Title

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Publication Date

2001-06-15

High Flux Compact Neutron Generators[‡]

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Abstract. Compact high flux neutron generators are developed at the Lawrence Berkeley National Laboratory. The neutron production is based on D-D or D-T reaction. The deuterium or tritium ions are produced from plasma using either a 2 MHz or 13.56 MHz radio frequency (RF) discharge. RF-discharge yields high fraction of atomic species in the beam which enables higher neutron output. In the first tube design, the ion beam is formed using a multiple hole accelerator column. The beam is accelerated to energy of 80 keV by means of a three-electrode extraction system. The ion beam then impinges on a titanium target where either the 2.4 MeV D-D or 14 MeV D-T neutrons are generated. The MCNP computation code has predicted a neutron flux of ~10^{11} n/s for the D-D reaction at beam intensity of 1.5 A at 150 kV. The neutron flux measurements of this tube design will be presented. Recently new compact high flux tubes are being developed which can be used for various applications. These tubes also utilize RF-discharge for plasma generation. The design of these tubes and the first measurements will be discussed in this presentation.

INTRODUCTION

The RF-driven multicusp ion source developed at Lawrence Berkeley National Laboratory has found numerous applications ranging from neutral beam injection systems for fusion reactors to particle accelerators, proton therapy machines and ion implantation systems. Sources such as this are simple to operate, have long lifetime, high gas efficiency and provide high-density plasmas with high yield of monatomic species. These characteristics make the RF driven multicusp source a viable candidate for compact, high-output, neutron generators, utilizing the D-D and D-T fusion reactions.

Various different neutron generators systems are being made and tested at the Plasma and Ion Source Technology Group in the Lawrence Berkeley National Laboratory. The most conventional system utilizes multicusp ion source, multiple hole beam extraction system with three electrodes and a titanium-coated copper target. Beam current and neutron yield measurements will be discussed. Also smaller, compact setup has been developed. This neutron generator uses a quartz plasma chamber with an external antenna, a diode accelerator system and a titanium target in very compact dimensions. The development of this very compact neutron generator will also be mentioned in this presentation.

1. PLASMA GENERATOR DESIGN

In the conventional neutron generator, a 30-cm-diameter multicusp ion source is used to generate plasma. The chamber is stainless-steel and it is surrounded by columns of samarium-cobalt magnets. The plasma is generated by using RF induction discharge. The RF power supply is operated at 13.56 MHz for cw or low power pulsed operation (up to 5 kW) or 2 MHz for high power (up to 90 kW) pulsed operation.

The terminating impedance of the plasma typically ranges between 0.5-2 Ohms, whereas the coaxial transmission line and the output impedance of the RF- amplifier are both

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[‡] *This Work was supported by Sandia National Laboratory and the US Department of Energy under Contract No. DE-AC03-76SF00098.*

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50 Ohms. An RF-matching network is used to match the plasma and antenna impedance to the output impedance of the RF-amplifier and coaxial transmission line.

Conventional antenna arrangement is used. The coaxial titanium-quartz tube antenna is placed inside the plasma chamber. Very high atomic species percentage (>90%) can be achieved (Fig. 1).

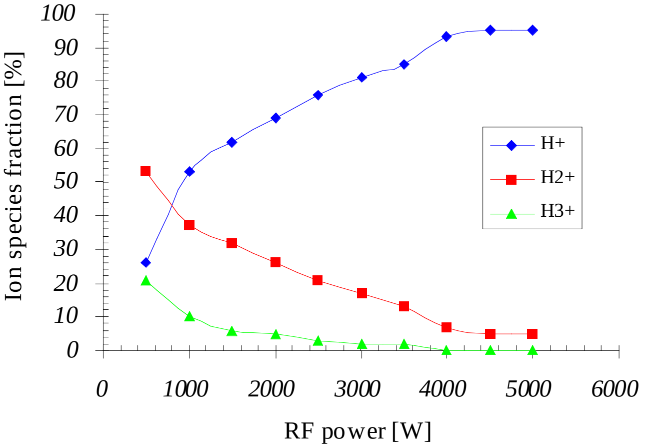

Figure 1. *The hydrogen ion species fraction as a function of the RF power. More than 90% pure atomic species can be obtained at power > 4.0 kW.*

The high atomic species fraction in the beam is important so that higher neutron yields can be achieved (Fig. 2).

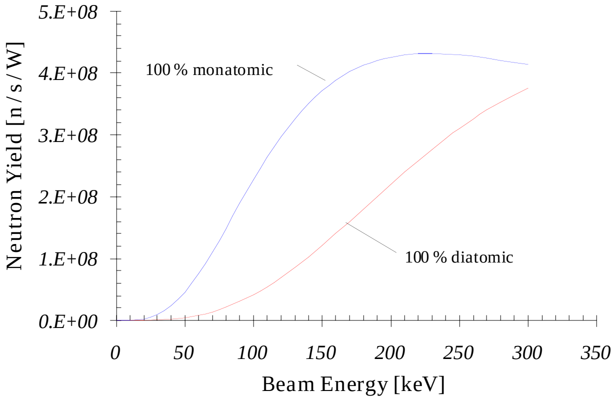

Figure 2. *The comparison of neutron yields between monoatomic beam (the upper curve) and the molecular beam (lower curve).*

The beam current density as a function of the RF power is shown in Fig. 3. The linear behavior of the obtainable, saturated beam current density to the RF power is typical for RF induction ion sources [**1**].

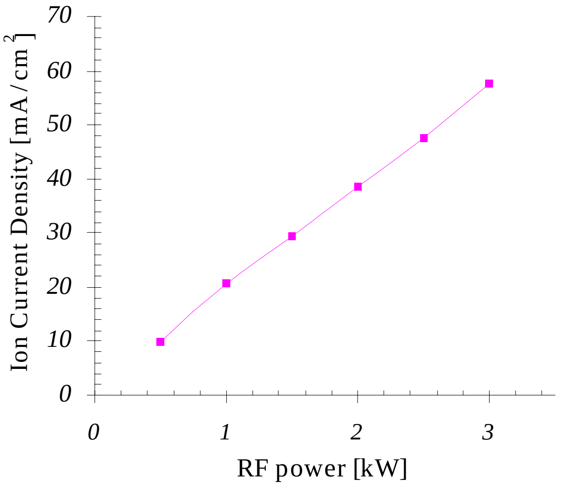

Figure 3. *Ion beam current density as a function of the RF power. The source pressure in this measurement was 2 mTorr. 30 cm in diameter multicusp source was used.*

The ion source, vacuum tank, vacuum pump and the high voltage feed through of the generator is shown in Fig. 4. The support structure around the neutron generator is used for lead and polyethylene shielding.

Figure 4. *The neutron generator in the test-stand. From left, the high voltage feed-through is shown. The turbo vacuum pump unit is on top of the vacuum vessel and the 30 cm diameter multicusp ion source is on the right.*

2. ACCELERATOR DESIGN

The beam extraction and accelerator system was simulated by using the IGUN [2] ion extraction simulation code. The ions are being extracted with low energy through a multi-aperture grounded plasma electrode and accelerated to high energy with a third electrode. The target is biased at slightly positive voltage to suppress the secondary electrons created by the beam from the target. In this design, the ion source is at ground potential and the target is at high negative potential. The arrangement allows the ion trajectories to cross-over, which then spreads the beam to larger area. Simulation of the beam behavior in the extraction gap is shown in Fig. 5. For the experiment described in this presentation, a seven hole extractor with a combined area of 1 cm^2 was used. The target was placed 50 mm from the third electrode downstream.

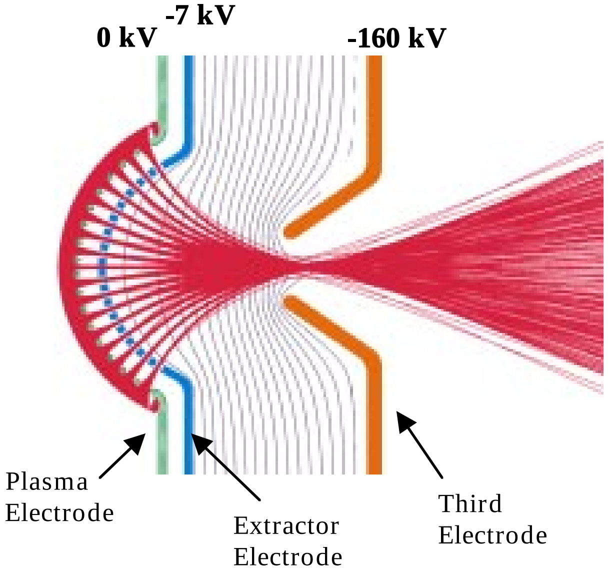

Figure 5. *The beam extraction geometry.*

3. MEASUREMENTS

The generator was operated using deuterium gas, producing 2.4 MeV neutrons. It was operated at various configurations. Two frequencies, 2 MHz and 13.56 MHz were tested. The ion source was operated in both cw and pulsed modes. Due to power supply and target temperature limitations, the output current was limited to 10 mA. For the neutron yield measurements, the source was operated at 1% duty factor, 2 ms pulse width and 5 kW of discharge power during the pulse. The accelerator was operated at 80 kV. The neutron yield was measured using ^{3}He detectors.

Using two different detectors in two different positions inside the polyethylene-lead enclosure, a neutron yield of ~3×10^6 n/s (for D-D reaction) was measured. Fast rise and fall time for the neutron pulse was also obtained. This makes the generator ideal for applications that require detection of the thermal neutron flux after the beam is turned off.

4. COMPACT NEUTRON TUBE DEVELOPMENT

In addition to the conventional generator design, a very compact 2-inch diameter neutron generator has been designed and fabricated. In this new generator, the plasma is produced by using RF induction discharge, but the RF antenna is placed outside a quartz plasma chamber. The accelerator in this tube is a single gap diode structure. A pair of magnets are incorporated in the target to suppress the secondary electron emission. In Fig. 6, the compact tube is being tested with hydrogen gas.

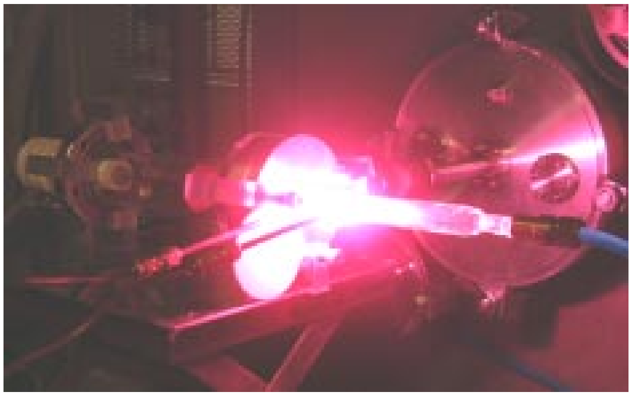

Figure 6. *The compact neutron tube under first hydrogen tests. The high voltage feed through and target assembly is shown on the left.*

The tube is designed to work only in a pulsed mode. The first deuterium beam extraction tests showed that the extractable current density is higher than 300 mA/cm^2.

5. DISCUSSION

D-D neutrons have been generated by using compact neutron tubes. The neutron yield measurements showed that ~3x10^6 n/s can be generated using 10 mA of deuterium beam, at 80 kV beam energy and at 1% duty factor. A new target design has been implemented, which would allow higher power operation. D-D neutron yields of 10^{12} n/s can be achieved if the generator is operated at 1.5 A of cw deuterium beam at 120 kV. New compact cw neutron tube designs are now being tested and the results will be reported in the near future.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the effort of Ted de Castro and Alan Smith from LBNL's Radiation Safety Group in assisting in the neutron yield measurements. This work was supported by Sandia National Laboratory and the U.S. Department of Energy, under Contract No. DE-AC03-76SF00098.

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