SN: 578,118 (87)
FD. 9-06-1990

W-7405-ENG-48

Carl E. Walter
Richard Van Konynenburg
James H. VanSant

THULIUM-170 HEAT SOURCE

578,118

THULIUM-170 HEAT SOURCE

By

Carl E. Walter   USA
627 Rowell Lane
Pleasanton, CA   94566

Richard Van Konynenburg   USA
444 Ontario Drive
Livermore, CA   94550

James H. VanSant   USA
25957 Tesla Court
Tracy, CA   95376

MASTER

DISCLAIMER

THULIUM-170 HEAT SOURCE

BACKGROUND OF THE INVENTION

Field of the Invention

The invention relates to a neutron activated heat source, in particular, an isotopic heat source using the isotope thulium-170.

Description of Related Art

Isotopic heat sources use the release of energy from a radioactive isotope. The isotope is created either as a result of fission or by irradiating a target material with neutrons in a nuclear reactor. In neutron irradiation, the target atomic nuclei capture irradiating

neutrons and are converted into a neutron activated
isotope. The target material is chosen to provide the
energy release rate and decay characteristics of interest
in the activated target. This energy release can be

5   absorbed as heat and exploited for many uses, such as for
a power conversion system.

Typically, reactor target materials are formed
into thin flat disks. During irradiation, neutrons are
highly absorbed at the target surface, resulting in fewer

10   neutrons available for absorption in the center of the
target. The reduction in neutrons, called flux
depression, results in lower activation in the target
center compared to the target surface. Thin targets
provide a more efficient use of target material by

15   reducing flux depression.

Targets may contain a material that acts as a
moderator during irradiation. Neutrons that pass through
the target atoms unabsorbed can collide with moderator
atoms, slow down, and become more susceptible to capture

20   by other target nuclei. Moderators thereby increase the
efficiency of the production of the activated isotope. An
ideal amount of moderation causes the neutron energy
distribution to peak in the energy region of high
cross-section for the target material.

Isotopic heat sources are useful when combined with a power conversion system because the energy release is reliable, and the power output diminishes in a known manner as the isotope decays. The heat sources have greater energy density, by several orders of magnitude, than chemical batteries. Depending on the half-life of the isotope, the heat sources can be used for months or years, rather than having a life of hours or weeks that is typical of a chemical battery. The sources are compact and portable, which is especially useful for exploration or surveillance in remote areas such as Antarctica, in space, or underwater.

Presently, isotopic heat sources are available that use isotopes such as strontium-90, cobalt-60, and plutonium-238. These isotopes are environmentally hazardous because they are easily dispersed, and their half-lives are on the order of years.

Thulium-170 has also been considered as a fuel for heat sources. Targets with stable thulium-169 are irradiated and converted into thulium-170 (and thulium-171, etc.). Thulium-169 has a high neutron cross-section, lowering the irradiation time (and cost) needed to produce thulium-170. Thulium is advantageous as a fuel because of its refractory properties; that is, thulium is very stable at high temperatures and has a high

melting point (heat of fusion). Thulium-170 is a better heat source from an environmental standpoint because of its relatively short half-life (129 days), its chemical stability, and refractory nature.

Several isotopic heat sources using thulium-170 have been developed. The thulium fuel has been in the form of thulium hydride, thulium metal, thulium oxide, and a mixture of thulium oxide and thulium metal. The thulium fuel is usually encapsulated or encased in a material with a high melting point and low neutron cross-section. These materials are usually metals or high atomic weight (high Z) materials, such as molybdenum, tantalum, tungsten, zirconium, steel, nickel, or platinum-rhodium alloy. The casings provide containment of the target material before and after irradiation.

Using high Z material to encapsulate targets presents several problems: the heat source weight is increased, pre-fabrication of the capsules is needed, and high Z materials produce more bremsstrahlung radiation after target irradiation than low Z materials. Accordingly, a more useful heat source would comprise a refractory fuel with a short half-life and a diluent of low atomic weight (low Z) material. The low Z material would reduce the weight of the heat source. The low Z material would also produce less bremsstrahlung radiation

than a high Z material, requiring less shielding. The

reduction in shielding and source weight is advantageous

in creating portable power sources. Individual thulium

fuel parts would not be encapsulated, minimizing

5   pre-fabrication time and expense. Suitable containment

would be provided by an outer vessel containing all of the

thulium fuel parts.

SUMMARY OF THE INVENTION

The present invention provides a heat source fuel

stack that is internally moderated during irradiation and

10   requires minimal shielding due to minimal production of

bremsstrahlung radiation. The fuel stack needs little or

no post-activation handling, which saves time and prevents

prolonged radiation exposure. The invention also provides

a heat source apparatus for efficient heat removal.

15   The fuel stacks comprise an isotopic fuel and a

low atomic weight diluent. The fuel, preferably thulium

oxide, is refractory and produces an isotope during

neutron irradiation with a relatively short half-life.

The diluent is refractory and heat conductive, preferably

20   graphite. A stack of thulium oxide fuel and graphite

disks is irradiated in a reactor in a conventional manner

to form a fuel stack.

In the described embodiment, the heat source apparatus comprises heat pipes for heat removal, a heat block, holes in the heat block for inserting irradiated fuel stacks and heat pipes, a structural container,

5   insulation, and radiation shielding. The irradiated fuel stacks and heat pipes are mounted in the heat block. The heat block, preferably made of graphite, is encased in a sealed structural container that is surrounded by layers of insulation and shielding. The heat pipes extend beyond

10   the container and shielding and contain a heat pipe working fluid. The working fluid transfers heat from the heat source to a heat exchanger. A single phase gas restricts the flow of the heat pipe working fluid at an established interface.

15   The low atomic weight diluent in the fuel stack has several advantages. In the preferred embodiment, graphite dilutes the thulium oxide fuel and acts as a moderator, increasing the efficiency of thulium-170 production. Graphite and other low Z materials do not

20   produce as much bremsstrahlung radiation as high Z materials; therefore, the fuel stacks require less shielding, reducing the weight of the heat source. Graphite is also an excellent heat conductor, increasing heat removal efficiency.

In the preferred embodiment, the heat source
apparatus provides two passive mechanisms for containment
and heat dissipation in the case of source overheating.
In the first mechanism, the heat pipes are oversized in

5   length to permit passive cooling. A heat pipe working
fluid circulates in the heat pipes between the heat source
and the heat exchanger. Beyond the heat exchanger, the
heat pipe contains a single phase gas. The interface
between the working fluid and the single phase gas is

10   preferably located at the heat exchanger. If the heat
source temperature increases, the working fluid vapor
pressure increases and moves the working fluid-gas
interface away from the heat source so the heat pipes have
more surface area for cooling. As a second mechanism for

15   providing containment and cooling, the insulation layer is
designed to fail at a temperature below the failure
temperature of the inner container and its contents.

          The present invention has many potential uses.
The heat source coupled with a power conversion system

20   provides a reliable, refuelable and relatively
long-lasting power source. This type of power system
could be used for autonomous or remotely controlled
vehicles. These power sources are particularly useful for
exploration or surveillance in remote environments such as

25   space or underwater.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a schematic drawing of a heat
source in which a heat pipe extends from the heat source
to a heat exchanger and is attached to a reservoir of
single phase gas.

5   Figure 2 is a vertical cross-section of an
embodiment wherein fuel stacks are positioned next to heat
pipes, encased in the heat source apparatus.

Figure 3 is a horizontal cross-section of an
embodiment wherein cylindrical fuel stacks are arranged
10   with heat pipes in the heat source apparatus.

DESCRIPTION OF PREFERRED EMBODIMENTS

The preferred embodiment of the invention, shown
schematically in Figure 1, comprises an isotopic heat
source 10. For purposes of illustration, one fuel stack
12 is shown adjacent to one heat pipe 14 which extends
15   from the heat source 10 to a heat exchanger 16. The
heat pipe 14 contains a working fluid 18 that
transfers heat from the heat source 10 to the heat
exchanger 16. The working fluid 18 flows along an
inner surface 20 of the heat pipe 14 which comprises
20   means for capillary action. The heat pipe working fluid
18 can be restricted by the pressure of a single phase
gas 22, the source of which is a gas reservoir 24.

Figure 2 is a vertical cross-section of a preferred embodiment of the heat source **10**. **Figure 3** is another view of the embodiment shown in **Figure 2** along line 3-3. **Figure 2** illustrates a plurality of fuel stacks **12**. The fuel stacks **12** comprise a refractory fuel **26** and diluent **28**. The fuel **26** is neutron activated to form a relatively short-lived isotope that produces heat. The preferred embodiment for the fuel **26** is thulium-169 in the form of thulium oxide (Tm_2O_3). The diluent **28** is a refractory, heat conductive, and low atomic weight material. The preferred embodiment for the diluent **28** is graphite.

In the preferred embodiment, the fuel stacks **12** are formed of a plurality of thin individual layers of thulium fuel **26** and graphite **28**. The thulium layers **26** and graphite layers **28** are stacked in an alternating pattern. The fuel stacks **12** are irradiated in a conventional manner with thermal neutrons, converting thulium-169 to thulium-170 (and thulium-171, etc.).

After irradiation, one or more of the fuel stacks **12** are mounted in one or more holes **32** in a heat block **34**, preferably made of graphite. In the preferred embodiment, the fuel stacks **12** are cylindrical and fit snugly into the heat block **34**. A plurality of heat pipes **14** for heat removal are arranged in a plurality of

holes 36 in the heat block 34. In the preferred

embodiment, the heat pipes 14 are enclosed at both ends

and may be oversized in length, extending beyond the heat

exchanger 16 to provide additional heat rejection area.

5   The heat block 34 is surrounded by a sealed

structural container 38, which is surrounded by an

insulation layer 40. The heat block 34 is also

encased in at least one layer of radiation shielding

42,44, made from a suitable structural material such as

10   iron or tantalum. In the preferred embodiment, an inner

layer of the shielding 42 surrounds the insulation layer

40 and an outer layer of the shielding 44 surrounds

the inner layer of the shielding 42. Free convection

space fills the cavity 46 defined by the two layers of

15   the shielding 42,44.

Holes 48 defined by the outer layer of the

shielding 44 are located along the inside perimeter of

the outer layer of the shielding 44. The holes 48 are

present at both the top 50 and bottom 52 ends of the

20   heat source apparatus 10.

In the preferred embodiment, the neutron

activated fuel 26 is thulium in the form of thulium

oxide. However, thulium in the form of thulium hydride or

thulium carbide, as well as an altogether different

25   radionuclide, might be used.

In the preferred embodiment, the diluent 28 is graphite. Alternative embodiments for the low atomic weight diluent 28 are possible, including: zirconium hydride (hydrogen), beryllium oxide (beryllium), boron,

5 lithium, and beryllium.

Graphite is advantageous as a diluent 28 for several reasons. Graphite is highly refractory, which allows the heat source 10 to operate at high temperatures. Graphite and thulium oxide do not react

10 appreciably at high temperatures. Also, graphite is readily available and inexpensive.

Diluting thulium layers 26 with intervening graphite layers 28 may enhance the production of thulium-170 in the irradiation reactor and reduce the

15 shielding needed around the fuel stack 12. The production of thulium-170 is increased because graphite acts as a moderator during irradiation. Shielding of the fuel stack 12 is reduced because graphite, being a low atomic weight material, produces less bremsstrahlung

20 radiation than high atomic weight materials. Graphite also stops the beta particles and secondary electrons produced in radioactive decay.

In the preferred embodiment, the fuel stack 12 comprises alternating layers of fuel 26 and diluent

25 28. The layers of thulium fuel 26 and graphite

diluent 28 may be thin, flat, circular individual disks or wafers. The layers of thulium fuel 26 do not exceed one centimeter thickness in order to reduce flux depression. The thulium fuel layers 26 are placed with

5   alternating layers of diluent 28 to form the fuel stack 12. In an alternate embodiment, the thulium fuel 26 can be flame sprayed or plated on graphite disks 28. Thulium oxide powder and graphite powder could also be mixed and heated to form a sintered body.

10   After the fuel stacks 12 are irradiated, the stacks 12 may be placed directly into the heat block 34, eliminating post-activation handling. Alternatively, graphite layers 28, possibly of another thickness, may be substituted or inserted in the fuel

15   stacks 12 to further minimize bremsstrahlung radiation. Excess graphite layers 28, of course, could be removed.

The fuel stacks 12 are designed to maximize the opportunity for salvaging and recycling thulium fuel 26 and graphite diluent 28 from expended fuel stacks 12.

20   The heat source 10 is designed to permit refueling for long term use.

The heat pipes 14 provide means for heat removal. The heat pipes 14 contain a heat pipe working fluid 18, such as sodium, which is chosen according to

25   the desired heat block 34 temperature. The working

fluid 18 transfers heat from the heat source 10 to the heat exchanger 16. The heat pipes 14 are oversized in length to carry the working fluid 18 to the heat exchanger 16 and to permit passive cooling.

5   In the preferred embodiment, the working fluid 18 transfers heat by repeated cycles of vaporization and condensation. The working fluid 18 vaporizes in the region of the fuel stack 12. The vapor expands and travels through the heat pipe 14 to the heat exchanger 10   16. The vapor cools, releases heat and condenses onto an inner surface 20 of the walls of the heat pipe 14 in the region of the heat exchanger 16. The inner surface 20 has means to allow capillary action. The condensed working fluid 18 flows back to the heat source 15   10 region by the capillary action means on the inner surface 20 to begin another cycle of vaporization and condensation. This heat transfer system can operate in a zero gravity environment or in a modest gravity field in any orientation.

20   During the operation of the heat source 10 with the heat exchanger 16, the flow of the heat pipe working fluid 18 is restricted at an easily controlled interface by a single phase gas 22. The single phase gas 22, such as argon, is supplied from a sealed reservoir 24 25   attached to a heat pipe 14. The pressure of the single

phase gas **22** restricts the flow of the working fluid **18** to direct heat to the heat exchanger **16** for maximum efficiency. Therefore, if the heat block **34** overheats, the vapor pressure of the working fluid **18** increases,

5   causing displacement of the single phase gas **22**, thereby expanding the heat rejection surface of the heat pipes **14** and permitting passive cooling. Conversely, if the pressure of the single phase gas **22** is increased, the working fluid **18** is displaced and the surface area of

10   the heat pipes **14** for heat rejection is reduced (shortened).

In an alternative embodiment, the heat pipes **14** need not extend linearly, but may be designed to fold back around toward the heat source **10** to reduce space

15   requirements. Additionally, the number and arrangement of the heat pipes **14** and fuel stacks **12** are variable, depending on the power density and efficiency of heat removal required.

The structural container **38**, the insulation

20   layer **40** and the radiation shielding **42,44** may be made of a variety of materials, depending on the particular use requirements. One embodiment for the structural container **38** is an x-ray absorbing material such as tantalum. The preferred embodiment for the insulation layer **40** is a

25   material designed to fail at a high temperature that is

below the failure temperature of the structural container 38. In the case of heat block 34 overheating, the insulation layer 40 would melt away, allowing thermal radiation to occur from the structural container 38 to

5   the layer of inner shielding 42, thus providing containment and heat dissipation. Aerogel is one example of such an insulation material.

The free convection space 46 between the layers of the shielding 42,44 provides yet another opportunity

10 for passive cooling of the heat source 10 in the event of heat block 34 overheating.

The description of the invention presented above is not intended to encompass all variations of the system but has attempted to present illustrative alternatives.

15 The scope of the invention is intended to be limited only by the appended claims.

THULIUM-170 HEAT SOURCE

ABSTRACT

An isotopic heat source is formed using stacks of thin individual layers of a refractory isotopic fuel, preferably thulium oxide, alternating with layers of a low

5   atomic weight diluent, preferably graphite. The graphite serves several functions: to act as a moderator during neutron irradiation, to minimize bremsstrahlung radiation, and to facilitate heat transfer. The fuel stacks are inserted into a heat block, which is encased in a sealed,

10   insulated and shielded structural container. Heat pipes are inserted in the heat block and contain a working fluid. The heat pipe working fluid transfers heat from the heat block to a heat exchanger for power conversion. Single phase gas pressure controls the flow of the working

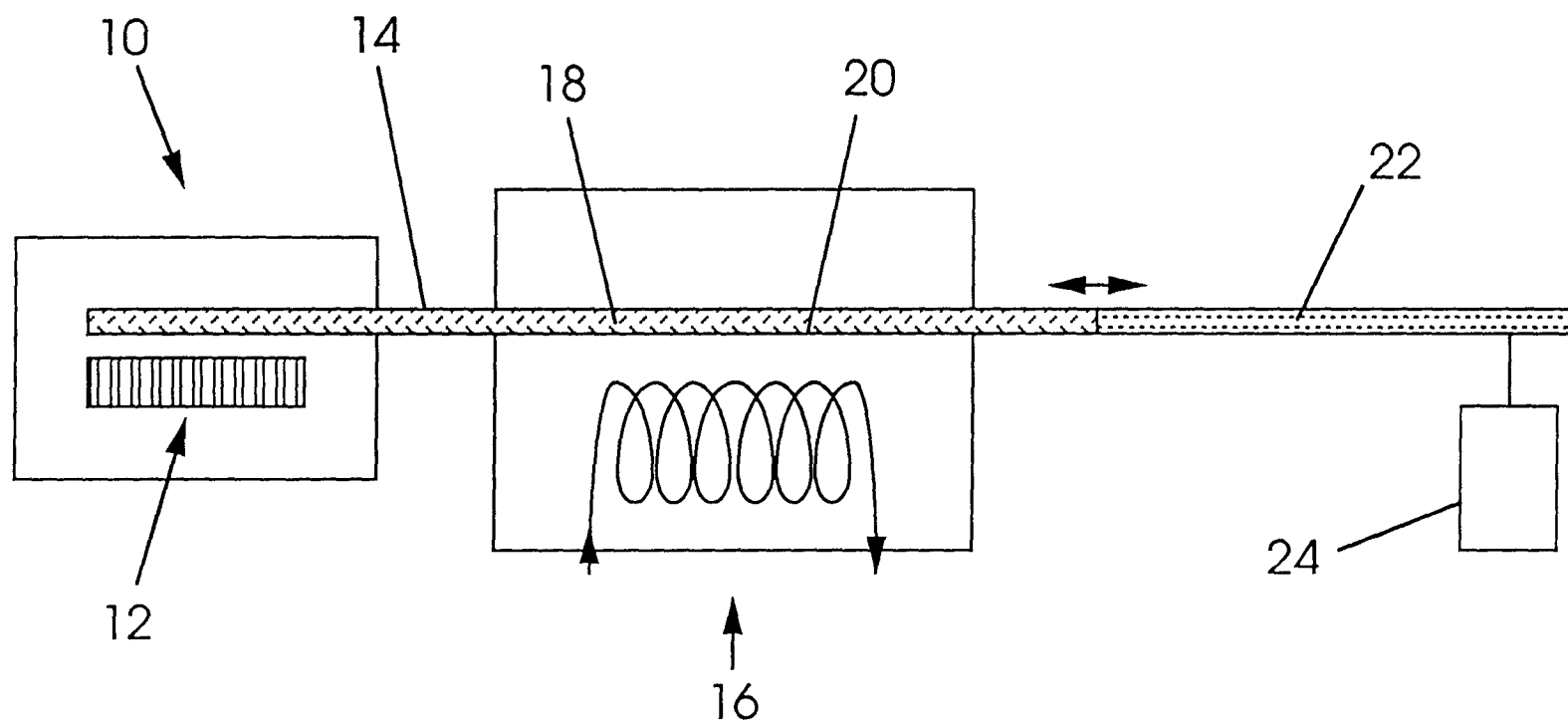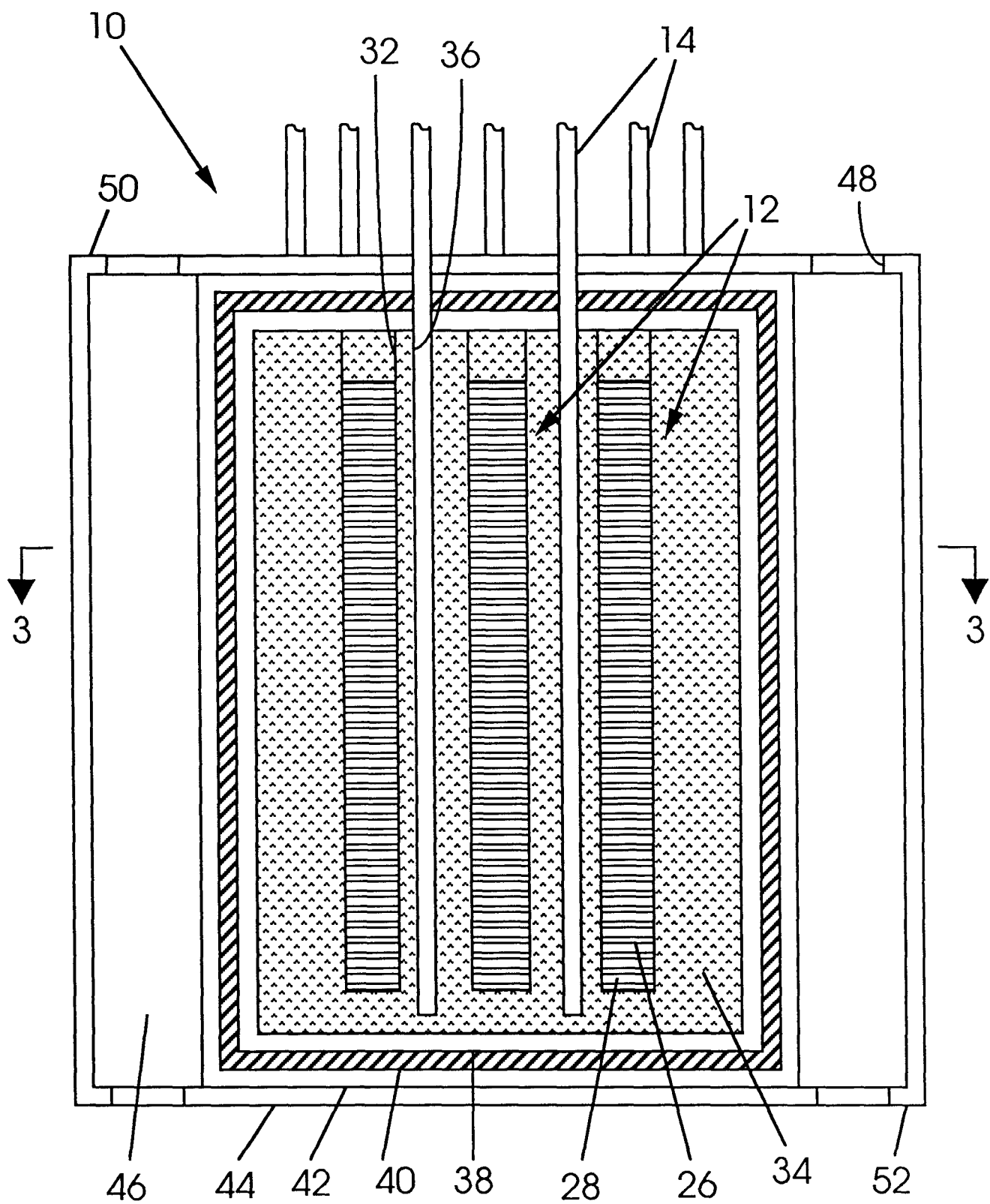15   fluid for maximum heat exchange and to provide passive cooling.

FIGURE 1

FIGURE 2

FIGURE 3