# Energy Multiplication Factor of $^3$He+$^6$Li fusion in a TCT Reactor

Dyavappa B.M, H.C. Manjunatha*
*Government College for Women, Kolar, Karnataka, India*
*· * email: manjunathhc@rediffmail.com*

## Introduction

Two component torus (TCT) reactor is a torus type plasma-containment reactor in which the plasma consists of two components of ion energy distribution. In a TCT reactor high energy ion beam is shot into target plasma to cause nuclear fusion between the ions of plasma and beam, proposed by the scientists of Princeton University. The energy produced by fusion is caught by fuel, causing self-heating. When energy multiplication factor $\varsigma_{^3He+^6Li} = 1$, the fusion power is equal to heating power needed to fusion to occur and it is known as breakeven, then the plasma cooled down without any external heating. If $\varsigma_{^3He+^6Li} \geq 1$, the growth of self-heating eliminates the need of an external heat resource. The process becomes self-sustaining and ignition occurs at the high temperature and no injected energy from external sources is required. Therefore high value of $\varsigma_{^3He+^6Li}$ is essential for practical TCT fusion reactor. The most favorable injection energy of $^3$He beam for fusion is the energy which gives maximum energy multiplication factor. The nuclear fusion reaction $^3He + ^6Li \rightarrow p + 2\alpha + 16.88 MeV$ has a large positive energy and calculation of its energy multiplication factor is very important. The energy multiplication factor of $^3$He+$^6$Li increases gradually upto 0.0175 for injected $^3$H**e** beam energy of 1MeV and different suitable conditions are to be studied to increase its value.

## Theory

The compound nuclei created in fusion reactions are typically characterized by large intrinsic angular momenta (J), GEMINI and GEMINI$^{++}$ models explicitly consider the influence of spin (S) and orbital angular momentum (L) on particle emission [1]. The fusion cross-section of $^3He + ^6Li \rightarrow p + 2\alpha + 16.88 MeV$ is obtained from GEMINI$^{++}$ statistical decay model. The fusion cross-section is given by

$$\sigma(J) = \frac{\pi\lambda^2 (2J+1)}{1+\exp\left(\frac{J-J_0}{\delta J}\right)} \qquad (1)$$

Where, $J_0$ is initial angular momenta, $\delta J$ is change in angular momenta. The fusion reaction rate is the Maxwellian average of the product of the fusion-cross section and relative velocity of fusing nuclei. The fusion reaction rate is [2].

$$\langle \sigma v \rangle = \left(\frac{8}{\pi}\right)^{\frac{1}{2}} \left(\frac{\mu}{k_B T_i}\right)^{\frac{3}{2}} \frac{1}{m_1^2} \int_0^\infty E\sigma(E) \exp\left(-\frac{\mu}{m_1 k_B T_i}\right) dE \qquad (2)$$

Where $\mu$ is reduced mass of $^3$He and $^6$Li, $T_i$ is ion temperature, $m_1$ is mass of $^3$He, $E$ is energy of $^3$He beam. The mean rate of energy loss of injected beam by all the thermal electrons and ions is determined using Fokker-Planck slowing-down model of Sivukkin given by[3,4].

$$\left\langle \frac{dE}{dt} \right\rangle = -\frac{4\pi n_s Z_{He}^2 Z_{Li}^2 e^4 \Lambda}{m_s} \sqrt{\frac{m_{He}}{E_{He}}} \sum_{s=i,e} F_{err}(\beta_s, x_s) \qquad (3)$$

Where, $n_s$ is number density of plasma, $Z_{He}, Z_{Li}$ are charge states, $\Lambda$ is Coulomb logarithm, $m_s$ is mass of plasma species, $F_{err}$ is error integral. The energy multiplication factor of nuclear fusion is the ratio of fusion energy released from the nuclear fusion reaction to the energy of injected $^3$He beam. The energy multiplication factor of nuclear fusion $^3He + ^6Li$ is determined from [2]

$$\varsigma_{^3He+^6Li} = \frac{16.88 (MeV) n_s}{E_{He}} \int_{E_{th}}^{E_{He}} \frac{\langle \sigma v \rangle}{\left| -\frac{dE}{dt} \right|} dE \qquad (4)$$

## Results and Analysis

The fusion cross-section obtained for different values of centre of mass energy of injected $^3$He beam from obtained from GEMINI$^{++}$ is used in the calculation of fusion reaction rate. The fusion reaction rate between the Maxwellian thermal $^6$Li plasma and mono-energy $^3$He beam is plotted $\langle \sigma v \rangle$ v/s $E_{^3He}$.

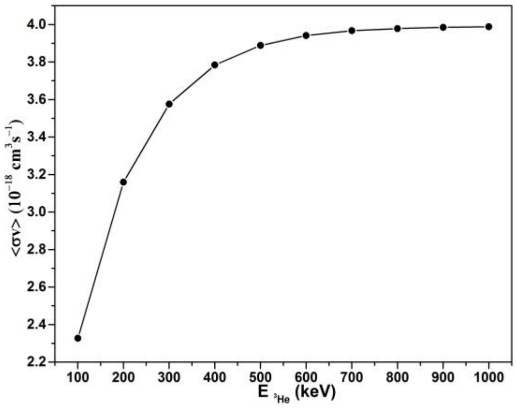

**Fig.1 Fusion reaction rate of $^3$He+$^6$Li**

The fusion reaction rate $\langle \sigma v \rangle$ of $2.3 \times 10^{-18} cm^3 s^{-1}$ at 100keV increases gradually and remains almost constant at $3.9 \times 10^{-18} cm^3 s^{-1}$ between 0.7 MeV and 1MeV as shown in Fig.1.

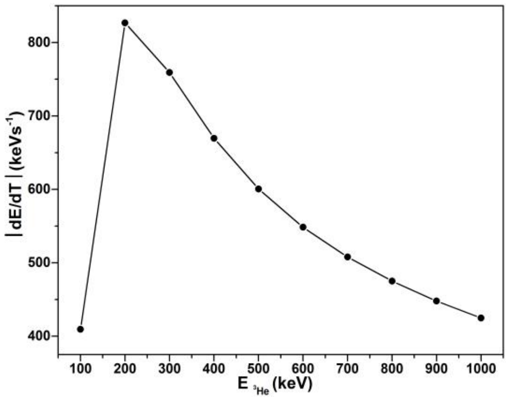

**Fig.2 Energy loss rate of $^3$He beam due to $^6$Li ions**

The mean rate of energy loss of $^3$He by all electrons and ions of $^6$Li plasma is plotted v/s $E_{^3He}$. The energy loss rate increases steeply between 100keV and 200keV and decreases gradually up to 1MeV as shown in Fig.2. The energy multiplication factor of $^3$He+$^6$Li increases gradually from -0.0025 at 100keV to 0.0175 at 1MeV as shown in Fig.3.

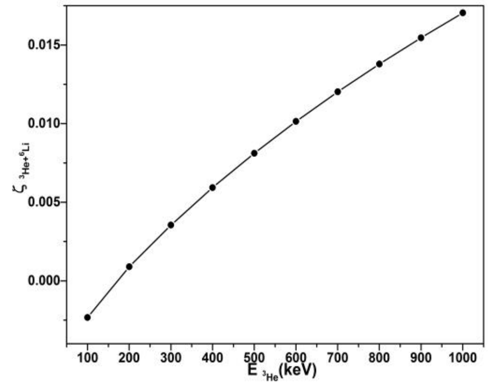

**Fig.3 Energy Multiplication Factor of $^3$He+$^6$Li nuclear fusion**

## Summary

The fusion cross-section is obtained from GEMINI$^{++}$ statistical decay model. The fusion reaction rate is obtained as the Maxwellian average of the product of the fusion-cross section and relative velocity of fusing nuclei. The mean rate of energy loss of injected beam by all the thermal electrons and ions of the target is determined. High value of energy multiplication factor is essential for practical TCT fusion reactor. The most favorable injection energy of $^3$He beam for fusion is the energy which gives maximum energy multiplication factor which corresponds to 1MeV.

## References

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