CLM - P 488

CLM - P 488

UKAEA

Preprint

MULTIKILOJOULE CO_2 LASER HEATING OF POLYTHENE PELLETS

A C WALKER
M W McGEOCH
T STAMATAKIS
S WARD
B L WILLIS
I J SPALDING

CULHAM LABORATORY
Abingdon Oxfordshire

1977

CLM-P 488

MULTIKILOJOULE CO_2 LASER HEATING OF POLYTHENE PELLETS

A.C. Walker, M.W. McGeoch, T. Stamatakis, S. Ward, B.L. Willis
and I.J. Spalding

Euratom-UKAEA Fusion Association, Culham Laboratory,
Abingdon, OX14 3DB, United Kingdom.

ABSTRACT

A multikilojoule CO_2 laser ('TROJAN') has been used to heat $\frac{1}{2}$-1 mm polyethylene cubes at incident intensities $\lesssim 4 \times 10^{12}$ Wcm^{-2}, in preliminary assessments for a laser plasma stellarator-filling experiment. Measurements of transmission through the resulting laser-plasma, and of refraction and back-reflection, indicate energy losses of $\lesssim$ 1, 10 and 5% respectively. These and other measurements will be discussed.

To be presented at VIII European Conference on Controlled Fusion and Plasma Physics, Prague, September 1977.

May, 1977.

1. INTRODUCTION

Ohmic-heating typically generates a plasma having an energy content of ~ 300J in CLEO Stellarator.(1) This paper examines the efficiency with which multikilojoule CO_2 lasers may be used to create laser-plasmas, as an alternative means of filling CLEO and other toroidal traps.(2) Earlier measurements of reflection from plane carbon targets(3) have indicated that back-reflection can be small, since absorption is significantly stronger than that attributable to inverse-bremmstrahlung alone;(4,5) the present work extends such observations by investigating transmission and refraction losses when finite targets are irradiated. It is hoped to use free-falling cryogenic deuterium targets(6) for this cooperative Euratom programme, but for these preliminary assessments the targets were (suspended) polythene cubes.

2. EXPERIMENTAL TECHNIQUE

The experimental arrangement is illustrated in Fig.1. The electrical characteristics of the electron beam preionized laser ('TROJAN') have been described previously.(5) For the present experiments the system was filled with gas at one standard atmosphere, with a $He:N_2:CO_2$ ratio of 0:1:2; its active volume was ~ 180 cm x 20 cm x 25 cm. An unstable confocal optical resonator having a magnification of 2.8 was used to ensure low-order transverse mode, gain-switched, output pulses. The initial spike typically had a peak power of $\gtrsim$ 30 GW and exhibited mode beating; its envelope had a duration of 50 ns (FWHM) and a tail lasting some 2 μs. The energy contained in this tail could be conveniently controlled by adjusting the duration of the electron-gun pulse; Fig.2 illustrates typical pulse shapes generated for the present experiments. The incident power and energy were monitored by the photon-drag (P1) and large area pyroelectric (E1) detectors illustrated in Fig.1; similarly P2 and E2 measured the power and energy back-reflected from the target. The effective (17 x 20 cm^2) cross section of the laser beam was focused by a 4.5m focal length spherical mirror on to the target; the focal spot size, determined by a grating technique,(7) was 750 μm (FWHM). The polythene targets were hand cut from sheet, and stuck with a minimum of epoxy resin to 10 μm diameter glass fibres supported on a micromanipulator within the target chamber at a vacuum pressure of 10^{-4}-10^{-5} torr.

3. EXPERIMENTAL RESULTS

Energy balance measurements have been made in which 0.6 - 1.6 kJ laser pulses, of duration 50 ns to 2 μs respectively (cf Fig.2), have been focused centrally on to both 1 mm and $\frac{1}{2}$ mm polythene cubes. These have given reproducible results showing, for all cases, high coupling of the laser energy into the pellet plasma.

Detector E2, sampling light directed back through the focusing optics with an effective aperture of f/17, indicated $\lesssim$ 5% direct energy reflection. A cone calorimeter, E3, placed behind the target and matched in size to the beam diameter gave a response typically < 8% of that recorded with no pellet in position. Such a device, however, considerably underestimates the magnitude of high energy (unattenuated) pulses, because of plasma formation at its entrance aperture. To investigate further, calibrated film was placed behind the pellet to give a spatial measure of the energy density of both transmitted <u>and</u> refracted CO_2 laser radiation. (The calibration was obtained by directing various known intensities of 10 μm radiation on to the film, in vacuum, and observing the colour of the resulting burn.) Fig.3 illustrates typical energy density contours, derived in this way, for CO_2 radiation transmitted and refracted through the plasma. It indicates that the direct transmission is < 1% of the incident energy, but that refraction, confined to a cone of (full) angle $\lesssim 60^{\circ}$ contributes the major energy loss, of $\lesssim$ 10%. Film placed at other positions within the target chamber gave no detectable response except when close to the laser beam direction, indicating that additional <u>back</u>-scattered light not reaching the focusing optics amounted to no more than 1% of the incident energy.

Detector P2, sampling the reflected intensity, showed enhanced back-reflection of the long μs tail of the pulse, relative to the intense (50 ns) initial spike (Fig.4).

4. CONCLUSION

These energy balance measurements demonstrate that small, submillimetre,

$(CH_2)_n$ targets can be efficiently heated using (relatively slow) kilojoule CO_2 laser pulses. Measurements of total charge, using ion probes, etc., are in hand to establish whether pre-pulses of the type discussed in ~ 100J Nd laser heating experiments(6,8) will be necessary to ensure full ionization in the present higher energy, microsecond duration experiments. (A highly simplified model suggests that this practical complication may be avoided,(5) or perhaps restricted to the use of only a 10.6 μm prepulse.(9))

REFERENCES

1. ATKINSON, D.W. ET AL - 'Plasma Physics and Controlled Nuclear Fusion Research 1976' Nucl.Fusion Suppl.1977, IAEA-CN-35/D1.
2. Culham Study Group on Heating and Injection (1970); and SPALDING, I.J. - Kvantovaya Elektron 4, 40 (1972)
3. DONALDSON, T.P. ET AL - Phys.Rev.Lett.37, 1348 (1976)
4. DONALDSON, T.P., SPALDING, I.J. - Phys.Rev.Lett.36, 467 (1976)
5. SPALDING I.J. ET AL - 'Plasma Physics and Controlled Nuclear Fusion Research 1976', Nucl.Fusion Suppl.1977, IAEA-CN-35/G3-3.
6. BAUMHACKER, H. ET AL - Appl.Phys.Lett.30, 461 (1977)
7. MARQUET, L.C. - Appl.Opt.10, 960 (1971)
8. GREIG, J.R., PECHACEK, R.E. - Appl.Phys.Lett.29, 798 (1976) and J.Appl. Phys.48, 596 (1977)
9. cf DONALDSON, T.P. ET AL - Culham preprint CLM-P480 (1977)

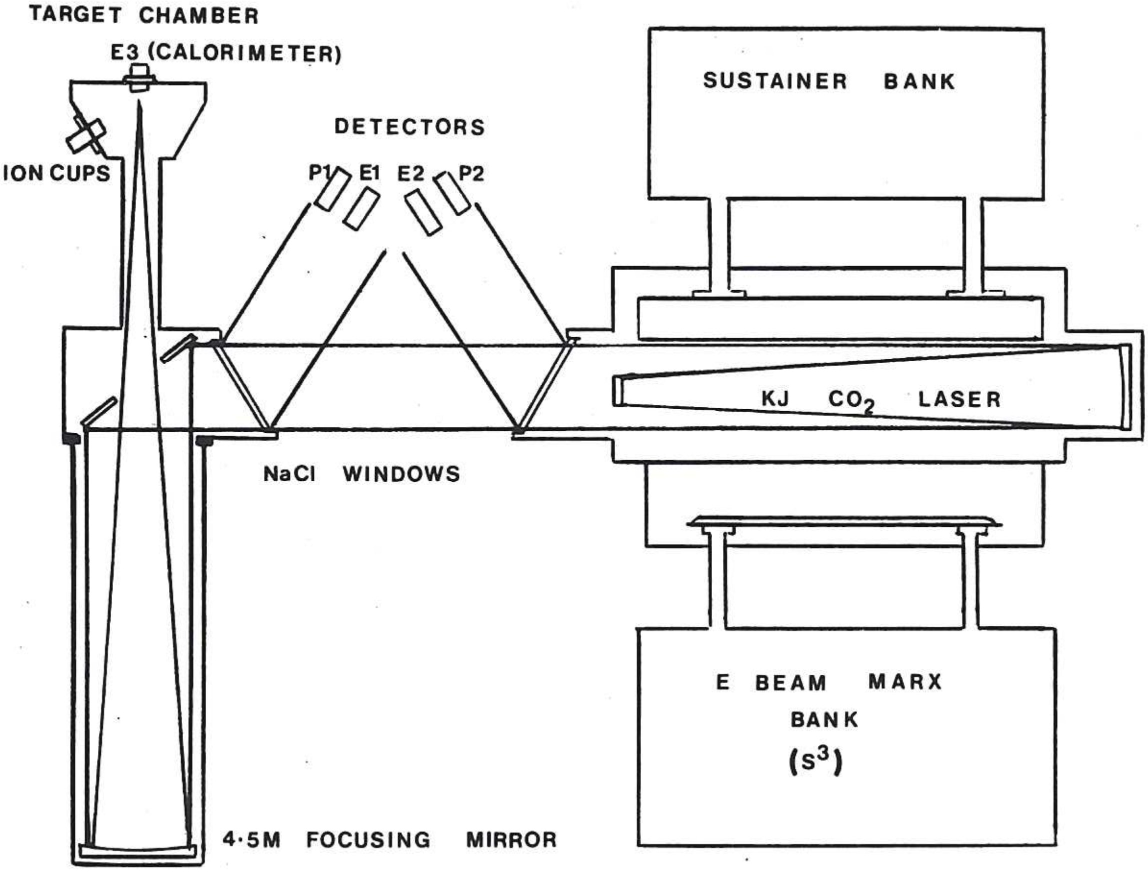

FIGURE 1 Plan-view of experimental arrangement

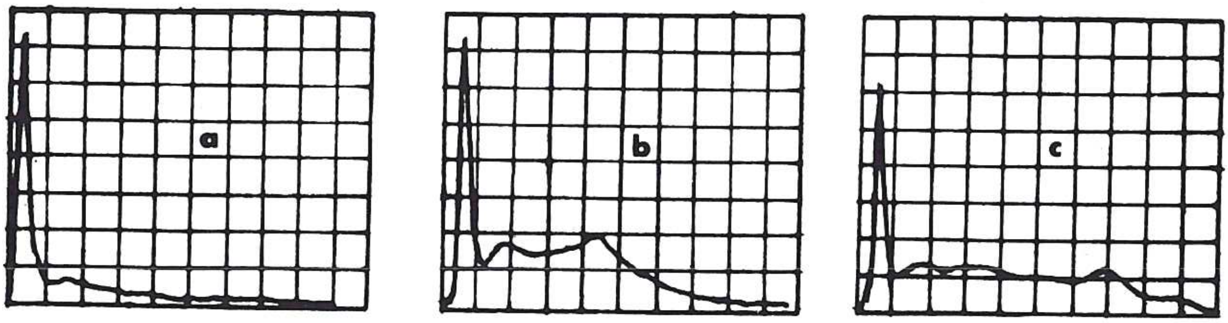

FIGURE 2 Time variation of 'TROJAN' output power, using an electron beam of (a) 0.8, (b) 1.6 and (c) 2 μs duration. (Vertical: ~ 3 GW/div., horizontal: 200 ns/div.)

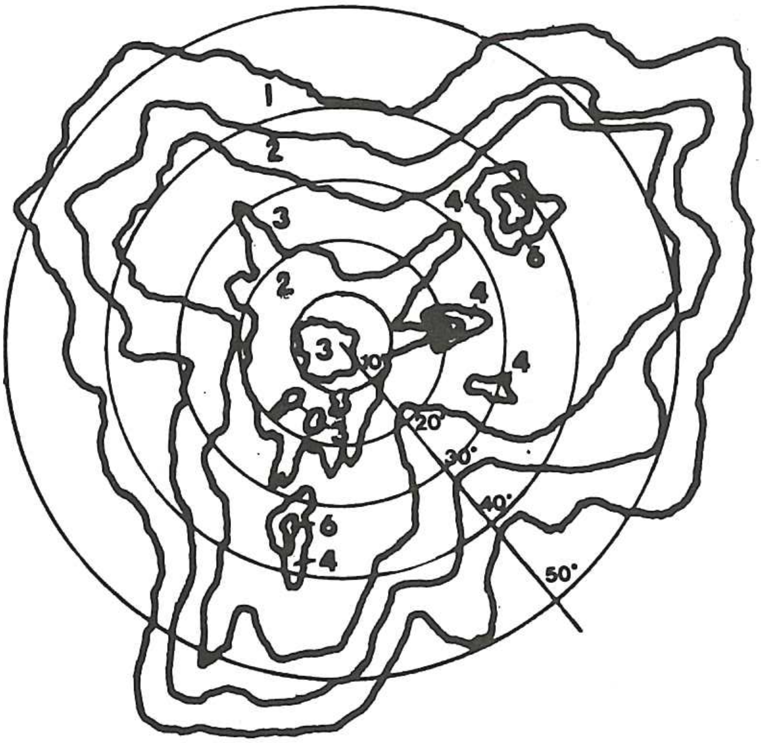

FIGURE 3 Distribution of transmitted and refracted laser radiation on a plane 7.5 cm behind a $\frac{1}{2}$ mm polythene cube irradiated by a 1.5 kJ (2 μs) pulse. Numbers indicate average energy density in joules/cm^2 between contours. Circles show cone (full) angles relative to pellet position.

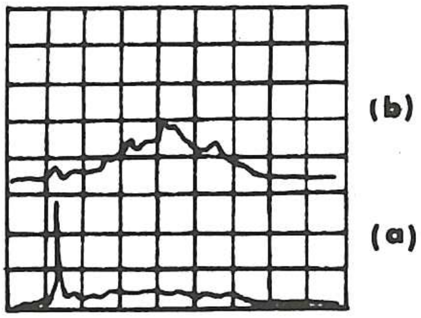

FIGURE 4 Incident (a) and back-reflected (b) pulse shapes for experiment of Fig.3 (500 ns/div).