US006800835B1 MFS 31823

(12) **United States Patent**
Sims, III et al.

(10) **Patent No.: US 6,800,835 B1**
(45) **Date of Patent: Oct. 5, 2004**

(54) **RADIO-FREQUENCY DRIVEN DIELECTRIC HEATERS FOR NON-NUCLEAR TESTING IN NUCLEAR CORE DEVELOPMENT**

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(73) Assignee: **The United States of America as represented by the Administrator of the National Aeronautics and Space Administration**, Washington, DC (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **10/463,935**

(22) Filed: **Jun. 16, 2003**

(51) **Int. Cl.^{7}** **H05B 6/54**

(52) **U.S. Cl.** **219/780**; 219/548; 219/553; 219/672

(58) **Field of Search** .... 338/238, 274; 174/77 R, 102 P, 118; 219/538, 544, 546, 552, 553, 780, 542, 548, 550, 600, 601, 635, 672

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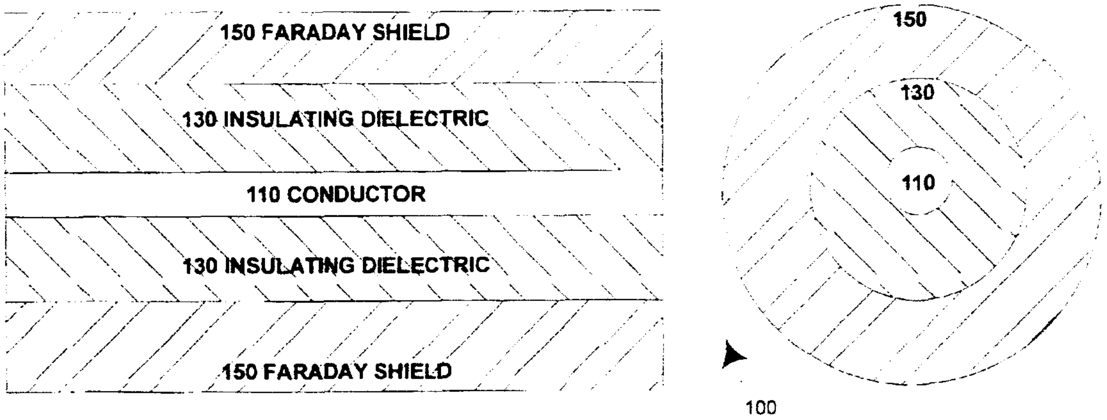
Primary Examiner—Tu Ba Hoang
(74) *Attorney, Agent, or Firm*—James J. McGroary; Michael G. Smith

(57) **ABSTRACT**

Apparatus and methods are provided through which a radio-frequency dielectric heater has a cylindrical form factor, a variable thermal energy deposition through variations in geometry and composition of a dielectric, and/or has a thermally isolated power input.

16 Claims, 8 Drawing Sheets



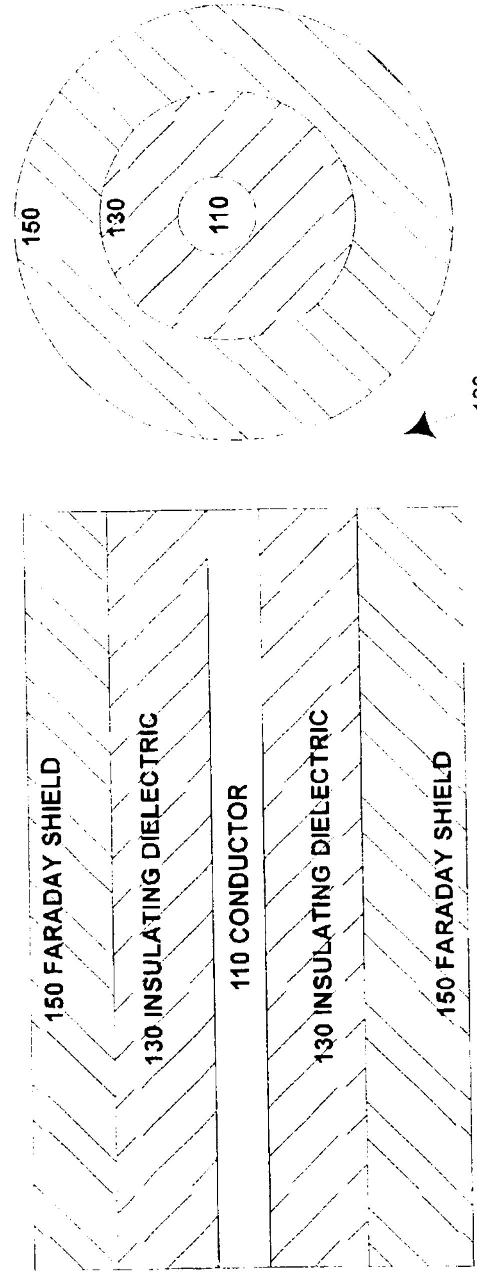

150
130
110
100
150 FARADAY SHIELD
130 INSULATING DIELECTRIC
110 CONDUCTOR
130 INSULATING DIELECTRIC
150 FARADAY SHIELD

FIG. 1

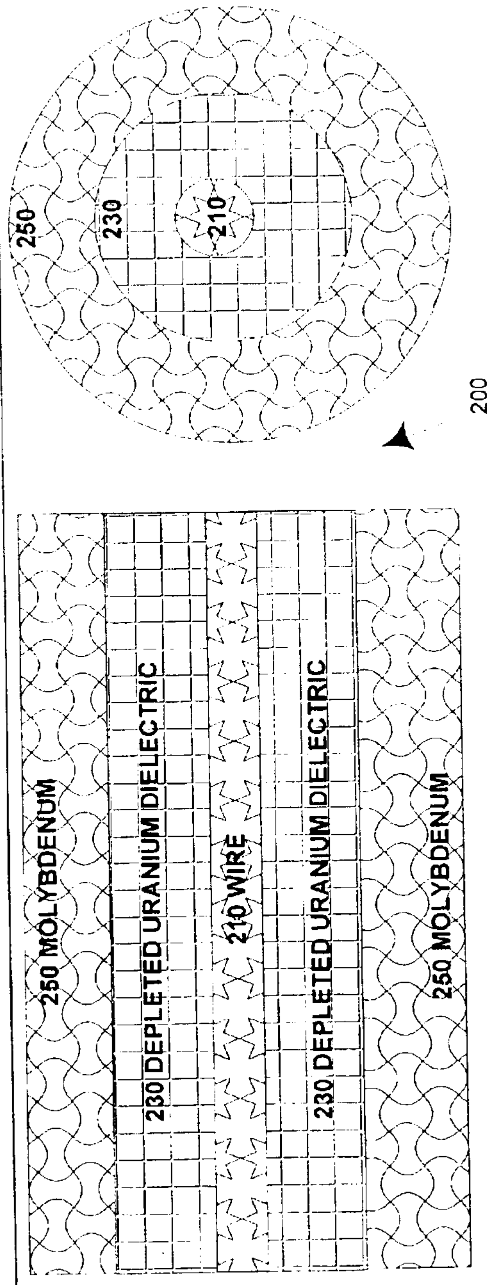

250
230
210
200
250 MOLYBDENUM
230 DEPLETED URANIUM DIELECTRIC
210 WIRE
230 DEPLETED URANIUM DIELECTRIC
250 MOLYBDENUM

FIG. 2

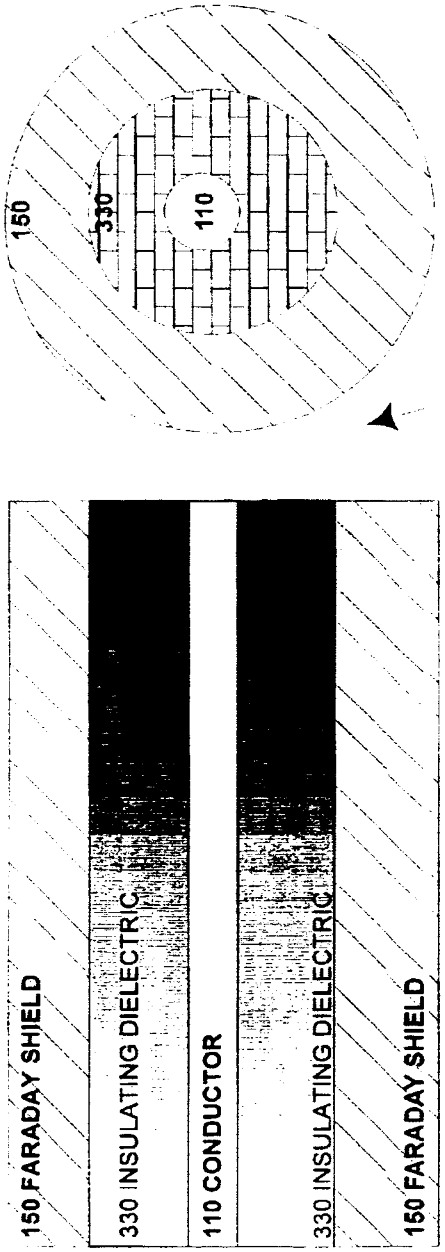

150
330
110
300
150 FARADAY SHIELD
330 INSULATING DIELECTRIC
110 CONDUCTOR
330 INSULATING DIELECTRIC
150 FARADAY SHIELD

FIG. 3

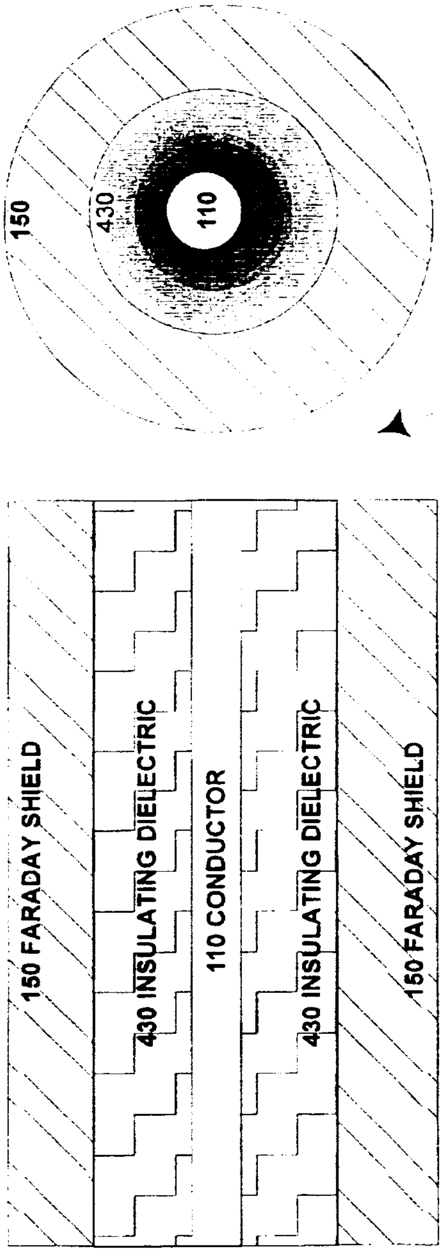

150
430
110
400
150 FARADAY SHIELD
430 INSULATING DIELECTRIC
110 CONDUCTOR
430 INSULATING DIELECTRIC
150 FARADAY SHIELD

FIG. 4

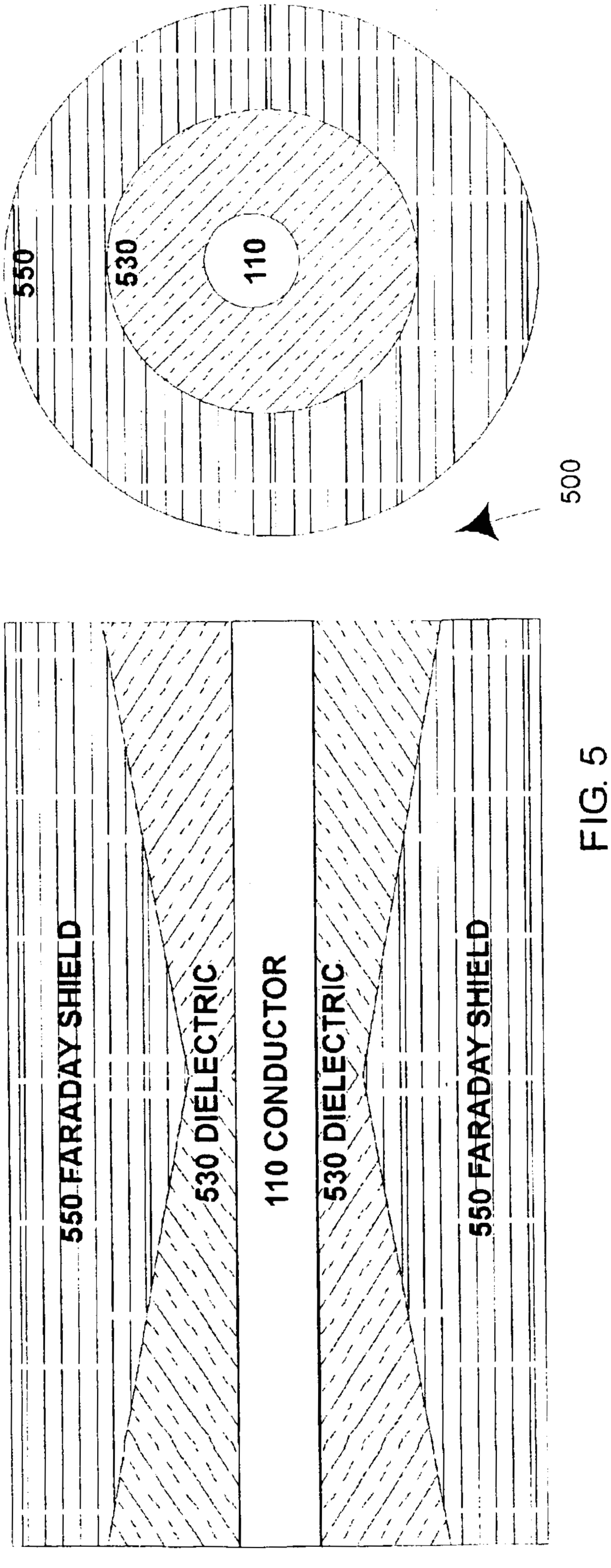

550
530
110
500
550 FARADAY SHIELD
530 DIELECTRIC
110 CONDUCTOR
530 DIELECTRIC
550 FARADAY SHIELD

FIG. 5

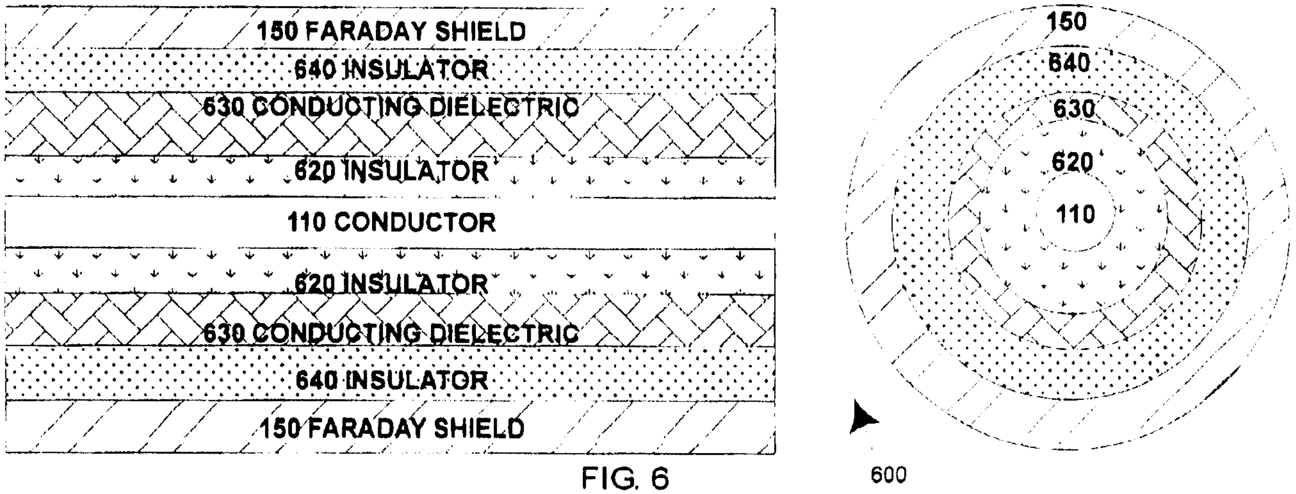

150 FARADAY SHIELD
640 INSULATOR
630 CONDUCTING DIELECTRIC
620 INSULATOR
110 CONDUCTOR
620 INSULATOR
630 CONDUCTING DIELECTRIC
640 INSULATOR
150 FARADAY SHIELD
150
640
630
620
110
600

FIG. 6

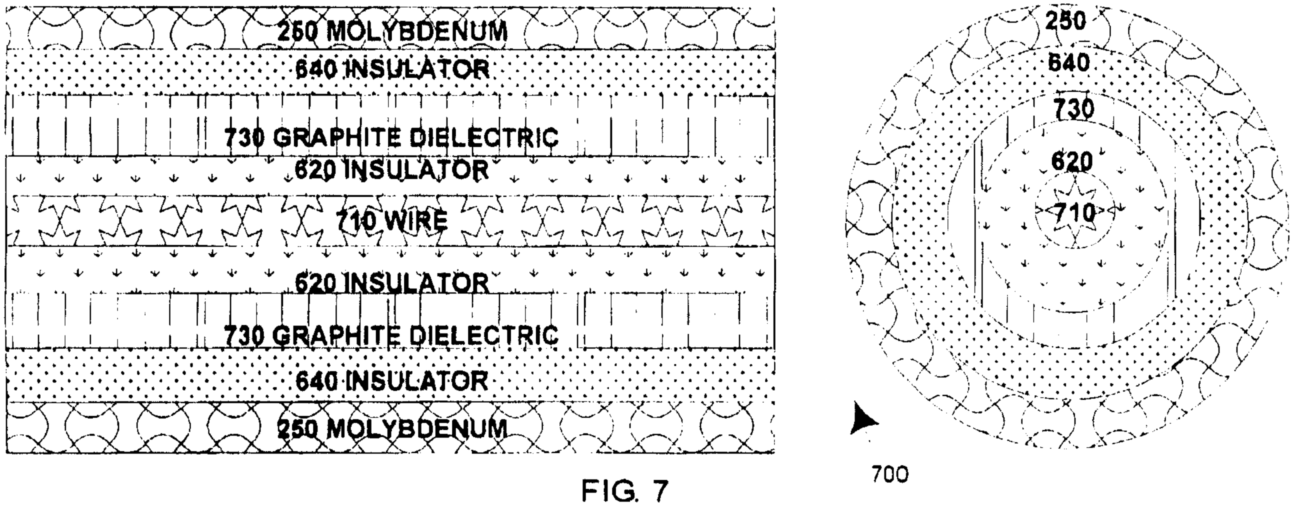

250 MOLYBDENUM
640 INSULATOR
730 GRAPHITE DIELECTRIC
620 INSULATOR
710 WIRE
620 INSULATOR
730 GRAPHITE DIELECTRIC
640 INSULATOR
250 MOLYBDENUM
250
640
730
620
710
700

FIG. 7

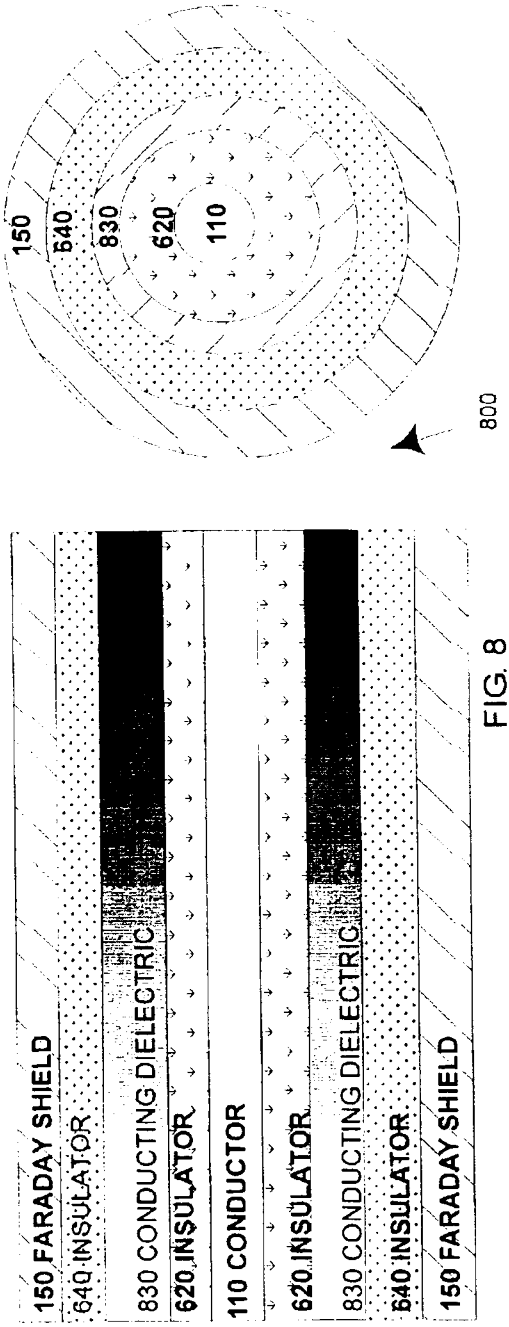

150
640
830
620
110
800
150 FARADAY SHIELD
640 INSULATOR
830 CONDUCTING DIELECTRIC
620 INSULATOR
110 CONDUCTOR
620 INSULATOR
830 CONDUCTING DIELECTRIC
640 INSULATOR
150 FARADAY SHIELD

FIG. 8

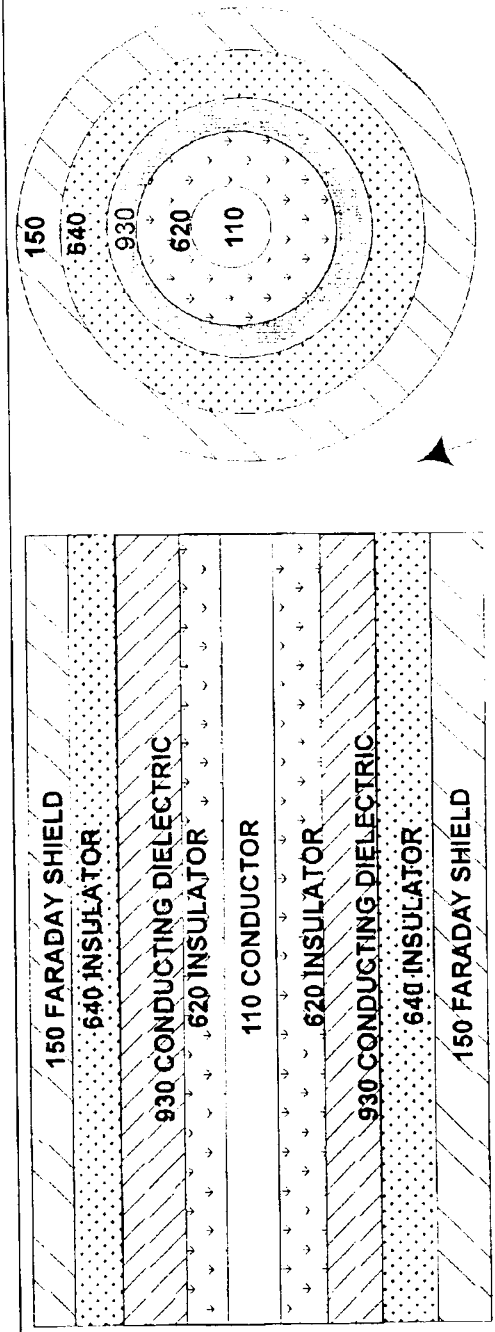

150
640
930
620
110
900
150 FARADAY SHIELD
640 INSULATOR
930 CONDUCTING DIELECTRIC
620 INSULATOR
110 CONDUCTOR
620 INSULATOR
930 CONDUCTING DIELECTRIC
640 INSULATOR
150 FARADAY SHIELD

FIG. 9

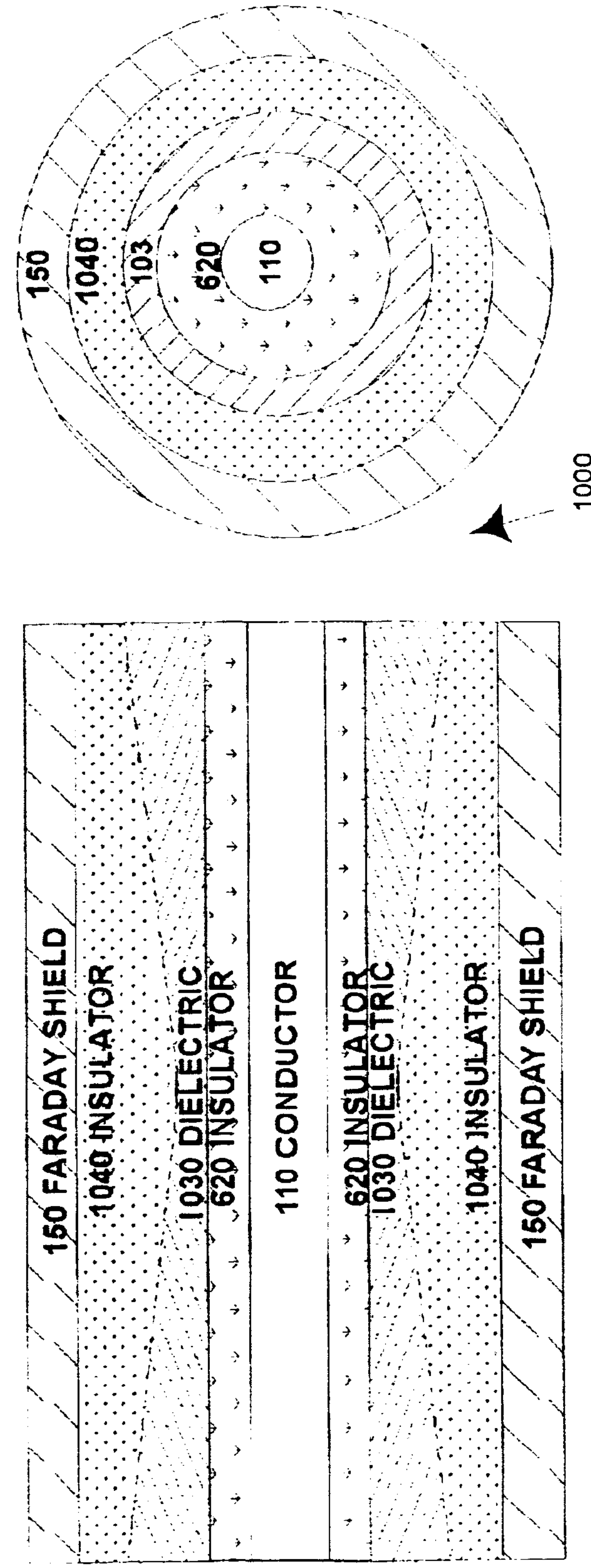

150
1040
103
620
110
1000
150 FARADAY SHIELD
1040 INSULATOR
1030 DIELECTRIC
620 INSULATOR
110 CONDUCTOR
620 INSULATOR
1030 DIELECTRIC
1040 INSULATOR
150 FARADAY SHIELD

FIG. 10

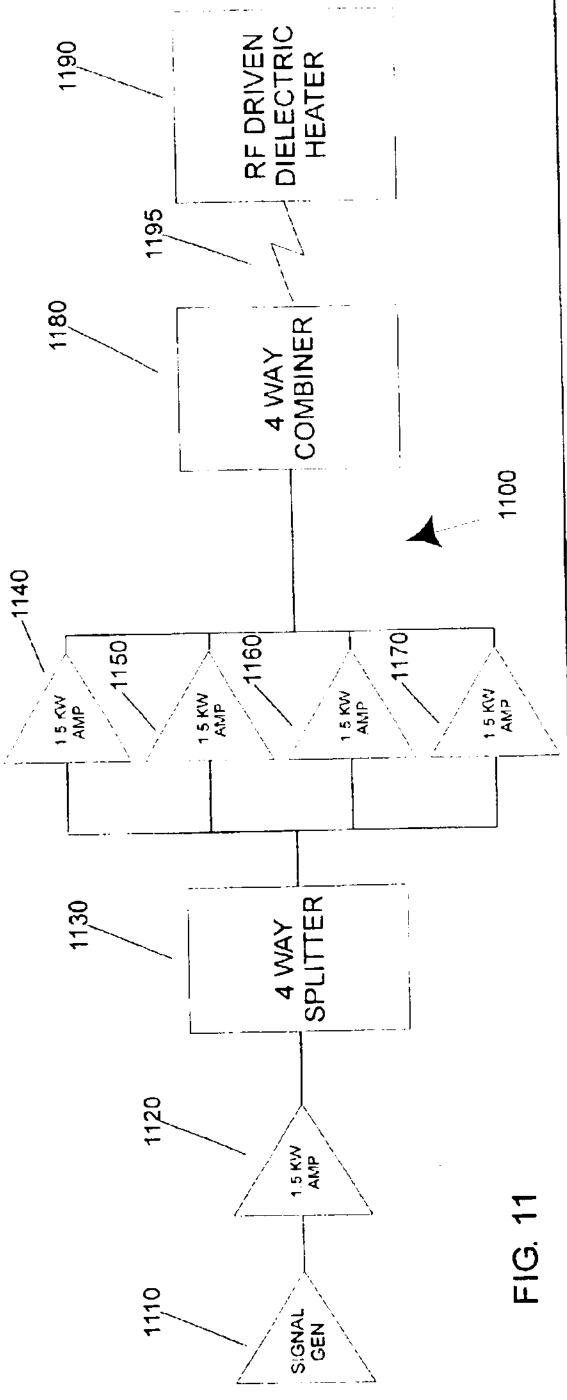

1190
RF DRIVEN DIELECTRIC HEATER
1195
1180
4 WAY COMBINER
1100
1140
1150
1160
1170
1.5 KW AMP
1.5 KW AMP
1.5 KW AMP
1.5 KW AMP
1130
4 WAY SPLITTER
1120
1.5 KW AMP
1110
SIGNAL GEN

FIG. 11

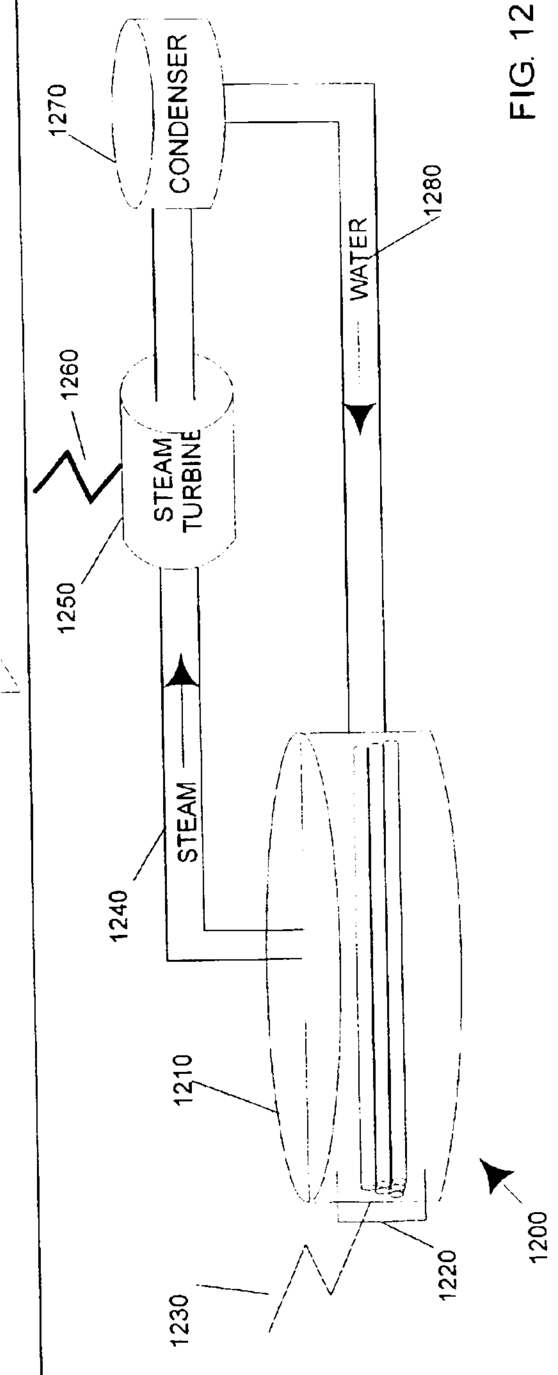

CONDENSER
WATER
STEAM TURBINE
STEAM

FIG. 12

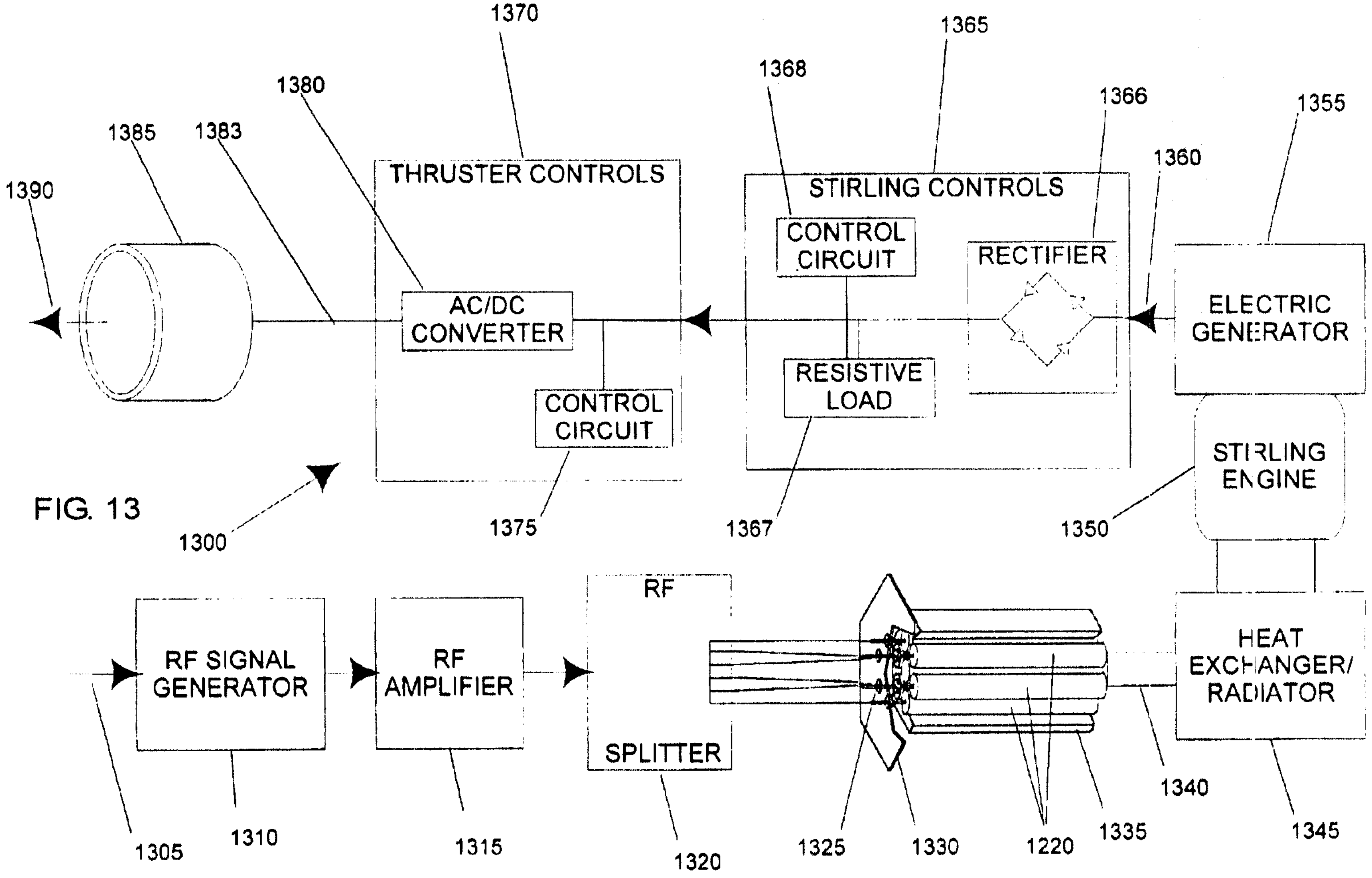

THRUSTER CONTROLS
STIRLING CONTROLS
CONTROL CIRCUIT
RECTIFIER
AC/DC CONVERTER
ELECTRIC GENERATOR
RESISTIVE LOAD
CONTROL CIRCUIT
STIRLING ENGINE
RF
HEAT EXCHANGER/ RADIATOR
RF SIGNAL GENERATOR
RF AMPLIFIER
SPLITTER

FIG. 13

RADIO-FREQUENCY DRIVEN DIELECTRIC HEATERS FOR NON-NUCLEAR TESTING IN NUCLEAR CORE DEVELOPMENT

ORIGIN OF THE INVENTION

The invention described herein was made by employees of the United States Government and may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefore.

FIELD OF THE INVENTION

This invention relates generally to beaters, and more particularly to a radio-frequency driven dielectric heater for use in non-nuclear testing in nuclear core development.

BACKGROUND OF THE INVENTION

Development of space nuclear power and propulsion systems is difficult and costly due to radiation-related health and safety problems during system testing. In order to reduce the health and safety problems, researchers have pursued means for non-nuclear testing of nuclear systems. The non-nuclear testing includes simulation of a nuclear reactor core with electrical heaters. Using a simulated reactor core, various characteristics of the nuclear system that are not directly related to the nuclear operation are tested.

Early stages of conventional nuclear system development utilized resistive electrical heater elements. The resistive electrical heater elements simulate nuclear reactor pins. Conventional resistive electrical heater elements are designed with the same form factor as the simulated nuclear reactor pins, namely a cylindrical structure with an outer metallic clad surrounding a graphite resistive element. The resistive electrical heater elements are bound in a hexagonal packing pattern to simulate the shape of the core structure of the nuclear reactor assembly. Other elements of the reactor design are also incorporated including heat transfer mechanisms, power conversion systems, radiators, and loads. However, the simulated core has thermal loss through the power leads that provide electrical power to the conventional resistance heaters.

Resistance heaters have nuclear pin diameters that are relatively large, greater than 0.5 inches. Power leads of the conventional resistive heaters require relatively large diameter wires to minimize losses in the leads. Since the power leads have electrical resistance, the current passing through the leads produces thermal energy in the leads. In order to minimize the thermal loss, larger diameter wires are used. However, as the lead wire diameter increases, two complications arise. First, the physical placement of the power leads entering the simulated core is problematic. Second, the conduction of thermal energy out of the core via the power leads increases, resulting in a less robust simulation of the nuclear reactor core.

Later reactor designs require smaller pin diameters, such as less than 0.5 inches, and require more pins, such as hundreds, for higher power systems, further exacerbating these problems. These requirements make the use of resistance heaters less attractive.

Inductive heating is commonly used for applications where a metallic structure must be heated. In general, inductive heating uses a coil that carries alternating current (AC) to produce an alternating magnetic field in the test article. The magnetic field induces currents in the test article, which in turn produce thermal energy via resistive losses. However, inductive heating requires high currents in the coil and hence large diameter power leads. Inductive heating also requires that the active heating element be metallic.

For the reasons stated above, and for other reasons stated below which will become apparent to those skilled in the art upon reading and understanding the present specification, there is a need in the art for a heater with reduced thermal coupling to the outside environment. There is also a need for a heater with a reduced size relative to the power leads. Furthermore, there is a need to generate high thermal energy in a relatively small space to simulate fission reactions for non-nuclear testing in nuclear core development. The abovementioned shortcomings, disadvantages and problems are addressed by the present radio-frequency driven dielectric heater, which will be understood by reading and studying the following specification.

SUMMARY OF THE INVENTION

A cylindrical radio-frequency (RF) driven dielectric heater includes a conductor, surrounded by a dielectric, which is in turn surrounded by a Faraday shield. An RF electromagnetic field generated by the conductor is dissipated by the dielectric, converting an RF signal into thermal energy. The thermal energy is conducted outward from the RF driven dielectric heater. The Faraday shield confines the RF electromagnetic energy within the perimeter of the RF driven dielectric heater. The RF driven dielectric heater can be made smaller than conventional heaters. The conductor of the RF driven dielectric heater can receive the RF signal either capacitively or inductively, thus requiring no physical coupling for delivery of the RF signal to the RF driven dielectric heater and reducing the thermal coupling. to the outside environment.

The present RF driven dielectric heater describes systems, methods, and apparatus of varying scope. In addition to the aspects and advantages of the present RF driven dielectric heater described in this summary, further aspects and advantages of the RF driven dielectric heater will become apparent by reference to the drawings and by reading the detailed description that follows.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram of an apparatus implementation of a radio-frequency driven dielectric heater having an insulating dielectric;

FIG. 2 is a block diagram of an apparatus implementation of a radio-frequency driven dielectric heater having an insulating dielectric and having layers that comprise certain materials;

FIG. 3 is a block diagram of an apparatus implementation of a radio-frequency driven dielectric heater having an insulating dielectric that varies along an axial dimension;

FIG. 4 is a block diagram of an apparatus implementation of a radio-frequency driven dielectric heater having an insulating dielectric that varies along a radial dimension;

FIG. 5 is a block diagram of an apparatus implementation of a radio-frequency driven dielectric heater having an insulating dielectric that varies geometrically along a dimension;

FIG. 6 is a block diagram of an apparatus implementation of a radio-frequency driven dielectric heater including insulators surrounding a conducting dielectric;

FIG. 7 is a block diagram of an apparatus implementation of a radio-frequency driven dielectric heater including layers comprising certain materials and including insulators surrounding a conducting dielectric;

FIG. **8** is a block diagram of an apparatus implementation of a radio-frequency driven dielectric heater having a dielectric that varies along an axial dimension and including insulators surrounding a conducting dielectric;

FIG. **9** is a block diagram of an apparatus implementation of a radio-frequency driven dielectric heater having a dielectric that varies along a radial dimension and including insulators surrounding a conducting dielectric;

FIG. **10** is a block diagram of an apparatus implementation of a radio-frequency driven dielectric heater having a dielectric that varies geometrically along a dimension and including insulators surrounding a conducting dielectric;

FIG. **11** is a block diagram of an apparatus implementation of an electrical circuit that provides electrical energy to a radio-frequency driven dielectric heater;

FIG. **12** is a block diagram of an apparatus for non-nuclear testing in nuclear core development that includes a radio-frequency driven dielectric heater; and

FIG. **13** is a block diagram of an apparatus for non-nuclear testing in nuclear core development that includes a radio-frequency driven dielectric heater.

DETAILED DESCRIPTION OF THE INVENTION

In the following detailed description of embodiments of the radio-frequency driven dielectric heater, reference is made to the accompanying drawings that form a part hereof, and in which is shown by way of illustration specific embodiments in which the radio-frequency driven dielectric heater may be practiced. These embodiments are described in sufficient detail to enable those skilled in the art to practice the radio-frequency driven dielectric heater, and it is to be understood that other embodiments may be utilized and that logical, mechanical, electrical and other changes may be made without departing from the scope of the present radio-frequency driven dielectric heater. The following detailed description is, therefore, not to be taken in a limiting sense, and the scope of the present radio-frequency driven dielectric heater is defined only by the appended claims.

RF dielectric heating techniques utilize a rapidly fluctuating electromagnetic field which applies an alternating torque on polar molecules in a material under test. This torque either causes the molecules to flip orientation or to attempt to flip orientation, depending on the material. As a result, thermal energy is produced via the frictional resistance to the molecules motion. This technique is commonly used to heat nonmetallic materials in a very controlled manner including plastics, ceramics, and food products. The effectiveness of the heating process is dependent on the dielectric properties of the test article. Similarly, the ideal choice of frequency of the electromagnetic field is based on the electrical properties of the material. Materials that are very efficient at converting the RF power to thermal power are termed lossy dielectrics,

In some embodiments, RF energy source transmitters are limited to a number of predetermined frequencies. The dielectric constant of materials (e.g., graphite, nuclear pellets, soils, etc.) varies with the frequency that is applied to the subject material. For any given RF frequency, various subject materials are likely to have various different dielectric constants. For example, the impedance of a conventional system has been observed to vary depending on the frequency to which the RF source is tuned and with soil. See, Garbe Et. Al.; "Calculation of Electromagnetically and Thermally Coupled Fields In Real Soil Decontamination"; 15th International Wroclaw Symposium on EMC, 2000.

FIG. **1** is a block diagram of an apparatus implementation of a radio-frequency (RF) driven dielectric heater **100**. The RF driven dielectric heater **100** is also known as a rod or a pin.

The RF driven dielectric heater **100** includes a cylindrical conductor **110**. Examples of the conductor **110** include an antenna, a wire, or any other combination. A signal transmission source (not shown) passes an RF signal into the conductor **110**, generating an RF electromagnetic field (not shown).

The conductor **110** is further surrounded by an insulating dielectric **130**. An insulating dielectric is a dielectric that has electrical insulating properties. The RF electromagnetic field readily passes from the conductor **110** and into the insulating dielectric **130**.

The RF electromagnetic field is dissipated by the insulating dielectric **130**. The RF electromagnetic energy causes rapid fluctuations in the orientation of molecules in the insulating dielectric **130**, converting the RF electromagnetic energy into thermal energy. The thermal energy is conducted outward from the insulating dielectric **130**.

In some embodiments, the insulating dielectric **130** includes zirconia, a carbide, and/or titania. In some other embodiments, the insulating dielectric **130** includes a non-metallic depleted nuclear fuel, which in various examples can take the form of powder, rods, pellets, liquid and/or gas. The non-metallic depleted nuclear fuel allows precise simulation of thermal energy transfer and thermodynamic properties.

The insulating dielectric **130** is surrounded by a Faraday shield **150**. The Faraday shield **150** provides a system ground for the RF electromagnetic energy and confines the RF electromagnetic energy within the perimeter of the RF driven dielectric heater **100**. A Faraday shield is also known as a Faraday cage.

In some embodiments, the Faraday shield **150** is comprised of a refractory metal, such as tungsten, tantalum, molybdenum and/or osmium. In other embodiments, the Faraday shield **150** is comprised of a non-refractory metal such as aluminum or copper.

The conductor **110** is an active radiator of electromagnetic energy. The electromagnetic energy has the ability to deliver energy into the surrounding environment, or other dielectric heaters when more than one is being used.

The insulating dielectric **130** substantially prevents a short circuit from forming between conductor **110** and the Faraday shield **150**. For these reasons the insulating dielectric **130** can not be electrically conductive, but must have some dielectric loss.

In some embodiments, the RF driven dielectric heater **100** simulates fission thermal energy in a nuclear reactor for non-nuclear testing in nuclear core development. In those embodiments, the insulating dielectric **130** can be selected to match the thermal characteristics of the nuclear material that is simulated in order to accurately simulate thermodynamics and thermal energy transfer effects and properties of the thermodynamically simulated nuclear material. In some embodiments, the RF energy source ranges from 2,000 to 5,000 volts with RF frequencies up to 50 MHz. Those of ordinary skill in the art would understand that the selection of voltage and frequency is a function of the materials of the conductor **110**, the dielectric **130** and the Faraday shield **150**.

RF dielectric heating has several advantages over other techniques for application to non-nuclear testing of nuclear systems. Unlike resistive and inductive heating techniques, dielectric heating techniques depend on high field potential at low current to produce thermal energy. Therefore, smaller diameter power leads can be used to transmit the RF signal for the frequency range of interest, typically less than 100 MHz. The Faraday shield **150** provides a return path for the RF signal, therefore only a single power lead is required. Nuclear fuels are typically in the form of ceramic compounds. Therefore, the simulated reactor pin can use depleted forms of the nuclear fuel material as the dielectric material resulting in precise matching of thermodynamic and material characteristics, as shown in figures below.

Particular implementations of the RF driven dielectric heater **100** are described below in FIGS. **2**–**5**. FIG. **2** is a block diagram of an apparatus implementation of a RF driven dielectric heater **200** having an insulating dielectric and having layers that comprise certain materials. In the RF driven dielectric heater **200**, the conductor **110** of FIG. **1** is a wire **210**. Furthermore, the insulating dielectric **130** of FIG. **1** is a depleted uranium oxide (UO_2.) dielectric **230**. Lastly, the Faraday shield **150** of FIG. **1** is a molybdenum tube **250**.

The depleted uranium oxide dielectric **230** obviates the need for an insulator around the dielectric. The depleted uranium oxide dielectric **230** is a substantial insulator. Thus, no short will develop between the wire **210** and the molybdenum tube **250**. Therefore, no insulator is required between the wire **210** and the depleted uranium oxide dielectric **230**, and no insulator is required between the depleted uranium oxide dielectric **230** and the molybdenum tube **250**. Thus, a RF signal is supplied to the conductor **110** which radiates into the depleted uranium oxide dielectric **230** at a resonant frequency, yielding thermal energy.

In some embodiments, the RF driven dielectric heater **100** has a diameter of approximately 0.125" as required in high power fission core applications. Thus, the RF driven dielectric heater **200** provides a RF driven dielectric heater with high thermal output, relatively small physical size and a simplified construction that requires no insulators surrounding the depleted uranium oxide dielectric **230**.

FIGS. **3**–**5** show RF driven dielectric heaters having an insulating dielectric with a variable thermal energy deposition. The variable thermal energy deposition results from variations in impedance of the insulating dielectric. Variation in the impedance of the insulating dielectric is achieved through a variation of at least one characteristic of the insulating dielectric along at least one dimension. The characteristics include the density profile and the geometry of the dielectric. The dimensions include a radial dimension and an axial dimension. One example of varying density is creating or forming air pockets or vacuum pockets in position(s) or area(s) of the dielectric where different thermal energy deposition is desired. The air or vacuum pockets have dielectric properties that are taken into account in a design of a RF driven dielectric heater, but the effect is to alter the dielectric properties on a local level. One example of varying geometry is varying the thickness of the dielectric.

FIG. **3** is a block diagram of an apparatus implementation of a RF driven dielectric heater **300** having an insulating dielectric that varies along an axial dimension. The RF driven dielectric heater **300** includes a conductor **110** and a Faraday shield **150** as in FIG. **1**. However, the RF driven dielectric heater **300** also includes an insulating dielectric **330** that varies along an axial dimension. The insulating dielectric **330** varies in density of dielectric material along the axial dimension to create a thermal energy deposition that increases from one end of the axial dimension to the other end of the axial dimension.

FIG. **4** is a block diagram of an apparatus implementation of a radio-frequency driven dielectric heater **400** having an insulating dielectric that varies along a radial dimension. The RF driven dielectric heater **400** includes a conductor **110** and a Faraday shield **150** as in FIG. **1**. However, the RF driven dielectric heater **400** also includes an insulating dielectric **430** that varies along a radial dimension. The insulating dielectric **430** varies in density of dielectric material outward from the center to create a thermal energy deposition that decreases outwardly from the center.

FIG. **5** is a block diagram of an apparatus implementation of a RF driven dielectric heater **500** having an insulating dielectric that varies geometrically along an axial dimension. The RF driven dielectric heater **500** includes a conductor **110** as in FIG. **1**. However, the RF driven dielectric heater **500** also includes an insulating dielectric **530** that varies in thickness along an axial dimension. In one embodiment, the insulating dielectric **530** is thinner in the middle of the axial dimension to create a thermal energy deposition that is greatest in the middle along the axial dimension. This embodiment is particularly well-suited to simulate the thermal energy deposition of fission reactors that have the greatest thermal energy deposition in the middle along an axial dimension. The RF driven dielectric heater **500** also includes a Faraday shield **150** that inversely varies in thickness along an axial dimension corresponding to the variance in thickness of the dielectric **530**.

FIG. **6** is a block diagram of an apparatus implementation of a RF driven dielectric heater **600** including insulators surrounding a conducting dielectric. The RF driven dielectric heater **600** includes a conductor **110** that has a form factor (i.e. shape) that is cylindrical. A RF signal passes into the conductor **110**.

The conductor **110** is surrounded by an inner insulator **620**. The inner insulator **620** presents little impedance to an RF electromagnetic field that radiates from the conductor **110**. Molecules in the inner insulator **620** readily flip back and forth with the alternating electromagnetic field produced by the RF signal in the conductor **110**. Because the molecules in the inner insulator **620** flip orientation easily, the RF electromagnetic field readily passes from the conductor **110**, through the inner insulator **620** and outward.

The inner insulator **620** is further surrounded by a conductive lossy dielectric **630**. A conducting dielectric is a dielectric that has electrical conducting properties. The inner insulator **620** electrically isolates the conductor **110** from the dielectric **630**. Notwithstanding the inner insulator **620** confining the RF signal in the conductor **110**, an RF electromagnetic field radiates from the conductor **110** through the inner insulator **620** and into the conducting dielectric **630**. One example of a conducting dielectric material is graphite as discussed below in conjunction with FIG. **7**.

The conducting dielectric **630** is surrounded by an outer insulator **640**. The inner insulator **620** may be made from the same materials as the outer insulator **640**, but not necessarily. The outer insulator **640** is surrounded by a Faraday shield **150**.

In some embodiments either of the insulators **620** and **640** comprise a very efficient dielectric (i.e. not lossy) material in order to minimize loss of the RF electromagnetic energy in the insulator. In some other embodiments, either of the insulators **620** and **640**, have insulating properties, as well as sufficient material strength, at an expected maximum operating temperature. In yet other embodiments, either of the insulators **620** and **640** are chemically compatible with the adjoining materials over a range of expected operating conditions. Examples of materials that either of the insulators **620** and **640** are composed of include oxides and/or oxide compounds (e.g. alumina, silica and magnesia), polymers, carbides, nitrides.

An electrical RF signal (not shown) is received by the conductor **110**. The insulators **620** and **640** on both sides of the insulating dielectric **630** prevent the signal in the conductor from electrically shorting to the Faraday shield **150**. Absence of the insulators **620** and **640** would allow the RF signal to flow to the Faraday shield **150**, which would in turn radiate RF electromagnetic energy outward. Thus, the insulators **620** and **640** help confine energy within the heater **600**, which increases the efficiency of the heater **600**.

FIG. **7** is a block diagram of an apparatus implementation of a RF driven dielectric heater **700** having layers that comprise certain materials and including insulators surrounding a conducting dielectric. In the RF driven dielectric heater **700**, the conductor **110** of FIG. **6** is a wire **710**. Furthermore, the conducting dielectric **630** of FIG. **6** is a graphite dielectric **730**. Lastly, the Faraday shield **150** of FIG. **6** is a molybdenum tube **250**.

The graphite dielectric **730** necessitates electrical insulation around the outer and inner sides of the graphite dielectric **730**. The graphite dielectric **730** is a poor insulator. Thus, a short will develop between the wire **710** and the molybdenum tube **250**. Therefore, an insulator is required between the wire **710** and the graphite dielectric **730**, and an insulator is required between the graphite dielectric **730** and the molybdenum tube **250**. Thus, the RF driven dielectric heater **700** provides a heater with high thermal output and relatively small physical size.

FIGS. **8**–**10** show RF driven dielectric heaters having insulators surrounding a conducting dielectric with variable thermal energy deposition.

FIG. **8** is a block diagram of an apparatus implementation of a RF driven dielectric heater **800** having a conducting dielectric that varies along an axial dimension. The RF driven dielectric heater **800** includes a conductor **110** and a Faraday shield **150** as in FIG. **6**. However, the RF driven dielectric heater **800** also includes a conducting dielectric **830** that varies along an axial dimension. The conducting dielectric **830** varies in density of dielectric material along the axial dimension to create a thermal energy deposition that increases from one end of the axial dimension to the other end of the axial dimension.

FIG. **9** is a block diagram of an apparatus implementation of a radio-frequency driven dielectric beater **900** having a conducting dielectric that varies along a radial dimension. The RF driven dielectric heater **900** includes a conductor **110** and a Faraday shield **150** as in FIG. **6**. However, the RF driven dielectric heater **900** also includes a conducting dielectric **930** that varies along a radial dimension. The conducting dielectric **930** varies in density of dielectric material outward from the center to create a thermal energy deposition that decreases outwardly from the center.

FIG. **10** is a block diagram of an apparatus implementation of a RF driven dielectric heater **1000** having a conducting dielectric that varies geometrically along an axial dimension. The RF driven dielectric heater **1000** includes a conductor **110** as in FIG. **6**. However, the RF driven dielectric heater **1000** also includes a conducting dielectric **1030** that varies in thickness along an axial dimension to create a thermal energy deposition that is greatest in the middle along the axial dimension. In some embodiments, the RF driven dielectric heater **1000** also includes an insulator **1040** that varies in thickness in inverse proportion to the conducting dielectric **1030** along an axial dimension in order to maintain a constant thickness of the RF driven dielectric heater **1000** in accommodation to the conducting dielectric **1030**. The RF driven dielectric heater **1000** is particularly well-suited to simulate the thermal energy deposition of fission reactors that have the greatest thermal energy deposition in the middle along an axial dimension.

FIG. **11** is a block diagram of an apparatus implementation of an electrical circuit **1100** that provides electrical energy to a RF driven dielectric heater. The electrical circuit **1100** includes a signal generator **1110** electrically coupled to a 1.5 kW amplifier **1120**. The electrical circuit **1100** also includes two electrically identical combiners **1130** and **1180**. The first combiner, 4 way splitter **1130**, is used as a splitter to provide four equal drive signals from the 1.5 kW amplifier **1120** to four 1.5 kW amplifier modules **1140**, **1150**, **1160** and **1170**. The second combiner **1180** takes the output of the four modules **1140**, **1150**, **1160** and **1170** and combines the output into a single RF signal. Electrical circuit **1100** yields the RF signal in a desired voltage output such as 2,000 to 5,000 volts with RF frequencies up to 50 MHz.

The RF signal is transmitted to a RF driven dielectric heater **1190** through transmission medium **1195**. Examples of the RF driven dielectric heater **1190** include RF driven dielectric heaters **100**, **200**, **300**, **400**, **500**, **600**, **700**, **800**, **900** and **1000**. In some embodiments, the transmission medium is an electrically conductive physical wire, such as a copper wire. In other embodiments, the transmission medium **1195** includes a capacitive coupling means. In yet other embodiments, the transmission medium **1195** includes an inductive coupling means. The capacitive and inductive coupling means provide a means of transmitting the RF signal without a physical connection to the RF driven dielectric heater **1190**. The lack of a physical connection increases the thermal isolation of the RF driven dielectric heater **1190**.

FIG. **12** is a block diagram of an apparatus **1200** for non-nuclear testing in nuclear core development that includes a RF driven dielectric heater. Apparatus **1200** includes a steam generator **1210**. The steam generator **1210** is substantially full of water. The steam generator **1210** includes a plurality of RF driven dielectric beaters **1220** immersed in the water. The plurality of RF driven dielectric heaters **1220** are bundled in close proximity and typically require the same volume of physical space as a fission core. In some embodiments, the plurality of RF driven dielectric heaters **1220** are electromagnetically coupled **1230** to a thermally isolated power source (not shown). Thermal energy from the plurality of RF driven dielectric heaters **1220** vaporizes some of the water in the steam generator **1210**, yielding pressurized steam **1240**. The pressurized steam drives a steam turbine electrical generator **1250**, yielding electricity **1260**. The waste steam is cooled to a liquid state **1280** by a condenser **1270** and returned to the steam generator **1210**. In the aggregate, the steam generator **1210**, the steam turbine electrical generator **1250** and condenser **1270** are also known as a power converter. Thus, apparatus **1200** satisfies the need to generate high thermal energy in a relatively small space to simulate fission reaction for non-nuclear testing in nuclear core development.

FIG. **13** is a block diagram of an apparatus for non-nuclear testing in nuclear core development that includes a RF driven dielectric heater. Apparatus **1300** receives alternating current (AC) **1305** into an RF signal generator **1310**. The RF signal generator **1310** transmits an RF signal to an

RF amplifier **1315**. An amplified RF signal is transmitted from the RF amplifier **1315** to an RF splitter **1320**. Split RF signals are transmitted from the RF splitter **1320** through capacitive RF power coupling **1325**. The capacitive RF power coupling **1325** is mounted in a thermal barrier **1330** that encapsulates a plurality of RF driven dielectric heaters **1220**. The thermal barrier **1330** also encapsulates a refractory core **1335**. A heat pipe **1340** transfers material that is heated in the refractory core **1335** to a heat exchanger **1345**. Thermal energy from the heat exchanger **1345** is transferred to a Stirling Engine **1350**. The Stirling Engine **1350** powers an electrical generator **1355**. The electrical generator **1355** produces an alternating current (AC) **1360**. The AC is transmitted to a Stirling Control **1365**.

The Stirling Control **1365** includes a rectifier **1366** that converts the AC to direct current (DC) **1383**. The Stirling Control **1365** also includes a resistive load **1367** and a control circuit **1368**. The DC **1383** exits the Stirling Control **1365** and enters a thruster control **1370**. The thruster control **1370** includes a control circuit **1375** and a DC/DC converter **1380** to convert the DC **1383** to a required voltage and current. The DC **1383** is received by an ion thruster **1385**, providing thrust **1390**. Thus, apparatus **1300** satisfies the need to generate large amounts of thermal energy in a relatively small space to simulate a fission reactor in non-nuclear testing.

Conclusion

A radio-frequency (RF) driven dielectric heater has been described. Although specific embodiments have been illustrated and described herein, it will be appreciated by those of ordinary skill in the art that any arrangement which is calculated to achieve the same purpose may be substituted for the specific embodiments shown. The RF driven dielectric heater is not limited to any particular conductor, dielectric and/or insulator. For sake of clarity, simplified conductors, dielectrics, insulators and/or Faraday shields have been described. This application is intended to cover any adaptations or variations of the present RF driven dielectric heater. In particular, one of skill in the art will readily appreciate that additional layers of materials may be disposed between any two layers of materials to isolate the layers of two materials that would become reactive in direct contact at high temperature without departing from the scope of embodiments of the radio-frequency driven dielectric heater. The additional materials may be selected to ensure the dielectric heating occurs primarily in the dielectric material. The additional layers of material may also include non-solid forms of matter such as a gas interface, or a liquid interface, depending on the particular requirements. One of skill in the art will readily recognize that embodiments of the radio-frequency driven dielectric heater are applicable to future non-nuclear core development.

The terminology used in this application with respect to is meant to include all dielectric and heater environments and alternate technologies which provide the same functionality as described herein. Therefore, it is manifestly intended that this radio-frequency driven dielectric heater be limited only by the following claims and equivalents thereof.

We claim:

1. A cylindrical dielectric heater comprising:
   a substantially cylindrical electrical conductor, the substantially cylindrical electrical conductor being operable to generate a radio-frequency electromagnetic field;
   a substantially cylindrical dielectric surrounding the conductor; and
   a substantially cylindrical Faraday shield surrounding the dielectric.

2. The cylindrical dielectric heater of claim **1**, wherein the substantially cylindrical dielectric further comprises a substantially cylindrical insulating dielectric.

3. The cylindrical dielectric heater of claim **1**, wherein the substantially cylindrical dielectric varies in a composition of at least one dielectric material along a dimension.

4. The cylindrical dielectric heater of claim **3**, wherein the dimension further comprises a radial dimension.

5. The cylindrical dielectric heater of claim **3**, wherein the dimension further comprises an axial dimension.

6. The cylindrical dielectric heater of claim **1**, wherein the substantially cylindrical dielectric has a dimension that varies in a density of a dielectric material.

7. The cylindrical dielectric heater of claim **6**, wherein the dimension further comprises a radial dimension.

8. The cylindrical dielectric heater of claim **6**, wherein the dimension further comprises an axial dimension.

9. A dielectric heater comprising:
   an electrical conductor being operable to produce an alternating electromagnetic field from a radio-frequency signal;
   a dielectric within range of the alternating electromagnetic field, the dielectric having a characteristic that yields a variable thermal energy deposition; and
   a Faraday shield disposed opposite from the electrical conductor.

10. The dielectric heater of claim **9**, wherein the dielectric varies in a composition of at least one dielectric material along a dimension.

11. The dielectric heater of claim **10**, wherein the dimension further comprises a radial dimension.

12. The dielectric heater of claim **10**, wherein the dimension further comprises an axial dimension.

13. The dielectric heater of claim **9**, wherein the dielectric has a dimension that varies in a density of a dielectric material.

14. The dielectric heater of claim **13**, wherein the dimension further comprises a radial dimension.

15. The dielectric heater of claim **13**, wherein the dimension further comprises an axial dimension.

16. The dielectric heater of claim **9**, wherein the electrical conductor, the dielectric and the Faraday shield have a cylindrical shape.

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