DETECTION OF $^{4}$HE GENERATED DURING THE REACTION OF $^{3}$HE($^{3}$HE,2P)$^{4}$HE IN A PLASMA FOCUS DEVICE USING LEXAN SOLID STATE NUCLEAR TRACK DETECTOR

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Abstract

The plasma focus device is a well known laboratory fusion device. It has been reported to produce neutrons due to D-D or D-T fusion reaction. Fusion of heavier elements is difficult to achieve in laboratory due to high coulomb barrier for reaction. One such type of fusion $^{3}$He($^{3}$He,2p)$^{4}$He was attempted here using a compact 11.5 kJ (40 μF, 24 kV) plasma focus device operated with high purity $^{3}$He gas at 4mb filling pressure. Detection of $^{4}$He along with proton generated during the reaction of $^{3}$He($^{3}$He,2p)$^{4}$He was done using Lexan and CR-39 (covered with 24 μm thick aluminium foil) solid state nuclear track detectors respectively. The estimated ratio between the fusion products is close to expected ratio in such reaction. The observation of tracks in Lexan film (for $^{4}$He) and in CR-39 film (for proton) suggests the occurrence of fusion reaction $^{3}$He+$^{3}$He in a plasma focus device.

Introduction

The fusion reactor appears to be the promising energy source for the galloping mankind. The fuel (D-D, D-T) for fusion reactions proposed to be used in a fusion reactor for energy generation will produce neutrons of high energies. Such neutrons are likely to cause the components of the reactor vessel radioactive on bombardment. Moreover, indirect ways like thermal process similar to the fission reactor will be required for the power generation. Helium-3 ($^{3}$He) as a fusion fuel is more attractive because of aneutronic nature of its reaction products. The fusion products alpha and proton can be contained using electric and magnetic fields. These particles will not induce any radioactivity in components of the reactor vessel. The fusion products can directly be used for the electricity generation. Thus $^{3}$He is conceived as the third generation fusion fuel. Because of the higher coulomb barrier, the energy required for $^{3}$He$_2$ + $^{3}$He$_2$ fusion will be much higher than the conventional D$_1$ + $^{2}$D$_1$ or $^{2}$D$_1$+T$_1$ fusion. Display of $^{3}$He fusion in a laboratory will have positive impact on the commercial viability. The plasma focus (PF) device [1] is a simple and low cost fusion unit. It produces intense pulsed neutrons on use of deuterium gas with or without tritium gas. The working principle of this unit is based on plasma pinching phenomena. Most of the neutrons produced in this device are due to beam target mechanism. Experiment has been done [2] with deuterium and helium as filling gas in a plasma focus device to measure the energy of the produced protons and to locate the spatial distribution of the fusion regions. But for the $^{3}$He($^{3}$He,2p)$^{4}$He reaction for cross section study [3] underground accelerator facility was employed. We have attempted here to fuse $^{3}$He with $^{3}$He in a compact 11.5 kJ compact plasma focus device. The fusion products $^{4}$He ($\alpha$ particle) and proton are measured using
Lexan and CR-39 (covered with 24 μm thick aluminium foil) solid state nuclear track detectors respectively. The experimentally estimated ratio between the fusion products is close to the expected ratio for such reaction products. The detailed of the experiments and the results are reported here.

**Experimental Set Up**

The schematic of the setup is shown in Fig. 1. The device used for the fusion of $^3$He is a compact plasma focus device developed [4] in house. The central electrode (anode) of the unit is of 77 mm effective (exposed) length and 60 mm in diameter. Twelve SS304 rods each of 12 mm in diameter and 122 mm in length arranged in a circle (122 mm PCD) around the anode formed the cathode (squirrel cage geometry). A quartz tube of 50 mm effective (exposed) length, 54 mm outer diameter and 2 mm wall thickness separates the anode and the cathode at the bottom. The electrode assembly is put inside a high vacuum compatible experimental plasma chamber as shown in Fig. 1. The plasma chamber is fabricated using SS304 material and it has a volume of about 7.5 L. The device is driven by an 11.5 kJ (40 μF, 24 kV) capacitor bank. The PF device is operated with high purity $^3$He gas at 4mb filling pressure. The device is evacuated using a diffstac vacuum pump up to $10^{-5}$ mb of pressure before filling the required gas. The current derivative (dl/dt) of the discharge circuit is monitored by a multi-turn Rogowski coil. The time resolved hard X-ray emission is recorded with a plastic scintillator detector (PSD) positioned at 2 m from the PF device. The PSD consists of a NE102 plastic scintillator and a photomultiplier tube (XP 2012) housed in a cylindrical brass casing covered with lead shields. One of the fusion products, $^4$He (α particle, 4.3 MeV) generated during the reaction of $^3$He($^3$He,2p)$^4$He inside the plasma focus device is measured with a Lexan solid state nuclear track detector (SSNTD) film. The other product, the proton is recorded using a CR-39 SSNTD film. The CR-39 film is covered with a 24 μm thick high pure (more than 99%) aluminium foil to stop α particle or any accelerated $^3$He particle reaching the film. The SSNTD (Lexan, CR-39) is kept at a distance of 16 cm from the top of the anode in axial direction and is irradiated one at a time. The Lexan film is exposed to 6 PF shots and CR-39 film is exposed to 3 PF shots. After exposing the film to the desired PF shots, it is removed and is etched off line under the standard conditions (6N KOH at 60°C) for a period of 4-7 hours to develop visible tracks. The tracks are counted using Zeiss axiscope motorised microscope at 100X magnification.

**Result & Discussion**

The typical current derivative (dl/dt) signal with hard X-ray signal is shown in Fig. 2. The sharp dip in dl/dt signal suggests maximum compression of plasma due to plasma pinching action. The width of hard X-rays is 40 to 50 ns. The production of hard X-ray indicates the generation of high energy electrons due to creation of high electric and magnetic fields. It also envisages the production of high energy ions the necessary condition for fusion reaction. The energy of α particle produced...
in fusion reaction of $^3\text{He} + ^3\text{He}$ is around 4.3 MeV. The Lexan film can detect alpha particles when its energy loss rate is nearing Bragg peak (4 MeV/mg/cm²). The alpha tracks recorded in Lexan film are shown in Fig. 3. This is the accumulated tracks in the film exposed to 6 PF discharges. The measured track density is $5.4 \times 10^6$ tracks/cm². The energy of the other particle, the proton is also around 4.3 MeV. The accelerated $^3\text{He}$ will have energy up to a few hundred keV. The Lexan film is insensitive for $^3\text{He}$ and protons [5]. Thus it is evident that the tracks in Lexan film are due to $^4\text{He}$ generated in fusion of $^3\text{He}$ and $^3\text{He}$. The proton tracks appeared in CR-39 film covered with 24 μm aluminium filter are displayed in Fig. 4. The film is exposed to 3 PF discharges. The proton track density is $4.9 \times 10^6$ tracks/cm². The range of 4.3 MeV α particles in aluminium is less than 18 μm [6]. The range of accelerated $^3\text{He}$ will be much less than 24 μm (used filter). Since $^4\text{He}$ and $^3\text{He}$ are stopped by the aluminium filter, it is clear that the tracks in CR-39 film are due to protons produced in the $^3\text{He} + ^3\text{He}$ fusion reaction. Moreover, in a $^3\text{He} + ^3\text{He}$ fusion reaction, two protons and one $^4\text{He}$ are produced. The ratio of number of protons to number of α particles is 2.0. The estimated ratio from the recorded track densities (Figures 3 & 4) is 1.8, which is close to 2.0. From the above observations it is quite clear that fusion of $^3\text{He}$ with $^3\text{He}$ is possible in a compact plasma focus device.

**Conclusion**

It is shown here for the first time, the possibility of fusion of $^3\text{He}$ with $^3\text{He}$ in a compact plasma focus device operated at 11.5 kJ of bank energy with pure $^3\text{He}$ as filling gas. The fusion products $^4\text{He}$ and proton are recorded quite convincingly to establish the claim. Generation of hard X-ray during the fusion process indicates the presence of high energy electrons. This also envisages the presence of high energy $^3\text{He}$ ions, which is required for fusion. The estimated ratio of fusion products proton to $^4\text{He}$ recorded through SSNTDs is 1.8. It is close to the expected ratio of 2.0.

**References**