June 13, 1961 S. SOLOWAY 2,988,642

PARTICLE ACCELERATING SYSTEM

Filed June 30, 1958

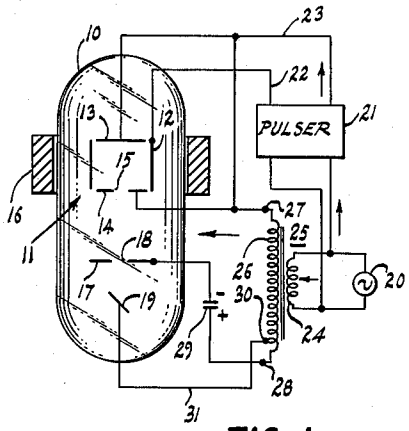


FIG. 1

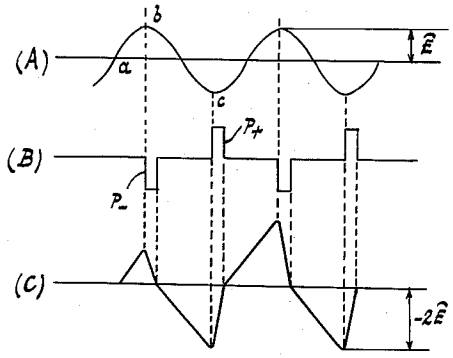


FIG. 2

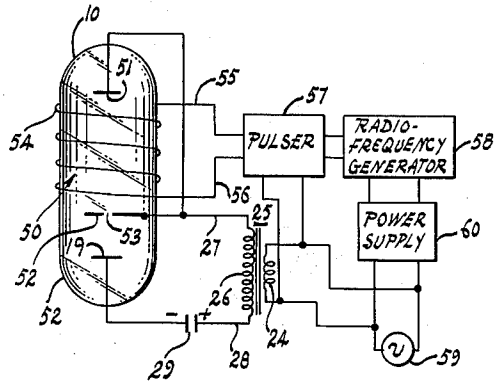


FIG. 4

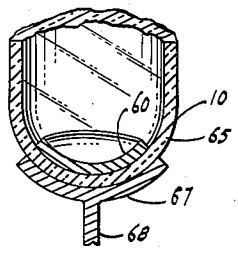


FIG. 5

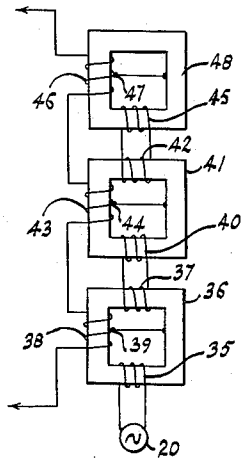


FIG. 3

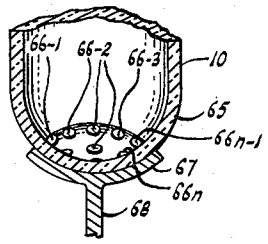


FIG. 6

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PARTICLE ACCELERATING SYSTEM

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11 Claims. (Cl. 250—84.5)

This invention relates to particle accelerating systems and, more particularly, pertains to new and improved particle accelerating systems adapted to utilize an undulating potential.

There are in present use various devices for deriving radioactive radiation which, in general, comprise a source of electrically-charged particles and a charged-particle accelerator for directing the particles at a high velocity against a reactive target. By properly selecting the type of particles, the target material and the particle velocity at the instant of bombardment, a particular type of nuclear reaction may be obtained at the target.

To energize the particle accelerator in apparatus of the foregoing type, ordinarily a unidirectional potential is employed. For example, to energize one type of apparatus in which ions of deuterium are accelerated toward a target containing tritium to produce nuclear reactions from which neutrons are derived, a potential in a range from 50–100 kilovolts is needed. Of course, there are many other reactions in which even higher voltages are required.

Various forms of generators and power supplies have been proposed to provide the high voltages required for particle accelerators of the foregoing type. For instance, van de Graaf machines have been employed in which an insulating conveyor carries charges deposited at a relatively low potential to a relatively high potential where they are removed. These generators, while satisfactory for laboratory use, are usually quite bulky and are not well suited for applications in which the source of radioactive radiation must be portable, such as in apparatus for use in a borehole drilled into the earth.

High voltages may also be obtained through the use of a step-up transformer and associated voltage-multiplying rectifier and a smoothing filter. This type of power supply, however, may be relatively complex in design where a large number of stages of multiplication is required. If fewer such stages are used, the design requirements on the step-up transformer become quite severe to maintain a given D.C. output voltage.

It is an object of the present invention, therefore, to provide a new and improved A.C. operated particle accelerating system.

Another object of the present invention is to provide a new and improved particle accelerating system wherein the effective accelerating potential is equal to the peak-to-peak voltage of an applied alternating voltage.

Yet another object of the present invention is to provide a new and improved particle accelerating system and associated power source relatively small in size and thereby compatible with the space requirements of well logging service.

A particle accelerating system in accordance with the present invention is adapted to be energized by an alternating potential and includes an envelope containing an ionizable gas, discharge-producing means for selectively producing ions and electrons in the envelope, and particle accelerating means having at least one electrode. Means including a series capacitance is provided for applying the alternating potential between the electrode of the particle accelerating means and a reference point within the envelope. The system further comprises means synchronous with the applied alternating potential for operatively conditioning the discharge-producing means during a relatively short interval of time in each of alternate half-cycles of the applied alternating potential.

The novel features of the present invention are set forth with particularity in the appended claims. 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 connection with the accompanying drawing in which:

FIG. 1 is a schematic diagram of a radiant energy source including a particle accelerating system featuring the present invention;

FIG. 2 includes a series of curves representing various operating conditions in the apparatus illustrated in FIG. 1 plotted as a function of time and useful in explaining its operation;

FIG. 3 is a schematic diagram of a power supply arrangement which may be used with the apparatus shown in FIG. 1; and

FIGS. 4, 5 and 6 represent various modifications which may be made to the apparatus illustrated in FIG. 1.

As shown in FIG. 1 of the drawing, a particle accelerating system embodying the present invention may employ a cylindrical, elongated envelope **10** which may be manufactured, for example, of out-gassed glass, or other electrically insulating material. The envelope is evacuated, and filled with an ionizable gas such as deuterium at a pressure in a range from 0.1–10 microns of mercury.

Envelope **10** includes an ion source section **11** having a cylindrical anode **12** and disc-like cathodes supported at the open ends of the anode. One of the cathodes **14** is provided with an ion-admitting aperture **15**. A cylindrical magnet **16** encloses the section of envelope **10** containing the ion source and is essentially coextensive with cylindrical electrode **12**. The spacing between the anode and cathode electrodes of the ion source section **11** is selected in a known manner so that an ionic discharge occurs when a given potential is applied.

Another disc-like electrode **17** is supported in parallel relation to electrode **14** and is provided with a central aperture **18** axially aligned with aperture **15**. Electrode **17** is spaced from electrode **14** at appropriate distance to minimize the possibility of electrical break-down at a given potential. This spacing is selected in a known manner. Supported adjacent electrode **17**, on the side thereof opposite electrode **14**, is a target **19** which may, for example, be composed of zirconium in which another isotope of hydrogen, tritium, is occluded. If desired, however, a deuterium containing target may be employed.

Suitable electrical connections may be made to the electrodes within envelope **10** by various leads which pass through the envelope through appropriate fluid-tight seals.

To energize the device thus-far described, a source of alternating potential **20** is coupled to and powers a conventional direct current pulser **21**. The pulser is arranged in a conventional manner to provide pulses in synchronism with the undulations of the applied voltage and having a magnitude sufficient to energize the ion source **11**. These pulses occur during respective half-cycles of the applied alternating potential. They have a relatively short duration compared to such half-cycles, may alternate in polarity and are applied between anode **12** and cathodes **13**, **14** over leads **22** and **23**.

Source **20** is also coupled to a primary winding **24** of a step-up transformer **25**. The transformer has a high voltage secondary winding **26**, one terminal **27** of which is connected to cathodes **13**, **14**. The opposite terminal **28** is connected via a charging condenser **29** to electrode **17**. A tap **30** on winding **26**, relatively close to terminal **28**, is connected by a lead **31** to target **19**. Transformer **25** is constructed in a known manner so that the voltage de-

rived at secondary **26** has a peak-to-peak value of, for example, 65 kilovolts supplied at terminals **27** and **28** at a current of one milliampere.

In describing the operation of the apparatus illustrated in FIG. 1, occasional reference will be made to FIG. 2 in which the wave forms of the voltages at various points in the system are plotted to a common time scale.

Let it be assumed that ion source section **11** of the system is energized by a suitable voltage at leads **22** and **23**, and that initially anode **12** is positive relative to cathodes **13** and **14**. Any stray electrons within the envelope are attracted toward the positively charged electrode **12**, but because of the presence of the field produced by magnet **16** these electrons travel in spiral paths and have a good chance of experiencing ionizing collisions with molecules of deuterium gas. Of course, from each such collision a plurality of electrons are derived all of which travel in spiral paths toward anode **12**. This action is cumulative, i.e., an avalanche-type discharge occurs with both ions and electrons being formed in a plasma within anode **12**. Ions, of course are attracted toward the negatively-charged electrodes **13** and **14**, while electrons are attracted toward the positively-charged electrode **12**. Ions that are driven against the negatively-charged electrodes also produce collisions in which electrons are derived thereby assisting in the cumulative action.

A similar action takes place if the potential of the opposite polarity is applied to the electrodes. However, it is evident that the positively charged ions would then be attracted toward electrode **12** while electrons would be attracted toward cathodes **13** and **14**.

As seen in FIG. 2A, the voltage between terminals **27** and **28** alternates in polarity so that during successive half-cycles the voltage between electrodes **14** and **17** is correspondingly positive and negative. During the portion *a, b,* of a positive half-cycle represented in FIG. 2A, the voltage at terminal **28** and thus at electrode **18** becomes increasingly positive relative to the voltage at terminal **27** (and electrode **14**). At the instant this voltage is a maximum, a negative pulse is initiated by pulser **21** and supplied to ion source **11**, as represented by the pulse $p-$ in FIG. 2B. Thus, the voltage at electrode **12** is driven sharply negative relative to electrodes **13** and **14** to a value at which a discharge occurs in ion source section **11** and, as mentioned hereinbefore, ions and electrons are derived within the ion source. Since electrode **17** is positive relative to electrode **14**, electrons are drawn from within the plasma through aperture **15** and impinge on electrode **17**. Those of the electron which pass through aperture **18**, of course, are collected at anode **19**. Accordingly, electrons from ion source section **11** effectively short circuit electrodes **14** and **17**, and condenser **29** is effectively connected across secondary winding **26**. This permits condenser **29** to charge to a potential equal to the peak value, E, of the voltage at secondary **26**. Pulse $p-$ persists long enough for the condenser to charge completely, however, this interval is usually short compared to the period of the alternating wave represented in FIG. 2A.

After the termination of pulse $p-$ the discharge in ion source **11** ceases and the circuit to condenser **29** is effectively opened. The condenser thus retains the charge it derives during the occurrence of pulse $p-$ while the voltage at terminal **28** changes from the maximum positive value *b,* passes through zero and reaches the maximum negative value, *c,* represented in FIG. 2A.

At this point in time *c,* terminal **28** is negative relative to terminal **27**, and added to the voltage at the secondary **26**, is the charge voltage of condenser **29**. Thus, the voltage between electrodes **14** and **17** is equal to the peak-to-peak value of the applied alternating potential, represented as $-2E$ in FIG. 2C. It is at this instant that pulser **21** supplies a positive pulse $p+$ (FIG. 2B) to ion source **11** to produce a discharge. Positive ions derived in this discharge, namely deuterons, are accelerated by the potential between electrodes **14** and **17**, and many pass through aperture **18** and impinge on target **19**.

Because of its connection at tap **39**, the target is at a potential slightly more positive than electrode **17**, tap **30** and secondary electron acceleration is minimized.

Since deuterons are accelerated through a potential of 65 kilovolts before impinging on target **19**, they reach velocities sufficient to enter into interactions with tritium in the target to produce neutrons of an energy of 14 million electron volts. This occurs during each pulse $p+$, i.e., a burst of neutrons is produced.

During the occurrence of pulse $p+$, electrodes **14** and **17** are effectively short circuited by the ion beam and condenser **29** charges to the polarity opposite to that represented in FIG. 1. This charge remains until the succeeding half-cycle when pulse $p-$ occurs and the condenser is discharged before it is charged in the opposite direction in a manner explained hereinbefore.

It is thus evident that by coupling the source of alternating potential to the accelerating means through a capacitor, and effectively short circuiting the capacitor at the peaks of the applied voltage, the excursions of the electrodes **14** and **18** extend through a voltage 2E, where E is the peak value of the applied alternating potential.

By pulsing the ion source **11**, the accelerator section **14, 17** itself performs as the switch for effectively short circuiting the condenser **29**. Accordingly, there is no need to provide external voltage multipliers.

Because the effective voltage is equal to the peak-to-peak voltage of the secondary **26**, rather than the average voltage, as would occur in a typical rectifier system, the design requirements for transformer **25** are much less stringent than heretofore required. As a result, the transformer may be small in size and compatible with the space requirements of well logging service.

If desired, a system ground may be connected at any desired point in the circuit. For example, terminal **27** may be grounded. In this case terminal **28** would exhibit a voltage relative to ground equal to the peak-to-peak value of the developed alternating voltage at secondary **26**. If, for example, a center tap for winding **26** is grounded, the voltage between terminal **27** and the system ground would be equal to an appropriate fraction of the developed peak-to-peak voltage.

An arrangement for achieving a high alternating potential in a narrow diameter is represented in FIG. 3. Source **20** is coupled to primary winding **35** of a first transformer having a rectangular core **36**. This transformer has a secondary winding **37** having a turns ratio to primary winding **35** of 1:1, and a high voltage secondary winding **38** whose center tap **39** is connected to core **36**.

Secondary winding **37** is connected to primary winding **40** of another transformer having a rectangular core **41** and a low voltage secondary winding **42** similar to winding **37**. On core **41** is a high voltage winding **43** like winding **38** provided with a center tap connected to core **41**.

Secondary **42** is connected to primary winding **45** of a third transformer having a rectangular core **48** and a high voltage secondary winding **46** similar to the other high voltage secondary windings. Winding **46** has a center tap **47** connected to core **48**.

The several secondary windings **38, 43** and **46** are connected in series-aiding relationship and the cores **36, 41** and **46** are electrically insulated from one another. In this way the transformers act as isolation as well as step-up transformers. The cores may be of conventional construction, for example, they may be fabricated in the usual way of laminated iron. High voltages and small size may be achieved by using cores made of ferro-magnetic particles bound together by an electrical insulator. One core material of this general class is known as ferroxcube and an operating frequency of 50 kilocycles per second may be employed for source **20**.

In FIG. 4, the invention is illustrated as applied to a

device in which ions are derived by the use of a radio-frequency field. Elements which are similar to ones represented in FIG. 1 are denoted by the same reference numerals.

Here, a portion of envelope **10**, designated as an ion source section **50**, is provided with a pair of opposed electrodes **51** and **52**, the latter of which is provided with an ion-admitting aperture **53**. Enclosing the envelope in a zone between electrodes **51** and **52** is a radio-frequency coil **54** connected by leads **55** and **56** to a pulser **57** driven by a radio-frequency generator **58**. If desired, an appropriately energized suppression electrode may be positioned adjacent to target **19**.

An alternating potential source **59** is connected to a power supply **60** which provides a unidirectional potential for energizing generator **58**. Source **59** is also connected to primary winding **24** of a step-up transformer **25** whose secondary winding **26** develops the required high voltage. Terminal **27** of winding **26** is connected to electrodes **51** and **52**, and terminal **28** is connected via condenser **29** to target electrode **19**. Connections from source **59** extend to pulser **57** for synchronizing its operation.

The operation of the system of FIG. 4 is similar to the one illustrated in FIG. 1, however, during each of the pulses $p-$ and $p+$ of FIG. 2B, a burst of radio-frequency energy is supplied to coil **54**. As is well known, if the radio-frequency field thus created is of sufficient intensity, an ionic discharge is produced in which both electrons and ions are derived. During one portion of an operating cycle, electrode **52** operates as a probe for electrons which pass through aperture **53**. During alternate half-cycles it acts as a probe for deuterium ions which also pass through the aperture. It should thus be evident that condenser **29** attains a charge of the polarity represented during half-cycles of one polarity and then its voltage is added to the developed A.C. voltage during the other half-cycle as described in connection with FIG. 1.

In selecting a value for the capacitance of condenser **29** in either of FIGS. 1 or 4, it has been found that a capacitance of, for example, 25 micromicrofarads may be employed with an operating potential of 65 kilovolts. Under these conditions, the condenser accumulates a charge of 1.63×10^{-6} coulombs. At an operating frequency of 1,000 cycles per second, 20% of the energy is delivered by the condenser and thus an average current of 0.33 milliampere is obtained. This is entirely satisfactory for the proper operation of apparatus embodying the invention, as a neutron producer.

A convenient way of constructing condenser **29** is illustrated in FIG. 5. Here, glass envelope **10** includes a lower semi-cylindrical section **65** and a modified target **66** is conformed to and disposed in interfitting relation with the inner wall of envelope portion **65**. A metallic plate **67** is conformed to the outer wall of envelope portion **65** and is substantially coextensive with target **66**. Plate **67** is provided with a central terminal **68** to facilitate electrical connection to it. In this way, glass envelope **10** operates as a dielectric for a condenser constituted by target **66** and plate **67**. The surface areas of the target and of the plate are selected in view of the thickness of envelope portion **65** to obtain a desired capacitance in a known manner.

This arrangement of FIG. 5 may be modified in the manner illustrated in FIG. 6 where the target is shown to be constituted of a plurality of small, discrete metal hydride plates **66–1**, **66–2**, **66–3**, . . . **66*n*–1**, and **66*n*** electrically insulated from one another. Each of these plates forms a capacitance with plate **67** and a charge is built up in the same manner described hereinbefore. However, when the ion beam comes into action, it discharges the capacitance formed by the central plates, while charges retained on adjacent plates tend to pull the beam apart. In this way, the beam is defocussed and the life of the target is improved.

In the arrangement of FIG. 6 it may be desirable to provide a suitable electrode between targets **66** and the other member of the accelerating gap and operated in such a way so that during the portions of operating cycles when electrons are accelerated, i.e., electrons effectively short circuit the accelerating gap, the beam is defocussed so that all of the several capacitors are charged. During the portion of each operating cycle when the ion beam is produced, this defocussing is disabled so that the ions impinge on the target plates in the form of a beam which is appropriately defocussed in the manner described.

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 broad aspects, and therefore the aim in the appended claims is to cover all such changes and modifications as fall within the true spirit and scope of this invention.

I claim:

1. A particle accelerating system comprising: an envelope containing an ionizable gas; discharge-producing means associated with a portion of said envelope for selectively producing ions and electrons therein; a pair of accelerating electrodes within said envelope, one of said electrodes being in the vincinity of said discharge-producing means; a source of alternating potential having a pair of terminals connected to respective ones of said pair of electrodes; a capacitor in series circuit relation with one of the connections between said source and said electrodes; and means coupled to said discharge-producing means and operative synchronously with the alternating potential of said source for energizing said discharge-producing means during relatively short intervals of time in the vicinity of maximum negative and positive excursions of the alternating potential.

2. A particle accelerating system comprising: an envelope containing an ionizable gas; discharge-producing and ion accelerating means associated with said envelope; a source of alternating potential coupled to the ion accelerating portion of the aforesaid means; a capacitor in series circuit relation with said source; and means coupled to the discharge-producing portion of said means and operative synchronously with the alternating potential of said source for energizing said discharge-producing portion during relatively short intervals of time in the vicinity of maximum negative and positive excursions of the alternating potential.

3. A particle accelerating system comprising: an envelope containing an ionizable gas; discharge-producing means including at least one electrode disposed within said envelope; at least one accelerating electrode disposed within said envelope in the vicinity of said discharge-producing means; a source of alternating potential coupled to said accelerating electrode and to a reference point; a capacitor in series circuit relation with said source; and means coupled to said discharge-producing means and operative synchronously with the alternating potential of said source for energizing said discharge-producing means during relatively short intervals of time in the vicinity of maximum negative and positive excursions of the alternating potential.

4. A particle accelerating system comprising: an envelope containing an ionizable gas; discharge-producing means associated with said envelope for selectively producing ions and electrons therein; a first electrode supported within said envelope and associated with said discharge-producing means; a second electrode supported within said envelope and operatively associated with said first electrode to constitute an ion accelerating gap; a target supported within said envelope in the vicinity of said second electrode; a source of alternating potential having a pair of terminals connected to respective ones of said first and second electrodes; a capacitor in series circuit relation with one of the connections between said source and said electrodes; means coupling said target to said source of alternating potential; and means coupled

to said discharge-producing means and operative synchronously with the alternating potential of said source for energizing said discharge-producing means during relatively short intervals of time in the vicinity of maximum negative and positive excursions of the alternating potential.

5. A particle accelerating system comprising: an envelope containing an ionizable gas; discharge-producing means associated with a portion of said envelope for selectively producing ions and electrons therein; an electrode supported within said envelope and associated with said discharge-producing means; a target electrode supported within said envelope and operatively associated with said first-mentioned electrode to constitute an accelerating gap; a source of alternating potential having a pair of terminals connected to respective ones of said first-mentioned electrode and said target; a capacitor in series circuit relation with one of the connections between said source and said electrode; and means coupled to said discharge-producing means and operative synchronously with the alternating potential of said source for energizing said discharge-producing means during relatively short intervals of time in the vicinity of maximum negative and positive excursions of the alternating potential.

6. A particle accelerating system comprising: an envelope containing an ionizable gas and having a wall portion constructed of an electrically insulating material; discharge-producing means associated with a portion of said envelope for selectively producing ions and electrons therein; an electrode supported within said envelope and associated with said discharge producing means; a target electrode supported within said envelope on said wall portion thereof; a conductive member supported outside said wall portion of said envelope adjacent said target and defining therewith a capacitor; a source of alternating potential having one terminal connected to said first-mentioned electrode and another terminal connected to said conductive member; and means coupled to said discharge-producing means and operative synchronously with the alternating potential of said source for energizing said discharge-producing means during relatively short intervals of time in the vicinity of maximum negative and positive excursions of the alternating potential.

7. A particle accelerating system comprising: an envelope containing an ionizable gas and having a wall portion constructed of an electrically insulating material; discharge-producing means associated with a portion of said envelope for selectively producing ions and electrons therein; an electrode supported within said envelope and associated with said discharge-producing means; target means supported within said envelope and including a plurality of conductive elements disposed adjacent to said wall portion of said envelope and electrically insulated from one another; a conductive member supported outside said wall portion of said envelope adjacent said conductive elements and defining capacitors with said elements; a source of alternating potential having one terminal connected to said first-mentioned electrode and another terminal connected to said conductive member; and means coupled to said discharge-producing means and operative synchronously with the alternating potential of said source for energizing said discharge-producing means during relatively short intervals of time in the vicinity of maximum negative and positive excursions of the alternating potential.

8. In a particle accelerating system including an envelope containing an ionizable gas, discharge-producing means for selectively producing ions and electrons in said envelope and particle accelerating means having at least one electrode, an energizing system comprising: means including a series-capacitance for applying an alternating potential between said electrode of said particle accelerating means and a reference point within said envelope; and means synchronous with the applied alternating potential for operatively conditioning said discharge-producing means during a relatively short interval of time in each of alternate half-cycles of the alternating potential in the vicinity of maximum negative and positive excursions of the alternating potential.

9. In a particle accelerating system including an envelope containing an ionizable gas, discharge-producing means for selectively producing ions and electrons in said envelope and particle accelerating means having at least one electrode, an energizing system comprising: means including a series-capacitance for applying an alternating potential between said electrode of said particle accelerating means and a reference point within said envelope; and means synchronous with the applied alternating potential for operatively conditioning said discharge-producing means during a relatively short interval of time in each of alternate half-cycles of the alternating potential.

10. In a particle accelerating system including an envelope containing an ionizable gas, discharge-producing means for selectively producing ions and electrons in said envelope and particle accelerating means having at least one electrode, an energizing system comprising: means including a series-capacitance for applying an alternating potential between said electrode of said particle accelerating means and a reference point within said envelope; a pulse generator for deriving a pulse signal synchronous with the applied alternating potential, each pulse in said signal occurring during a relatively short interval of time in a respective one of alternate half-cycles of the alternating potential; and means for supplying said pulse signal to said discharge-producing means.

11. In a neutron generator, an envelope containing an ionizable gas, an electrode and a target spaced apart in said envelope to define an ion accelerating gap, discharge-producing means responsive to a pulse signal for producing electrons and ions of said gas in a region of said envelope outside said gap during the continuance of said pulse signal, means including a capacitor for series-connection with an A.C. source to produce a peaked alternating potential accelerating field between said target and said electrode, and means for applying a pulse signal to said discharge-producing means synchronously with the alternate peaks of said potential field to produce said electrons and ions for acceleration in said gap during respective alternate intervals and for alternate charging of said capacitor, said gaseous ions and said target being reactive to produce neutrons during alternate intervals when said ions are accelerated by the peaked gap potential supplied by said A.C. source and charged capacitor.

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