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THE NEUTRON PRODUCTION RATE MEASUREMENT OF AN INDIGENOUSLY DEVELOPED COMPACT D-D NEUTRON GENERATOR

by

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One electrostatic accelerator based compact neutron generator was developed. The deuterium ions generated by the ion source were accelerated by one accelerating gap after the extraction from the ion source and bombarded to a target. Two different types of targets, the drive – in titanium target and the deuteriated titanium target were used. The neutron generator was operated at the ion source discharge potential at +Ve 1 kV that generates the deuterium ion current of 200 μA at the target while accelerated through a negative potential of 80 kV in the vacuum at 1.3 10^{-2} Pa filled with deuterium gas. A comparative study for the neutron yield with both the targets was carried out. The neutron flux measurement was done by the bubble detectors purchased from Bubble Technology Industries. The number of bubbles formed in the detector is the direct measurement of the total energy deposited in the detector. By counting the number of bubbles the total dose was estimated. With the help of the ICRP-74 neutron flux to dose equivalent rate conversion factors and the solid angle covered by the detector, the total neutron flux was calculated. In this presentation the operation of the generator, neutron detection by bubble detector and estimation of neutron flux has been discussed.

Key words: neutron generator, D-D fusion, neutron detection, bubble detector

INTRODUCTION

The neutron generators based on the fusion reactions of the hydrogenous isotopes in electrostatic accelerator are becoming important instruments for many applications in the detection of illicit material [1, 2], special nuclear material [3], landmines [4], and many other applications in coal and cement detection, archaeology, *etc*. The compact neutron generator has several advantages over other type of neutron sources like nuclear reactors and radioisotope sources. The neutron generator is more environmentally friendly, safer for the operators, more sensitive to an elemental analysis. It is easier to control the neutron characteristics like the neutron yield, the pulse repetition rate and the duration in neutron generator. One such type of neutron generator is under development in our laboratory. In this generator, the neutron generation was carried out by the fusion of deuterium with deuterium. From this reaction the energy of the neutron is 2.45 MeV. For many applications where pulsed thermal neutrons are required, the D-D neutron generator becomes important as it is easier to thermalize 2.45 MeV neutrons rather than higher mono energetic neutrons produced from other fusion reactions like deuterium and tritium. In this work, two types of target *i. e.* the drive in titanium and the deuteriated titanium were used. The drive in titanium target is a pure titanium target of 30 mm outer diameter and 1 mm thickness. In this case the deuterium ions are implanted during the operation and the deuterium ions that follow do the collision and produce neutrons. The neutron flux in this case is lower but the life of this target is higher than the second one. On the other hand, the deuteriated titanium targets have deuterium inside the thin titanium film on the copper substrate. The titanium has the property to make solid solutions with hydrogenous isotopes. The ratio of the deuterium to titanium atom is 0.92 in our case. The detection of neutron flux is a challenge; as neutrons are electrically neutral it is difficult to have direct detection methods and indirect methods also become difficult due to the complementary presence of the gamma rays because of the neutron interaction with matter. There are many methods for neutron detections. The passive detectors like thermo luminescent dosimeter, foil activation detection, track etch detectors and bubble detectors and the active detectors like gas proportional counters, semiconductors detectors, scintillation detectors [5] are employed for

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the neutron detection. As neutrons can have different energies (*i. e.* thermal neutrons and fast neutrons) and interact differently with different materials, it is difficult to use a single detector directly for the detection of neutrons for the entire energy range except the bubble detectors. In this work, the measurement of neutrons was done by the bubble detectors, known as BD-PND *i. e.* The Bubble Detector Personal Neutron Dosimeter, procured from the Bubble Technology Industries. A detailed description of the bubble detector is given in the following section.

BUBBLE DETECTOR

This detector consists of superheated liquid droplets of ~20 μm in diameter, dispersed throughout the 8 cm^3 of clear elastic polymer. A liquid, when continues to exist in the liquid state above its normal boiling point, is said to be superheated. The boiling or nucleation can be retarded until the temperature of the liquid reaches its superheat limit. The maximum attainable superheat, at atmospheric pressure can be predicted on thermodynamic and kinetic grounds to be ~90% of the liquid's critical temperature [6]. There are two types of nucleation, one is the heterogeneous nucleation and the other is known as the homogeneous nucleation. In heterogeneous nucleation, the phase transition occurs when nucleated particle gets support from other liquid particle or the liquid solid interface like normal boiling process. In the homogeneous nucleation normal boiling is suppressed and liquid is heated up to its superheat limit. The thermal spike theory [7] is well known to explain the nucleation mechanism. According to this theory, highly localised hot regions are produced due to the interaction of ionizing radiation with superheated liquid. These hot regions otherwise known as temperature spikes explode into bubbles through the evaporation of the superheated liquid. The physical processes responsible for the production of bubbles in superheated liquid are viewed to be similar in nature like radiation damage in solid. The formation of bubbles in superheated liquid due to the interaction of ionizing radiation is a two step process. The first step involves formation of a critical sized vapour bubble whereas in the second step, this vapour bubble grows to a visible macroscopic bubble. The radius of the bubble is dependent on various parameters like external pressure, internal pressure and surface tension. The calculation for the critical bubble size and the response of the bubble detector to the monoenergetic neutrons are well explained by Ing *et al.*, [8].

The interaction of neutrons with the bubble detector produces various energetic secondary charged particles including recoil ions. These charged particles slow down in the medium due to the stopping power of the ions in the immediate interaction site. The energy dissipation during this process produces thermal spikes which is responsible for the visible bubble formation. Once a bubble greater than the critical size is formed, the remaining liquid in the superheated droplet vaporizes into the bubble forcing it to grow very quickly. This process takes place in order of microseconds. The size of the visible bubble is determined by the size of the droplet within which the energy deposition occurs. All the processes related to the neutron interaction like energy deposition, thermal spike, vaporization have taken place before the formation of the bubble. Hence, the size of the visible bubble is not related to the neutron energy. The visible bubbles formed by the neutron interaction in the bubble detector remain fixed at the initial droplet sites. After exposure to the neutrons the number of these bubbles is used to determine the neutron dose.

EXPERIMENTAL TECHNIQUES

In this work, the neutron flux of a D-D neutron generator was measured. The photograph of the experimental system is shown in fig. 1. The schematic diagram of the generator is shown in fig. 2. This neutron

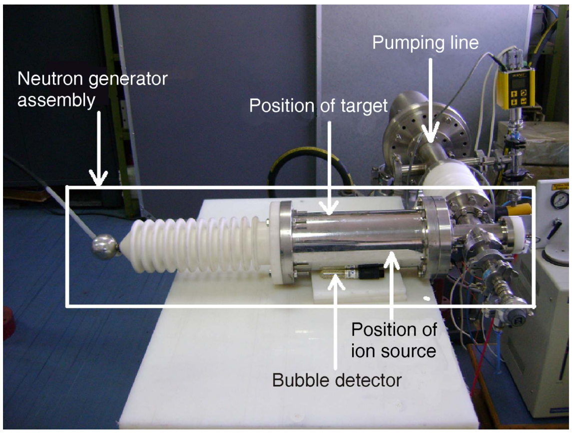

Figure 1. The experimental system

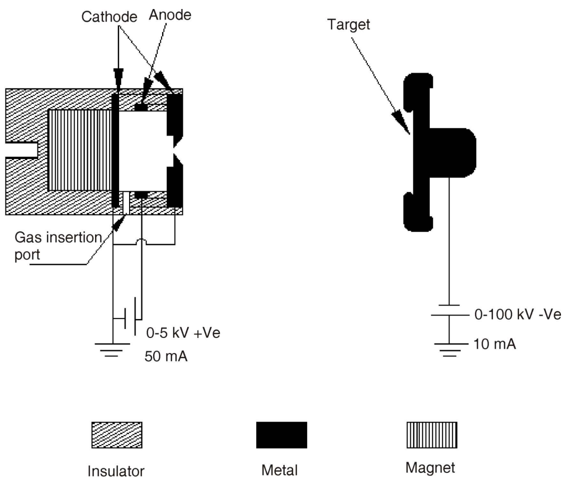

Figure 2. A schematic diagram of the neutron generator

generator consists of a hollow anode penning ion source [9] for deuterium ion production, an accelerating electrode for acceleration of the deuterium ions, the deuteriated titanium target and the high voltage feed-through. All these components are housed in a standard 100 conflat flange (CF) nipple of 300 mm axial length. The bubble detector from Bubble Technology Industries with sensitivity of 0.35 bubbles per μSv and precision up to ±20% was used for measurement of the neutron flux. This detector has a built in compensation for temperature effects on the response of bubble detector. The bubble detector was activated by unscrewing the cap used for re-compression. The bubble detector was placed outside and closed to the wall of the 100 CF nipple exactly at the position of the target in the axial direction and at an angle of 90° to the direction of the deuterium ion beam, as shown in fig. 1. Though it is wise to measure the neutron flux at the forward direction of the ion beam, due to the high voltage feed-through position, it was difficult to get the correct dose by placing the bubble detector at the end of the feed-through. We may get neutrons with less and unknown energy at this position, so the correct estimation of the neutron flux needs the particle simulation in MCNP, FLUKA, *etc*. for neutron interaction and the thermalization which will be carried out in future tasks. The assembly was evacuated to the 6.6 10^{-5} Pa vacuum by a turbo molecular pump. The deuterium gas was injected directly into the plasma region of the ion source by the help of one manual gas leak valve. The deuterium pressure was maintained at 1.3 10^{-2} Pa during the operation. The neutron generator was operated at an ion source potential of 1 kV and acceleration potential of negative 80 kV. With these potentials an ion current of 200 μA was achieved at the target. The generator was operated for one minute. After the operation, the bubble detector was taken out, the bubble formed during operation was well visible to naked eye but the bubbles were photographed and counted by one automatic bubble reader. The above experiment was repeated for deuteriated titanium target as well as for drive in titanium target with the unchanged operational parameters.

RESULTS

The photograph of the bubble detector before neutron generation is shown in fig. 3. Figures 4 and 5 represent the images of the bubble detectors exposed to neutron with drive in titanium target and deuteriated titanium target, respectively. In both cases, two separate detectors with same sensitivity of 0.35 bubbles per μSv were used. The bubble detector those were exposed to the neutrons has shown good response. Visible bubbles were formed immediately during the irradiation. The number of bubbles was found to be 9 in the bubble detector exposed during operation with

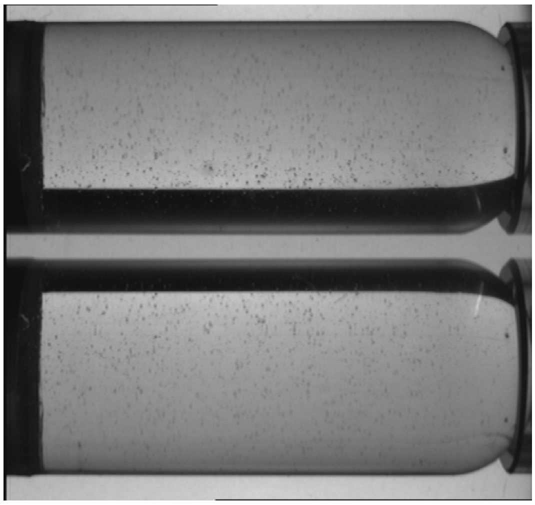

Figure 3. The image of the bubble detector taken by the automatic bubble reader before the exposure to neutron

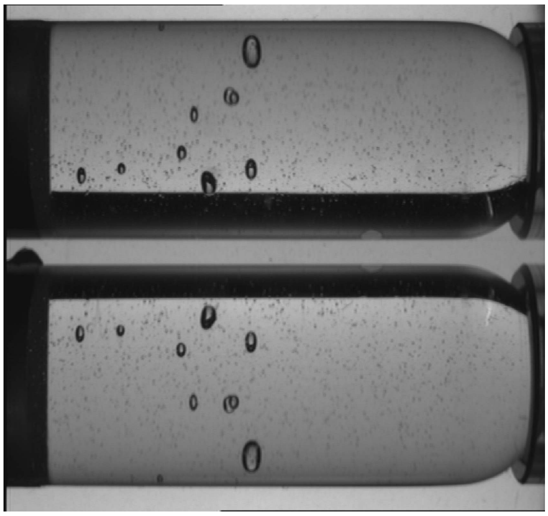

Figure 4. The image of the bubble detector taken by the automatic bubble reader after the exposure to neutron operated with the drive in titanium target

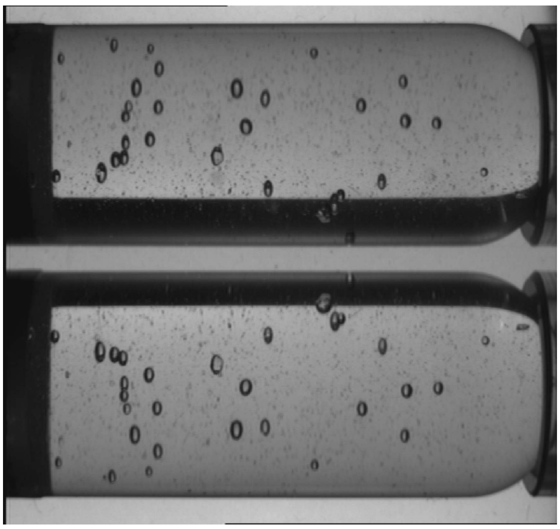

Figure 5. The image of the bubble detector taken by the automatic bubble reader after the exposure to neutron operated with the deuteriated titanium target

drive in titanium target and 31 during operation with deuteriated titanium target. From the sensitivity of the bubble detector, the number of visible bubbles, the dose equivalent for 2.45 MeV neutrons according to ICRP-74 [10], the time of operation and the solid angle covered by the detector, the neutron production rate was calculated to be 5.6 10^5 neutrons per second in case of drive in titanium target and 1.5 10^6 neutrons per second in case of deuteriated titanium target. This number is in good agreement with the analytical values of neutron yield for the ion beam current and the ion energy for D-D fusion reaction.

CONCLUSIONS

This report explains the use of the bubble detector for the neutron production rate measurement in different target material. As the experiments were carried out with the same ion beam parameters, the results with deuteriated titanium target had shown better neutron production rate than the drive in titanium target, due to the high concentrations of deuterium. The configuration of the generator assembly was inappropriate to measure the neutron flux in the forward direction, hence, in future work, it will be focused to have modified configuration with feed-through arrangement for better access to measure the neutron flux in that direction. The angular distribution of the D-D reaction is not homogenous; the deviation is greater in low energy of the deuterium ion beam [11]. Therefore, it is useful to know its distribution.

AUTHOR CONTRIBUTIONS

The Penning Ion Source and Neutron Generator were designed and developed by B. K. Das. Experiments were carried out by B. K. Das and R. Das and the manuscript was written by B. K. Das. All the figures were prepared by B. K. Das. B. K. Das and A. Shyam had participated in the discussion regarding the designing of the ion source and the neutron generator. B. K. Das, A. Shyam, R. Das, and A. D. P. Rao had participated in the discussion of the result.

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МЕРЕЊЕ БРЗИНЕ СТВАРАЊА НЕУТРОНА САМОСТАЛНО НАПРАВЉЕНОГ КОМПАКТНОГ D-D НЕУТРОНСКОГ ГЕНЕРАТОРА

Направљен је компактни генератор неутрона заснован на електростатичком акцелератору у коме деутеријумски јони настали екстракцијом из јонског извора, бомбардују мету, пошто су убрзани кроз акцелераторски процеп. Коришћене су две врсте мете: титанијумска мета и деутеризована титанијумска мета. Неутронски генератор радио је при потенцијалу отпуштања јонског извора од +Ve 1 kV, који успоставља деутеријумску јонску струју од 200 A у мети, после убрзавања кроз вакуум испуњен деутријумским гасом при притиску од 1.3 10^{-2} Pa и негативном потенцијалу од 80 kV. Спроведена је компаративна студија приноса неутрона за обе мете. Мерење неутронског флукса обављено је употребом детектора на принципу мехурасте коморе произвођача BTI Technology. Број мехура насталих у детектору одговара укупној енергији депонованој у детектору. Укупна доза процењена је бројањем насталих мехура, укупни неутронски флукс израчунат је уз помоћ конверзионих фактора за неутронски флукс и јачину дозног еквивалента према документу ICRP-74 и на основу доброг угаоног одзива детектора. На крају, размотрен је рад генератора, детекција неутрона мехурастом комором и процена неутронског флукса.

Кључне речи: генератор неутрона, D-D фузија, детекција неутрона, мехураста комора