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[21] Appl. No. **581,506**
[22] Filed **Sept. 23, 1966**
[45] Patented **Sept. 21, 1971**
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Apollo, Pa.
Continuation of application Ser. No. 817,271, Apr. 14, 1969, which is a continuation-in-part of application Ser. No. 554,874, June 2, 1966, now abandoned.

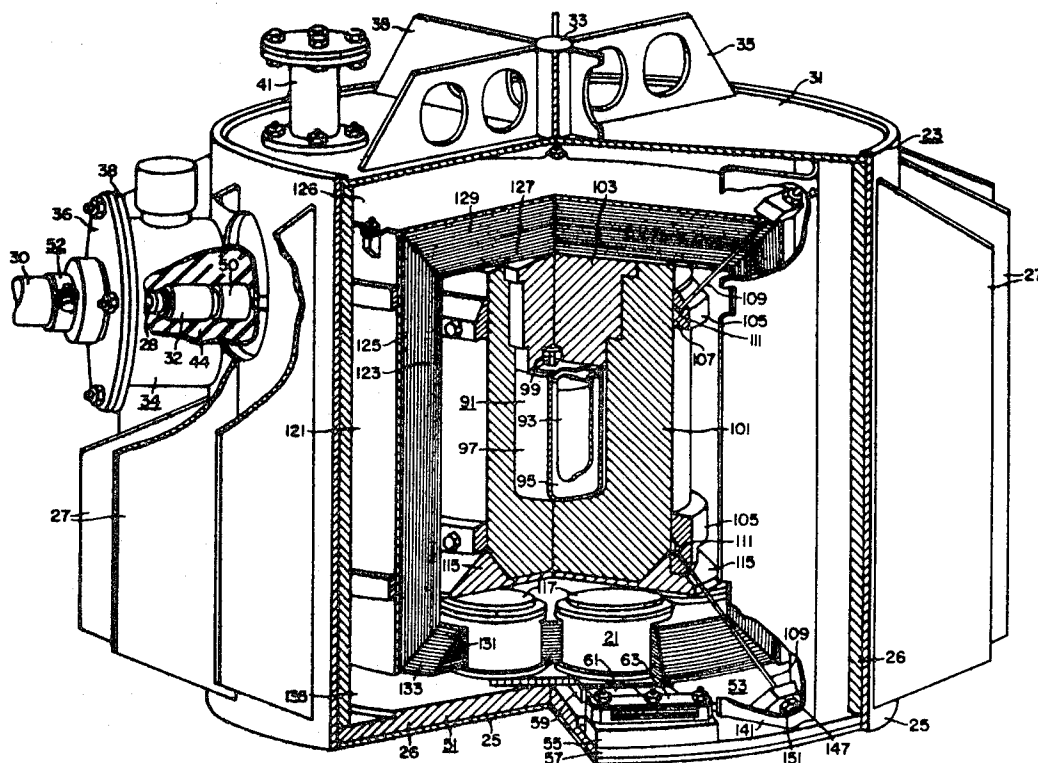
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[54] **ELECTRICAL GENERATOR**
10 Claims, 8 Drawing Figs.

[52] U.S. Cl..... **136/202,**
136/205, 136/212
[51] Int. Cl..... **G21h 1/10,**
H01v 1/30
[50] Field of Search..... **136/202,**
203, 205, 211, 212, 208, 209, 210

ABSTRACT: A radioactive thermoelectric generator is disclosed. The radioactive fuel is enclosed within a biological shield of tungsten to which a heat-transfer saddle is brazed. The thermoelectric converter includes modules with heat-transfer plates which are diffusion bonded to the shield so that the heat transfer to the hot junctions of the modules is through a metallurgical joint. The shield, fuel and thermoelectric converter are enclosed within an evacuated container in a heat shield of sheets of titanium nearer the biological shield and aluminum more remotely. Each module is enclosed in a second container within the evacuated container. The second container has gas at a substantial pressure to protect the thermoelectric elements.



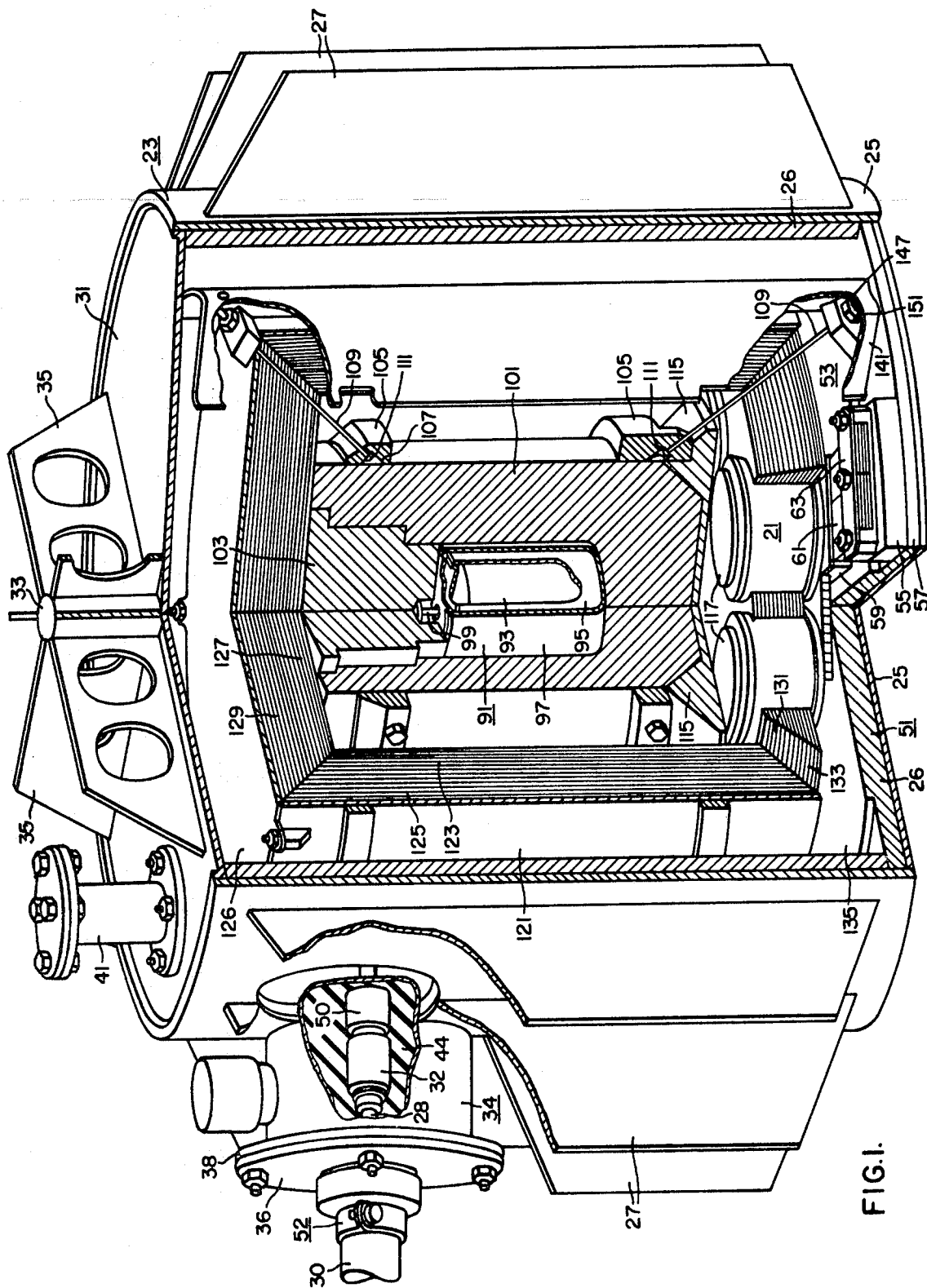


FIG. 1.

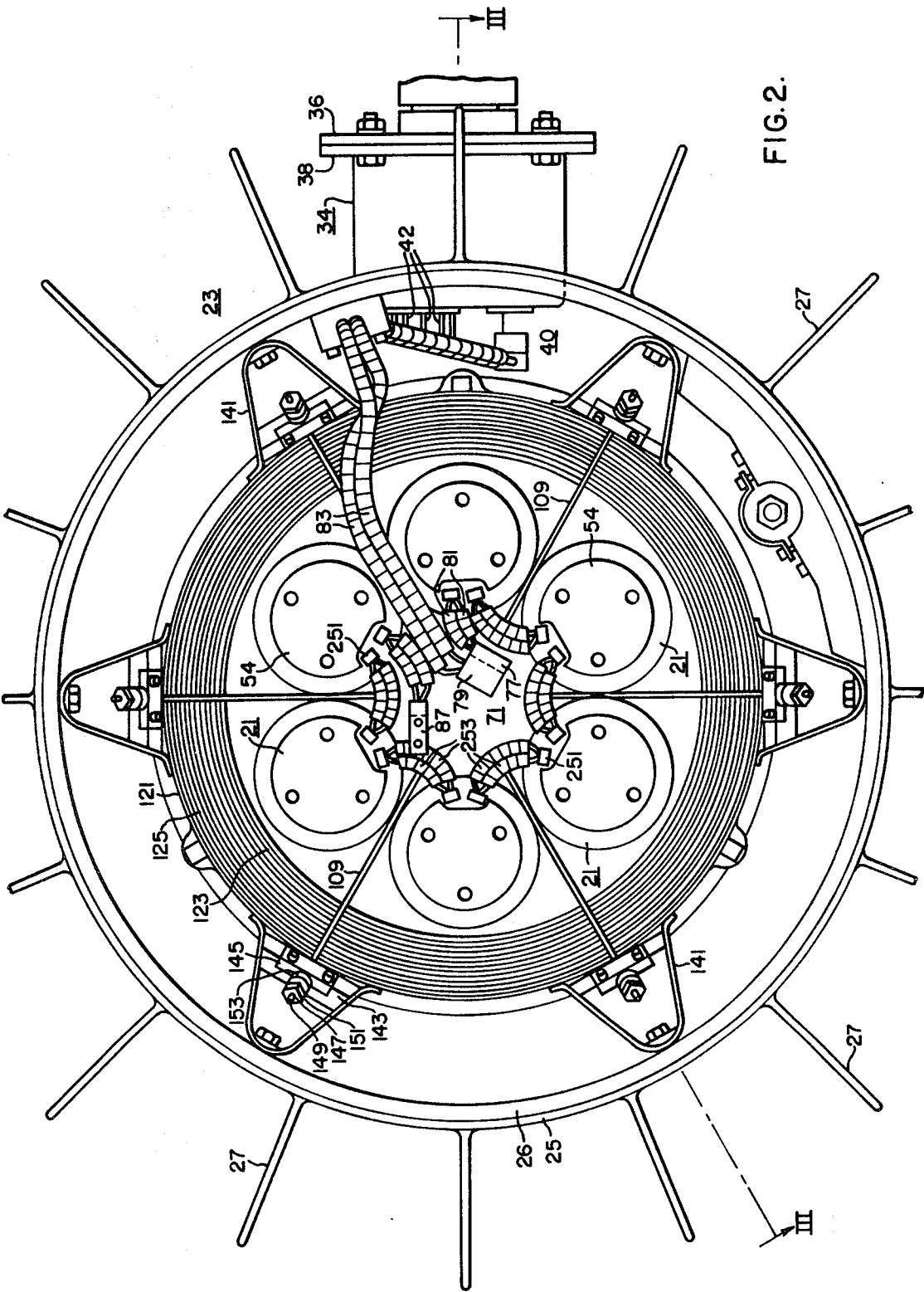
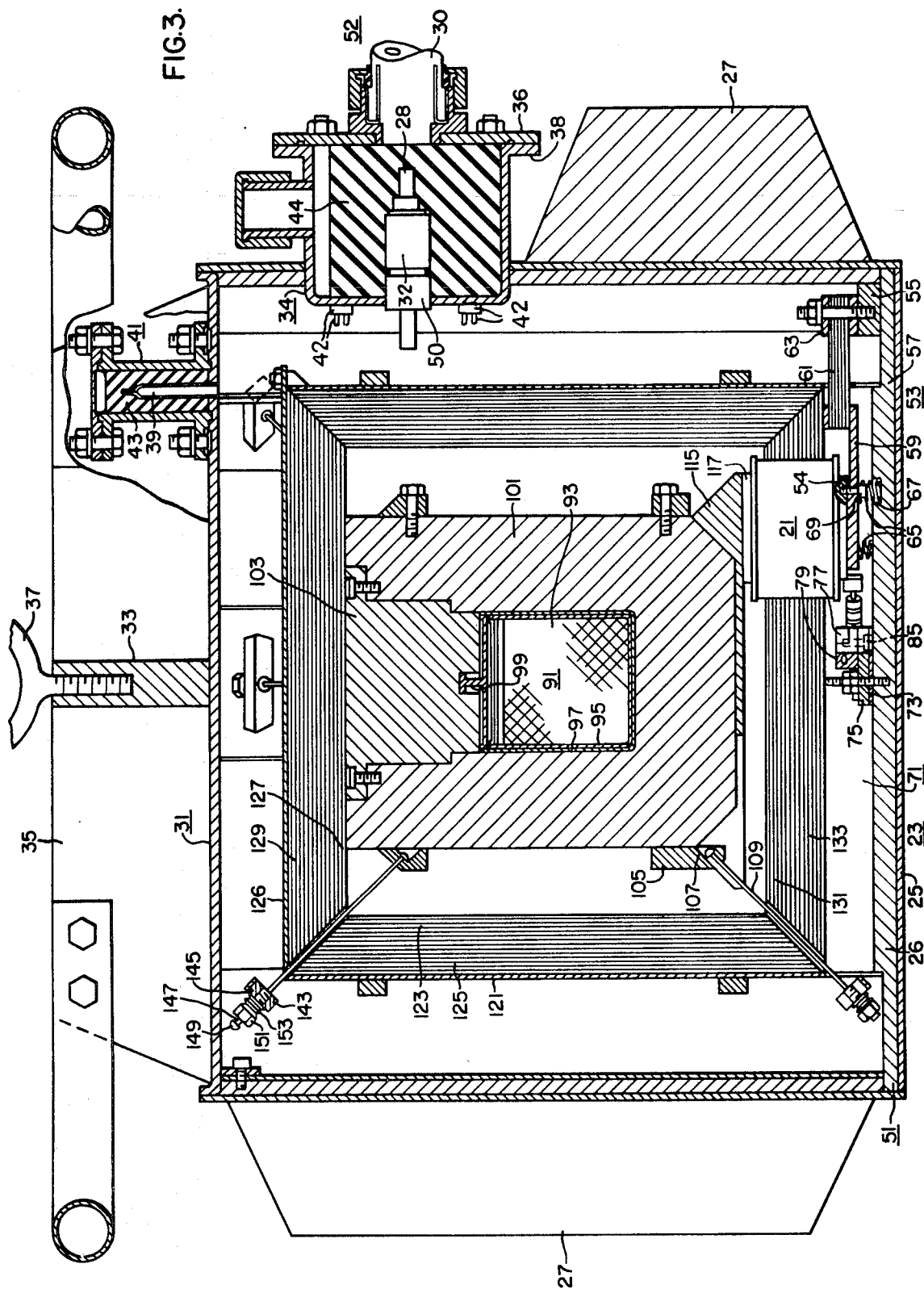


FIG. 2.

FIG. 3.



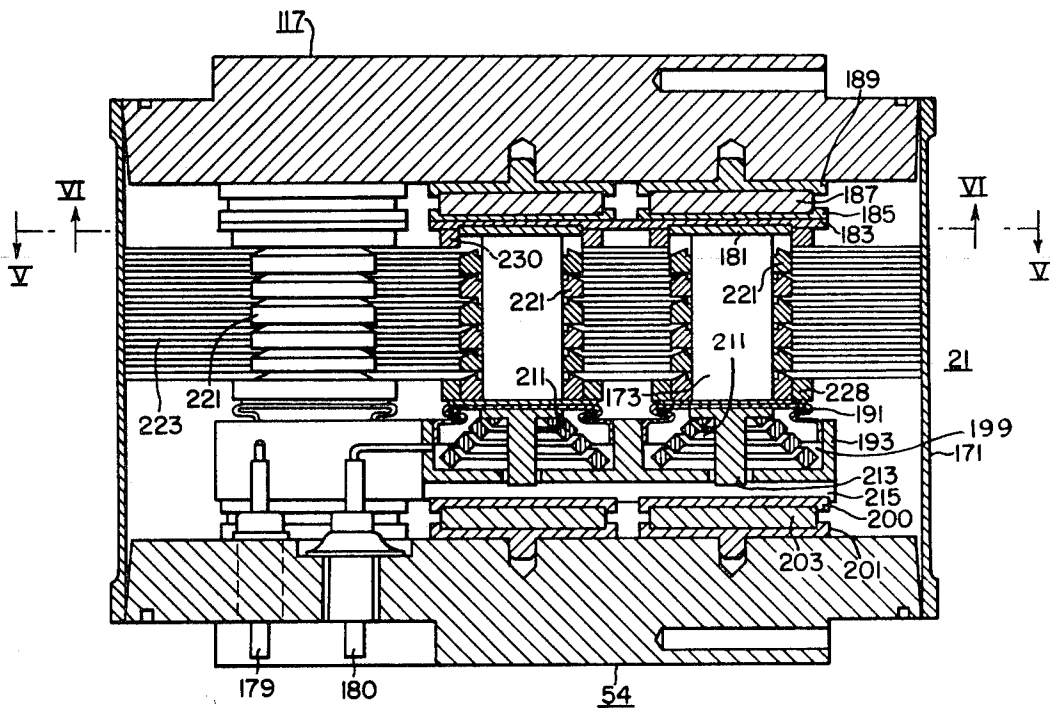


FIG. 4.

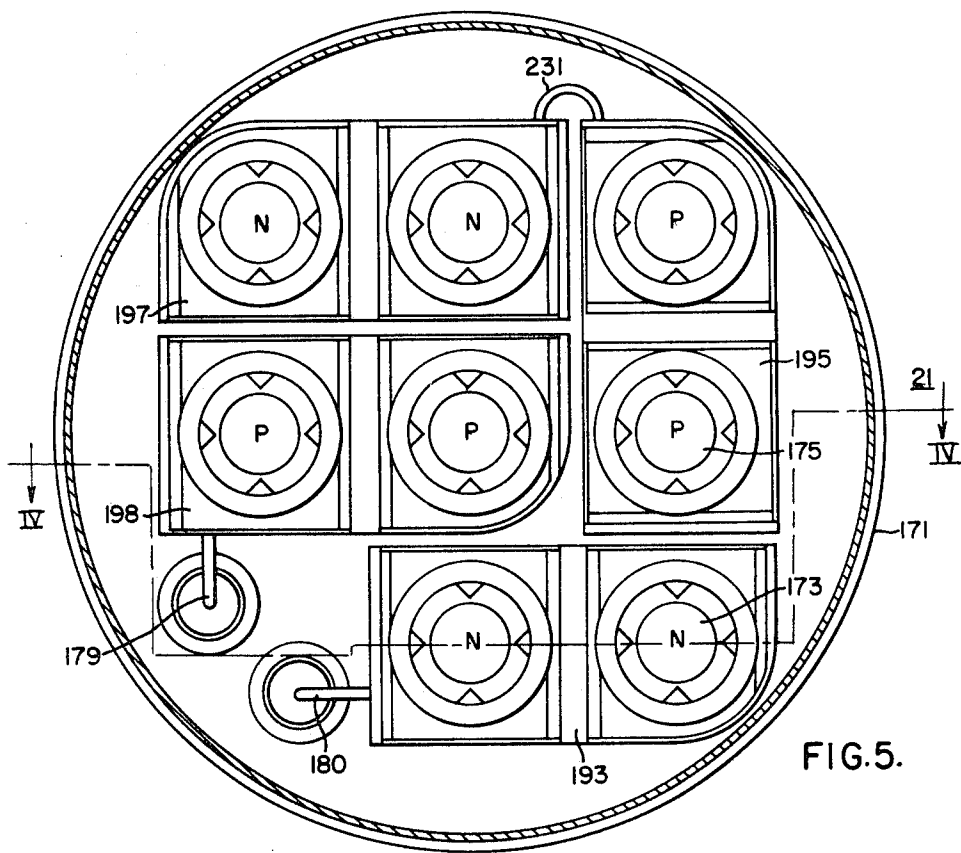
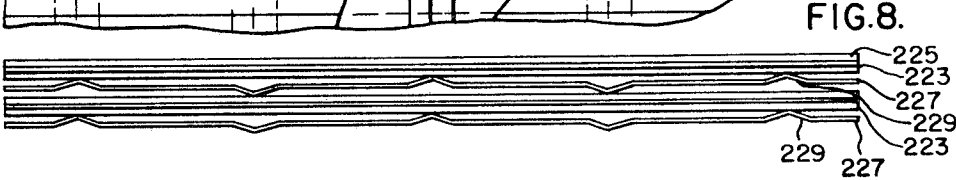
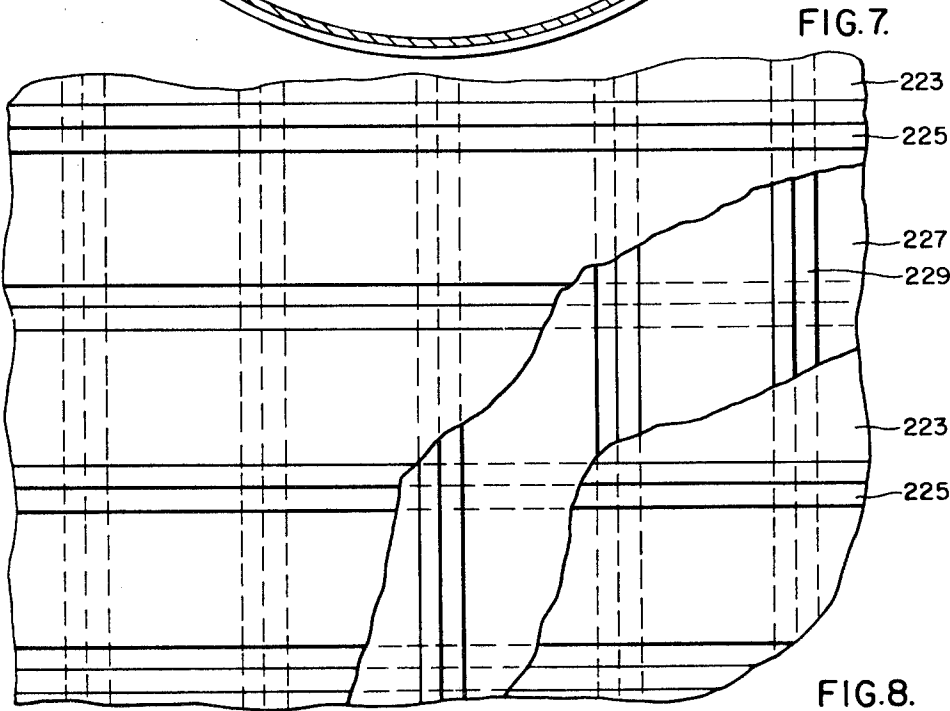
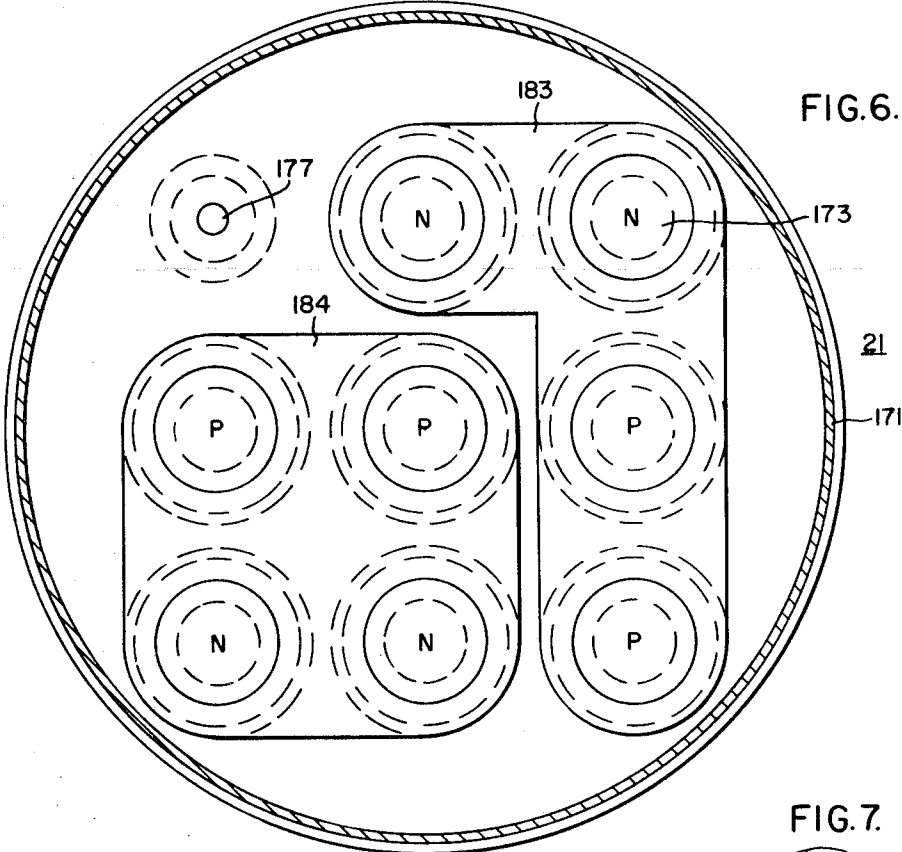


FIG. 5.



ELECTRICAL GENERATOR

This application is a continuation-in-part of application Ser. No. 554,874, filed June 2, 1966 to David L. Purdy for Electrical Generator, now abandoned, and whose subject matter is now being disclosed and claimed in a continuation of application Ser. No. 554,874, Ser. No. 817,271 filed Apr. 14, 1969, for Electrical Generator. This invention relates to the generation of electrical power and has particular relationship to electrical generators for use in places where commercial or utility power is not available, as in outer space or in remote sparsely inhabited regions of the world. Specifically this invention concerns itself with generators of the thermoelectric conversion type in which the heat energy which is converted is provided by radioactive material or fuel. It is an object of this invention to provide such a conversion generator capable of supplying appreciable or substantial power of the order of 1 to 100 watts or more.

Conversion generators in accordance with the teachings of the prior art include a radioactive source typically strontium 90 or plutonium 233 and a bank of thermoelectric elements in heat-interchange relationship with the source. Protection against the radioactive material is afforded by radioactive shield which may be composed of a material such as tungsten or an alloy of tungsten. The efficiency of prior art generators has been low and it is an object of this invention to overcome this deficiency and to provide a highly efficient conversion generator of the thermoelectric type.

In the generators under consideration the thermoelectric elements are of the solid-state type. Typical of such elements are doped lead telluride or silicon-germanium germanium blocks. The use of these blocks in generators subject to shock has revealed that they are fragile and tend to crack, spall or break. The stress to which these elements are subject by reason of thermal expansion or contraction has a like effect on them. It is an object of this invention to overcome this deficiency of the thermoelectric generators and to provide such generator in which the elements shall effectively resist shock and the stresses of thermal expansion and contraction.

In accordance with this invention a conversion generator is provided in which the thermal path, through the radioactive shield, from the radioactive source to the hot junction of the thermoelectric converter is throughout conducting material, the joint between each component and the next one in the path being metallurgical. Specifically the shield is brazed to a saddle of copper or other highly thermally conducting material and the saddle is in turn diffusion bonded to the hot junction. In the practice of this invention the thermoelectric converter comprises one or more modules including a plurality of opposite-polarity elements connected in parallel redundancy. Each module is in the form of a block or cylinder with hot and cold junction plates at the bases. The hot junction plate is diffusion bonded to the saddle which is brazed to the shield.

Another aspect of this invention arises from the realization that the solid-state thermoelectric elements are capable of withstanding substantial compressive stresses but do not readily resist tensional stresses. In accordance with this invention the elements of each thermoelectric module are subjected to a compressive prestress so that when the elements are subjected to shock or temperature variation (increase) the prestress is relieved and the elements are not subjected to tension. Specifically the prestress is applied to the elements of each module by a volute spring. During a portion of its force-displacement characteristic, the restoring force of a volute spring varies at a low rate with displacement. The spring is set to apply force to the thermoelectric elements during this low-rate portion of the characteristic and the force which the spring applies does not vary materially with shock or thermal expansion. In accordance with another aspect of this invention the unit including the shield and the thermoelectric converter is mounted on shock absorbers which also serve to conduct heat effectively to the heat sink.

For a better understanding of this invention, both as to its organization and as to its method of operation, together with

additional objects and advantages thereof, reference is made to the following description taken in connection with the accompanying drawings in which:

FIG. 1 is a view in perspective of a generator according to this invention with a part of the wall broken away;

FIG. 2 is a plan view of the generator in the direction of the arrow II of FIG. 1 and with the base of the casing removed;

FIG. 3 is a view in section taken along line III—III of FIG. 2;

FIG. 4 is a view in longitudinal section of a thermoelectric module 21 in accordance with this invention, the section being taken generally along a line IV—IV of the module 21 with reference to FIG. 5 but including the shoe 117;

FIG. 5 is a plan view generally diagrammatic in the direction of arrow V of the module shown in FIG. 4 with the heat-transfer shoe 117 connected to the heat source removed;

FIG. 6 is a plan view generally diagrammatic in the direction of the arrow VI of the module shown in FIG. 4 with heat-removal shoe 54 connected to the heat sink removed;

FIG. 7 is a fragmental plan view of the heat shield of the modules according to this invention; and

FIG. 8 is a fragmental view in end elevation of the heat shield shown in FIG. 7. The generator shown in the drawings includes a Container within which there is a Heat Source of the radioactive type enclosed in a Radioactivity Shield which protects from radioactivity personnel in the vicinity of the generator. The Radioactivity Shield and the Source are enclosed in a Heat Shield. A Support for the Radioactivity Shield is secured to a shell which extends around the Heat Shield. Within the Container, below the Radioactivity Shield, there is also a Thermoelectric Converter including a plurality of thermoelectric modules 21 (FIG. 4, 5 and 6).

The Container is of generally hollow cylindrical form and is vacuum tight. This container includes a cylindrical wall 23 typically of DURANEL structure. This structure is composed of a stainless steel shell 25 lined with aluminum 26. Fins 27 of stainless steel (AISI 304) or the like are welded to the shell 25 spaced around the shell. An output conductor 28 extends through the wall 23 and is connected to the power conductor (not shown) of a coaxial cable 30. The conductor 28 is sealed through a graded alumina seal 32 which is in turn sealed to stainless steel ring 50 welded through the base of a stainless steel cup 34. The cup 34 extends through the wall 23 and is seal-welded to the shell 25. The cup 34 has a cover 36 which is secured to the flange 38 of the cup with gaskets (not shown) interposed between the cover and the flange. The cable 30 extends through the cover 36 and is held by a gasketed clamp 52 sealed through the cover 36. An additional seal 40 for measurement conductors 42 (FIG. 2) also extends through the base of the cup 34. The conductor 28 and seal 32 and the conductors (not shown) for measurement are potted in an epoxy or silicone-rubber resin 44. The Container also includes a top cover 31, typically of stainless steel. The cover has a central bar 33 from which rib supports 35 extend. A raising eye 37 may be secured to the cover. The cover 31 is sealed vacuum-tight to the wall 23.

A tube 39 (FIG. 3) for evacuating the Container extends from the cover 31 in communication with the interior of the Container. After the Container is evacuated, this tube 39 is pinched off and sealed in a flanged shell 41 secured to the cover 31 potted in epoxy resin or a silicone-rubber compound 43.

The Container includes a base 51 of DURANEL structure which is welded pressure tight to the wall 23. The base 51 carries a plurality of shock-mount supports 53 for the mechanical assembly including the Source, Radioactivity Shield and Thermoelectric Converter. There are as many supports 53 as there are modules 21 and each serves both for shock mount purposes and in addition to transfer the heat from the heat removal shoe 54 of the module 21.

Each shock-mount support 53 includes a block 55 secured to the aluminum lining 57 of the base and a floating L-shaped plate 59. A stack 61 of rippled straps of copper or like good thermal conductor extend between plate 59 and block 55 and

are secured to block 55 by clamping plates 63, on one side, and to the plate 59 on the opposite side (FIG. 3). The L-plate 59 of each support 53 is urged into engagement with the associated shoe 54 by springs 65 which rest in holes 67 in the lining 57 and extend around the heads of bolts 69 secured in shoe 54 and extending loosely through the plate 59.

A composite connector 71 (FIG. 3) is secured to the base 51. This connector serves to transmit the output of the Thermoelectric Converter to the output conductor 28. This connector included a pair of insulating plates 73 and 75 (typically of boron nitride). These plates are secured to the base 51. The upper plate 75 has countersunk holes. The conducting terminals 77 and 79, to which are connected the output conductors 81 (FIG. 2) from the output module 21 and the conductors 83 to the conductor 28, are held by screws 85 which pass through these holes. These screws 85 are insulated by plate 73 from the conductor below. A grounding lug 87 (FIG. 2) is also secured in good electrical contact with the base 51 and the ground conductors from the converter are secured in this lug.

The Heat Source is a heat capsule 91 having a radioactive fuel block or cylinder 93, typically of strontium oxide in which the strontium is strontium 90 and which is radioactive. The cylinder 93 is enclosed in a shell 95 of a corrosion and high temperature resistant material which does not react with the SrO, typically HASTELLOY-X. The shell 95 is enclosed in a shell 97 of an oxidation and high temperature resistant material, typically HASTELLOY-C. HASTELLOY-X and C are nickel alloys are disclosed respectively in Stellite leaflets F-30,037D of Oct. 1964 and F-30,107C of June 1963 issued by Union-Carbide Stellite Company of Kokomo, Ind. These leaflets can be obtained from Stellite and are incorporated herein by reference. A stud 99 for raising the capsule 91 extends from shell 97.

The Radioactivity Shield includes a cylinder 101 of material which absorbs gamma rays. Typically the cylinder 101 may be composed of an alloy of 97.6 percent tungsten and 2.4 percent nickel and copper, KENNERTIUM W-2 alloy. KENNERTIUM W-2 alloy is described in leaflet L-502 which may be obtained from Kennametal Inc. of Latrobe, Pa., and is incorporated herein by reference.

The cylinder 101 has a cylindrical cavity for the fuel capsule 91. The capsule 91 is inserted through an opening in the cylinder 101 which is then closed by a plug 103. The cavity is dimensioned to allow for expansion of the fuel capsule as it is heated. Typically an SrO fuel capsule 91 may have a diameter of 2.193 inches; for this capsule 0.040 inch inches should be allowed for expansion.

A pair of supporting rings 105 are bolted on the outer surface of the cylinder 101. These rings 105 should be of a material which has high strength, low weight, and low thermal conductivity and typically are composed of a titanium alloy including 6 percent aluminum and 4 percent vanadium. (See page 163 of Mid-October 1963 issue of Materials in Design Engineering). Each ring 105 has a plurality of counterbored holes 107 through which supporting rods 109 for the cylinder 101 extend. The rods 109 are of a high-tensile strength low thermal conductivity material typically such as INCONEL-X alloy. INCONEL alloy is a nickel-chromium alloy described in International Nickel Company leaflet entitled Handbook of Huntington Alloys, Third Edition, Copyright Jan. 1965, incorporated herein by reference. The rods 109 are movable in the holes 107 but are swaged at the ends 111 so that they are retained.

At its base the cylinder 101 is brazed to saddle 115 of copper. The brazing between the KENNERTIUM W-2 alloy and the copper may be effected by a copper-silver (B-T; Cu-72 Ag-28) brazing compound but where the brazing may be carried out in a vacuum a more satisfactory joint is produced by interposing a shim (0.002 inch) of titanium between the cylinder 101 and the saddle 115 and heating to 950° C.

The modules 21 are urged into engagement with the bottom of the saddle 115 by the springs 65. The heat transfer plates 117 of the modules engage the saddle 115 under pressure. The

plates 117 are composed of HASTELLOY-C alloy and are copper plated. Under pressure the plating is diffusion bonded to the saddle 115.

The Heat Shield includes a shell 121. Within the shell 121 there is a truncated stack of heat-reflecting cylindrical sheets. The internal sheets 123, 125 are composed of an oxygen reactive material such as titanium and the external sheets 125 of a material such as aluminum. Typically there are about 75 titanium sheets 123 and 25 aluminum sheets 125. The Heat Shield also includes a cover 126 under which there is a truncated stack of heat reflecting discs 127 and 129; there being about 75 inner discs 127 of titanium and 25 outer discs of aluminum 129. The sheets 123 and 125 and 127 and 129 miter. The lower end of the stack of cylindrical sheets 123-125 miters with a truncated stack of discs 131 and 133 of titanium and aluminum; the discs 131-133 have holes for the modules 21 within which the modules are movable. The discs 131-133 rest on a shoulder 135 of the aluminum lining of the base 151. The titanium sheets 123, 127 and 131 serve not only for heat shielding but also to getter the vacuum within the Container and it also attenuates the gamma rays from the Heat Source. The shell 121 and cover 126 are composed of the Ti-90 Al-60 Va-4 alloy. The stacks 127-129 and 131-133 have holes through which the rods 109 pass.

The Support includes a plurality of generally U-shaped brackets 141 (FIG. 2) flared at their ends. The flared ends are welded along the shell 121 of the Heat Shield. The brackets 141 are bolted to the wall 23 of the Container. At their lower ends the brackets 141 engage the shoulder 135. When the cover 31 is sealed to the wall 23 the upper edges of the brackets 141 are also held by the cover.

Anchors 143 for the rods 109 are welded within each of the brackets 141 near their ends. Each anchor 143 (FIG. 3) has a removable plug 145 through which the rods 109 are inserted. The rods 109 pass through threaded boltheads 147. The ends 149 of the rods 109 are swaged so as to be held in the boltheads 147. The plugs 145 are bolted in place and then nuts 151 are screwed onto the boltheads with Belleville springs 153 interposed between the nuts 151 and the anchors 143. The Radioactivity Shield is thus firmly but resiliently held in place.

The Thermoelectric Converter (FIGS. 4 through 8) includes a plurality of modules 21. Each module 21 is sealed in a cylindrical enclosure having wall 171, heat-transfer shoe 117 and heat-rejection shoe 54. Wall 171 and shoes 117 and 54 are composed of HASTELLOY-C.

Each container contains a plurality of negatively and positively doped solid-state thermoelectric cylinders 173 and 175. The cylinders 173 and 175 are labeled N and P in FIGS. 5 and 6. Typically the cylinders 173 and 175 are composed of lead-telluride. The lead-telluride would deteriorate in a vacuum and to avoid deterioration the container is filled with an inert gas typically highly pure 0.0001 percent argon. In the cold state of the container the argon is at about one-third atmosphere but during use when the module is heated the pressure rises to about one atmosphere. For filling with argon the heat-transfer shoe 117 is provided with an opening 177. Terminals 179 and 180 for the potential developed in the module 21 are sealed through the heat-rejection shoe 54.

Thermal connection from the shoe 117 to the hot-junction ends of the cylinders 173 and 175 is effected through iron disc 181, copper straps 183 (FIG. 4) and 184 (FIG. 5), copper disc 185, insulating disc 187, typically of LUCALOX insulator (alumina), and copper disc 189. Disc 189 is brazed to shoe 117, disc 187 to 189, disc 185 to 187, straps 183 and 184 to disc 185, and disc 181 to 183. The brazing is effected by copper-titanium brazing alloy at about 878° C. Disc 181 engages the cylinders 173 and 175 mechanically.

On the heat-rejection or cold junction side the heat and electrical power is transferred through bellows 191 of copper which are soldered by 40 lead-60 tin solder to the cylinders 173 and 175 and to copper connecting straps 193, 195, 197 and 198 having slots 199. To prevent the lead from the solder from diffusing into the cylinder 173 and 175 a thin diffusion

barrier is painted on the end of the cylinders. The heat is transferred from the straps 193, 195, 197 and 198 through copper discs 200 and 201 and insulating disc 203, typically of LUCALOX insulator, to the shoes 54. From each shoe the heat flows through the associated shock absorber 53 to the wall 23 and fins 27 of the Container. The straps 193, 195, 197 and 198 are brazed to the disc 200 by copper-silver brazing alloy, the discs 200 and 201 to the insulator disc 203 by copper-titanium alloy and the disc 201 to the shoe 54 by copper-silver brazing alloy. The copper-titanium has a eutectic temperature of 878° C. and the copper-silver 779° C.

Within each slot 199 there is a volute spring 211 which is compressed between the base of the opening and the underside of a floating stud 213 and exerts a substantially constant pressure on the cylinders 173 and 175 compressing these cylinders. During assembly the stud 213 is held by a wire which passes through a slot 215 in the straps 193, 195, 197 and 198 and a hole (not shown) in the stud 213.

Each of the cylinders 173 and 175 is encircled by ring insulators 221 typically of boron nitride. A heat shield consisting of a stack 223 of titanium sheets is mounted around the cylinders 173 and 175. The sheets have cross-grooves 225 and 227 (FIGS. 7 and 8) and the heat path between the sheets is restricted to the point contacts 229 between the grooves. Short circuit of the sheets 223 to the straps 183 or bellows 191 is prevented by insulator rings 230 and 232 typically of boron nitride.

The cylinders 173 and 175 are connected in parallel redundancy by the straps 183 and 184 and 193, 195, 197, and 198. A current path through a module is as follows: Terminal 179 to the positive cylinder 175 connected by strap 198, through these cylinders to negative cylinders 173 through strap 184, through conductor 231 to positive cylinders 175 connected by strap 195, through these latter cylinders to the negative cylinders 173 through strap 183 to terminal 180. The terminals 179 and 180 are connected through connecting lugs 251 and wires 253 so as to connect the thermoelectric elements of the modules 21 in series.

In the assembly of the apparatus the container of each module 121 is formed by welding the shoes 117 and 54 to the wall 171 by electron beam welding. The apparatus is then assembled in the Container and the container is evacuated through tube 39 and then back filled with high purity argon (0.0001 percent) at appropriate pressure, typically one-third atmosphere. The argon flows into the container 117, 171, 54 through opening 177. Opening 177 is then sealed off by tungsten-arc fusion welding. The container is then evacuated and tube 39 sealed off.

While a preferred embodiment of this invention has been disclosed herein many modifications thereof are feasible. This invention then is not to be restricted except insofar as is necessitated by the spirit of the prior art.

I claim:

1. A thermoelectric generator including a first container which is evacuated and includes therein at least one thermoelectric module having a second container which is gastight and has therein an inert-gas atmosphere at substantial pressure, said module including in said second container a plurality of opposite polarity thermoelectric elements electrically connected to form a hot junction and a cold junction for said module, said module also having a heat-transfer conductor thermally connected to said hot junction and a heat-removal conductor thermally connected to said cold junction, said first container also including therein a radioactive heat source and a radioactivity shield for said source, said shield being in thermal interchange relationship with said source and with said heat transfer conductor.

2. The generator of claim 1 wherein the module, the source, and the radioactivity shield are enclosed [in an evacuated container] in a radiation-reflecting heat shield of a gettering material which is in the first container.

3. The generator of claim 2, including a heat shield that provides the dual function of gettering, as well as providing low

thermal losses (high insulating capability) and also provides gamma-energy attenuation biological shield protection.

4. A thermoelectric generator including at least one thermoelectric module having a plurality of opposite-polarity thermoelectric elements electrically connected to form a hot junction and a cold junction for said module and said module also having a heat-transfer conductor thermally connected to said cold junction, a radioactive heat source, and a radioactivity shield for said source, a heat sink, and means for resiliently supporting said module, said supporting means including means for resiliently urging said heat transfer conductor into heat transfer engagement with said shield so that said source is in heat transfer relationship between said source and module; and said supporting means also including shock-mount means for suspending said module from said container, said shock-mount means interconnecting said heat-removal conductor and said heat sink and providing a highly thermally conducting path between said heat-removal conductor and said heat sink.

5. A thermoelectric generator including a container, a radioactive heat source and a radioactivity shield for said source in heat deriving relationship with said source, a spider of tensioned connectors anchored to the walls of said container and connected to said shield for supporting said source and shield from said walls of said container in low thermal transfer relationship, at least one thermoelectric module having a plurality of opposite polarity thermoelectric elements electrically connected to form a hot junction and a cold junction, and a heat-transfer conductor thermally connected to said hot junction, and a heat-removal conductor thermally connected to said cold junction, and means connecting said shield in heat transfer relationship with said heat-transfer conductor.

6. A module for a thermoelectric generator including a plurality of opposite-polarity thermoelectric elements connected to form a hot and cold junction, a stack of sheets of heat shielding material encircling said elements, the said sheets being ridged and the successive sheets of the stack being engaged only at the intersection points of the ridges to minimize thermal conduction loss between sheets, and thermally and electrically insulating means interposed between said sheets and said elements.

7. A module for a thermoelectric generator including a plurality of opposite-polarity thermoelectric elements connected to form a hot and a cold junction, and a stack of sheets of heat shielding material encircling said elements, the said sheets being ridged and the successive sheets of the stack being engaged only at the intersection points of the ridges to minimize thermal conduction loss between sheets.

8. A thermoelectric generator including an evacuated container, a heat source in said container, a thermoelectric converter in said container, means connecting said connector to said source in heat-to-electricity converting relationship, and a heat reflecting shield enclosing said source and converter in source-to-converter heat-concentrating relationship, said shield including a stack of sheets, said stack including a plurality of sheets of one material nearer said source and a plurality of sheets of another material more remote from said source, the sheets nearer said source being composed of a gettering heat-reflective material and the sheets more remote from said source being composed of heat-reflecting material.

9. The generator of claim 8 wherein the sheets nearer said source are composed substantially of titanium and the sheets more remote from said source are composed substantially of aluminum.

10. A thermoelectric generator including a first container which is evacuated and includes therein at least one thermoelectric module having a second container which is gastight and has therein an inert-gas atmosphere at substantial pressure, said module including in said second container a plurality of opposite-polarity thermoelectric elements electrically connected to form a hot junction and a cold junction for said module, said module also having a heat-transfer conductor thermally connected to said hot junction and a heat-removal

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conductor thermally connected to said cold junction, said first container also including therein a radioactive heat source and a radioactivity shield for said source, said shield being in thermal interchange relationship with said source and with said heat-transfer conductor, and a radiation-reflecting heat shield in said first container for reflecting the heat radiation from

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said source toward said heat-transfer conductor, said heat shield including a stack of sheets said stack including sheets substantially of titanium nearer said source and sheets substantially of aluminum more remote from said source.

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