3.14 Suprathermal Fusion Reactions in Laser-imploded D-T Pellets: Applicability to Pellet Diagnosis and Necessity of Nuclear Data

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Abstract

The suprathermal fusion reaction is examined on the basis of coupled transport/ hydrodynamic calculation. We also calculate the energy spectrum of neutrons bursting from DT pellet. Because of suprathermal fusion and rapid pellet expansion, these neutrons contain fast components whose maximum energy reachs about 40MeV. The pellet ρR diagnosis by the detection of suprathermal fusion neutrons is discussed.

1.Introduction

In inertial confinement fusion (ICF) plasmas, fusion-born neutrons interact to some extent with the plasma and create new energetic ions by recoil. Some of the recoil ions can undergo fusion during slowing down(*i.e.*, suprathermal fusion) with the background ions (B.G. ions). The neutrons emitted from the suprathermal fusions contain high energy components (11MeV $\leqq E_n \leqq$ 30MeV), because the recoil ions introduce thier kinetic energy into these reactions.

Welch, *et al.* [1] showed that the ratio of "suprathermal" to "primary" fusion neutrons, *i.e.*, the suprathermal fusion probability, gives the information about the fuel density-radius products (ρR) of pellets. Therefore, they pointed out that the detection of high energy neutrons from the pellets is useful for fuel ρR diagnosis. In actual ICF pellets, however, the energy spectrum of burst neutrons becomes more broadened, because the fusion reactions occur during rapid expansion of imploded DT pellets. For the purpose of obtaining useful data for pellet ρR diagnosis, we must take into account the effect of medium expansion.

In this paper, we examine the suprathermal fusion reactions in laser-imploded DT pellets and calculate the realistic enegy spectrum of burst neutrons from the pellets, on the basis of coupled transport/hydrodynamic calculation. We also discuss the realtion between the high energy components of neutron energy spectrum and the pellet ρR.

2.Method of Calculation

2.1 Transport calculation

We use the simultaneous neutron/recoil-ion transport model formulated by Nakao, *et al* [2]. In this model, transport equations are described in the modified Eulerian coordinate[3], *i.e.*, the energy and angular variables are defined in terms of the velocity relative to the medium.

The transport equation for neutrons is the Boltzmann equation; the source neutrons come not only from thermal fusions but also from suprathermal ones. Neutron interactions we consider are elastic scattering and D break-up reaction. The cross-sections for these processes are given by Seagrave, *et al* [4]. The fundermental equation to describe the transport of recoil ions and alpha particls is the Boltzmann-Fokker-Planck equation. Coulomb scattering and DT suprathermal fusion are taken into acount as the interactions between recoil ions and B.G. ions. The cross section for DT fusion reaction is taken from Duane [5] and is averaged over the velocity distribution of B.G. ions.

We coupled these transport routines for neutrons and charged particles to one-dimensional hydrodynamic code, MEDUSA [6].

2.2 Implosion-burn simulation

For analysis of the suprathermal fusion, we use a reactor-grade pellet model taken from conceptual ICF reactor design, KOYO [7]. **Figure 1** illustrates the configuration and composition of the pellet. This pellet is irradiated by tailored pulse, *i.e.*, a prepulse and a following main pulse; the wave length of laser is taken as 0.35 μm.

At first, we carry out the implosion simulation for this pellet, using the one-dimensional hydrodynamics code ILESTA-1D [8]. In the implosion simulation, neutron interactions are neglected. The temperature, density and hydrodynamic velocity distributions of the medium obtained around the final stage of implosion are used as the imput of the initial state for the burn simulation carried out with the MEDUSA code.

Examination is also given on the ρR dependence of suprathermal fusion resctions for the various values of laser energy E_L ($E_L = 2.35 \sim 3.35$MJ).

3.Results and Discussion

The ρR value of burning DT pellet changes momentarily. Therefore, we use two values representing the ρR. One is the maximum ρR attained ($\rho R_{\max}$), and the other is the burn-averaged ρR ($<\rho R>$) definited as follows:

$$< \rho R > \equiv \frac{\int_0^\tau \rho R(t)\, R_F(t)\, dt}{\int_0^\tau R_F(t)dt}$$

where R_F is the rate of fusion reactions in the pellet and τ is the implosion-bum time.

Figure 2 shows the suprathermal fusion probability as a function of the ρR of pellets. In the reactor-grade pellet such as KOYO model, the probability is 1~2%. We can observe a linear dependence of the probability on the $<\rho R>$ of pellets. On the other hand, the dependence of probability on the ρR_{max} of pellets is not linear. Therefore, the detection of suprathermal fusion neutrons is useful for $<\rho R>$ diagnosis and not useful for ρR_{max} one.

Figure 3 represents time-integrated energy spectrum of neutrons bursting from burning DT pellet imploded by 3.35-MJ laser. The energy variable is now written in terms of the neutron velocity in the rest frame. The burst neutrons contain the high energy components whose maximum energy exceeds 40MeV. These high-energy neutrons are produced, when the suprathermal fusion reactions occur during rapid expansion of DT pellet and emit neutrons in the same direction as the medium expansion velocity. On the other hand, the maximum energy of neutrons emitted from thermal fusions is about 21MeV. Therefore, it is possible to detect high-energy neutrons emitted only from the suprathermal fusions, if we use a neutron activation reaction whose threshold energy is above 21MeV.

Here, we propose to detect the high energy neutrons as above by the following activation reaction,

$$^{23}\mathrm{Na} \xrightarrow[E_n \geqq 23.5\mathrm{MeV}]{(n,3n)} {}^{21}\mathrm{Na} \xrightarrow[t^{1/2}=22.5\mathrm{s}]{\beta\text{-decay}} {}^{21}\mathrm{Ne}\,.$$

The relations between the ratio of the number of high-energy neutrons, $N(E_n \geqq 23.5MeV)$, to the number of total neutrons, N_t, and pellet ρR are estimated and plotted in **Fig.4**. This figure shows that it may be possible to know the pellet $<\rho R>$ by the detection of β-decay of ^{21}Na and by the estimation of the ratio $N(E_n \geqq 23.5MeV) / N_t$. For example, if the ratio is 0.0002, $<\rho R>$ could be estimated to be 2.15 g/cm^2.

4.Concluding Remarks

We have examined the suprathermal fusion reactions in laser-imploded DT pellet, on the basis of transport/hydrodynamic calculation. The energy spectrum of neutrons bursting from DT pellet is fairly broadened and contains the high energy components whose energy reachs about 40MeV. We have also shown that it may be possible to know the pellet $<\rho R>$ using the ^{23}Na foil activated by the suprathermal fusion neutrons.

In the pellet currently adopted for implosion or ignition experiment, however, it is expected that the neutron yield is not so sufficient as to activate the ^{23}Na foil. Therefore, in such a pellet, we have to detect the suprathermal fusion neutrons by the activation reaction whose threshold energy is lower, for example, than that of ^{23}Na. The determination of the most suitable method for each pellet to detect suprathermal fusion neutrons needs calculations for various-sized pellets and the cross-sections for activation reactions (*e.g.* ^{23}Na(*n,3n*)).

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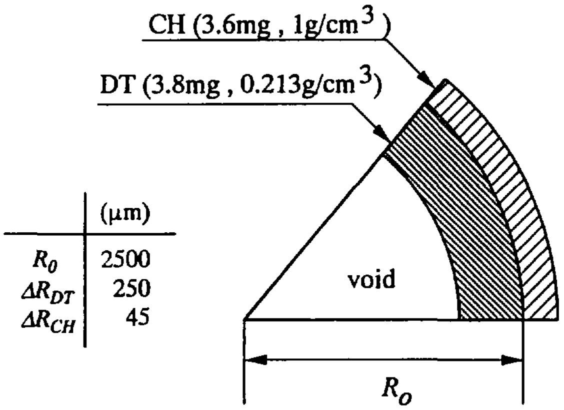

Fig. 1 Initial configuration of pellet for the implosion simulation

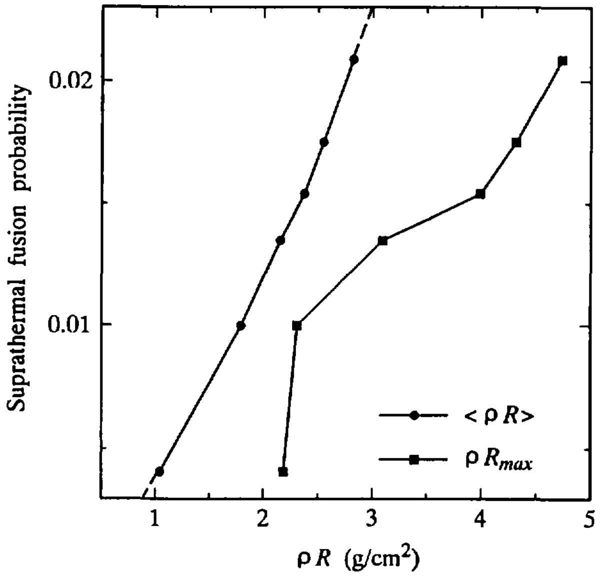

Fig.2 The suprathermal fusion probability as a function of pellet ρR

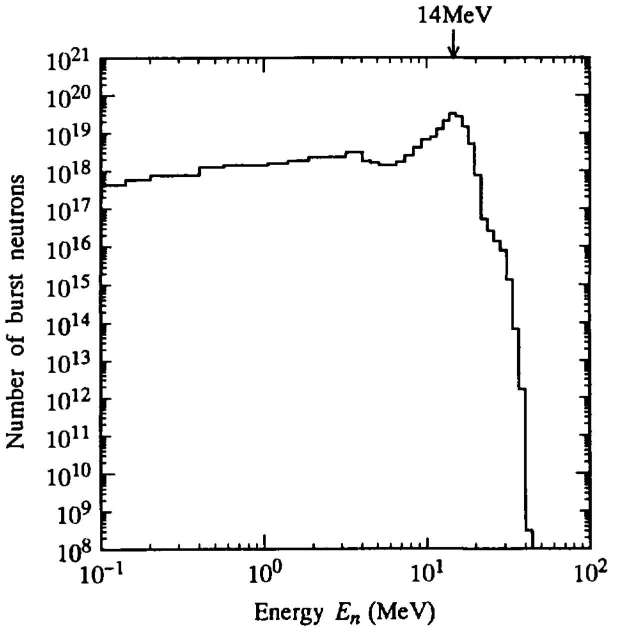

Fig. 3 Time-integrated energy spectrum of neutrons bursting from a laser-imploded DT pellet ($E_L = 3.35$MJ)

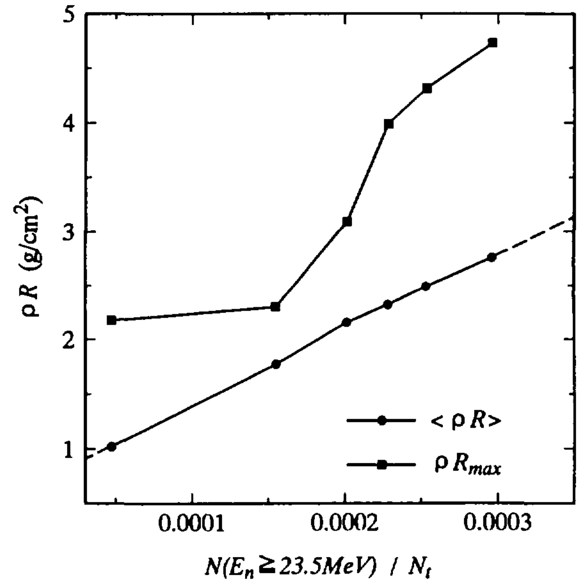

Fig. 4 The relation between the fraction of high energy neutrons and pellet ρR