Plasma Power Density Produced by D-T Fusion Reaction

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Abstract

Calculation of the power density of the nuclear fusion reactions plays an important role in the construction of any power plants. It is clear that the power released by fusion reaction strongly depended on the fusion cross section and fusion reactivity. Our calculation concentrates on the most useful and famous fuels (Deuterium-tritium) since it represents the principle fuels in any large scale system like the so called tokomak.

Key words: D-T reaction, fusion cross section, plasma power density, reactivity.

Introduction

Fusion energy is considered as a clean source of energy with a basic fuel that is abundant, cheap, and available to all of humanity. It is now being realized in the Cosmos in stellar systems and on Earth in the form of thermonuclear or hydrogen weapons. However, a controlled fusion reaction releasing energy on Earth in a controlled manner remains unfulfilled until some time in the future. Hydrogen isotopes such as deuterium and tritium can be used to produce fusion energy.

Fusion fuels are cheap and uniformly distributed on Earth. Seawater contains deuterium D in practically inexhaustible quantities Tritium, a radioactive isotope of hydrogen with a short half-life of 12.33 years, hardly occurs in nature. It can, however, be produced in a power plant from lithium, which is likewise abundantly available.

Since a fusion power plant will have ecologically favorable properties, fusion could make an enduring contribution to the future energy supply. The following applications are foreseen for fusion energy:[1]

1. Electrical power production.
2. Fresh water desalination.
3. Hydrogen production.
4. Deactivation of fission reactors waste.
5. Production of fissile fuel for fission reactors.
6. Space rocket propulsion.

Advantages of Fusion Energy

1-Abundant fuel supply. The major fuel, deuterium D, may be readily extracted from ordinary water, which is available to all nations. The surface waters of the earth contain more than 1012 metric tons of deuterium, an essentially inexhaustible supply. The tritium required would be produced from lithium, which is available from land deposits or from sea water which contains thousands of years' supply. The world-wide availability of these materials would thus eliminate international tensions caused by the imbalance in the fossil fuel supplies.

2- Non critical design. Since no fossil fuels are used, there will be no release of chemical combustion products because they will not be produced.

3- No air pollution. Since no fossil fuels are used, there will be no release of chemical combustion products because they will not be produced.

4- No high level nuclear waste . Similarly, there will be no fission products nor transuranic

formed to present a handling and disposal problem. Radioactivity will be produced by neutrons

activating the reactor structure, but careful materials selection is expected to minimize the handling and ultimate disposal of the activated materials.

5- No generation of weapons material . Another significant advantage is that the materials and by-products of fusion are not suitable for use in the production of nuclear weapons The DT reaction produces neutrons that can activate the structure of the reactor, creating some radioactivity. A fast neutron from the fusion reaction can in principle produce two tritons in these two reactions, sine it is re-emitted from the fast reaction, and is available, if not absorbed by other nuclei, to induce the second reaction at low energy. [2, 3]

Theory

Fusion Reaction Cross Section

For the D-T fusion reaction, which is by far the most important one for present fusion research, the following expression is used to calculate the fusion cross section [4].

$$\sigma(E) = \frac{A_5+\left(A_2\left((A_4-A_3E)^2+1\right)\right)}{E\left(exp\left(A_1/\sqrt{E}\right)-1\right)} \qquad (1)$$

where the coefficients A_1,A_2, A_3, A_4, are called the Duane coefficients and are given in the table[1] for D-T fusion reaction.

Plasma reactivity calculations require reaction cross sections for energies well below those at which direct measurement are practicable [5]. And the equation bellow is used to calculate the reactivity for D-T reaction.

$$\langle\sigma v\rangle_{DT} = 3.68\times10^{-12}T^{-2/3}e^{\left(-19.94\,T^{-1/3}\right)} \qquad (2)$$

where T is plasma temperature in keV.

The power density released in the form of charged particles, for the D-T Reaction is:

$$P_{DT} = 5.6\times10^{-13}\,n_D\,n_T\,\langle\sigma v\rangle_{DT} \qquad (3)$$

where n_D, n_T represent the deutron and tritium density in cm^{-3}respectively, $\langle\sigma v\rangle_{DT}$ represents the reactivity as discribed in eq(2)

Calculations and Results

It is necessary to note that there exists many experimental or empirical formulas for measuring the fusion cross section for D-T reaction; and we found that each formula gives a different data or results corresponding to other. As shown in Fig. 1, the fusion reaction cross sections are dependent on the temperature of the plasma or its energy in units of keV.And the calculated results about the total D-T fusion reaction are presented in Table (2) and described in Fig. (2).

The D-T fusion reactivity as a function of the deuteron temperature is calculated according to Eq.(2) and their calculated results are completely presented in Table(3) and described in Fig.(3)

Discussion and Conclusion

It is clearly shown that the most important parameter in deducing the accuracy for our results is the fusion plasma power density since it included reactivity in addition to the physical parameters that describe any fusion collision phenomena i.e., incident energy for the projectile , target energy , density and ignition temperature.

By comparing the cross section behavior for the D-T fusion reaction presented in Fig. (2) with the corresponding experimental published ,we observed a right agreement between our results and experimental published and this behavior leads to a fact that there exists a real precession for the choices of cross section formula which in turn reflect on the results about both the two other parameters $\langle\sigma v\rangle$ and P respectively. The above conclusions are very clearly shown in the physical behaves for the D-T plasma power density and reactivity in which a very approximated behavior with the other corresponding published results shown in figure (5).

Finally, we suggest to support our efforts by using the above physical description in the future work by consideration to arrive a more suitable empirical cross section formulas especially the works that deal with the general thermonuclear fusion reaction.

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Table No.(1): coefficient used to represent the energy dependence of the total cross section
^{3}H (d,n)^{4}He fusion reaction ref.[4]

Coefficient	$^{3}H(d,n)^{4}He$ fusion reaction
A_1	45.95
A_2	50200
A_3	1.368×10^{-2}
A_4	1.076
A_5	409

Table No.(2): Energy dependence cross-section for D-T nuclear fusion reaction

Deutron energy	Cross section (ba	Deutron energy	Cross section (ba
5	$6.024\times 10^{-}$	140	4.390
10	$1.324\times 10^{-}$	160	3.775
20	$5.337\times 10^{-}$	180	3.181
30	0.2666	200	2.673
40	0.693	220	2.258
60	2.102	240	1.922
80	3.714	260	1.652
100	4.714	280	1.434
120	4.830	300	1.255

Table No. (3): Temperature dependence fusion reactivity and plasma power density for D-T fusion reaction

Temperature(keV)	Reactivity(cm^3/sec)	Plasma Power density(Watt/cm^3)
5	1.085×10^{-17}	6.077×10^{10}
10	7.579×10^{-17}	4.244×10^{11}
20	3.222×10^{-16}	1.804×10^{12}
30	6.224×10^{-16}	3.485×10^{12}
40	9.239×10^{-16}	5.174×10^{12}
50	1.209×10^{-15}	6.772×10^{12}
60	1.473×10^{-15}	8.252×10^{12}
70	1.716×10^{-15}	9.61×10^{12}
80	1.937×10^{-15}	1.085×10^{13}
90	2.141×10^{-15}	1.198×10^{13}
100	2.327×10^{-15}	1.303×10^{13}
200	3.556×10^{-15}	1.991×10^{13}
300	4.176×10^{-15}	2.338×10^{13}
400	4.527×10^{-15}	2.535×10^{13}
500	4.736×10^{-15}	2.652×10^{13}
600	4.864×10^{-15}	2.723×10^{13}
700	4.940×10^{-15}	2.766×10^{13}
800	4.984×10^{-15}	2.791×10^{13}
900	5.005×10^{-15}	2.802×10^{13}
1000	5.01×10^{-15}	2.805×10^{13}

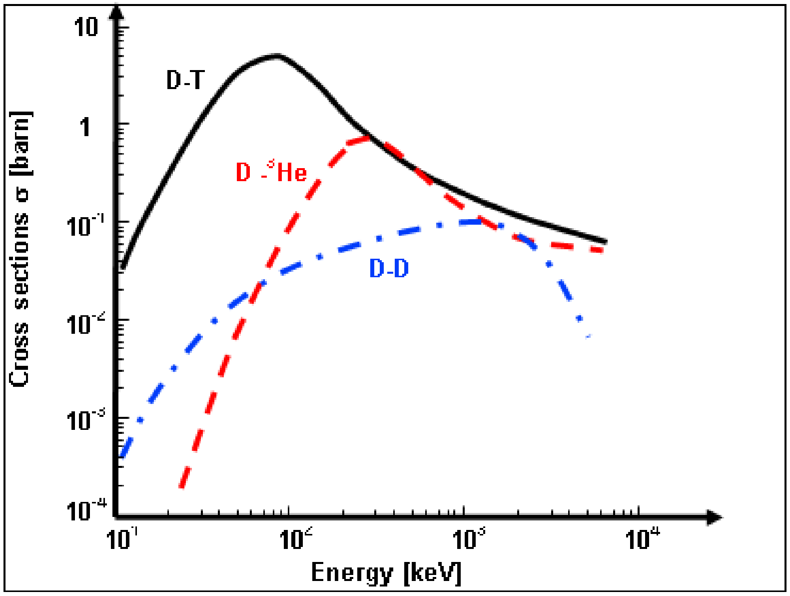

Figure No. (1): Measured cross sections for different fusion reactions as a function of the averaged centre of mass energy. Reaction cross sections are measured in barn (1 barn= 10^{-28} m^2) [6].

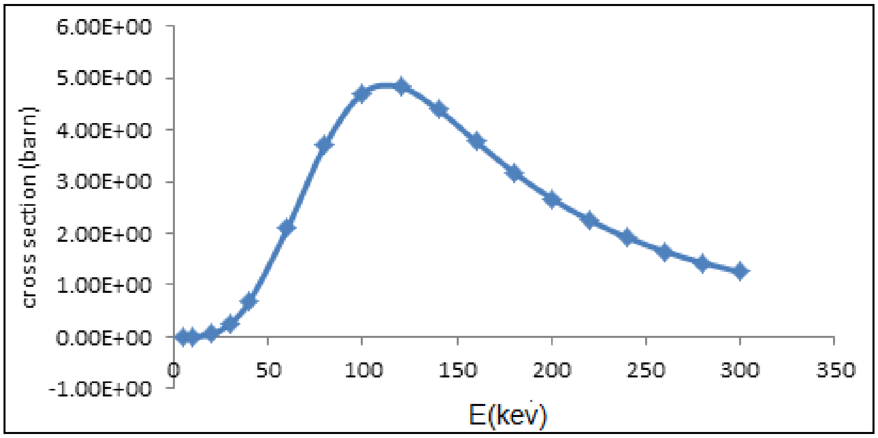

Figure No. (2): Variation of the D-T cross section with the incident deuteron temperature

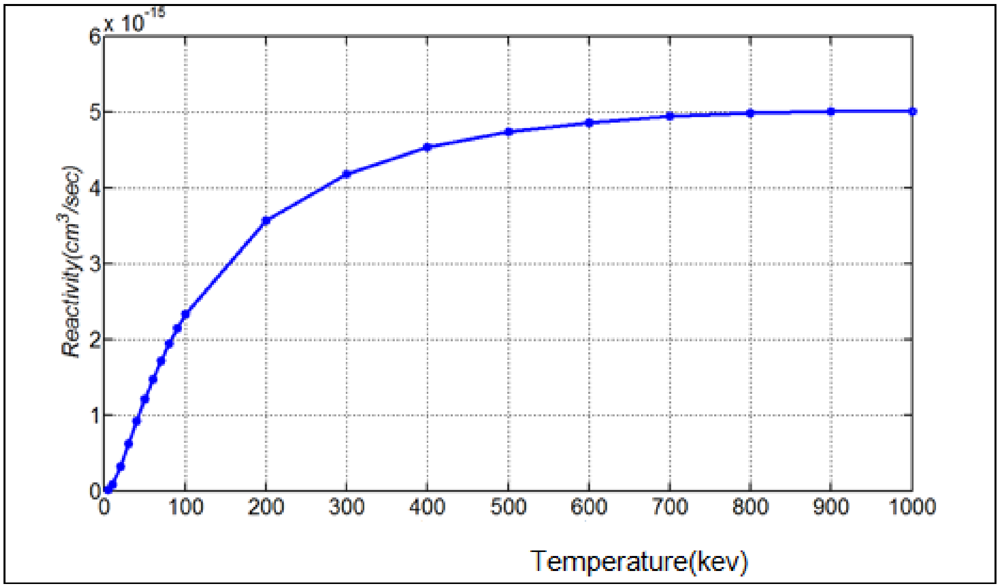

Figure No.(3) Variation of the D-T Reactivity with the incident deuteron temperature

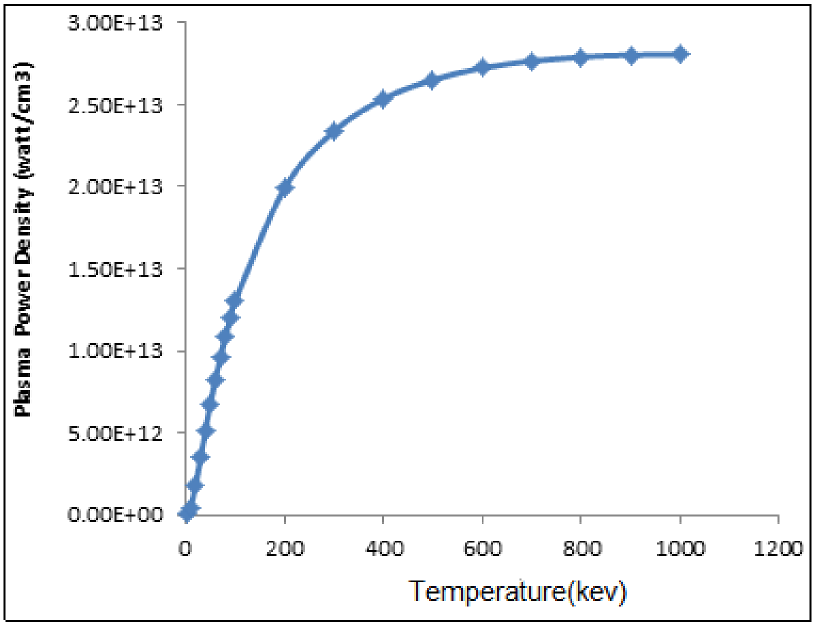

Figure No. (4): Variation of the D-T plasma power density with the incident deuteron temperature

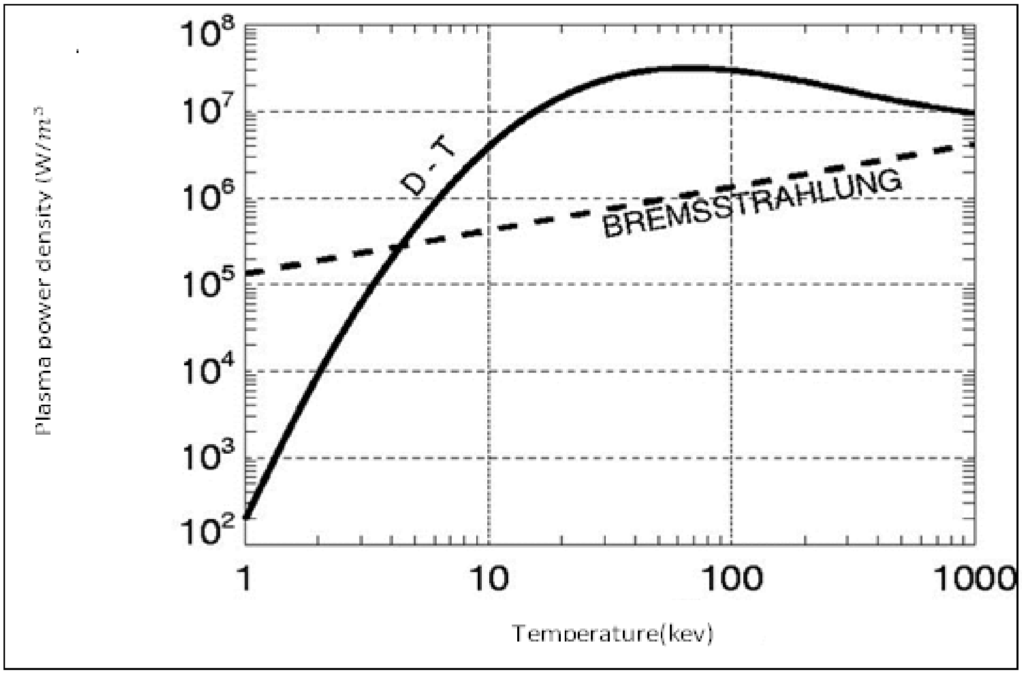

Figure No.(5):Variation of the D-T plasma power density with the incident deuteron temperature.[7]

كثافة قدرة البلازما الناتجة بوساطة التفاعل الاندماجي ديتريوم- ترتيوم

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الخلاصة

حساب كثافة القدرة للتفاعلات النووية الاندماجية تؤدي دورا مهما في بناء اي محطة لتوليد القدرة .ويتضح ان القدرة المتحررة بوساطة التفاعل الاندماجي تعتمد بشدة على المقطع العرضي الاندماجي و التفاعلية الاندماجية ,حساباتنا الحالية تتركزعلى انواع الوقود الاكثر فائدة والشهير (ديتريوم- تريتيوم) لانه يمثل وقودا اساسيا في اي نظام وعلى نطاق واسع والمعروف بالتوكوماك.

الكلمات المفتاحية : ديتريوم-تريتيوم , المقطع العرضي الاندماجي , كثافة قدرة البلازما , التفاعلية.