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[31] **53519**

[54] **NEUTRON GENERATOR WITH RADIATION
ACCELERATION**
9 Claims, 5 Drawing Figs.

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250/51, 250/106, 313/61
[51] Int. Cl. **G21g 3/04**
[50] Field of Search **250/845,**
106 S, 106 T, 51; 313/61

[56] **References Cited**
UNITED STATES PATENTS
3,027,312 3/1962 Lanning 250/49.5
3,448,314 6/1969 Bounden et al. 250/84.5
Primary Examiner—William F. Lindquist
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ABSTRACT: Method of and apparatus for generating high neutron flux at a sample zone maintained at atmospheric pressure and surrounded by an annular evacuated generator housing along whose inner peripheral wall is provided a neutron emitter target. An annular array of ion-particle sources or an annular ion source surrounds the annular target to direct radial charged-particle beams thereagainst. The acceleration may be effected by radially spaced accelerator plates disposed between the source and the target within the chamber or by radio waves supplied to the chamber; the latter is then constituted as a coaxial resonant cavity.

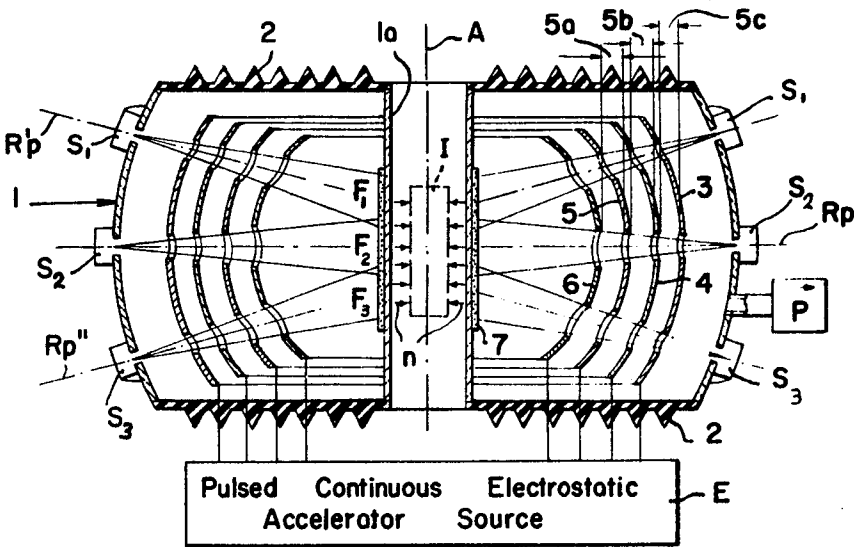


FIG. 1-A

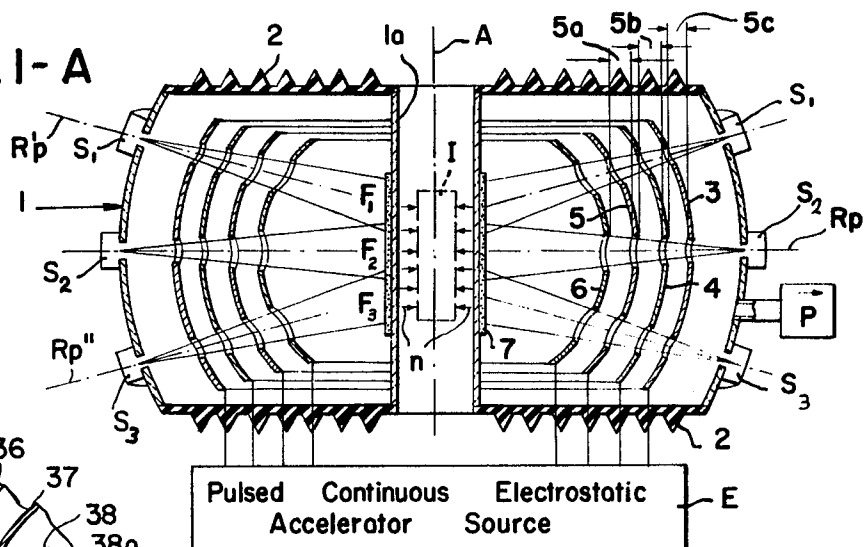


FIG. 1-C

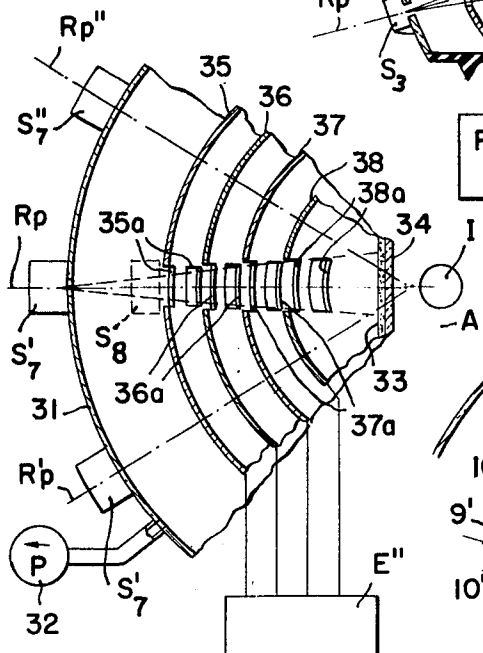


FIG. 1-B

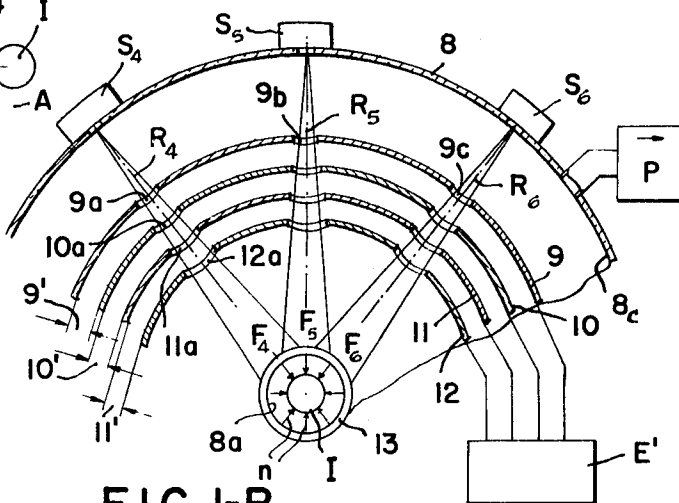


FIG. 2

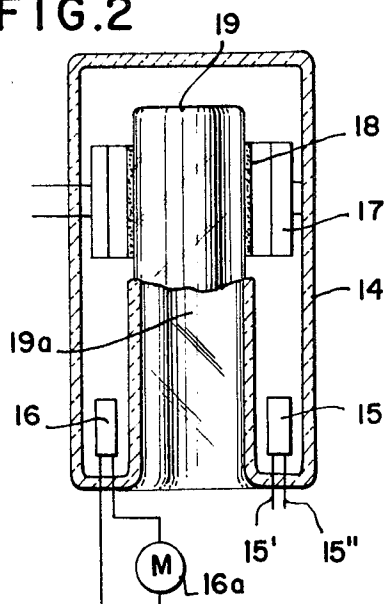
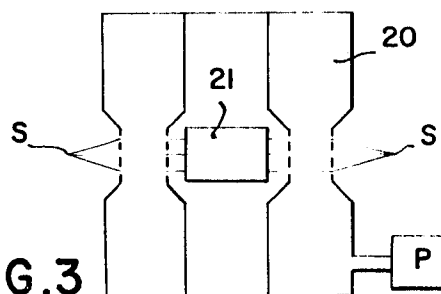


FIG. 3



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NEUTRON GENERATOR WITH RADIATION ACCELERATION

My present invention relates to a method of generating neutrons at high intensity and of irradiating a sample with high-intensity neutrons, and to an apparatus capable of producing high-intensity neutron fluxes in a sample-accommodating region.

In general, neutron generators and apparatus for the production of a neutron flux, referred to generally in the art as "neutron sources," comprise a mass of materials capable of undergoing nuclear reaction and transformation to yield neutrons. Such neutron sources may make use of a particle-generating substance capable of radioactive decay to yield bombarding particles, e.g. particles (${}^2\text{He}^4$), which impinge upon a target (e.g. lithium, beryllium,...) to yield neutrons for irradiating a specimen or sample. Typical α -particle sources are radium, plutonium, and the like. In these systems, the bombarding source is intimately combined with the target material, e.g. as an alloy.

In the other E.G. type of neutron generator, usually referred to as an e.g. or C.W. generator, a high or low energy, linear or nonlinear direct charged-particle accelerator is used for neutron production. The accelerated charged-particle beam is allowed to impinge on a suitable target such that a neutron flux is produced by the resulting nuclear reactions. Thus the neutrons may result from nuclear reactions between a beam of deuterons (D or ${}^2\text{H}^2$ ion), tritons (T or ${}^3\text{H}^3$ ion), or a mixture of these charged particles, which are accelerated to high-energy in an electric field via an electrostatic high-voltage accelerator (E.G.) or a Cockcroft-Walton high-voltage accelerator (C.W.) and are focused on a target which may contain tritium or deuterium or mixtures thereof, beryllium, and like materials known to have a high neutron yield when bombarded with the high-energy-charged particles. A typical reaction is that of the deuteron undergoing nuclear transformation with a tritium nucleus to form an α -particle and a neutron ($\text{D} + {}^3\text{H}^3 \rightarrow {}^4\text{He}^4 + {}^1_0\text{n}$). Such neutron generators may be of a variety of different constructions although, in general, a single linear beam source directs its beam upon a stationary or rotating target disk. In these systems, at the sample level, the neutron flux (in terms of the number of neutrons/cm.²) is much lower than the specific rate or rating of the target. It is possible to reduce the difference between the neutron flux at the sample level and the specific rate of the target by using large-diameter targets although this increase is accompanied by difficulties in obtaining high-intensity beams of large aperture and constant density at the target.

It is, therefore, the principal object of the present invention to provide an improved method of increasing the neutron flux intensity at the sample irradiation zone in a neutron generator using a charged-particle accelerator as previously described.

A further object of this invention is to provide an improved neutron generator with direct charged-particle acceleration, adapted to provide high neutron flux and neutron irradiation of high intensity at the sample irradiation zone.

Still another object of this invention is to provide a neutron generator of the character described, in the form of a neutron tube with high neutron flux in the sample zone.

Yet a further object of this invention is to provide an improved neutron generator using charged-particle acceleration in a radiofrequency field having intensive neutron flux in a sample zone.

I have found that these objects and other which will become apparent hereinafter, can be attained by providing an annular target capable of undergoing nuclear interaction with an accelerator-particle beam which closely surrounds an axis of symmetry and may extend along that axis in the form of a tube or cylinder while a charged-particle (i.e. ion) beam is directed at this target from at least one, but preferably a plurality of, charged-particle injectors or sources while radially effective accelerator means is provided in the common continuously evacuated envelope housing the target for radial acceleration of the incident ion beam toward the cylindrical target. The re-

gion surrounded by the target constitutes the sample irradiation zone and may be unevacuated (i.e. at atmospheric pressure) while the target may contain deuterium, tritium, beryllium or other neutron emitters undergoing neutron production upon interaction with the ion beams. The sample is thus located within the axial limits of the cylindrical target and in the interior thereof so that, at the sample level, the neutron flux will generally be equal to the specific rate of the target. According to a further feature of this invention, the impinging charged-particle beams are directed from a number of sources against the cylindrical target, the source being angularly spaced around the axis of the target and, therefore, its cylindrical periphery; angular equispacing is preferred. Furthermore, the angularly equispaced, radially directed and preferably divergent charged-particle beams impinge upon mutually overlapping zones of the target and thus ensure a substantially uniform radiation intensity.

Still another feature of this invention resides in the use, independently of but possibly in combination with the preceding feature, of a plurality of axially offset beams of charged particles which impinge upon axially overlapping zones of the cylindrical target. Advantageously, the axially overlapping zones may derive from charged-particle beams whose axes lie in a common axial plane of the cylindrical target but converge with respect to one another at the target so that, for example, a central beam is directed normal to the surface of the target in each of the axial planes while at least a pair of outer beams are oriented toward one another and thus converge toward the normal to the surface corresponding to the axis of the central beam.

The term "cylindrical" used with reference to the target, is intended to refer also to prismatic configurations having axial symmetry. Thus, the target may be a right-circular cylinder or a body of revolution produced by a line generatrix rotated about the axis of the device along a closed path which may be noncircular. With the use of a prismatic target, the generatrix will be rotated about the axis along a polygonal path with angularly adjoining sides, thereby imparting a transverse cross section to the target corresponding to the polygon. The charged-particle sources are preferably located equidistantly from the surface of the target as measured along the axis of the respective beam, while the particle-accelerator means comprises a plurality of electrodes forming acceleration gaps which also are equidistant from the target surface at each acceleration region.

According to still another feature of this invention, an annular ion source is provided (as distinct from a plurality of charged-particle sources equispaced around the surface of the target) and its ion particles are directly and radially accelerated in the direction of the target by continuous or pulsed electric field or by a radio frequency field of a coaxial cavity resonator.

The above and other objects, features and advantages of the present invention will become more readily apparent from the following description, reference being made to the accompanying drawing in which:

FIG. 1-A is an axial cross-sectional view, partly in diagrammatic form of a neutron-irradiating generator, according to the present invention;

FIG. 1-B is a transverse cross-sectional view through another arrangement of this character;

FIG. 1-C is an axial cross-sectional view through a system embodying principles of both these systems;

FIG. 2 is a diagrammatic cross-sectional view of a neutron tube capable of generating high-intensity neutron flux; and

FIG. 3 is a longitudinal section, partly in diagrammatic form through a neutron generator using a resonant coaxial cavity and a radiofrequency electric field as the acceleration means.

In FIG. 1, I show a neutron generator which comprises an envelope 1 having an inner tubular core 1a receiving the specimen I to be irradiated and centered upon the axis of symmetry A of the neutron generator. The tubular core 1a and the outer housing wall 1b form a vacuum tight enclosure with a

pair of electrically insulating thermal disks 2 which is subjected to continuous evacuation and suction by the pumping system represented at P. The pumping system may be any of those described at pages 843-856 of the "Concise Encyclopedia of Nuclear Energy," Interscience Publishers, New York, 1962. Within the accelerator chamber and coaxially therewith, I provide a cylindrical target 7 containing deuterium, tritium, beryllium or like material capable of generating neutrons upon radiation with an accelerated charged-particle beam.

In a number of axial planes, I provide along the outer wall 1b of the housing 1, a number of ion sources S_1, S_2, S_3 , these sources generating annular beams F_1, F_2 and F_3 , respectively, in the form of inwardly diverging sheetlike distributions of charged particles. Instead of the single annular-ion source at each of a plurality of axially spaced locations, duoplasmatron or Penning ion sources may be used. When the annular sources (centered on the axis A and axially spaced therealong) are employed, they may be of the type described in "Journal de Physique et Radium," vol. 12 (1951), p. 563.

Three such beams are shown in FIG. 1-A including a central beam lying in the radial plane R_p and a pair of inwardly directed beams whose axes are represented at R_p' and R_p'' , respectively. The beams diverge toward the target 7 and overlap upon impingement thereagainst.

The radial accelerator means of this system includes a plurality of inwardly concave generally coaxial accelerator electrodes 3, 4, 5 and 6 which are provided with circular slits 3', 3'', 3''', etc. permitting passage of the beams F_1, F_2 and F_3 , respectively. A pulsed or continuous electrostatic accelerator source (E.G. as described in my concurrently filed copending application Ser. No. 719,963, now Pat. No. 3,551,728, entitled "HIGH-INTENSITY LINEAR ACCELERATORS" or as described in the "Concise Encyclopedia of Nuclear Energy" mentioned earlier), is represented at E and is connected to the electrodes 3, 4, 5, 6 to apply a continuous or pulsed electrostatic field across the gaps 3a, 4a, 5a between the pairs of the electrodes, thereby accelerating the charged-particle beams F_1, F_2, F_3 in the direction of the target 7. The charged particles, preferably high-energy deuterons and tritons as indicated earlier, undergo nuclear reaction with the target 7 with generally radial inward emission of neutrons as represented by the arrows n, thereby subjecting the sample 1 to a high-energy neutron flux.

In the embodiment illustrated in FIG. 1-B the cylindrical housing 8 is hermetically sealed and has a tubular core 8a carrying the neutron-emitting target 13 in the form of a cylinder. The sample 1 is received with the cylinder for neutron irradiation in the direction of arrows n. In this embodiment, however, a plurality of duoplasmatron or Penning-type ion sources S_4, S_5, S_6 etc. are disposed in a common radial plane and are angularly equispaced along the outer wall of housing 8 to direct beams F_4, F_5 and F_6 etc. of charged particles radially inwardly along the respective radii R_4, R_5 and R_6 of the target 13. These beams F_4, F_5, F_6 ... diverge inwardly and overlap along the angular zones of the target against which they impinge. In this embodiment, the electrodes 9, 10, 11 and 12 are radially spaced but coaxially disposed within the chamber 8c of the housing 8, which is evacuated by the continuous pumping system P. The electrodes 9-12 are provided with angularly equispaced slits 9a, 9b, 9c ... extending along generatrices and parallel to the axis of the device. The slits associated with each beam are radially aligned as represented for the slits 9a, 10a, 11a and 12a for the beam F_4 . The slits increase progressively in angular width to ensure the divergence of the beams. The electrostatic field source E' is connected to each of the electrodes to sustain an accelerating potential difference across the gaps 9', 10' and 11' as described in the aforementioned copending application and in connection with FIG. 1-A.

Since the housing 8 is hermetically sealed and of generally toroidal shape, the sample 1 is located at the high-flux zone and is at atmospheric pressure.

In FIG. 1-C, I show an arrangement in which the housing 31 approaches a torus in configuration and is evacuated by the continuously operating pump 32. A cylindrical neutron-emitting target 33 is disposed along the core 34 of the toroid in which the sample 1 is positioned at atmospheric pressure. In each of the radial planes R_p, R_p' and R_p'' of the device, oriented as in FIG. 1-A, a plurality of ion sources S_7, S_8 , etc. are angularly equispaced from one another about the axis A. The corresponding sources S_7, S_7' and S_7'' are located in common axial planes of the device represented, for example, by the plane of the paper in FIG. 1-C. The accelerator electrodes conform to coaxial spherical segments as shown for the electrodes 35, 36, 37 and 38 which are provided with the slits 35a, 36a, 37a and 38a in this Figure. The continuous or pulsed electrostatic field source E'' is connected to these electrodes as previously described.

In FIG. 2, I show a neutron-generating tube in which a tubular glass envelope 14, which is sealed after evacuation, is provided with a pressure-regulating getter 15, heated via leads 15' and 15'' by an electric current supplied from the exterior. In another leg of the annular housing, I provide a mechanical/electrical transducer 16 serving as a pressure gauge and designed to indicate the pressure within the tube 14 via a meter 16a connected to the leads of the gauge period. Within the tube 14, whose inner relatively thin wall 19 receives a cylindrical deposit of the target material 18 (a tritium or deuterium/tritium substance of conventional composition), I provide a ring-shaped ion source 17 including radially spaced accelerator electrodes as described in connection with FIGS. 1-A and 1-B previously. Again, a well 19a is provided within the housing at atmospheric pressure for receiving the sample.

The embodiment of FIG. 3 comprises a ring-shaped ion source S whose charged particles are accelerated radially toward a target 21 sealed within an annular zone of the cavity resonator 20 which is supplied, e.g. as described in the aforementioned copending application, with radiofrequency waves adapted to accelerate the charged particles. Within the ring formed by the target and the angular cavity resonator, the sample may be disposed at atmospheric pressure. The pumping system P operates continuously to evacuate the system. In all of the aforementioned devices, the neutron flux at the sample zone is generally equal to the specific rate of the target.

The invention described and illustrated is believed to admit of many modifications within the ability of persons skilled in the art, all such modifications being considered within the spirit and scope of the appended claims.

I claim:

1. A high-intensity neutron generator comprising an annular evacuated housing having an annular inner wall adapted to surround a sample at ambient pressure; an annular neutron-emissive target activatable by accelerated charged particles disposed along said wall for subjecting said sample to high-intensity neutron flux; a plurality of charged-particle sources spaced radially from said target for radially directing charged-particle beams substantially uniformly against said target and across the evacuated space between said source and said target; and particle-accelerator means for radially accelerating the particles of said beam, said particle-accelerator means including radially spaced generally annular electrodes disposed in said space around said target and provided with openings passing said beam and means for applying an accelerating field across said electrode.

2. The generator defined in claim 1, further comprising continuously operable pumping means connected with said housing for maintaining said space under reduced pressure.

3. The generator defined in claim 1, further comprising a gettering means in said housing for maintaining said space at a reduced pressure.

4. The generator defined in claim 1 wherein said source is an annular ionized-particle source directing charged particles against said target generally uniformly therealong.

5. The generator defined in claim 1 wherein said charged-particle source includes a plurality of angularly spaced ionized

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particle sources trained on said target for producing overlapping charged particle beams impinging thereagainst.

6. The generator defined in claim 1 wherein said source includes a plurality of axially spaced ionized-particle sources training coplanar axially overlapping beams against said target.

7. The generator defined in claim 1 wherein said particle-accelerating means includes means for sustaining a particle-accelerating radiofrequency field in said space.

8. The generator defined in claim 1 wherein said target is generally cylindrical.

9. A high-intensity neutron generator comprising an annular evacuated housing having an annular inner wall adapted to

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surround a sample at ambient pressure; an annular neutron-emissive target activatable by accelerated charged particles disposed along said wall for subjecting said sample to high-intensity neutron flux; at least one annular charged-particle source spaced radially from said target for radially directing at least one charged-particle beam substantially uniformly against said target and across the evacuated space between said source and said target, said annular ionized-particle source directing charged particles against said target generally uniformly therealong; and particle-accelerator means for radially accelerating the particles of said beam.

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