COPY

UCRL 21167
P.O. 9301105
DDV-88-0029
Page 1

UCRL--21167

DE89 009909

2 Dimensional Analysis of a NOVETTE Laser Generated Stress-Impulse Experiment

by

Glen Dahlbacka, PhD

PLASMA RESEARCH CORPORATION

WORK PERFORMED UNDER

LLNL CONTRACT #9301105

October 13, 1988

D Division-Weapons Effects Group

Lawrence Livermore National Laboratory

Livermore, CA 94550

ABSTRACT

The NOVETTE Laser was used to irradiate aluminum disks at fluences of 100 to 20,000 J/cm^2. Besides the intrinsic interest in the coupling coefficient for .53 micron light in highly 1D (1ns) interactions, the shots were used to qualify diagnostics to be used in other tests. The coupling coefficient data has been analyzed with respect to 1D calculations by Bookless. The results indicate that the experiments generate twice the impulse calculated by a 1D model- at least at 12,000 J/cm^2.

2D calculations predict an impulse of 16.3 ktaps vs a measured 12.5 ktaps at 12,000 J/cm^2. **1D calculations predict 6.3 ktap. 46% of the 2D impulse is from plume reradiation to target surface outside the spot at times much later than the initial interaction time of 1 ns.**

The 2D calculation predicted a peak stress of 90 kbars at a depth of 1.5mm into the target. Observations using a Manganin gage were 68 kbars. The ratio of calculated to observed stress is about the same as the ratio of calculated to observed impulse. The difference in stresses may be due to a lack of material strength in the EOS for LASNEX. Alternatively, an error in the estimate of the gauge depth by as little as .2 mm can also explain the stress discrepancy as could an absorption of 75% of the incident light from that calculated. At this time, however, there is a 50% apparent uncertainty in the calculation of impulse at 10 $terawatts/cm^2$ on Aluminum when 2D effects are accounted for.

The measurements of stress were made by General Research Corporation and those of impulse by Science Applications Incorporated. The experiments were very useful as diagnostics development shots also, since they pointed out difficulties with both the stress and impulse gages fielded by GRC. The conditions of the experiment were needed and uniquely suited to this screening.

The laser coupling experiment is shown in Figure[1]. A laser beam of .53 micron wavelength, 1 ns duration and roughly 2000 joules is focussed to a spot on an aluminum target that is instrumented for stress and/or impulse. The spot diameter is parametric in translation of the focal length of the lens. Thus several intensities (or fluences) can be chosen at the same energy input. In all experiments conducted here, the blowoff during the laser interaction time is spatially small compared to the spot size. In principle, these experiments should be 1 Dimensional.

The laser spot is spatially modulated with obscuring optics that are part of the doubling system and of the beam diagnostics. This leads to a complex initial imprint on the target and, as will be seen in the calculations, a subsequent imprint on the shock wave until the shock is deeper than the diameter of the incident structure.

The LASNEX mesh used is shown in Figure [2]. The laser is incident from the right and has a hole in the center that simulates the incident light in the experiment. The spot size is 5 mm diameter and for shot #8 (Nova #15100209) the intensity was 12 terawatts/cm^2 at a fluence of 12,000 J/cm^2. This corresponds to a brightness temperature of about 100 eV and is in a region where the coupling is .9-1. dyne-s/J. This shot was chosen for analysis since the intensities were high enough to overlap the regime of inertial confinement fusion where the code has been tested extensively and where the pressure will be high enough to minimize the complications of material strength on the results.

The large initial zone shown is vacuum to allow for radiation transport to the surface outside the spot during the development of the plume. The fine zoning at the front surface is feathered to provide for resolution of blowoff during the laser shine. The zones are made slightly thicker as the front surface is passed until the zones are made constant thickness to the back surface. The Aluminum slab is 5 mm thick and 15 mm in diameter. The z axis is an axis of rotation. There are 75 zones in the z direction, and 20 zones in the r direction, with k=20 on axis and l=1 at the r plane. The stress gauge located at 1.5 mm from the front surface is shown on axis at 3.5 mm z. A gauge was also located at .5 mm from the front surface, but since no data was obtained on this shot from that gauge, its position is not shown. X-radiation was transported through multigroup diffusion.

Figure [3] shows the time evolution of the mesh to 450 ns after laser shine. Contours of pressure are plotted in units of 10^9 joules/cc (10,000 Mbar). The first frame at 180 ns shows a ring shaped shock (contour D) at about 1 mm depth with a strength of between 100 and 300 kbar. The slight mesh distortion from the ring shape of the laser is also apparent. This frame also shows radiant heating to the edge of the disk from plume re-radiation. It is this material removal that will lead to additional impulse above 1 D calculations. Figure 3b shows the ring filled in due to radial shock propogation. In addition, edge rarefaction has caused the E contour (30 kbar) to decrease in radius from 3a. These 2 Dimensional rarefactions substantially effect the predicted peak stress at these depths.

Mesh picture 3c is at the end of the calculation. It shows a tilted front contour outside the initial laser spot and a filled in center contour. Substantial blowoff is noted out to the edge of the disc. Zones are noted in tension inside the laser ring interaction region and would suggest front surface spalling if the material was not melted. Figure 3d shows the low density plume development at 450 ns. The flow is highly collimated.

Figure [4] shows the maximum electron, ion and radiation temperature as a function of time. The electron temperature climbs to 1 keV during the laser shine reflecting the high temperatures in the low density blowoff near the laser critical density of .004 g/cc. The ion temperature lags the electrons due to the coupling times and the radiation temperature climbs to 50 eV, below the laser brightness temperature of 100 eV -- as expected for a system that radiates 850 of the 1976 joules incident. The Figure also shows that the radiation temperature drops to the vaporization temperature of Al of .24 eV well after the problem end time of 450 ns. In fact the extrapolation shows radiant temps above .24 eV until 10,000 ns. Thus impulse can be delivered by a low temperature plume that continues to evolve from the sample. The high electron and ion temperatures shown in the Figure at the end of the problem are trapped at the leading edge of the plume and don't carry substantial energy.

Figure [5] shows stress gauge measurements at 1.5 mm depth into aluminum compared to 1D Puff74 calculation [by GRC]. The 1D calculation stress of 120 kbar compares poorly to the measured peak stress of 68 kbar. Figure [6] show the pressure versus time history at two depths in the aluminum sample from the 2D LASNEX calculation. The curves are parametric in radius and can be compared to the gages because the thicknesss of the zones is such that the shock traverses the zone in about the same time as the risetime response of the gage (10 ns). Thus the calculation has a bandwidth built in as does the experiment. At .5 mm depth, the ring shock is apparent since curve e (k=19) is on axis and is 50% of the peak intensity which is at k=16 which is curve c. The curve c result agrees with 1D calculations with Puff74 that show a 170 kbar pressure at this depth. The large radial gradients in pressure shown here are the likely explanation for the .5 mm gauge failure, since the gauge cannot withstand large shears without the electrical leads failing.

The 1.5 mm depth pressure curves show that the ring has filled in by the time the shock arrives. Curve f is on axis and is only a few percent lower than a and b which are at the laser ring radius. Thus the gauge survived the radial gradients and yielded a 68 kbar pressure vs a calculated 90 kbar pressure. The timing of the arrivals also differ. The measured peak is at 260 ns vs the calculated 230 (both 1 and 2D). The discrepancy could either be due to Equation of State (EOS) errors or due to gauge location errors. The Figure shows the locus of the peak versus time. Also shown is the 68 kbar isobar. They intersect at 300 ns. Thus if the gauge was deeper by as little as .2 mm, the pressures would match more closely as would the timing of the shock arrival. The difference in stresses may also be due to a lack of material strength in the EOS for LASNEX. The ratio of calculated to observed stress is about the same as the ratio of calculated to observed impulse. This argues that the code needs other EOS treatments at low stresses.

Figure [7] shows the radial distribution of impulse at the end of the calculation. The crossed curve is the differential value and the solid curve is the integral from the edge of the Al puck toward the center. The calculated value is then 16.3 ktap vs the 1D calculation of 6.3 ktap. In the 2D calculation 46% of the impulse is from outside the spot, which agrees with experiments at microsecond pulse lengths. Thus even though the laser is on for a short time, so that the interaction appears 1D, the plume develops later in time with enough energy stored due to the slow radiative decay times to increase the impulse as if the laser pulse was as long as the radiative decay time.

Considering that the impulse is likely to increase until 10,000 ns vs the calculated 450 ns due to evaporation and melt ejection, the overestimate of the calculated impulse is likely to get worse if the calculation could be carried further. Thus in this calculation, there may be a factor or 50% overestimate of the impulse. The reasons for this are not apparent at this time, but inclusion of material strength will reduce the impulse since material that is moving in the calculation would be unable to move if bound by material strength. Thus, more acccurate predictions can be made if the code is upgraded to include material strength or a link is made to another code at pressures where material strength is not an issue.

In summary, the NOVETTE Laser was used to irradiate aluminum disks at fluences of 100 to 20,000 J/cm^2. Besides the intrinsic interest in the coupling coefficient for .53 micron light in highly 1D (1ns) laser interactions, the shots were used to qualify diagnostics to be used in other tests. The coupling coefficient data has been analyzed and compared to to 1D calculations by Bookless. The results indicate that the experiments generate twice the impulse calculated by a 1D model- at least at 10,000 J/cm^2 where the 1D approximation is very poor.

2D calculations predict an impulse of 16.3 ktaps vs a measured 12.5 ktaps at 12,000 J/cm^2. 1D calculations predict 6.3 ktap. 46% of the 2D impulse is from plume reradiation to target surface outside the spot at times much later than the initial interaction time of 1 ns.

The 2D calculation predicted a peak stress of 90 kbars at a depth of 1.5mm into the target. Observations using a Manganin gage were 68 kbars. The ratio of calculated to observed stress is about the same as the ratio of calculated to observed impulse. The difference in stresses may be due to a lack of material strength in the EOS for LASNEX. Alternatively, an error in the estimate of the gauge depth by as little as .2 mm can also explain the stress discrepancy as could an absorption of 75% of the incident light from that calculated. At this time, however, there is a 50% apparent uncertainty in the calcualtion of impulse at 10 terawatts/cm^2 on Aluminum when 2D effects are accounted for.

The experiments were also very useful as diagnostics development shots also, since they pointed out difficulties with both the stress and impulse gages fielded by GRC. The conditions of the experiment were needed and uniquely suited to this screening.

1.--The experimental setup on the NOVETTE LASER

2.--The initial LASNEX mesh. Laser is incident from the right. The large initial zone is vacuum

3.-- Contours a-d represent the time evolution of the mesh to 450 ns after laser shine. 3. Contours of pressure are plotted in units of 10^9 joules/cc.

4.--The maximum electron, ion and radiation temperature as a function of time.

5.--Stress gauge measurements at 1.5 mm depth into aluminum compared to 1D Puff74 calculation [by GRC].

6.--The pressure versus time history at two depths in the aluminum sample from the 2D LASNEX calculation. The curves are parametric in radius.

7.--The radial distribution of impulse at the end of the calculation. The crossed curve is the differential value and the solid curve is the integral from the edge of the Al puck toward the center.

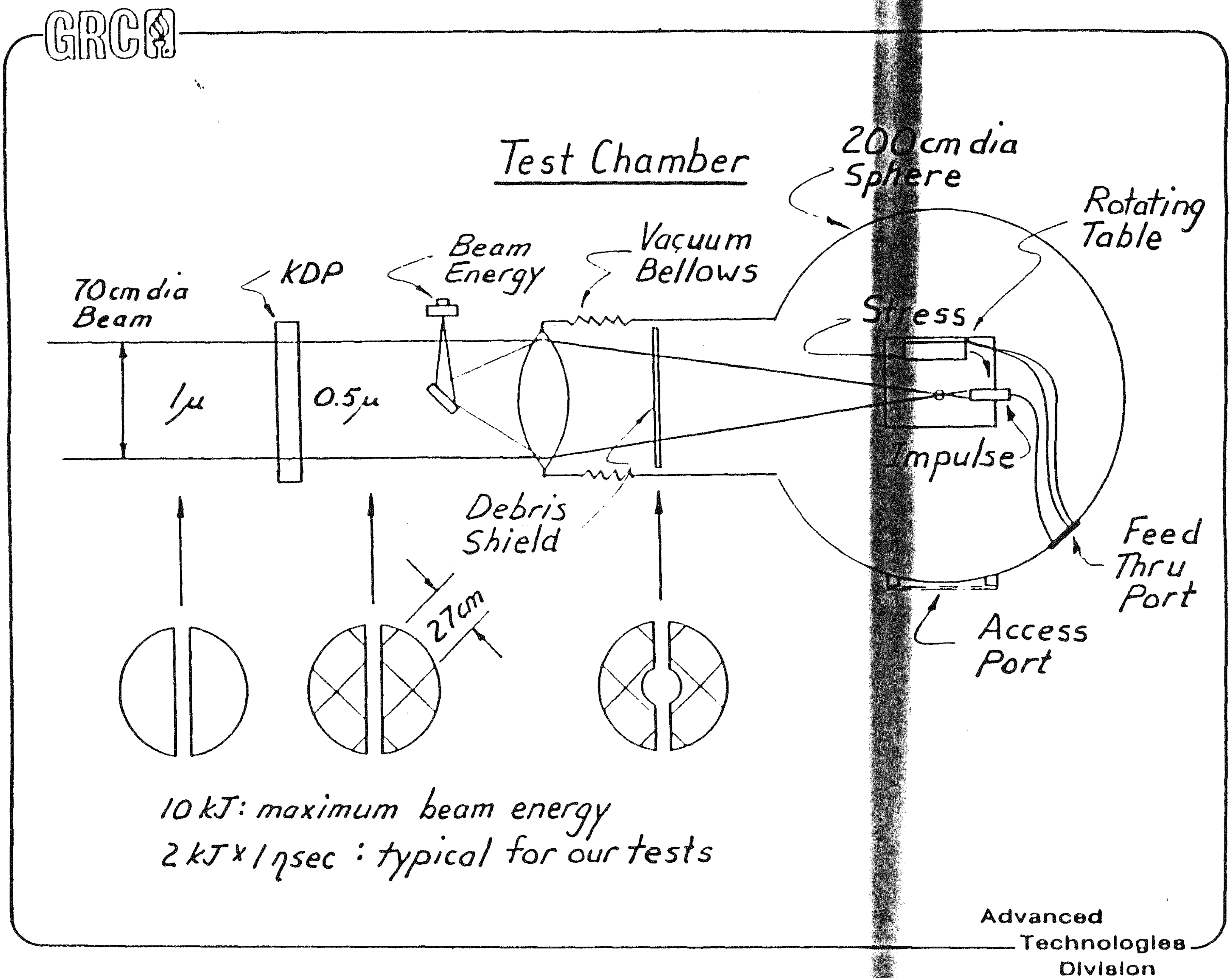

GRC
Test Chamber
200 cm dia Sphere
Rotating Table
Beam Energy
Vaçuum Bellows
KDP
70 cm dia Beam
1μ
0.5μ
Stress
Impulse
Debris Shield
Feed Thru Port
Access Port
27 cm
10 kJ: maximum beam energy
2 kJ × 1 ηsec : typical for our tests
Advanced Technologies Division

Figure 1.

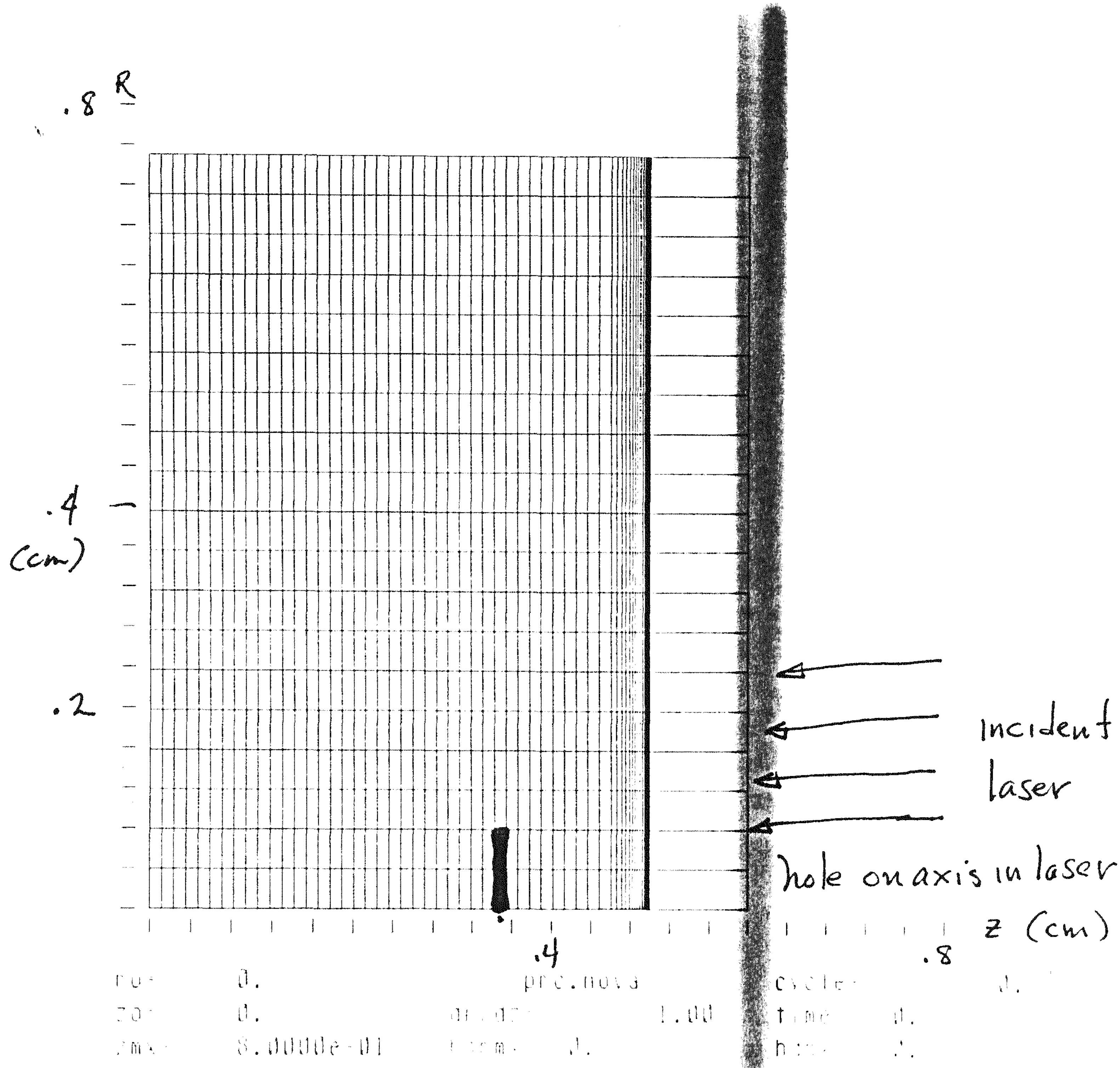
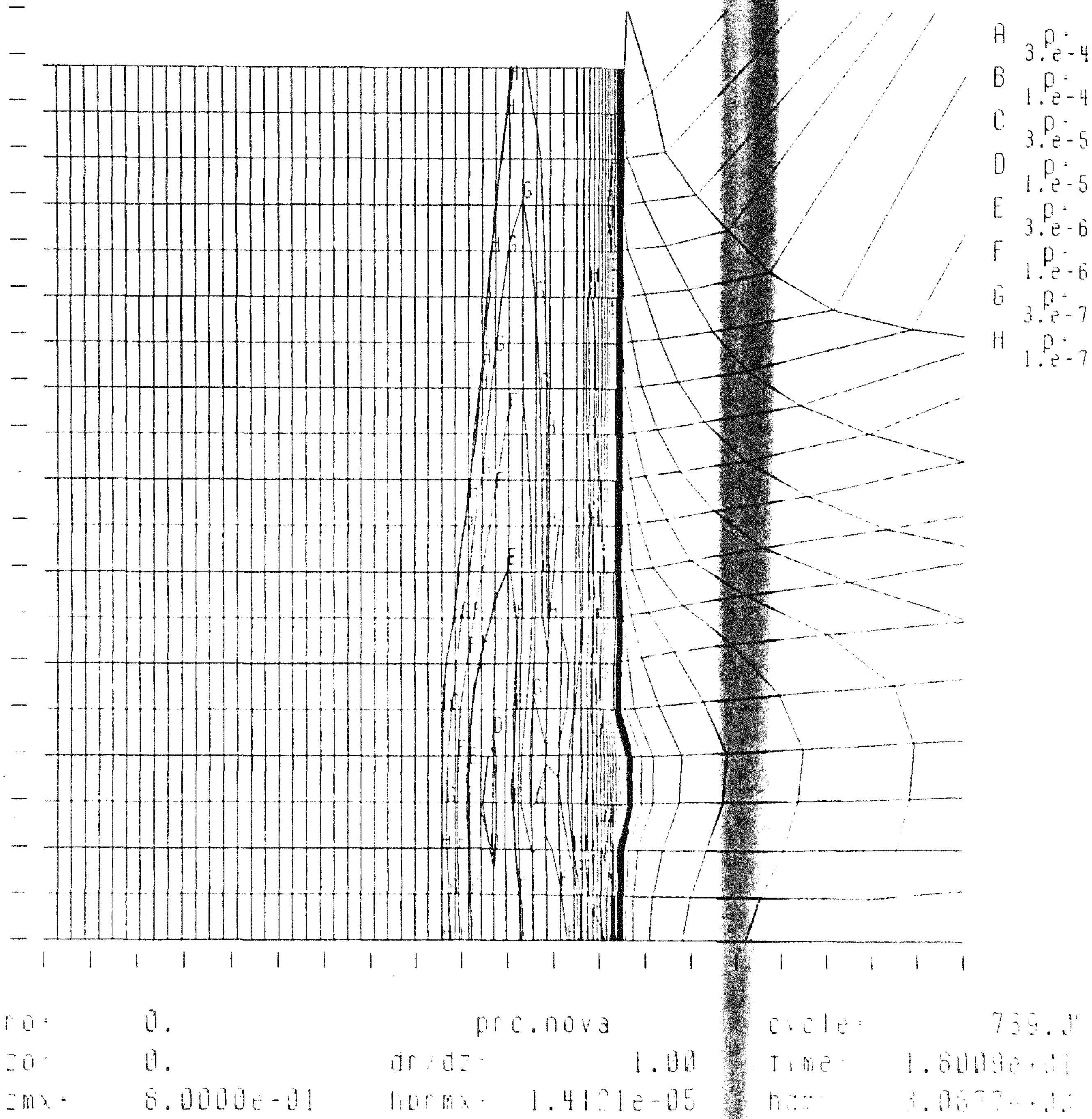
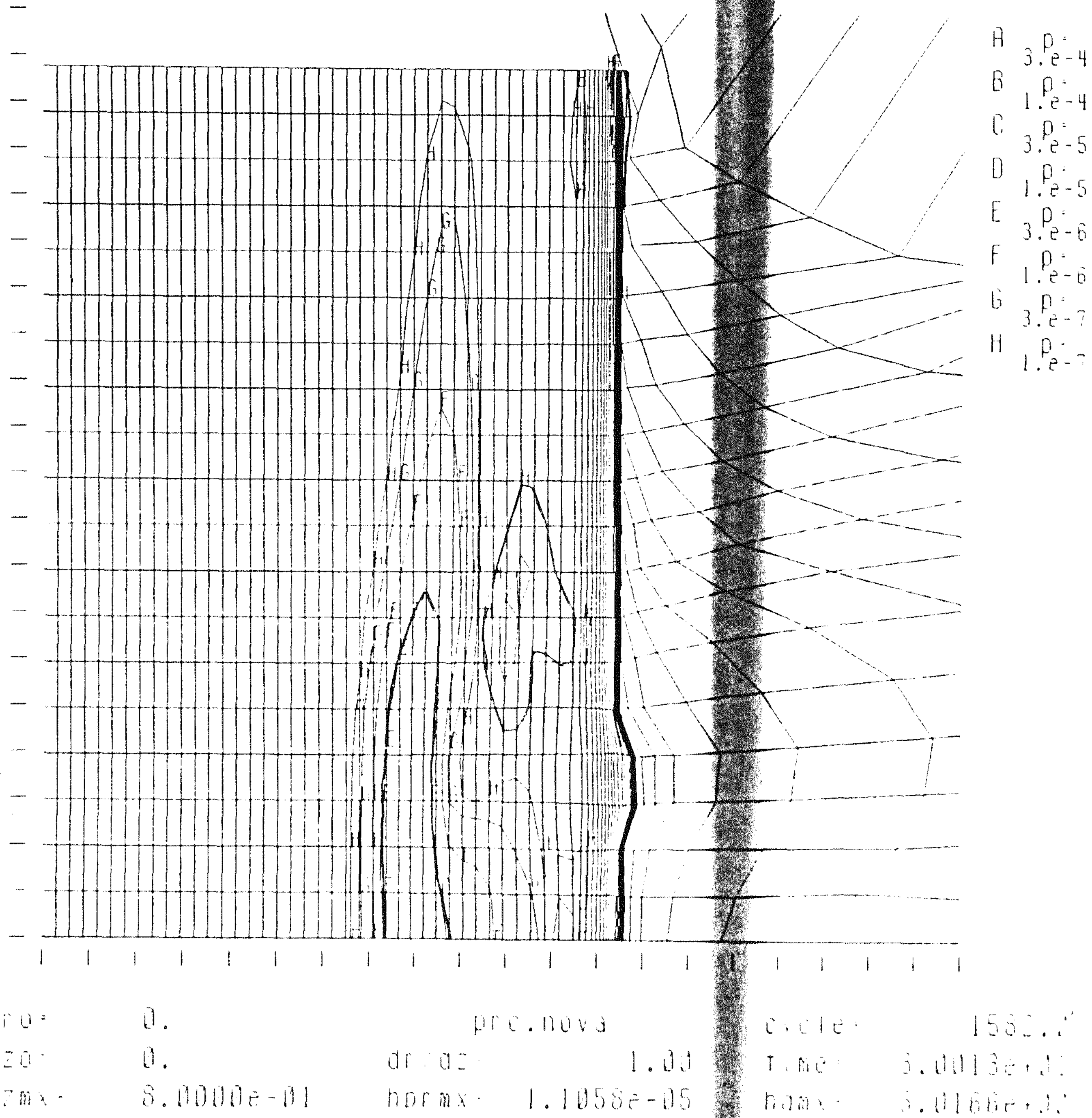


Figure 2.



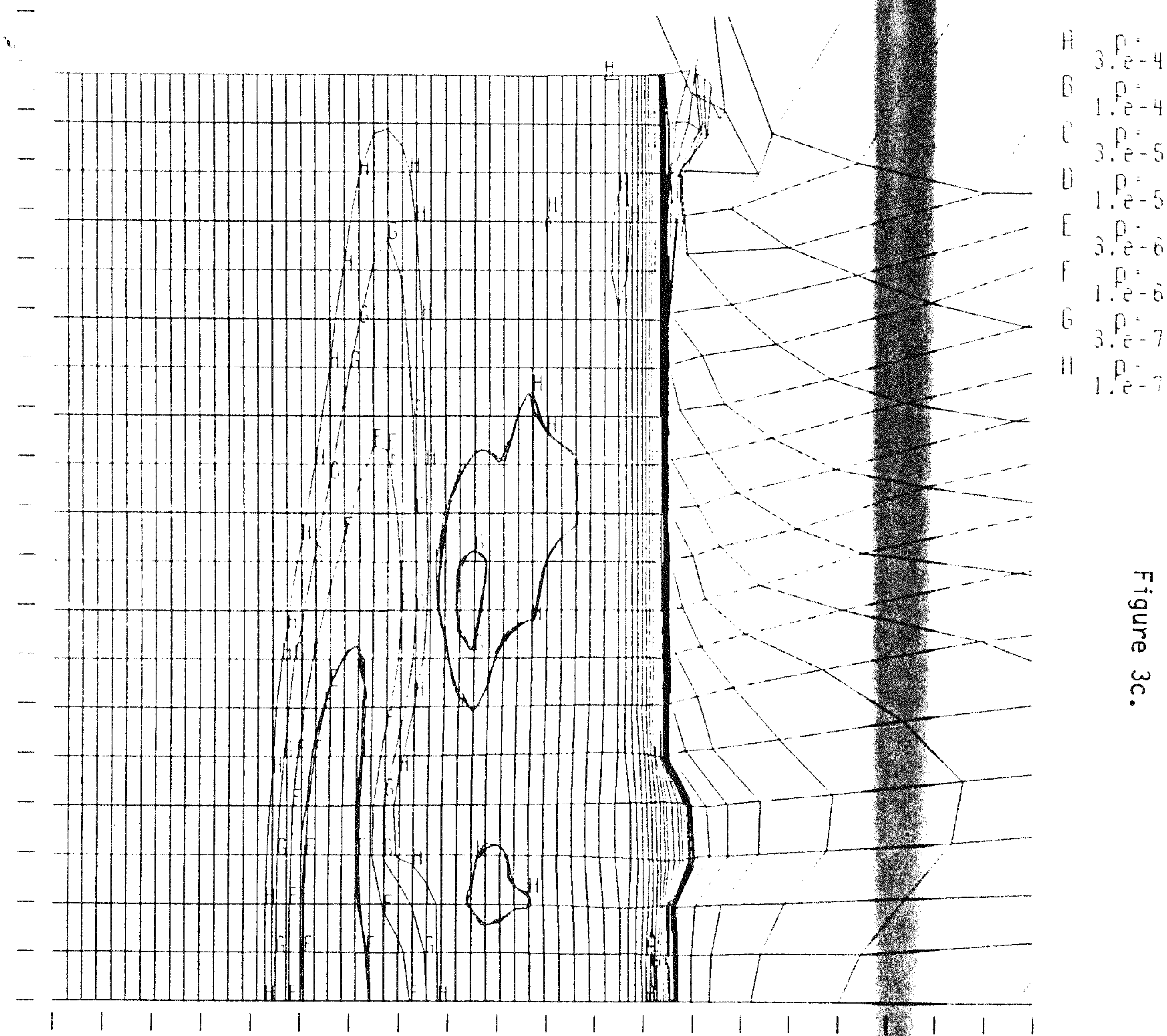
A p= 3.e-4
B p= 1.e-4
C p= 3.e-5
D p= 1.e-5
E p= 3.e-6
F p= 1.e-6
G p= 3.e-7
H p= 1.e-7
ro= 0.
prc.nova
zo= 0.
dr/dz= 1.00
zmx= 8.0000e-01

Figure 3a.



A p=3.e-4
B p=1.e-4
C p=3.e-5
D p=1.e-5
E p=3.e-6
F p=1.e-6
G p=3.e-7
H p=1.e-7
ro= 0.
prc.nova
zo= 0.
dr/dz= 1.00
zmx= 8.0000e-01
hprmx= 1.1058e-05

Figure 3b.



ro=	0.	prc.nova		cycle=	2560.0
zo=	0.	dr/dz=	1.00	time=	4.5007e+01
zmx=	8.0000e-01	hormx=	8.7342e-06	hdmx=	2.9586e+00

Figure 3c.

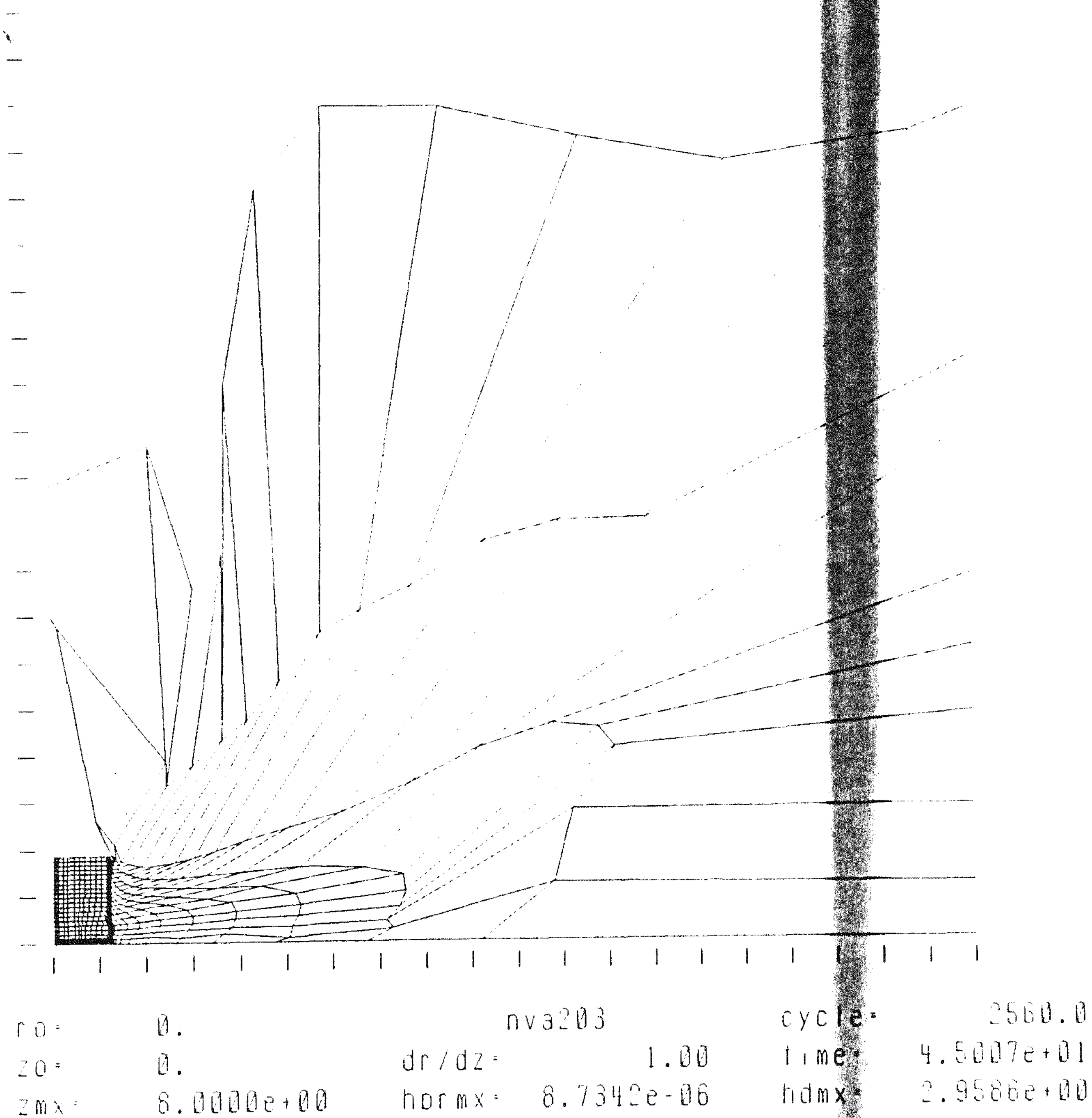
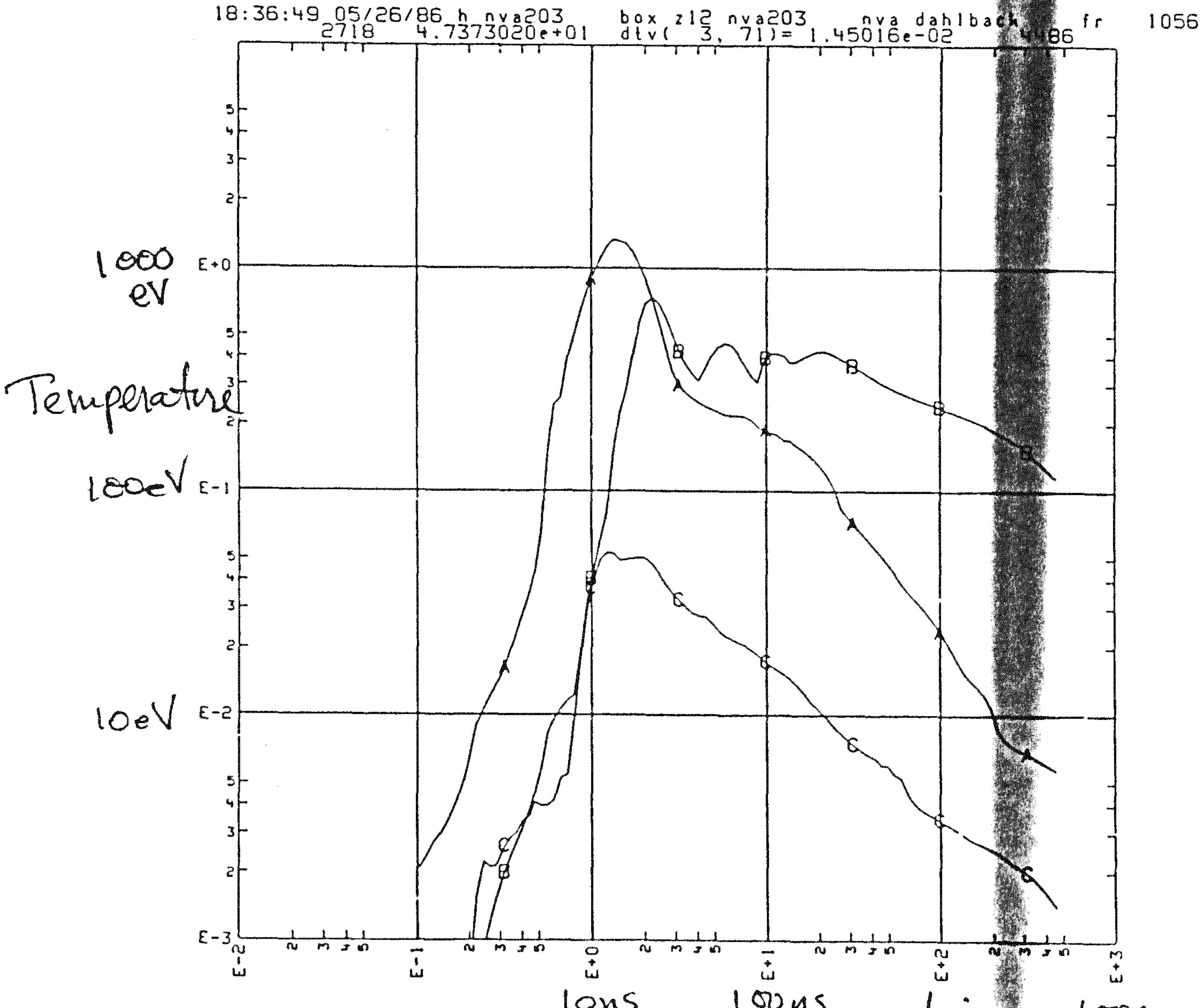
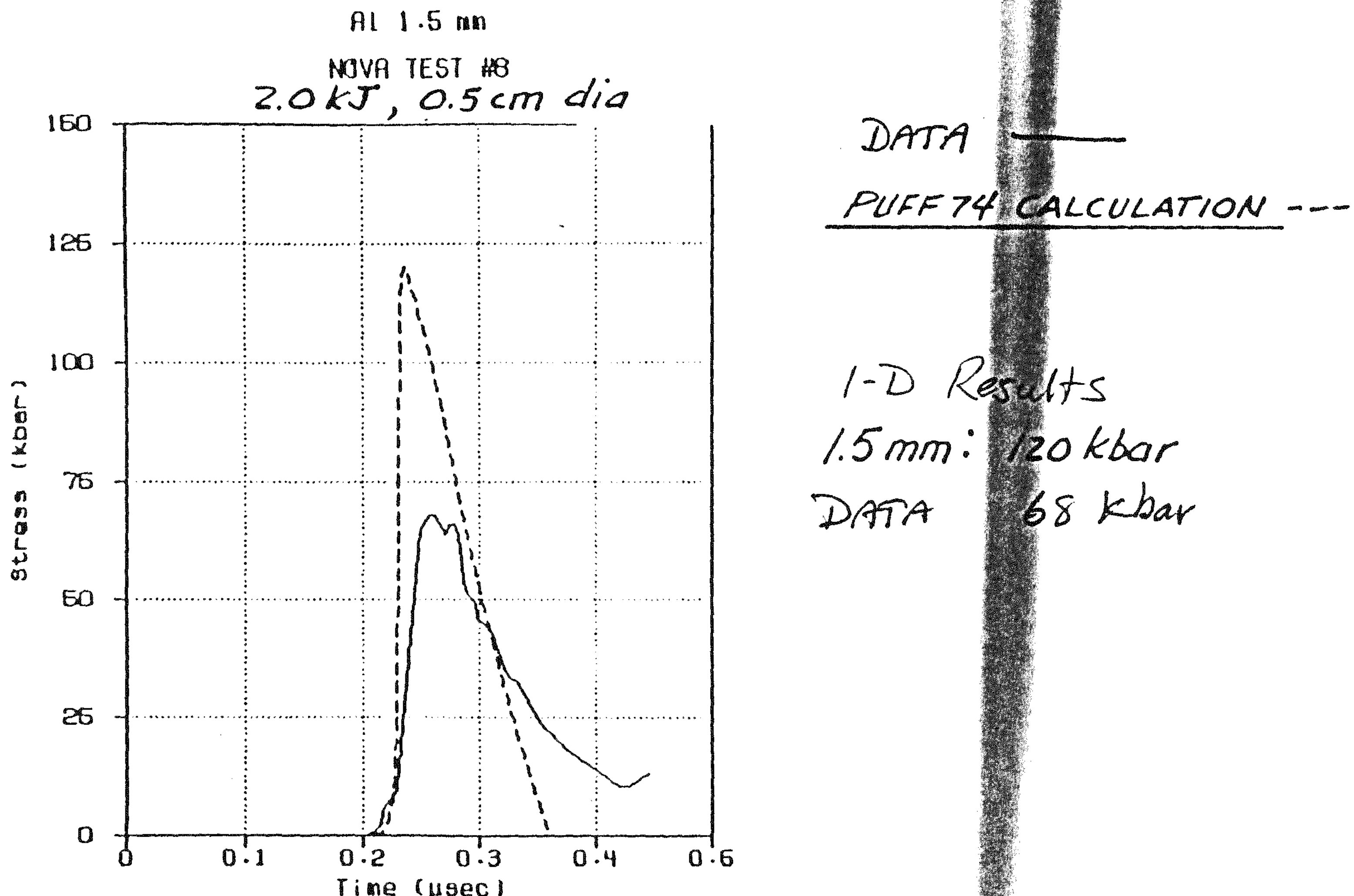

r0= 0.
z0= 0.
zmx= 8.0000e+00
nva203
dr/dz= 1.00
hormx= 8.7342e-06
cycle= 2560.0
time= 4.5007e+01
hdmx= 2.9586e+00

Figure 3d.



-A- plot te(max) vs. time*10.
-B- plot ti(max) vs. time*10.
-C- plot tr(max) vs. time*10.

Figure 4.



GRC

Advanced Technologies Division

Figure 5.

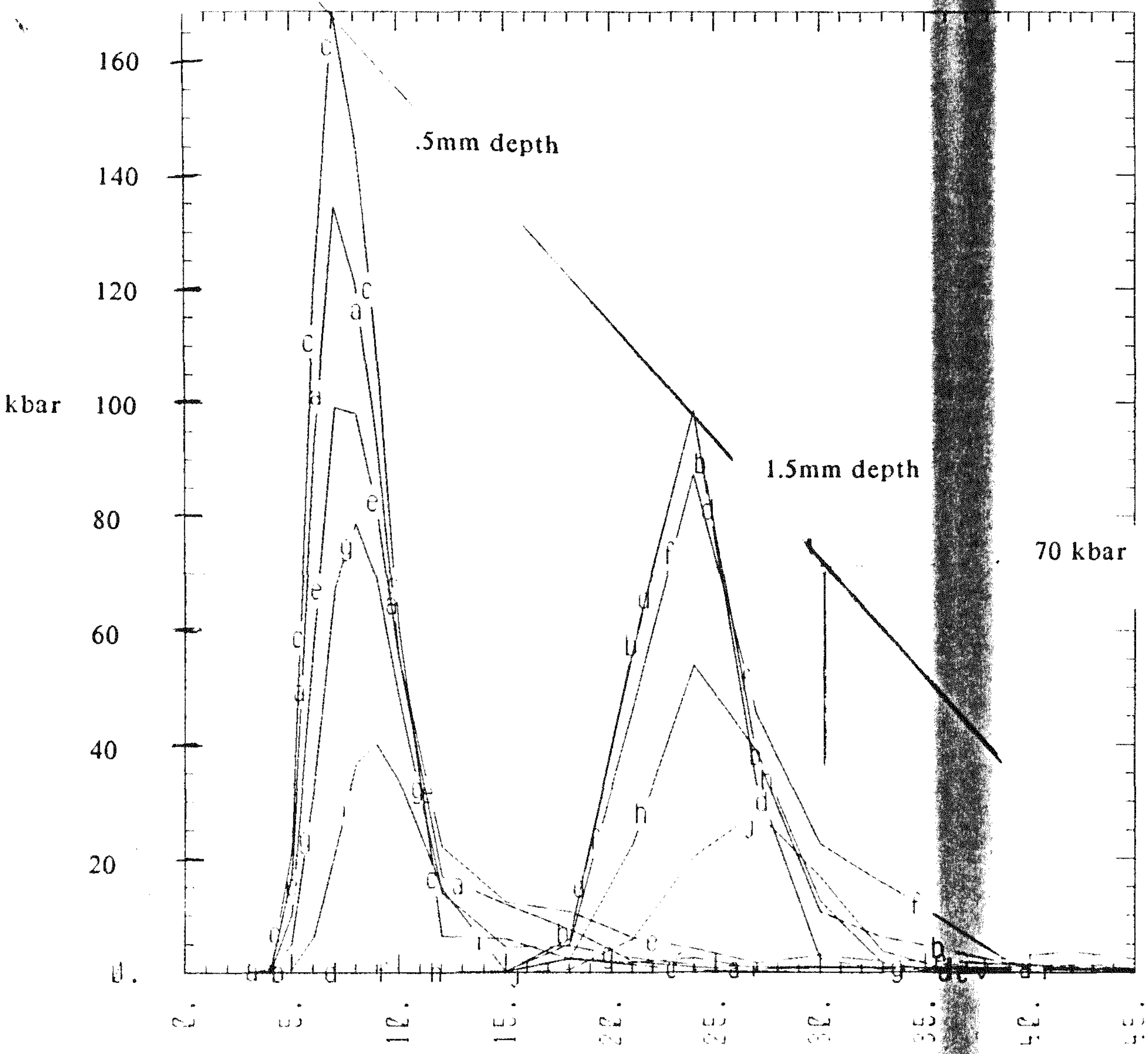


Figure 6 time (10 ns)

a: plg prvst(39,1,timex(39,1) } 18
b: plg prvst(31,1,timex(31,1)
c: plg prvst(39,1,timex(39,1) } 16
d: plg prvst(31,1,timex(31,1)
e: plg prvst(39,1,timex(39,1) } 14
f: plg prvst(31,1,timex(31,1)

g: plg prvst(39,1,timex(39,1)
h: plg prvst(31,1,timex(31,1)
i: plg prvst(39,1,timex(39,1
j: plg prvst(31,1,timex(31,1)

Figure 7

Impulse vs. Radius - NOVA @ 2000 J/cm2