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ON HYDRODYNAMIC ENERGY TRANSFER BETWEEN TWO FOILS OF A LASER IRRADIATED DOUBLE FOIL TARGET AT 0,35 M WAVELENGTH

F. MUCCHIELLI, D. JURASZEK, B. MEYER, J.N. RICHET, G. THIELL, J.W. WEILL
CEA Centre de Limeil/Valenton, 94- Villeneuve-Saint-Georges (France)

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THIS POSTER PRESENTS RESULTS ON THE HYDRODYNAMICS OF THE ACCELERATED LAYER OF A PLANAR TARGET USING THE DOUBLE-FOIL TECHNIQUE.

SUCH A TECHNIQUE, FIRST STUDIED AS A PROMISING DESIGN IN THE CONTEXT OF SPHERICAL TARGET IMPLOSION, IS ALSO A VALUABLE DIAGNOSTIC METHOD IN HYDRODYNAMICS EXPERIMENTS (1-2).

DOUBLE-FOIL TARGETS HAVE BEEN IRRADIATED WITH 0.35 μM LASER WAVELENGTH AT IRRADIANCE OF 2×10^{14} W CM^{-2}. THE HYDRODYNAMIC BEHAVIOUR HAS BEEN INVESTIGATED BY MEANS OF TIME AND SPACE-RESOLVED X-RAY BACKLIGHTING.

COMPARISON WITH A 1D LAGRANGIAN CODE SHOWS DISCREPANCIES BETWEEN MEASURED AND CALCULATED VELOCITIES ATTRIBUTED TO 2D EFFECTS.

FIRST RESULTS OBTAINED WITH A 2D CODE ARE PRESENTED FOR A SINGLE THIN TARGET AND FOR A DOUBLE-FOIL TARGET WHEN THE FOIL SEPARATION IS EQUAL TO 40 μM.

WE INFER THAT THE HYDRODYNAMIC LATERAL EXPANSION OF THE ACCELERATED LAYER IS THE DOMINANT PROCESS OF ENERGY LOSS.

(1) B. MEYER, C. MORIN AND G. THIELL
J. APPL. PHYS. 53 (1982) 2947

(2) G. THIELL, B. MEYER, P. AUSSAGE AND X. FORTIN
OPTICS COMM. 46 (1983) 305

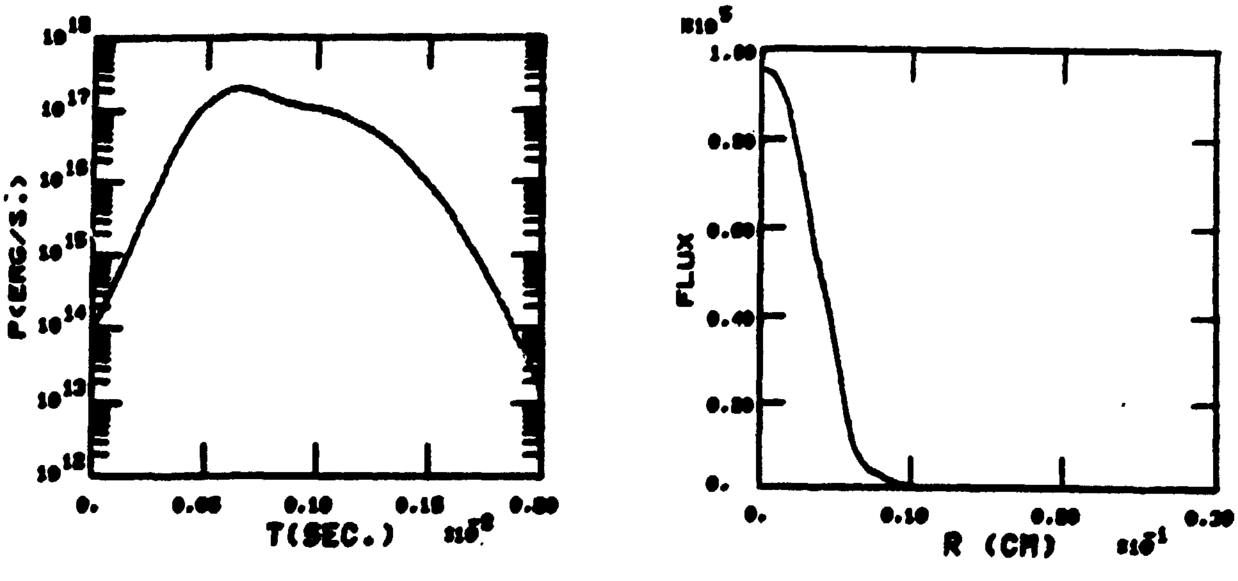
EXPERIMENTAL AND NUMERICAL CONDITIONS

LASER WAVELENGTH : 0.35 μm
PULSE DURATION : 850 ps FWHM
MAXIMUM IRRADIANCE : 2×10^{14} W cm^{-2}
ENERGY ON TARGET : 10 J
TARGET MATERIAL : ALUMINUM
TARGET STRUCTURE : PLANE DOUBLE-FOIL
IRRADIATED FOIL : 3 μm
IMPACT FOIL : 1.5 μm
FOIL SEPARATION : 40 AND 110 μm
DIAGNOSTIC METHOD : TIME AND SPACE-RESOLVED X-RAY BACKLIGHTING

THE EXPERIMENTAL DATA ARE COMPARED TO THE NUMERICAL RESULTS FROM THE FCI 1 CODE I.E., THE TARGET VELOCITY V ALONG THE LASER AXIS AND THE HYDRODYNAMIC EFFICIENCY η_H OF THE ACCELERATED LAYERS.

NUMERICAL SIMULATIONS OBTAINED WITH THE FCI 2 CODE ALLOW TO DEDUCE THE DIAMETER OF THE ACCELERATED PART OF THE IRRADIATED TARGET.

IN BOTH 1D AND 2D SIMULATIONS, THE ACTUAL TEMPORAL IRRADIANCE HISTORY IS FITTED WITH A DOUBLE-GAUSSIAN PULSE. IN 2D SIMULATIONS, THE LASER IRRADIANCE PROFILE MEASURED IN THE FOCAL SPOT (80 μM FWHM) IS INTRODUCED IN THE CODE AFTER SMOOTHING OF HOT SPOTS.



DOUBLE-GAUSSIAN PULSE

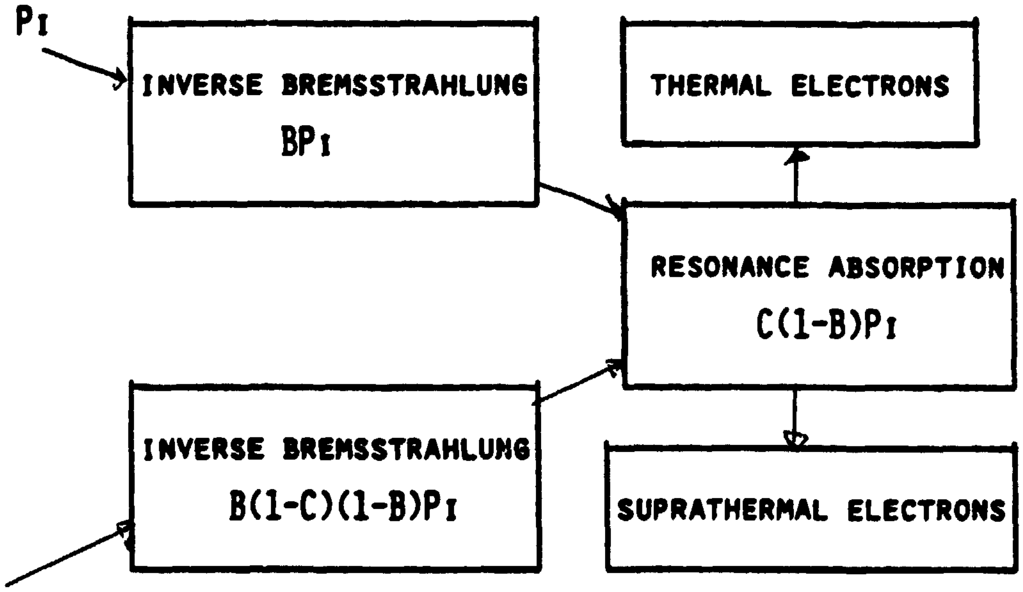
IRRADIANCE PROFILE

INCIDENT LASER BEAM

FCI 1 CODE

THE FCI 1 CODE IS A ONE-DIMENSIONAL LAGRANGIAN CODE BASED ON A ONE-FLUID, TWO-TEMPERATURE MODEL. SUPRATHERMAL ELECTRON TRANSPORT IS TREATED BY A FLUX-LIMITED MULTIGROUP DIFFUSION METHOD WHICH ENSURES QUASI-NEUTRALITY AT ALL TIMES AND WHERE SLOWING-DOWN IS BROUGHT ABOUT BY COULOMB COLLISIONS WITH THERMAL ELECTRONS. RADIATIVE TRANSFER IS TAKEN INTO ACCOUNT WITH THE HELP OF A MULTIGROUP-GRAY METHOD.

IN THE SIMULATIONS PRESENTED HERE, THE TREATMENT OF THE ABSORPTION OF THE LASER ENERGY IS REPRESENTED BY THE DIAGRAM :



$P_R = (1-C)(1-B)^2 P_I$

FOR ALUMINUM TARGETS AND IRRADIANCES LOWER THAN 2×10^{14} W cm^{-2}, THE ENERGY FRACTION ASSIGNED TO SUPRATHERMAL ELECTRONS IS EQUAL TO ZERO. FURTHERMORE, WE OBTAIN $B \approx 98$ %, $C(1-B) \approx 0$, $P_R \approx 0$.

THE THERMAL FLUX LIMITER f EQUALS 0.05, BUT THE DEPENDANCE OF FINAL VELOCITY ON f BETWEEN 0.15 AND 0.01 HAS BEEN CHECKED TO BE VERY MODEST.

FCI 2 CODE

THE FCI 2 CODE IS A BI-DIMENSIONAL LAGRANGIAN CODE WITH CYLINDRICAL REVOLUTION SYMMETRY.

IN THE SIMULATIONS PRESENTED HERE, THE INCIDENT LASER BEAM IS PARALLEL TO THE SYMMETRY AXIS.

THE ABSORPTION OF THE LASER ENERGY IS TREATED BY MEANS OF A RAY-TRACING METHOD WITH A MAXIMUM OF 100 LASER BEAMLETS.

A FRACTION OF THE INCIDENT POWER IS ABSORBED BY INVERSE BREMSSTRAHLUNG ALONG THE LASER BEAMS AND A FRACTION OF THE POWER REACHING THE CUT-OFF DENSITY IS TAKEN TO SIMULATE RESONANT ABSORPTION ONLY WITH THERMAL ELECTRONS.

f IS EQUAL TO 0.05.

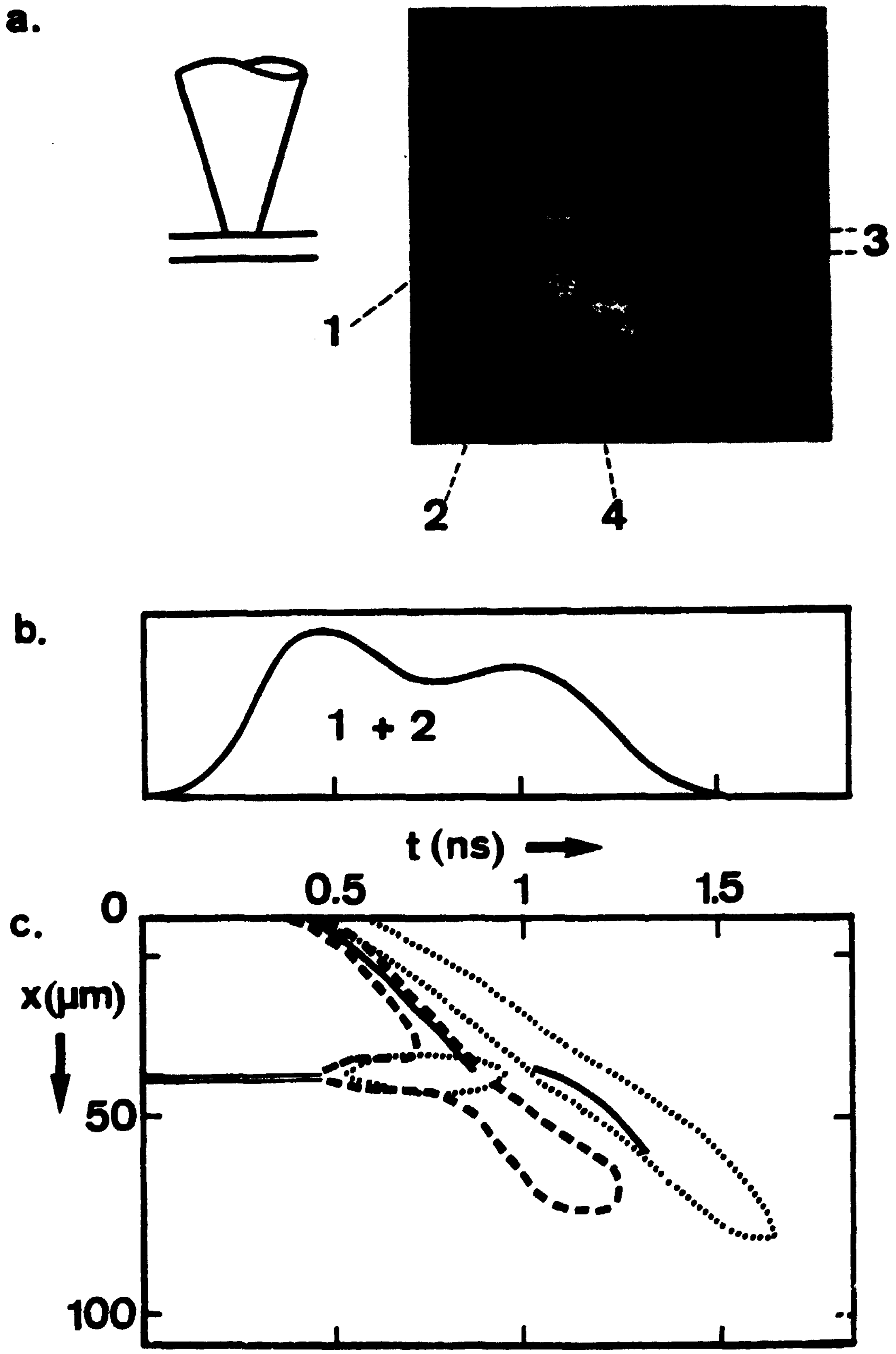

a.
3
1
2
4
b.
1 + 2
t (ns)
c.
0
0.5
1
1.5
x(μm)
50
100

FIG. 1. EXPERIMENTAL AND 1D NUMERICAL RESULTS FOR A 40 μm FOIL SEPARATION

A) SPACE-TIME RESOLVED X-RAY SHADOWGRAM OF AN AL DOUBLE-FOIL. THE THICKNESSES OF THE IRRADIATED FOIL AND THE IMPACT FOIL ARE 3 AND 1.5 μm RESPECTIVELY. THE FOIL SEPARATION IS 40 μm AND NEARLY EQUAL TO THE FOCAL SPOT RADIUS.

(1) : TARGET PLASMA EMISSION ;
(2) : EMISSION FROM BACKLIGTHER SOURCE ;
(3) : INITIAL FOIL POSITIONS ;
(4) : TIMING MARK.

THE LASER IS INCIDENT FROM THE TOP.

B)

(1) : TEMPORAL LASER PROFILE ;
(2) : X-RAY FLASH PROFILE.
INSET : EXPERIMENTAL PROFILE.

C) SPACE-TIME DIAGRAM OF THE ABOVE DOUBLE-FOIL, FOR THE $10^{-1}\rho_0$ DENSITY. SOLID LINE REPRESENTS THE EXPERIMENTAL RESULTS, DASHED AND DOTTED LINES THE NUMERICAL 1D CALCULATIONS FOR LASER IRRADIANCE OF 2×10^{14} AND 8×10^{13} W.cm^{-2} RESPECTIVELY.

IN FIG. 1A, IT IS SEEN THAT THE DENSE PART OF THE ACCELERATED FOIL MOVES ON ABOUT 450 PS AFTER THE BEGINNING OF THE LASER PULSE AND REACHES A VELOCITY V = $(1+0.2)\times10^{7}$ CM/S. THE COLLISION WITH THE IMPACT FOIL OCCURS 400 PS LATER. THE FINAL TARGET VELOCITY REACHED AT 1 NS IS NEAR V OR LOWER THAN V.

THE KINETIC ENERGY TRANSFER GIVEN BY THE CODE AT THIS TIME IS 7 % OF THE LASER DEPOSITED ENERGY.

THE NUMERICAL CALCULATION ASSUMING 2×10^{14} $W.cm^{-2}$ ABSORBED IRRADIANCE PREDICTS A MAXIMUM VELOCITY OF THE IMPACT FOIL ($10^{-1}\rho_0$ DENSITY) OF 1.5×10^{7} CM/S AT 1 NS, WHICH DISAGREES WITH THE MEASUREMENTS. WHEN THE LASER IRRADIANCE IS REDUCED TO 8×10^{13} $W.cm^{-2}$, WE GET A BETTER FIT OF THE IMPACT FOIL VELOCITY AND TIMING (FIG. 1c). THIS RESULT GIVES AN IDEA OF THE IMPORTANCE OF THE 2D EFFECTS BETWEEN BOTH FOILS : ONLY ABOUT 40 % OF THE ENERGY TRANSFER WOULD BE USEFUL TO ACCELERATE THE IMPACT FOIL ; IN OTHER WORDS, THE IMPACT SURFACE WOULD BECOME 2.5 TIMES LARGER THAN THE FOCAL SPOT SURFACE FOR 40 μm FOIL SEPARATION. AT 2×10^{14} $W.cm^{-2}$, THE EXPANSION OF THE SECOND FOIL BEFORE THE IMPACT (FIG. 1c) IS DUE TO X-RAY PREHEATING.

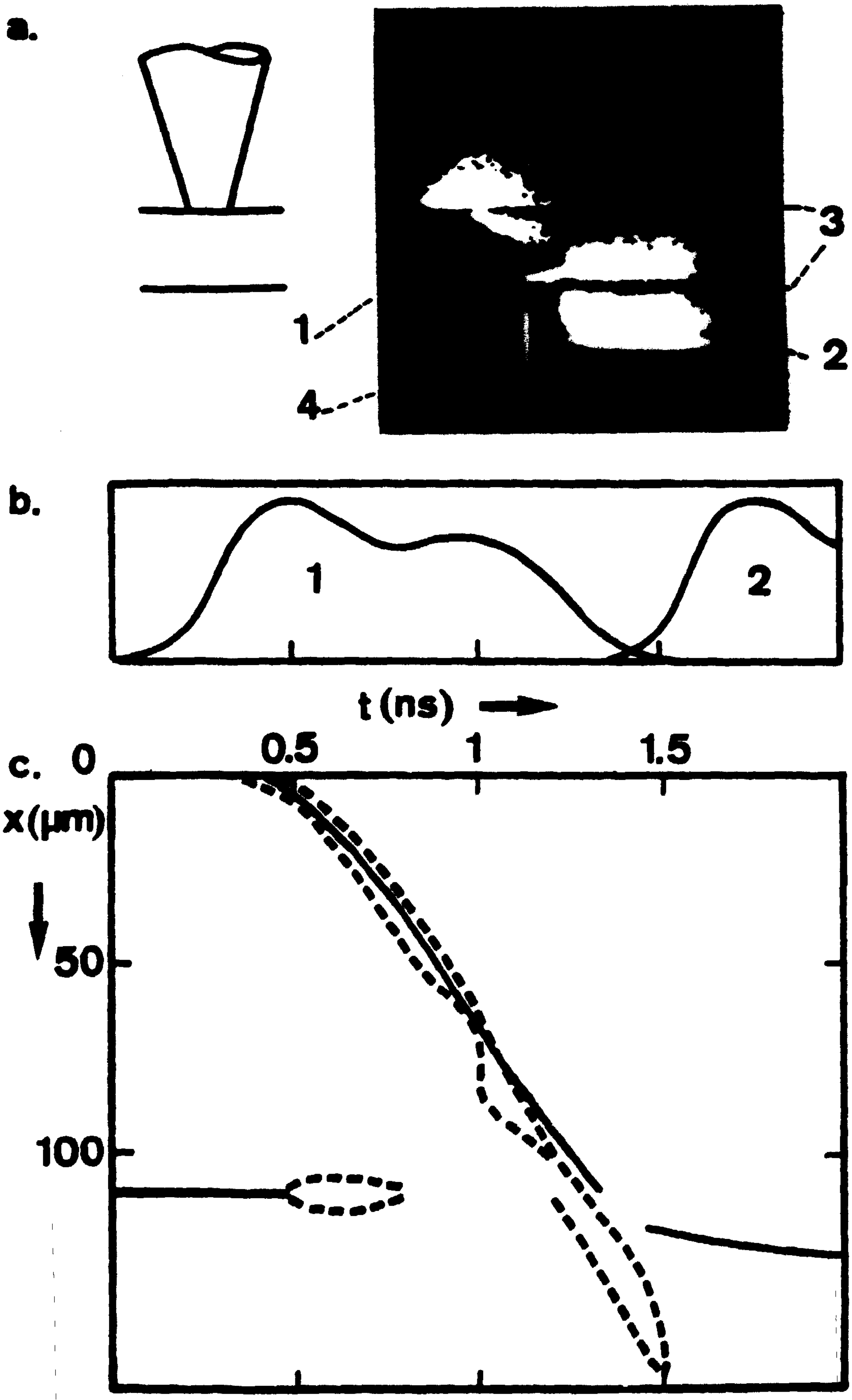


Fig . 2

FIG. 2. EXPERIMENTAL AND 1D NUMERICAL RESULTS FOR 110 μM FOIL SEPARATION

A) SPACE-TIME RESOLVED X-RAY SHADOWGRAM OF AN AL DOUBLE-FOIL. THE THICKNESSES OF THE IRRADIATED FOIL AND THE IMPACT FOIL ARE 3 AND 1.5 μM RESPECTIVELY. THE FOIL SEPARATION IS 110 μM. SEE ALSO FIGURE CAPTION 1A.

B) THE X-RAY FLASH (2) OCCURS 1.5 NS AFTER THE BEGINNING OF THE LASER PULSE (1).

C) SPACE-TIME DIAGRAM OF THE ABOVE DOUBLE-FOIL, FOR THE 10^{-1} ρ_0 DENSITY. SOLID LINE REPRESENTS THE EXPERIMENTAL RESULTS AND DASHED LINE THE NUMERICAL DATA FOR AN IRRADIANCE OF 2×10^{14} W.CM^{-2}.

WHEN THE FOIL SEPARATION IS 110 μm, ABOUT THREE TIMES HIGHER THAN THE FOCAL SPOT RADIUS, THE IMPACT TIME IS 1.25 ns AFTER THE BEGINNING OF THE LASER PULSE, IN ACCORDANCE WITH THE EXPERIMENT.

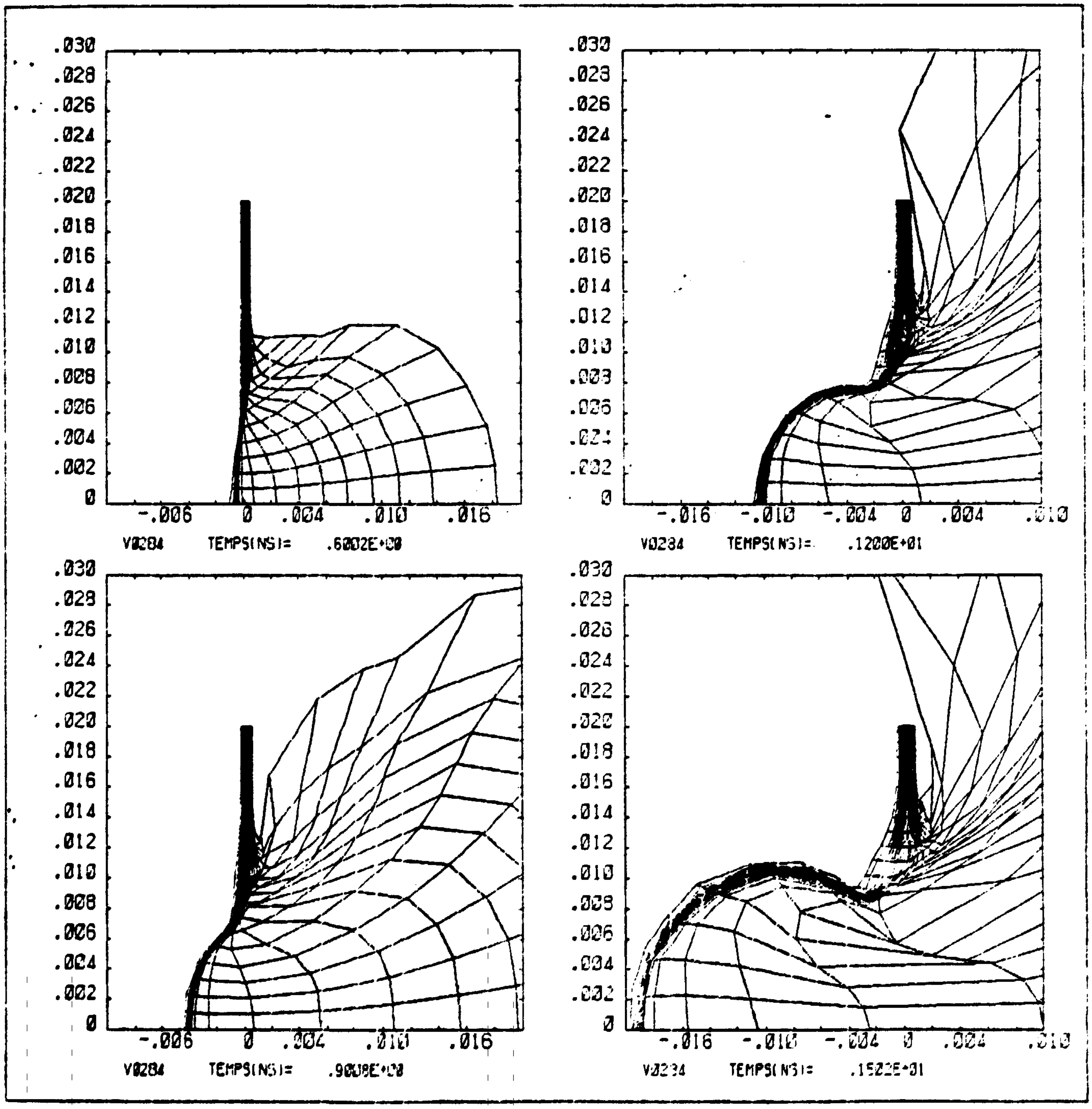
TO EXPLAIN THE OBSERVED X-RAY EMISSION ON THE IMPACT FOIL DURING 300 ps WE HAVE TO TAKE INTO ACCOUNT PLASMA JETS ON THE REAR SIDE OF THE IRRADIATED FOIL AND, POSSIBLY, SELF-FOCUSING, THERMAL INSTABILITIES AND LOCAL BURN-THROUGH THAT PREHEAT THE IMPACT FOIL.

WITH A 2×10^{14} W cm^{-2} LASER IRRADIANCE, THE SIMULATION GIVES A REARWARD VELOCITY OF THE IMPACT FOIL EQUAL TO 1.5 10^{7} cm.s^{-1}, IN QUITE DISAGREEMENT WITH THE EXPERIMENTAL RESULT.

TO FIT THE 2×10^{6} cm.s^{-1} MEASURED VELOCITY, A LASER IRRADIANCE OF ABOUT 2×10^{13} W.cm^{-2} WOULD BE NECESSARY.

THIS SHOWS AGAIN THAT 2D EFFECTS BECOME VERY STRONG IN THESE EXPERIMENTS.

MUCCHIEL   I0500   16/10/85   11.52.11.



NUMERICAL 2D RESULTS FOR A SINGLE FOIL (3 μM AL)

FIGURES 3 TO 6 SHOW THE HYDRODYNAMIC EVOLUTION OF THE FOIL VERSUS TIME.*

AT 600 PS, THE DENSE PART OF THE ACCELERATED LAYER MOVES ON, IN GOOD AGREEMENT WITH THE EXPERIMENT.

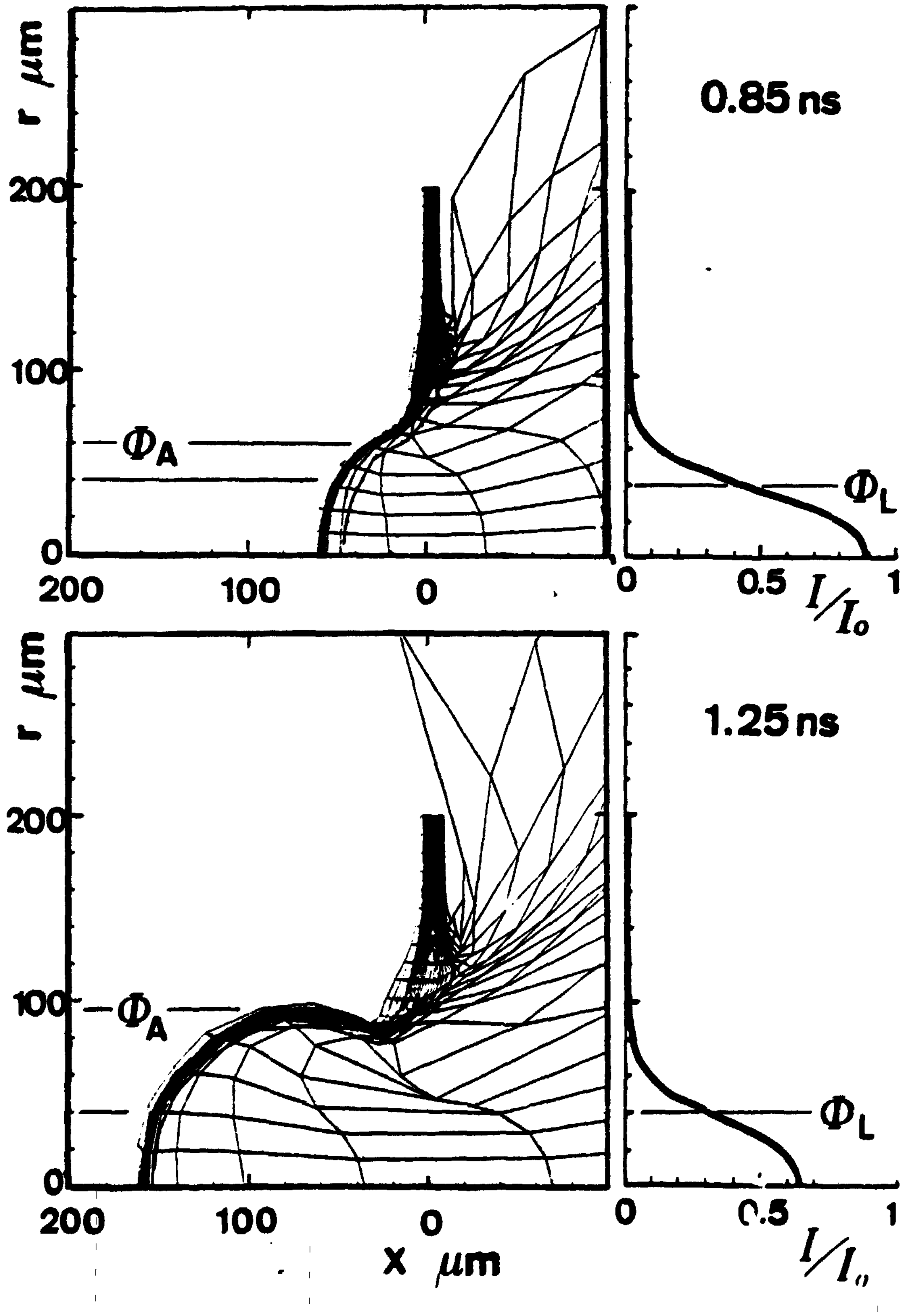
THE LATERAL EXPANSION OF THE ACCELERATED PART OF THE TARGET IS CLEARLY SEEN IN THESE FIGURES.

THE RESULTS SHOW THAT THIS EXPANSION IS NOT A THERMAL EXPANSION BUT IT IS DUE TO THE 2D STRUCTURE OF THE ABLATIVE FLOW.

NOTE THAT AT 1.5 NS (FIG. 6), IN SPITE OF AN APPARENT TIGHTENING OF THE MESHES, THE PLASMA BECOMES LOCALLY UNDERDENSE ON THE EDGES OF THE ACCELERATED LAYER. THE RESULT IS IN ACCORDANCE WITH THE EDGE BURN-THROUGH OBSERVED IN REF.3 AND CAN EXPLAIN THE OBSERVED X-RAY EMISSION OF THE IMPACT FOIL.

(3) F. COTTET, J.P. ROMAIN, R. FABBRO AND B. FARAL
J. APPL. PHYS. 55 (1984) 4125 ;
J. APPL. PHYS. 56 (1984) 3204

* NOTE THAT THE BEGINNING OF THE COMPUTATION IS 150 PS EARLIER THAN THE CORRESPONDING TIME IN 1D SIMULATIONS.


r μm
200
100
0
Φ_A
Φ_L
0.85 ns
200
100
0
0
0.5
1
I/I_o
r μm
200
100
0
Φ_A
Φ_L
1.25 ns
200
100
0
0
0.5
1
x μm
I/I_o

THE LASER IRRADIANCE PROFILE I IS NEARLY GAUSSIAN (ϕ_L = 80 μM FWHM). IF WE ASSUME A VARIATION OF THE REAR VELOCITY SUCH AS $v \, \alpha \, I^{2/3}$ (I.E. WITHOUT 2D EFFECTS) THE RADIAL DIMENSION OF THE ACCELERATED LAYER ϕ_A WOULD BE APPROXIMATELY 96 μM. IN FACT, IT IS SEEN ON FIGURE 7 THAT AT 850 PS WHICH IS THE IMPACT TIME FOR A 40 μM FOIL SEPARATION, $\phi_A \gtrsim 120$ μM $\longrightarrow \phi_A/\phi_L = 1.5$, SO THAT THE SURFACE OF THE ACCELERATED LAYER IS 2.3 TIMES LARGER THAN THE FOCAL SPOT SURFACE CORRESPONDING TO THE FULL DIAMETER AT HALF MAXIMUM.

AT 1,25 NS CORRESPONDING TO A 110 μM FOIL SEPARATION, THE SAME CALCULATION LEADS TO AN IMPACT SURFACE ABOUT 6 TIMES HIGHER. FINALLY, THESE RESULTS ARE IN A FAIRLY GOOD AGREEMENT WITH THE OBSERVED VELOCITIES OF IRRADIATED AND IMPACT FOILS

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MUCCHIEL     V0283                          10/05/85     012421
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            CAS  V0283  DU  10/05/85   0124 ·               PROT NO    3                 CODE FCI2
EMPHO= .T.  HYDRO = .T.      ECH = .T.     BREM = .T.     CONDI = .T.     FLIMI = .T.     CONDE = .T.     FLIME = .T.
            P LAS = UPDATE
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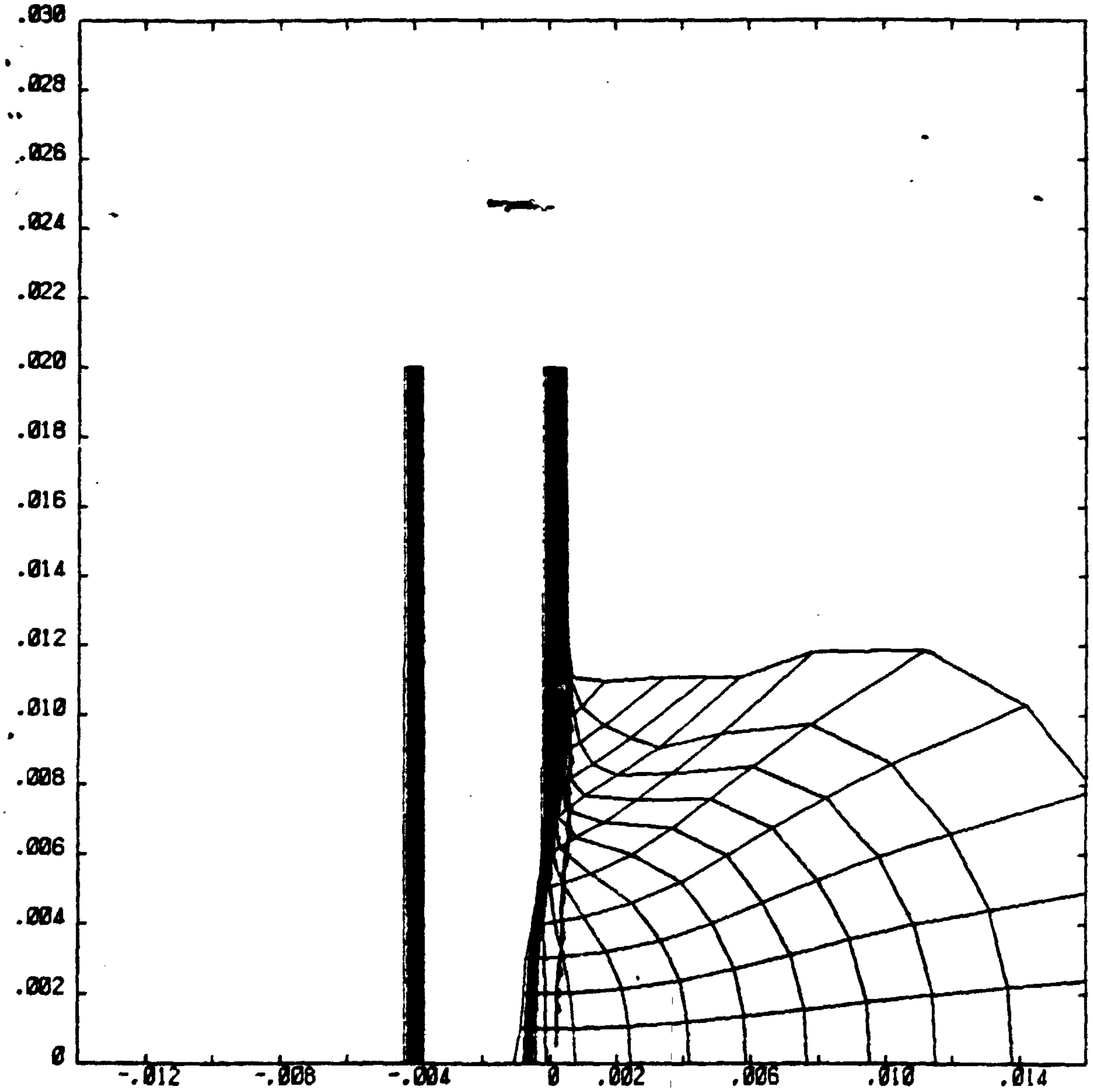

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TEMPS(PS) = 601.07          NONEUT = 0.    E+00       EL.I(JOULE) =     2.7400         P.I(WATT) = 0.1937E+11
ITER =  673             TIMAX(KEV) =  0.516400        E.ABS(JOULE)= 0.2735E+01         P.ABS(WATT) = 0.1932E+11
DT= 0.100E-11           TEMAX(KEV) =  1.432431                                         RO MAX  =     7.6173
```

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MUCCHIEL     V0283                    10/29/85     231140
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          CAS  V0283  DU  10/29/85    2311            PROT NO   30             CODE FCI2
MEMPHO= .T.  HYDRO = .T.     ECH = .T.     BREM = .T.     CONDI = .T.     FLIMI = .T.     CONDE = .T.     FLIME = .T.
          P LAS = UPDATE
```

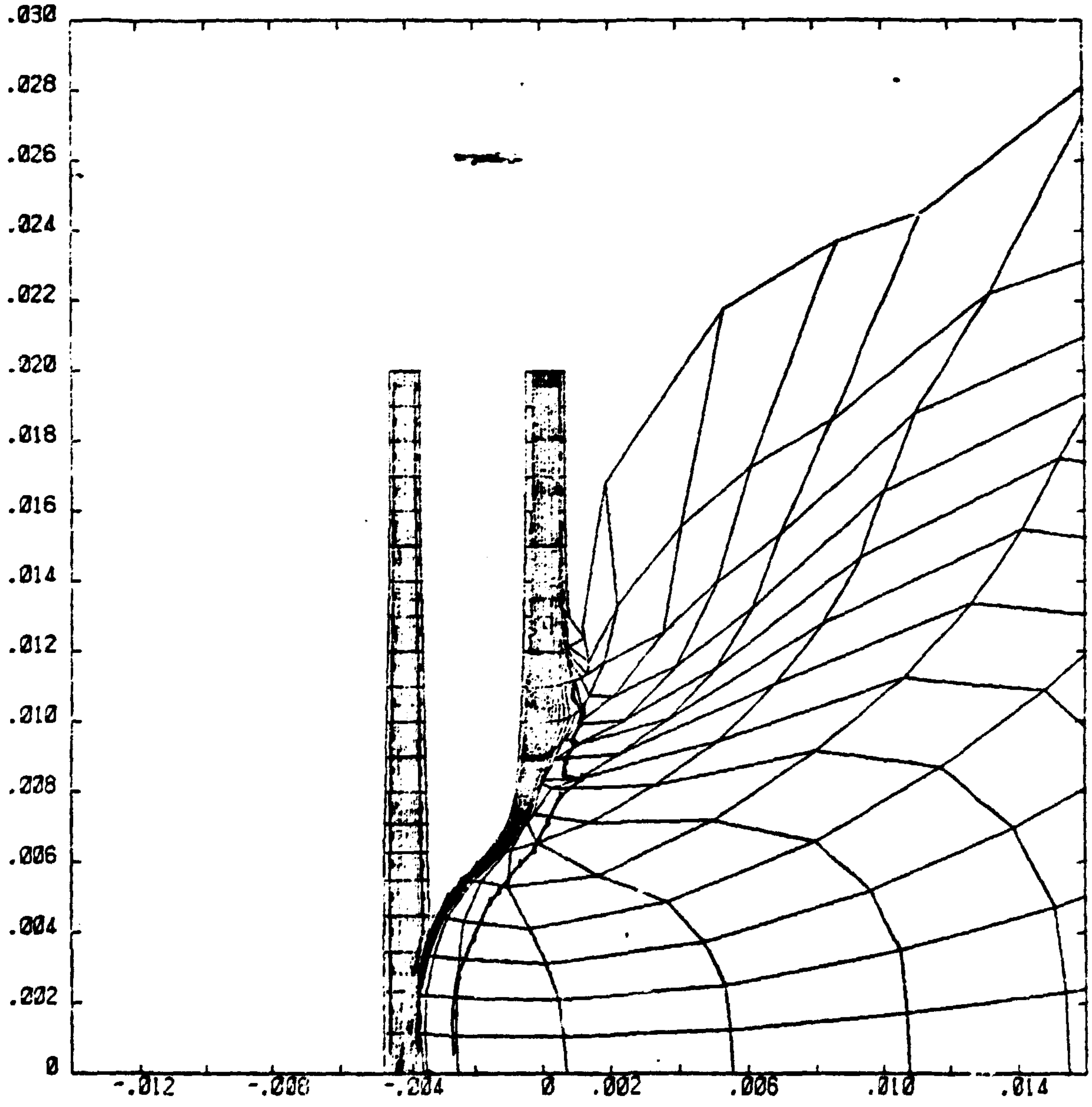

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TEMPS(PS) = 920.02          NBNEUT = 0.    E+00      EL.I(JOULE) =     7.7180          P.I(WATT) = 0.1179E+11
ITER = 3921               TIMAX(KEV) =  0.585566     E.ABS(JOULE)= 0.7708E+01       P.ABS(WATT) = 0.1179E+11
DT= 0.190E-13             TEMAX(KEV) =  1.295395                                    RO MAX  =     6.8953
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NUMERICAL 2D RESULTS FOR A DOUBLE FOIL

FIGURES 8 AND 9 SHOW THE FIRST NUMERICAL 2D RESULTS OBTAINED WITH A DOUBLE FOIL WHEN THE FOIL SEPARATION IS EQUAL TO 40 μm.

THESE RESULTS ARE IN GOOD AGREEMENT WITH THE RESULTS OBTAINED FOR A SINGLE FOIL.

AT 600 ps, THE DENSE PART OF THE ACCELERATED LAYER MOVES ON. THE COLLISION WITH THE IMPACT FOIL OCCURS AT 900 ps. AT THIS TIME, THE AXIAL VELOCITY v_z OF THE DENSE PART OF THE ACCELERATED LAYER IS EQUAL TO 10^7 cm/s, EXCEPT ON THE LASER AXIS, WHERE HIGHER VELOCITY IS OBSERVED. THIS PHENOMENA SEEMS TO BE IN RELATION WITH THE MESH DEFORMATION DUE TO NUMERICAL PROBLEMS. THE PRESSSURE IS APPROXIMATELY EQUAL TO 30 MBARS CLOSE TO THE LASER AXIS IN THE FIRST LAYER OF THE IMPACT FOIL.

CONCLUSIONS

2D HYDRODYNAMIC EXPANSION INFLUENCES GREATLY THE EVOLUTION OF A DOUBLE FOIL TARGET.

IF THE FOIL SEPARATION IS 40 μm FOR A 80 μm FOCAL SPOT, THE VELOCITY OF THE IMPACT FOIL REAR SURFACE CORRESPONDS TO AN IMPACT SURFACE 2,5 TIMES HIGHER THAN THE FOCAL SPOT SURFACE.

THAT MEANS THAT UP TO 60 % OF THE ENERGY TRANSFER IS USED TO ACCELERATE THE IMPACT FOIL OUTSIDE AN AREA CORRESPONDING TO THE FOCAL SPOT.

THE SINGLE FOIL 2D NUMERICAL SIMULATIONS ARE IN A FAIRLY GOOD AGREEMENT WITH THE RESULTS.

FIRST RESULTS IN DOUBLE FOIL 2D SIMULATIONS ARE OBTAINED UP TO 100 ps AFTER THE IMPACT. THE NUMERICAL PROBLEMS ON THE LASER AXIS ARE UNDER WORK.