CALCULATIONS OF A SPHERICAL SHELL OF DT IRRADIATED BY 10.6 μ LASER LIGHT

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ABSTRACT

LLL calculation of CO₂ imploded pellets reported by LASL show failure due to electron preheat and decoupling even though optimistic Maxwellian spectra were assumed.

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Recently an article appearing in Physical Review Letters\(^1\) afforded us an opportunity to calculate the performance of some pellet geometries investigated by our LASL colleagues. A comparison will be made of LASNEX\(^2\) ID calculations of a spherical shell of DT irradiated by a 5.3 KJ shaped pulse of 10.6 μ laser light with those presented in the above mentioned article. In addition, the fundamental role played by multigroup electron transport in the calculation of near isentropic compression of DT is illustrated by the divergence of results reported by the LASL workers and the results obtained with the LASNEX code using the Multigroup Electron Transport Model\(^3\).

The pellet geometry of interest is given by Fig. 1.

![Fig. 1](image)

\(^1\) Laser Driven Implosion of Spherical DT Targets; Clarke, Fischer and Mason, Phys. Rev. Letters 30, 89 (1973).
The thin spherical shell weighs 7.5 μg and has a ratio of shell thickness to radius of one part in fifty-six. The shell was irradiated by a 10.6 μm shaped pulse of laser light. In all calculations complete absorption of the laser light is accomplished by forcing the laser energy not absorbed by inverse bremsstrahlung to be deposited near the critical radius. The pulse shape is given by eq. 1.

\[ E(t) = E_0 (1 - \frac{t}{\tau})^m \]  

where

- \( E_0 \) is the initial laser power
- \( E(t) \) is laser power at time \( t \)
- \( \tau \) and \( m \) are parameters
- \( t \) is the time

The published values of these quantities for the pellet of interest are

- \( E_0 = 5.7 \times 10^8 \) WATTS
- \( E_{\text{MAX}} = 3.85 \times 10^{13} \) WATTS
- \( \tau = 30 \) ns
- \( m = 1.875 \)

and were used in the LASNEX calculations. The LASL fusion yield was 55 KJ.

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\(^4\text{Pulse shape presented at VII Quantum Electronics Conference in Montreal, Canada, May 1972 - Paper J64.}\)
For the first attempt to reproduce the published result a calculation was made using the three temperature (one electron temperature) model. Although the pellet performed satisfactorily (producing ~70 KJ TH yield from the 5.3 KJ laser input energy) the agreement with the published result was not particularly good. The spatial distribution of electron temperature and collapse time of the pellet differed significantly in the comparison calculations. A series of snapshots of the electron temperature plotted against the pellet radius is given in the P.R.L. article. An examination of these results strongly suggested that the calculations had been made with non-flux limited electron transport. A LASNEX calculation was then made, as before, with the flux limiting of the electrons removed. The results of this calculation agree quite well with the LASL results. The spatial distribution of electron temperature, as far as can be determined from the article, was virtually constant at 10 keV from the exterior of the pellet into some radius < 50 μ at t = 29.95 ns. Figure 2 is a plot of electron temperature against radius for the three calculations described above at the same time. As is seen the removal of the electron flux limiter lowered the LASNEX electron temperature from 15 keV to ~10 keV. Also the thermal front penetrated more deeply into the core. Detailed comparison of this depth of penetration could not be made since the resolution of the plots given in the article was poor. In addition the collapse time of the pellet now agreed closely with the LASL result. A TH energy production of 64 KJ resulted from the non-flux limited LASNEX calculation—-in fairly good agreement with the LASL calculations.
The three temperature model is not a good approximation to the coupling of laser light to the core of DT pellets. It does not take into account the effects of electron decoupling and preheat. These effects play a dominate role in the design of pellet implosions for electron distributions even as optimistic as inverse bremsstrahlung. To illustrate this point a LASNEX calculation of the pellet of interest was made using the Multigroup Electron Transport model. An inverse bremsstrahlung distribution of electrons generated near the critical radius was transported to the pellet core now taking into account the energy distribution of the electrons. The striking results are given in Figure 3. This is a comparison of the adiabat of a typical zone in the interior of the compressed core of the pellet calculated with and without multigroup electron transport. As is seen there are enough energetic electrons in the tail of even an inverse bremsstrahlung distribution to seriously preheat the core of the pellet when 10.6 μ laser light is used. Also note that the reduction in peak pressure due to electron decoupling is catastrophic. The TN energy production was less than 1 joule.

Figure 4 shows the suprathermal electron spectra at 29.94 ns (during severe shell preheating) in the corona and in the core. The electrons have energies extending beyond 50 keV, in contrast to the 10 keV electrons obtained in the LASL calculations. Simple hand calculations with the flux limiter and

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5Core-Corona Decoupling, Kidder and Zink: Nuclear Fusion 22 (1972) 325.

6The inverse bremsstrahlung electron spectrum \(v^2 e^{-\frac{mv^2}{2/kT}}\) is somewhat softer than Maxwellian \(v^2 e^{-\frac{mv^2}{2/kT}}\).
electron range equations show that such electrons will be generated, will
decouple from the thermal electrons, and will disastrously preheat the
imploding shell.

It should be noted in summary that the most optimistic electron
spectrum was assumed in this study. With more realistic electron spectra
the results would have been more disastrous. Further these results do not
depend on the differences between flux limited diffusion and Monte Carlo
electron energy transport (see previous article). Hopefully, pellets can
be found which will show more promise for CO$_2$ lasers in fusion/implosion
applications.
Figure Captions

Fig. 1. Initial Pellet Configuration - Radius given in microns. Mass given in μg. Initial shell density is 0.21 gm-cm$^{-3}$.

Fig. 2. Spatial distribution of electron temperature (keV) given as function of pellet radius (μ).

Fig. 3. Comparison of the effect of electron decoupling and preheat on the adiabat of a typical zone in compressed core of pellet. Compression is relative to $p_0 = 0.21$ gm-cm$^{-3}$. Pressure is given in Mb.

Fig. 4. Number density of electrons per unit energy interval (cm$^{-3}$ keV$^{-1}$) as a function of electron energy (keV) at $t = 29.94$ ns. The solid dots represent the distribution near the critical radius. The circles represent the distribution in a typical zone in the core of the pellet.