surfaces of the cask where it may be dissipated through the cask walls.

It is another object of this invention to provide means utilizing liquid metals for combining both cooling and shielding radioactive material contained within a shipping container.

It is yet another object of this invention to provide a method of conveniently handling liquid metal coolant and liquid metal radiation shielding in a shipping cask during loading and unloading procedures.

These and other objects and advantages of my invention will be readily apparent from the following drawings, specification and claims.

My invention comprises briefly an apparatus for transporting exothermal radioactive material comprising a pressure retaining cask and a quantity of low melting temperature metal adapted to both cool the radioactive material and attenuate nuclear radiation emanating therefrom and means for transferring the molten metal into and out of the cask after loading and prior to unloading the radioactive material.

FIGURE 1 is a cross sectional view of a preferred embodiment of my invention shown mounted on a specially fitted railroad car;

FIGURE 2 is a horizontal cross sectional view taken on line 2-2 through the cask illustrated in the embodiment of FIGURE 1;

3

FIGURE 3 is a cross sectional view of the embodiment in FIGURE 1 showing the cask, storage tank and means for transferring molten metal therebetween illustrating the apparatus prior to transferring the molten metal from the tank to the cask; and

FIGURE 4 is a cross sectional view similar to that shown in FIGURE 3 illustrating the apparatus subsequent to transfer of the molten metal from the tank to the cask.

Referring now to the drawings wherein a preferred embodiment of my invention is shown, a cask 10 is positioned on a specially adapted railroad car 12. In addition to the cask 10 a storage tank 14 is mounted on the railroad car adjacent the cask. The cask illustrated in the drawings is adapted to the cross country transport of spent nuclear reactor fuel rods. A typical fuel rod assembly contains a plurality of fuel rods fastened together in a bundle, the rods are eleven feet two inches long and the assembly is approximately four inches square. Twelve such assemblies of irradiated spent rods emit gamma and beta radiation of an intensity of 4.15×10^5 roentgens per hour on the inside of the cask. A radiation dosage of not greater than 5.5 milliroentgens per hour on the outer surface of the cask is considered safe. At the same time, twelve fuel rod assemblies produce 73,000 B.t.u. per hour which must be dissipated through the outer surfaces of the cask. Such a quantity of heat would soon melt the fuel assemblies and other adjacent structures if it were not efficiently conducted away. A temperature of up to 800° F. is considered a maximum safe temperature for the apparatus in transit.

The cask 10 is comprised of an outer shell 16 preferably made of stainless steel, a gamma radiation attenuator liner 18 such as lead, and an inner shell of strong temperature resistant material such as stainless steel or other corrosion resistant steel. The lead liner 18 is held securely in place between the inner and outer shells by a series of fins 22 attached to the inner wall of the outer shell 16 and extending into the lead liner 18. A removable lid 24 is provided at the top of the cask 10 which is always carried in a vertical position as shown in FIGURE 1. The lid 24 is fastened to the top of the cask and seats on a recessed contour which provides a pressure seal between the cask walls 26 and the lid 24.

The lid 24 is provided with a pressure release check valve 28, having an adjustable pressure release mechanism 30 which connects the interior of the cask with the atmosphere through an indirect channel 32 when the pressure within the cask exceeds the preset pressure release valve. The variable pressure release mechanism is conventional and comprises a spring loaded check valve and a means for adjusting the tension load on the spring. The indirect channel 32 assures that there will be no direct path between the interior and exterior of the cask which will allow the escape of unattenuated radiation. A second indirect passage 34 is provided through the cask wall, and as shown in the drawings, may be conveniently mounted on the lid 24. Exterior of the cask the passage 34 is connected through a conventional check valve 36 mounted to limit flow of fluids outward from the cask, a gate valve 38, and a coupling 40 which may be connected to a supply of compressed air, or water as the need arises. The detailed operating procedures which includes the sequence of valve manipulation required for loading and unloading the cask are described below.

The bottom of the cask is provided with a sump 42 or low reservoir into which fluids will drain; the sump is preferably positioned at one side of the cask directly beneath the port 44 in the cask wall through which connections to the storage tank 14, which are described below, enter the cask 10.

The storage tank 14 is a pressure retaining tank having a heavy outer shell 46 constructed to attenuate some nu-

4

clear radiation in the event that radioactive material is inadvertently transferred to the storage tank. A plenum 48 separates the outer shell 46 from an inner shell 50. The plenum 48 is connected through a port 52 and a pressure release check valve 54 to the exterior of the tank. The interior of the inner shell 50 is connected to the exterior of the tank through a second port 56 which discharges through a check valve 58 adapted to only permit inflow through the port and a gate valve 60. A coupling link 62 is connected with the outer port of the gate valve 60 and is adapted to connect with a source of compressed air.

A larger passage 64 and a smaller conduit or pipe 66 connects the interior of the cask 10 through the cask port 44 to the interior of the storage tank 14 through the port 68 in the outer shell and the port 70 in the inner shell. The larger passage comprises essentially a steam jacket coaxially mounted about the conduit 66. The passage or steam jacket 64 is terminated midway between the tank and the cask and coupled by means of a gate valve 72 and a union 73. The conduit 66 is terminated in the sump 42 of the cask at one end 74 and is terminated at the other end 76 in the lower portion of the storage tank. The conduit 66 is also provided with a gate valve 72a and a union 73a. Thus, with this arrangement fluids may be transferred from the tank through the conduit 66 into the cask interior and conversely, by pressurizing the cask with respect to the interior of the tank fluids may be transferred from the cask through the conduit back into the tank. The cask 10 and the tank 14 may be disconnected by uncoupling the unions 73 and 73a and either one removed from its mounting on the railroad car 12.

The larger passage 64 terminates at a first end 78 in the interior of the upper portion of the cask immediately adjacent the cask port 44; at its other terminal the passage 64 is branched into a plurality of smaller passages 80 which terminate in the plenum 48 at the storage tank. Thus, a readily vaporized substance, such as water, may be added and passed as steam from the cask through the passage 64 coaxially with the conduit 66 and then through the interior of the storage tank whereupon as condensate or low quality steam it is discharged into the plenum 48 whereupon it may then be passed to the exterior of the storage tank through port 52 and pressure release check valve 54.

There is a wide selection of possible low melting temperature metals which constitute suitable coolants and offer a source of nuclear radiation attenuation. Examples of this are mercury, sodium potassium eutectic, or NaK, Wood's metal, bismuth alloys and, in particular, lead bismuth alloy. All liquid metals are excellent heat conductors both by virtue of the fact that metals are intrinsically excellent heat conductors and in the liquid state, readily form good heat transfer junctions with the parts of which the heat is to be conducted. The various possible liquid metal coolants each attenuate nuclear radiation and, in particular, gamma rays substantially in proportion to their density. Accordingly, selection of a liquid metal coolant may be influenced by the factor of its suitability as a coolant which, for the particular application disclosed here, by its compatibility with the materials with which it comes into contact and by the radiation attenuation characteristics which it affords.

In my invention lead bismuth alloys are favorite liquid metal coolants because they are relatively stable and inactive chemically and particularly they afford a large degree of gamma ray attenuation. A quantity of lead bismuth alloy 84 is placed within the interior of the inner shell 50 of the tank 14. This initial charge of lead bismuth into the tank 14, can be accomplished by pouring lead bismuth in shot form through port 56 into the tank.

Water boils at 212° F. at atmospheric pressure; lead bismuth boils at 3,038° F. at atmospheric pressure. This very high boiling temperature of the alloy precludes the possibility of loss of the coolant due to boiling action at

5

temperatures allowable for shipping radioactive materials cross country. A safe temperature for such shipments is 800° F. Lead bismuth alloy freezes at a temperature of 257° F.; and water vaporizes into steam at 280° F. at 35 p.s.i. gage pressure. The combination of water which may be formed into a good heat transfer medium at relatively low pressures such as 35 p.s.i.g. and lead bismuth alloy which possesses a low melting temperature but a very large temperature range in the liquid state constitutes a preferred selection of working fluids for both cooling and shielding exothermal radioactive materials stored for shipping within the cask.

The procedure for loading radioactive materials into the cask preparatory to shipping is as follows: Fuel rod assemblies 82 are positioned within the interior of the cask 10 by removal of the cask lid 24 and insertion through the upper end of the cask. The lid is then replaced and secured to the cask. Low melting temperature metal 84, which may be in the liquid or solid state, is stored within the inner shell 50 of the storage tank 14. The fuel assemblies 84 prior to shipping will have been stored under water and be wet at the time they are loaded. Water from the surfaces of the fuel rods and additional water introduced through the indirect passage 34 will begin to form steam within the cask cavity. The pressure release valve 30 may be set at a pressure greater than atmospheric depending upon the temperature and pressure required to transfer the metal 84 in liquid state stored in the tank 14 into the cask. For example, if the metal coolant and shield substance is lead bismuth alloy, setting the pressure release valve at 35 p.s.i. gage pressure will produce steam at 280° F.

After the steam has reached its maximum pressure and temperature within the cask, the valve 72 in the passage 64 is opened, steam at 280° F. then passes into the tank 14 through the branched terminals 80 of the steam passage 64 and discharges into the plenum 48. Condensate 84 collects in the lower portion of the plenum 48 and is discharged through the port 52 and check valve 54. The hot steam passing through the tank melts the low melting temperature metal 84, which for lead bismuth requires only 257° F.

Compressed air is then introduced into the tank 14 through the port 56 which forces the molten metal 84 through the conduit 66, the open valve 72a, and into the cask. Once in the cask, the heat evolved by the fuel rods keeps the metal 84 in a molten state without danger of boiling the coolant away. For instance, lead bismuth alloy boils at 3,038° F. at atmospheric pressure, and it boils at higher temperatures in pressures greater than atmospheric; the extreme upper safe temperature at which the cask may be shipped is 800° F. However, cooling by conduction of heat through the cask walls in an ambient temperature of 100° F. would permit the temperature of the contents of the cask to rise to about 500° F. at equilibrium.

Removing the fuel rods at the destination of the shipment is accomplished by reversing the conditions of flow of the liquid metal 84 in the conduit 66. Water is introduced into the cask through the indirect passage 34. The valve 72 in the steam jacket or steam passage 64 is closed. Pressure then increases due to the heating and expansion of the steam in the cask above the liquid metal 84 as is shown in FIGURE 4. The liquid metal is forced through the conduit 66, the open valve 72a, and then back into the tank 14. Pressure within the tank may be reduced by opening valves 58 and 60 exterior of the port 56. Once the liquid metal is removed from the cask, the pressure in the cask is reduced to atmospheric by opening the valve 30. The lid 24 may then safely be removed and the fuel rod assemblies lifted out of the cask. At that time the cask is ready to receive another charge of radioactive material.

The cask 10 and storage tank 14 are conveniently carried on a specially adapted railway car 12. The car 12

6

has a car bed 90 a portion of which, 92, has been lowered to accommodate the height of the cask 10, which must be carried in a vertical position at all times. Frame members 94, 96 hold the cask securely in place on the car bed 92. The storage tank 14 is positioned adjacent the cask and is held in place by frame members 98 and 100.

The foregoing specification, specific examples and descriptions of my invention and the methods of utilizing it are intended as illustrative of the invention, the scope of which is limited only by the following claims.

My invention is hereby claimed as follows:

1. An apparatus for transporting and storing exothermal radioactive material comprising an elongated vertical pressure retaining cask, a vertical storage tank, a quantity of low melting point metal contained with the cask and tank, and a larger and a smaller pipe mounted coaxially one about the other, each pipe separately connecting the interior of the cask with the interior of the tank, the larger pipe terminating within the cask in the upper portion thereof, the smaller pipe passing through the length of the interior of the cask and terminating in the lower portion thereof, and both pipes passing the length of the interior of the tank, the smaller pipe terminating in the lower portion thereof and the larger pipe terminating exteriorly of the tank after passing in a heat transfer relationship through the tank, whereby the metal in a molten state may be transferred under pressure from the tank to the cask and from the cask to the tank.

2. The apparatus of claim 1 wherein the low melting point metal is adapted to both conduct heat from the radioactive material and to attenuate nuclear radiation emanating from the radioactive material.

3. The apparatus of claim 2 in combination with a support for the cask having a section of the support lower for receiving the cask, and a support frame adapted to hold the cask in a vertical position.

4. An apparatus for transporting exothermal radioactive material comprising an elongated vertical pressure retaining cask having a removable lid, a vertical storage tank, pressure release valves on the cask and the tank, a source of compressed air and means on the tank through which compressed air may be introduced into the tank, a quantity of lead bismuth alloy contained within the cask and the tank, a smaller pipe and a larger pipe mounted coaxially one about the other, each pipe respectively separately connecting the interior of the cask with the interior of the tank and the atmosphere exterior of the tank, the larger pipe terminating within the cask in the upper portion thereof, the smaller pipe passing through the length of the interior of the cask and terminating in the lower portion thereof, and both pipes passing the length of the interior of the tank, the smaller pipe terminating in the lower portion thereof and the larger pipe passing in heat transfer relation through the tank and terminating exteriorly of the tank, and a quantity of water contained within the interior of the cask and the tank whereby exothermal radioactive material placed in the cask vaporizes the water into pressurized steam which is conducted through the larger pipe and hence through the tank where it melts the lead bismuth alloy, compressed air introduced through said means forcing the molten metal through the smaller pipe into the cask, the molten metal convectively circulating about the radioactive material in the cask where it both cools and attenuates nuclear radiations emanating from the radioactive material.

5. An apparatus for transporting exothermal radioactive material comprising a pressure retaining cask, a storage tank, a low melting temperature metal within the tank, means interconnecting the cask and tank, a quantity of water contained within the interior of the cask and tank, means utilizing heat from exothermal radioactive material placed in the cask to vaporize the water into pressurized steam which is conducted through the first

mentioned means through said tank where it melts the metal and whereby the metal in a molten state may be transferred under pressure from the tank to the cask.

6. An apparatus for transporting exothermal radioactive material comprising a pressure retaining cask, a storage tank, a low melting temperature metal within the tank, means interconnecting the cask and tank, a quantity of water contained within the interior of the cask and tank, means utilizing heat from exothermal radioactive material placed in the cask to vaporize the water into pressurized steam which is conducted through the first mentioned means through said tank where it melts the metal and means for selectively transferring the metal in a molten state under pressure from the tank to the cask and from the cask to the tank.

7. An apparatus for transporting exothermal radioactive material comprising a pressure retaining cask, a storage tank, a low melting point metal within said tank, means interconnecting the cask and tank, a quantity of water within the interior of the cask and tank, means utilizing heat from exothermal radioactive material placed within the cask to vaporize the water into pressurized steam which is conducted through said interconnecting means through said tank to pressurize the cask and tank and melt the metal and transfer the molten metal under pressure from the tank to the cask and from the cask to the tank.

8. An apparatus for transporting exothermal radioactive material comprising a pressure retaining cask, a storage tank, a quantity of low melting point metal coolant within the tank, a larger and a smaller pipe coaxially mounted one about the other, each pipe separately connecting the interior of the cask with the interior of the tank, a quantity of water contained within the interior of the cask and tank, means utilizing heat from exothermal radioactive material placed in the cask to vaporize the water into pressurized steam which is conducted through the larger pipe and through the tank where it melts the metal coolant whereby to selectively transfer the metal in a liquid state between the tank and the cask and between the cask and the tank.

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