# NEUTRON TUBES

## RELATED APPLICATIONS

[0001] This application claims priority of Provisional Applications Ser. Nos. 60/355,576 filed Feb. 6, 2002 and 60/356,350 filed Feb. 13, 2002, which are herein incorporated by reference.

## GOVERNMENT RIGHTS

[0002] The United States Government has rights in this invention pursuant to Contract No. DE-AC03-76SF00098 between the United States Department of Energy and the University of California.

## BACKGROUND OF THE INVENTION

[0003] The invention relates generally to neutron tubes, and more specifically to neutron tubes based on plasma ion sources.

[0004] Conventional neutron tubes employ a Penning ion source and a single gap extractor. The target is a deuterium or tritium chemical embedded in a molybdenum or tungsten substrate. Neutron yield is limited by the ion source performance and beam size. The production of neutrons is limited by the beam current and power deposition on the target. In the conventional neutron tube, the extraction aperture and the target are limited to small areas, and so is the neutron output flux.

[0005] Commercial neutron tubes have used the impact of deuterium on tritium (D-T) for neutron production. The deuterium-on-deuterium (D-D) reaction, with a cross section for production a hundred times lower, has not been able to provide the necessary neutron flux. It would be highly desirable and advantageous to make D-D neutron sources. This will greatly increase the lifetime of the neutron generator, and it would greatly reduce transport and operational safety concerns.

[0006] Brachytherapy is a type of radiation therapy in which radioactive materials are placed in direct contact with the tissue being treated. The currently available fast neutron source for brachytherapy treatment of tumors is a spontaneous fission source such as the radioactive isotope Cf-252 which is implanted into a patient. All present U.S. Cf-252 neutron source designs require manually afterloaded systems. Because Cf-252 is a radioactive source, it cannot be turned off to prevent excessive exposure of clinical personnel. The average energy of the spontaneous neutrons emitted from a Cf-252 source is 2.3 MeV which is very close to the energy of a D-D neutron source, 2.45 MeV. By utilizing a D-D neutron tube which can be turned on and off, the patient can be subjected to radiation treatment at desired times, and clinical personnel will receive no occupational dose from the source while it is turned off during patient preparation.

[0007] The utilization of in-situ fast neutrons in treating radioresistant tumors has been demonstrated to be more effective than external neutron sources where the neutrons have been slowed down while penetrating the body. Since the dose is delivered to the tumor by fast neutrons, it is not necessary to inject any drug for the delivery of neutron absorbing boron into the tumor, as is often done to increase the capture of slow neutrons. However, boron can be used to enhance the dose delivery to neighboring metastases. Therefore, another advantage of a fast neutron brachytherapy source over an external source is its capability of tailoring the dose distribution around the region of the tumor.

[0008] Therefore, a miniaturized inplantable neutron generator design adapted for brachytherapy would be highly advantageous.

[0009] It would also be desirable, in many other applications such as cargo screening, airport luggage screening, and explosives detection, to have a sealed tube neutron generator which provides a high neutron flux with long life operation and with variable source size. The neutron generator would overcome many of the shortcomings of the presently available neutron tubes.

## SUMMARY OF THE INVENTION

[0010] The invention is a generic class of neutron tubes or generators based on a RF driven plasma ion source having a quartz or other chamber surrounded by an external RF antenna. A deuterium or mixed deuterium/tritium (or even just a tritium) plasma is generated in the chamber and D or D/T (or T) ions are extracted from the plasma. A neutron generating target is positioned so that the ion beam is incident thereon and loads the target. Incident ions cause D-D or D-T (or T-T) reactions which generate neutrons. The invention may be implemented in numerous embodiments. The general principles and features are the same for all embodiments which differ primarily in size of the chamber and position and shape of the neutron generating target.

[0011] The invention includes a miniaturized implantable neutron generator or tube that produces fast neutrons from a D-D reaction which can be used for brachytherapy applications. The tube is formed of a small RF-driven deuterium ion plasma ion source and a nearby target to which the ions are accelerated.

[0012] This embodiment provides a small size D-D neutron generator, typically less than 8 mm in diameter and 2 cm in length, which allows the source to be put right into a tumor. Absorbed dose is delivered by fast neutrons rather than thermal neutrons. The targeted tumor size is less than 5 cm in diameter. The dose delivered to the healthy tissue outside the tumor is expected to be less than other approaches utilizing an external neutron source. Unlike other brachytherapy approaches such as Cf-252, there will be zero occupational dose for clinical personnel.

[0013] The invention also includes another miniaturized neutron generator or tube that produces fast neutrons from a D-D reaction which can be used for brachytherapy applications. The tube is again formed of a small RF-driven deuterium ion plasma ion source and has a target to which the ions are accelerated. However, in this embodiment, the target is at the end of a small diameter drift tube, which can be inserted into the body like a catheter. The target also has a tapered or conical shape so that greater surface area is provided for higher neutron flux and lower energy loading.

[0014] The invention includes another embodiment of the neutron generator in which the RF driven ion source is substantially larger in size than the first two embodiments since it is not designed for implantation in the human body. The ion source has a chamber with external RF antenna in which a deuterium tritium, or mixed deuterium/tritium ion plasma is produced. The ions are extracted through a large