New Laser Fusion without Implosion

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●Goal of fusion research is to get the clean and the sustainable energy besides an economical energy. Today, laser fusion has been developed precisely, and ignition of burring of D-T fuel may be expected in near future.

●But there are many issues for commercial reactors in ICF as the cost of complicated and precise pellet targets, irradiation uniformly, required high repetition rate of such large laser and so on. So it is hard to satisfy the economical condition even though we can achieve the ignition.

●From these points of view, a new laser fusion has been proposed. We have investigated a feasibility of the approach of laser driven nuclear reaction by intense laser field along this concept at laser peak. [1] We added and summarized an additional penetration around the laser peak and focusing point here.

●The intense laser field distorts the coulomb barrier, which enhances the tunneling. This forms the cloud by the tunneled nucleon and they react when they meet each other. This is a usual nuclear reaction.

●A more than 100PW laser is required to distort the coulomb barrier to obtain enough penetrability for tunneling, however, the total energy of the laser and the cost of the energy by this way are significantly reduced. In this article, the model and gain for D-D reaction by this way are discussed.

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- **Concerning the laser fusion, Nuckolls and Livermore scientists proposed an attractive way of compression by the implosion and since then the high performance lasers have been developed. [3]**

- **But an ignition is required in this case. We need the symmetry and the uniformity with high accuracy for irradiation**

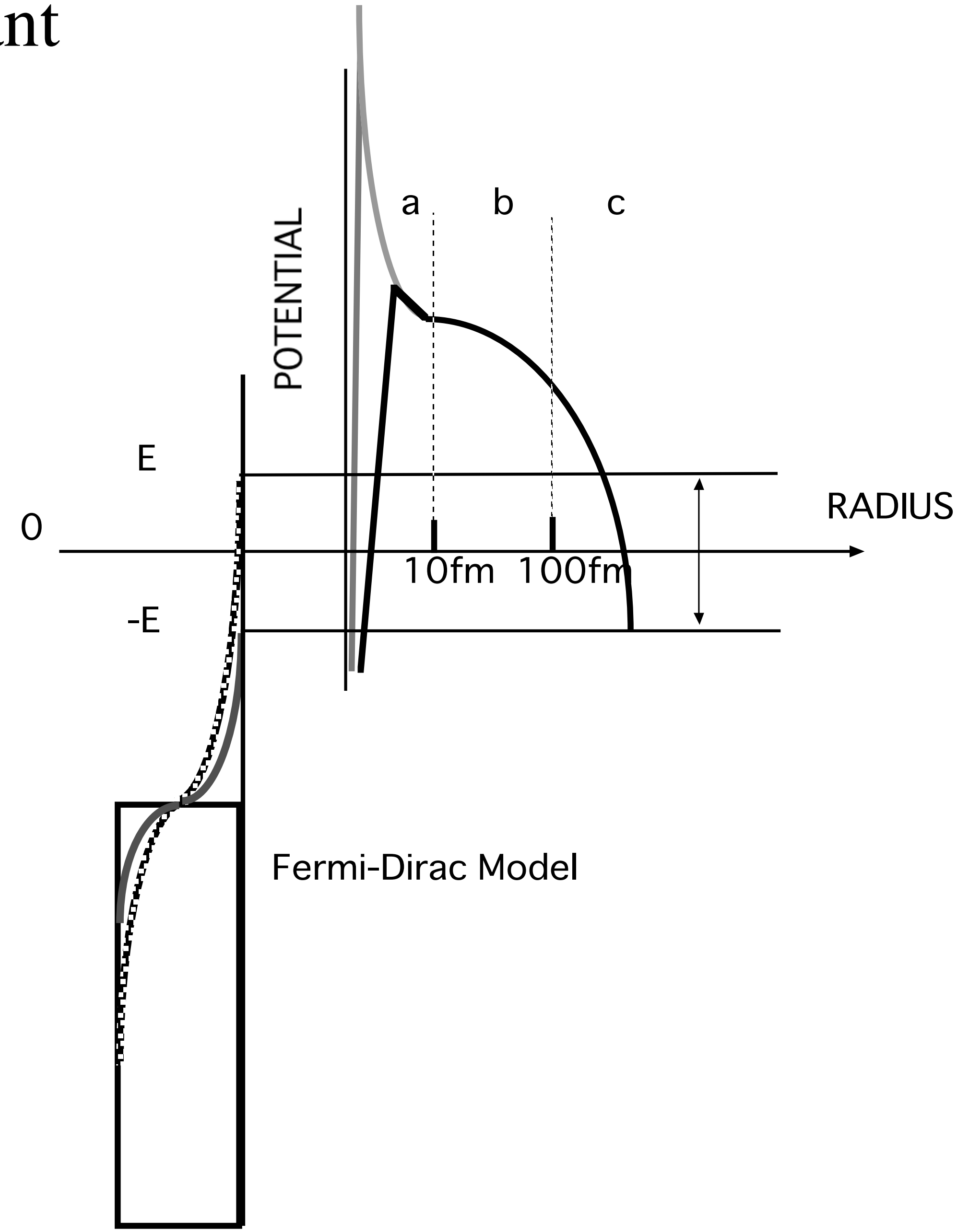
- **Using such lasers we have proposed a feasibility of new approach of laser induced nuclear reaction using intense laser field. Such intense laser field distorts the coulomb barrier, which enhances the tunneling. This forms the cloud by the tunneled nucleon and they react when they meet each other.**

- **This is a non-Gamov nuclear and cross section is rather large, although more than 100PW laser was required to distort the coulomb barrier to obtain enough penetrability for tunneling. [3] In this way, ignition is not an essential point in usual ICF as a first point.**

- **Another point of this is the increment of fusion reaction rate due to the tunneling and cloud formation.**

- **The detail is discussed. We can expect a reactor using deuterium plasma.**

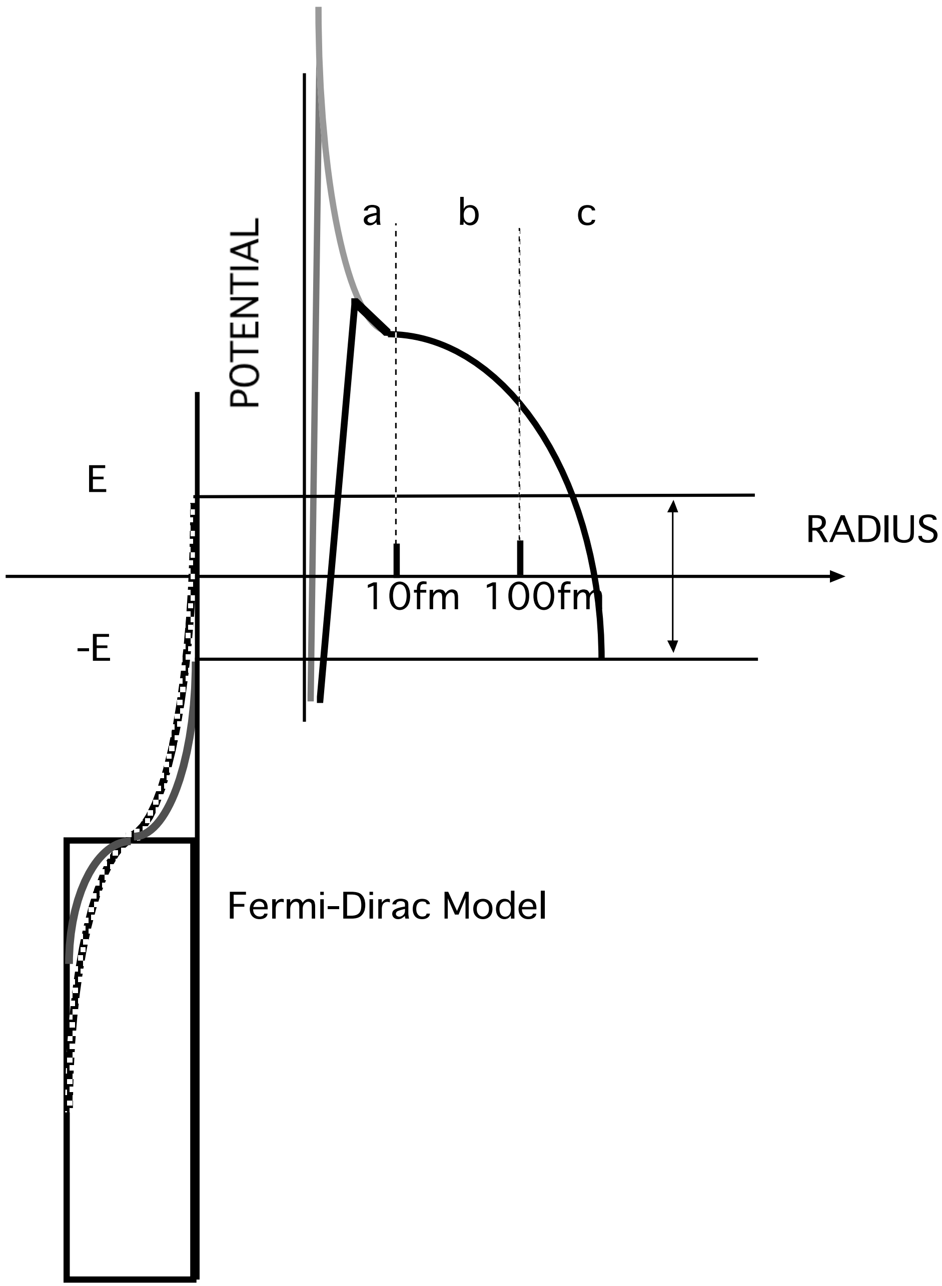
Coulomb barrier is dominant in outer region and this is schematically shown.



- During this, intense field by the laser is applied along the center of laser path. This field distorts the Coulomb barrier in each peak of each laser cycle, which promotes the tunneling.

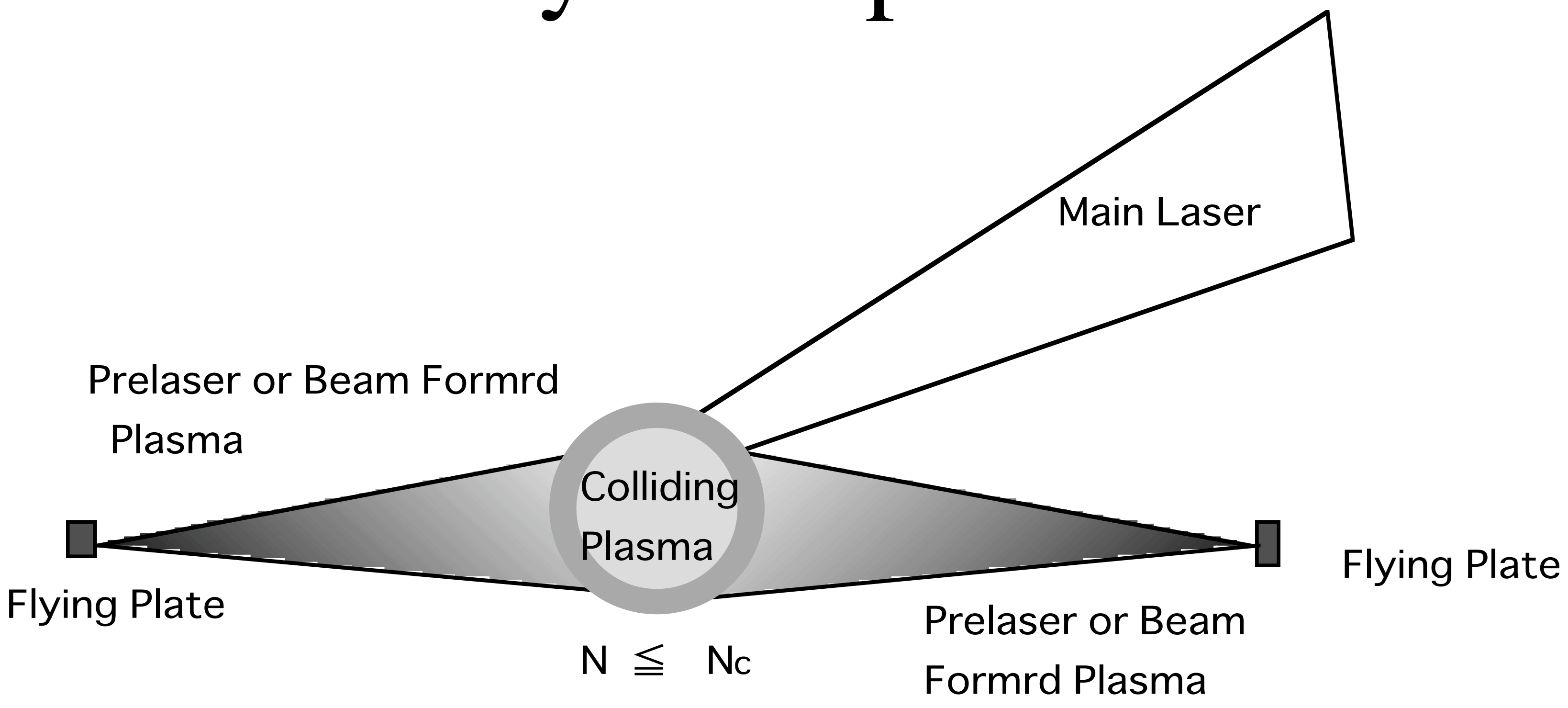
- The tunneled nucleon forms a cloud of probability of de Broglie wave of nucleon. The cloud expands with group velocit v_g of tunneled nucleon. This expansion is kept in oscillating lase field with the energy of Heisenberg uncertainty.

- Tunneled nucleons form cloud around nuclei. When the clou of tunneled nuclei meets each other, they immediately make a compound nucleus and react as a usual nuclear reaction. This is taken place during the laser pulse.

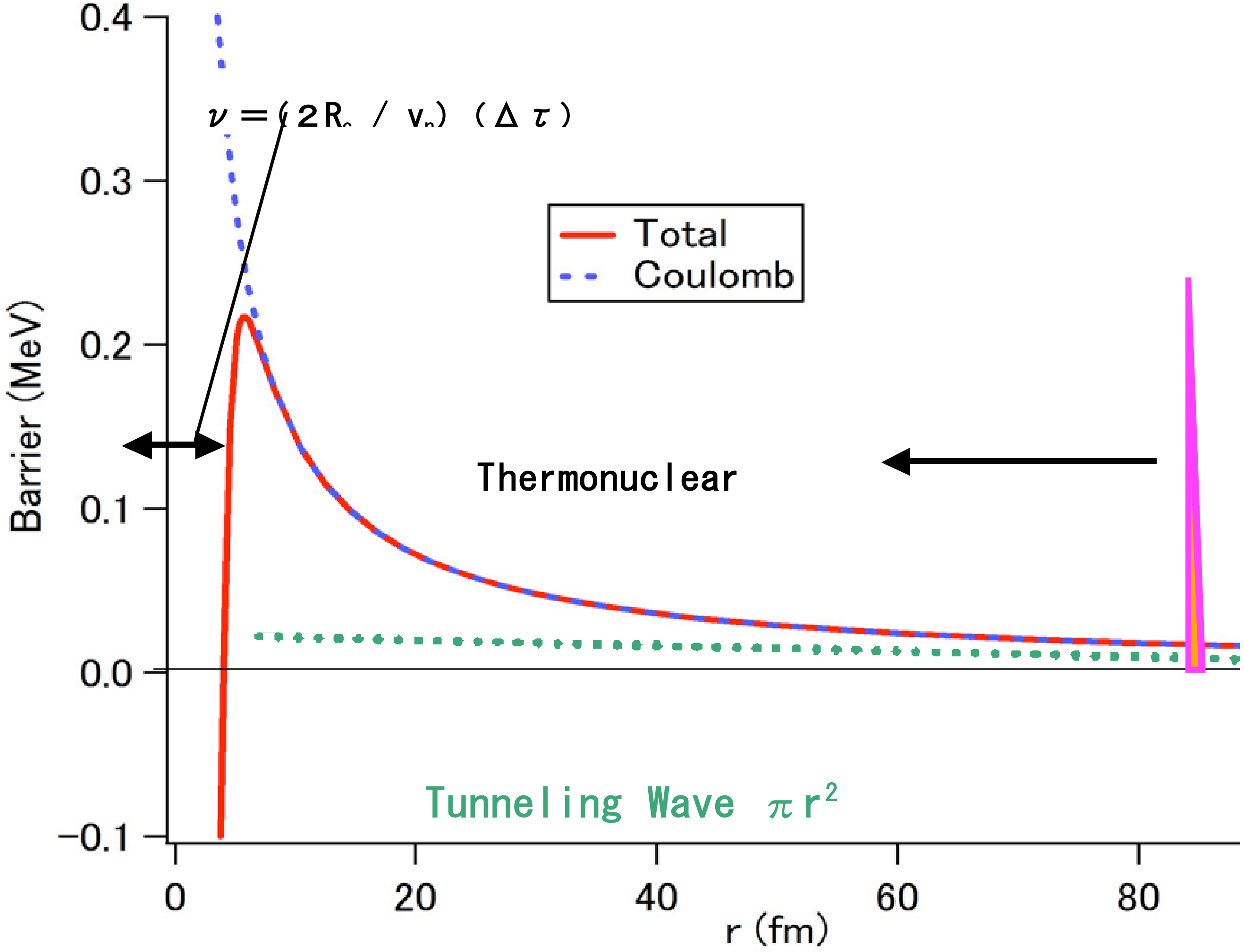


●At the foot of Coulomb barrier with intense laser, laser field becomes dominant. This is shown as a region c of Fig1. This shows a picture at peak laser field. In the laser-dominated region, field is oscillated with the laser field. The distribution of nucleon is along the Fermi-Dirac model.

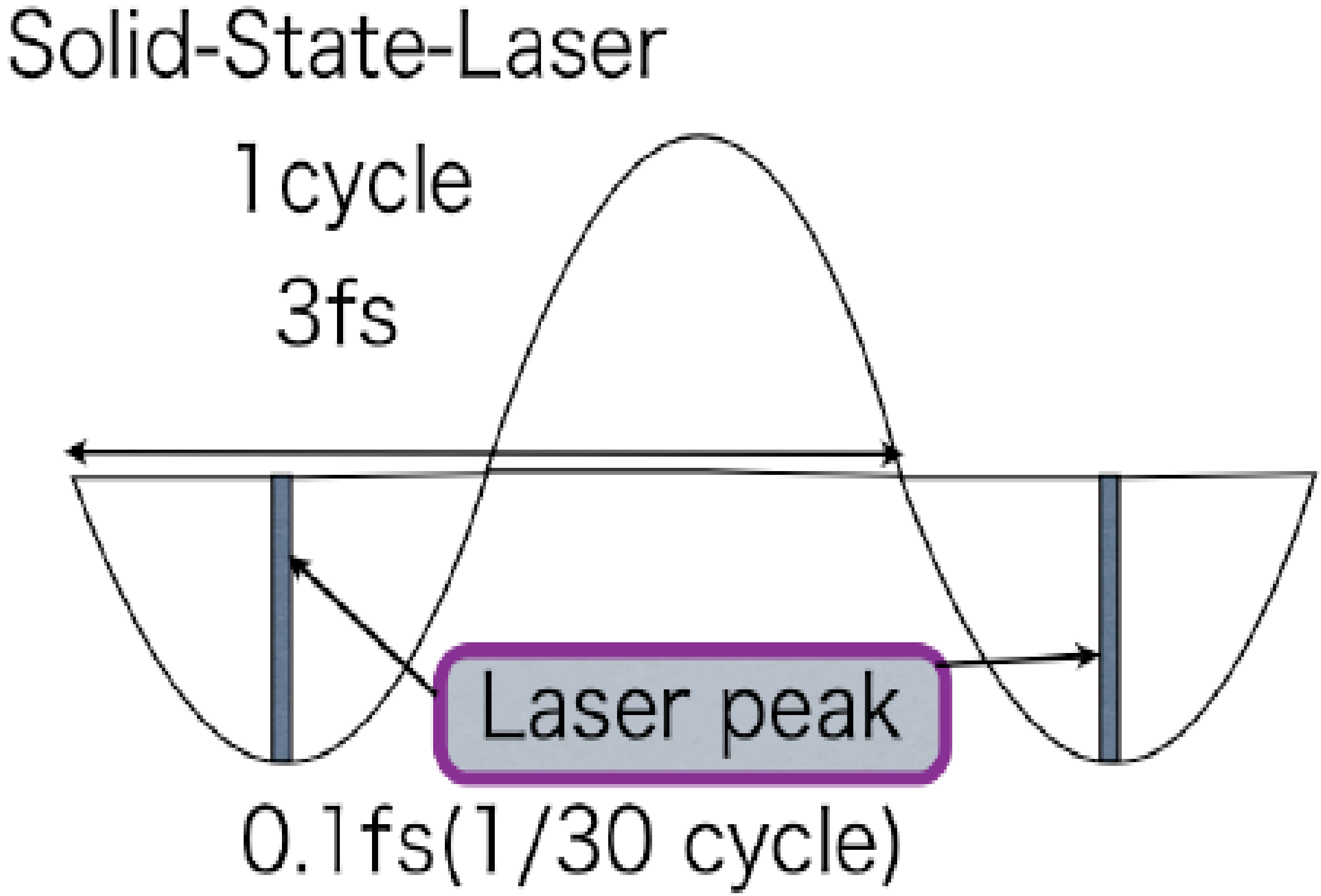
Laser Plasma is produced in many examples.



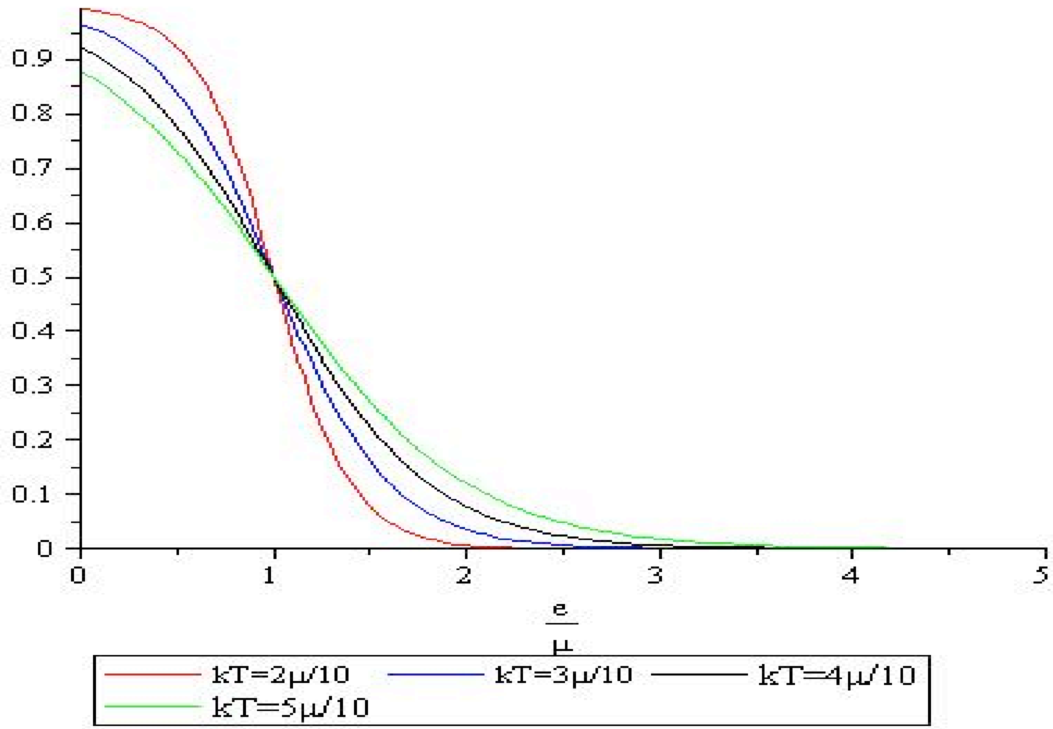
In the first stage without the intense laser, nucleons are trapped in nuclear potential and hit the inner wall of Coulomb barrier in many times of laser power peak with nucleon kinetic energy up to a few kilo eV. The ty to be 10^{-20} to 10^{-21}sec so this is much shorter than the laser peak period. This is shown for normal nuclei.



Waveform of laser

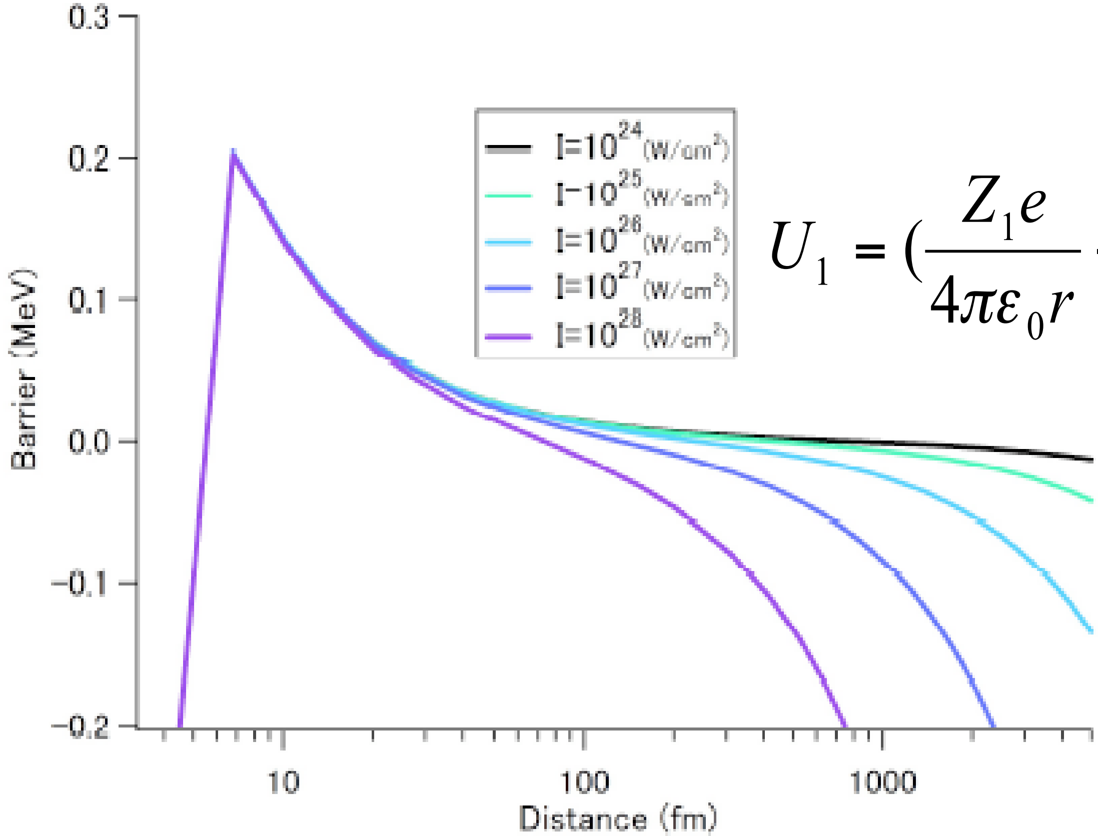


Distribution of Nucleon



Coulomb Barrier with Laser Field

When intense laser is applied, the field in the foot of Coulomb barrier is distorted at the laser intensity peak. Coulomb barrier and laser as the first term is Coulomb field, the second term is laser field and the third term is nuclear potential with paions. Let us consider two extreme cases for this potential at the laser peak. Let us focus on providing Z_1=Z_2=1, then we calculate and Figure out .Under this assumption, each line indicates the calculated results of fields with various laser intensity peak.



$$U_1 = \left(\frac{Z_1 e}{4\pi\varepsilon_0 r} - Ar\right)Z_2 e - V_0 \frac{e^{-\frac{r}{r_0}}}{\frac{r}{r_0}}$$

●Figure 7. indicates the detail of the barrier potential around grand level with various lasers. In actual case, tunneled nucleons are traveling through the barrier and come out to the free space, which make a cloud.

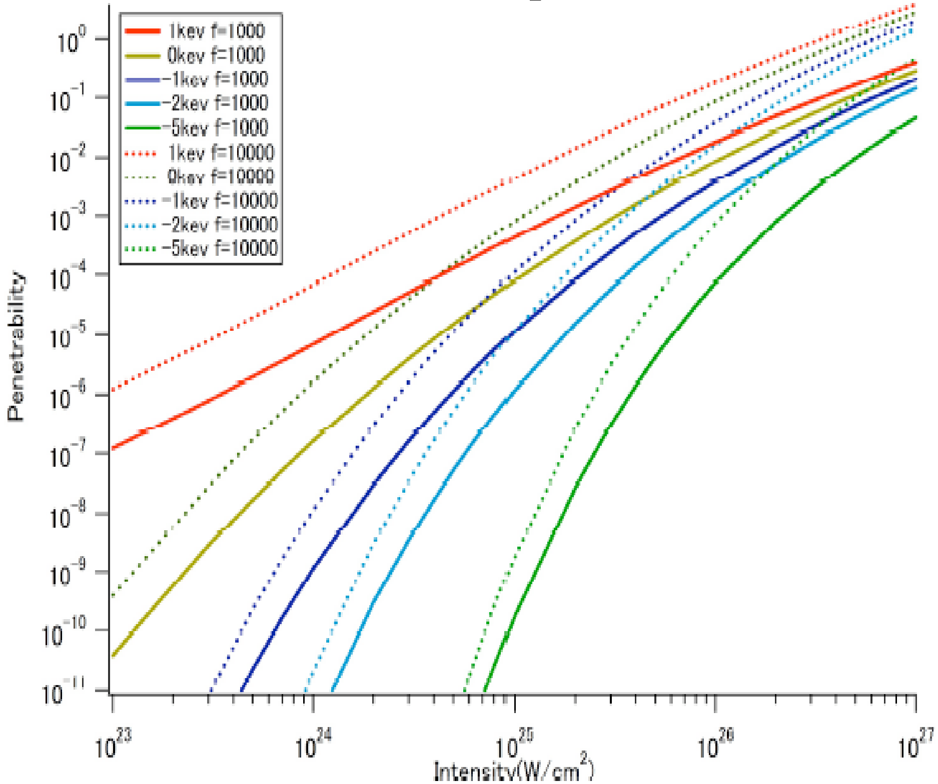
The transmission rate T is calculated as follows using a potential of nuclei discussed in section 3.2.

Then transmission rate of the nucleon passing through the barrier is expressed as where

Here, is for proton, and . A simple transmission rate T is modified and penetrability, P is defined as

P = fT. (7)

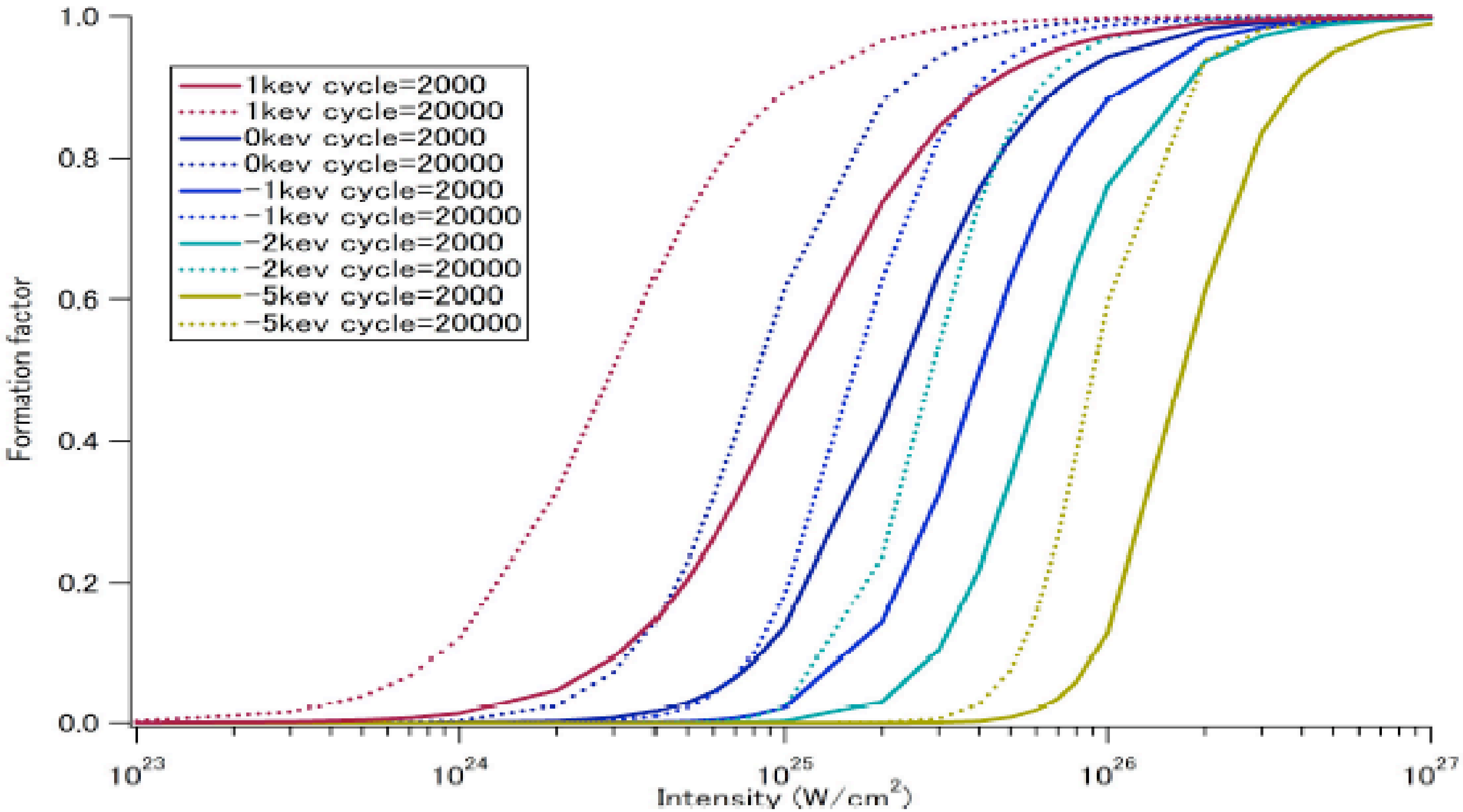
Here, f is a collision time of the nucleon with inner wall produced by nuclear potential and Coulomb barrier. Setting nuclear potential radius 5fm in usual case, one can estimate f to be more than 10000 through nucleon kinetic energy corresponding to 1MeV during the laser peak. In actual case, E in Eq. 6 corresponds to this relation of energy level of the nucleon. It should be determined by experiments, but for this simple calculation in this paper, we use parameters 0eV to 10keV. Then, the penetrability is calculated as shown in Fig.7 from the equations 5, 6 and 7 with various parameters.



●Here Nc is a cycle number of laser pulse crest, which can be taken as 200 to 2000 in this case. When F is approaching to one, the saturation with depletion of nuclei and so on will be taken place. On the calculation result, this effect is included. In this region, the Fs for saturation level can be roughly written using F as,

$$F_s = F / (F + 1) \qquad (8)$$

Typical results are shown. Here, two cases of cycle number for 200in 900fs pulse length and 20000 in 10ps of pulse length as a various pulse cases are shown.



- **When clouds meet each other, nuclear reactions are taken place. From this model reaction rate is estimated and is shown. A radius of cloud is calculated as**
    - **$r = V_g \langle t \rangle$. (9)**
- **Here, V_g is the group velocity of de Broglie wave of nucleon and <t> is a average time of cloud holding in the reacting area. In the unit period of t, each nucleus has a relative velocity of V_r with cloud density of n_c. We introduce r, a radius of the cloud diffusion area of tunneled nucleon wave during the laser pulse of 1ps to 100ps.**
- **Thereafter, the reaction rate is written as**
    - **$Rr = F_1 F_2 \pi r^2 v_r$. (10)**
- **In this equation, F1 and F2 are formation factors of laser tunneling nuclei for n_1 and n_2. of two species. n_1 and n_2 are number density of reacting plasma.**
- **In the unit period of t, each nucleus has a relative velocity of V_r with cloud density of n_c. This is given by the group velocity of tunneled nucleon wave and is estimated to be 10^6cm/s. So r is 10^{-6}cm in our case. v is a relative velocity of nuclei each other by the thermal motion or differential accelerated particle velocity by laser. We use a typical velocity of 2×10^6cm/s.**
- **Then reaction rate can be calculated for a density of plasma using parameters of relative velocity as shown.**

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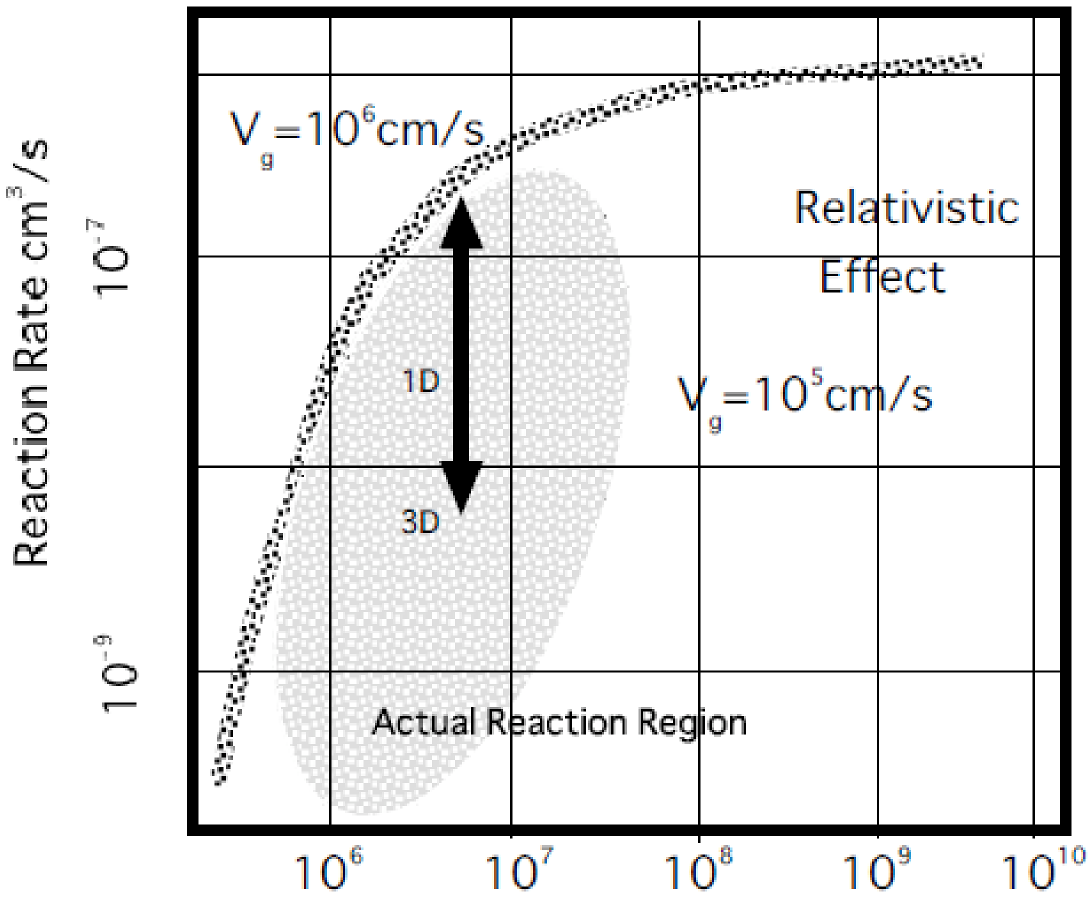
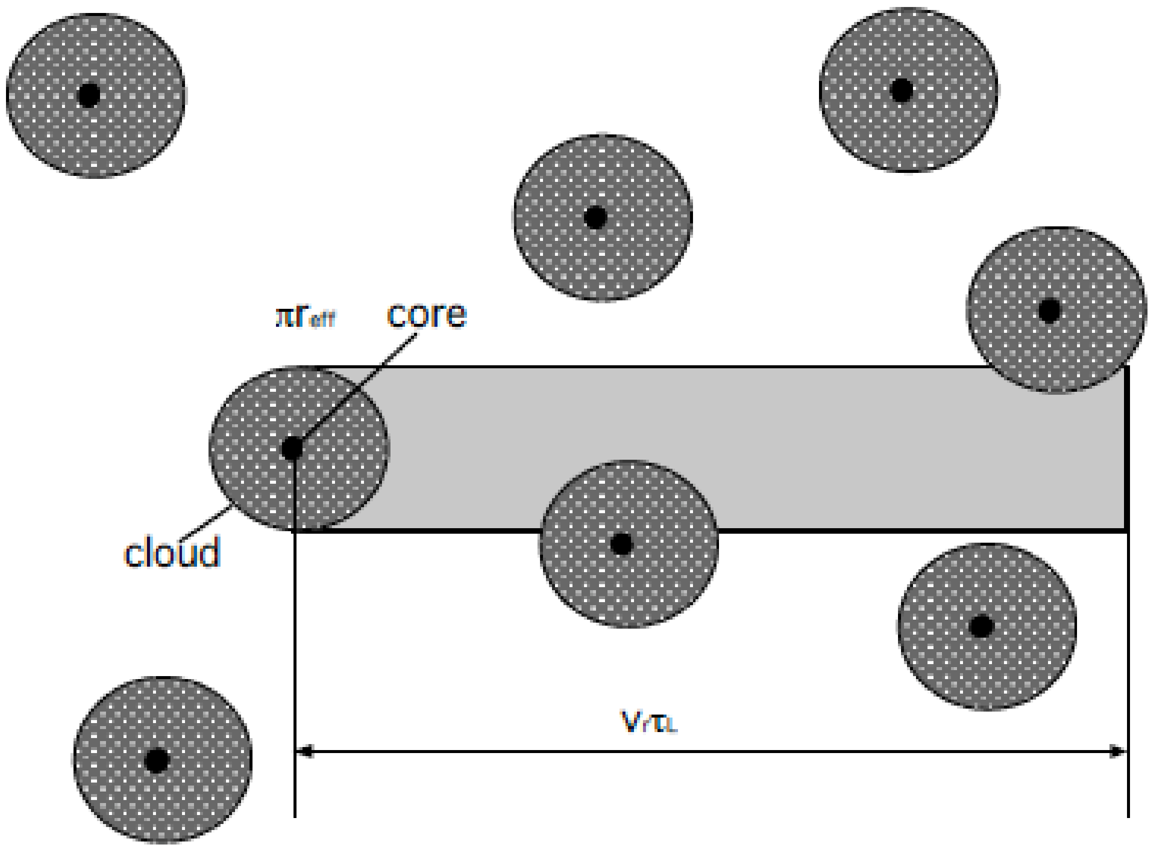
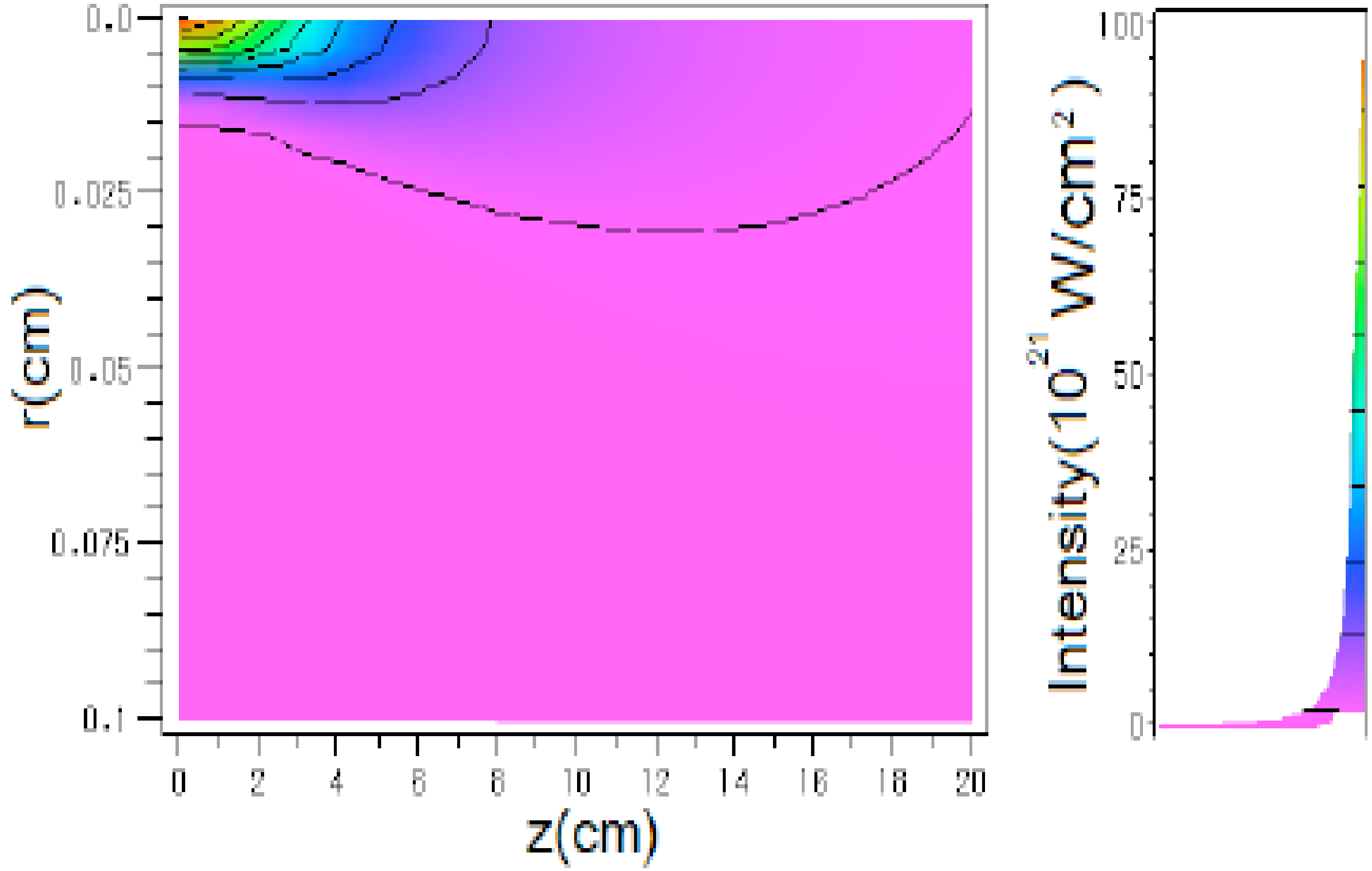
Then reaction rate can be calculated for a density of plasma using parameters of relative velocity as shown in Fig9.



Here, we can use a usual reaction model between the molecules.



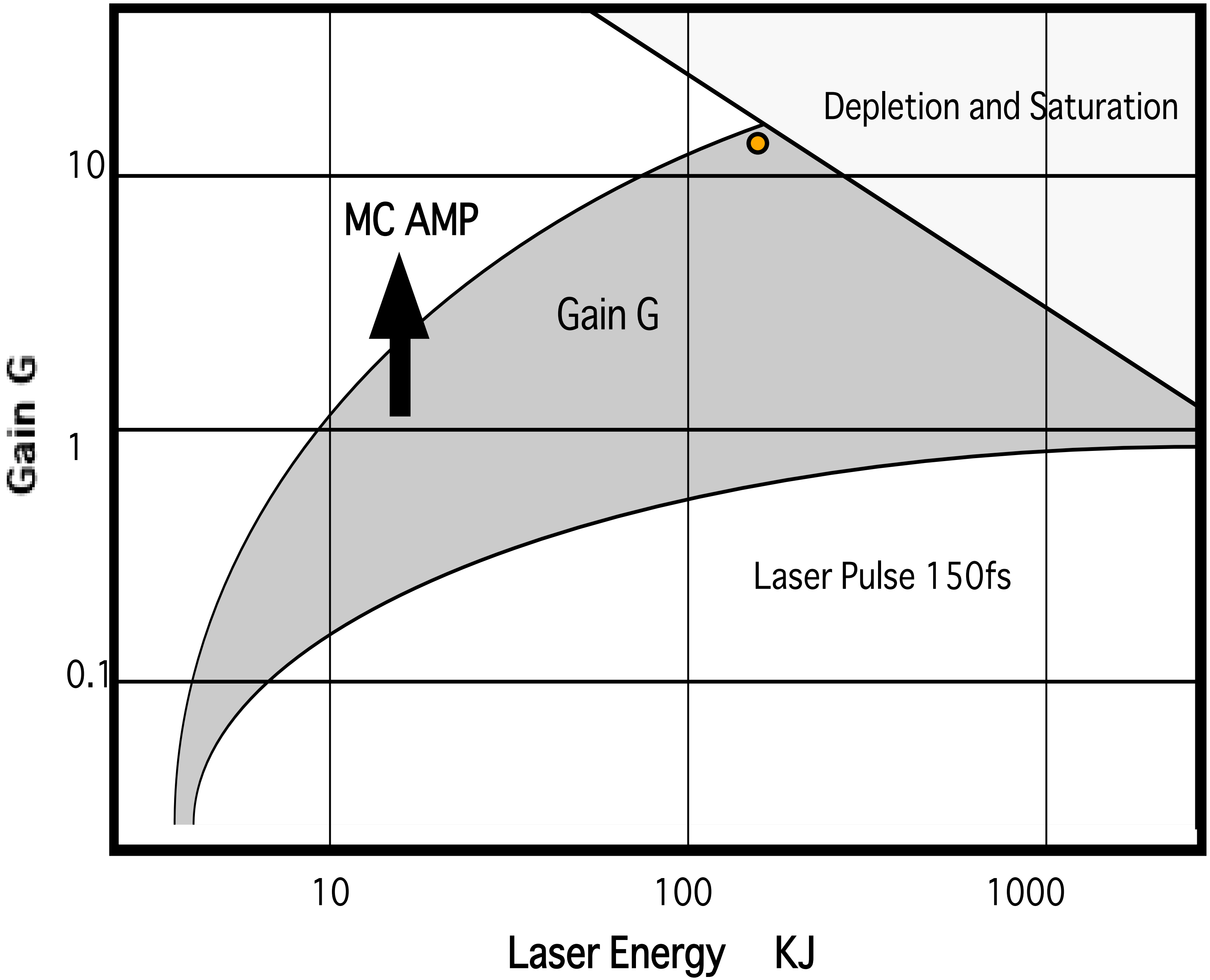
Gaussian intense laser with tightly focusing is injected into such plasma. This shows a contour of laser intensity in such plasma.



Reactor parameters as the inner radius, which is the same as first wall radius, the neutron density on the first wall should be chosen with 10 to 30MW/m^2 for usual cases. But the neutron density exceeded in our case at the center part. The length is determined from mirror magnet field. The mirror ratio of 10 is taken for a confinement of plasma and to obtain a conversion to electricity for a breakeven. From conservative parameters, the length of 8m is given. The blanket thickness for neutron energy deposition is calculated using Monte Carlo code of MCNP5.

Direct plasma energy converter is set both sides of the reactor as a MHD energy converter.

A Gain curve in the scheme is shown.



Depletion and Saturation
10
MC AMP
Gain G
Gain G
1
Laser Pulse 150fs
0.1
10
100
1000
Laser Energy KJ

Many issues

1. Saturation region on formation factor F.
2. Cloud behavior and life span.
3. Group velocity of nucleon and relative velocity of nucleon after tunneling.
4. Self-consistent field of Coulomb barrier region during the tunneling.
5. First wall structure to replace per several months

Summary

- New Laser Fusion is shown. It is a natural way.
- We can expect gain without implosion.
- There are many issues and I am waiting your comments.