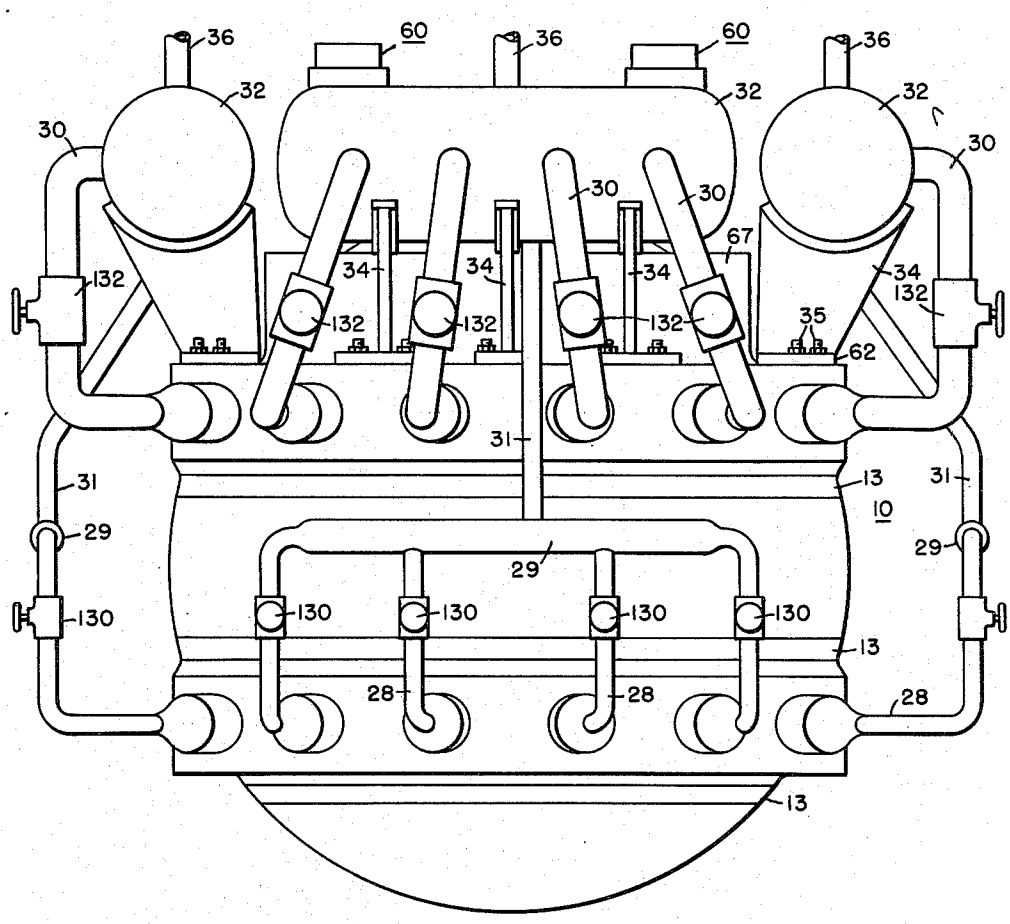
Dec. 12, 1961 P. C. OSTERGAARD ET AL 3,012,547

UNITIZED STEAM GENERATOR

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Fig. 1.



WITNESSES

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Fig. 4.

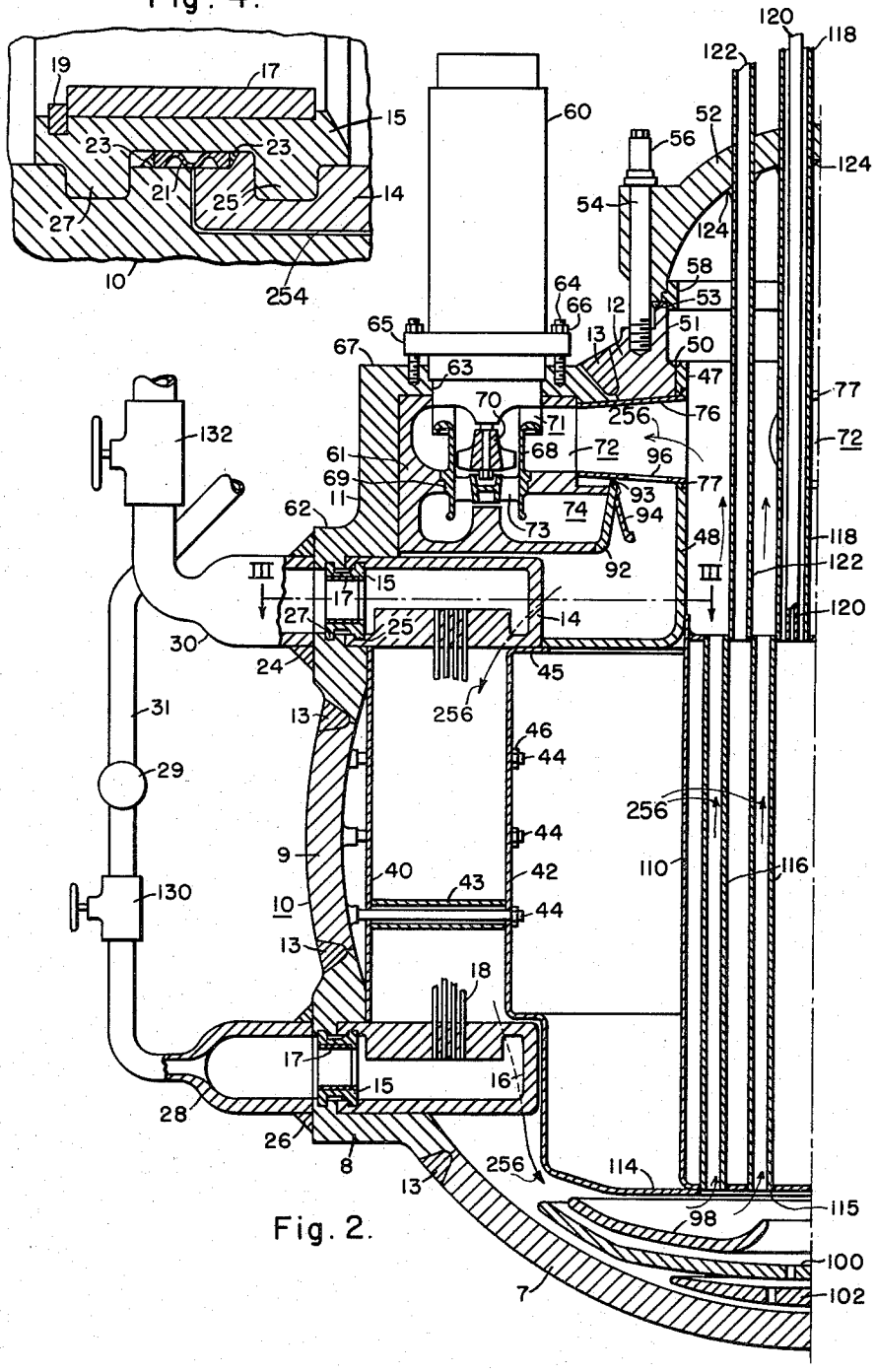


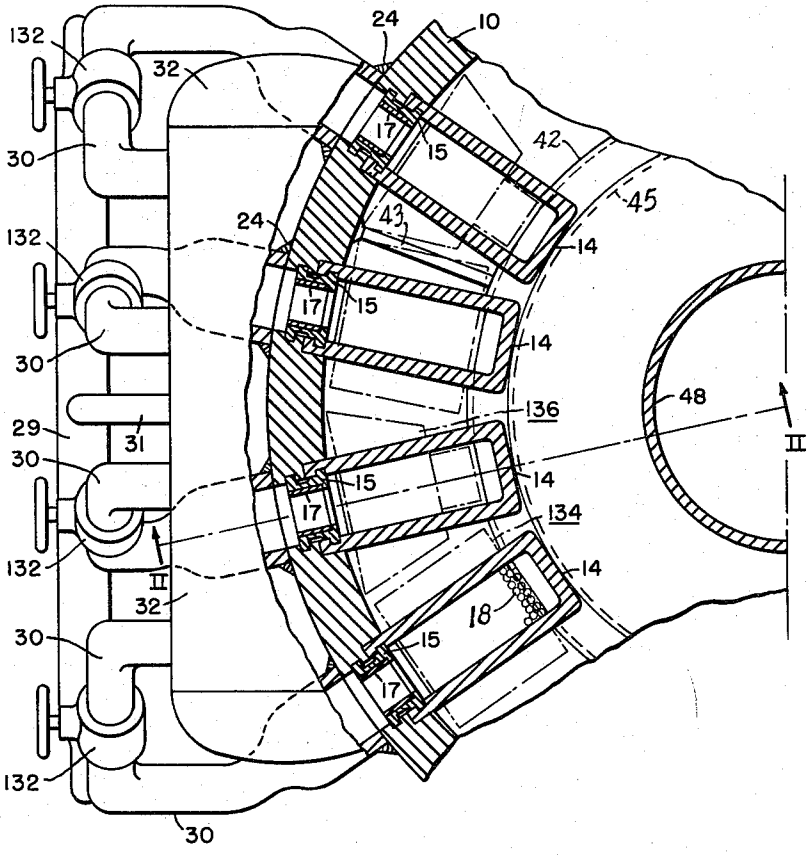
Fig. 2.

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UNITIZED STEAM GENERATOR

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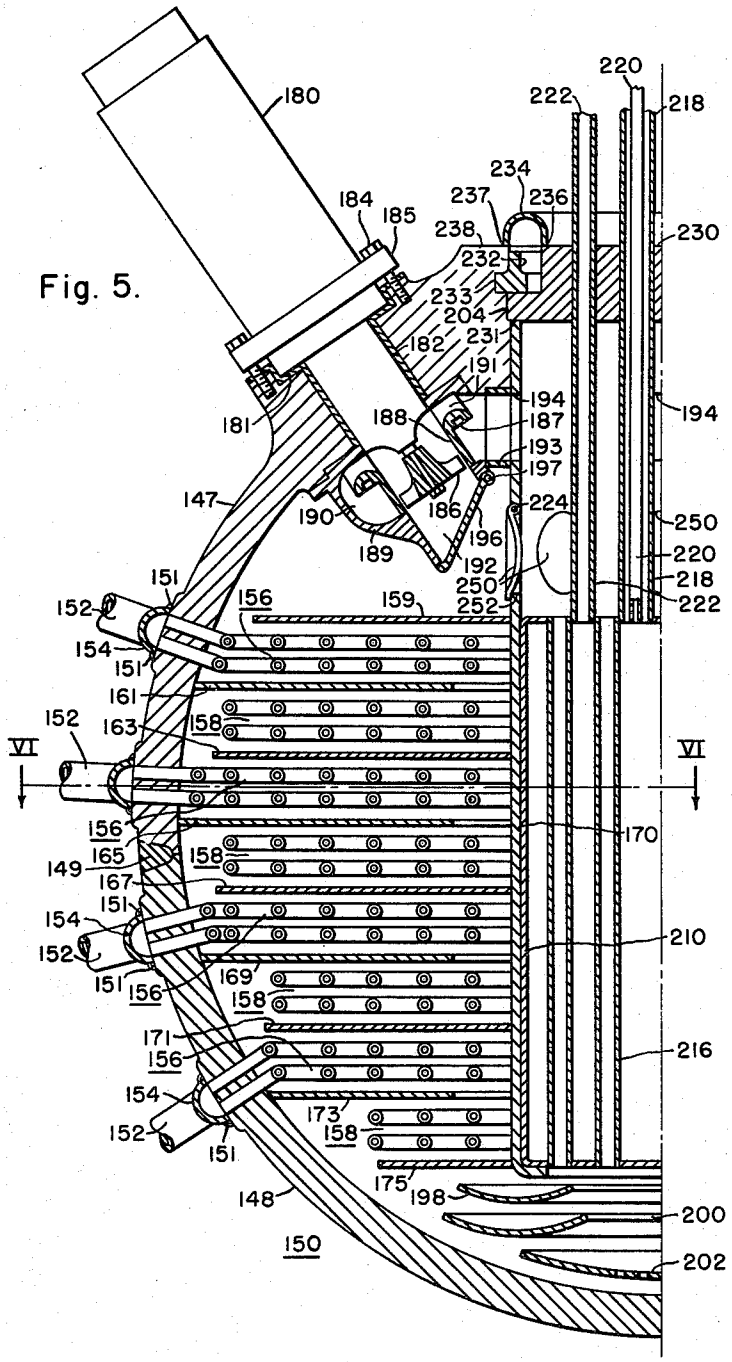
Fig. 3.



UNITIZED STEAM GENERATOR

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Fig. 5.

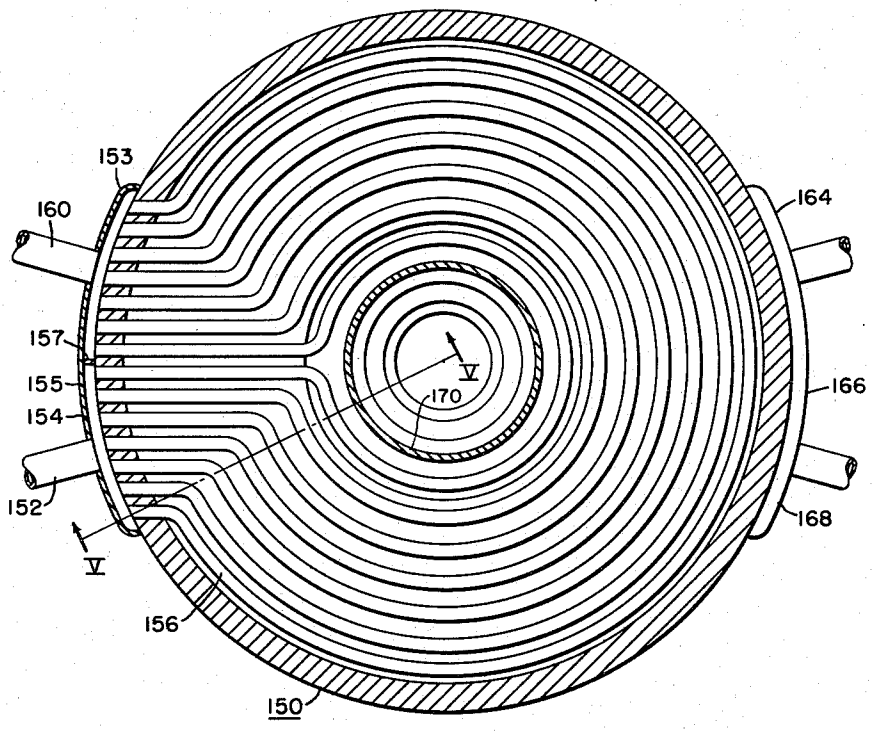


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UNITIZED STEAM GENERATOR

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Fig. 6.



United States Patent Office 3,012,547 Patented Dec. 12, 1961

3,012,547

UNITIZED STEAM GENERATOR

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Filed Apr. 21, 1955, Ser. No. 502,898
20 Claims. (Cl. 122—32)

Our invention relates generally to steam generators, and more particularly to a unitized steam generator having separate compartments for the water which is to be converted to steam and for the heat source, with both of the compartments being contained in a sealed outer shell which is filled with a fluid.

There are many sources of heat available for use in generating steam that are not presently used due to a lack of suitable steam generating equipment. Some of these sources are the heat contained in the products and by-products of chemical plants. Another source of heat would be the heat released when fluorine reacts with various metals, and many organic and inorganic compounds. While all of the above sources supply large quantities of heat, they are highly corrosive, poisonous and dangerous, thus prohibiting their use in the more conventional type of steam generators.

In addition to the above described difficulties, many heat sources react violently with water to form an explosive combination and, in addition, some heat sources react with water to form poisonous compounds. Thus, in case of a leak in the generating tubes of a conventional steam generator, water would come in direct contact with the heat source and a dangerous reaction could take place.

We have solved the problems of using such heat sources by providing a novel type of steam generator wherein these sources of heat may be used by isolating the heat source from the steam generating tubes, and using a fluid, which we call the primary coolant, to transfer heat from the heat source to the steam generating tubes. Thus, the water in the steam generating tubes will not directly contact the products of the heat source in case of a leak in one of the steam generating tubes, but only the primary coolant. In addition, we enclose our heat source, steam generator and primary coolant in a sealed outer container to eliminate the possibility of the heat source contaminating the surrounding atmosphere in case of a casualty.

The primary coolant used in our steam generator may be water, diphenyl oxide, liquid metals or other fluids depending upon the heat source used, an important factor being that the coolant should not react with the products used in the heat source. In order to prevent a complete shutdown of our steam generating unit in case of a casualty to some of the steam generating tubes, we have divided them into a plurality of small individual bundles which may be isolated individually. In addition, our steam generator is relatively compact in design, yet is capable of producing large quantities of steam and can be easily transported from one location to another. The use of such a compact design also allows the use of relatively expensive materials having good corrosion resistance without increasing the cost of the complete unit an excessive amount. The use of such corrosion resistant materials substantially eliminates the damage caused by corrosive heat sources.

It is to be noted that several aspects of the present invention are not limited to unitized steam generators or to steam generators generally. More particularly, the present invention is directed to and contains innovations in the field of flow circuits generally.

Accordingly, an important object of our invention is

to provide a novel unitized steam generator with means for enclosing within a sealed outer container a heat source, steam generating tubes and a primary coolant system.

Another object of our invention is to provide a novel unitized steam generator in the form of a complete package having a heat source, steam generating tubes and primary coolant all enclosed within a sealed outer container so that the steam generator may be easily removed and replaced in a relatively short time.

Another object of this invention is to provide a new and improved flow circuit between a heat source and a heat sink wherein a forced circulation flow path is provided together with a natural circulation flow path wherein the circulation forcing means is bypassed.

Another object of our invention is to provide a novel unitized steam generator having a sealed outer shell in the general form of a sphere which contains a heat source, steam generating tubes and a primary coolant system.

Another object of our invention is to provide a unique arrangement of steam generating tubes in the form of individual bundles, so that each bundle may be isolated separately in case of failure of any individual tube in the bundle.

Another object of our invention is to provide a unitized steam generator having a novel arrangement of a heat source and steam generating tubes in a sealed outer shell where the effective center of the steam generating tubes is located above the effective center of the heat source so that natural convection will assist circulation of a primary coolant between the heat source and the steam generating tubes.

Another object of our invention is to provide a unitized steam generator having a heat source, steam generating tubes and a primary coolant, with a unique arrangement of a plurality of pumps for circulating the primary coolant and with means for isolating one or more of the pumps from the primary coolant system.

Another object of our invention is to provide a unitized steam generator having steam generating tubes, a heat source and a primary coolant system wherein the steam generating tubes are arranged in the form of separate bundles to which access may be had for plugging individual tubes in case of tube failure.

These and other objects and advantages of our invention can more easily be understood from the following detailed description with reference to the attached drawings, in which:

FIGURE 1 is a front view of one form of a unitized steam generator constructed according to our invention;

FIG. 2 is a half longitudinal section taken along the line II—II of FIG. 3 of the unitized steam generator shown in FIG. 1, with the steam drums omitted for the purpose of clarity, and with certain parts shown in elevation;

FIG. 3 is a top view of a portion of the unitized steam generator shown in FIGS. 1 and 2 with a portion shown in section taken substantially on the line III—III of FIG. 2;

FIG. 4 is an enlarged view of part of FIG. 2 showing the mounting of the upper header for a steam operating tube bundle;

FIG. 5 is a half longitudinal section taken along line IV—IV of FIG. 6 showing another form of unitized steam generator constructed according to our invention; and

FIG. 6 is a horizontal section drawn to a reduced scale taken along line VI—VI of FIG. 4 with the inner container 210 omitted for the purpose of clarity.

FIGS. 1, 2, 3 and 4 show one form of a steam generator constructed according to our invention showing the

mounting of the steam generating tubes, a container for enclosing the heat source and the motor pump units used in circulating the primary coolant, all of which are enclosed within a sealed generally spherical shaped outer shell **10**. The outer shell consists of a dish-shaped bottom section **7** which is attached to an annular lower section **8** which has a spherical shaped inner surface, by any suitable means such as an annular weld **13**. Attached to the top edge of the lower section **8** by any suitable means such as an annular weld **13** is a spherical shaped center section **9**. An annular shaped section **11** is attached to the upper edge of the center section **9** by any suitable means such as an annular weld **13**, and the outer container is completed by an annular top member **12** which is attached to the top edge of the upper member **11** by any suitable means such as an annular weld **13**. The circular opening **51** in the top member **12** is closed by means of a dome-shaped cap **52** which is held in place by any suitable means such as studs **54** and nuts **56**. A suitable sealing ring **58** having a deformable annular flange is located between the edges of the cap **52** and the top member **12** to insure a complete seal, and if it is desired the closure between cap **52** and top member **12** may be hermetically sealed by a small annular weld **53**. All of the sections of the outer shell may be constructed of any suitable material that is unaffected by the material comprising the heat source and the fluid used as the primary coolant, such as stainless steel, or plain carbon steel clad on the inner surface with suitable corrosion resistant alloy.

The steam generating tubes **18** of our steam generator are separated into individual bundles and the upper and lower ends of the generating tubes **18** of each individual bundle are permanently attached to suitable headers **14** and **16**, respectively, and these in turn are adapted to be removably mounted on outer shell **10** as will be described. The individual tube bundles are spaced circumferentially around the inner surface of the outer spherical shell so that a space exists between adjacent headers **14** and **16**, respectively, as shown in FIG. 3. Some of the generating tubes **18** comprising an individual tube bundle are bent laterally as they leave the headers **14** and **16** to form either a substantially square section at **134** or a trapezoidal section **136**. Arrangement of these differently shaped bundles alternately allows easy installation and removal of the tube bundles while at the same time filling substantially all of the circumferential space around the central portion of the outer shell. The upper and lower headers **14** and **16** are preferably of a material that is unaffected by the primary coolant and the products used in the heat source, such as stainless steel, and the generating tubes **18** should be of a similar material, such as copper-nickel alloy.

This arrangement of the individual tube bundles also allows for installation and removal of the individual tube bundles through the top opening **51** in the outer spherical shell **10**. Of course, it would be necessary to first remove some of the internal baffles to be described later, and possibly some of the adjacent tube bundles in order to install or remove any particular tube bundle. We have provided removable tube bundles in order to eliminate the need for cutting away part of the spherical shell **10** in order to replace a faulty tube bundle. The spherical shell **10** is a pressure vessel, thus any opening would have to be closed with the same care used in fabricating the original pressure vessel in order to insure that the original strength of the vessel is restored.

Each header **14** is hollow and has an open outer end which is received in enlarged inner end of a suitable opening in the outer shell. Each header **14** is secured in its opening by means of an annular key **15** partially located therein and which has two outwardly projecting radial flanges **25** and **27** (FIG. 4) which engage cooperating grooves in the header **14** and the outer spherical shell, respectively. Each header **14** is sealed to the outer spherical shell to prevent the escape of the primary coolant by means of an annular corrugated expansion member **21**, preferably of a flexible corrosion resistant metal, such as stainless steel, which is attached to the header **14** and the outer spherical shell by any suitable means such as small annular welds **23**. The use of the corrugated expansion member **21** and the provision of clearances **254** (FIG. 4) allows a restricted movement between the header **14** and the outer spherical shell without fracturing the welds **23**. The annular key **15** may be formed in individual arcuate sections for ease of installation which are held in place by a solid ring member **17** placed within the key sections, which is in turn held in position against a shoulder at the inner edges of the key sections by a split snap ring **19**. Header **16** is attached and sealed to the outer shell by means of a key **15** in the same manner as described above for header **14**.

By means of the above described construction, we have provided a means for sealing the headers **14** and **16** to the outer spherical shell and yet allow for a restricted movement between the headers and the outer shell to take care of any slight movement between the two caused by variation in mechanical clearances between the various parts. It is necessary to provide mechanical clearances between the headers **14** and **16** and the outer spherical shell **10** during manufacturing in order to ensure that the parts will fit when assembled.

Each opening in the outer shell communicating with the lower headers **16** is connected to a suitable inlet pipe **28** which has an enlarged cross section at its lower end where it is attached to the outer spherical shell by any suitable means, such as a weld **26**. A number of adjacent inlet pipes **28** (for example four, as shown in FIG. 1) are attached to a distribution manifold **29** which is connected to the bottom of a steam drum **32** by means of a downcomer **31**. A plurality (for example four) of steam drums **32** are mounted on the top of the outer spherical shell of our steam generator by any suitable means, such as cradles **34**. The cradles **34** may be attached to a suitable flat surface **62** joined on the outside of the upper intermediate section **11** of shell **10** by any suitable means, such as bolts **35**. Each opening in the outer spherical shell communicating with the upper headers **14** is connected directly to an intermediate portion of the steam drum **32** immediately thereabove by means of steam line **30**. Each steam line **30** has an enlarged lower end which is attached to the outer spherical shell by any suitable means, such as a weld **24**. While we have shown the steam drums **32** as supported by means of the cradles **34**, the cradles **34** may be omitted and the steam drums **32** supported directly by the steam pipes **30** and the downcomers **31** and manifold **29** in the inlet pipes **28**, directly from the outer shell **10**.

Mounted on the outer spherical shell **10** above the upper header **14** are a plurality (for example four) of motor pump units each having an outer casing **60**. The motor pump units may be mounted in openings **63** in the top of the upper intermediate portion **11** of shell **10** by means of studs **64** which pass through a radial flange **65** formed on the outer casings **60**. The nuts **66** are used to draw each outer casing **60** into sealing engagement with a shoulder in its opening **63**. The lower end of the outer casing **60** is reduced in size and projects through the opening **63** in the outer spherical shell into the interior thereof. The motor for each unit may be located in the upper portion of its casing **60** and a suitable propeller type pump impeller **70** is mounted on the lower end of the motor shaft extension. A substantially cylindrical inner pump casing **68** is attached to the lower end of the outer casing **60** by any suitable means, such as bolts (not shown).

An outer pump casing **61** is provided in shell **10** and it has an opening in the top wall thereof registering with the opening **63** in shell **10** for receiving the inner reduced end of motor pump unit casing **60**. The outer pump casing **61** is attached to the inner surface of the upper intermediate portion **11** of the outer shell **10** in any de-

sired way, for example by welding. The outer pump casing 61 has an intermediate horizontal partition wall having an opening for receiving the inner pump casing 68, and the partition wall divides the outer pump casing into an upper suction chamber 72 and a lower discharge chamber 74. The outer pump casing thus entirely encloses the inner pump casing 68 except for an upper intake opening at the inner side of the outer casing providing access to the suction chamber 72, and a lower outlet opening provided in a lower part of the outer casing which is offset inwardly of shell 10, for a purpose to be described. The impeller 70 is designed to draw the primary coolant from the suction chamber 72 formed above the central internal partition in the outer pump casing 61 through suitable openings 71 in the top portion of the inner pump casing 68, and impel it downwardly and out the bottom 73 of the inner pump casing 68 into the discharge chamber 74 formed below the partition in the outer pump casing 61. The inner open end of the suction chamber 72 of the outer pump casing has connected thereto a diverging tubular member 76, which may be attached to a baffle member 48, to be described later, by any suitable means such as a weld 77.

The flow of the primary coolant from the inner opening of the discharge chamber 74 is directed downwardly and then radially outward to the spaces between the upper header 14 for generating tubes 18 by means of a suitable baffling arrangement. This baffling arrangement consists of a circular baffle 48 which has an L-shaped crosssection. The vertical leg of baffle 48 is attached at its upper edge 47 to the top 12 of the outer shell 10 by any suitable means such as a weld 50. The outer edge of the horizontal leg of baffle 48 rests on the inwardly projecting upper flange 45 of a vertical tubular shaped baffle 42. Baffle 42 is positioned inwardly of the generating tubes 18 and is secured to the outer spherical shell by any suitable means, such as studs 44 and nuts 46. Suitable spacing tubes 43 are placed on the studs between a tubular outer baffle 40 and the baffle 42 to maintain proper spacing between the outer baffle 40 and the inner baffle 42. The outer baffle 40 is mounted on the inner surface of the outer shell 10 by means of studs 44 and nuts 46 or, if desired, may be attached to the outer shell by cap screws (not shown). The baffles 40 and 42 thus form an annular passage and direct the primary coolant over the generating tubes 18 which are positioned in the passage formed by baffles 40 and 42. The baffles 40, 42 and 48 should be formed of a plurality of arcuate sections so that the individual sections will pass through the top opening in the outer shell. A series of circular dish-shaped baffles 98, 100 and 102 are supported from the bottom of the outer shell in vertically spaced relation by any suitable means (not shown). The circular baffle 98 is provided with a central opening while baffles 100 and 102 are provided with a series of holes so that the primary coolant will flow radially inward and upward through the central portion of the outer shell which is adapted to contain the heat source of our steam generating unit. The baffles 98, 100 and 102 are designed to effect this change in the direction of flow of the primary coolant with a minimum of hydraulic losses. The flow through the internal coolant circuit is designated by flow arrows 256.

The heat source of our generating unit may be contained in a sealed cylindrical container 110, the lower end of which rests on an inwardly projecting radial flange 114 formed on the bottom of baffle 42. The upper end of the container 110 is supported against lateral movement by the vertical leg of the baffle 48. A plurality of tubes 116 may pass through the container 110 and be sealed to the top and bottom walls of the container 110 by any suitable means, such as small welds 115. These tubes 116 serve to conduct the primary coolant through the container 110 where it is heated by the heat source and back to the suction side of the motor pump units. Attached to the top of the container 110 are a plurality of tubular members 118 and 122. Each tubular member 118 may have a second tubular member 120 mounted in its interior. The tubular members 118 and 122 are attached and sealed to the top cap 52 where they pass through the cap by any suitable means such as welds 124. The container 110 and tubular members 118 and 122 are designed so that they can be installed and removed through the central opening 51 of the outer shell 10. The tubular members 118 and 122 may be used to introduce the reaction products used for supplying heat in our steam generator into the container 110. For example, fluorine may be introduced through the tubular member 120 and a suitable hydroxide introduced through the annular area of the tubular member 118 which surrounds the tubular member 120. When the fluorine contacts the hydroxide in the container 110 a reaction will take place which will release great quantities of heat which can readily be absorbed by the primary coolant flowing through the tubes 116. The tubular member 122 may be provided for venting the products of the fluorine hydroxide reaction from the container 110. Of course, if materials, are used for producing heat in our steam generating unit which form no waste products which must be removed, and which do not require periodic replacement as they are consumed, the tubular member 122 may be omitted and the tubular members 118 and 120 used as a means of controlling the amount of heat produced in the container 110.

A swing type check valve 92 is provided for closing the outlet from the discharge chamber 74 of each outer pump casing 61 when the particular motor pump unit is not operating. Each swing check valve 92 has a tongue at its upper edge which is pivoted on a pin 93 which is secured to its outer pump casing by any suitable means (not shown). Also pivoted on the pin 93 are a pair of ears on the upper end of a second swing type check valve 94, which is used at times to close a circular opening 96 formed in the lower surface of the tubular member 76. By means of these two swing check valves we have provided a means whereby the individual motor pump units will be isolated when they are not operating. The discharge pressure from the motor pump units that are operating will open the valves 92 for these units but will tend to hold both check valves 92 and 94 closed on the motor pump units that are not operating, thus preventing backward circulation of the primary coolant through these non-operating units. This also decreases the resistance to the flow of the primary coolant by natural circulation when none of the motor pump units are operating, because the openings 96 will then be open to provide a much more direct path for the flow of the primary coolant by natural circulation than if it was forced to flow through the pump casing 68 and past the impeller 70 and then out the discharge chamber 74. It is necessary to provide some means for natural circulation of the primary coolant in our steam generator in cases where all of the motor pump units might be rendered inoperative because of an unforeseen casualty. In such cases it might be impossible to remove the residual heat contained in the container 110 after the generation of heat had been stopped fast enough to prevent local overheating of the primary coolant and subsequent damage to our steam generator if no natural circulation of the primary coolant was provided.

When our steam generating unit is operating the primary coolant from the discharge chambers 74 of outer pump casings 61 will be directed radially outward through the space between adjacent headers 14 by means of the baffle 48. The primary coolant will then flow downward over the steam generating tubes 18 through the annular area between the baffles 40 and 42. As the primary coolant passes over the steam generating tubes 18, it will transfer its heat to the water contained in the generating tubes, thus partially converting it to steam. After passing over the generating tubes 18, the primary coolant

will flow to the bottom portion of the outer shell where it will be directed radially inward and upward by means of the baffles 98, 100 and 102. The primary coolant will then flow upward through the tubes 116 where it will be heated by the heat produced in the container 110. After passing through the tubes 116 the primary coolant will flow from the upper central portion of the outer shell through the tubular members 76 to the suction inlets 71 of the pump casings 68. The pump impellers 70 will then impel the primary coolant downward through the bottom of the inner pump casing 68 to the discharge chamber 74 where it will again begin its circulation over the steam generating tubes 18 as described above.

The water and steam mixture produced in the steam generating tubes 18 as the primary coolant flows over the outer surface of the generating tube will flow upward into the headers 14. From the headers 14 the steam and water mixture will pass into the steam drums 32 by means of the steam pipes 30. The steam will be separated from the water in the steam drums 32 and led out by means of suitable outlets 36 to any desired steam operated equipment (not shown). The water separated from the steam in the steam drums 32 will fall to the bottom of the steam drums 32 from where it will return to the bottom headers 16 by means of downcomers 31, distribution manifolds 29 and the inlet pipes 28. From the bottom headers 16 the water will flow upward through the generating tubes 18 where it will again be partially converted to steam by the primary coolant flowing over the outer surface of the generating tubes 18. Of course, additional feed water must be supplied to the steam drums 32 to equal the quantity of steam led away from the steam drum in order for the steam generating unit to continue to operate.

The headers 14 and 16 of our steam generating unit are constructed so that in case a generating tube 18 should develop a leak it can be isolated by means of suitable plugs inserted in each end of the leaking tube. Of course, in order to plug the ends of the leaking tube, it would be necessary to remove the steam line 30 and the inlet pipe 28 from the associated headers 14 and 16, respectively. The steam line 30 and inlet pipe 28 may be removed by any suitable means such as by cutting welds 24 and 26 and then rewelding them after the leaking tube has been plugged. With the steam line 30 and inlet pipe 28 removed it would be a simple matter to drive a suitable plug into each end of the leaky tube 18, as is well known in boiler operating procedures. A leaking generating tube 18 may also be isolated by isolating the complete tube bundle. This can be done by closing suitable valves such as valves 130 and 132 in the inlet pipe 28 and the steam line 30, respectively. Of course, this method would effect a greater decrease of the capacity of our steam generator since it isolates a complete bundle of the generating tubes 18.

Whenever it becomes necessary to remove one of the individual tube bundles from the steam generator shown in FIGS. 1, 2 and 3 it can be readily accomplished by first removing the top cap 52. As the top cap 52 is removed the container 110 which encloses the heat source of our steam generator will be withdrawn from the central portion of the outer shell. After the top cap 52 and container 110 have been removed the circular baffle 48 can be removed by breaking the small weld 50 at the top edge of its vertical leg and removing it a section at a time through the top opening in the outer shell. Then the circular baffle 42 may be removed by loosing the nuts 44 and taking a section at a time out the top opening in the outer shell. Of course, if only one tube bundle is to be removed only the sections of baffles 42 and 48 adjacent the tube bundle to be removed need be disassembled and taken out the top opening.

After the baffles have been removed it will be necessary to remove the inlet 28 and steam line 30 from the outer surface of the outer shell for the particular tube bundle to be removed. As explained above, in some cases it may be necessary to remove adjacent tubes bundles in order to remove any particular tube bundle, for example, in order to remove a trapezoidal-shaped bundle 136 (FIG. 3) it would be necessary to remove square-shaped tube bundles 134 on each side, in which case additional inlets 28 and steam lines 30 would be removed. After the necessary inlet 28 and steam line 30 have been removed, the headers 14 and 16 can be disconnected from the outer shell by removing snap rings 19 and ring members 17. Then the sections of the annular keys 15 may be removed and the welds 23 sealing each of the corrugated expansion members 21 to the headers 14 and 16 respectively. The tube bundle can then be easily withdrawn to the center portion of the outer shell where it can be removed through the top opening in the outer shell.

The reverse procedure to that described above would be followed to install a new tube bundle. This arrangement for removing and reinstalling the tube bundles of our steam generator does not require the disassembly of any of the structural parts of our steam generator, and except for replacing the various welds can be accomplished by relatively unskilled labor. This means of removal also allows all of the parts to be reused except, of course, the tube bundle which was removed.

A second embodiment of our invention is illustrated in FIGS. 5 and 6, in which the individual bundles of generating tubes 18 illustrated in FIG. 1 are replaced by a series of horizontal tube sets which encircle the central portion of the outer shell. The horizontal tube bundles of FIG. 5 do not terminate in headers as did the generating tubes 18 of FIG. 1, but the ends of the tubes pass through the outer shell where they are connected to suitable distribution manifolds. Also in this embodiment all motor pump units are placed so that their axes of rotation lie on an extension of one of the radii of the outer shell. This arrangement allows for easier fabrication of the outer shell 150 since no irregular surface such as surface 67 is required for mounting the motor pump units.

The outer shell of the embodiment shown in FIG. 5 is formed of two generally hemispherical sections 147 and 148 of a material similar to the material used for the outer shell of FIG. 1 which are joined by means of an annular weld 149. The upper section 147 has a suitable circular opening 204 formed in its top portion which is used for the installation and removal of a container 210 similar to container 110 of FIG. 2 which contains the heat source for this embodiment. Mounted on the outer surface of the outer shell at one side are a plurality of vertically spaced inlet manifolds 154, each of which is formed in one end of a semitubular member 155 by means of a central partition 157 which serves to supply water to the horizontally arranged vertically spaced sets of steam generating tubes 156, respectively. The members 155 may be attached to the outer shell by any suitable means such as welds 151 and the inlet manifolds 154 are supplied with water by means of a suitable inlet pipe 152. The generating tubes 156 at one end pass through the outer shell and open into the manifolds 154. As seen in FIG. 6, the generating tubes 156 completely encircle the central portion of the outer shell and again pass through the outer shell where they connect with other manifolds 153, each of which is formed in the other end of a member 155 by partition 157. Also connected to the manifolds 153 are suitable steam lines 160. Thus, water introduced through the manifold 154 will flow through the generating tubes 156 where it will be converted to steam by the primary coolant flowing over the outer surface of the generating tubes 156, and the steam will flow into the manifold 153 where it may be led away to any suitable steam operating equipment. Interposed between the spaced sets of tubes 156 are sets of generating tubes 158 which originate in manifolds 164 which are diametrically opposite manifolds 154, and terminate in manifolds 168 which are opposite manifold 153. Manifolds 164 and 168 are formed in a semitubular member 166 in the same manner as described

above for forming manifolds 154 and 153 in semitubular member 155. Instead of leading the steam collected in the manifolds 153 and 168 directly to the steam operated equipment, it may be led to a suitable steam drum (not shown) similar to steam drums 32 of FIG. 1. In the steam drum the steam can be separated from any water contained therein by a method similar to that described for FIG. 1. We prefer in this arrangement to have forced circulation of the water through the generating tubes 156 and 158 and omit entirely the steam drums 32 of FIG. 1. Such a system would greatly simplify the construction of our steam generating unit and reduce its cost since the steam drums and connecting piping is eliminated. The tube sets 156 of this embodiment can be isolated in case of a leaky tube by removing the inlet 152 and outlet 160 of the manifolds 154 and 153, respectively, by any suitable means and driving plugs in the inlet 152 and outlet 160. Another method would be to install suitable valves similar to valves 130 and 132 of FIG. 1 in the inlet 152 and outlet 160 which could be closed to isolate the tube set 156 containing the leaky tube. Individual tubes could be plugged by removing the manifolds 154 and 153 and plugging both ends of the leaky tubes.

Placed alternately between adjacent tube sets 156 and 158 and at the top and bottom of the tube sets are a series of circular baffles 159, 161, 163, 165, 167, 169, 171, 173 and 175 of varying size which serve to direct the flow of the primary coolant in a zig-zag path downward through the various tube bundles. These baffles have a generally circular dish shape with a central opening. The inner edge of baffle 59 is attached to a central tubular baffle 170 to be described later, while the outer edge of baffle 161 is attached at its outer edge to the inner surface of the outer shell 150. The baffle 161 is spaced from tubular baffle 170 so that a small annular passage exists at its inner edge through which the primary coolant may flow and the baffle 159 is spaced so that an annular passage exists at its outer edge. The remaining baffles 163, 167, 171 and 175 are secured at their inner edge to the tubular baffle 170, while baffles 165, 169 and 173 are secured at their outer edges to the shell 150. Thus, baffles 159 through 175 will direct the flow of the primary coolant in a zig-zag path over the tube sets 156 and 158. The tubular baffle 170 has a generally cylindrical shape and extends from the top of the central opening 204 in the outer shell 150 to below the lowest tube bundle 158. The upper edge of the baffle 170 may be attached to the outer shell by any suitable means such as welding or cap screws (not shown).

A plurality of motor pump units, similar in construction to the motor pump units described in FIG. 1, and each of which has an outer casing 180, are attached to the outer shell by means of bolts 184 which pass through an outwardly projecting flange 185 formed on the outer casing 180 and thread into the outer shell. The bolts 184 serve to draw a flange 181 formed on the outer casing 180 into sealing engagement with the outer shell. The motor of the motor pump unit may be enclosed in the upper portion of the outer casing 180 as described above for the motor in the pump units of FIG. 1. The lower end of each motor pump unit projects through an opening 182 in the outer shell and carries at its lower end an impeller 186. Each impeller 186 operates in a tubular inner pump casing 188 which is attached to the outer shell 150 by means of bolts (not shown). An outer pump casing 189 is provided in the top portion of the outer shell 147 and has a substantially annular shape with a central opening that is registered with the opening 182 in the shell and is adapted to receive the lower end of the motor pump unit 180. The outer casing 189 has a circular suction chamber 190 formed in the top portion which surrounds the inner casing 188 and has a circular opening in one side to allow the coolant to flow into the suction chamber as will be described later. The central opening of the outer pump chamber terminates in a discharge opening 192 at the bottom of the outer casing 189. The outer pump casing 189 may be attached to the inner surface of the outer shell by any desired means such as cap screws or welding (not shown). The impeller 186 is designed to draw the primary fluid through suitable suction openings 191 formed in the top of the inner pump casing 188 and impel it downward through a discharge opening 192 formed in the bottom of the outer pump casing 189. The suction openings 191 in the inner pump casing 188 are connected to a circular opening 194 in the top portion of a baffle 170 by means of the outer pump casing 189 and a tubular member 193. The tubular member 193 may be secured to the baffle 170 by any suitable means such as a small weld (not shown). The discharge opening 192 of the pump unit may be closed by means of a swing type check valve 196 which is pivoted at its top on a pin 197 which is secured to the outer pump casing 189 by any suitable means (not shown). The check valves 196 serve to prevent the backward circulation of the primary coolant through those motor pump units that are not operating.

When this embodiment of our steam generator is operating, the primary coolant flowing from the discharge opening 192 will be directed in a zig-zag path through the tube bundles 156 and 158 by the baffles 159, 161, 163, 165, 167, 169, 171, 173 and 175 as previously described. The flow of the primary coolant at the bottom of the outer shell is directed inwardly and upwardly by means of vertically spaced circular baffles 198, 200 and 202 which are mounted in the bottom of the spherical shell by any suitable means (not shown). The upper baffles 198 and 200 both have a central opening through which the coonant flows while the lower baffle 202 has a series of holes in its central portion to allow the coolant to flow upward through them. As the primary coolant flows upward it will pass through suitable tubes 216 similar to the tubes 116 described in FIG. 1. The tubes 216 are sealed to the top and bottom surfaces of a cylindrical container 210 similar to the container 110 of FIG. 1. Also sealed to the top surface are suitable tubular members 218, 220 and 222 similar in construction to the tubular members 118, 120 and 122 of FIG. 1. Suitable materials may be introduced into the tubular members 218, 220 and 222 into the container 110 to produce heat for our steam generating unit similar to the method described in FIG. 1. After passing through the tubes 216 the primary coolant will return to the suction inlets 193 of the motor pump units to begin a new cycle of circulation through the steam generating unit.

The top opening 204 of the outer shell may be closed by any suitable means such as a circular plate 230, the lower edge of which rests upon a suitable shoulder 231 formed on the inner surface of the top opening 204. The circular plate 230 is held in position by means of a retaining ring 232 which fits in an outwardly projecting circumferential groove 233 formed on the inner surface of the opening 204. The retaining ring 232 may be formed in a series of sections to allow easy installation and may be retained in place by any suitable means such as cap screws (not shown). The closure is sealed by means of a ring member 234 which is U-shaped in section, one leg of which is welded to the circular plate 230 by means of a small annular weld 236, and the other leg of which is welded to the top surface 238 of the outer shell by means of a second annular weld 237.

To facilitate the natural circulation of the primary fluid when the motor pump units 180 might be rendered inoperative, a series of swing check valves 250 are provided in the upper portion of baffle 170. Check valves 250 serve to close circular openings 252 in the baffle 170 when the motor pump units are operating, but due to their light weight, will easily swing open upon failure of the motor pump units to allow for natural circulation of the primary coolant.

In order to provide sufficient strength to the check valves 250 without unduly increasing their weight, we have provided them with a slightly dished shape as shown

in FIG. 5. Thus, these check valves can be made out of relatively thin metal and will still have sufficient strength to withstand the discharge pressures of the motor pump unit.

In the above described embodiment of the invention we have greatly simplified the construction of the outer shell by providing a radial mounting for the motor pump units and using only two sections to form the shell. In addition, we have provided a somewhat more direct path for natural circulation of the primary coolant than is provided in FIG. 2 by means of the double check valve arrangement **92** and **94**. Also the circular tube bundles **156** and **158** of FIG. 5 are considerably simpler to manufacture than the header and tube type arrangement used in FIG. 2. Thus, the cost of the steam generating unit shown in FIG. 5 is considerably less than that shown in FIG. 2

The embodiment shown in FIGS. 5 and 6 could be further simplified by omitting the pump units **180** used for circulating the primary fluid and relying solely on natural circulation to circulate the primary fluid. A design of our steam generator using natural circulation would be very desirable where remote operation of the steam generator is desired.

While we have shown only two embodiments of our invention, it is capable of many other modifications. For instance, the header and tube type arrangement illustrated in FIG. 2 could be substituted in FIG. 5 for the tube bundles **156** and **158** and the advantages of the radially mounted pumps and the easy path for natural circulation of primary coolant would still be desirable. Likewise, the openings **250** and the check valves **252** in the baffle **170** of FIG. 5 could be substituted in the baffle **48** of FIG. 2 in place of openings **96** in member **76** and would provide a much better path for the natural circulation of the primary coolant than the arrangement illustrated in FIG. 2. Also, while we have shown pump units **60** and **180** mounted in the upper portion of the sealed outer shells **10** and **150** respectively, they could be mounted in the lower portion and draw the primary coolant through the heat exchangers which would be mounted above the pumps, also, the embodiment shown in FIG. 1 could be modified so that the water is completely converted to steam in the generating tubes **13** thus eliminating the need for steam drums **32**. Thus, it is desired that our invention be not limited to the specific constructions shown and described herein for illustrative purposes because it will be apparent to those skilled in this art that our invention may be embodied in a number of different forms.

We claim as our invention:

1. A unitized steam generator comprising, a generally spherical shaped outer shell having a plurality of vertical tube bundles mounted circumferentially around the inner surface thereof, each of said tube bundles comprising two spaced apart headers connected together by a plurality of relatively small bent tubes, the bent tubes of alternate tube bundles being bent so as to form a tube bundle having a generally square outer shape, the tubes of the remaining tube bundles being bent so as to form a tube bundle having a generally trapezoidal outer shape, said tube bundles being arranged around the inner surface of said outer shell to cover substantially all of said inner surface, a central opening in the upper portion of said outer shell through which said tube bundles may be inserted and removed from said outer shell, means for closing said central opening, said outer shell being filled with a cooling medium, and means for supplying heat to said cooling medium and additional means for circulating said heated cooling medium over said tube bundles.

2. A unitized steam generator comprising, a generally spherical outer shell having an even number of vertical tube bundles mounted circumferentially around the inner surface thereof, each of said tube bundles comprising two spaced apart headers, said headers being connected by a plurality of relatively small bent tubes, the bent tubes of half of said tube bundles being bent so as to form a tube bundle having a generally square outer shape and the bent tubes of the remaining tube bundles being bent to form a tube bundle having a generally trapezoidal outer shape, said tube bundles being arranged so as to line substantially all of the inner surfaces of said outer shell, a central opening in the upper portion of said outer shell through which said tube bundles may be inserted and removed from said outer shell, means for closing said opening, said outer shell being filled with a cooling medium, means for heating said cooling medium and additional means for circulating said heated cooling medium over said tube bundles.

3. A steam generator comprising, an outer shell, enclosure means adapted to contain a source of heat and located substantially centrally within said shell, said enclosure means having passageways therethrough, heat exchange means located in the space within said shell surrounding said enclosure means but spaced outwardly of said enclosure means, a heat transfer fluid substantially filling said shell, means in said shell for circulating said heat transfer fluid in a recurrent substantially circuitous path within said shell through said passageways in said enclosure means and past said heat exchange means, said shell having an aperture formed therein in alignment with said enclosure means and cover means detachably secured to said shell for closing said aperture.

4. A steam generator comprising, an outer shell, enclosure means adapted to contain a source of heat and located substantially centrally within said shell, said enclosure means having passageways therethrough, heat exchange means located in the space within said shell surrounding said enclosure means but spaced outwardly of said enclosure means, means in said shell closing off the space between said enclosure means and said heat exchange means, a heat transfer fluid substantially filling said shell, and means in said shell for circulating said heat transfer fluid in a recurrent substantially circuitous path within said shell through said passageways in said enclosure means and past said heat exchange means, said shell having an aperture formed therein in alignment with said enclosure means and cover means detachably secured to said shell for closing said aperture.

5. A unitized steam generator comprising, a generally spherical shaped outer shell having a plurality of vertical tube bundles mounted circumferentially in the annular space adjacent the inner surface thereof, each of said tube bundles comprising two spaced apart headers connected together by means of a plurality of relatively small tubes, hollow enclosure means disposed in a central portion of said shell and adapted to receive a source of heat therein, said enclosure means having passageways therethrough, said outer shell being filled with a cooling medium, means for circulating said cooling medium through said passageways in said enclosure means and over said tube bundles comprising a plurality of motor pump units each having a suction inlet and a discharge outlet and mounted on the exterior surface of said outer shell so that the pump portion of said motor pump units extends into said outer shell, the suction inlet of each of said pumps communicating with one end of at least one of said passageways, the discharge outlet of each of said pumps communicating with said annular space, and the other end of said passageway communicating with said annular space.

6. A steam generator comprising, an outer shell having a plurality of vertical tube bundles mounted therein, each of said tube bundles having two spaced apart headers connected by a plurality of small tubes, each of said headers having a tubular portion, said outer shell having openings therein adapted to receive said tubular portions, a flexible sleeve member in each shell opening which is attached to each tubular portion of said headers and said outer shell, an annular key in each shell opening and having spaced outwardly extending flanges disposed

thereon to straddle said flexible member, cooperating annular grooves formed in each of said tubular portions of said headers and said outer shell for receiving the flanges of said key, respectively, and additional means for circulating a heated cooling fluid over said tube bundles.

7. A steam generator comprising, a generally spherical shaped outer shell having a plurality of vertical tube bundles mounted circumferentially in the space adjacent the inner surface thereof, an enclosure mounted in said outer shell, a heat source disposed within said enclosure, said enclosure having passageways therethrough, said outer shell being filled with a cooling medium, means forming a recurrent circuitous path in said shell for circulating said cooling medium through said passageways in heat exchange relationship with said heat source and over said tube bundles into heat exchange relationship with said tubes bundles, said last mentioned means including a plurality of motor pump units having a suction inlet and a discharge outlet and mounted on the exterior surface of said outer shell so that the pump portion of said motor pump units extends into said outer shell, the suction inlet of each of said pumps being in communication with at least one of said passageways, the discharge outlet of each of said pumps being in communication with said space so that the cooling medium is passed from said outlet into heat exchange relationship with the tube bundles.

8. A steam generating unit comprising, an outer shell having a plurality of generating tubes mounted therein adjacent its inner surface and about a central space, a heat source, a vessel mounted in said space in said outer shell and containing said heat source, said vessel having passageways therethrough, the effective center of said heat source being lower in said outer shell than the effective center of said generating tubes, a cooling medium substantially filling said shell, means including natural circulation of said cooling medium for transferring heat from said heat source to said generating tubes thereby converting water in said generating tubes to steam, said means forming a recurrent substantially circuitous path within said shell through said passageways in said vessel, said shell having an opening therein disposed in alignment with said heat source vessel so that said vessel may be removed therefrom as a unit, and closure means detachably secured to said shell to close said opening.

9. A steam generator comprising, an outer shell, a vessel removably mounted substantially centrally within said outer shell, a source of heat disposed in said vessel, a plurality of horizontal steam generating tubes, each of said tubes being mounted in the space between said shell and said vessel and substantially surrounding said heat source, said tubes having inlet and outlet portions respectively which pass through said shell, said tubes being divided into a plurality of separate tube sets, the tubes in each of said tube sets being connected to a manifold at the inlet and a manifold at the outlet of said tubes respectively, means for preventing flow in each of said tube sets, a heat transfer fluid substantially filling said shell, means in said shell forming a recurrent substantially circuitous path within said shell, and including said passageways through said vessel so that said heat transfer fluid flows along said path through said vessel and past said steam generating tubes, said shell having an aperture formed therein in alignment with the outer periphery of said vessel, and closure means detachably secured to said shell for closing said aperture.

10. A steam generator comprising, an outer shell, a vessel removably mounted substantially centrally within said outer shell, a source of heat disposed in said vessel, said vessel having passageways therethrough, a plurality of horizontal steam generating tubes disposed in the space between said shell and said vessel, each of said tubes substantially surrounding said heat source and having inlet and outlet portions which pass through said shell, said tubes being divided into a plurality of separate tube sets, the tubes in each of said tube sets being connected to a manifold at the inlet and a manifold at the outlet of said tubes respectively, means provided for isolating the manifolds connected to the inlet and outlet of the tubes of one tube set from the remaining manifolds, a heat transfer fluid substantially filling said shell, means in said shell forming a recurrent substantially circuitous path within said shell, said means including said passageways through said vessel so that said heat transfer fluid flows along said path through said vessel and past said steam generating tubes, additional means comprising a plurality of pumps mounted with their axis of rotation perpendicular to the adjacent outer surface of said outer shell, each of said pumps including a casing and an impeller, at least the pump casing and impeller of each of said pumps being disposed in said circuitous path and said pumps forming a portion of said circuitous path, said shell having an aperture formed therein in alignment with the outer periphery of said vessel, and cover means detachably secured to said shell for closing said aperture.

11. A steam generator comprising, a generally spherical shaped outer shell having a plurality of vertical tube bundles mounted circumferentially in the annular space adjacent the inner surface thereof, a hollow enclosure adapted to receive a source of heat and mounted in said outer shell, said outer shell being filled with a cooling medium, means forming a recurrent circuitous path in said shell for circulating said cooling medium through said hollow enclosure and over said tube bundles including a plurality of motor pump units mounted on the exterior surface of said outer shell so that the suction inlet and discharge outlet of said motor pump units are located in said outer shell, said pumps forming a portion of said recurrent circuitous path, the discharge outlet of each of said pumps being in communication with said annular space, and a swing check valve mounted in the discharge outlet of each of said pumps.

12. A steam generator comprising, an outer shell, a vessel removably mounted substantially centrally within said outer shell, a heat source disposed in said vessel, said vessel having passageways therethrough, a plurality of horizontal steam generating tubes disposed in the space between said shell and said vessel, each of said tubes substantially surrounding said heat source and having inlet and outlet portions which pass through said shell, said tubes being divided into a plurality of separate tube sets, a manifold connected to the inlet and a manifold connected to the outlet of each of said tube sets respectively, so that said sets of tubes may be individually removed from service, a heat transfer fluid substantially filling said shell, means in said shell forming a recurrent circuitous path within said shell, said means including said passageways through said vessel so that said heat transfer fluid flows along said path through said vessel and past said steam generating tubes, said shell having an aperture formed therein in alignment with the outer periphery of said vessel, and cover means detachably secured to said shell for closing said aperture.

13. A steam generator comprising, an outer shell, enclosure means removably mounted substantially centrally within said shell and adapted to contain a source of heat, said enclosure means having at least one passageway therethrough, heat exchange means mounted in the space between said shell and said enclosure means and substantially surrounding said enclosure means, a heat transfer fluid substantially filling said shell, means in said shell forming a recurrent circuitous path within said shell, said means including said passageway through said enclosure means so that said heat transfer fluid flows along said path through said enclosure and past said heat exchange means, said shell having an aperture formed therein in alignment with the outer periphery of said enclosure means, and cover means detachably secured to said shell for closing said aperture.

14. A steam generator comprising, an outer shell hav-

ing steam generating tubes mounted around the inner surface of said outer shell and each having portions passing through said outer shell, a container having a heat source disposed therein and mounted in said outer shell, said container having substantially vertical passageways therethrough, a vertical baffle member surrounding said container and vertically spaced from the bottom of said outer shell, means including a plurality of pumps for moving a cooling fluid along a flow path from the top of the volume enclosed by said baffle member and circulating it downward over said generating tubes past the bottom of said baffle member and upward through said passageways to return to said circulating means, additional means for allowing circulation of said cooling fluid by natural convection comprising swing check valves mounted in the upper portion of said baffle above said generating tubes and container.

15. A steam generator comprising, an outer shell, enclosure means having passageways therethrough and adapted to contain a source of heat and located substantially centrally within said shell, heat exchange means located in the space within said shell surrounding said enclosure means, means in said shell forming a recurrent substantially circuitous path within said shell through said passageways in said enclosure means and past said heat exchange means, means for circulating said heat transfer fluid in said circuitous path, said circuitous path including conduit means connected between said circulating means and said passageways, fluid passage means in said shell forming a by-pass between said conduit means and said space, and check valve means for closing said passage means in response to operation of said fluid circulating means.

16. A steam generator comprising, an outer shell, enclosure means having passageways therethrough, and adapted to contain a source of heat and located substantially centrally within said shell, heat exchange means located in the space within said shell surrounding said enclosure means, means in said shell forming a recurrent substantially circuitous path within said shell, means in said shell for circulating a heat transfer fluid in said recurrent substantially circuitous path within said shell through said passageways in said enclosure means and past said heat exchange means, means in said shell confining a portion of said fluid path to said fluid circuating means, said circuitous path including conduit means connected between said circulating means and said passageways, fluid passage means in said shell forming a by-pass between said conduit means and said space, and check valve means for closing said passage means in response to operation of said fluid circulating means.

17. A steam generator comprising, an outer shell, enclosure means having passageways therethrough and adapted to contain a source of heat and located substantially centrally within said shell, heat exchange means located in the space within said shell surrounding said enclosure means, means in said shell forming a recurrent circuitous path, means in said shell for circulating a heat transfer fluid in said recurrent circuitous path within said shell through said passageways in said enclosure means and past said heat exchange means, means in said shell confining a portion of said fluid path to said fluid circulating means, said circuitous path including conduit means connected between said circulating means and said passageways, fluid passage means in said shell forming a by-pass between said conduit means and said space, check valve means for closing said passage means in response to operation of said fluid circulating means, and a second check valve means normally closing said fluid confining means but operable to open said fluid confining means in response to operation of said fluid circulating means.

18. A steam generator comprising, an outer shell, enclosure means having passageways therethrough and adapted to contain a source of heat and located substantially centrally within said shell, heat exchange means located in the space within said shell surrounding said enclosure means, means forming a recurrent substantially circuitous path in said shell, a plurality of spaced means in said shell for circulating a heat transfer fluid through said recurrent substantially circuitous path within said shell through said passageways and past said heat exchange means, said circuitous path including conduit means connected between said passageways and said circulating means, a plurality of fluid passage means in said shell forming by-passes between said conduit means and said space, and means for closing each corresponding passage means in response to operation of its associated fluid circulating means.

19. A steam generator comprising, an outer shell, enclosure means having passageways therethrough and adapted to contain a source of heat and located substantially centrally within said shell, heat exchange means located in the space within said shell surrounding said enclosure means, means forming a recurrent substantially circuitous path in said shell, a plurality of spaced means in said shell for circulating a heat transfer fluid through said recurrent substantially circuitous path within said shell through said passageways in said enclosure means and past said heat exchange means, said circulating means having an inlet and an outlet means in said shell connecting portions of said fluid path to said fluid circulating means, said circuitous path including conduit means connected between said passageways and the inlet of said circulating means, a plurality of fluid passage means in said conduit means forming by-pass flow paths between said conduit means and said space, respectively, and means for closing the corresponding passage means in response to operation of its associated fluid circulating means.

20. A steam generator comprising, an outer shell, enclosure means having passageways therethrough and adapted to contain a source of heat and located substantially centrally within said shell, heat exchange means located in the space within said shell surrounding said enclosure means, means forming a recurrent substantially circuitous path in said shell, a plurality of spaced means in said shell for circulating a heat transfer fluid in said recurrent substantially circuitous path within said shell through said passageways in said enclosure means and past said heat exchange means, means in said shell confining a portion of said fluid path to said fluid circulating means, said circuitous path including conduit means connected between said passageways and said circulating means, a plurality of fluid passage means in said shell forming by-passes between said conduit means and said space, respectively, means for closing the corresponding passage means in response to operation of its associated fluid circulating means, and a second means normally closing each of said fluid confining means but operable to open its corresponding fluid confining means in response to operation of its associated fluid circulating means.

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