Dec. 26, 1961 W. A. HOYER ETAL 3,015,032

RADIATION GENERATING DEVICE

Filed March 23, 1959

FIG. 1.

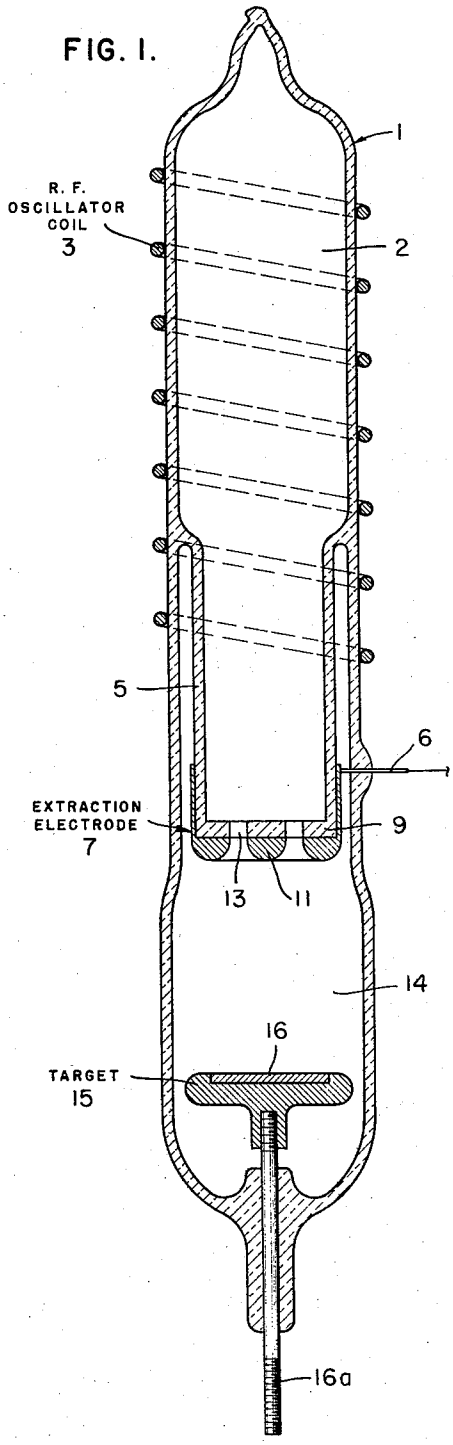
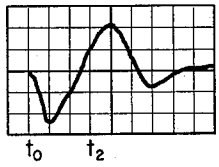


FIG. 3a



FIG. 3b



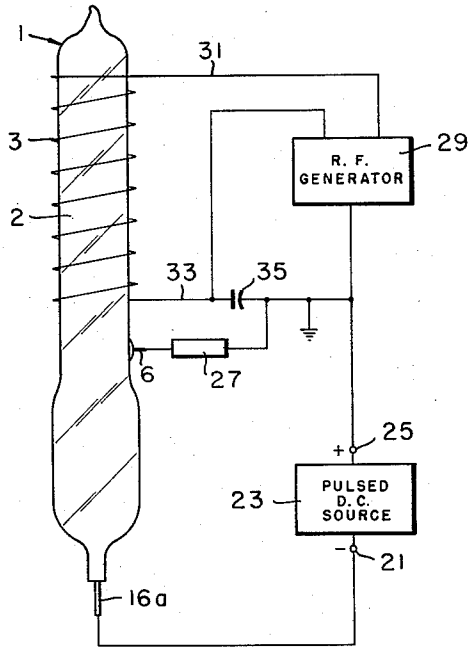


FIG. 2.

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United States Patent Office 3,015,032 Patented Dec. 26, 1961

3,015,032

RADIATION GENERATING DEVICE

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Filed Mar. 23, 1959, Ser. No. 801,292
11 Claims. (Cl. 250—84.5)

This invention relates to atomic particle generating devices, and more particularly to controllable atomic particle generators adapted for logging boreholes.

There have been devised in the past a number of atomic particle generators, particularly neutron generators, making use of a source of electrically charged particles and a charged particle accelerator for directing said particles at a high velocity against certain targets. When the target material, the type of particle, and the particle velocity at the instant of bombardment are all properly selected, a particular nuclear reaction, such as the generation of neutrons, may be obtained. For example, deuterium ions directed at a tritium-containing target by a 100 kv. potential source will produce 14 mev. neutrons from the target. Other nuclear reactions may be used to produce neutrons; such reactions are described in U.S. Patent No. 2,816,242, Goodman.

Neutron generators of the type described above have become particularly useful in connection with the logging of boreholes. However, generation devices known heretofore have been unduly complex and, as a result, often have given considerable trouble in the field. When a neutron generator is lowered down a borehole, it is almost inevitable that the generator will receive strong shocks and suffer vibrations that may damage the constituent parts thereof sufficiently to produce inoperability. Furthermore, as a result of the great number of electrodes and electrical connections in the devices used heretofore, manufacturing costs and the number of rejects due to improper vacuum seals may be unduly high.

According to the teachings of the present invention, use is made of an elongated, gas-tight envelope or housing adapted to be divided into an ionization compartment and an ion accelerating compartment. The gas within the ionization compartment is ionized by generating a radio frequency electromagnetic field therein; a coil may be placed around the ionization compartment and energized from a suitable radio frequency source for this purpose. To maintain an ion plasma in the ionization compartment, a perforated plate is used that divides the envelope into the ionization compartment and the ion accelerating compartment. The plate maintains a partial separation between the two compartments. (The word "plasma" is used here to describe that state of an ionized gas in which the concentrations of negative and positive charges are almost equal. Reference may be had to the article "Operating Characteristics of a High Yield R.F. Ion Source," by H. P. Eubank, R. Truell, and R. A. Peck, Jr., appearing in Review of Scientific Instruments, vol. 25, No. 10 at pp. 989–995, for a discussion of ionized gas plasma.)

A target is placed in the ion accelerating compartment so that ions from the ionization compartment will impinge thereon after passing through the perforations in the plate. A high voltage pulse source is connected between the coil and the target. Electric lines of force will pass between the coil and the target through the ionized gas plasma; the capacitive coupling between the coil and the plasma, and the low impedance drop in the plasma will cause the lines of force to preferentially pass through the plasma rather than to follow other paths between the coil and the target. Secondary electrons

emitted from the target will tend to collect on the plate and may be drained off through an impedance element connected between the coil and the plate. The voltage drop across the impedance element will place the plate at a negative potential with respect to the coil to facilitate the extraction of ions out of the ionization compartment and to further accelerate the removal of secondary electrons.

The invention will be described in more detail with respect to the accompanying drawings, wherein:

FIG. 1 is a cross-sectional side view of an embodiment of the invention;

FIG. 2 is a schematic diagram of the generator shown in FIG. 1 and electrical equipment for controlling the operation of the neutron generator; and

FIGS. 3*a* and 3*b* illustrate voltage waveforms that appear at the output terminals of the pulsed voltage source in FIG. 2 and across the impedance element **27** of FIG. 2.

The neutron generator comprises a suitable housing **1** which may be an elongated, gas-tight envelope of glass, boron nitride, quartz, or other suitable non-conductive material that does not tend to absorb or adsorb gases. The housing is divided into an ionization compartment **2** and an accelerating gap compartment **14** by a partition including a glass neck **5** supporting an extraction electrode **7** which may comprise a layer **9** of glass or other vitreous material facing the ionization compartment, and a layer **11** of conductive metal facing the accelerating gap. The metallic portion **11** of the electrode may be extended up the neck **5** a small distance to facilitate mechanical attachment of the extraction electrode **7** to the glass neck. A connection pin **6** that extends through housing **1** is electrically connected to the conductive metallic portion **11** of the extraction electrode.

Perforations are provided in glass layer **9** and conductive metal layer **11** for the purpose of permitting ions to pass from ionization compartment **2** into the accelerating gap **14**. The perforations preferably are between .08 and .2 inch in diameter and should not comprise more than 15 percent of the area of layer **9** facing compartment **2**. The perforations in glass layer **9** match the perforations in conductive metal layer **11** to provide substantially continuous passages **13** through the extraction electrode. One purpose of the glass layer **9** is to prevent lines of force from terminating on the side of the extraction electrode facing the ionization compartment. The lines of force tend to be constricted to the perforations to facilitate the extraction of ions out of the compartment. Another purpose of glass layer **9** is to keep the ions in compartment **2** in the monoatomic state; the ions are converted to the diatomic state on contact with metal. Having the ions remain monoatomic increases the efficiency of the neutron generator because less acceleration voltage is required to accelerate the ions to the desired acceleration level. The number of perforations in the extraction electrode should be great enough to permit a fairly diffused beam of ions to be directed against the target in the accelerating gap compartment, hereinafter described. The total area of the perforations, however, should not be so great as to destroy the ion plasma produced in the ionization compartment.

An ion target **15** is positioned in the accelerating gap compartment **14** at the opposite end of the compartment from the extraction electrode **7**. The surface of the target **15** facing toward compartment **2** may be recessed to receive a wafer **16** of tritium-containing target material upon which ions from ionization compartment **2** impinge. The entire interior of the housing may be filled with deuterium gas at a prsesure of between 15 and 60 microns of mercury.

As shown more clearly in FIG. 2, a radio frequency coil 3 is positioned around the ionization compartment 2. The coil is connected to a suitable source of radio frequency energy 29 by electrical leads 31 and 33. For the purpose of providing an electric field to extract ions from the accelerating compartment 2 toward target 15, there is provided a pulsed voltage source 23 having output terminals 21 and 25. Terminal 21 is connected to conductive rod 16*a* which extends through housing 1 to support target 15. Terminal 25 is connected to electrical lead 33 by capacitor 35 to place coil 3 at ground potential insofar as alternating currents are concerned. Capacitor 35 may be included in radio frequency generator 29, if this is convenient.

An impedance element 27 is connected between terminal 25 and extraction electrode pin 6. Preferably the impedance element 27 is a resistor having a resistance of between 1000 and 100,000 ohms. An electrical capacitor having a capacity of between 20 and 100 $\mu\mu$fd. may be utilized. The function of impedance element 27 is to bleed secondary electrons that may collect on extraction electrode 7.

In operation, the radio frequency energy source 29 is energized to produce an ionized gas plasma in ionization compartment 2. Assume now that a voltage pulse having substantially the waveform shown in FIG. 3*a* is applied between coil 3 and target 15. For the portion of the pulse from time t_0 to time t_2, target 15 will be at a negative potential with respect to coil 3. By virtue of the electrical capacity existing between oscillating coil 3 and the plasma, elecrical lines of force will tend to pass through the plasma, through the perforations in extraction electrode 7, and through the accelerating gap 14 to attract a limited number of ions toward target 15. Secondary electrons are produced along with neutrons by the ions striking the target. The secondary electrons will be attracted toward extraction electrode 7 and will be bled off by impedance element 27. The current flow through impedance element 27 will produce a potential difference between coil 3 and the extraction electrode that will increase the number of ions swept through the perforations in the extraction electrode. The number of secondary electrons emitted by target 15 will increase, thereby increasing the potential difference across impedance element 27. The waveform of the voltage across element 27 will be similar to the voltage waveform between terminals 21 and 25. The voltage waveform of voltage that will be produced across impedance element 27 is shown in FIG. 3*b* using the same time scale as the waveform of the output voltage of source 23 shown in FIG. 3*a*. In operation, it will be found that a peak voltage of between 2000 and 5000 volts may be easily produced across impedance element 27.

It should be emphasized that the voltage drop through the plasma in the ionization compartment 2 will be relatively small inasmuch as the impedance drop through the plasma is small. Therefore, the major portion of the voltage drop between coil 3 and target 15 will appear between the target and the extraction electrode.

There is provided by the invention a very rugged, trouble-free neutron source. Inasmuch as there are only two electrical connections to be made through the housing, the neutron source is mechanically very strong and sturdy. High intensity radiation may be produced from the source that is particularly suitable for borehole logging purposes.

The invention is not to be restricted to the specific structural details, arrangement of parts, or circuit connections herein set forth, as various modifications thereof may be effected without departing from the spirit and scope of this invention.

What is claimed is:

1. A neutron generator comprising: an elongated vitreous envelope for deuterium gas, adapted to be divided into an ion generating compartment and an ion accelerating gap compartment; a partition dividing said envelope into said ion generating compartment and said accelerating gap compartment, said partition comprising a first perforated layer of conductive metal facing the accelerating gap compartment and a second perforated layer of vitreous material facing the ion generating compartment, the perforations in said first layer matching the perforations in said second layer; a tritium-containing ion target in said accelerating gap compartment adapted to emit neutrons and electrons when stricken by ions from said ion generating compartment; a radio-frequency coil around said ion generating compartment adapted to produce an ionized gas plasma in said ion generating compartment when energized by a source of radio frequency energy; a pulse generator having first and second output terminals, adapted to produce pulses with a peak voltage of between 60 and 120 kilovolts, having a duration of between 3 and 8 microseconds, and with a repetition rate of between 100 and 5000 pulses per second; means connecting said first terminal to said radio frequency coil and connecting said second terminal to said target so that positive ions are attracted to said target; and electrical resistance means having a resistance of between 1000 and 100,000 ohms connected between said first perforated layer and said target.

2. A neutron generator comprising: an elongated vitreous envelope for deuterium gas, adapted to be divided into an ion generating compartment and an ion accelerating gap compartment; an ion permeable partition dividing said envelope into said ion generating compartment and said accelerating gap compartment, said partition comprising a first perforated layer of conductive metal facing the accelerating gap compartment and a second perforated layer of vitreous material facing the ion generating compartment, the perforations in said first layer matching the perforations in said second layer, said perforations being between .08 and .2 inch in diameter; a tritium-containing ion target in said accelerating gap compartment adapted to emit neutrons and electrons when stricken by ions from said ion generating compartment; a radio-frequency coil around said ion generating compartment adapted to produce an ionized gas plasma in said ion generating compartment when energized by a source of radio frequency energy; a pulse generator having first and second output terminals, adapted to produce pulses with a peak voltage of between 60 and 120 kilovolts, a duration of between 3 and 8 microseconds, and with a repetition rate of between 100 and 1500 pulses per second; means connecting said first terminal to said radio-frequency coil and connecting said second terminal to said target so that positive ions are attracted to said target; and electrical resistance means having a resistance of between 1000 and 100,000 ohms connected between said first perforated layer and said target.

3. A neutron generator comprising: an elongated vitreous envelope for deuterium gas, adapted to be divided into an ion generating compartment and an ion accelerating gap compartment; an ion permeable partition dividing said envelope into said ion generating compartment and said accelerating gap compartment, said partition comprising a first perforated layer of conductive metal facing the accelerating gap compartment and a second perforated layer of vitreous material facing the ion generating compartment, the perforations in said first layer matching the perforations in said second layer; a tritium-containing ion target in said accelerating gap compartment adapted to emit neutrons and electrons when stricken by ions from said ion generating compartment; a radio-frequency coil around said ion generating compartment adapted to produce an ionized gas plasma in said ion generating compartment when energized by a source of radio frequency energy; a pulse generator having first and second output terminals; means connecting said first terminal to said radio-frequency coil and connecting said second terminal to said target so that

positive ions are attracted to said target; and electrical resistance means having a resistance of between 1000 and 100,000 ohms connected between said first perforated layer and said target.

4. A neutron generator comprising: an elongated vitreous envelope for deuterium gas, adapted to be divided into an ion generating compartment and an ion accelerating gap compartment; an ion permeable partition dividing said envolpe into said ion generating compartment and said accelerating gap compartment, said partition comprising a first perforated layer of conductive metal facing the accelerating gap compartment and a second perforated layer of vitreous material facing the ion generating compartment, the perforations in said first layer matching the perforations in said second layer; a tritium-containing ion target in said accelerating gap compartment adapted to emit neutrons and electrons when striken by ions from said ion generating compartment; a radio-frequency coil around said ion generating compartment adapted to produce an ionized gas plasma in said ion generating compartment when energized by a source of radio frequency energy; a pulse generator having first and second output terminals, adapted to produce pulses with a peak voltage of between 60 and 120 kilovolts, a duration of between 3 and 8 microseconds, and with a repetition rate of between 100 and 5000 pulses per second; connection means connecting said first terminal to said radio-frequency coil and connecting said second terminal to said target so that positive ions are attracted to said target; and electrical impedance means connected between said first perforated layer and said coil adapted to drain secondary electrons emitted by said target, said impedance means having an impedance sufficient to place said first perforated partition at a voltage of at least 1000 volts negative with respect to said radio-frequency coil.

5. A neutron generator comprising: an elongated, electrically nonconductive envelope for an ionizable gas; an ion permeable partition in said envelope dividing said envelope into an ion generating compartment and an accelerating gap compartment, said partition having a plurality of openings therein through which ions may pass, said openings having a diameter less than .2 inch; an ion target in said accelerating gap compartment adapted to emit neutrons and electrons when stricken by ions from said ion generating compartment; a radio-frequency field producing means operatively associated with said ion generating compartment for inducing a radio-frequency field in said ion generating compartment to produce an ionized gas plasma in said compartment; a voltage pulse generator having first and second terminals; and circuit means connecting said first terminal to said target and said second terminal to said radio-frequency field producing means so that said target is at a negative potential with respect to said coil during at least a portion of each pulse.

6. A neutron generator comprising: an elongated, electrically nonconductive envelope for an ionizable gas; a partition in said envelope dividing said envelope into an ion generating compartment and an accelerating gap compartment, said partition having a plurality of openings therein through which ions may pass, said openings having a diameter less than .2 inch; an ion target in said accelerating gap compartment adapted to emit neutrons and electrons when stricken by ions from said ion generating compartment; a radio-frequency field producing means operatively associated with said ion generating compartment for inducing a radio-frequency field in said ion generating compartment to produce an ionized gas plasma in said compartment, said radio-frequency field producing means including a coil positioned around said ion generating compartment and adapted to be energized by radio frequency current; a voltage pulse generator having first and second output terminals; and circuit means connecting said first terminal to said target and said second terminal to said coil so that said target is at a negative potential with respect to said coil for at least a portion of each pulse.

7. A neutron generator comprising: an elongated, electrically nonconductive envelope for an ionizable gas; an ion permeable partition in said envelope dividing said envelope into an ion generating compartment and an ion accelerating gap compartment; an ion target in said accelerating gap compartment adapted to emit neutrons and electrons when stricken by ions from said ion generating compartment; means including a radio frequency coil operatively associated with said ion generating compartment for inducing a radio frequency field in said ion generating compartment to produce an ionized gas plasma in said ion generating compartment; a voltage pulse generator connected between said coil and said target to periodically place said target at a negative potential with respect to said coil; and an electrical impedance means connected between said partition and said coil adapted to drain secondary electrons emitted by said target and collected on said partition.

8. A neutron generator comprising: an elongated, electrically nonconductive envelope for an ionizable gas; an ion permeable partition in said envelope dividing said envelope into an ion generating compartment and an ion accelerating gap compartment; an ion target in said accelerating gap compartment adapted to emit neutrons and electrons when stricken by ions from said ion generating compartment; means including a radio frequency coil operatively associated with said ion generating compartment for inducing a radio frequency field in said ion generating compartment to produce an ionized gas plasma in said ion generating compartment; a voltage pulse generator connected between said coil and said target to periodically place said target at a negative potential with respect to said coil; and means including an electrical resistance means having a resistance of between 1000 and 100,000 ohms connected between said partition and said coil and adapted to drain from said partition the secondary electrons emitted by said target and collected on said partition.

9. A neutron generator comprising: an elongated envelope, electrically nonconductive for an ionizable gas; an ion permeable partition in said envelope dividing said envelope into an ion generating compartment and an ion accelerating gap compartment; an ion target in said accelerating gap compartment adapted to emit neutrons and electrons when stricken by ions from said ion generating compartment; means including a radio frequency coil operatively associated with said ion generating compartment for inducing a radio frequency field in said ion generating compartment to produce an ionized gas plasma in said ion generating compartment; a voltage pulse generator connected between said coil and said target to periodically place said target at a negative potential with respect to said coil; and electrical capacitor means having a capacitance between 20 and 100 $\mu\mu$fd. connected between said partition and said coil and adapted to drain from said partition the secondary electrons emitted by said target and collected by said partition.

10. A neutron generator comprising: an elongated, electrically nonconductive envelope for an ionizable gas; an ion permeable partition in said envelope dividing said envelope into an ion generating compartment and an ion accelerating gap compartment, said permeable partition comprising an electrically nonconductive layer facing said ion generating compartment and an electrically conductive layer facing said ion accelerating gap compartment; an ion target in said accelerating gap compartment adapted to emit neutrons and electrons when striken by ions from said ion generating compartment; means including a radio frequency coil operatively associated with said ion generating compartment for inducing a radio frequency field in said ion generating compartment to produce an ionized gas plasma in said ion generating

compartment; a voltage pulse generator connected between said coil and said target to periodically place said target at a negative potential with respect to said coil; and an electrical impedance means connected between said electrically conductive layer of said ion permeable partition and said coil adapted to drain secondary electrons emitted by said target and collected on said electrically nonconductive layer.

11. A neutron generator comprising: an elongated, electrically nonconductive envelope for an ionizable gas; an ion permeable partition in said envelope dividing said envelope into an ion generating compartment and an ion accelerating gap compartment, said permeable partition comprising an electrically nonconductive layer facing said ion generating compartment and an electrically conductive layer facing said ion accelerating gap compartment; an ion target in said accelerating gap compartment adapted to emit neutrons and electrons when stricken by ion from said ion generating compartment; means including a radio frequency coil operatively associated with said ion generating compartment for inducing a radio frequency field in said ion generating compartment to produce an ionized gas plasma in said ion generating compartment; a voltage pulse generator connected between said coil and said target to periodically place said target at a negative potential with respect to said coil; and means including electrical resistance means

having resistance of between 1000 and 100,000 ohms connected between said electrically conductive layer of said ion permeable partition and said coil, adapted to drain from said electrically conductive layer the secondary electrons emitted by said target and collected on said electrically conductive layer.

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