June 27, 1961 J. D. GOW 2,990,476

RADIATION SOURCE

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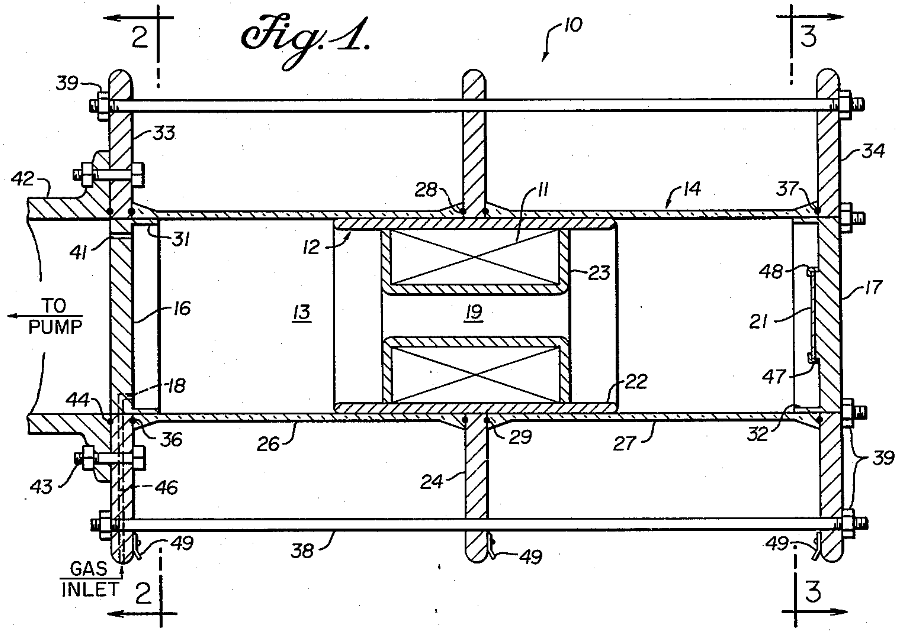
*Fig. 1.*



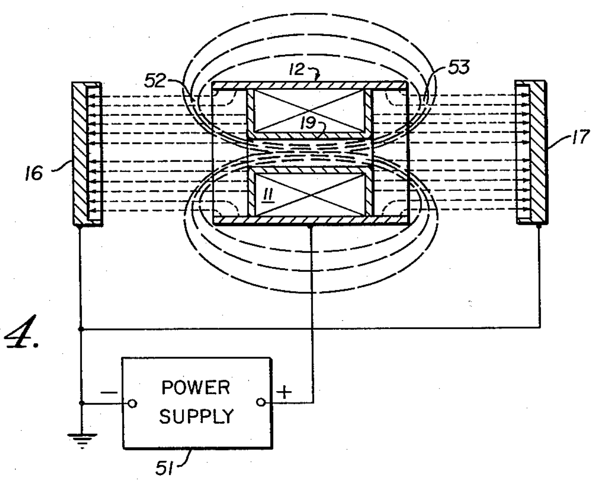




*Fig. 4.*

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Fig.2.

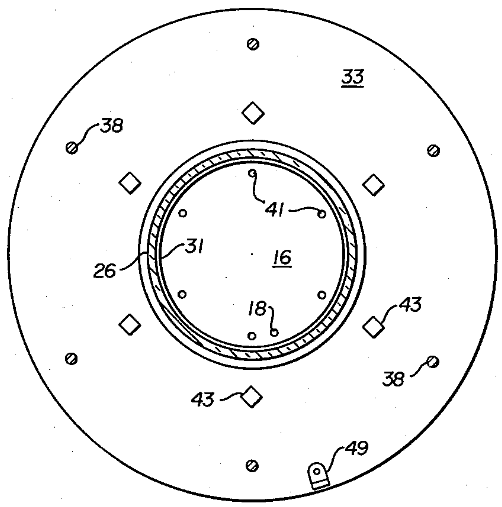
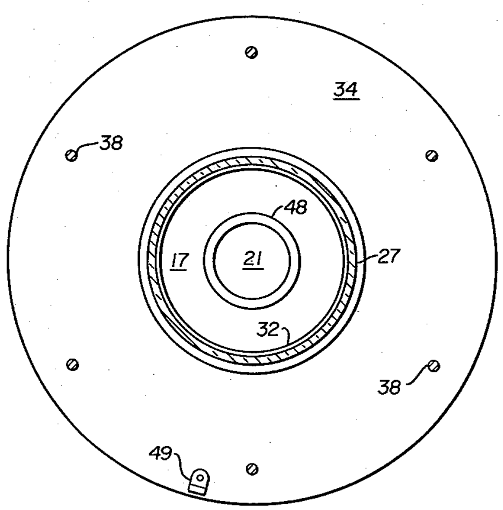



Fig.3.

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United States Patent Office

2,990,476

Patented June 27, 1961



2,990,476

# RADIATION SOURCE

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Filed Oct. 14, 1959, Ser. No. 846,517

7 Claims. (Cl. 250—84.5)

The present invention relates generally to the production and containment of an energetic plasma in crossed electric and magnetic fields, and is particularly directed to an improved source of intense nuclear radiations based on crossed-field trapping.

This application is a continuation-in-part of my copending application Serial No. 743,219, which issued January 10, 1961 as U.S. Patent No. 2,967,943, and hereby incorporates by reference pertinent subject matter disclosed therein. Said patent discloses a gaseous discharge device which employs crossed electric magnetic fields to produce and contain an energetic plasma. More specifically, the prior discharge device generally comprises an annular magnet disposed outwardly coaxially adjacent a centrally apertured anode. A cathode is coaxially spaced from the anode and an evacuated space is established therebetween into which ionizable gas is introduced. The magnetic field lines emanating from the magnet diverge radially outward in the region in front of the anode and hence cross the electric field lines extending axially between the anode and cathode. This annular region where the magnetic and electric field lines cross is effective in trapping and accelerating electrons therein. The electrons undergo ionizing collisions with the gas molecules in the region, thus releasing additional electrons. Thus the electrons are multiplied and trapped in the crossed fields to establish a region of intense ionization. The ions produced in the region are accelerated to the cathode and arrive thereat with substantial energy. A suitable target may hence be disposed at the cathode to undergo neutron productive reactions with the accelerated ions. In addition, by virtue of the region of high-density electrons existing close to the anode, soft X-rays are emitted therefrom.

Although the previous device of my prior patent is effective in trapping substantial quantities of electrons in the cross-field region, a significant quantity of the available electrons therein as exist near the axis of the magnet are not trapped owing to the parallelism of the magnetic and electric field lines thereat. These electrons are instead accelerated rearwardly through the bore of the magnet and lost from the ionization region. The degree of ionization and radiation emission from the prior device are hence limited by the electrons escaping through the magnet bore.

The loss of electrons from the crossed field trapping region of the previous device are overcome by the improvement of the present invention with a resultant substantial increase in radiation emission. More specifically, two devices of the character disclosed in my prior patent are in effect placed back to back with communication therebetween being provided through the throat of a common magnet encased within a common anode. Electrons not trapped in either of the crossed field regions existing adjacent the opposite end faces of the anode are hence accelerated into the throat of the magnet. Emerging on the opposite side they are reflected by the electron decelerating field of the corresponding crossed field region back into the magnet throat. The magnet throat region becomes a region of intense ionization due to the accumulation therein of the electrons escaping from the crossed field trapping regions disposed on opposite sides thereof. The degree of ionization and radiation emission in the improved device of the present



invention is materially more than double that of two of the devices of the character disclosed in the copending application operating separately.

It is, therefore, an object of the present invention to provide a relatively small, compact intense source of neutrons and/or X-rays.

Another object of my invention is to provide a crossed magnetic electric field trapping device for containing an energetic plasma with materially minimized losses of electrons therefrom.

It is still another object of the present invention to provide a crossed magnetic electric field radiation source wherein the degree of ionization and emission of radiation are materially increased.

Yet another object of this invention is the provision of a device of the class described wherein the intense bombardment of the anode is avoided by an axially collimated electron beam.

A further object of the present invention is to provide a device of the class described wherein the operating range is independent of the type of gas employed therein.

The invention, both as to its organization and method of operation, together with further objects and advantages thereof, will best be understood by reference to the following specification taken in conjunction with the accompanying drawings of which:

FIGURE 1 is a sectional view taken at a plane through the axis of a preferred embodiment of the improved radiation source in accordance with the present invention;

FIGURE 2 is a sectional view taken at line **2—2** of FIG. 1;

FIGURE 3 is a sectional view taken at line **3—3** of FIG. 1; and

FIGURE 4 is a schematic wiring diagram of the embodiment of FIG. 1.

Considering now the invention in some detail and referring to the illustrated form thereof in the drawings, there is provided a radiation source **10** which generally comprises an annular magnet **11** encased in a metallic shell **12**. The encased magnet is disposed within a low pressure region **13** as established interiorly of a vacuum envelope **14**, together with a pair of disc electrodes **16, 17** symmetrically coaxially spaced on opposite sides of the magnet. The source **10** further provides for the introduction of ionizable gas to low pressure region **13** as by means of an inlet **18**. Upon pulsing of the metallic magnet encasing shell **12** positive relative to disc electrodes **16, 17**, the shell thus serving as an anode and the disc electrodes as cathodes, electric fields of decreasing potential are established extending longitudinally in either direction from the anode shell to the cathodes. In addition, an axially symmetric magnetic field is generated by magnet **11** which eytends longitudinally through the throat **19** of the encasing shell and diverges radially outward in space in the regions adjacent the opposite ends of the shell thus crossing the electric field lines therein. Each of the annular or toroidal crossed magnetic electric field regions thus established on opposite sides of the anode shell **12**, trap and accelerate electrons in the manner described in detail with reference to the single annular crossed field region of the device disclosed by my prior Patent No. 2,967,943. Electrons situated near the axis of the crossed field trapping regions, however, are not trapped, but are accelerated into the throat **19** of the magnet encasing member **12**. These electrons lost from the trapping regions would normally seriously detract from the degree of ionization attainable therein by ionizing collisions between the electrons and molecules of gas introduced into the low pressure region **13**. This difficulty is overcome by the double ended structure of the present invention by virtue of the electrons accelerated into the throat 19 being effectively constrained therein by the opposed decelerating electric fields presented at the opposite ends of the throat. Electrons accelerated into one end of the throat upon emerging from the opposite end thereof are reflected by the decelerating field thereat back into the throat and vice versa. Hence the throat 19 becomes another source of intense ionization and the previously lost electrons which are accumulated therein augment, rather than detract, from the degree of ionization produced in the source 10. The resulting ion current attracted to the cathodes 16, 17 is of materially greater proportions than heretofore realizable. Accordingly, the neutron flux produced by ion bombardment of suitable targets attached to the cathodes, e.g., target 21 secured to cathode 17, is similarly increased.

Considering now preferred structure of the improved neutron source 10 described generally hereinbefore, it is first to be noted that the annular magnet 11 may be a solenoid or equivalent electromagnet; however, a permanent magnet of a material such as Indox-V is preferred. The magnet is concentrically enclosed within a hollow cylindrical member 22 with the end faces of the magnet equally inwardly spaced from the opposite ends thereof. The end faces and bore surface of the magnet 11 are enclosed by a metallic spool shaped member 23 concentrically secured at the rims thereof within cylindrical member 22. Members 22, 23 are best fabricated from an electrically conducing material also suitable for high vacuum service, such as stainless steel, and together comprise the magnet encasing anode shell 12 of previous mention. An annular flange 24 is preferably concentrically secured about the medial region of the shell member 22 to facilitate the ready attachment of the magnet 11 and enclosing anode shell 12 to other components of the source. Such flange 24 is preferably of a metallic material such as brass.

Inasmuch as the low pressure region 13 within which the magnet 11 and encasing anode shell 12 are disposed extends on opposite sides thereof, the vacuum envelope 14 defining such low pressure region is preferably provided in two sections. More particularly, envelope 14 is preferably formed from a pair of elongated wall defining hollow cylinders 26, 27 of insulating material also suitable for high vacuum service, e.g., boro silicate glass. The cylinders 26, 27 are respectively placed concentrically about the opposite ends of member 22 in end abutment with the opposite faces of flange 24. Vacuum tight seals are provided between the envelope cylinders 26, 27 and the flange 24 as by means of O-rings 28, 29 respectively disposed within conformed annular grooves in the faces of the flange and end faces of the respective cylinders.

The opposite end faces of envelope cylinders 26, 27 are similarly respectively secured in pressure sealed relation to the cathode disc electrodes 16, 17 of previous mention, which electrodes define the end walls of the vacuum envelope. More specifically, electrodes 16, 17 are preferably cupped in their construction to include longitudinally projecting peripheral rims 31, 32 at their inner end faces and have an outer diameter equal that of the anode cylindrical member 22. The electrodes 16, 17 like anode shell 12 are fabricated from an electrically conducting material also suitable for vacuum service, e.g., stainless steel. In addition, the electrodes 16, 17 are preferably provided with annular flanges 33, 34 of brass or the like concentrically secured about their respective outer end regions with such flanges having outer diameters equal that of anode flange 24. With the foregoing construction of electrodes 16, 17 the outer ends of envelope cylinders 26, 27 are readily concentrically disposed about the rims 31, 32 and in end abutment with the flanges 33, 34. O-rings 36, 37 may then be disposed between the outer end faces of the envelope cylinders and flanges 33, 34 in conformed annular grooves



provided therein to facilitate the requisite vacuum seals therebetween.

The flanges 24, 33, 34 facilitate rigid attachment of the various components of the source 10 and compression of the O-rings 28, 29, 36, 37 between these flanges and the ends of envelope cylinders 26, 27 by means of tie rods 38 extending longitudinally through the flanges. Circumferentially spaced bores are provided through the flanges in respective registry to permit traversal by the tie rods. The opposite ends of the tie rods extending outwardly through the bores in the cathode flanges 33, 34 are threaded to engage nuts 39. The nuts 39 are tightened against the outer end faces of the cathode flanges 33, 34, hence urging same tightly against the envelope cylinders 26, 27 and these members in turn tightly against the opposite end faces of anode flange 24. The tie rods 38 are fabricated from an insulating material having adequate mechanical strength, for example nylon, in order that electrical conduction paths between the electrodes are not formed.

Considering now the preferred structural details of the individual cathode electrodes 16, 17, it is to be noted that the electrode 16 includes a plurality of perforations 41, preferably in a circumferentially spaced array as best shown in FIG. 2, to facilitate evacuation of the interior of the envelope 14 and establishment of low pressure region 13. A flanged pump out conduit 42 may then be attached coaxially to the outer end face of electrode 16 as by means of flange bolts 43 extending through the flanged end of the conduit and electrode flange 33 with an O-ring 44 being interposed therebetween to provide a vacuum seal. The conduit 42 is connected to a pump (not shown) to exhaust the envelope interior to appropriate low pressure dimensions. The gas inlet 18 of previous mention is best provided in the electrode 16 as a L-shaped passage extending from the inner face of the electrode to substantially the medial transverse plane thereof then radially outward to the periphery of the electrode. The inner face opening of the inlet is preferably disposed in the peripheral portions of the electrode face, in addition, a radially extending passage 46 is provided through flange 33 in communication with inlet 18, which passage 46 may be communicably connected to an exteriorly disposed source of ionizable gas (not shown).

As regards the other cathode electrode 17, it is to be noted that same is advantageously provided with a central circular boss 47 on its inner face. Such boss facilitates attachment of the target 21 of previous mention which undergoes neutron productive nuclear reactions with ions produced within the envelope 14, as by means of a clamp ring 48 (see FIG. 3).

Considering now the manner in which the source 10 is electrically energized, it should be noted that each of the electrode flanges 24, 33, 34 is provided with a terminal lug 49 or equivalent means to facilitate connection of an electrical energizing circuit thereto. As illustrated in the wiring diagram of FIG. 4, the energizing circuit may simply comprise a power supply 51, either pulsed or continuous, having its positive terminal connected to anode shell 12 and its negative terminal connected to ground together with cathode electrodes 16, 17. It is important to note that the double ended design of the source 10 in accordance with the present invention permits the pump out flange as well as the target flange, viz., flanges 33, 34 to be maintained at ground potential.

With the source 10 constructed and arranged for energization, as hereinbefore described, the envelope 14 is continuously evacuated and ionizable gas such as deuterium, introduced thereto to establish a gas pressure of suitable proportions in low pressure region 13. The power supply 51 pulses the anode shield 12 positive with respect to cathodes 16, 17 to hence establish a longitudinal electric field through region 13 as indicated by the dotted lines of FIG. 4. The potential of the electric field symmetrically negatively increases in opposite directions from substantially the center of the throat **19** of the anode toward the cathodes **16, 17.** The electric field hence crosses the magnetic field generated by magnet **11** and indicated by the dashed lines in the figure. More particularly, the magnetic field is substantially longitudinally uniform in the throat **19** and has portions which diverge radially outward from both ends thereof, hence the electric field lines cross the magnetic field lines in the regions adjacent the end faces of the anode **12**. Annular crossed field trapping regions **52, 53** of the type extensively considered in my copending application Serial No. 743,219 are consequently established concentrically about the axis of the source adjacent the opposite ends of the anode **12** upon pulsing same positive with respect to cathodes **16, 17.** Initially, stray electrons in the trapping regions are accelerated toward anode **12** by the electric field established upon pulsing same. The radial component of the magnetic field acting on the axial velocity of the electron thus acquired tends to deflect the motion towards the positive azimuthal direction, finally returning the electron to the axial plane from which it originally came. The force due to the axial component of the magnetic field on the azimuthal component of velocity is directed toward the axis and thus results in a composite motion in the form of cycloids which encircle the axis. During these excursions of each electron, an ionizing collision may occur with a molecule of the gas introduced to the low pressure region **13**. Another electron and an ion are produced in the collision and the average axial position of the original electron is moved slightly toward the anode. Hence electrons are multiplied and trapped in the regions **52, 53** and same become regions of intense ionization. Electrons near the axis of the envelope, however, are not trapped, but accelerated into the throat **19** of anode shell **12** as mentioned hereinbefore. Inasmuch as the electric field symmetrically decreases in potential in opposite longitudinal directions from the center of throat **19**, the electric field tends to longitudinally confine these latter electrons to the region of throat **19**. The longitudinally oriented magnetic field lines passing through throat **19** radially restrict the electrons from the wall surface of the throat. Consequently, the throat **19** becomes a third electron trapping region and source of intense ionization augmenting the regions **52, 53.**

The ions formed as a result of the ionization processes occurring in regions **52, 53** and throat **19** are accelerated by the electric field longitudinally toward the cathodes **16, 17.** By virtue of the augmenting source of ionization produced in the throat **19** of anode **12**, the ion current is materially increased over that attainable in previous devices of comparable size, e.g., devices of the character disclosed in my hereinbefore referenced prior patent. Such ion current may be utilized for a variety of applications with substantial advantages and improvement being derived by virtue of the increased magnitude of the current. One or both of the cathodes may be centrally apertured to permit the accelerated ions to pass therethrough for ready employment with ion utilizing equipment such as various particle accelerators and the like. Alternatively, the target **21** may be centrally secured to cathode **17** in the manner previously described whereby the ions accelerated to such cathode bombard the target. The energy of the accelerated ions is sufficiently great that same undergo nuclear reactions with the target material. By appropriate selection of the target material relative to the ionizable gas introduced to the envelope **14**, such reactions are productive of neutrons in copious quantities. For example, where deuterium is introduced in the envelope and accelerated deuterons are formed, the target **21** may be advantageously fabricated from titanium occluded with deuterium. The well-known $H^2(d,n)He^3$ reaction hence occurs at the target with a resultant yield of neutrons in copious quantities. By



virtue of the increased ion current reaching the target, the neutron yield is materially greater than that obtainable with previous devices of comparable size. A second neutron-productive target may of course be additionally centrally secured to the other cathode **16** to increase even further the neutron yield from the source **10**.

Aside from the neutron productive capabilities of the source **10**, it will be appreciated that intense X-rays are also produced therein. More particularly, inasmuch as extremely high density of electrons with high average energies are continuously accelerated and decelerated in the trapping regions **52, 53** and anode throat **19**, such regions function as a very intense source of soft X-rays.

As an example of the operation of the source **10** in accordance with the present invention, the following parameters are presented:

| | |
|---|---|
| Vacuum envelope: | |
| Total length | 12½ inches. |
| Inner diameter | 3 inches. |
| Anode shell: | |
| Length | 4 inches. |
| Throat diameter | 1 inch. |
| Magnet | 6 Indox V face magnetized rings coaxially aligned, each 1⅛ inch I.D., 2¾ O.D., ⅜ inch thick. |
| Target | Deuterium occluded titanium. |
| Diameter | 2 inches. |
| Gas | Deuterium. |
| Gas pressure | 12 microns. |
| Magnetic field | 300 gauss. |
| Applied voltage: | |
| Peak | 125 kv. |
| Pulse width | 1 μsec. |
| Pulse rate | 60 per sec. |
| Tube current | 15 amperes. |
| Neutron yield | $16.6 \times 10^3$ per μsec. |
| X-ray energy | 10–30 kev. |

While the invention has been disclosed with respect to a single preferred embodiment, it will be apparent to those skilled in the art that numerous variations and modifications are possible within the spirit and scope of the invention, and thus it is not intended to limit the invention except as defined n the following claims.

What is claimed is:

1. An ionization device comprising envelope means for establishing a low pressure region, electrode means disposed within said region for establishing a pulsed electric field therein symmetrically uniformly decreasing in potential in opposite directions from a point of maximum potential, magnetic field generating means carried by said envelope means for establishing a magnetic field within said low pressure region, said magnetic field having flux lines parallel to said electric field and diverging at points symmetrically spaced on opposite sides of said point of maximum potential in the directions of negatively increasing potential to thereby establish annular crossed field regions disposed concentrically about the axis of said electric field and magnetic field on longitudinally opposite sides of the point of maximum potential, and inlet means communicating with said envelope means for admitting ionizable gas to said low pressure region, stray electrons existing within said low pressure region initiating ionization of said gas with the resulting multiplied quantity of electrons being trapped in said crossed field regions and the portions of the electric and magnetic fields longitudinally interposed therebetween and ionization of said gas cumulatively continuing by collision with the accumulation of trapped electrons.

2. A device according to claim 1, further defined by at least one target disposed within said low pressure region transverse to the axis of said electric field in spaced relation to said point of maximum potential, said target of a material that undergoes neutron productive nuclear re-

actions with the ions of the gas ionized within the low pressure region.

3. A radiation source comprising means for establishing a low pressure region, an annular magnet disposed within said low pressure region and generating a magnetic field extending longitudinally through the throat of the magnet and diverging symmetrically on opposite sides thereof, electrode means disposed within said low pressure region for establishing an electric field therein extending through the throat of said magnet and coaxially on opposite sides of the end faces thereof, said electric field having a maximum potential within the throat of said magnet and uniformly negatively increasing potential in opposite longitudinal directions therefrom, said electric field crossing the diverging portions of said magnetic field and forming therewith annular crossed field electron trapping regions, and means for admitting ionizable gas to said low pressure region.

4. A radiation source comprising envelope means for establishing a low pressure region, an annular magnet disposed within said low pressure region, an electrically conducting shell disposed in enclosing relation to the inner and outer peripheries and end faces of said magnet, a pair of electrodes symmetrically coaxially spaced on opposite sides of said magnet, voltage supply means coupled to said shell and said electrodes for rendering the shell positive with respect to the electrodes, and inlet means communicating with said low pressure region for introducing ionizable gas thereto.

5. A radiation source as defined by claim 4, further defined by a target secured centrally transverse to at least one of said electrodes, said target being of a material that undergoes neutron productive nuclear reactions with the ions of the ionizable gas.

6. A radiation source comprising an annular magnet, a metallic anode shell disposed in enclosing relation to the surfaces of said magnet, a pair of cathode disc electrodes equally coaxially spaced on opposite sides of said magnet, a pair of insulating hollow cylinders respectively secured coaxially between said anode shell and said cathode electrodes and in pressure sealed relation thereto to define therewith a vacuum envelope for enclosing a low pressure region, voltage supply means having a positive terminal coupled to said anode shell and a negative terminal coupled to said cathode electrodes and to ground, inlet means communicating with the interior of said envelope for admitting ionizable gas thereto, and a neutron productive target centrally coaxially secured to the inner face of one of said cathode electrodes.

7. A pulsed radiation source comprising an annular magnet, a metallic shell concentrically enclosing the periphery, throat, and end faces of said magnet with the periphery enclosing portion projecting coaxially beyond the end face enclosing portions thereof by equal amounts, said periphery enclosing portion having an annular flange concentrically about the medial region thereof, a pair of disc electrodes equally coaxially spaced on opposite sides of said magnet and each having a coaxially projecting annular rim at the inner face thereof with an annular flange concentrically thereabout, one of said electrodes having an inlet aperture and a plurality of circumferentially spaced concentrically disposed outlet apertures, a pair of hollow cylindrical members of insulating material respectively disposed with their inner ends concentrically about the periphery enclosing portion of said shell and in end abutment with the faces of the flange thereof, said members respectively disposed with their outer ends concentrically about the rims of said electrodes and in end abutment with the inner faces of the flanges thereof, pressure sealing elements respectively interposed between the ends of said cylindrical members and the abutting faces of said shell and electrode flanges, a plurality of circumferentially spaced longitudinal tie rods secured between said flanges and tightening same longitudinally against the ends of said cylindrical members to form vacuum seals therebetween, a voltage supply having its positive terminal connected to said shell and its negative terminal connected to said electrodes and to ground, a source of ionizable gas communicably coupled to said inlet aperture, a pump out conduit attached in pressure sealed relation to the outer face of said first electrode in communication with the outlet apertures therethrough, and a neutron productive target centrally coaxially secured to the inner face of said second electrode.

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