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Time dependent studies on the energy gain of D-T fuel using determination of total energy deposited of deuteron beam in hot spot

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Abstract: In fast ignition (FI) mechanism, a pellet containing the thermonuclear fuel is first compressed by a nanosecond laser pulse, and then irradiated by an intense "ignition" beam, initiated by a high power picosecond laser pulse, is one of the promising approaches to the realization of the inertial confinement fusion (ICF). If the ignition beam is composed of deuterons, an additional energy is delivered to the target, in which coming from fusion reactions of the beam-target type, directly initiated by particles from the ignition beam .In this article, the D+T fuel is selected and at first step we compute new average reactivity using three parameter cross section formula in terms of temperature at second step we use the obtained results of step one and calculate the total deposited energy of deuteron beam inside the target fuel at available physical conditions, then in third step we write the nonlinear point kinetic balance equation of D+T mixture and solve numerically these nonlinear differential coupled equations versus time .In forth step ,we estimate the power density and energy gain under physical optimum conditions and finally we conclude that maximum energy deposited in the target from D+T and D+D reaction are equal to 19269.39061 keV and 39198.58043 keV, respectively.

Keywords: Deuteron Beam, Fast Ignition, Gain, Dynamics

1. Introduction

The fast-ignition concept has been described thoroughly in literature as one alternative to direct-drive hot-spot ignition. In this scheme a high-energy, high-intensity laser is used to compress a cold shell containing fusion fuel to high areal densities. A short-pulse, ultrahigh-intensity laser is then used to generate megavolt electrons to heat the core of the dense fuel assembly in a time that is short compared to hydrodynamic time scales. The use of two independent laser drivers to compress the fuel assembly and subsequently heat the core allows for higher target gains, in principle, for the same amount of driver energy. This is because high fuel-areal-density cores can be assembled with slow implosion velocities and ignition is achieved by efficiently coupling the short-pulse beam energy to the dense core. In comparison to conventional hot-spot ignition, the symmetry requirement of the fuel assembly in fast ignition is not as stringent; this relaxes the illumination uniformity and power-balance constraints of the driver.

In 1975 A. W. Maschke suggested the use of relativistic heavy ion beams to ignite an inertially confined mass of thermonuclear fuel [1]. As in conventional inertial confinement fusion, the fuel was assumed to be precompressed by a factor of the order of 100 in order to minimize the energy needed for ignition. Maschke suggested that lasers might compress the fuel, by high velocity impact, or by ion beams other than the ignition beam. Maschke’s “fast ignition” scheme was finally abandoned in favor of the more conventional approach to inertial fusion where the implosion supplies the energy for both compression and ignition. In 1994 an important paper by Tabak et al. [2] rekindled interest in fast ignition ,this time using short-pulse lasers to provide the ignition temperature. Later, at the 1997 HIF Symposium, Tabak estimated requirements for heavy-ion-driven fast ignition [3].This approach is now the subject of intense investigation in a number of countries. If ion beams could be made to deliver the energy density needed for ignition, they would have a number of distinct advantages. The reliability, durability, high repetition rate, and high driver efficiency are expected to be advantages of any accelerator driven inertial fusion system. In the case of fast ignition, there are some additional advantages. Moreover, for ions of the appropriate range, the beam energy can be deposited directly in the fuel, eliminating the inefficiency of converting laser light to electrons or ions that then deposit their energy in the fuel. Finally, because of the reduced requirements on illumination symmetry and stability, it may be possible to devise simple illumination schemes using direct drive or tightly coupled indirect drive, or use of single sided ion illumination for indirect drive fuel compression. This could simplify chamber design and, since direct drive and or tightly coupled indirect drive are efficient implosion methods, it could lead to lower driver energy and, as in the laser case, higher energy gain. We consider ion beam requirements for fast ignition in general, where a single short pulse of ions comes in from one direction onto one side of a pre-compressed D+T fuel mass, heating a portion of that fuel mass to conditions of ignition and propagating burn in a pulse shorter than the time for the heated region to expand significantly. The igniter beam (or beams) would be arranged to penetrate the target in such a way that the Bragg peak occurs at the usual target hot spot. Or one might increase the expansion time by tamping the ignition region. In fact Magelssen published a paper in 1984 [4] in which he presented calculations of a target driven by ion beams having two very different energies. The lower energy ions arrived first and imploded the target to a spherical configuration with a rather dense pusher or tamper surrounding the fuel. The higher energy beams were then focused onto the entire assembly, heating both the fuel and the pusher. The combination of the exploding pusher and the direct ion energy deposition heated the fuel to ignition.

In summary, the fast ignition (FI) mechanism, in which a pellet containing the thermonuclear fuel is first compressed by a nanosecond laser pulse, and then irradiated by an intense "ignition" beam, initiated by a high power picosecond laser pulse, is one of the promising approaches to the realization of the inertial confinement fusion (ICF). The ignition beam could consist of laser-accelerated electrons, protons, heavier ions, or could consist of the laser beam itself. It had been predicted that the FI mechanism would require much smaller overall laser energies to achieve ignition than the more conventional central hot spot approach, and that it could deliver a much higher fusion gain, due to peculiarities of the pressure and density distributions during the ignition. It is clear, however, that interactions of electrons and ions with plasma, and most importantly the energy deposition mechanisms are essentially different. Moreover, if the ignition beam is composed of deuterons, an additional energy is delivered to the target, coming from fusion reactions of the beam-target type, directly initiated by particles from the ignition beam [5]. These and other effects had been of course taken into account in later works on this topic [6,7]. In this work, we choose the D+T fuel and at first step we compute the new average reactivity in terms of temperature for first time at second step we use the obtained results of step one and calculate the total deposited energy of deuteron beam inside the target fuel at available physical condition then in third of step we introduced the dynamical balance equation of D+T mixture and solve these nonlinear differential coupled equations by programming maple-15 versus time .in forth step we compute the power density and energy gain under physical optimum conditions and at final step we analyzed our obtained results .

2. New Calculation of Average Reactivity for D+T and D+D Reactions

In order to fuse two nuclei, they must be brought close to each other such that the strong nuclear force dominates the repulsive Coulomb force. Since this Coulomb force preventing two nuclei from getting closer is an increasing function of the atomic number Z, the most promising fusion reactions are those involving Hydrogen and its isotopes, namely Deuterium and Tritium. The most widely investigated reactions are so-called D+D reaction and D+T reaction which are listed below.

The D+D reaction:

$$D + D \rightarrow {}^3_2He(0.82MeV) + n(2.45MeV) \quad \%50 \quad (1)$$

$$D + D \rightarrow T(1.01MeV) + p(3.03MeV) \quad \%50 \quad (2)$$

The D+T reaction:

$$D + T \rightarrow {}^4_2He(3.5MeV) + n(14.1MeV) \quad (3)$$

The rate of thermonuclear reaction is a function of reaction cross section, temperature, and density. For a mixture of two species with densities n_i and n_j, the reaction rate is given by the following expression [6]:

$$R_{ij} = \frac{n_i n_j}{1+\delta_{ij}} < \sigma v > \quad (4)$$

where σ is the reaction cross section and δ_{ij} is the Kronecker symbol .If the fusion is “Thermonuclear”, i.e. if the energy provided to the reacting particles is the result of heating the system to a temperature T, then we need to use the averaged $< \sigma v >$. Assuming a Maxwellian distribution, equation (4) becomes,

$$R_{ij} = \frac{n_i n_j}{1+\delta_{ij}} \left[\frac{8}{\pi\mu}\right]^{3/2} \left[\frac{1}{kT}\right]^{\frac{3}{2}} \int_0^\infty \sigma(E) E exp\left(-\frac{E}{kT}\right) dE \quad (5)$$

By comparing equation (4) and (5) we have

$$< \sigma v > = \left[\frac{8}{\pi\mu}\right]^{3/2} \left[\frac{1}{kT}\right]^{\frac{3}{2}} \int_0^\infty \sigma(E) E exp\left(-\frac{E}{kT}\right) dE \quad (6)$$

Since the D+T reaction has the highest reaction rate at relatively low fuel temperature, it is the easiest fuel to assemble and burn. However, the presence of neutrons as a product (see D+T reaction) makes it unattractive for fusion reactors. The formula of fusion cross section for D-D and D-T fusion reactions is given by [8]:

$$\sigma(E_{lab}) = -16389 C_3 \left(1+\frac{m_a}{m_b}\right)^2 \times \left[m_a E_{lab}\left[Exp\left(31.40\, Z_1 Z_2 \sqrt{\frac{m_a}{E_{lab}}}\right)-1\right]\left\{(C_1 + C_2 E_{lab})^2 + \left(C_3 - \frac{2\pi}{[Exp(31.40 Z_1 Z_2\sqrt{m_a/E_{lab}})-1]}\right)^2\right\}\right]^{-1} \quad (7)$$

with 3 adjustable parameters (C_1, C_2 and C_3) only. In (7), m_a and m_b are the mass number for the incident and target nucleus, respectively (e.g. m_a = 2 for incident deuteron);E_{lab} (deuteron energy in lab system) is in units of KeV and σ is in units of barn. The numerical values of C_1, C_2 and C_3 for these reactions are listed in Table.1.

Table 1. *Numerical values ofC_1, C_2 and C_3 for reactions D+T and D+D[8].*

	D+T	**D+D (p+T and n+^{3}He)**
C_1	−0.5405	−60.2641
C_2	0.005546	0.05066
C_3	−0.3909	−54.9932

From this formula, we calculated and plotted the variations of fusion cross sections for these reactions in terms of E_{lab} and our results are shown that in Figure.1.Also by comparing our calculated numerical values with available experimental results (see ref.[8]),we concluded that this formula is very exact.

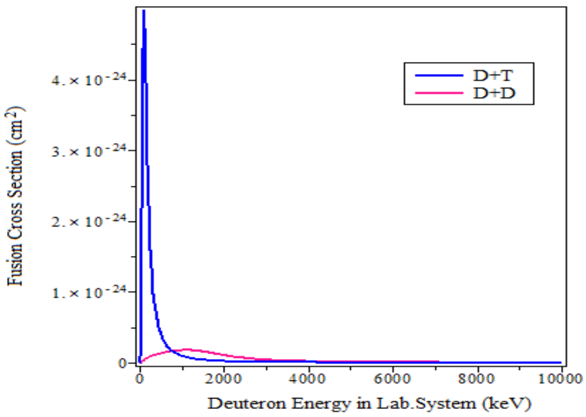


Figure 1. *Variations of fusion cross sections versus deuteron energy in lab system for two fusion reactions: D+T and D+D.*

Using data in T able.1 and inserting equation (7) into equation(6) and integrate it for these two reactions we can obtain the numerical values of averaged reactivity parameter in terms of temperature and plotted it for D+T and D+D in the Figure.2.Note that $E_{lab} = \frac{m_a+m_b}{m_b} E$,where$E$ is energy in the center of mass frame. By observing Figs.1 and 2 we conclude that the cross section and averaged reactivity of D+T fusion reaction is greater than D+D, also$< \sigma v >_{D+T}$ *and* $< \sigma v >_{D+D}$ are strongly temperature dependent .From Fig.2, it will therefore be recognize that at resonant temperature in which the probability for occurring fusion is maximized for D+T fusion reaction is approximately 60KeV.

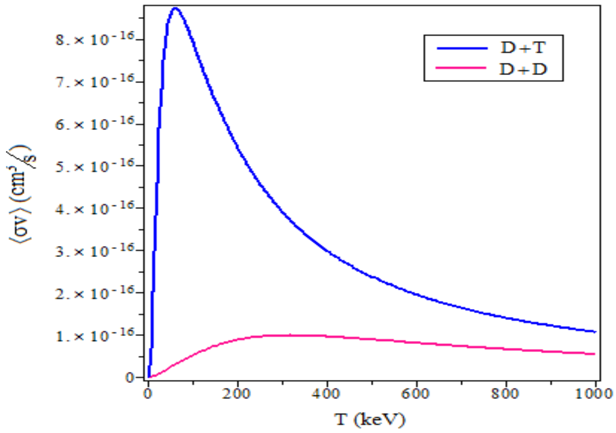


Figure 2. *Variations of averaged reactivity in terms of temperature for* $< \sigma v >_{D+T}$,$< \sigma v >_{D+D}$.

3. Gain Requirement

In order to have economically fusion, an attractive energy source is necessary that the energy from thermonuclear reaction exceeds both the energy invested in achieving it and the losses due to radiation, reactor wall, conversion inefficiencies, etc. A simple estimate of the driver efficiency and target gain can be obtained using energy bookkeeping approach (Fig.3).

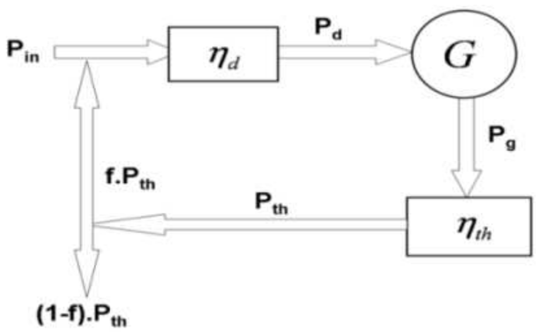


Figure 3. *Power cycle.* P_{in}, *the input power (this could be the electrical power from the outlet).*P_d, *the power at the output of the driver.*P_g,*the power fromthermonuclear fusion.* P_{th} *,the power after converting the thermal energy to electricalenergy.*

Let P_{in}be the electrical power that we intend to invest in achieving fusion and let $\eta_d$be the efficiency of conversion of this power to laser light power P_d. If we definethe target gain as the ratio of the power obtained from the fusion reaction to the driver power, then

$$P_g = GP_d = G\eta_d P_{in} \quad (8)$$

taking into account the conversion efficiency from thermal to electrical power, the available electrical power is given by,

$$P_{th} = \eta_{th} P_g = G\eta_{th}\eta_d P_{in} \quad (9)$$

A fraction $fG\,\eta_{th}\,\eta_d P_{in}$ of this power is used to run the driver and the remaining fraction $(1-f)G\,\eta_{th}\,\eta_d P_{in}$ is send to the customers. The closer factor $(1-f)$to unity, more electricity is available to customers. This can be achieved using small values of f, however, f has a lower bound determined by the equation,

$$P_{in} = f_{min} G\eta_{th}\eta_d P_{in} \rightarrow f_{min} = \frac{1}{G\eta_{th}\eta_d} \quad (10)$$

Using a typical η_{th} value of 40% and recycling less than 1/4 of the power to run the driver, we get, $G\eta_d \geq 10$.Solid state lasers for example have an efficiency of 1-10% [9] and to fulfill the available condition, gains of 100-1000 are needed.

4. Deuteron Beam and Deposited Energy in Pre-Compressed D+T Fuel

As we mentioned that in section 1, deuterons have been considered for fast ignition as well [9–17].Bychenkovs group, considered an accelerated deuteron beam, but decided that deuterons would have too high an energy (7–8 MeV) to form the desired hot spot [11]. Deuterons would not only provide proven ballistic focusing, but also fuse with the target fuel (both D and T) as they slow down[18] , providing a “bonus” energy gain. Depending on the target plasma conditions, this added fusion gain can be a significant contribution [19]. We must notice that the idea of bonus energy for first time is presented by Xiaoling Yang and her group in low temperatures[20]. In this work we use of this idea , to compute the added energy released as the energetic deuterons interact with the target fuel ions in different range of temperatures (0-70keV) that is contained resonant temperature. This added energy increases total energy gain of the system. We use a modified energy multiplication factor φ to estimate the bonus energy in terms of the added “hot spot” heating by beam-target fusion reaction for D+T [18]. The deuteron beam deposited energy and stopping range and time are also calculated for this reaction. Also we determine energy gain time dependent in different temperatures.

F value is the ratio between the fusion energy E_f produced and the ion energy input E_I to the plasma and for D+T fuel is given by[18]:

$$F_{D+T} = n_T \frac{\int_{E_{th}}^{E_I} S(E)dE}{E_I} \quad (11)$$

where E_I and E_{th} are, the average initial energy and the asymptotic thermalized energy of the injected single ion for each reaction, respectively [18,21,22] and

$$S(E) \equiv \sum_k K_k [<\sigma v(E)>_b]_{Ik} (E_f)_{Ik} / \left(\frac{dE}{dt}\right) \quad (12)$$

Such that for this reaction we have:

$$\frac{1}{n_T}\left(\frac{dE}{dt}\right) = -\frac{Z_I^2 e^4 m_e^{1/2} E \ln \Lambda_{D+T}}{3\pi(2\pi)^{1/2}\varepsilon_0^2 m_I (kT_e)^{3/2}} \times \left[1 + \frac{3\sqrt{\pi} m_I^{3/2}(kT_e)^{3/2}}{4 m_k m_e^{1/2} E^{3/2}}\right] \quad (13)$$

Where m_e and m_I are mass of electron and mass of injected ion, respectively and both of them are in atomic mass unit (amu).$<\sigma V>_{Ik}$ is the fusion reactivity for the injected ion I of species k having atomic fraction K_k in the target, $(E_f)_{Ik}$ is the corresponding energy released per fusion, and T_e is the target electron temperature[22] .Combining equations (11),(12) and (13) we can estimate F_{D+T}.

$\ln \Lambda_{D+T}$is Coulomb logarithm for D+T fusion reaction that is given by [20]:

$$\ln \Lambda_{D+T} \approx 6.5 - \ln\left(Z_k \sqrt{\rho}/T_e^{3/2}\right) \quad (14)$$

Where $Z_k$is the atomic number of target fuel ions andT_e here is in kilo-electron-volt, ρ is in $\frac{g}{cm^3}$.We plotted the two and three dimensional variations of $\ln \Lambda_{D+T}$ in terms of target density and temperature (see Figure 4).

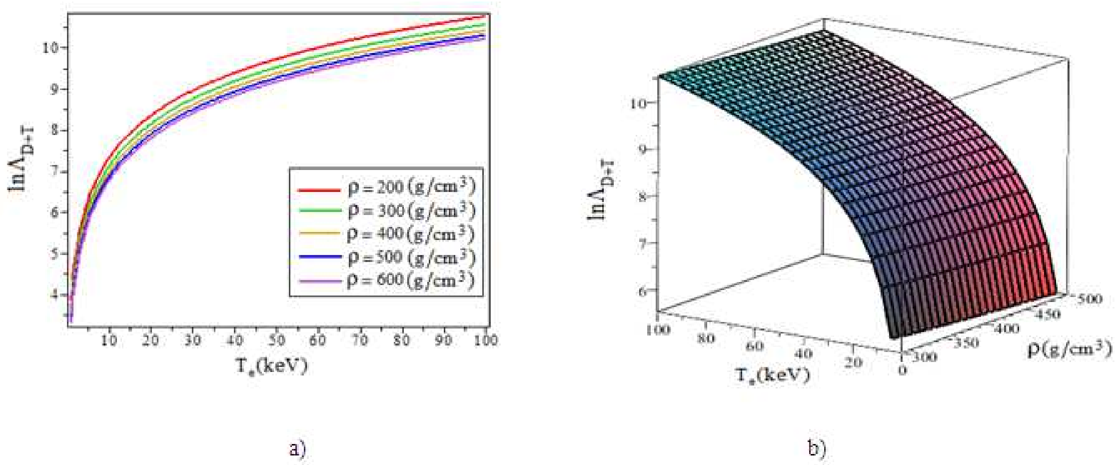


***Figure 4. a)** The two and b) three dimensional variations of $\ln \Lambda_{D+T}$ in terms of target density and temperature.*

From this figure we see that by temperature enhancement and target density reduction, $\ln \Lambda_{D+T}$ is increased. The $(E_f)_{Ik}$in Eq. (12) gives the energy released in the fusion reaction carried by both fast neutrons and charged particles. However, for hot spot heating, the ρR of the hot spot is too low to significantly slow down the neutrons, so only charged particles contribute. Thus, for D+T reaction in the target(see reaction (3)) only the 20% of the fusion energy carried by the alphas is useful for heating while for the D+D reaction about 63% of the total is useful(see reactions (1) and (2))[20].Therefore, to prevent confusion, we introduce a new factor φ to represent the energy multiplication for the hot spot heating by the charged particles, and then $\varphi_{D+T} = 20\%\ F_{D+T}$ for D+T fusion and for occurring D+D fusion in D+T mixture $\varphi_{D+D} = 63\%\ F_{D+D}$.

In summary, the total energy that could be deposited into the target due to combined deuteron ion heating and beam-target fusion for D+T and D+D, respectively becomes:

$$\varepsilon_{D+T} = E_I(1 + \varphi_{D+T}) \tag{15}$$

$$\varepsilon_{D+D} = E_I(1 + \varphi_{D+D}) \tag{16}$$

so it is seen that parametersφ_{D+T} ,φ_{D+D} play the major role in the "bonus energy" for deuteron driven fast ignition in these two reactions. To avoid confusion, please note that the ε here is the total energy deposited by the ion beam plus any contribution from its beam-target fusion in the hot spot, but not the total input energy to the target that is often cited in energy studies and represents the total laser compression plus fast ignition energy delivered to the total target, also the deuteron stopping range and stopping time can be calculated by following equations [20]:

$$R_S = \int_{E_{th}}^{E_I} v_D dE/\left(\frac{dE}{dt}\right) \tag{17}$$

$$t_S = \int_{E_{th}}^{E_I} dE/\left(\frac{dE}{dt}\right) \tag{18}$$

Where, $\left(\frac{dE}{dt}\right)$is calculated from equation (13) for D+T, and the deuteron velocity is $v_D = \sqrt{\frac{2E}{m_D}}$.

For calculating the total energy deposited into the target of D+T at first step we substitute equation (14) into equation (13),then at second step the obtained result is substituted into equation (12) and at third step the results of second step are inserted into equation (11) and we compute F_{D+T} and F_{D+D} for D+T reaction, at forth step we use of these parameters for determination of φ_{D+T}andφ_{D+D} , finally the obtained results from forth step inserted into equations (15) and (16) thus we can obtain the numerical values of $\varepsilon_{D+T}$and ε_{D+D} in D+T mixture for $300 \le \rho(\frac{g}{cm^3}) \le 500$, $0 \le T_e(keV) \le 70$ and deuteron energyE, with range of $0 \le E(MeV) \le 10$. Also under these conditions we can calculate the deuteron stopping range and stopping time by using equations(17) and (18).Figure.5 shows the results of our calculations of φ_{D+T} , φ_{D+D} , ε_{D+T} and ε_{D+D} in the case of $\rho = 500(g/cm^3)$ and in Table.2numerical values computed for maximum of $\varphi_{D+T}, \varphi_{D+D}$, ε_{D+T} and ε_{D+D} are given for studying D+T reaction at different temperatures and target density $300 \le \rho(g/cm^3) \le 500$.

We see clearly that from Fig.5,variations of, ε_{D+T} and ε_{D+D} by increasing temperature is such that we have the maximum value of them in resonance temperature of 60 KeV. We must be notice that the temperature 60 keV is a resonant temperature for D+T reaction such that in this temperature we have maximum probability for occurring fusion reaction. Also from Table.2 we find that the maximum total deposited energy of ε_{D+T} and ε_{D+D} inside hot spot and also the maximum of φ_{D+T} and φ_{D+D} by increasing target density from 300 to 500 (g/cm^3) are raised very slowly.The total energy deposited inside the hot spot (ε_{D+T} and ε_{D+D}) is also function of deuteron energy beam (E_I)such that by increasing energy from 1 to 10000KeV is increased.Fig.5 shows that the values of multiplication factors φ_{D+T} , φ_{D+D} increased by increasing deuteron energy (please note that our calculations show that in temperature lower than 5keV at first by raising the deuteron energy, parameters φ_{D+T} and φ_{D+D} are increased and then slowly decreased).In all temperatures ε_{D+D} is higher than ε_{D+T} .From Fig.6 we see that by increasing temperature stopping time ($t_{S_{D+T}}$) is increased because by raising temperature particle energy is increased then the stopping time become large. Since that by increasing temperature stopping range is increased then particle can move more distance (see Fig.7). The effective parameter that decreased stopping time and stopping range, is n_T. Our calculations show that by changing n_T from 10^{22} to $10^{24} cm^{-3}$, $t_{S_{D+T}}$ and $R_{S_{D+T}}$ are decreased by the order of 10 to 100. By increasing target density from 300 to 500 (g/cm^3), $R_{S_{D+T}}$ and $t_{S_{D+T}}$ are increased, but this changes for $t_{S_{D+T}}$ is not very sensitive.

5. Balance Equations of Deuterium-Tritium Mixture

The following system of equations is used to describe the temporal evolution of plasma parameters averaged over the volume (the density of deuterium ions and tritium are n_D and n_T , respectively . n_α is density of thermal alpha-particles, E is plasma energy, for D+T nuclear fusion reaction:

$$\frac{dn_D}{dt} = -\frac{n_D}{\tau_P} - n_D n_T \langle\sigma v\rangle_{D+T} + S_D \tag{19}$$

$$\frac{dn_T}{dt} = -\frac{n_T}{\tau_P} - n_D n_T \langle\sigma v\rangle_{D+T} + S_T \tag{20}$$

$$\frac{dn_\alpha}{dt} = -\frac{n_\alpha}{\tau_\alpha} + n_D n_T \langle\sigma v\rangle_{D+T} \tag{21}$$

Energy balance equation is written as

$$\frac{dE}{dt} = -\frac{E}{\tau_E} + Q_\alpha n_D n_T \langle \sigma v \rangle_{D+T} - P_{rad} \quad (22)$$

S_D and S_T are the source terms which give us the fuel rates; τ_α, τ_p, and τ_E are lifetimes of thermal alpha-particles, deuterium and tritium, and the energy confinement time, respectively, also the energy of the alpha particles are: $Q_\alpha = 3.52 MeV$. The radiation loss P_{rad} is given by:

$$P_{rad} = P_{brem} = A_b Z_{eff} n_e^2 \sqrt{T} for D + T \quad (23)$$

Where $A_b = 4.85 \times 10^{-37} \frac{Wm^3}{\sqrt{KeV}}$ is bremsstrahlung radiation coefficient. No explicit evolution equation is provided for the electron density n_e since we can obtain it from the neutrality condition $n_e = n_D + n_T + 2n_\alpha$, whereas the effective atomic number, the total density and the energy are written as

$$Z_{eff} = \frac{\sum_i n_i Z_i^2}{n_e} = \frac{n_D + n_T + 4n_\alpha}{n_e} \quad (24)$$

where , Z_i is the atomic number of different ions. The fusion energy gain is defined as:

$G(t) = \frac{E_f(t)}{E_{driver}}$ where $E_f(t)$ is equal to the energy due to the number of occurred fusion reactions in target in terms of time and E_{driver} is the required energy for triggering fusion reactions in hot spot and is equal to 4MJ[23].Also the fusion power density for D+T reaction is given by $P_{D+T} = n_D(t) n_T(t) < \sigma v >_{D+T} Q_{D+T}$ where $Q_{D+T} = 17.6 MeV$ .We solve time dependent nonlinear coupled differential equations (19) to (22) with the use of computers (programming, Maple-15) under available physical conditions. Our computational obtained results are given , in Figs.8 to 10 and Table.3.

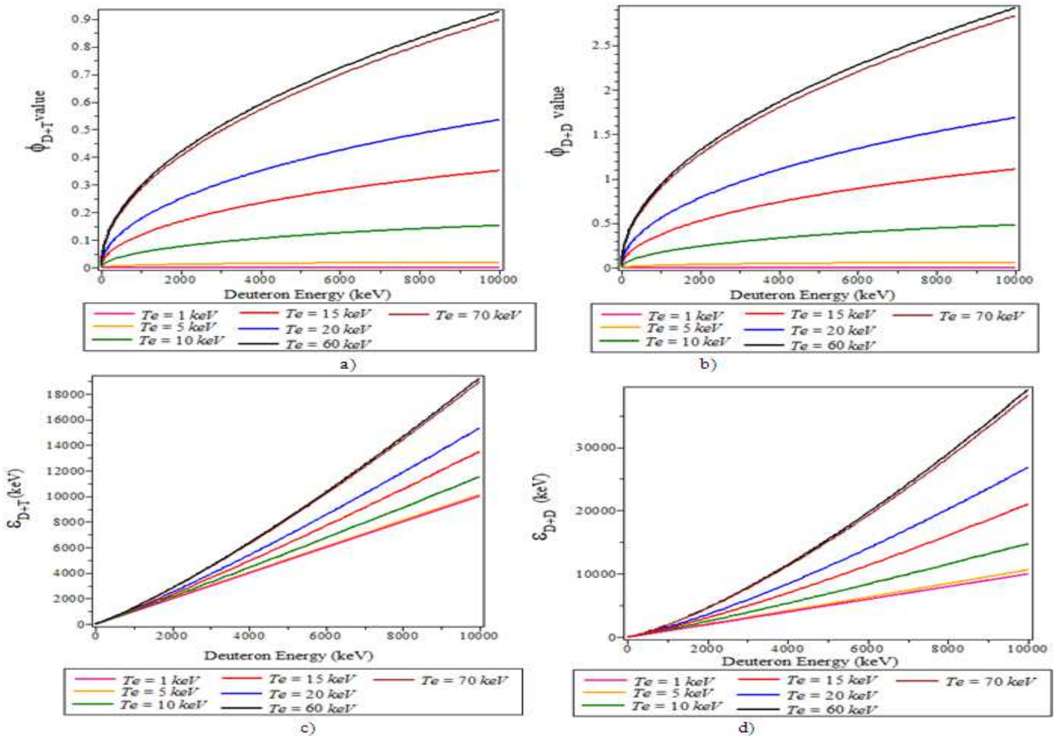
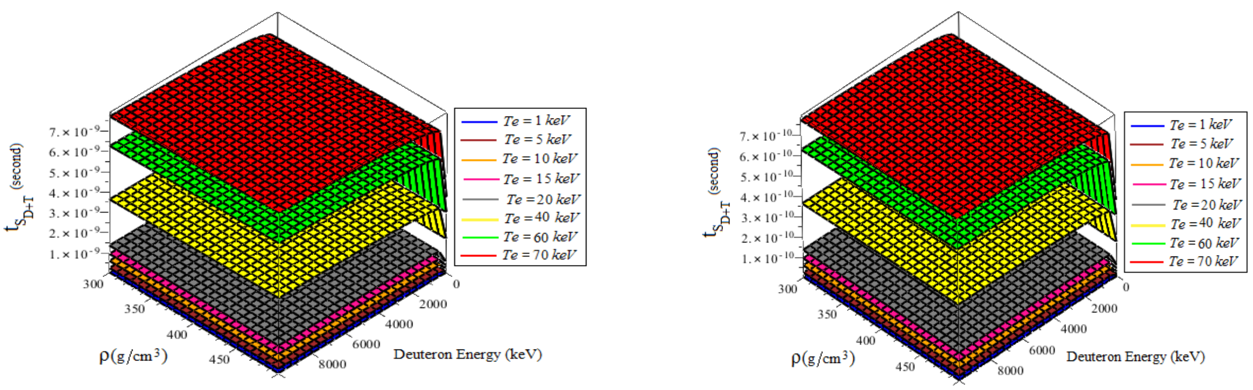
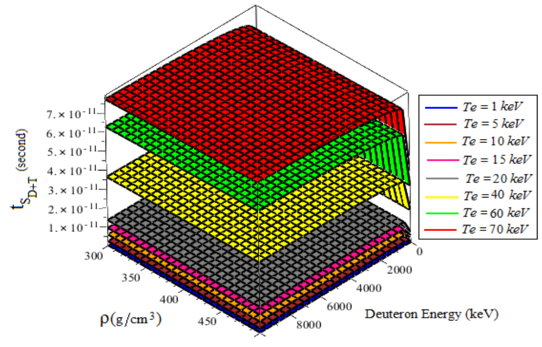


Figure 5. *The two dimensional variations of a) φ_{D+T} b) φ_{D+D} c) ε_{D+T} d) ε_{D+D} in terms of deuteron energy in different temperatures in D+T mixture for $\rho = 500 \left(\frac{g}{cm^3}\right)$*

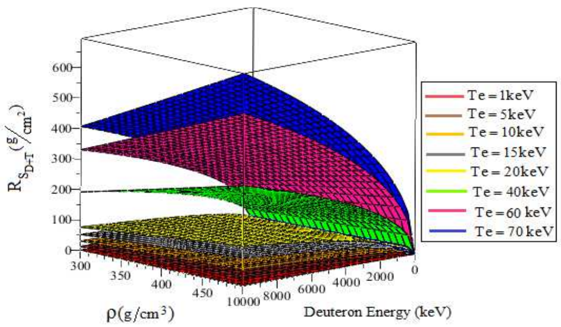


a) b)



c)

Figure 6. *The three dimensional variations of stopping time versus target density and deuteron energy in different temperatures in D+T mixture at a)*$n_T = 10^{22}(cm^{-3})$ *, b)*$n_T = 10^{23}(cm^{-3})$ *, c)*$n_T = 10^{24}(cm^{-3})$.



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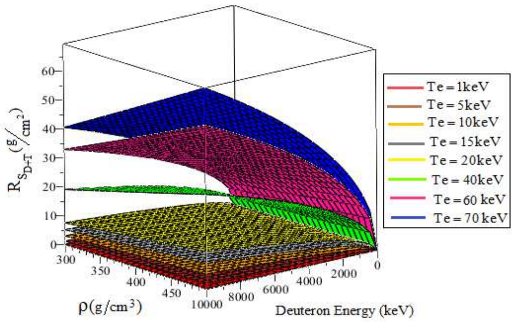

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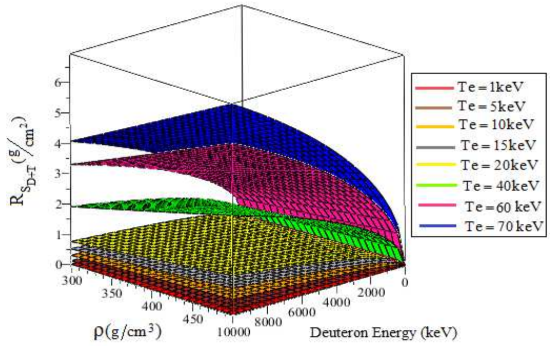

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Figure 7. *The three dimensional variations of stopping range versus target density and deuteron energy in different temperatures in D+T mixtureat a)* $n_T = 10^{22}(cm^{-3})$ *, b)* $n_T = 10^{23}(cm^{-3})$ *, c)* $n_T = 10^{24}(cm^{-3})$.

Table 2. *Maximum numerical values of total energy deposited and multiplication factors in D+T mixture at different temperature for* $300 \le \rho(\frac{g}{cm^3}) \le 500$.

			D+T		
$\rho(g/cm^3)$	T_e(keV)	$\varepsilon_{D+T_{max}}(keV)$	$\varepsilon_{D+D_{max}}(keV)$	$\varphi_{D+T_{max}}$	$\varphi_{D+D_{max}}$
300	10	11463.92692	14611.36978	0.146392691	0.461136978
300	20	15185.35591	26333.87112	0.518535591	1.633387112
300	60	19020.60063	38414.89199	0.902060063	2.841489199
300	70	18763.52452	37605.10224	0.876352452	2.760510224
400	10	11494.18969	14706.69751	0.149418969	0.470669751
400	20	15278.61416	26627.63459	0.527861416	1.662763459
400	60	19159.04394	38850.98842	0.915904394	2.885098842
400	70	18891.14962	38007.12129	0.889114962	2.800712129
500	10	11518.539	14783.39786	0.151853900	0.478339786
500	20	15353.29364	26862.87495	0.535329363	1.686287495
500	60	19269.39061	39198.58043	0.926939061	2.919858043
500	70	18992.73249	38327.10736	0.899273249	2.832710736

From Figs.8 to 10 we see clearly, increasing temperature from 1 keV to 70 keV the variations of deuterium and tritium density in terms of time ($n_D(t), n_T(t)$) are decreased since that by increasing time the consumption rate of $n_D(t)$ and $n_T(t)$ are increased but variations of $n_D(t)$and $n_T(t)$, in all temperature are similar and as we see in Figs.8 to 10 they coincide each other. Thus, by increasing temperature 1 keV to 70 keV the variations of alpha density ($n_\alpha(t)$) versus time at first by increasing time is increased and then decreased while the production rate of fusion plasma energy ($E_f(t)$) is increased until in resonant temperature ,60 KeV, is maximized because in this temperature the highest number of D+T fusion reaction is occurred. Also, our calculations show that enhancement of the injection rate of deuterium and tritium(S_D *and* S_T) from 10^{22} to $10^{24} cm^{-3}$ the rate of variations of $n_D(t)$ and $n_T(t)$ in terms of time are increased while $n_\alpha(t)$ and $E_f(t)$ are raised. Therefore, for having optimum value of power density and fusion energy gain using the above discussions we select injection rate of deuterium and tritium and resonant temperature respectively equal to $10^{24} cm^{-3}$ and T_e =60keV(see Table.3).

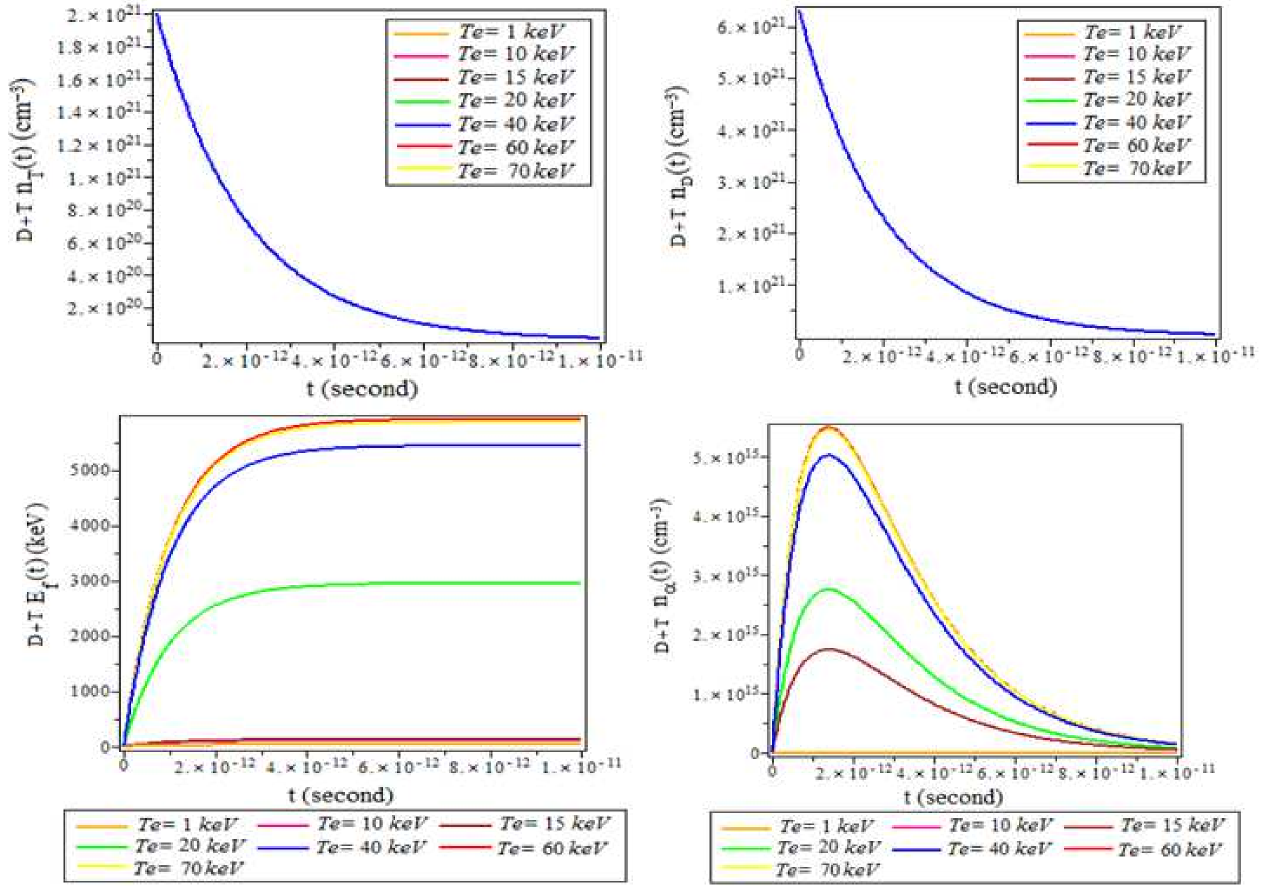

Figure 8. *The two dimensional variations of deuterium , tritium ,alpha particles densities and plasma energy in terms of time at different temperatures for D+T mixture under choosing* $S_T = 0.20 \times 10^{22}(cm^{-3})$ *and* $S_D = 0.63 \times 10^{22}(cm^{-3})$.

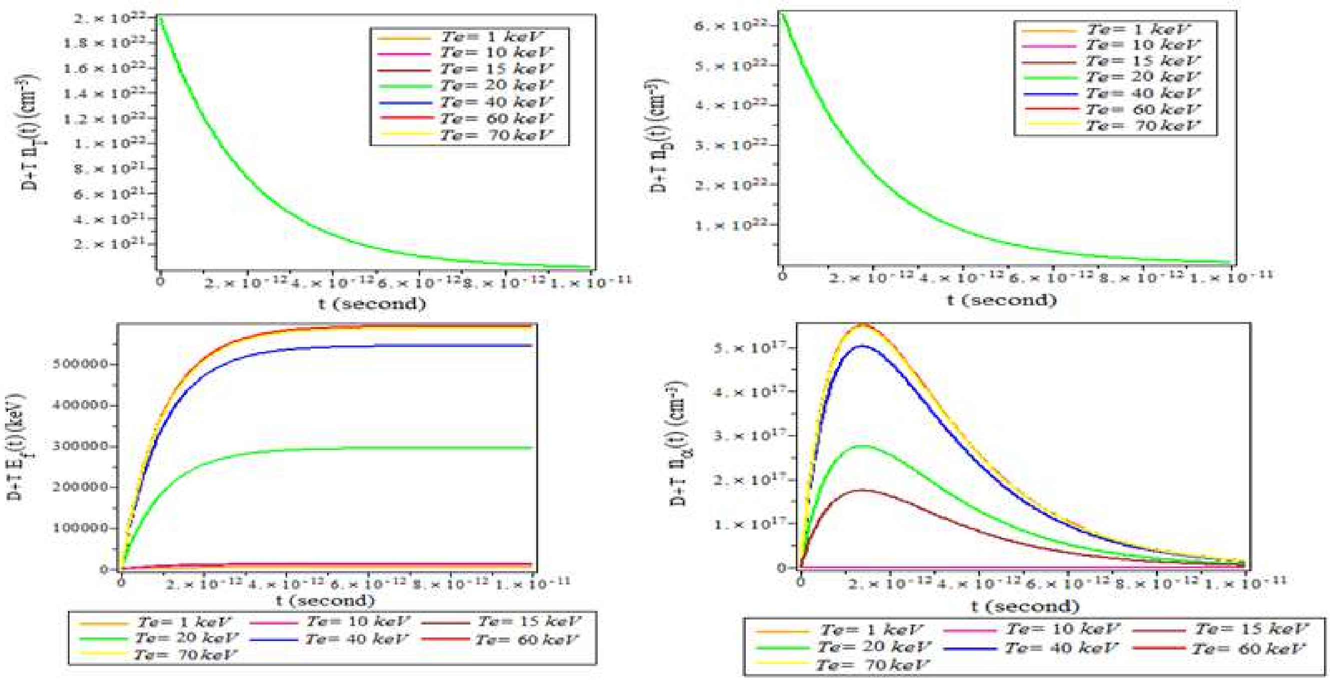

Figure 9. *The two dimensional variations of deuterium , tritium , alpha particles densities and plasma energy in terms of time at different temperatures for D+T mixture under choosing* $S_T = 0.20 \times 10^{23}(cm^{-3})$ *and* $S_D = 0.63 \times 10^{23}(cm^{-3})$.

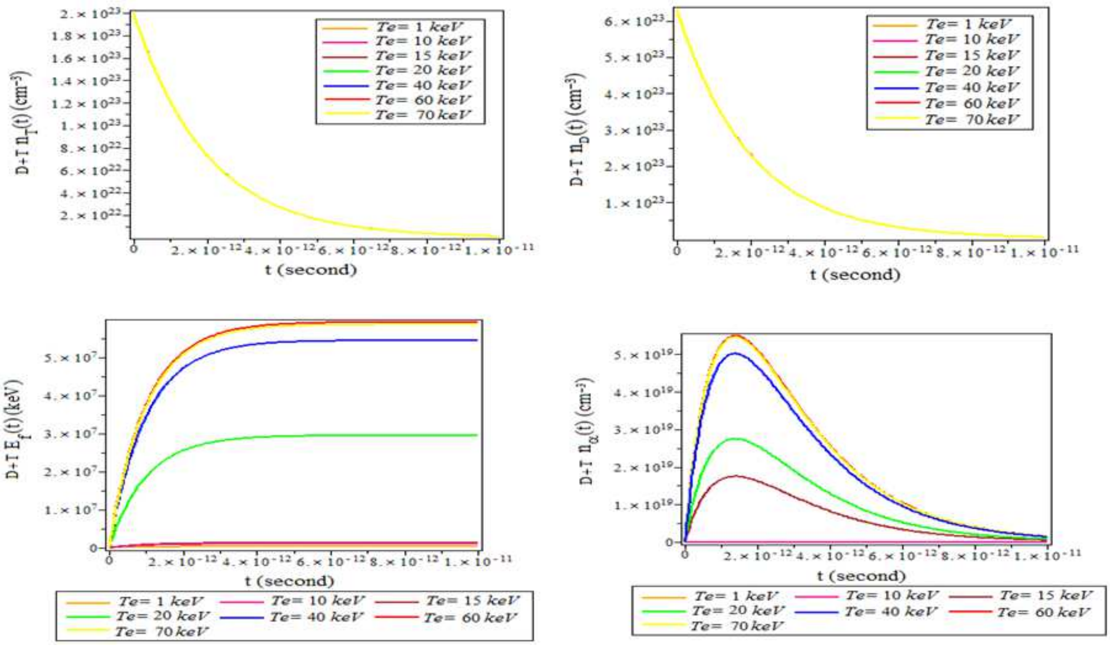

Figure 10. *The two dimensional variations of deuterium, tritium , alpha particles densities and plasma energy in terms of time at different temperatures for D+T mixture under choosing* $S_T = 0.20 \times 10^{24}(cm^{-3})$ *and* $S_D = 0.63 \times 10^{24}(cm^{-3})$.

Table 3. *Time dependent of numerical values for fusion power density and target energy gain.*

D+T $S_D = 0.63 \times 10^{24}(cm^{-3})$, $S_T = 0.20 \times 10^{24}(cm^{-3})$			
T_e **(keV)**	**t (s)**	$P_{D+T}(t)(\frac{W}{cm^3})$	$G_{D+T}(t)$
20	10^{-20}	1549.2E17	0.11802E-22
20	10^{-11}	702.75E13	1.1798E-15
20	60	619.61E-6	0.572432E-7
20	110	619.61E-6	0.99075E1
40	10^{-20}	2827.6E17	0.21788E-22
40	10^{-11}	1282.1E13	2.1777E-15
40	60	1131.4E-6	1.0566E-6
40	110	1131.4E-6	1.8288E1
60	10^{-20}	3092.4E17	0.23718E-22
60	10^{-11}	1401.9E13	2.3705E-15
60	60	1236.9E-6	1.1501E-6
60	110	1236.9E-6	1.9906E1
70	10^{-20}	3073.8E17	0.23485E-22
70	10^{-11}	1393.5E13	2.3473E-15
70	60	1229.5E-6	1.1389E-6
70	110	1229.5E-6	1.9711E1

6. Conclusion

From this work, we conclude that resonant temperature for D+T mixture is 60 keV and in this temperature we have maximum energy gain. Our computational results show that numerical values of stopping time ($t_{s_{D+T}}$) are increased very strongly by raising temperature , while slowly increase by raising target density ρ. Another effective parameter on the value of stopping time is the deuteron energy such that by increasing this energy stopping time is increased. But by raising n_T in D+T reaction numerical values of stopping time strongly decreased. The important parameter that effect on the value of stopping range , is target density, by increasing target density $R_{s_{D+T}}$ is strongly increased. The multiplication factors and total deposited energies are time independent because in calculating these parameters n_T is omitted. By observing the related figures and tables we will conclude that the maximum variations of particle densities , plasma energy ,power density and target energy gain are occurred in resonant temperature. From table.3 we have maximum gain equal to 19.906 at resonant temperature 60 keV under optimum conditions $S_D = 0.63 \times 10^{24}(cm^{-3})$, $S_T = 0.20 \times 10^{24}(cm^{-3})$,t=110s.Finally, we concluded that the maximum energy deposited in the target from D+T and D+D reaction are equal to 19269.39061keVand 39198.58043keV,respectively. So, deposited energy can reduce laser driver energy.

Nomenclature

$\sigma(E_{lab})$ Fusion cross section
C_1, C_2,C_3 3 adjustable parameters
m_a Mass number for the incident nucleus
m_bMass number for the target nucleus
E_{lab} Deuteron energy in laboratory system
Z_1 ,Z_2 Charge numbers of the colliding nuclei
$< \sigma v >$ Reactivity
m_r Reduced mass
k_B Boltzmann constant
T Temperature
ε Energy in the center of mass frame
P_{in} Input power
P_d Driver power output
P_g Thermonuclear fusion power
P_{th} Thermal power
E_IAverage initial energy of the injected single ion
E_{th}Asymptotic thermalized energy of the injected single ion
F The ratio between the fusion energy produced and the ion energy input to the plasma

K_kAtomic fraction
$(E_f)_{Ik}$Energy released per fusion for the injected ion I of species k
m_eThe mass of electron
ln Λ_{D+T}Coulomb logarithm for D+T fusion reaction
m_IThe mass of the injected ion
T_eThe target electron temperature
Z_kThe atomic number of target fuel ions
ρTarget density
φ_{D+T} ,φ_{D+D} Energy multiplication factor for the hot spot heating by the charged particles in D+T and D+D
$\varepsilon_{D+T}, \varepsilon_{D+D}$The total energy that could be deposited into the target due to combined deuteron ion heating and beam-target fusion for D+T and D+D
R_SThe deuteron stopping range
t_SThe deuteron stopping time
v_DThe deuteron velocity
E The deuteron energy
n_DThe density of deuterium ions
n_TThe density of tritium ions
n_αThe density of thermal alpha-particles
S_D , S_TThe source terms which give us the fuel rates
τ_P The lifetimes of deuterium and tritium
τ_αThe lifetime of thermal alpha-particles
τ_EThe energy confinement time
Q_α The energy of the alpha particles
P_{rad} The radiation loss
A_bBemsstrahlung radiation coefficient
n_e The electron density
Z_{eff} The effective atomic number
Z_i The atomic number of the different ions
$G(t)$The fusion energy gain in terms of time
$E_f(t)$The energy due to the number of occurred fusion reactions in target in terms of time
E_{driver}The required energy for triggering fusion reactions in hot spot
$P_{D+T}(t)$The fusion power density in terms of time for D+T reaction

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