

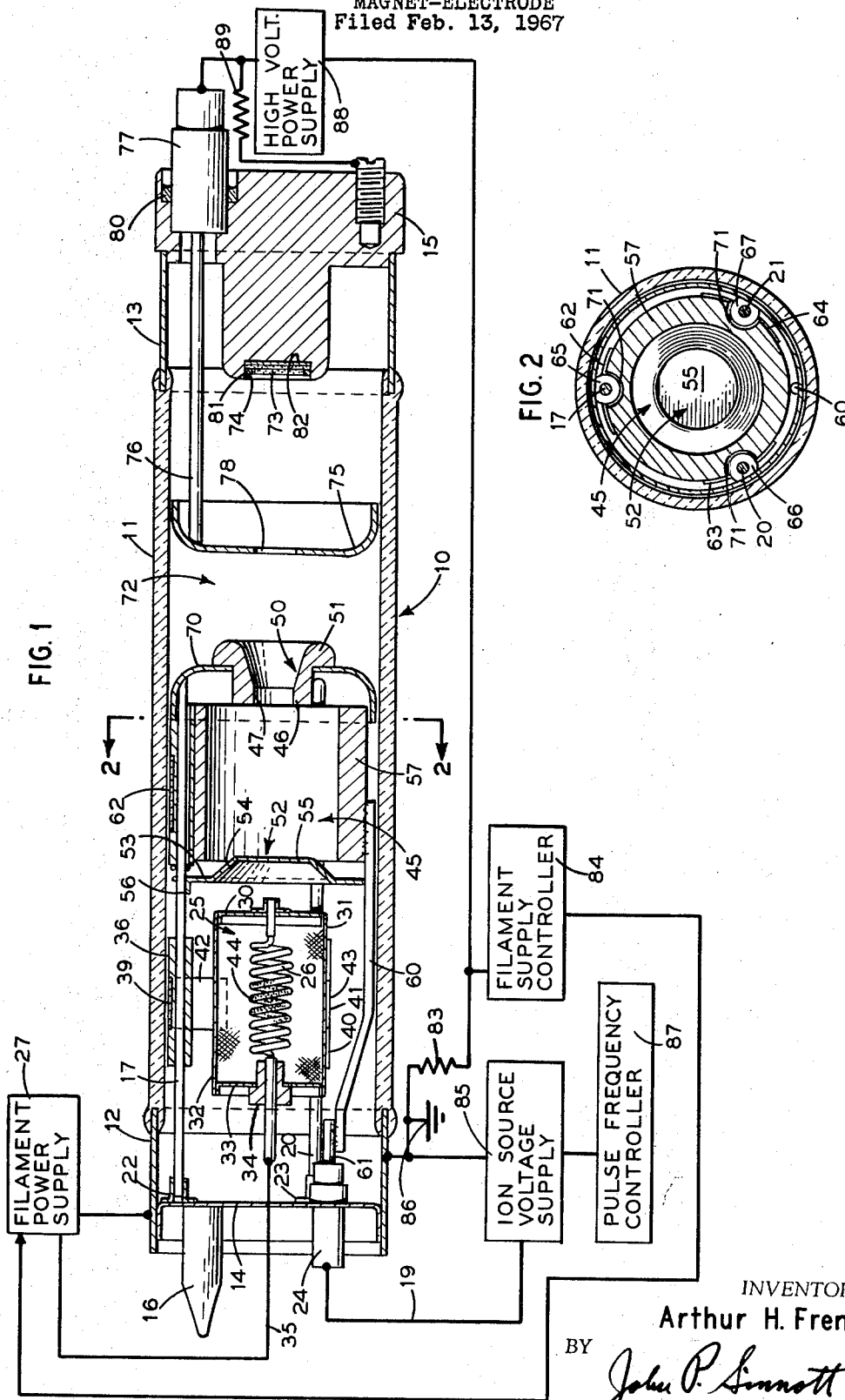
Dec. 8, 1970

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3,546,512

NEUTRON GENERATOR INCLUDING AN ION SOURCE WITH A MASSIVE
FERROMAGNETIC PROBE ELECTRODE AND A PERMANENT
MAGNET-ELECTRODE

Filed Feb. 13, 1967



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NEUTRON GENERATOR INCLUDING AN ION SOURCE WITH A MASSIVE FERROMAGNETIC PROBE ELECTRODE AND A PERMANENT MAGNET-ELECTRODE

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Filed Feb. 13, 1967, Ser. No. 615,638

Int. Cl. H01j 3/20; G21q 3/00

U.S. Cl. 313—61

1 Claim

ABSTRACT OF THE DISCLOSURE

A permanent magnet is outgassed for use in a controlled atmosphere by heating a ferromagnetic material to a temperature at which an irreversible loss of remanence takes place, but below the temperature at which material effects substantially reduce or remove all remanence without further special heat treatment. Gases emitted from the heated surfaces of the magnet then are evacuated. Permanent magnetic properties are not destroyed by this heat treatment, and a magnetic field of substantial strength subsequently is produced by magnetizing the outgassed material. A specific embodiment of the invention enables a hollow cylindrical ion source magnet to be placed within the envelope of a small neutron generator to provide both a magnetic field and an ion source electrode. The assembled generator then is outgassed and sealed. Subsequent magnetization enables the electrode to produce the high intensity magnetic field needed for ion generation.

BACKGROUND OF THE INVENTION

Field of the invention

This invention relates to methods and apparatus for expelling occluded gases from permanently magnetizable materials and more particularly, to a neutron generator in which one of the electrodes in the ion source also produces a permanent magnetic field, and the like.

DESCRIPTION OF THE PRIOR ART

Gases, through absorption or adsorption, tend to permeate the surfaces of almost all solid materials. Heat often causes these occluded gases to be emitted from the sorbent surfaces. In some types of industrial and scientific equipment that need vacuum or controlled atmospheric conditions, these released gases often degrade the quality of the vacuum or contaminate the special environment. Ordinarily, this problem is overcome through "outgassing" or expelling the occluded gases from the equipment by heating the equipment structure. Occluded gases emitted by the heated structure are drawn off, and, after a sufficiently long "baking out" period, the equipment is sealed hermetically and subsequently cooled.

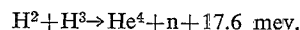
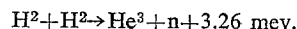
Intense magnetic fields often are required within the envelopes that enclose these controlled atmospheres. It is believed generally, however, that permanent magnetic materials, if heated to practical outgassing temperatures, such as 400° C. or greater, tend to lose their magnetic

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properties. Consequently, a permanent magnet capable of producing a desired field intensity within a controlled environment usually is placed outside the envelope. This solution naturally leads to relatively inflexible structural layouts that are characterized by heavy, bulky designs and a limited range of material choices.

Neutron generators used in oil well logging tools are typical industrial devices beset by these contamination problems, inasmuch as they usually require controlled low pressure atmospheres and high intensity magnetic fields. Accordingly, for illustrative purposes, the invention is described in more complete detail in connection with a neutron generator suitable for use in a well logging tool.

By way of background, generators that have been proposed for neutron generation through nuclear reactions that are induced by ion bombardment usually have three major features. First, a gas source is needed within the tube envelope to supply the reacting substances, such as deuterium (H²) and tritium (H³). Second, an ion source strips electrons from the gas molecules to provide positively charged ions. Third, an accelerating gap impels the ions to a target with such energy that the bombarding ions collide with deuterium or tritium target nuclei in neutron (n) generating reactions:



where He³ and He⁴ are helium isotopes, and the energy is expressed in millions of electron volts.

Ordinarily, negative electrons and positively charged ions are produced generally through electron and uncharged gas molecule collisions within the ion source. Electrodes of different potential contribute to ion production by drawing these ions and electrons in different direction. This electrically induced motion enables the electrons to collide with other gas molecules within the source, and thereby produce additional ions and ionizing electrons. Collision efficiency can be increased by lengthening the distance that the electrons travel within the ion source before they are neutralized by striking a positive electrode. One proposed path lengthening technique establishes a magnetic field in conjunction with the aforementioned electric field. The combined fields cause the electrons to describe helical paths within the source. These helical paths substantially increase the distance travelled by the electrons within the ion source and thus enhance the collision efficiency of the device.

Naturally, all contaminating gases adsorbed or otherwise incorporated in the structure of the generator components during manufacture and assembly must be removed before the tube is sealed and operated. Removal of these contaminants usually is accomplished by drawing a vacuum and heating the assembled tube to about 400° C. or more.

This outgassing temperature produces an irreversible effect in the magnetic characteristics of most suitable ion source magnet materials. This irreversible effect is distinguished by a permanent loss in the remanence of the magnet, which usually is defined as the magnet in-

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duction that remains in a magnetic circuit after the removal of an applied magneto-motive force.

A further increase in temperature will produce an effect that alters the properties of the material to such an extent that the material cannot be remagnetized after cooling. The nature of this effect is not entirely clear. The material effect may be caused by exceeding the Curie point of the material (the Curie point being the temperature above which spontaneous magnetic moments vanish). Changes in the crystalline structure of the material also may participate in this material effect. In any event, there is a generally recognized temperature and time dependency that, if exceeded, will render the material magnetically useless in the absence of further special heat treatment. Consequently, magnets external to the tube envelope have been suggested to avoid the need to subject the magnets to outgassing temperatures and the presumed resultant degradation in field strength.

In order to achieve a neutron output of about 10^9 neutrons per second, the minimum proposed generator envelope diameter is approximately one inch. A permanent external magnet circumscribing such an envelope and capable of establishing a flux density of 400 to 800 gauss (g.) within the ion source must have an outside diameter of about two inches. Accordingly, in well logging tools, the logging sonde necessarily must have a diameter greater than two inches. This restriction imposes a severe limitation on neutron logging tools because the diameter of many boreholes through which the sonde ought to pass freely is on the order of two inches.

Thus, it is an object of the invention to provide a new and improved permanent magnet that can produce an appreciable flux density in a high vacuum environment.

It is another object of the invention to provide a new and improved apparatus for reducing ion source dimensions.

It is still another object of the invention to provide a new and improved method for enabling a material to be outgassed and subsequently magnetized to produce a permanent magnetic field of appreciable strength.

It is still another object of the invention to provide a new and improved method and apparatus to enable an ion source magnet to be incorporated within the envelope of a high vacuum or controlled atmosphere tube.

It is still another object of the invention to provide a new and improved method and apparatus to enable an ion source electrode to produce a permanent magnetic field within the source.

SUMMARY OF THE INVENTION

In accordance with the invention, it has been found that permanently magnetizable materials can be heated to temperatures greater than that which ordinarily would produce an irreversible loss of remanent magnetic strength, but less than the threshold for the material effects that render the material useless for subsequent magnetization. This heat treatment drives out occluded contaminants from the magnet material and produces an outgassed permanent magnet with appreciable recoverable remanent magnetism.

More specifically, an electrode in an ion source within the envelope of a neutron generator is made of a ferromagnetic or permanently magnetizable material. The generator is outgassed before sealing by subjecting the assembly to a vacuum and heating it to a temperature higher than the irreversible effect temperature of the electrode material but less than the material effect temperature. The tube then is cooled to room temperature and sealed. Subsequently, the outgassed generator is placed in a strong magnetic field in order to magnetize the electrode. The magnetization thus induced in the electrode provides an ion source electrode that also is a permanent magnet, for example, of Alnico VI that can produce a flux density of 400 g. to 800 g. within the ion source.

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This specific technique enables the overall diameter of a complete neutron generator to be reduced to one inch or less. The relatively greater efficiency of the smaller diameter internal magnet is attained, in part, because flux leakages to other portions of the tube structure are minimized in contrast to the flux leakage paths available to larger, externally mounted magnets. The enclosed combination electrode and permanent magnet, moreover, eliminates the need for careful alignment between an externally mounted magnet and the ion source electrodes of the prior art. Materials for tube construction may be chosen from a larger group inasmuch as the magnetic characteristics of many of the structural members are a subordinate consideration with an internal magnet.

The novel features of the present invention are set forth with particularity in the appended claim. The present invention, both as to its organization and manner of operation, together with further objects and advantages thereof, may best be understood by reference to the following description taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a view in longitudinal section of an exemplary embodiment of the invention, in which the electrical circuits are shown in block diagram form; and

FIG. 2 is a transverse view of the embodiment of the invention shown in FIG. 1, taken along the line 2—2 and looking in the direction of the arrows.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

For a more complete appreciation of the invention, FIG. 1 shows a neutron generator 10 which may be used in well logging applications. The generator 10 comprises a hollow cylindrical tube 11 of glass, or the like. The longitudinal extremities of the tube 11 are fused to electrically conductive end caps 12 and 13. A transverse header 14 and a massive copper target electrode 15 close the end caps 12 and 13, respectively, to provide an air-tight or gas-tight envelope.

The header 14 supports a pinch-off tubulation 16 through which gases within the generator 10 are exhausted during manufacture. Spaced rods 17 and 20 are supported within the envelope by flanges 22 and 23, respectively, on the inner surface of the header 14. Rod 21 (FIG. 2) is supported by the header 14 in a similar manner (not shown) in order to form with rods 17 and 20 three structural support members that are spaced equidistantly from each other. The flanges 22 and 23, which are welded to the header 14, provide a sturdy support and an electrically conductive path for the generator components as described subsequently in more complete detail.

A gas-tight insulator 24 provides a passageway through the header 14 for a conductor 19.

A gas supply 25 is mounted between the mid-portions of the longitudinally extending rods 17, 20 and 21. The gas supply 25 comprises a helically wound filament 26 of tungsten, which may be heated to a predetermined temperature by an electric current from a filament power supply 27 through a subsequently described path. One end of the filament 26 is connected to a supporting end cap 30 which is welded to a perforated heat shield can 31 that is aligned with the longitudinal axis of the tube 11. A cylindrical wall 32 of the can 31 extends from the end cap 30 toward the header 14 for a distance that is greater than the length of the helical portion of the filament 26. The cylindrical wall 32 terminates in a transverse end cap 33 with a centrally disposed insulating ferrule 34 that receives a straight and longitudinally extending portion of the filament 26.

The gas supply 25 is supported in thermal isolation by cylindrical insulators 36 and 40 which are received on rods 17 and 20, respectively. The insulators are pro-

vided with circumferential strap engaging recesses 39 and 41. These recesses provide clearances between supporting straps 42 and 43 and the inner surface of the glass tube 11. The ends of the straps 42 and 43 are welded to the outer surface of the cylindrical wall 32 to complete the rigid support for the gas supply 25. The gas supply 25 is connected in a similar manner to the longitudinal rod 21 (FIG. 2) by a cylindrical insulator and strap (not shown).

A film 44 of zirconium or the like, for absorbing and emitting deuterium and tritium, is coated on the intermediate turns of the filament 26 in order to provide a supply of these gases and to control gas pressure during generator operation. Due to physical isolation, a substantially uniform temperature can be maintained along the coated intermediate turns of the filament helix. In contrast, the endwise turns of the filament helix have a relatively steep temperature gradient due to thermal conduction through the end cap 30 and the conductor 35.

Because gas emission, and hence gas pressure within the generator 10, is a function of the temperature of the film 44, the relatively uniform temperature provided by the intermediate portion of the helix produces a more stable and efficient means for gas pressure control. Thus, as the gases released from the film 44 are withdrawn from the atmosphere within the envelope for neutron generation, more gases are emitted to restore the envelope gas pressure to a level commensurate with the temperature of the intermediate portion of the filament 26. The gases emitted by the film 44 diffuse through the perforations in the can 31 and enter an ion source 45.

The ion source 45 (FIGS. 1 and 2) comprises a cathode 50 that has a massive probe 46, formed of nickel or some other ferromagnetic material, in alignment with the longitudinal axis of the tube 11. An aperture 47 in the cathode 50 diverges outwardly in a direction away from the gas supply 25 to produce a torus-shaped contour 51. The smooth contour 51 reduces a tendency to voltage breakdown that is caused by high electrical field gradients.

A second cathode 52 is spaced from and interposed between the cathode 50 and the end cap 30 of the gas supply 25. Structurally, the second cathode 52 comprises an annulus 53 of nickel, or the like, having an inner countersunk portion 54, the ends of which are disposed toward the probe 46 of the cathode 50. The structure of the second cathode 52 is completed by a thick member or plug 55 of molybdenum in the central aperture of the annulus 53. The plug 55 is brazed to the inner periphery of the nickel annulus 53. The outer periphery of the annulus 53 has small protrusions (such as the protrusion 56) that extend toward the header 14 and are welded to the longitudinally extending rods 17, 20 and 21 to secure the second cathode 52 rigidly to the generator structure. The cathodes 50 and 52, moreover, are connected to the filament power supply 27 and ground 86 through a path that includes the end cap 12, header 14, the flanges 22 and 23, and the rods 17, 20 and 21. The gas supply filament 26 also is connected to the filament power supply 27 through the conductor 35. This circuit is completed to ground 86 through the end cap 30, the cylindrical wall 32, a conductor (not shown), the rod 20, the flange 23, the header 14 and the end cap 12.

In accordance with the invention, a permanent magnetic field for the ion source 45 is provided by a hollow cylindrical anode 57. The anode 57 is interposed between the cathode 50 and the second cathode 52 and is aligned with the longitudinal axis of the generator 10. The anode 57 may be formed of any suitable ferromagnetic or permanently magnetizable material, for example, a ceramic magnet or any one of the Alnico materials, such as Alnico VI, an alloy composed largely of cobalt and nickel. Typically, a positive ionizing potential of about 1500 volts direct current (DC) relative to the cathodes

50 and 52 is applied to the magnetic anode 57 through a longitudinal conductor 60. The conductor 60 is welded on one end to the outer surface of the anode 57 and welded on the end near the header 14 to a lead 61 that enters the envelope through the gas-tight insulator 24.

In one exemplary embodiment of the invention, the anode 57 is about .75" long. The maximum outside diameter of the anode 57 is approximately 0.875" and the inside diameter is about 0.625". After treatment in the manner to be described subsequently, the permanently magnetizable anode 57 not only functions as an ion source electrode, but also establishes a 400 g. to 800 g. magnetic flux density between the cathodes 50 and 52 on the longitudinal axis of the generator 10.

The anode 57 is secured rigidly to the three support rods 17, 20 and 21 (FIG. 2) by means of straps 62, 63 and 64 which engage recesses in respective cylindrical insulators 65, 66 and 67. The insulators 65, 66 and 67 are received on the end portions of the rods 17, 20 and 21 and physically join the anode 57 to the generator structure in substantially the same manner as the gas supply 25. The outer surface of the anode 57 is fluted to accommodate the insulators 65, 66 and 67 and thereby provide a clearance between the inner surface of the tube 11 and the insulators.

The massive probe 46 in the cathode 50 promotes a high flux density within the ion source 45 by focussing the magnetic field established by the anode 57 in the vicinity of the longitudinal axis of the generator 10. The probe 46 is supported in fixed relation to the permanently magnetizable anode 57 by an apertured, concave plate 70 that is oriented toward the header 14 and brazed to the extremities of the support rods 17, 20 and 21. The cathode 50, moreover, provides one of the electrodes for an accelerating gap 72 that impels ionized deuterium and tritium particles from the source 45 toward a deuterium- and tritium-filled carbon target 73. The target 73 is received in an axially aligned recess 74 that is formed in the center of the inner surface of the target electrode 15. The potential that accelerates the ions to this target is established, to a large extent, between the cathode 50 and a suppressor electrode 75. The suppressor electrode 75 is a concave member that is oriented toward the target electrode 15 and has a centrally disposed aperture 78 which enables the accelerated ions to pass from the gap 72 to the target 73.

An electrically conductive rod 76 penetrates the target electrode 15 through a gas-tight insulator 77 and gasket 80. The insulated rod 76 enables a negative accelerating potential of about 40 kv. to 150 kv. relative to the cathode 50 to be applied to the suppressor 75, as described subsequently in more complete detail.

The suppressor 75 is kept approximately 1 kv. more negative than the target 73. This potential difference prevents secondary electrons that are emitted from the target 73 as a result of ion bombardment from traversing the accelerating gap 72 and unproductively draining high voltage accelerating power from the tube. The negative potential gradient in the electric field established between the suppressor 75 and the target 73 returns the negative secondary electrons to the more positive target electrode 15. This feature is favored for continuous generator operation, in which an envelope gas pressure of about one micron or more usually is satisfactory.

If pulses of neutrons are desired, however, the function of the suppressor electrode 75 is less important, inasmuch as the ion bombardment of the target may proceed in bursts spaced in time. If the bursts are sufficiently short, and well separated from each other, secondary electrons in the accelerating gap 72 are dissipated in the interval between the bursts without the presence of a special electrode. Accordingly, in pulse operation, the suppressor electrode may be maintained at a more negative potential than the target 73, or more positive than the target but more negative than the cathode 50 or entirely removed

from the generator 10. A typical generator gas pressure for pulse operation is on the order of 10 to 20 microns.

The carbon target button 73 is retained in the recess 74 of the target electrode 15 by a mounting ring 81 of copper, or the like, that fits in an annular groove between the carbon target 73 and the sides of the recess 74. A brazing compound 82, such as a copper-silver eutectic, joins the mounting ring 81 to the side of the recess 74. The ring 81 overlaps the carbon target button 73 and retains the button securely in alignment with the probe aperture 47 and the aperture 78 in the suppressor electrode 75.

To assemble the generator 10, all of the structural components individually are outgassed of contaminants by heating them in hydrogen at atmospheric pressure to approximately 900° C. for about an hour. The permanently magnetizable anode 57, however, is heated in a vacuum of about 10^{-5} mm. of Hg to about 600° C. for an hour. The components then are fixed in their proper relative positions as hereinbefore described. The assembled components are placed in the center of a radio frequency induction heating coil (not shown). The excited coil produces a temperature of about 600° C. or more in the generator structural components. A vacuum is drawn of about 10^{-5} mm. of Hg pressure, or less, in order to evacuate contaminants absorbed by the structural components during assembly. This baking-out step is continued for approximately 15 minutes or more to insure that all significant quantities of occluded contaminants have been expelled. The entire assembly then is placed within the glass tube 11 and heated in an oven to about 400° C. for fourteen hours at a pressure of about 10^{-8} mm. of Hg or less. When baking-out is complete, the tube first is cooled to room temperature before sealing. The exhaust tubulation 16 then is pinched off and sealed as shown in FIG. 1, after the deuterium-tritium mixture has been introduced into the generator 10 and absorbed by the filament coating 44.

The generator now is aligned longitudinally with a magnetic field (not shown) of sufficient strength to magnetize the anode 57 permanently to produce a field strength of 400 g. to 800 g. on the anode axis. Typically, a magnetizing field established by about 20,000 ampere turns per inch of magnet length is adequate to produce this result. Thus, in accordance with the invention, an outgassed electrode 57 within the generator 10 also establishes a permanent magnetic field for the ion source 45.

In accordance with the invention, at no time during tube assembly and decontamination should the temperature of the anode 57 exceed the material effects temperature of the material being processed. Thus, for example, most of the Alnico compositions must not be heated above about 900° F. to 1100° F., while 1800° F. appears to be the limit for Indox magnets. Inasmuch as material effects seem to be related to changes in the crystalline structure of the material, lower temperature thresholds for material changes must be observed if the period of time to be taken for outgassing is particularly long.

To provide a controlled output of neutrons, continuously or in recurrent bursts, an ion source voltage supply 85 provides power for the bombarding ion beam. For pulse operation a pulse frequency controller 87 can be provided to regulate the operation of voltage supply 85. Controller 87 may be of any suitable type that will emit timed pulses of a selected duration and rate, e.g., about 10 microseconds or more, repeated every second, or less.

A filament supply controller 84 regulates the intensity of the ion beam by controlling the gas pressure in the envelope in response to the voltage developed across a dropping resistor 83. The resistor 83 connects the filament supply controller 84 and a high voltage power supply 88 to the ground 86. The current flowing through the resistor 83 provides a measure of ion beam current that enables the filament controller 84 to adjust the generator gas pres-

sure accordingly. The voltage developed by the high voltage supply 88, moreover, is applied directly to the suppressor 75 and through a dropping resistor 89 to the target electrode 15. The voltages thus developed provide the accelerating and suppressor potentials, respectively. During operation, current is passed through the filament 26 of the gas supply 25 from the filament supply 27 in an amount regulated by the filament controller 84 to achieve a deuterium-tritium pressure within the generator envelope that is appropriate to a desired ion beam current and generator operating condition.

The orientation of the electrical field within the ion source 45 is cross-wise and generally perpendicular to the direction of the magnetic field due to the relative positions of the ion source electrodes. These combined fields increase the path length of the electrons within the ion source to enhance the ionization efficiency of the generator 10.

The high voltage established between the cathode 50 and the suppressor 75 produces a steep voltage gradient that accelerates deuterium and tritium ions from the probe aperture 47 toward the target 73. The energy imparted to the ions is sufficient to initiate neutron generating reactions between the bombarding ions and the target nuclei and to replenish the target 73 with fresh target material.

Initial bombardment of a fresh carbon target 73 by, for example, a half-and-half mixture of deuterium and tritium ions, produces relatively few neutrons. As increasing quantities of impinging ions penetrate and are held in the lattice of the carbon target, however, the probability for nuclear reactions increase. Thus, after a relatively short period of ion bombardment, a continuous or pulsed neutron output of 10^7 to 10^9 neutrons per second is reached.

As previously described, the controller 84 regulates the filament power supply 27 and thereby manipulates the tube gas pressure and the ion beam intensity to produce the desired neutron output. If the neutron output should increase as a result of an increase in the ion current, a corresponding increase in current through the resistor 83 causes the filament supply controller 84 to decrease the filament power supply and thereby reduce the gas pressure within the generator. The lower gas pressure in effect decreases the number of ions available for acceleration, and thus restores the neutron output to a stable, predetermined value. Similarly, a decrease in the current through the resistance 83 causes the filament controller 84 to increase the generator gas pressure.

If desired, the neutron output can be monitored directly, and either the ion source voltage supply 85 or the high voltage power supply 88 can be controlled automatically or manually to achieve stable generator operation.

In the event the generator is supplied only with deuterium gas, neutrons are produced as a result of deuterium-deuterium interactions, rather than the deuterium-tritium reactions considered in the foregoing illustrative description.

While particular embodiments of the present invention have been shown and described, it is apparent that changes and modifications may be made without departing from this invention in its broader aspects and, therefore, the aim in the appended claim is to cover all such changes and modifications as fall within the true spirit and scope of this invention.

What is claimed is:

1. A neutron generator comprising a gas-tight envelope that has at least one axis, a thermally responsive supply of deuterium and tritium gas for maintaining a pressure within said envelope of about 20 microns or less, a pair of spaced electrodes within said envelope and transverse to said one axis thereof, at least one of said electrodes having a massive probe formed of ferromagnetic material in alignment with said axis and entirely within said gas-tight envelope, a hollow Alnico cylinder within said envelope and parallel to said envelope axis interposed between said

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electrodes for establishing a magnetic flux density of about 400 Gauss or more on said envelope axis, said massive probe having a portion, protruding toward said cylinder, that has a maximum diameter that is less than the inside diameter of the cylinder, a conductor for applying an electrical potential of about 1500 volts or more to said hollow cylinder to produce an electrical field between said cylinder and said spaced electrodes generally crosswise to said magnetic field to ionize said deuterium and tritium gas, a target spaced from said pair of electrodes on said envelope axis for changing and replenishment by said deuterium and said tritium gas, and means for producing an electrical potential within said gas-tight envelope to accelerate said deuterium and tritium gas to said target.

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U.S. Cl. X.R.

313—155, 161; 250—84.5