

## DEVELOPMENT OF COMPACT D-D NEUTRON GENERATOR

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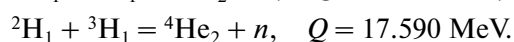
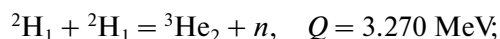
In recent years, due to specific features of compact neutron generators, their demand in elemental analysis and detection of the illicit materials has been increased in scientific community. Compact in size, controlled operation and radiation safety like features of neutron generator is suitable for research work with illicit materials. An accelerator based neutron generator can be operated in steady mode as well as in pulse mode. The main embodiment of this type of generator includes ion source, ion acceleration system and target. We are developing such type of neutron generator. This consists of one in-house developed penning ion source, a single electrode acceleration gap and one deuteriated titanium target or virgin titanium target. The neutron generator was operated at 80 kV acceleration potential, a deuterium pressure of 0.1 mTorr and ion source potential at 1 kV. The neutron generation was confirmed by the solid state nuclear track detector CR-39. In this report, we will discuss various physics and technical issues related to the important components of this generator, operation of the generator and neutron detection.

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## 1. INTRODUCTION

The threat from terrorist groups for the humanity has increased many folds in almost all corners of this earth. The restriction of the illegal movements of the illicit materials like explosive, drugs and special nuclear material (SNM) through air, sea and road routes become very important. Imaging of the cargo container, luggage bags is not enough but it becomes essential to do elemental analysis of all the containers. The development of a non-destructive technology that can detect illicit materials within very short period of time has become an important issue in the area of cargo and luggage inspection. Prompt Gamma activation Analysis (PGAA) in the form of Thermal Neutron Analysis (TNA) and Fast Neutron Analysis (FNA) [1, 2] is promising techniques in which the detection of the nature of the element as well as the quantity present inside the container is possible for detection of explosive and drug whereas Differential Die Away Analysis (DDAA) [3] and high energy fission product gamma ray detection [4] methods are under extensive research for the detection of the special nuclear materials. For this purpose, production of neutrons plays an important role. Compact neutron generator has several advantages over other type of neutron sources like nuclear reactors and radioisotope sources. Though the radioactive neutron sources are used in industry for various applications, ideal for fixed installations and for continuous operation, they are not well suited for pulse operation, they creates safety issues and logistic

complications. Neutron generator is more environmentally friendly, safer for operators, more sensitive for an elemental analysis. It is easier to control the neutron characteristics like the neutron yield, pulse repetition rate and the duration in neutron generator. This can be made as compact as ~600 mm length and ~100 mm diameter. The main feature of this type of accelerator is ion source, gas source, acceleration electrode system and a target. We are developing one compact neutron generator in our laboratory. The fusion reactions for the neutron production are as follows:



The production of neutrons from the D-T reaction is higher by orders of two than the D-D reactions. The maximum neutron yield from D-T reactions occurs at 130 keV of deuteron energy where as in case of D-D reaction the energy of deuteron required in the range of MeV. Energetic deuterium ions are required for both the reactions.

## 2. NEUTRON GENERATOR ASSEMBLY

The photograph of the experimental set up is shown in fig. 1. As per the schematic diagram of the electrostatic neutron generator as shown in fig. 2, it consists of ion source, accelerating electrode and the target. The ion source is one of the important components for the generator. In this generator, we have used

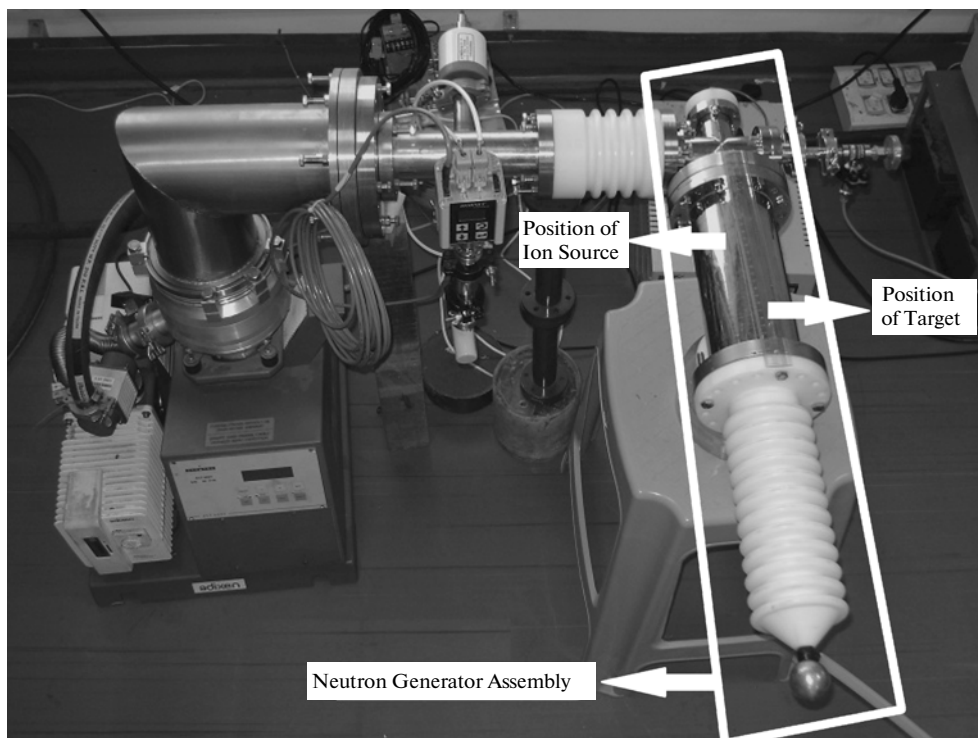


Fig. 1. Photograph of the experimental set up.

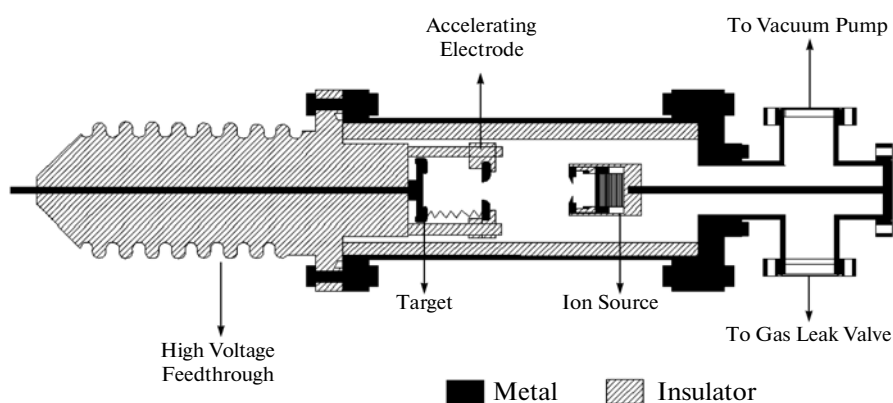


Fig. 2. Schematic diagram of the neutron generator.

one penning ion source that was developed in our laboratory. The detail design and performance of the ion source is described elsewhere [5]. Because of compactness, maintenance free and easy instrumentation, the penning ion source is suitable for this instrument rather than other type of ion sources. A typical penning ion source consists of plane metal cathodes and either ring shaped anode or cylindrical anode. In this case one cylindrical anode was used. The magnetic field due to the permanent magnet creates  $J \times B$  force along with the potential on the electrodes in the plasma region. The  $J \times B$  force helps for efficient ionization of the gas due to longer electron gyration. In this

type of ion source there is no need for extra electrode for the extraction of ions. The ions are extracted by the help of the potential on the electrode and the shape of the electrode. Earlier, we had studied the effect of the geometry and the angle of extraction of the plasma electrode on the extraction of the ions and reported in [6]. The angle of the plasma electrode helps in the distribution of the equipotential surface in the vacuum side of the ion source. A charged particle while crossing the triple point i.e. plasma, metal electrode and the vacuum, experiences an inward force due to the equipotential surface thus tends to converge.

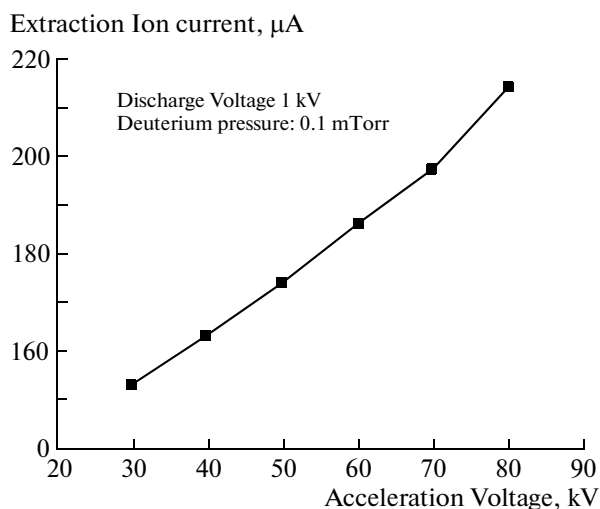


Fig. 3. Plot of the extraction ion current.

At higher voltages between the electrodes inside the vacuum enclosure, high voltage breakdown occurs for various reasons. The high voltage breakdown in vacuum gap depends upon various factors like, the gap distance, the area, geometry, material and surface condition of the electrode, gas pressure and the nature of the gas [7]. Considering these entire factors, electrodes have been made out of stainless steel. The surface has been elctropolished with roughness of  $<1 \mu\text{m}$ . For high voltage insulation, between the electrodes and the wall of the vacuum enclosure, one ceramic tube has been inserted. The assembly is housed in a standard 100 CF nipple. One Delryn flange with high voltage electrode was used for the high voltage connection to the target and the accelerating electrode. The enclosure was pumped by one turbo molecular pump as shown in the fig. 1 that created base pressure up to  $5 \cdot 10^{-7}$  Torr.

At the target, fusion takes place between two hydrogenous isotopes and neutrons are generated. Basically, the targets are of two types. First type of target is known as metal hydrides [8] where as the second type is known as drive in targets [9]. The metal hydride targets have hydrogenous isotopes embodied into them. They are prepared from thin films of reactive metals like titanium, zirconium, vanadium etc on substrates like copper. These types of targets are prepared from the vacuum thermal evaporation for the preparation of the thin film followed by hydrogenation. A drive in target is a virgin metal where the initial energetic hydrogenous ions get implanted and the neutrons are produced by the collision with the following energetic ions. The life of the first type depends upon the rate of depletion of hydrogenous elements from thin film. So the life is shorter whereas the life of the second type is much longer than the first one. In case of neutron generators, the incoming ions strike the target surface either at normal or very close to normal incident angles.

The sputtering yield of titanium by deuterium ions of energy at 100 keV at normal incidence is very low. Hence the life of a drive in target is very high. In our present experiment, one 1mm thick titanium drive in target was used.

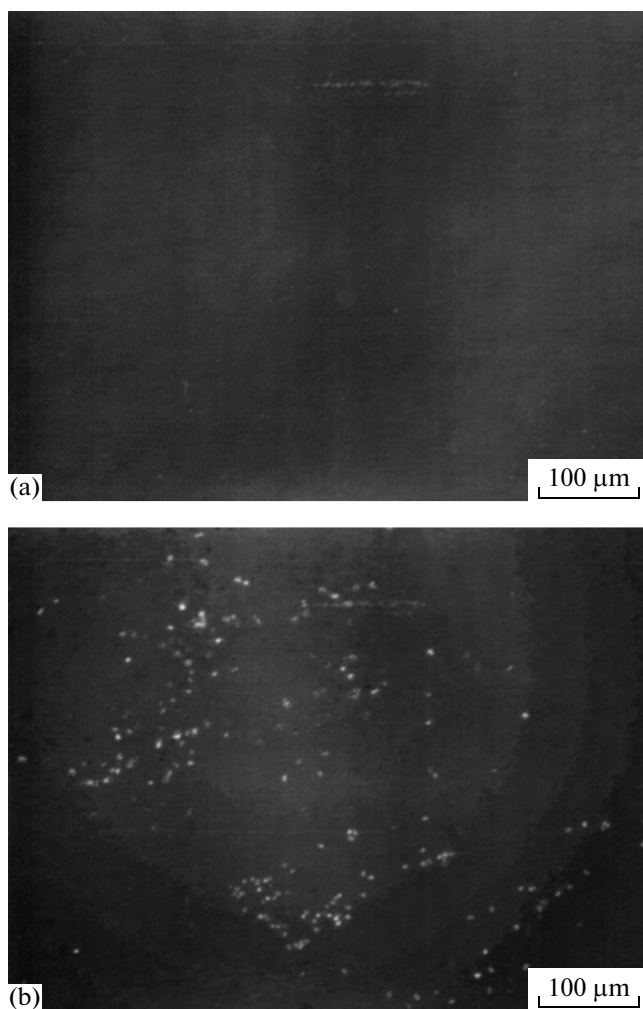
### 3. NEUTRON PRODUCTION AND DETECTION

The first experiment for the neutron production from this generator has been carried out. Ion source was operated with 1 kV potential difference between the electrodes and a deuterium filled pressure of  $10^{-4}$  Torr. In this experiment one pure titanium target of 30 mm diameter and 1mm thickness was used. The titanium has a property for the retention of hydrogenous isotopes. The initial batch of deutron ions were implanted into the target and the subsequent deutron ions collided with them producing neutrons of 2.5 MeV energy from the D-D reaction. The generator was operated for one minute with acceleration potential of 80 kV. The extracted deutron current with respect to the acceleration potential is shown in fig. 3.

Neutrons being electrically neutral, it is difficult to measure by direct methods. The detection of neutrons is possible only through nuclear reactions. In our case, one  $\text{LiI}(\text{Eu})$  [10] detector was used for the detection of neutrons. The detector was placed close to the target position in a radial direction. During the operation of the generator the detector reading was 300 cps. From the detector efficiency and the size, a neutron yield of  $3.5 \cdot 10^5$  neutrons/s was estimated. The neutrons from the target spread in isotropic direction with very little variation of energy.

In our experiments, we have used CR-39 Solid State Nuclear Track Detectors for the detection of neutrons. CR-39 is a transparent plastic whose chemical composition is  $\text{C}_{12}\text{H}_{18}\text{O}_7$ . When a charge particle passes through it, it leaves a trail of damage along its track in the form of broken molecular chains and free radicals. The amount of damage is directly related to the rate of energy lose by the incident particle. Neutron being electrically neutral, it does not create any tracks directly while passing through the detector. Detection of neutrons by CR-39 is a two step process. In the first step, this creates recoil proton, carbon and oxygen nuclei in the forward direction. Than these recoil nuclei creates tracks while moving in forward direction.

One sample of CR-39 was placed over the outer wall of the vacuum enclosure of the neutron generator. After irradiation with the neutrons for one minute during the operation of the generator, the sample was etched with 6 N NaOH solution for 7 hours. After etching, the sample was examined under one metalurgical microscope made by Olympus and model GX51. The microscope images of the samples are shown in fig. 4. The fig. 4a corresponds to the sample



**Fig. 4.** Microscope image of the CR-39 detector without exposure to neutrons (a), with exposure to neutrons (b).

after etching with aqueous solution of Sodium Hydroxide without exposure to the neutrons whereas the fig. 4b corresponds to the sample prepared with exposure to neutrons. The visible white tracks shown in the image confirm the generation of neutrons.

#### 4. CONCLUSION

In this study, the production of neutron from D-D reactions in an electrostatic accelerator based neutron generator was examined. The neutrons were produced at deuteron energy of 81 keV bombarded into a titanium drive in target. The neutron production was confirmed by CR-39 detector whereas yield of  $3.5 \cdot 10^5$  neutrons/s was measured by one LiI(Eu) detector. In future, detail energy and flux measurement experiments will be carried out with higher deuteron energy and different targets likes deuteriated titanium targets and pure zirconium and vanadium targets. We will endeavour for production of 14 MeV neutrons from D-T reactions in future experiments and vacuum sealing of the accelerator enclosure.

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