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DesChamps et al.

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[45] **Apr. 17, 1973**

[54] **RADIOISOTOPE MEANS**

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[21] Appl. No.: **753,344**

[52] **U.S. Cl.** .....**136/202,** 136/208, 250/106 S

[51] **Int. Cl.**.....**G21h 1/10**

[58] **Field of Search**.....136/202, 205, 208; 250/106 S

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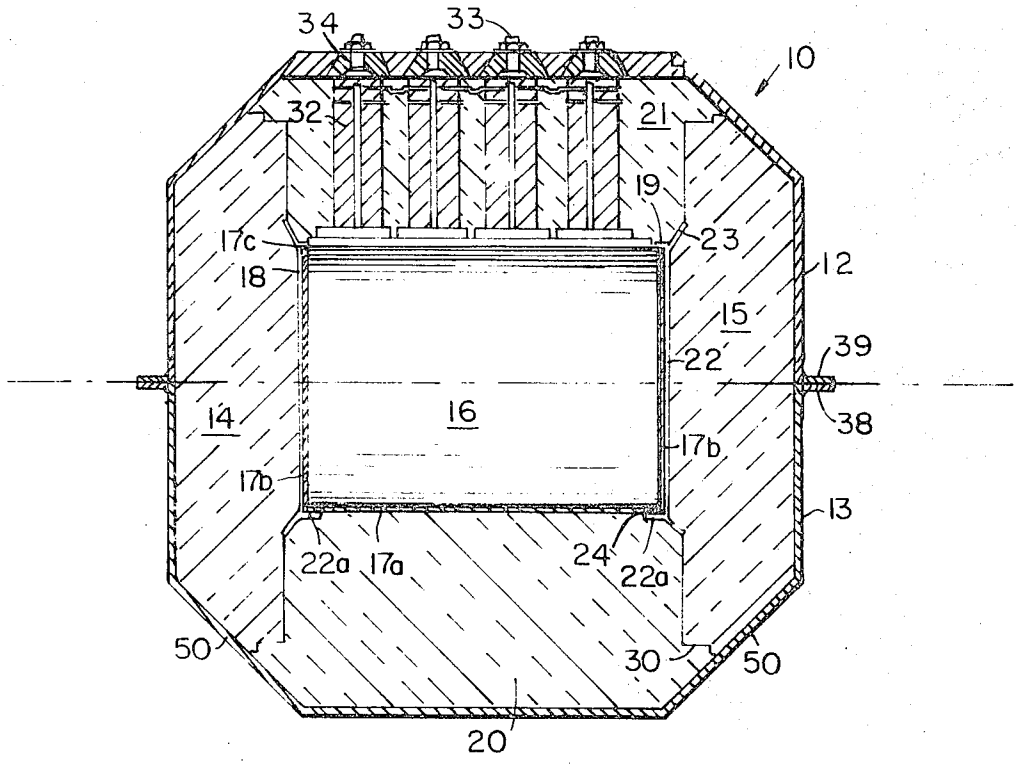
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[57] **ABSTRACT**

A radioisotope support structure has a fuel capsule defining a first and a second end preferably with a foil insulation surrounding the capsule and first and second insulating end sections adjacent the first and second capsule ends respectively. Means urge the end sections toward toe capsule to firmly support the capsule therebetween in fixed position with respect to the end sections. First and second end caps are interposed between the capsule and the first and second end sections respectively to distribute a pressure load on the end sections and preferably a two-part housing encloses the fuel capsule and insulation with sufficient space therein to mount means for utilizing heat generated by the fuel capsule. In the preferred embodiment, thermoelectric means are assembled within the housing to convert heat generated by the fuel capsule into electrical energy whereby the assembly provides an efficient low weight high wattage output generator. In some cases, the foil insulation is omitted or used as a heat sink means.

9 Claims, 10 Drawing Figures



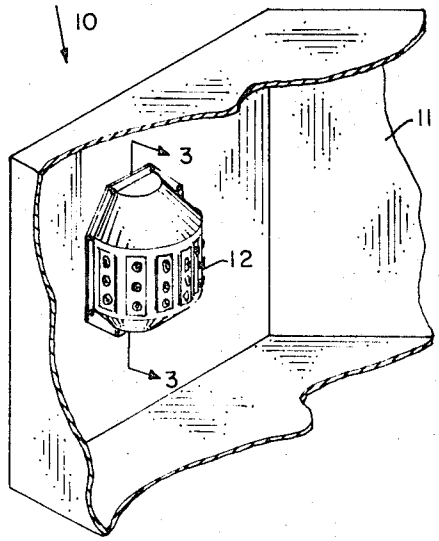


FIG. 1

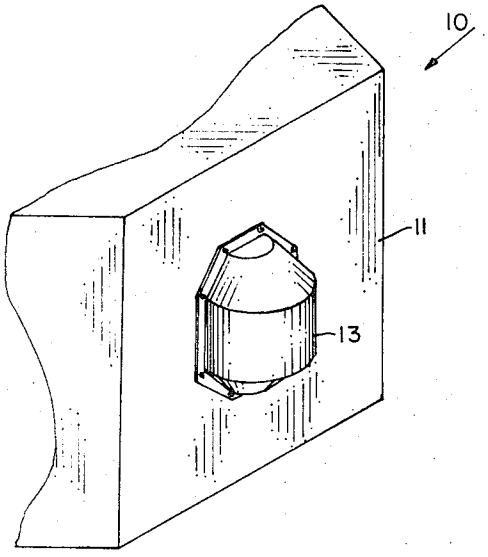


FIG. 2

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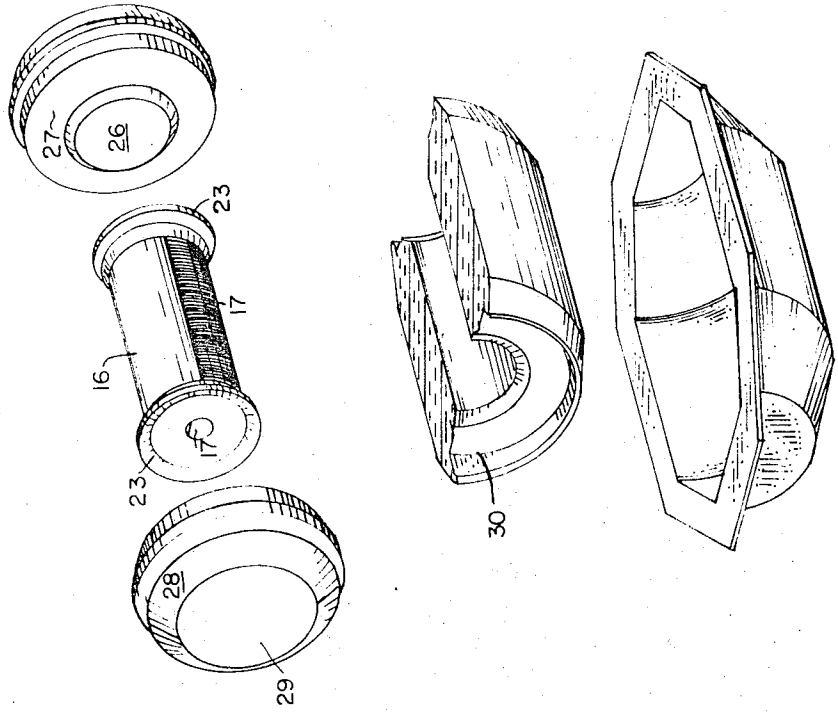


FIG. 4

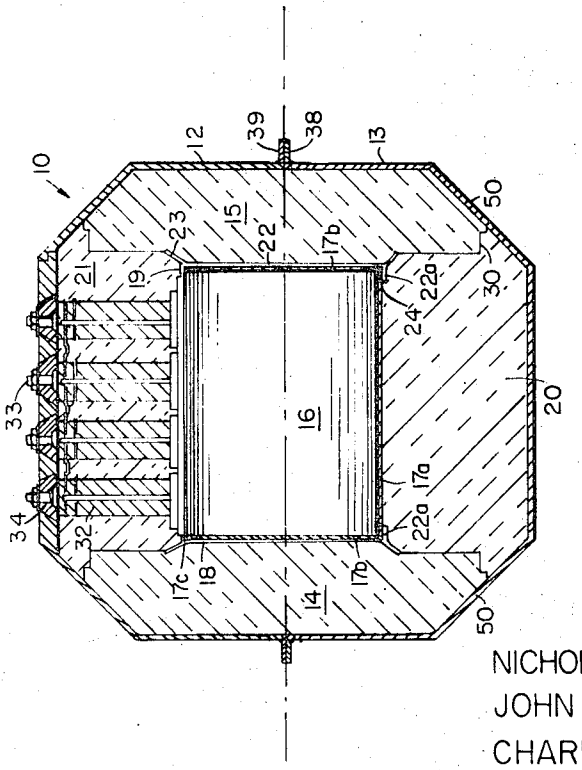


FIG. 3

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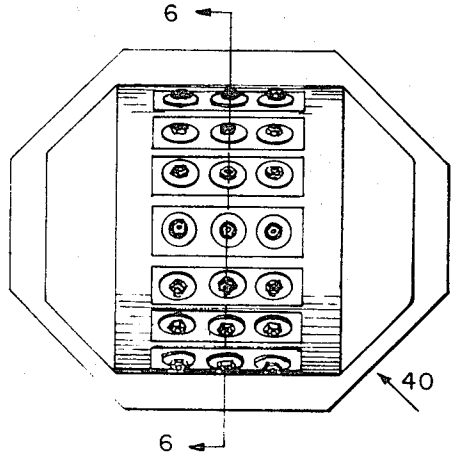


FIG. 5

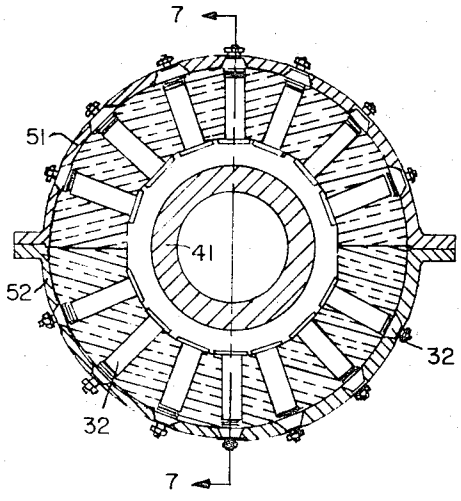


FIG. 6

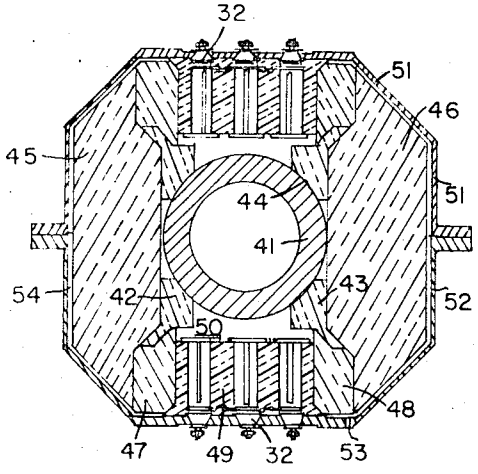


FIG. 7

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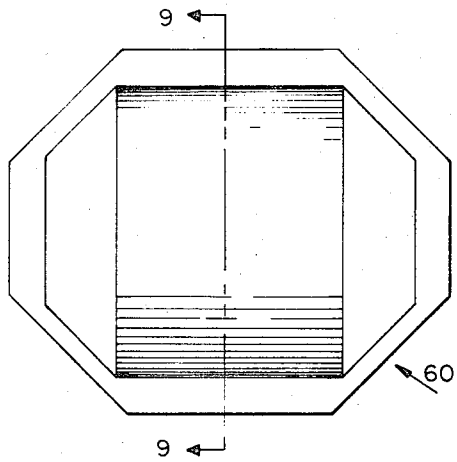


FIG. 8

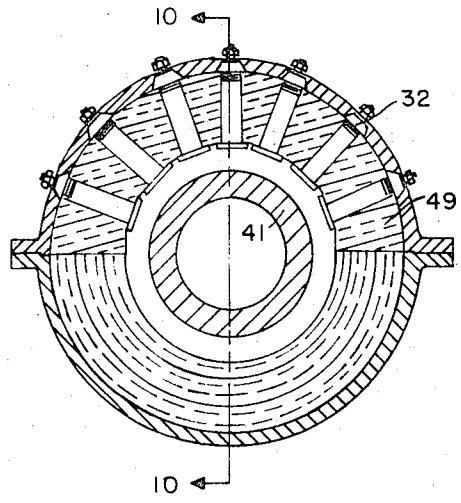


FIG. 9

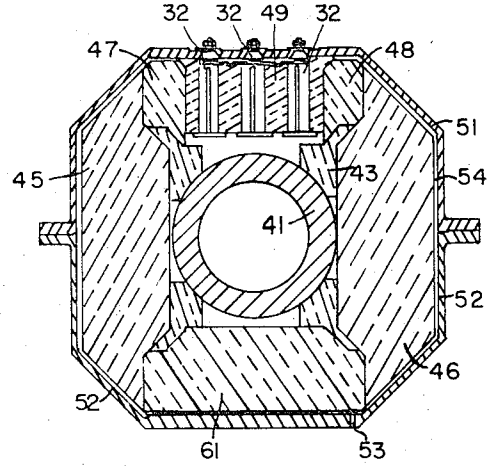


FIG. 10

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RADIOISOTOPE MEANS

BACKGROUND OF THE INVENTION

Particularly in the space satellite field there has been a need for radioisotope fuel support structures of low weight, small size and high reliability. For example, support structures for thermoelectric generator devices are needed which permit high power output at low weight for long periods of time and which are reliable in changing environmental conditions during space flight.

SUMMARY OF THE INVENTION

According to the invention, a radioisotope support structure comprises a radioisotope fuel capsule defining a first end and a second end with first and second insulating end sections adjacent the first and second capsule ends respectively. Means are provided for urging the end sections toward the capsule to firmly support the capsule therebetween in fixed position with respect to the end sections. Preferably a foil insulation partially surrounds the capsule and is held in place by first and second end caps interposed between the capsule and end sections to distribute a pressure load on the end sections. The means for urging the end sections toward the capsule preferably comprise a surrounding housing into which is incorporated means for utilizing heat generated by the radioisotope fuel capsule. In the preferred embodiment, the means for utilizing the heat comprises a thermoelectric means for converting heat energy to electrical energy as an electric generator.

In some embodiments, the foil insulation is omitted or arranged as a heat sink means.

Thermoelectric generators constructed in accordance with the present invention have high power outputs for low structural weight. Preferably the housing is made in two halves in a thermoelectric generator construction allowing the thermoelectric section to be shipped and installed in a space satellite or other environment while the fuel half can be shipped and/or assembled later to form an enclosing integral support structure.

High reliability and quality of structures are obtained in accordance with the present invention. The structures are highly resistant to shock and vibration and they have high power to weight ratios often at least as high as 2 watts electrical per pound of generator. The structures can be easily integrated into spacecraft. The two-part construction allows non-nuclear testing of flight generators. Semi-structural, medium to high temperature insulating material can be used with high temperature fuel capsules.

BRIEF DESCRIPTION OF THE DRAWINGS

The above and other features and advantages of the present invention will be better understood from the following specification when read in conjunction with the accompanying drawings in which:

FIG. 1 is a front view of a preferred embodiment of a thermoelectric generator of the present invention mounted on a space satellite;

FIG. 2 is a rear view thereof;

FIG. 3 is a cross sectional view thereof taken through line 3—3 of FIG. 1;

FIG. 4 is an exploded view of portions thereof;

FIG. 5 is a front view of an alternate embodiment of a thermoelectric generator in accordance with this invention;

FIG. 6 is a cross sectional view thereof through line 6—6 of FIG. 5;

FIG. 7 is a cross sectional view thereof through line 7—7 of FIG. 6;

FIG. 8 is a front view of another alternate embodiment of a thermoelectric generator in accordance with this invention;

FIG. 9 is a cross sectional view thereof through line 9—9 of FIG. 8; and

FIG. 10 is a cross sectional view thereof through line 10—10 of FIG. 9.

DESCRIPTION OF PREFERRED EMBODIMENTS

With reference now to the drawings, a preferred embodiment of the present invention is illustrated in FIGS. 1–4 at 10 attached to a portion of a space vehicle 11. The support structure for the thermoelectric generator comprises a housing having two quasi cylindrical metal, mating, shell halves 12 and 13 within which are placed insulating first and second end sections 14 and 15 with a fuel capsule 16 interposed between the end sections 14 and 15. The fuel capsule 16 is partially surrounded by a super insulation heat barrier 17 and is preferably maintained in position along with the heat barrier by first and second end caps 18 and 19. A semicylindrical flank section of thermal insulating material 20 fills the lower half of the housing as best seen in FIG. 3 while thermoelectric means 32 are operatively associated with the fuel capsule in the upper half of the housing.

The radioisotope containing fuel capsule 16 is preferably a right angle cylinder. Radioisotopic material which is preferably plutonium dioxide (PU–238), is contained within the capsule to act as a fuel supply and provide thermal energy. The casing of the capsule can be any high temperature refractory metal having high structural strength and resistant to temperatures in the order of at least 2000° F normally generated by the radioactive fuel material. Metal such as Hastelloy, Haynes 25 or other steel alloys known in the art can be employed as a metal of the fuel capsule. While a right angle cylinder form is used in connection with a preferred embodiment, the fuel capsule can have other forms with corresponding modification in the support structure such as a spherical fuel capsule which will be described in an alternate embodiment of the invention. It should be understood that various radioactive fuel materials can be used within the capsule depending upon the specific application and heat generation required over a predetermined lifetime.

The super insulation barrier partially surrounding the fuel capsule is a vacuum reflective radiation thermal insulation and is preferably formed of a multifoil thermal insulating layer well-known in the art for preventing heat transfer by radiation. Preferably the super insulation barrier has a thermal transfer coefficient of less than 0.004 B.T.U. per hr. ° F ft. at a vacuum of 10^{-3} torr or less and reduces radiation and conduction heat transfer. The multifoil insulation layer comprises alternate layers of a highly reflective metal such as stainless steel or refractory metals such as tungsten, molybdenum, columbium or tantalum interspersed with heat insulating materials preferably having an over-all mul-

tifoil thickness no greater than about one-eighth inch. In the preferred embodiment, ten stainless steel foil sheets each having a thickness of about 0.001 inch are used in the barrier **17**. The multifoil barrier **17** has little or no structural rigidity but is formed as a half cylinder **17***a* directly about the cylindrical portion of the capsule and in addition as two end discs **17***b* as best seen in FIGS. **3** and **4**. The use of the thin super insulation is important to reduce heat flow from the capsule. The capsule can thus be structurally supported in fixed position by thermal insulating material of the end sections which could not ordinarily be used adjacent the fuel capsule because of the high temperature of the capsule which might tend to degrade such thermal insulating material.

A semicylindrical air gap **17***c* spaces the upper portion of the fuel capsule **16** from the thermoelectric means. The gap typically spaces the thermoelectric means from the surface of the fuel capsule by about 0.2 inch and is automatically evacuated through an exhaust port not shown when the device **10** is operated in a vacuum.

End caps **18** and **19** are preferably made of a high temperature resistant structurally strong material such as refractory metals or graphite. The material must maintain its structural strength at the operating temperature of the fuel capsule often above 2000° F. The end caps act to attach the capsule to the insulating end sections **14** and **15** which compress the capsule therebetween to support it in fixed position.

The end caps **18** and **19** are preferably identical and each comprises a circular rim portion **22** having a hollow center with a truncated-conical-shaped continuous flange **23** adapted to receive a similar shaped portion of the end section adjacent it. A circular indentation **24**, best seen in FIG. **3** is formed by rim portion **22** and rim portion **22***a* and receives the fuel capsule **16** with its surrounding foil insulation to maintain the capsule in fixed position.

The insulating end sections **14** and **15** are preferably identical and are generally disc-shaped as best seen in FIG. **4**. Each end section has an inner raised boss **26** with a frustro-conical portion **27** adapted to mate with the frustro-conical flange **23** of an end cap. Thus, when the end sections **14** and **15** are urged toward the fuel capsule to maintain it in position, the resulting pressure is distributed over the end sections by the flanges **23** and corresponding frustro-conical portions **27**. The angle of contact between the end caps flanges **23** and the end sections distributes the weight of the fuel capsule substantially throughout the bulk of the insulating end sections. A second frustro-conical portion **28** which has a flat outer section **29** on the outside of each end section is designed to fit within the housing. Circumferentially continuous stepped portions **30** are provided to interconnect with similar stepped portions **30***a* of the semicylindrical insulating body **20** as best seen in FIGS. **3** and **4**.

The material of the end sections **14** and **15** and semicylindrical body **20** can be any medium to high operating temperature thermal insulating material such as Min-K, a Johns Mansville product containing inorganic fibers bound together by inorganic materials such as silica, asbestos and magnesium oxide. Other semistructural insulating materials such as Dyna quartz or ceramics can be used. It is important that the end sections provide for compression of the fuel capsule therebetween to fix the capsule in position within the housing. The housing when assembled acts as a means for compressing the end caps and end sections toward the fuel capsule.

The upper or thermoelectric means carrying portion of the housing is best seen in FIG. **3** and carries a plurality of pencil rod-shaped thermocouples **32** which are attached to the housing by means of bolts **33** passing through apertures **34** provided in the housing. Preferably the rods extend to a fixed position at a predetermined distance from the fuel capsule; thus there is constant spacing of the rods which enables predetermination of the amount of heat energy reaching ends of the rods. Preferably the thermocouples are radially aligned in rows with respect to a central axis passing through the capsule, end caps, end sections and housing. The thermocouples are interconnected by electrical wiring (not shown) which can pass out of the housing through the insulating material wherever desired. In between the thermocouples **32** there is placed insulating material **21** which can be in the form of fibers, powder or refractory insulating material which may be for example Dyna quartz or can be of the same material as the end sections. Thus, the entire inside of the housing is completely filled with the elements previously recited preferably with only the small air gap **17***c* being present. However, in some cases a portion of the housing can have parts of the insulation eliminated yet operate a high efficiency particularly in space vehicles where vacuum conditions are encountered.

The housing halves **12** and **13** are preferably identically shaped and designed with the configuration shown in the drawings, herein called "quasi cylinders," to permit ease of assembly and position holding of all members of the thermoelectric generator shown in embodiment **10**. Preferably continuous outwardly extending, peripheral, mating flanges **38** and **39** of each shell half **13** and **12** respectively, are welded or bolted together to form a completed unit. The flanges **38** and **39** act as mounting flanges for mounting the thermoelectric generator **10** to the wall of a spacecraft or mounting wall. The truncated conical portions **50** and **51** at each end of the housing mate with the end sections to urge them toward each other.

The material of the housing is any high mechanical strength material such as a metal. Preferably the metal is structurally strong and highly resistant to damage by heat although the temperature at the outside of the housing is low because of the insulating material contained within the housing.

In assembling the apparatus of this invention, it is possible to assemble the shell half **12** with the thermoelectric means and its insulation. The half **12** can then be attached directly to a wall of a spacecraft. Testing of the thermoelectric means can be carried out by placement of electrical heaters in the position corresponding to the position of the radioactive fuel capsule. At a later time, the fuel capsule, foil insulation, end caps and end sections are assembled and placed within the shell half **13** along with insulation **20**. All of the component elements are preferably designed to substantially completely fill the housing formed by the

shell halves 12 and 13 as best seen in FIG. 3. The second half of the housing and its associated fuel capsule and insulation can be assembled with the thermoelectric means carrying half of the housing at the site of a spacecraft just prior to launching merely by positioning the flanges 38 and 39 in juxtaposition and welding, bolting or otherwise attaching the housing halves together. Of course, the entire housing with its internal support structure and thermoelectric means can be assembled first and later positioned in use on a space vehicle.

In a specific embodiment of this invention, the fuel capsule 16 contains Pu238 in the form of plutonium dioxide and in an amount of 1.68 pounds. The fuel capsule has a diameter of 1.86 inch and a length of 2.50 inch. End caps 18 and 19 are formed of graphite and contain a fuel capsule in the position shown in FIG. 3 with 0.080 inch thick for multifoil insulation 17 therearound. End caps 18 and 19 have an outer diameter at the tips of sections 23 of 2.75 inches. End sections 14 and 15 as well as section 20 are formed of Min-K 2000 insulating material with the housing made of Aluminum, and having a maximum axial length of 6.25 inch, a maximum height of 6.50 inch and a maximum width of 6.0 inch. Silicon germanium thermocouples 32 are used extending into the housing and spaced 0.20 inch from the fuel capsule with five rows of thermocouples employed with four in each row. The thermocouples are of the Fleximod construction (manufactured by Radio Corporation of America). The total weight of the upper housing assembly with the thermocouples and Micro-Quartz insulation 21 is 893 grams while the weight of the lower housing is 191 grams, the insulating end sections 308 grams, the end caps 46 grams and the fuel capsule 762 grams adding up to a total weight of 2200 grams or 4.86 pounds. The thermoelectric silicon-germanium material is in the Fleximod construction with 20 couples provided. Each couple has a hot junction temperature of 950° C, a cold junction temperature of 344° C, (L/A)p of 10.8 cm−1, (L/A)n of 7.0 cm−1, L of 1 inch, r_p of 0.16 inch (semi-circular cross section), r_n 0.2 inch (semicircular cross section), hot shoe dimensions of 0.50 in. × 0.64 in. × 0.15 in., internal resistance of 423 milliohms, open circuit voltage of 7.6 volts, with instrumentation of 5 hot junction (tungsten-tungsten rhenium) and 5 cold side (chromel-alumel).

When the resultant thermoelectric generator is tested in a vacuum, it is found that over-all efficiency is at least 4.3 percent and peak power output occurs at 8.25w(e) output. The ΔT from the cold end of the thermoelectrics to the cold junction is between 25° and 30° C, resulting in a maximum cold junction temperature of 400° C. The device when subjected to shock and environmental testing has high endurance characteristics and high reliability. A 10w(e) power output level in a 2 to 3w(e)/1b thermoelectric power system is achieved.

Turning to an alternate embodiment of the invention, a thermoelectric generator 40 is shown in FIGS. 5-7 and is basically similar in construction to the embodiment 10. The basic differences in construction lie in the thermoelectric means 32 which are positioned completely about and encircle the fuel capsule, and in the shape of the fuel capsule which is spherical rather than cylindrical. In the embodiment 40, the fuel capsule 41 is identical to fuel capsule 16 except that its shape is spherical as best seen in FIGS. 6 and 7. Identical end caps 42 and 43 maintain opposing ends of the capsule 41 in position within the housing and are constructed as described with respect to end caps 18 and 19. However, due to the spherical shape of the ends of the capsule 41 held by the end caps, spherical surfaces 44 are provided rather than a cylindrical rim receiving means.

End sections 45 and 46 are identical to end sections 14 and 15 except that their shape is varied slightly to permit positioning of cylindrical insulating rings 47 and 48 filling the space between the insulating ring 49 which holds the thermoelectric means 32 with the insulating material of elements 47, 48 and 49 preferably being the same as the material of end sections 45 and 46. An air gap 50 is provided between the fuel capsule 41 and the inner ends of the substantially radially arranged thermocouples to radiation couple the thermocouples with the fuel capsule as in the embodiment 10.

The casing is formed by mating shell halves 51 and 52 which act to urge the insulating sections 45 and 46 toward each other as described in connection with the embodiment 10. A vent hole 53 is provided in the lower shell half 52 to permit evacuation of the air gap 50 when the device is operated in a vacuum. Normally there is sufficient leakage between the insulating members to insure vacuum conditions existing when the surrounding environment is evacuated as is the case in the embodiment 10.

An additional feature of the embodiment 40 includes a thin layer 54 of graphite felt or other resilient high temperature resistant material which is compressed when the elements are assembled within the shell halves 51 and 52 so as to resiliently urge the end sections 45 and 46 toward opposing ends of the spherical capsule 41. Use of the resilient means is preferred to allow for tolerances in manufacture of the elements although the resilient means can be eliminated if desired.

In this embodiment, the super insulation of radiation reflective material such as multifoil is eliminated. However, the air gap and insulating materials 47, 48, 49, 45 and 46 provide sufficient insulation for fuel capsules having lower initial temperatures than fuel capsules which may be used in the embodiment 10.

Turning now to a third embodiment of the present invention, a thermoelectric generator 60 is shown in FIG. 8 wherein identical reference numerals to the numerals used in the embodiment 40 refer to identical parts.

The embodiment 60 is basically identical to embodiment 40 except that the thermoelectric means 32 in the lower section as best seen in FIG. 9 are removed along with portions of insulating rings 47, 48 and 49 with the resulting semicylindrical space being filled with a thick layer of radiation reflective insulation. The radiation reflective insulation is preferably of the super insulation multifoil type previously described with respect to embodiment 10 and is preferably in the shape of a semicylinder denoted at 61. A portion of the inner surface of the semicylinder insulation layer 61 preferably abuts the lower portion of the fuel capsule 41 while the outer surface thereof abuts the casing shell 52. The insulation as is well-known in the art allows some heat

transfer by conduction and convection in air at ambient conditions while conduction and convection are substantially reduced if not eliminated under vacuum operating conditions. Thus, the insulation **71** acts as a heat sink in air as on the ground in a space satellite, while it acts as a good heat barrier under vacuum conditions, as when the satellite is in space. This feature is useful to vary the amount of heat provided to the thermoelectrics under different operating conditions. Thus, at ground level, when the multifoil insulation is operating in air at 14.7 p.s.i., there may be for example 700° F at the surface of the fuel capsule abutting the end sections **45** and **46** and opposite the thermoelectric means **32** since element **61** provides for removal of heat through the casing wall. However, when the surrounding environment is under vacuum conditions, conduction and convection of heat through the multifoil **61** is eliminated and it acts as a heat barrier no longer shunting heat therethrough which can, for example, result in the surface temperature of the fuel capsule adjacent end sections **45** and **46** and the thermoelectrics **32** rising to 1800° F. The heat sink property of vacuum reflective thermal insulation such as multifoil is known to vary by a factor of at least 92 from a vacuum of 10^{-3} torr as compared with operation in air under environmental conditions of 14.7 p.s.i.

The specific amount of multifoil or other vacuum reflective insulation used in the position shown in FIG. **10** can vary depending upon the value of the heat sink required for any particular application. This varation can be in thickness or area adjacent the fuel capsule or both.

While specific embodiments of this invention have been shown and described, it should be understood that many modifications thereof are possible. For example, the shape of the fuel capsule can vary although it is always preferred to use insulating means to compress the fuel capsule in order to maintain it in fixed position with respect to the insulating means and the thermoelectric material. In some cases, the support structure and fuel capsule can be used with other than thermoelectric means so as to provide a desired heat output. The specific outer shape of the insulating end sections can vary as can the particular shape of the end caps although truncated conical flared sections are preferred in order to maximize structural rigidity. Various features of any one of the three embodiments described can be used interchangeable. For example, the embodiment **10** can be designed to carry a spherical fuel capsule while a cylindrical fuel capsule can be incorporated in the embodiments **40** or **60**.

In view of the many modifications possible, this invention is to be limited only by the spirit and scope of the appended claims.

What is claimed is:

1. A radioisotope thermoelectric generator comprising

a radioisotope fuel capsule defining a first end and a second end,

first and second insulating end sections adjacent said first and second capsule ends respectively, each end section having an inwardly flared frustro-conical portion,

first and second high temperature resistant, structural strong end caps interposed between said capsule ends and end sections, and in contact with said capsule ends and end sections said end caps each having a capsule receiving portion on one side thereof and an outwardly flared frustro-conical portion in mating engagement with said inwardly flared frustro-conical portion of one of said end sections,

a multifoil vacuum reflective super insulation partially surrounding said fuel capsule and supported by said end caps,

housing means for urging said end sections toward said capsule to firmly support said capsule therebetween in fixed position with respect to said end section, and

a thermoelectric means adjacent said fuel capsule for converting heat from said capsule to electricity, said thermoelectric means being connected to said urging means, said urging means maintaining said thermoelectric means a predetermined distance from said fuel capsule.

2. A radioisotope thermoelectric generator in accordance with claim **1** wherein said means comprises a housing.

3. A radioisotope thermoelectric generator in accordance with claim **2** wherein said capsule is in the form of a cylinder,

said housing comprising a first half and a second half with said end sections lying partially in both halves,

said thermoelectric means being supported in fixed position in said housing between said end sections.

4. A radioisotope thermoelectric generator in accordance with claim **3** wherein said end caps, said capsule and said housing are all axially aligned.

5. A radioisotope thermoelectric generator in accordance with claim **3** wherein said fuel capsule contains a heat producing radioisotope material.

6. A radioisotope support structure in accordance with claim **2** wherein said housing comprises two mating shell halves with said thermoelectric means being mounted wholly within one of said shell halves whereby said one shell half and its associated thermoelectric means can be separately fabricated and tested.

7. A radioactive isotope support structure in accordance with claim **3** wherein said first and second housing halves each define mating outwardly extending peripheral flanges for attachment of said shell halves into an integral housing.

8. A radioisotope support structure in accordance with claim **7** wherein said end sections and said housing each define frustro-conical portions for positioning said end sections, end caps and fuel capsule within said housing.

9. A radioisotope thermoelectric generator in accordance with claim **1**,

said thermoelectric means being spaced from said fuel capsule by a gap.

* * * * *