A Correction Factor to Investigate a Theoretical Analysis Agreement for Determination of the Hot Plasma Parameters for the D-D fusion reactions

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Abstract

Many applications depend on the fundamental physical parameters involving with the phenomena of nuclear fusion reaction using the deuterium as a fuel.

For these cases available experimental or empirical data about the total cross-section and other parameters for D-D fusion reactions play an important rules in adjusting the operation of many mine devices such as plasma focus, z-pinch.

In the present work and in order to arrive to an agreement between the experimental and theoretical parameters it is necessary to insert a correction factor in the empirical formulas especially those deal with the total cross-section for D-D fusion reactions.

Keywords: Hot plasma parameters , plasma focus , z-pinch , D-D fusion reactions.

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حساب معامل التصحيح لدراسة التوافق التحليلي النظري في تعيين معلمات البلازما الساخنة لتفاعلا D-D الاندماجية

المستخلص

تعتمد العديد من التطبيقات على المعلمات الفيزيائية الأساسية المتعلقة بظاهرة التفاعل النووي الاندماجي الذي يستخدم الديتيريوم كوقود. في هذه الحالات، تلعب البيانات العملية والنظرية المتوفرة للمقطع العرضي الكلي والمعلمات الاخرى لتفاعلات D-D الاندماجية دورا مهما في التحكم بعمل كثير من الأجهزة كمركزات البلازما وضواغط – Z.

في الدراسة الحالية ولغرض الوصول الى توافق بين المعلمات العملية والنظرية كان من الضروري ادخال معامل تصحيح في المعادلات النظرية المتعلقة بحساب المقطع العرضي الكلي لتفاعلات D-D الاندماجية.

Introduction

The plasma focus (PF) devices are pulsed plasma generators with relativity simple operating principle. They were originally developed in early 1960 independently in the former Soviet Union(Filippov type), and the USA(Mather type). Because of the simple construction, cost effectiveness, and easy maintenance, PF devices have been investigated in many laboratories around the world. They may have diverse applications e.g., in study of neutron and X-Ray generation, as pulsed soft X-Ray source and pulsed neutron source [1,2].

The vacuum chamber is filled with a gas(Argon, Neon, Deuterium…), usually under a pressure of some tenths fraction to units of Torr. After triggering of spark gap, the power supply source voltage is applied to the chamber electrodes and a breakdown of the discharge gap takes place.

At the initial discharge stage(stage I),the current is skinned along the insulator(3) and a plasma current sheath is produced, the produced PCS lifts off from the insulator under the effect of ponder motive force and makes a complicated motion accompanied by the shock wave production. The shock wave ionized and sweep up the neutral gas, gradually increase the PCS mass (the so-called snow plow model)[3,4,5,6].

After a short time (~ 1μsec) the PCS reaches the anode surface, the accelerated motion of this PCS-part towards the chamber axis(stage II) occurs.

To optimize the machine the dimensions of electrodes and the operational pressure are chosen in the relationship with the characteristic of the energy source so that the current is maximum when the PCS reaches the axis,(stage III). At this instant a hot and dense column of plasma(pinch) is formed in the front of inner electrode.

When deuterium is used as a working gas, neutron are emitted from the pinch due to following nuclear fusion reactions:

$${}_{1}^{2}D+{}_{1}^{2}D\rightarrow{}_{0}^{1}n+{}_{2}^{3}He$$

$${}_{1}^{2}D+{}_{1}^{2}D\rightarrow{}_{1}^{1}H+{}_{1}^{3}T$$

PF-type facilities emit both neutrons, and hard X-rays with quantum energies of tens and hundreds electron volts [1].

We believe the Dense Plasma Focus(DPF) has possible applications as a unique high intensity neutron source when compared with conventional accelerator-driven neutron generators or ${}^{252}Cf$ isotope-based sources [2].

The dominant part of neutrons(70%) with energies in the range of (2.6-3.2 MeV)

was produced by deuterons moving downstream. The deuterons generating these neutrons have the energy in the range of (20-200 keV) with most probable value of

50 KeV. From theses energies we can calculate the mean free paths of D-D reaction for the convenient deuteron densities of (10^{18}-10^{20}cm^{-3}). On the basis of these results we can estimate

the number of fast deuterons lower than 10^{18} and the density of the deuteron target higher than $10^{19}cm^{-3}$.

The D-D fusion reaction is tested for the determination of basic parameters of hot plasma-temperature, density and duration of high value of these parameters. This reaction is tested mainly in tokomaks[7], high power lasers[8] and z-pinches[9].

The D-D reaction is realized in 2 branches with the probability of 50%.

These qualities make possible the usage of neutrons as a convenient tool for the diagnostics of fast deuterons with energies above 20 keV.

In this paper we refer about the determinations of velocities and number of fast deuterons producing neutrons in D-D reaction and the estimations of densities of the targets in plasma focus PF-1000 facility [10].

Fast neutrons from deuteron-deuteron fusion reactions were used for a study of fast deuterons in the PF-1000 plasma-focus device. Neutron energy-distribution functions enabled the determination of axial and radial components of energy of deuterons producing the fusion neutrons, as well as a rough evaluation of the total energy distribution of all fast deuterons in the pinch. It was found that the total deuteron energy-distribution function decreases with the deuteron energy more slowly than the tail of the Maxwellian distribution for (1-2 KeV) deuterons.[11]

Theory

The energy of fast deuterons producing neutrons can be calculated from the known neutron energy using the equilibrium of the momentum and energy.

The required energy of deuterons is about 200 KeV. The dominant part of neutrons with the energy of 2.6-2.8 MeV is produced with deuterons in the energy range between 20 and 80

KeV. The deuterons with the energy below 20 KeV have very low and cross-sections for the D-D fusion reaction and we do not take them into account. [10]

The hot plasma parameters such as the mean free path for D-D fusion reaction($\lambda_{D\text{-}D}$),the number of fast deuterons(N_D) and the probability for D-D fusion reaction,are all of them depend strongly on the total cross-section for the D-D fusion reaction ($\sigma(E_d)$).

The total cross-section for the D-D fusion reaction which is tested with experimental data is given as:

$$\sigma = K_v^{-k}\exp(-L/v) ------ (1) \ where\ k,K\ and\ L\ are\ constants.$$

Empirical for the D-D fusion reaction.

$$\sigma(Ed) = \frac{288}{\mathrm{Ed}} e^{-\left(\frac{45.8}{\sqrt{\mathrm{Ed}}}\right)} ----(1)\ \mathrm{Barns}$$

Where σ and E_d is the deuteron bombarding energy in(KeV) and $\sigma(Ed)$ is the total cross-section in barns respectively [12].

Another empirical formula is often used when we are deal with deuterons energies in the range of few MeV is given as :

$$\sigma(E_d) = \exp(4.727 - 0.03154E_d) ----- (1)\ milleBarns$$

In order to get suitable values for hot plasma parameters which given bellow, that have a large agreement with the corresponding experimental values:

$$\lambda_{\mathrm{DD}} = \frac{1}{n_i\sigma(Ed)} ----------- (2)$$

Where n_i is the ion density of the target (m^{-3})

$$N_D = N_Y * \lambda_{DD} / l \text{-----------} (3)$$

Where N_D is the number of fast deuterons

N_Y is the total neutron yield= 10^{11} in the target with length $l = 1$ cm [10].

It is necessary to modified the empirical formulas for the total cross-section given in equation(1),which are not compatible with a given agreement between the recently calculated parameters and the published experimental values. For this reason and to avoid the error factor in calculating the hot plasma parameter, we must need to inserting a correction factor for all the above formulas which described the hot plasma parameters.

Results

Our calculated results deal with the total cross-section for the D-D fusion reaction $(\sigma(Ed))$, the mean free path for D-D fusion reaction (λ_{DD}) for various values of ion densities and the number of the fast deuterons (N_D), before inserting the correction factor are listed in table(1) and also results are plotted in figures(1-3).

We can conclude from the figures that there are a shift between the calculated results and the acceptable published experimental results, thus it is necessary to make an agreement between the two values by inserting a correction factor about (1.86) in the formulas previously described and for this case we found results yield a good agreement as it is presented in table(1) also and plotted in figures(4-6).

Discussion and Conclusions

The reason for inserting a correction factor is related to the fact that the empirical formula for the total cross-section for D-D fusion reaction had been used in the previous decades and not involving the physical effect for the desecrating or dividing the bombarding deuteron energies into some intervals. And it is necessary to available a given special formula corresponding correlated to their energies intervals especially for the low range of the deuteron energy(1-10 KeV).an old and applied to sum facilities that designed for previous decades and we found it cannot be applied for the recent facilities such as the modern (PFdevices) so that we conclude that it is very important to modify these formulas by testing them for calculating sum fundamental hot plasma parameters.

Finally we have got a compatible formula by inserting a correction factor of values(1.86) which therefore make a good agreement between the calculated and experimental data.

Table (1) : Dependence the total cross – section , mean free path , and the number of the fast deuterons for the D-D fusion reactions on the incident deuteron energy .

K_d (KeY)	$\sigma(K_d)\times10^{-28}$ (m^2)	n_i (m^{-3})=10^{24}						n_i (m^{-3})=10^{25}						n_i (m^{-3})=10^{26}					
		* λ_{DD} (m)	** λ_{DD}	*** λ_{DD}	* N_D	** N_D	*** N_D	* λ_{DD}(m)	** λ_{DD}	*** λ_{DD}	* N_D	** N_D	*** N_D	* λ_{DD} (m)	** λ_{DD}	*** λ_{DD}	* N_D	** N_D	*** N_D
20	$10^{-4}\times5.136$	3.6 $10^{7}\times$	1.94 $10^{7}\times$	3.61 $10^{7}\times$	—	1.94 $10^{20}\times$	3.61 $10^{20}\times$	3.6 $10^{6}\times$	1.94 $10^{6}\times$	3.61 $10^{6}\times$	3.6 $10^{20}\times$	1.94 $10^{19}\times$	3.61 $10^{19}\times$	3.6 $10^{5}\times$	1.94 $10^{5}\times$	3.61 $10^{5}\times$	3.6 $10^{19}\times$	1.94 $10^{18}\times$	3.61 $10^{18}\times$
50	$10^{-3}\times8.860$	2.2 $10^{6}\times$	1.11 $10^{6}\times$	2.09 $10^{6}\times$	—	1.12 $10^{19}\times$	2.09 $10^{19}\times$	2.2 $10^{5}\times$	1.11 $10^{5}\times$	2.09 $10^{5}\times$	2.2 $10^{19}\times$	1.12 $10^{18}\times$	2.09 $10^{18}\times$	2.2 $10^{4}\times$	1.11 $10^{4}\times$	2.09 $10^{4}\times$	2.2 $10^{18}\times$	1.12 $10^{17}\times$	2.09 $10^{17}\times$
75	0.01938	—	5.15 $10^{5}\times$	9.59 $10^{5}\times$	—	5.15 $10^{18}\times$	9.59 $10^{18}\times$	—	5.15 $10^{4}\times$	9.59 $10^{4}\times$	—	5.15 $10^{17}\times$	9.59 $10^{17}\times$	—	5.15 $10^{3}\times$	9.59 $10^{3}\times$	—	5.15 $10^{16}\times$	9.59 $10^{16}\times$
100	0.02953	6.2 $10^{5}\times$	3.38 $10^{5}\times$	6.29 $10^{5}\times$	—	3.38 $10^{18}\times$	6.29 $10^{18}\times$	6.2 $10^{4}\times$	3.38 $10^{4}\times$	6.29 $10^{4}\times$	6.2 $10^{18}\times$	3.38 $10^{17}\times$	6.29 $10^{17}\times$	6.2 $10^{3}\times$	3.38 $10^{3}\times$	6.29 $10^{3}\times$	6.2 $10^{17}\times$	3.38 $10^{16}\times$	6.29 $10^{16}\times$
125	0.03831	—	2.61 $10^{5}\times$	4.85 $10^{5}\times$	—	2.61 $10^{18}\times$	4.85 $10^{18}\times$	—	2.61 $10^{4}\times$	4.85 $10^{4}\times$	—	2.61 $10^{17}\times$	4.85 $10^{17}\times$	—	2.61 $10^{3}\times$	4.85 $10^{3}\times$	—	2.61 $10^{16}\times$	4.85 $10^{16}\times$
150	0.04562	3.7 $10^{5}\times$	2.19 $10^{5}\times$	4.07 $10^{5}\times$	—	2.19 $10^{18}\times$	4.0710 $^{18}\times$	3.7 $10^{4}\times$	2.19 $10^{4}\times$	4.07 $10^{4}\times$	3.7 $10^{18}\times$	2.19 $10^{17}\times$	4.071 $0^{17}\times$	3.7 $10^{3}\times$	2.19 $10^{3}\times$	4.07 $10^{3}\times$	3.7 $10^{16}\times$	2.19 $10^{16}\times$	4.0710^{1} $^{6}\times$
175	0.05159	—	1.93 $10^{5}\times$	3.60 $10^{5}\times$	—	1.93 $10^{18}\times$	3.60 $10^{18}\times$	—	1.93 $10^{4}\times$	3.60 $10^{4}\times$	—	1.93 $10^{17}\times$	3.60 $10^{17}\times$	—	1.93 $10^{3}\times$	3.60 $10^{3}\times$	—	1.93 $10^{16}\times$	3.60 $10^{16}\times$
200	0.05647	2.8 $10^{5}\times$	1.77 $10^{5}\times$	3.29 $10^{5}\times$	—	1.77 $10^{18}\times$	3.29 $10^{18}\times$	2.8 $10^{4}\times$	1.77 $10^{4}\times$	3.29 $10^{4}\times$	2.8 $10^{18}\times$	1.77 $10^{17}\times$	3.29 $10^{17}\times$	2.8 $10^{3}\times$	1.77 $10^{3}\times$	3.29 $10^{3}\times$	2.8 $10^{15}\times$	1.77 $10^{16}\times$	3.29 $10^{16}\times$

* Published
** before using correct factor.
*** after using correct factor.

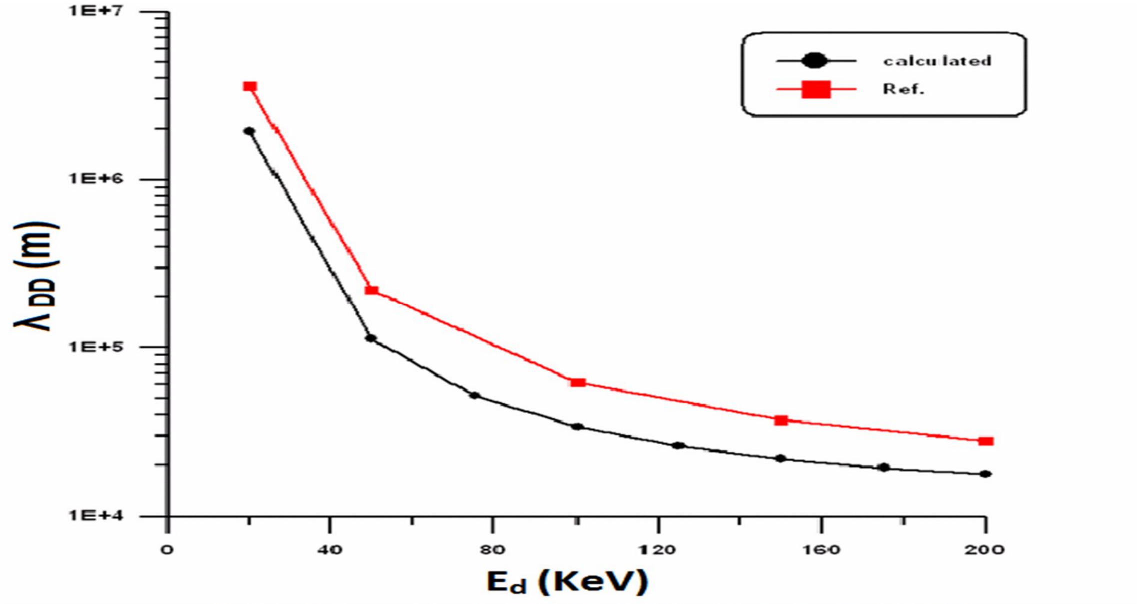

Fig.(1): Mean free path for D-D reaction versus incident deuteron energy for $n_i=10^{24}$ m^{-3} before correction.

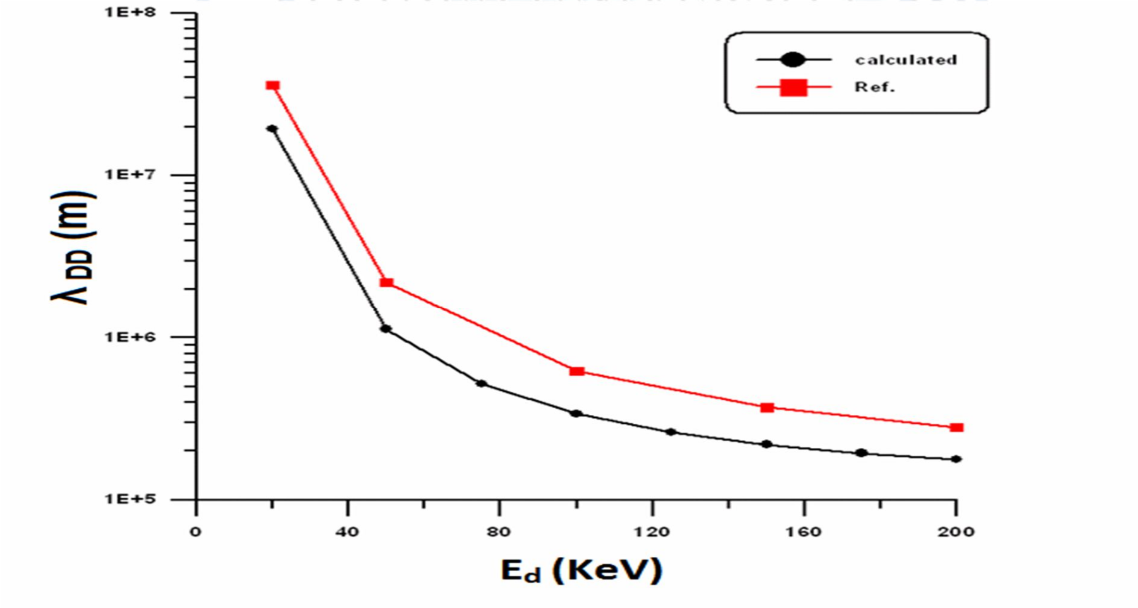

Fig.(2): Mean free path for D-D reaction versus incident deuteron energy for $n_i=10^{25}$ m^{-3} before correction.

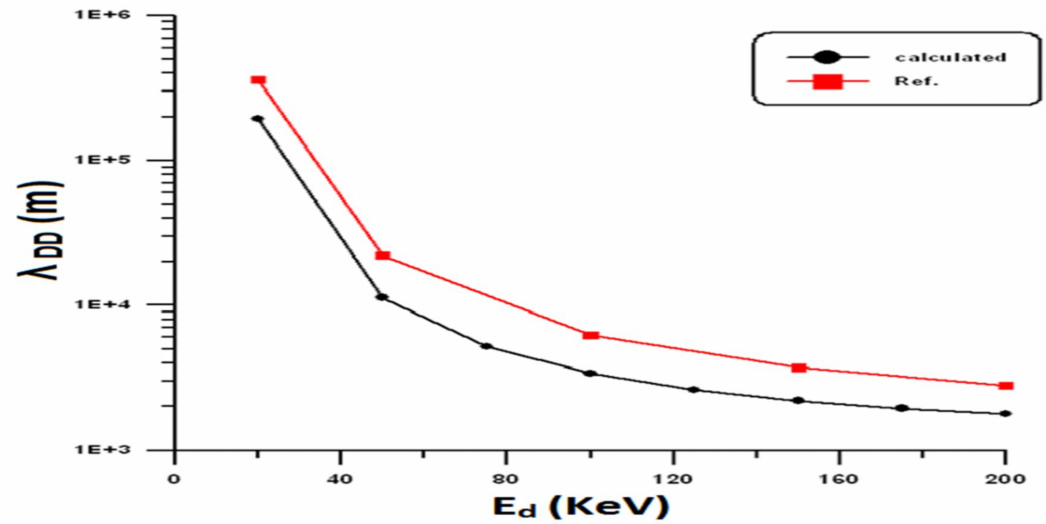

Fig.(3): Mean free path for D-D reaction versus incident deuteron energy for $n_i=10^{26}m^{-3}$ before correction.

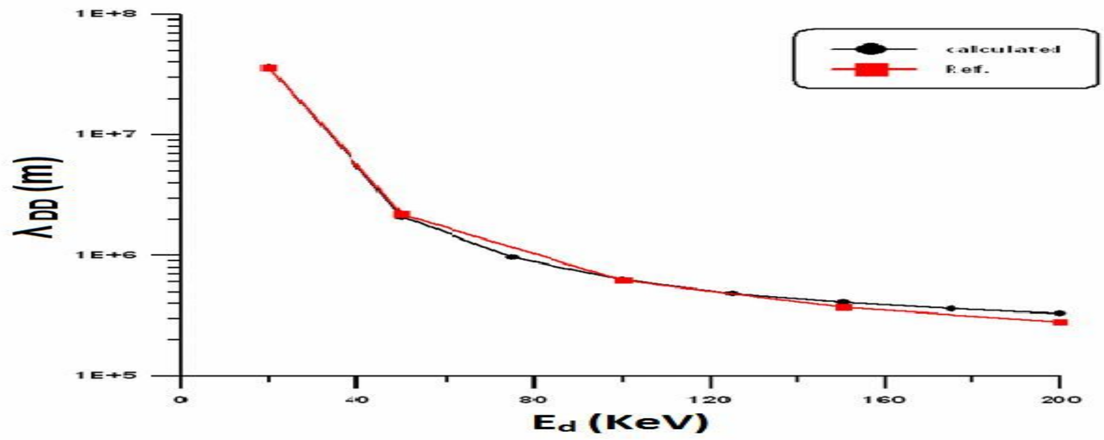

Fig.(4) : Mean free path for D-D reaction versus incident deuteron energy for $n_i=10^{24}$ m^{-3} after correction.

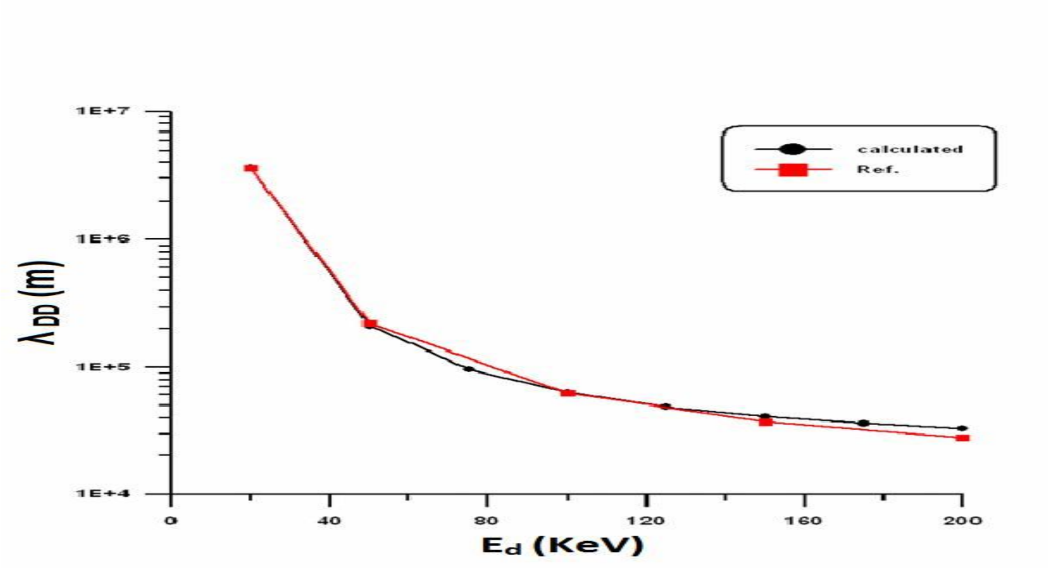

Fig .(5): Mean free path for D-D reaction versus incident deuteron energy for $n_i=10^{25}$ m^{-3} after correction.

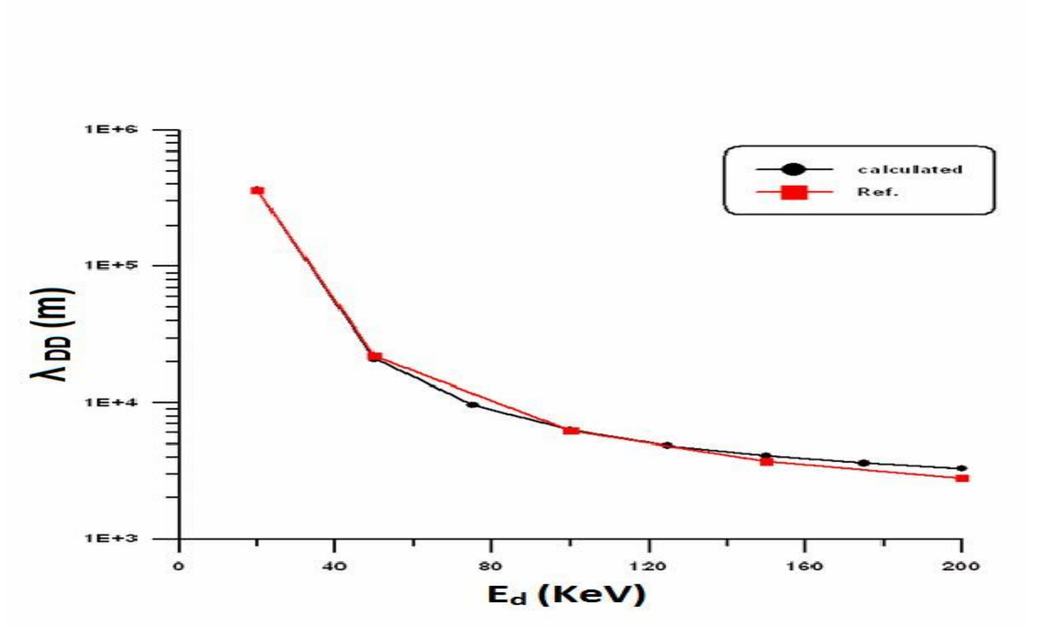

Fig.(6): Mean free path for D-D reaction versus incident deuteron energy for $n_i=10^{26}$ m^{-3} after correction.

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