

ARMY RESEARCH LABORATORY



Hydrocode Simulation of Flexilinear Shaped Charge Jet Penetration Into an Explosive Filled Cylinder

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ARL-TR-976

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13. ABSTRACT (Maximum 200 words)

This report presents the results of a combined numerical and experimental investigation of the penetration of a flexilinear shaped demolition charge into an explosive-filled, thin-walled aluminum cylinder. Computations and experiments were conducted using both CompB and LX-14 as the explosive fill in the aluminum cylinder. The 225 grains per foot (gpf) flexilinear shaped charge (FLSC) was composed of CH-6 high explosive encased in a seamless lead sheath liner. The numerical computations were conducted before the experiments using the Eulerian hydrocode CTH. The explosives encased in the cylinder were expected to detonate near the surface of the cylinder due to either a jet tip impact mechanism, or a liner "slap" mechanism. The hydrocode simulations show that neither of these mechanisms will initiate a detonation in the explosives in the geometry considered. However, minor decomposition occurred in the CompB simulation on the cylinder's symmetry axis. The LX-14 simulation predicts complete detonation of the explosive after initiation on the axis of the cylinder. The detonation initiates by superposition of shock waves as they converge upon the cylinder's symmetry axis. The simulations are qualitatively verified by experiments insofar as the CompB explosive did not detonate, whereas the LX-14 explosive did detonate.

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1. INTRODUCTION

Military demolition operations use a variety of shaped charge geometries (e.g., cylindrical, linear, curvilinear, and flexilinear) for the clearance of obstacles and barriers, the destruction of facilities and materiel, the construction of roads and trenches, and in land clearance and quarrying. The flexilinear shaped charge (FLSC) is commonly used in explosive ordnance disposal (EOD) as a means to sever the projectile from the body of an explosive-filled warhead. In this study, the Navy was interested in determining if the CTH hydrocode predictions of possible "go" or "no-go" detonation scenarios are verified by experiment. The FLSC used in this study consists of a continuous core, filled with CH-6 explosive, that is encased in a seamless lead sheath. The FLSC is available in 4-ft lengths with a density designation that ranges from 20 to 600 grains per foot (gpf). The density designation for the FLSC used in this study is 225 gpf (see Figure 1).

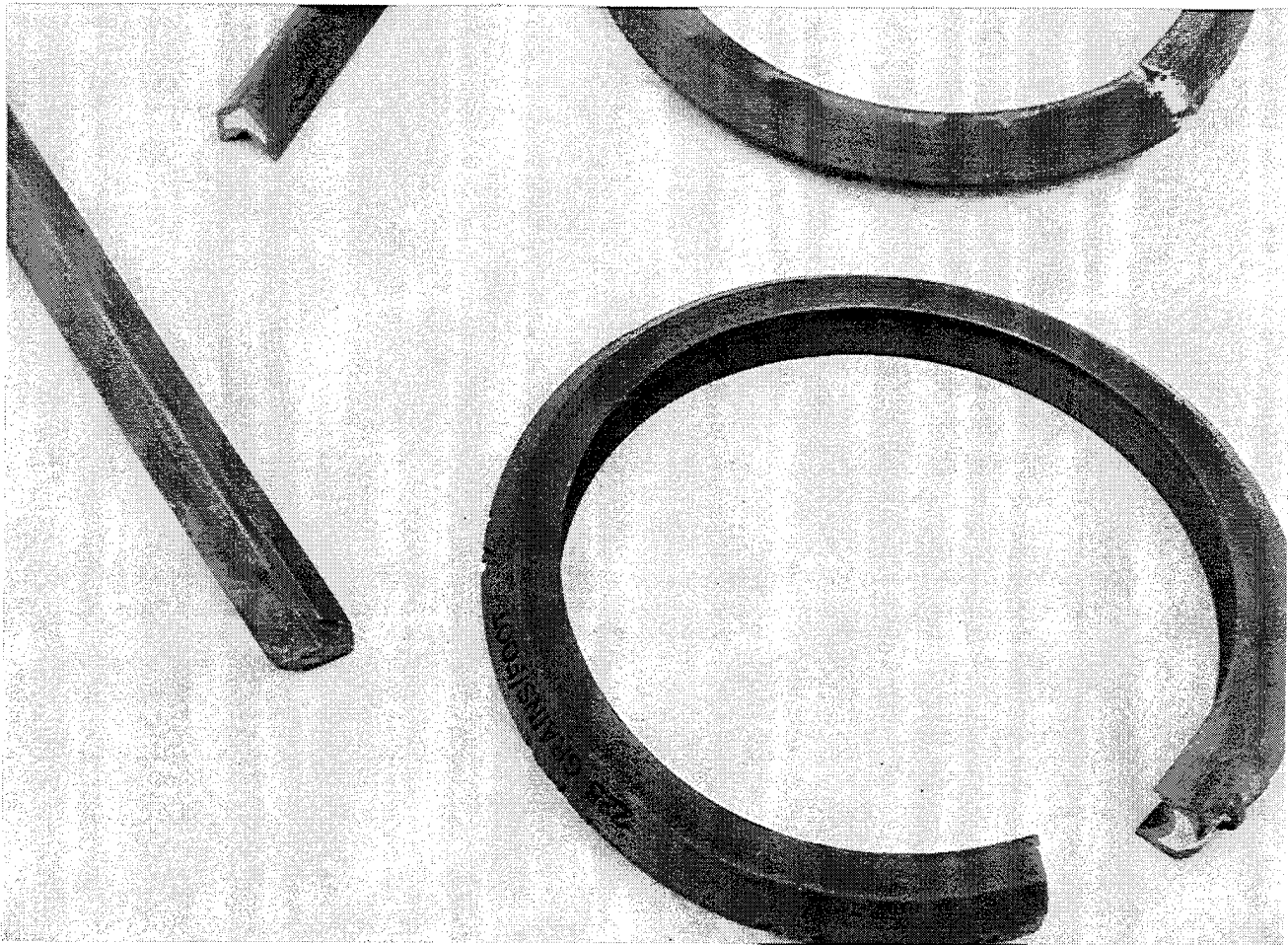


Figure 1. Photograph of the flexilinear shaped charge.

The FLSC is typically wrapped around the warhead and detonated at a single point using a blasting cap. The detonation wave travels around the circumference of the warhead and forms an inwardly directed shaped charge jet which severs the warhead into two pieces. The nominal dimensions of the FLSC used in this study (Figure 2) are: $A = 90^\circ$, $B = 0.240$ in (6.1 mm), $C = 0.480$ in (12.2 mm), $D = 0.450$ in (11.43 mm), and $E = 48.00$ in (1,219.2 mm) (see Department of the Navy EODB/Department of the Army TM/U.S. Air Force TO 60A-2-1-51 1992).

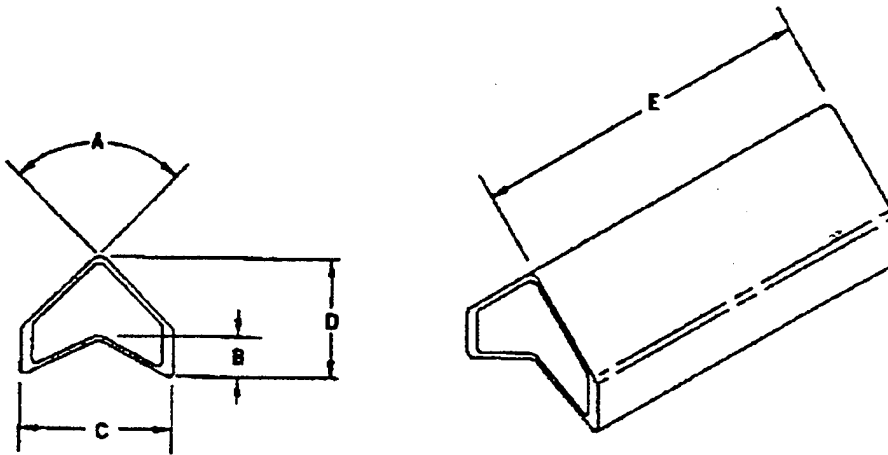


Figure 2. Critical dimensions of the FLSC (Department of the Navy EODB/Department of the Army TM/U.S. Air Force TO 60A-2-1-51 1992).

The Eulerian hydrocode CTH (McGlaun et al. 1988) is used in this study to model the penetrative and detonative performance of the FLSC as it collides into a thin-walled aluminum cylinder filled with either CompB and LX-14 high explosive (HE). Numerical simulations were conducted first, followed by experiments, in an attempt to evaluate the predictive capability of the hydrocode. Two different problem geometries were considered and are illustrated in Figure 3. In the first problem (Figure 3a), we want to determine if the explosive will detonate by impact from flying lead liner fragments. In the second problem (Figure 3b), the FLSC axis is centered directly over the explosive, which is encased in a thin-walled aluminum cylinder, and capped by thin copper discs (endcaps). In the second problem, we expected the explosive to detonate due to, 1) impact by the small diameter, high-velocity shaped charge jet tip, or 2) impact by the large-diameter, low-velocity liner. However, the hydrocode computations show that the LX-14 explosive detonates through shock-wave superposition at a location on the center axis of

the model. This prediction is qualitatively supported by experiment. Neither the hydrocode nor the experiment produced a detonation in the CompB model problem.

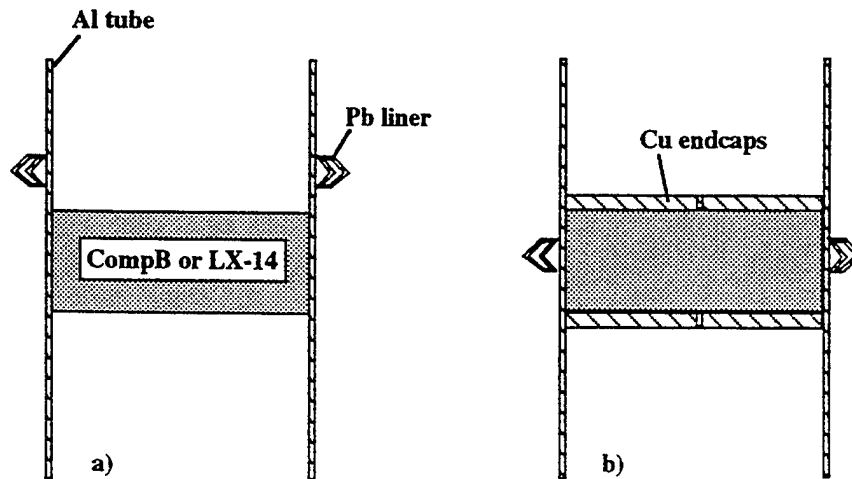


Figure 3. Axisymmetric problem geometry, a) FLSC centered at 0.5 in (12.7 mm) above bare explosive (indirect impact configuration), and b) FLSC centered over encased explosive (direct impact configuration).

2. COMPUTATIONS

Computations are performed using the Eulerian hydrocode, CTH (McGlaun et al. 1988), that has been primarily used in the analysis of problems involving large material distortions. We employed a two-dimensional, axisymmetric Eulerian description of the material body (Figure 4), wherein computational cells are fixed in space and quantities such as mass, momentum, and energy flux across cell boundaries. The Eulerian mesh density consisted of 200 and 182 cells in the x- and y-directions, respectively. The aluminum cylinder that encases the explosive is 6 in (152 mm) long, $3\frac{7}{8}$ in (98.4 mm) in outer diameter, and is $\frac{1}{16}$ in (1.59 mm) thick. The HE fill consists of cast CompB or pressed LX-14, 1 in (25.4 mm) thick, and $3\frac{3}{4}$ in (95.25 mm) in diameter. The copper endcaps are $\frac{3}{8}$ in (9.5 mm) thick. Although the nominal dimensions for the FLSC are given in the introduction, the actual dimensions used in the simulation are obtained by digitizing an enlarged photograph of an FLSC (Figure 5). The input deck for

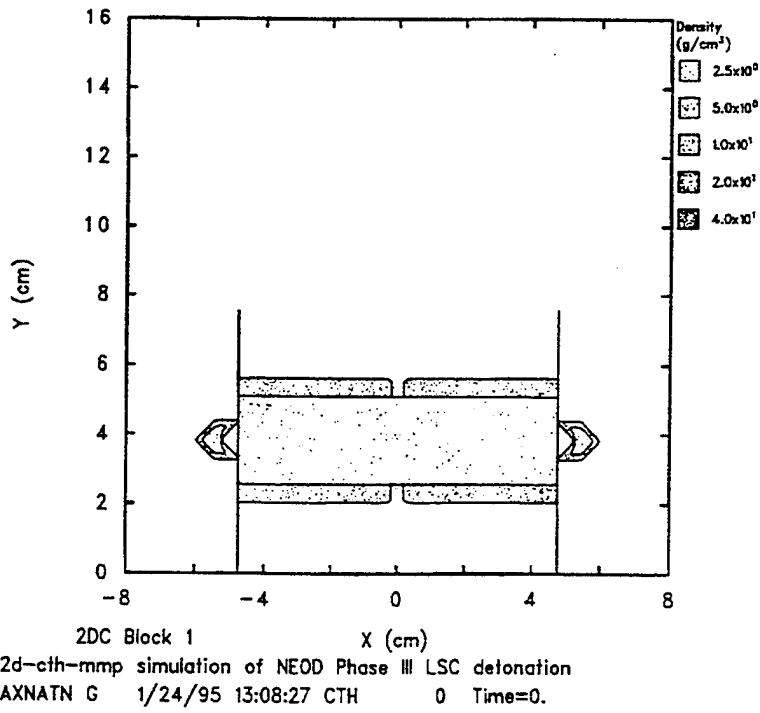


Figure 4. Axisymmetric geometry used in FLSC computations.



Figure 5. Cross section through the FLSC.

The CompB explosive-filled cylinder model appears in Appendix A, with corresponding computational results in Appendix B. The input deck for the LX-14 explosive-filled cylinder model appears in Appendix C, with corresponding computational results in Appendix D.

The distortional behavior of the aluminum cylinder (7075-T6), lead FLSC liner, and copper endcaps is modeled using the rate-independent version of the Steinberg-Guinan-Lund viscoplastic constitutive model (CTH material models 1, 4, and 5 respectively) (Steinberg and Lund 1989). The adiabatic yield stress vs. plastic strain for the metals is illustrated in Figure 6. The dilatational behavior of the metals is modeled with the Mie-Grüneisen equation of state (EOS) (Figure 7). The CompB and LX-14 HE are modeled using the Mie-Grüneisen EOS for the undetonated explosive, while the explosive detonation products are described with the SESAME EOS in conjunction with the history variable reactive burn (HVRB) model (see Kerley 1995). The coefficients for the various material models can be found in Appendix A and Appendix C input decks.

2.1 Computational Results. The axisymmetric nature of the model necessitates a simultaneous detonation of the FLSC around the periphery of the cylinder. This feature of the model differs from how the experiment is performed, since, in the experiment, the FLSC is detonated at one end, and the detonation wave travels unidirectionally around the circumference of the cylinder (Figure 8). The hypothetical location of the jet tip as it cuts through explosive cross section is determined by calculating the radius, r , or distance of the jet tip from the cylinder's symmetry axis defined as,

$$r = r_o - v_e \left(t - t_d - r_o \theta / v_f \right), \quad (1)$$

in which t is time, t_d is the estimated delay time required for the liner to impact the aluminum casing (approximately 5 μ s), r_o is the radius of the cylinder (0.049174 m), θ is the cylindrical coordinate ($0 < \theta < 2\pi$), and v_e and v_f are the jet tip cutting velocity (~1,700 m/s) and detonation wave velocity (7,800 m/s) in the explosive respectively. The locus of points in the x,y-coordinate system plotted in Figure 8 is obtained by substituting Equation 1 into the familiar equations for converting cylindrical coordinates to Cartesian coordinates,

$$\begin{aligned} x &= r \cos(\theta) \\ y &= r \sin(\theta) . \end{aligned} \quad (2)$$

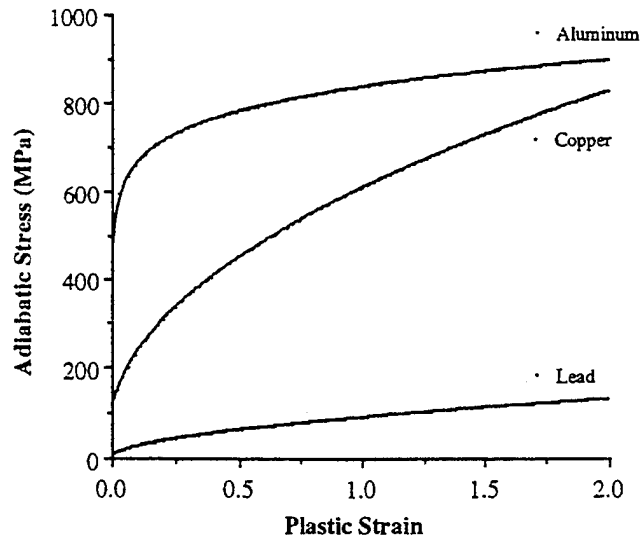


Figure 6. Adiabatic flow stress vs. equivalent plastic strain for aluminum (7075-T6), copper, and lead at ambient temperature and pressure.

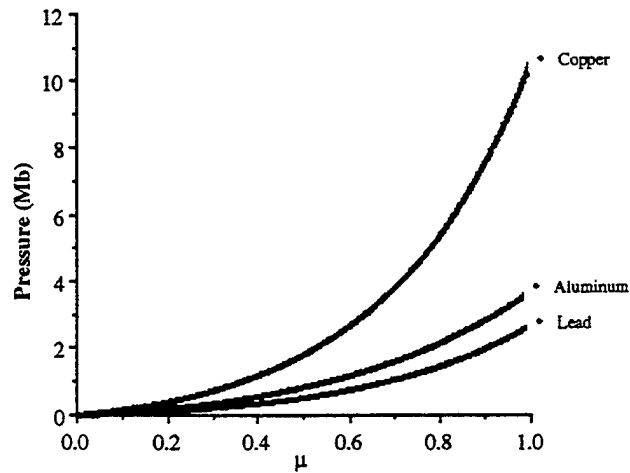


Figure 7. Hugoniot for copper, aluminum, and lead.

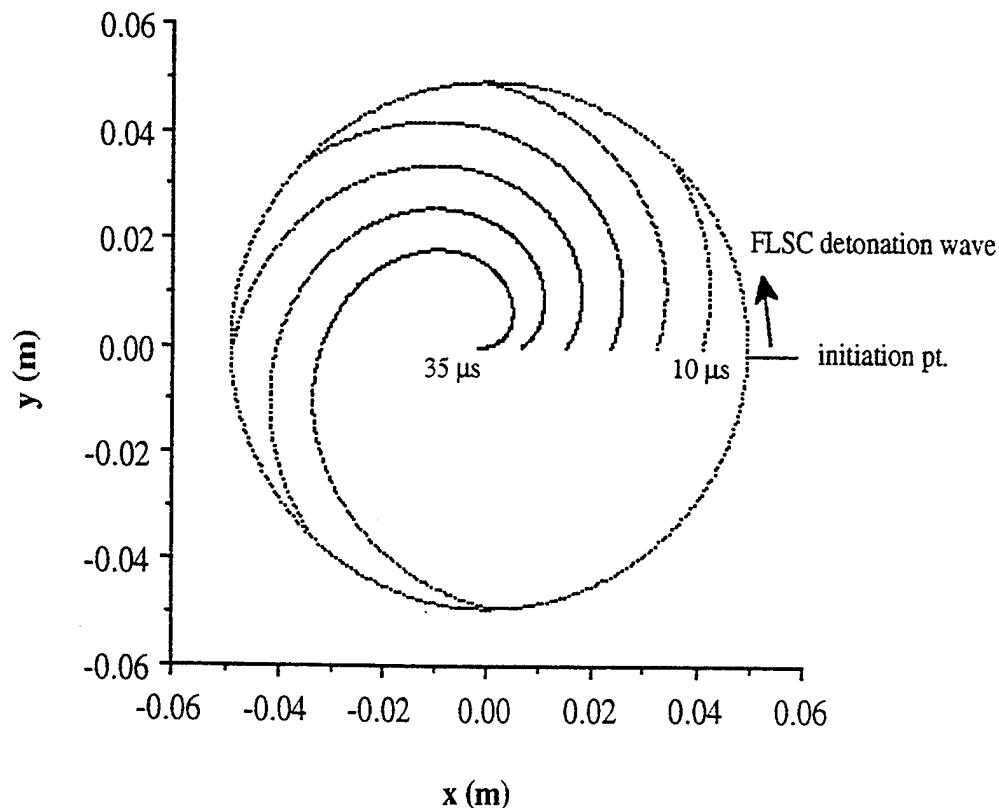


Figure 8. Hypothetical leading edge of jet tip as it cuts through explosive cross section from 10 μ s through 35 μ s after initiation.

The spiral nature of the leading edge profile is a result of the fact that the detonation wave velocity in the FLSC is much greater than the jet tip cutting velocity (i.e., $v_f = 7,800$ m/s $>$ $v_e = 1,700$ m/s in Figure 8). One can estimate the time, t_c , it takes for the detonation wave to travel around the circumference of the cylinder, by knowing the CH-6 detonation velocity, v_e , and length, l , of the FLSC. The travel time is estimated at, $t_c = l/v_e = 0.31$ m/7,800 m/s = 40 μ s. The plot shows that the leading edge of the jet tip in the experiment is not symmetrically disposed about the cylinder axis, and since the axisymmetric computations indicate that the detonation wave reaches the center axis of the cylinder in only 17 μ s (Appendix A), only the very short time ($t < 17$ μ s) results of the computational model should be compared with experiment.

The hydrocode simulations predict that neither the CompB or LX-14 explosive will detonate in the indirect impact model configuration (Figure 3a). Experiments conducted at Range 16 with this configuration corroborate the hydrocode predictions. However, with the direct impact configuration (Figure 3b), we believed the explosives would detonate by shock initiation either by 1) direct shaped charge jet impact, or 2) a liner "slap" impact (Figure 9). The hydrocode computations show, however,

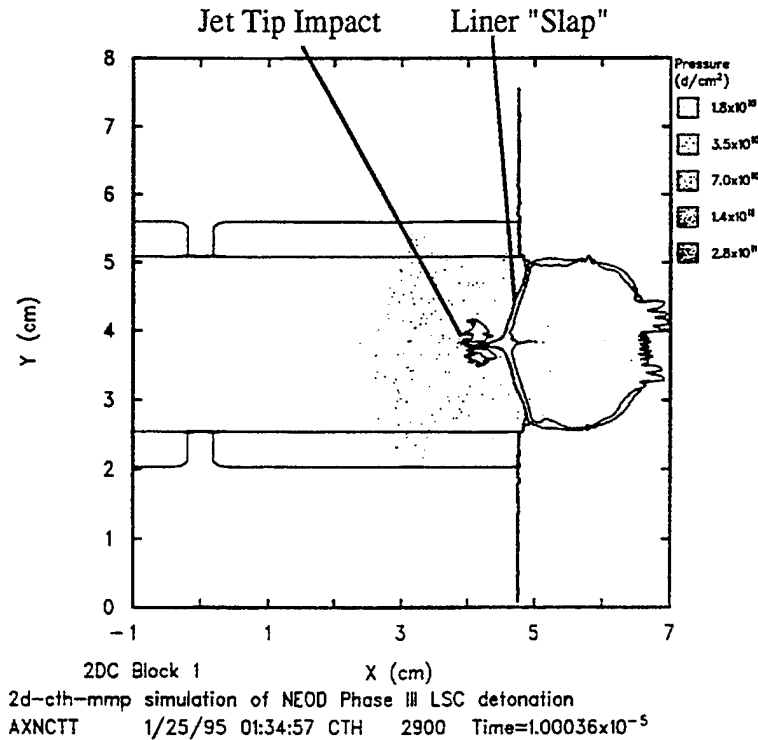


Figure 9. Detonation scenarios by jet tip impact and liner "slap."

that CompB explosive does not detonate under these impact conditions. Furthermore, using the $v^2 \cdot d = \text{constant}$ criterion for explosive detonation, we see that both the jet tip and liner "slap" impact scenarios plot below the critical value necessary for detonation (see Figure 10 modified from Starkenberg et al. 1984). The empirical Jacobs-Roslund formula is plotted as the solid line in Figure 10, and all combinations of projectile velocity and diameter that fall above this line should result in detonation for CompB explosive. Points that fall below the Jacobs-Roslund line predict no detonation for CompB explosive.

The CTH computational results for CompB and in Appendix B where quantities such as pressure, density, and a history-dependent reaction variable (Kerley 1995) which tracks chemical decomposition (detonation) of the explosive are plotted at 5 μs intervals for a total of 25 μs . The reaction variable is normally scaled between 0 and 1; however, we increase this limit to 2, to provide for a better visual presentation of the data. The CompB simulations do not reveal any chemical decomposition of the explosive beneath the jet tip or impacting liner. However, some decomposition is visible along the center axis of the model, as a result of the superposition of shock wave fronts at this location. The zone of decomposition remains localized, however, and does not follow the expanding shock wave as it reflects

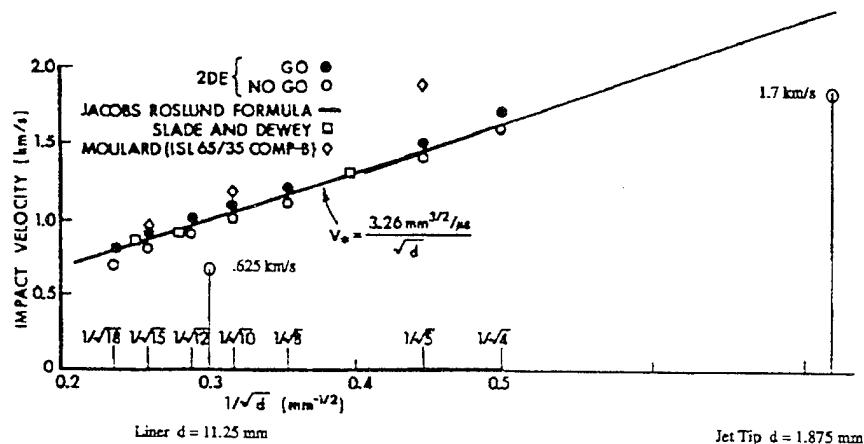


Figure 10. Critical impact velocity as a function of projectile diameter (modified from Figure 14) (Starkenberget al. 1984).

off the cylinder axis (see Appendix B plots at 25 μ s). We can infer then, that if a detonation were to occur in such an experiment, it would probably initiate as a result of shock wave superposition at an interior point of the body, and not as a result of impact by the jet tip or liner.

The CTH computational results for LX-14 are in Appendix D. A Jacobs-Roslund plot similar to that found for CompB is not available for LX-14 explosive (Starkenberget 1995). However, since LX-14 explosive is considerably more sensitive to impact than CompB explosive (Montesi and Bauldler 1990), we expected LX-14 to detonate by either the jet tip impact or liner "slap" mechanisms mentioned earlier. The results are somewhat different than anticipated, however, since the LX-14 detonation initiates on the center axis of the cylinder, and all the explosive detonates after 25 μ s. Recall that minor decomposition of CompB explosive is predicted to occur along the cylinder's symmetry axis.

Based upon the results of the hydrocode simulations, we infer that neither the CompB or LX-14 explosives will detonate as a result of either jet tip or liner impact. We further infer that LX-14 will fully detonate as a result of the superposition of shock waves at a point interior to the body, yet the CompB will not.

3. EXPERIMENTS

Both direct and indirect FLSC impact configurations were investigated and are illustrated in Figure 3. The indirect impact configuration (Figure 3a) consists of the FLSC centered 0.5 in (12.7 mm) above the bare explosive. The direct impact configuration (Figure 3b) consists of the FLSC centered over the aluminum-covered explosive and capped with thin copper disks. The copper disks are inserted into both ends of the aluminum cylinder and are manually press-fit onto the explosive surface. A small hole is predrilled into each copper disk to allow entrained air to escape as the disk is pressed into position. The FLSC is wrapped around the aluminum cylinder and is detonated at one end using a thin wafer of Detasheet. The detonation wave travels unidirectionally around the cylinder forming an inwardly directed jet which cuts into the explosive fill. The cylinder is horizontally positioned on a meter high styrofoam stand within a rectangular "explosion-proof" test fixture whose walls are constructed of 2-in (50.8 mm)-thick plates of rolled-homogeneous armor (RHA). A photograph of the indirect impact test configuration appears in Figure 11.

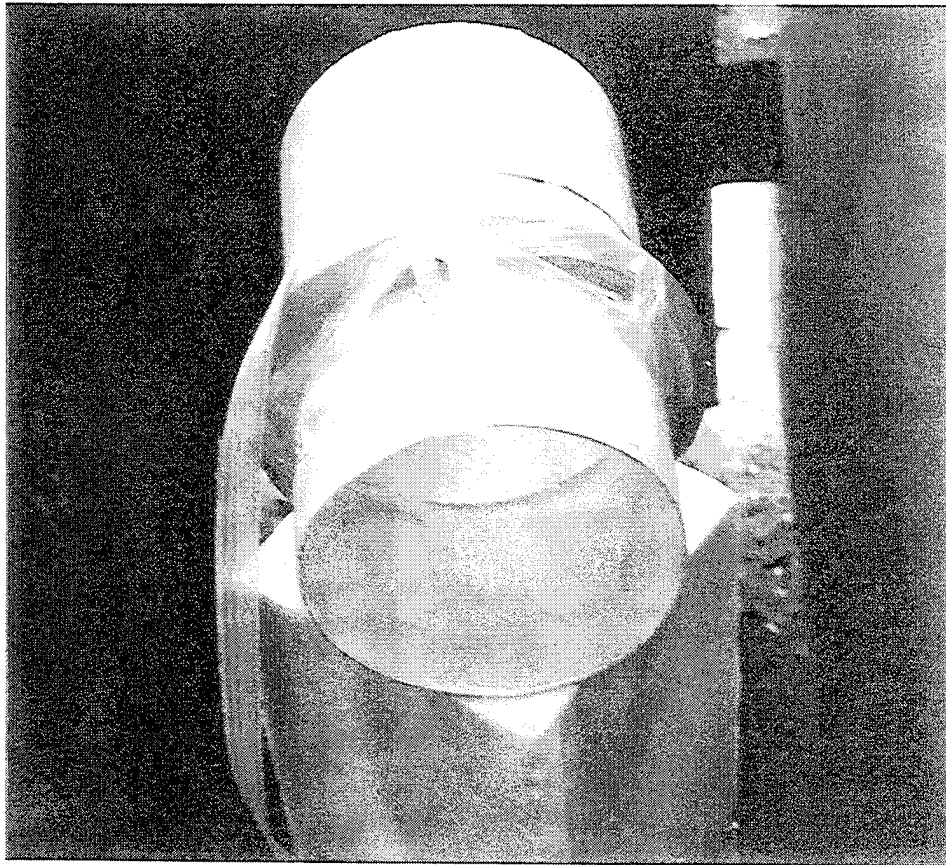


Figure 11. Photograph of test configuration (Figure 3a) showing FLSC surrounding aluminum cylinder.

Detonation did not occur with either explosive using the indirect impact test configuration. The direct impact test on CompB also did not reveal any evidence of detonation. However, the direct impact test on LX-14 produced a violent detonation that propelled the copper disks outward, forming a crater on the interior wall of the RHA test fixture (Figure 12). It could not be ascertained where the detonation initiated in the experiment since radiography was not used in the test series. However, based upon the hydrocode results, we surmise that the detonation initiated as a result of the superposition of shock waves at a point interior to the body.



Figure 12. Photograph of crater on interior wall of RHA test fixture formed by impact from thin copper disk.

4. CONCLUSIONS

CTH hydrocode simulations predict that detonation in both CompB and LX-14 explosives, encased in thin-walled, aluminum cylinders, will not initiate as a result of either direct impact by a 225 gpf FLSC jet tip, or by liner "slap" mechanisms. The CTH hydrocode predicts that detonation will initiate in the LX-14 explosive by shock wave superposition along the symmetry axis of the HE-filled cylinder. Some minor decomposition of CompB is also predicted to occur along the cylinder's symmetry axis, but detonation does not occur. Experiments conducted on HE-filled, thin-walled cylinders qualitatively verify the hydrocode predictions insofar as experiments that involve CompB did not detonate, whereas

experiments on LX-14 did detonate. The precise location of where the LX-14 detonation initiated could not be detected, as radiography was not used in this test series. We surmise that the LX-14 detonation initiated at a point interior to the body as a result of the superposition of shock waves. The actual detonation most likely initiated at a point not on the cylinder axis, since the experiment is fundamentally nonaxisymmetric. Radiography and a fully three-dimensional CTH simulation could be used to verify this inference in future work.

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- Steinberg, D. J., and C. M. Lund. "A Constitutive Model for Strain Rates From 10^{-4} to 10^6 s $^{-1}$." Journal of Applied Physics, vol. 65, no. 4, 1989.

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APPENDIX A:
COMPB SIMULATION INPUT DECK

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```

*
*eor*cgenin
*
2d-cth-mmp simulation of NEOD Phase III LSC detonation
*
control
  ep
  mmp
endcontrol
*
mesh
  block geometry 2dc type e
  x0=0.0
  x1 n=70 w=4.747 dxl=0.0055
  x2 n=3 w=0.0155 rat=1
  x3 n=110 w=1.252 dxl=0.0055
  x4 n=17 w=1.5 dxl=0.021
  endx
  y0=0.0
  y1 dyf 0.15 dyl 0.05 w 2.54
  y2 dyf 0.05 dyl 0.0055 w 1.27
  y3 dyf 0.0055 dyl 0.05 w 1.27
  y4 dyf 0.05 dyl 0.15 w 2.54
  endy
  xact=4.76,5.95
  yact=3.24,4.40
endblock
endmesh
*
insertion of material
  block 1
  *
  package 'AL Case - 1'
  material 1
  numsub 50
  pressure 1.0e6
  insert box
  x1 4.747 x2 4.76250
  y1 0.000 y2 15.24000
  endinsert
  endpackage
  *
  package 'HE Patty - 1'
  material 2
  numsub 50

```

```
pressure 1.0e6
insert box
  x1 0.000  x2 4.74700
  y1 2.540  y2 5.08000
endinsert
endpackage
```

*

```
package 'HE LSC - 1'
```

```
material 3
numsub 50
```

- * G. Kerley told me (12/1/94) that RDX @ $\rho=1.70$ g/cc detonates at
- * $T=3560\text{K}=0.30678\text{eV}$; $P_0=13.8\text{GPa}$. This calculation was done with BCAT
- * or PANDA. Specifying the insert at this temp is equivalent to
- * detonating the whole mass at time=0.

```
temperature 0.30678
```

```
insert uds
```

```
point 5.24615 3.81328
point 5.24615 3.77718
point 5.24615 3.71811
point 5.23957 3.66561
point 5.21983 3.60982
point 5.20009 3.56716
point 5.16719 3.51465
point 5.14087 3.46543
point 5.13758 3.44902
point 5.14416 3.42933
point 5.15403 3.41948
point 5.17706 3.41292
point 5.20338 3.41620
point 5.25273 3.41620
point 5.30538 3.41620
point 5.35473 3.41620
point 5.39421 3.42276
point 5.42382 3.43589
point 5.44685 3.45230
point 5.48304 3.48183
point 5.52253 3.51465
point 5.56859 3.56388
point 5.63768 3.63607
point 5.69361 3.69186
point 5.73639 3.73452
point 5.75284 3.75749
point 5.75613 3.77390
point 5.75942 3.80344
point 5.75613 3.82969
point 5.75613 3.84938
point 5.72652 3.88548
```

point 5.67058 3.95111
point 5.61465 4.00362
point 5.51595 4.10535
point 5.45672 4.15457
point 5.43040 4.17755
point 5.40737 4.19395
point 5.37118 4.20052
point 5.29551 4.21364
point 5.20667 4.22021
point 5.16390 4.22021
point 5.13429 4.22021
point 5.12113 4.21036
point 5.11784 4.19724
point 5.12113 4.18411
point 5.13100 4.17098
point 5.14087 4.14473
point 5.15732 4.11191
point 5.18035 4.07253
point 5.20338 4.03643
point 5.22641 3.99377
point 5.23628 3.95439
point 5.23957 3.91173
point 5.24286 3.87563
point 5.24286 3.83625
point 5.24615 3.81656

endinsert

endpackage

package 'Lead LSC - 1'

material 4

numsub 50

pressure 1.0e6

insert uds

point 5.19022 3.81000
point 5.19351 3.79031
point 5.19351 3.76078
point 5.18693 3.74437
point 5.17706 3.73452
point 5.13100 3.68202
point 5.06519 3.60982
point 4.93359 3.47527
point 4.80527 3.34401
point 4.77895 3.31775
point 4.77237 3.31119
point 4.76579 3.29478
point 4.76579 3.27509
point 4.77237 3.25868
point 4.78553 3.24556

point	4.80198	3.24227
point	4.82172	3.24227
point	4.87437	3.24227
point	5.12113	3.24556
point	5.29880	3.24227
point	5.33828	3.24556
point	5.39092	3.25212
point	5.43369	3.26196
point	5.46659	3.28494
point	5.52911	3.34072
point	5.66071	3.47199
point	5.79232	3.60326
point	5.91405	3.72468
point	5.93051	3.75093
point	5.94038	3.77390
point	5.94696	3.79359
point	5.94696	3.81656
point	5.94367	3.83625
point	5.93380	3.85266
point	5.92392	3.86579
point	5.89760	3.89532
point	5.83838	3.95767
point	5.76600	4.02659
point	5.70348	4.08894
point	5.63439	4.15457
point	5.55872	4.23333
point	5.46988	4.33178
point	5.45014	4.35147
point	5.43369	4.36788
point	5.41395	4.37444
point	5.38763	4.37773
point	5.30867	4.38101
point	5.20009	4.38101
point	5.03229	4.38429
point	4.84804	4.38757
point	4.80198	4.39085
point	4.78224	4.38101
point	4.77237	4.37116
point	4.76908	4.35804
point	4.76908	4.34819
point	4.77237	4.33178
point	4.78224	4.31537
point	4.81843	4.27928
point	4.88424	4.21036
point	4.95991	4.12504
point	5.05203	4.02987
point	5.11126	3.96424

```

point 5.15403 3.92486
point 5.17377 3.89204
point 5.18693 3.86579
point 5.19022 3.83953
point 5.19022 3.81656
endinsert
endpackage
*
package 'Cu Damper - Bottom'
material 5
numsub 50
pressure 1.0e6
insert box
x1 0.258 x2 4.747
y1 2.032 y2 2.540
endinsert
endpackage
*
package 'Cu Damper - Top'
material 5
numsub 50
pressure 1.0e6
insert box
x1 0.258 x2 4.747
y1 5.080 y2 5.588
endinsert
endpackage
*
endblock
endinsertion
*
eos
*
* Aluminum Mie-Grüneisen
mat1 mgrun eos=7075-t6_al feos='/b/scheffle/cth/MGR_data'
ro=2.804 cs=0.5200E6 s=1.360 go=2.20 cv=1.07E11
*
* Comp B Patty
* Parameters estimated to be roughly halfway between RDX and TNT.
* RP and R0 made identical per advice of G. Kerley, to avoid bug.
MAT2 SESAME EOS=8311 FEOS='/b/scheffle/cth/sesame'
RP=1.75 R0=1.75 CS=2.55E5 S=1.99 G0=1.0 CV=1.35E11
TYP=2.0 PR=9.0E10 ZR=3.00 MR=1.5 PI=0.5E10
RMAX=5.0 RMIN=0.01 TMAX=5.0 PT=1.0E13
** CEQ(I),I=1,40
** 8.3110E+03 0.0000E+00 1.0000E+00 1.7500E+00 2.5680E-02

```

```

** 0.0000E+00 -5.0519E+06 1.0000E+00 1.3500E+11 1.0000E-02
** 5.0000E+00 6.6333E-01 3.2835E-01 1.9371E-01 1.8038E-01
** 3.2767E+00 -1.9307E+12 4.4248E+12 1.3500E+09 2.0000E+00
** 5.0000E+00 1.5000E+00 3.0000E+00 9.0000E+10 7.0359E+10
** 2.5500E+05 1.9900E+00 5.0000E+09 1.7200E+00 9.6333E+00
** 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
** 0.0000E+00 0.0000E+00 0.0000E+00 5.1220E+01 9.9985E+01
*
* CH-6 (RDX=HMX) HE as LSC charge
mat3 SESAME EOS=8012 FEOS='/b/scheffle/cth/sesame'
  RP=1.70 R0=1.70
*
* Lead (6% Antimony) Mie-Gru (modified from Library data)
mat4 mgrun eos=lead_s feos='/b/scheffle/cth/MGR_data'
  ro=10.9 cs=0.2006E6 s=1.429 go=2.74 cv=1.5512E10
* Copper Mie-gruneisen
mat5 mgrun eos=copper feos='/b/scheffle/cth/MGR_data'
  ro=8.930 cs=3.940E5 s=1.489 go=1.99 cv=4.56E10
endeos
*
* heburn option not needed, with predetonated sesame option
**heburn
**endheburn
epdata
  vpsave
* Library 7075-T6 Al.
  matep 1 steinberg-guinan='7075-T6_ALUMINUM' fvp='/b/scheffle/cth/VP_data'
    poisson 0.16
  r0st=2.804 tm0st=0.105127 atmst=1.70 gm0st=2.20
  ast=6.52E-12 bst=7.148680 nst=0.10 c1st=0.00
  c2st=0.00 g0st=0.267E+12 btst=965.0 eist=0.00 ypst=0.00
  ukst=0.00 ysmst=0.00 yast=0.00 y0st=4.2E+09 ymst=8.1E+09
* Library Lead
  matep 4 steinberg-guinan='LEAD' fvp='/b/scheffle/cth/VP_data'
    poisson 0.43
  r0st=11.34 tm0st=0.065489 atmst=2.20 gm0st=2.74
  ast=11.63E-12 bst=13.461800 nst=0.52 c1st=0.00
  c2st=0.00 g0st=8.6E+10 btst=110.0 eist=0.00 ypst=0.00
  ukst=0.00 ysmst=0.00 yast=0.00 y0st=8.0E+07 ymst=1.0E+09
*
  matep 5 steinberg-guinan='COPPER' fvp='/b/scheffle/cth/VP_data'
    poisson 0.32
  r0st=8.93 tm0st=0.154244 atmst=1.50 gm0st=2.02
  ast=2.83E-12 bst=4.375085 nst=0.45 c1st=0.00
  c2st=0.00 g0st=0.477E+12 btst=36.0 eist=0.00 ypst=0.00
  ukst=0.00 ysmst=0.00 yast=0.00 y0st=1.2E+09 ymst=6.4E+09
*

```

```

mix 3
endep
*
*
*eor*cthin
*
2d-cth-mmp NEOD Phase III LSC detonation
*
control
  tstop=40.e-6
  * cpshift=900.
  * rdumpf=3600
  * ntbad 1000000
endcontrol
restart
  cycle=6832
  file='rs04h'
  newfile=all
endrestart
*
cellthermo
  mmp
endcell
*
convct
  convect=1
  nofrag=2
  interface=high
endc
*
discard
  material 3 density -0.01 pressure 5.0e6 ton 7.0e-6
endd
*
edit
  shortt
    tim=0. dt=10000.
  ends
  longt
    tim=0. dt=10000.
  endl
  plott
    time=0. dtfreq=5.0e-6
  endp
endedit
*
mindt

```

```

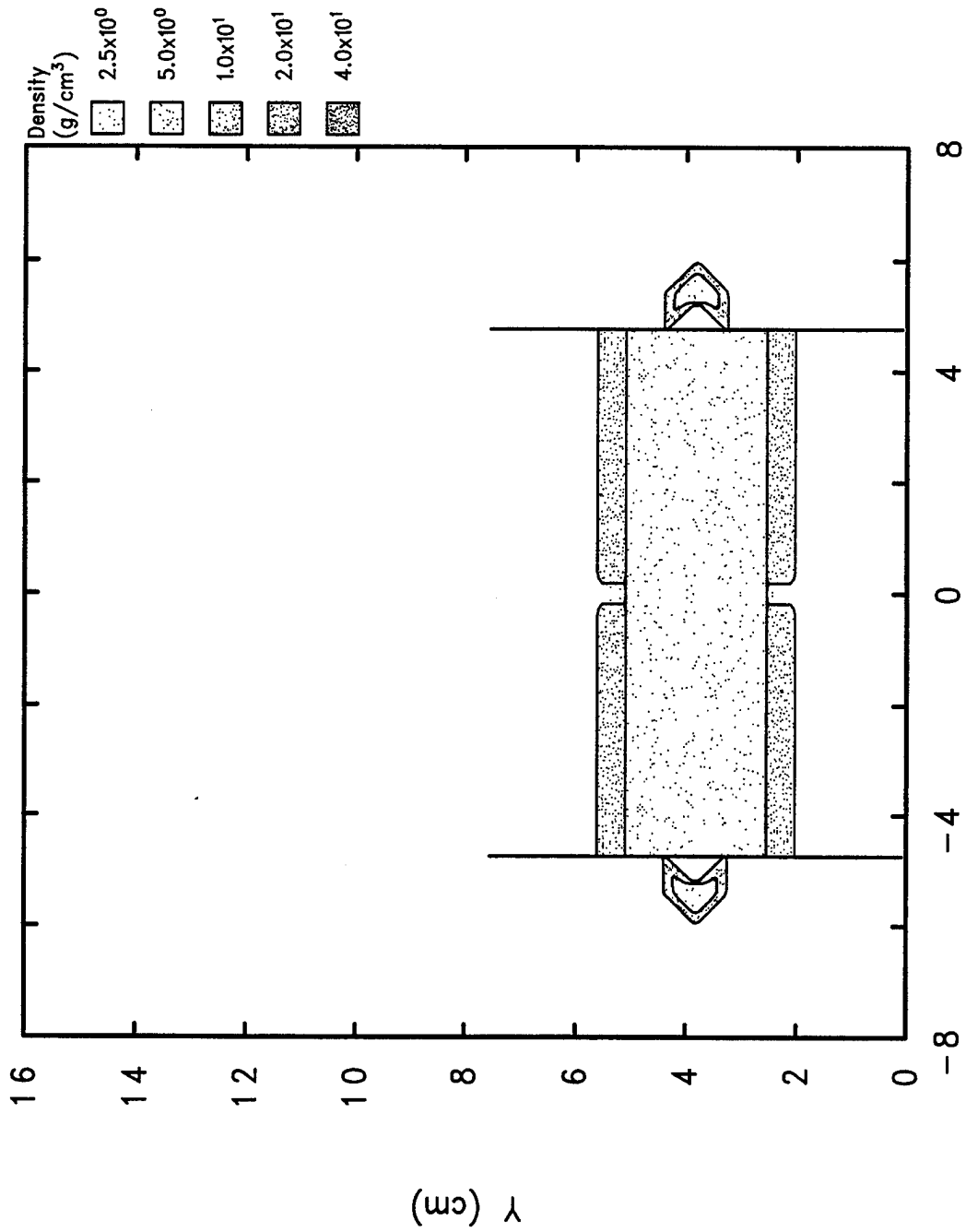
time=0.    dtmin=1.0e-13
endm
*
fracts
stress
pfrac1=-8.1E9
pfrac3=-1.0E9
pfmix =-5.0E6
pfvoid=-5.0E6
endf
*
boundary
bhydro
block=1
bxbot 0
bxtop 2
bybot 2
bytop 2
endb
endh
endb
*
*eor*pltin
*
units cgsev
*
nlegend=off
*
time,0.0e-6,rest
color table 4
units cgsk
limits x=-7.0,7.0,1 y=0.0,14.0,1
flegend=d
*2dplot,dots=density=2.,mirror,if

2dplot,materials,mirror
limits x=3.0,7.0,1 y=1.0,5.0,1
rbands, b1=1e6, b2=1e10, c1=256, c2=236, skip=-2
flegend=b
2dplot,materials
nlegend=on
2dplot bands=pressure, if
rbands, b1=0.0, b2=0.1, c1=256, c2=236, skip=-2
2dplot bands=hvb2, if
END OF FILE

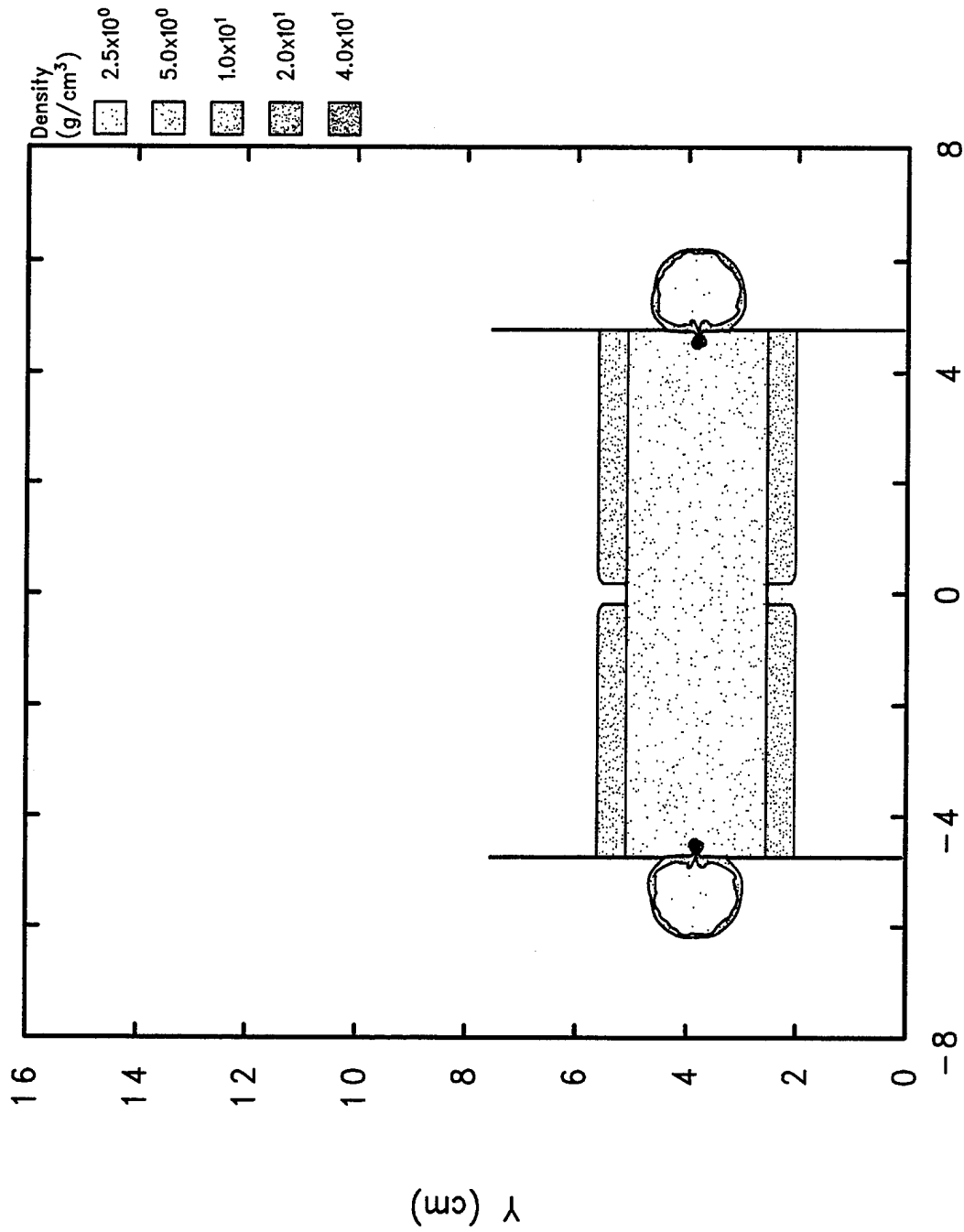
```

APPENDIX B:
COMPB COMPUTATIONAL RESULTS

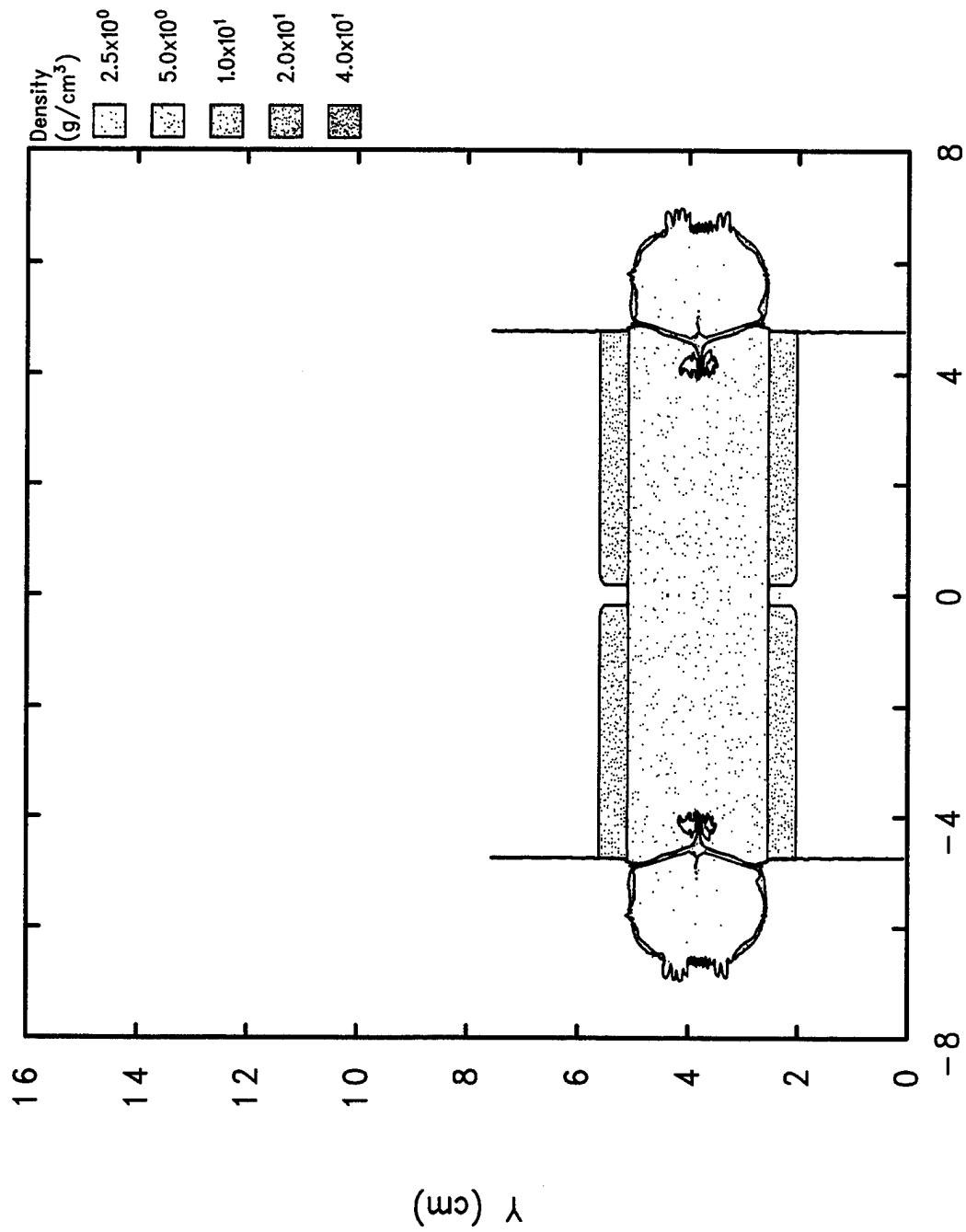
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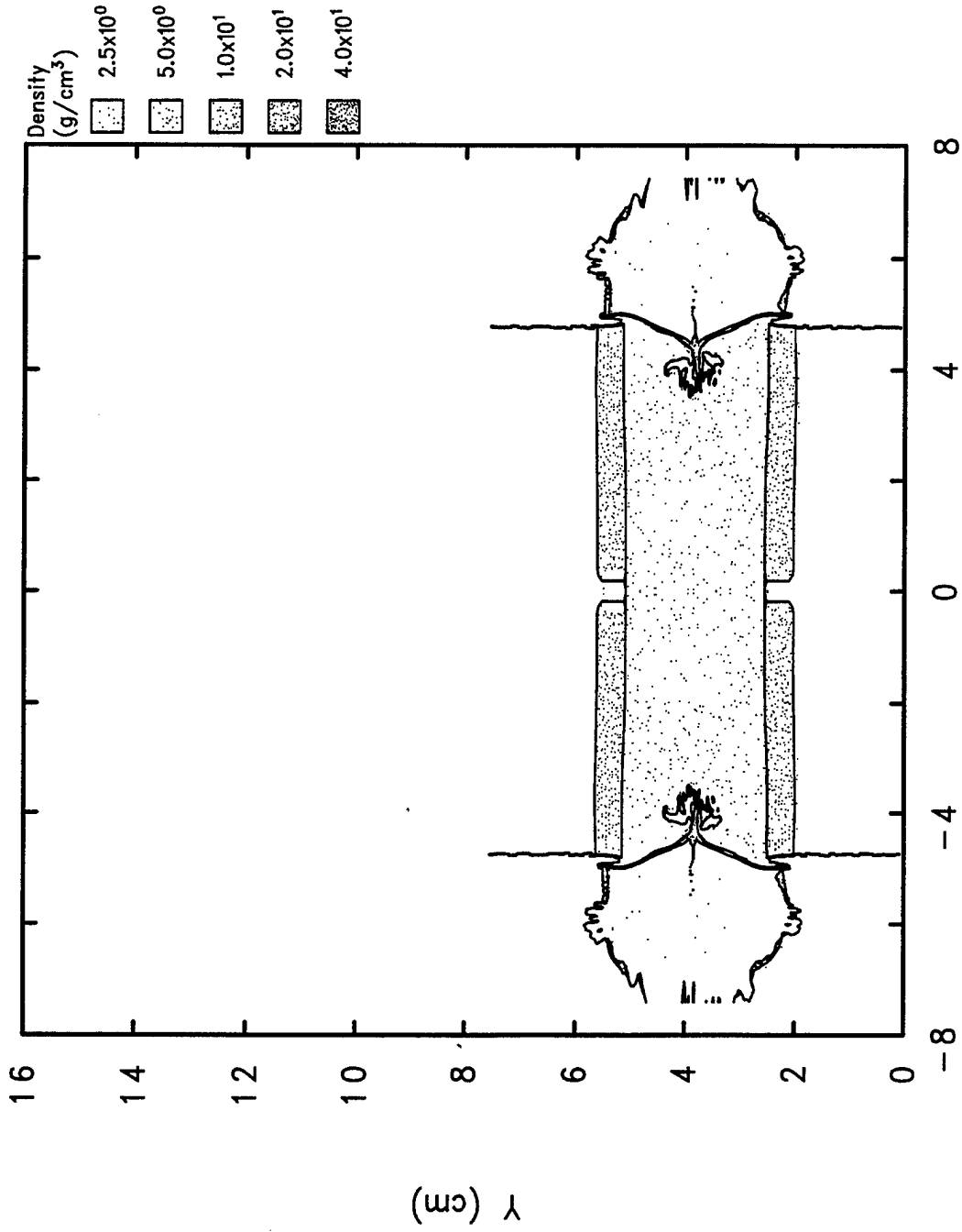
2DC Block 1
 2d-cth-mmp simulation of NEOD Phase III LSC detonation
 AXNATN G 1/24/95 13:08:27 CTH 0 Time=0.



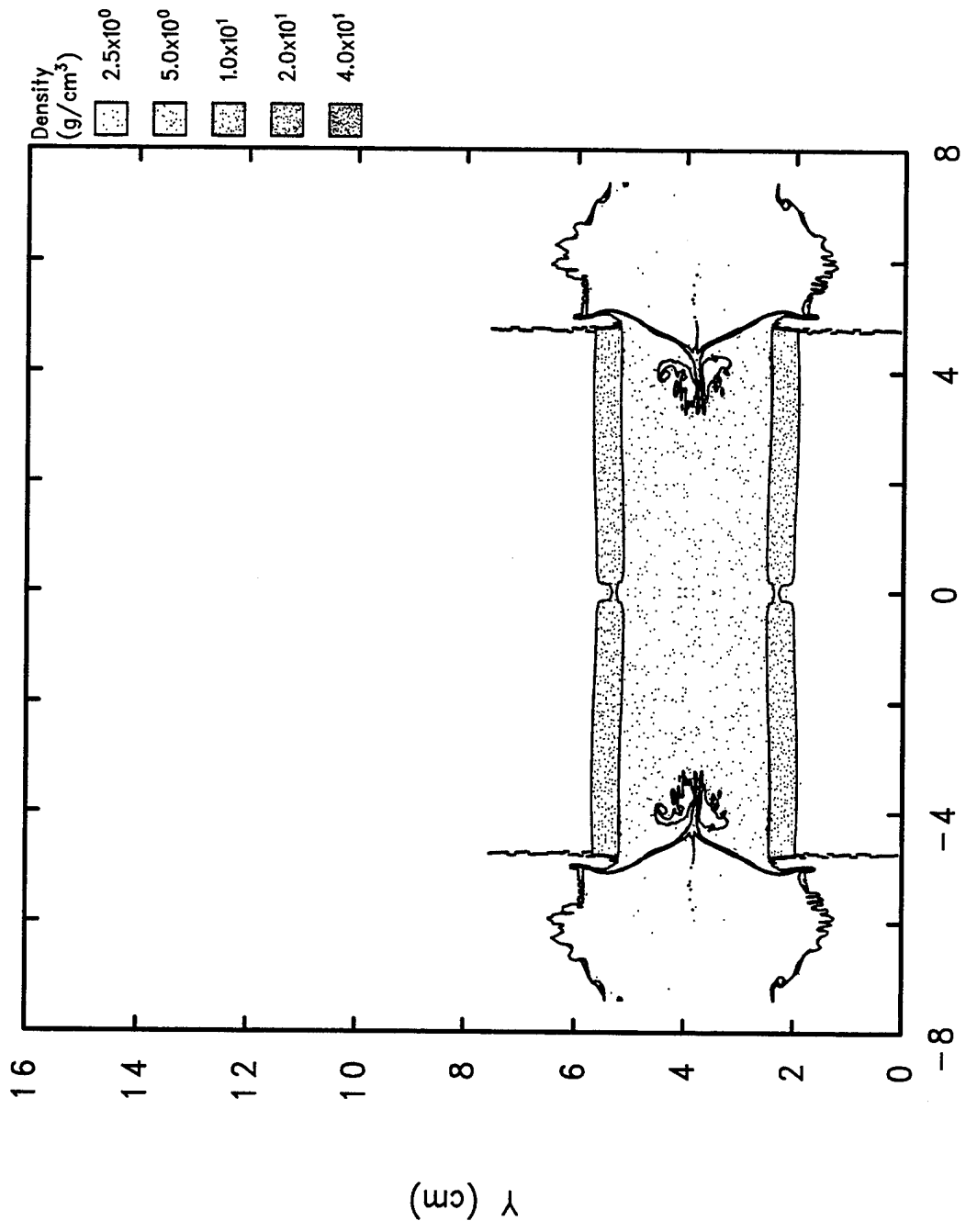
2DC Block 1
 2d-cth-mmp simulation of NEOD Phase III LSC detonation
 AXNCTT 1/24/95 19:45:27 CTH 1513 Time=5.00175x10⁻⁶



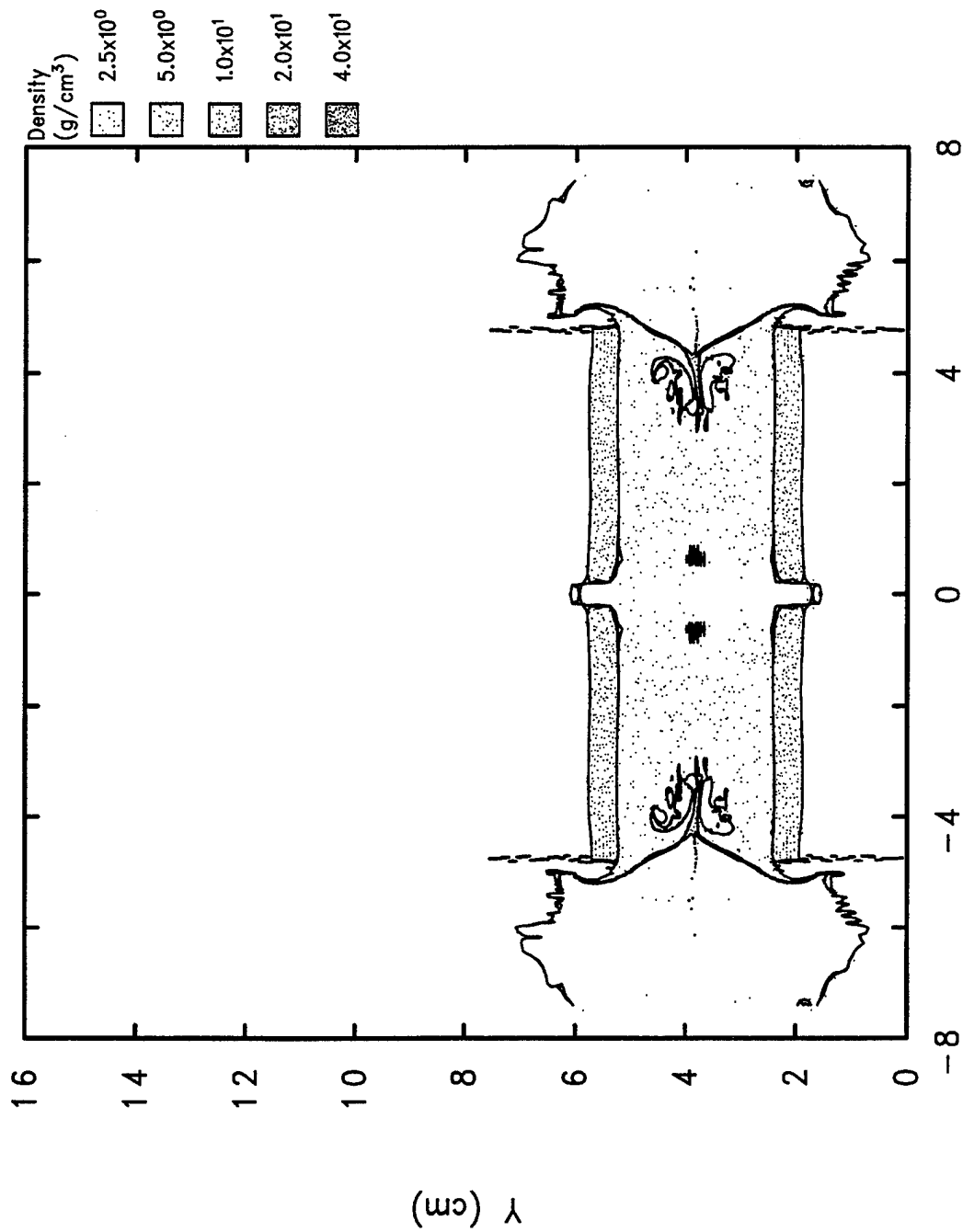
2DC Block 1
 2d-cth-mmp simulation of NEOD Phase III LSC detonation
 AXNCTT 1/25/95 01:34:57 CTH 2900 Time=1.00036x10⁻⁵



2DC Block 1
 2d-cth-mmp simulation of NEOD Phase III LSC detonation
 AYJAMT 1/25/95 10:03:14 CTH 4258 Time=1.50031x10⁻⁵



2DC Block 1
 2d-cth-mmp simulation of NEOD Phase III LSC detonation
 AYJAMT 1/25/95 18:13:15 CTH 5577 Time=2.00004x10⁻⁵

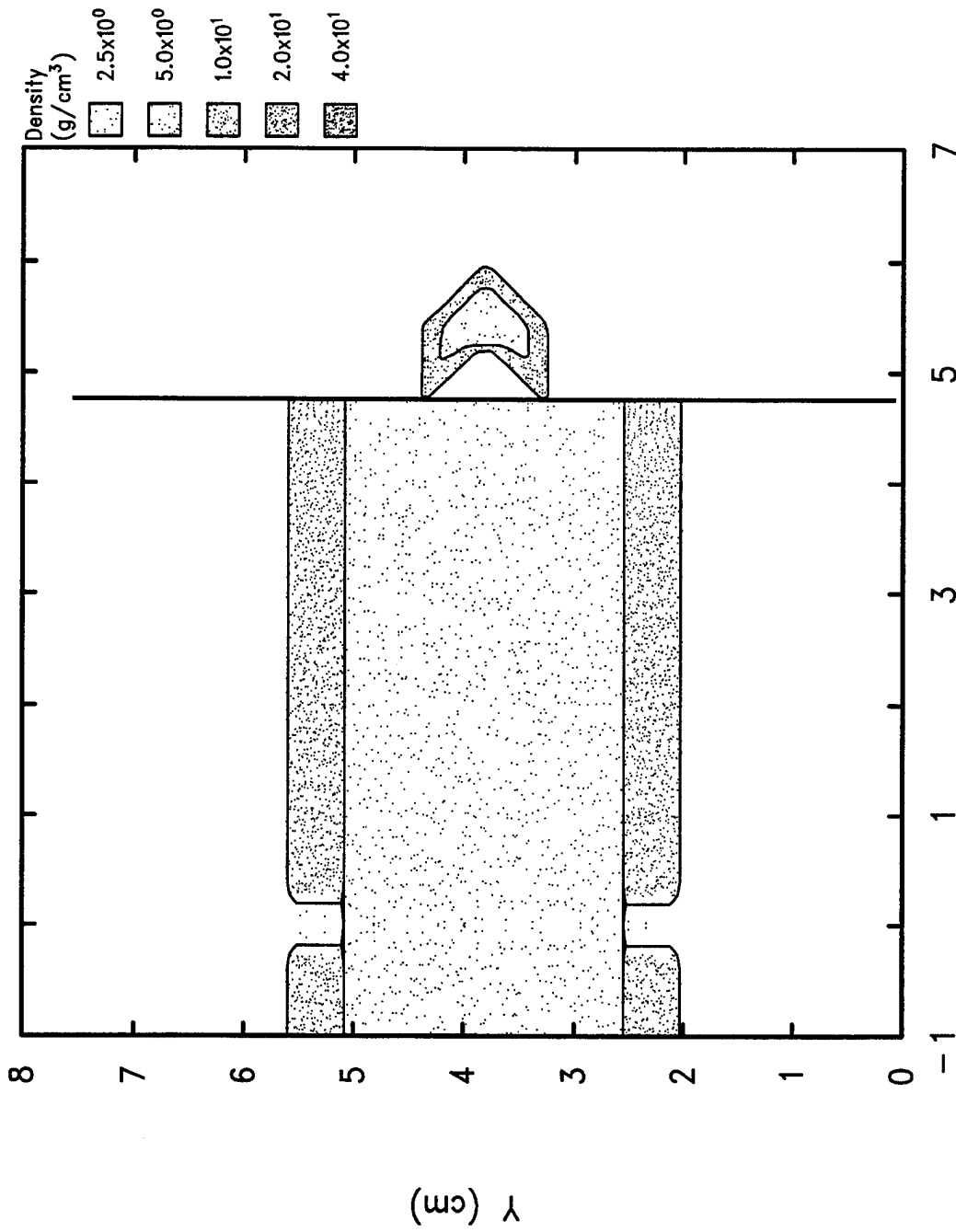


2DC Block 1

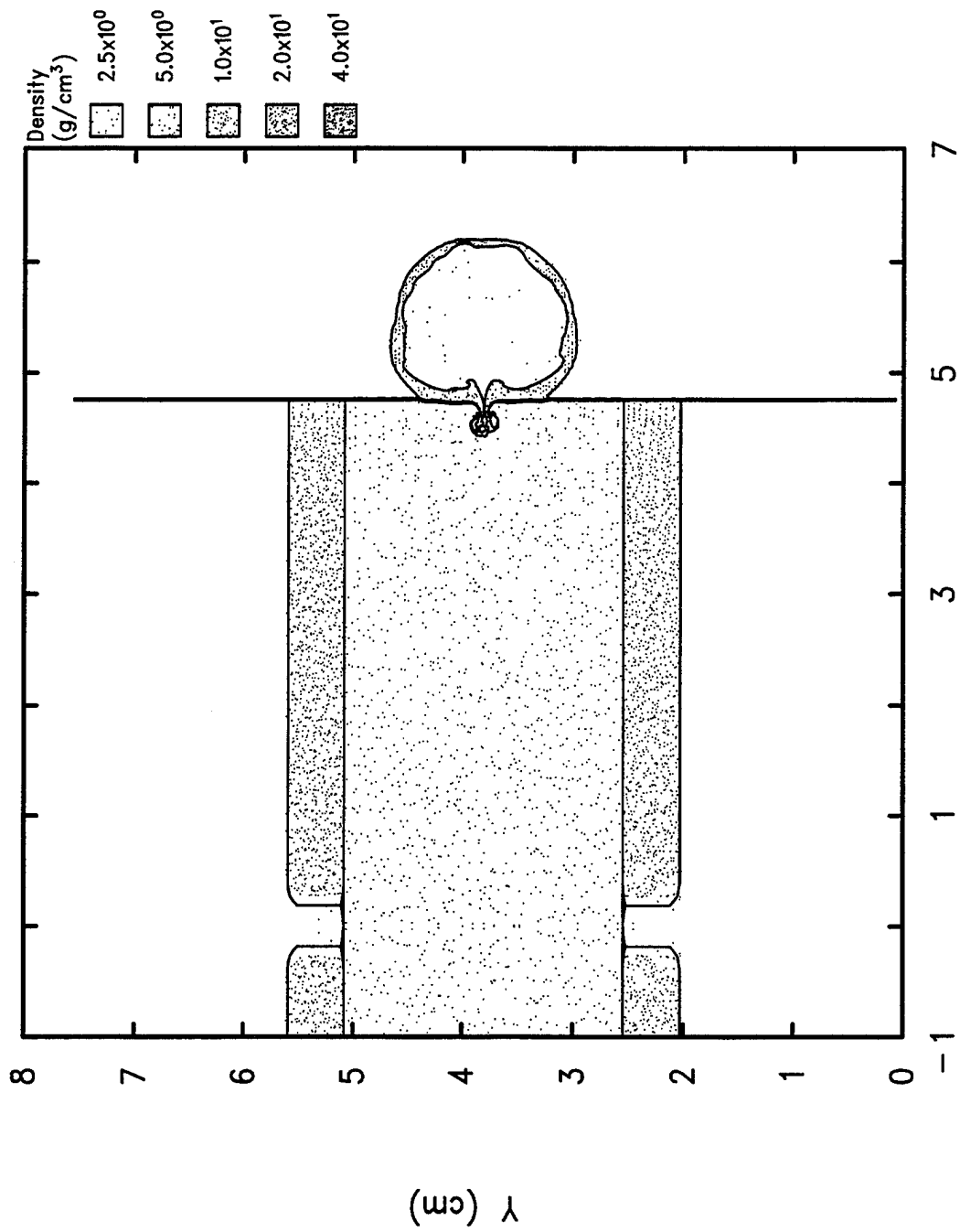
X (cm)

2d-cth-mmp simulation of NEOD Phase III LSC detonation

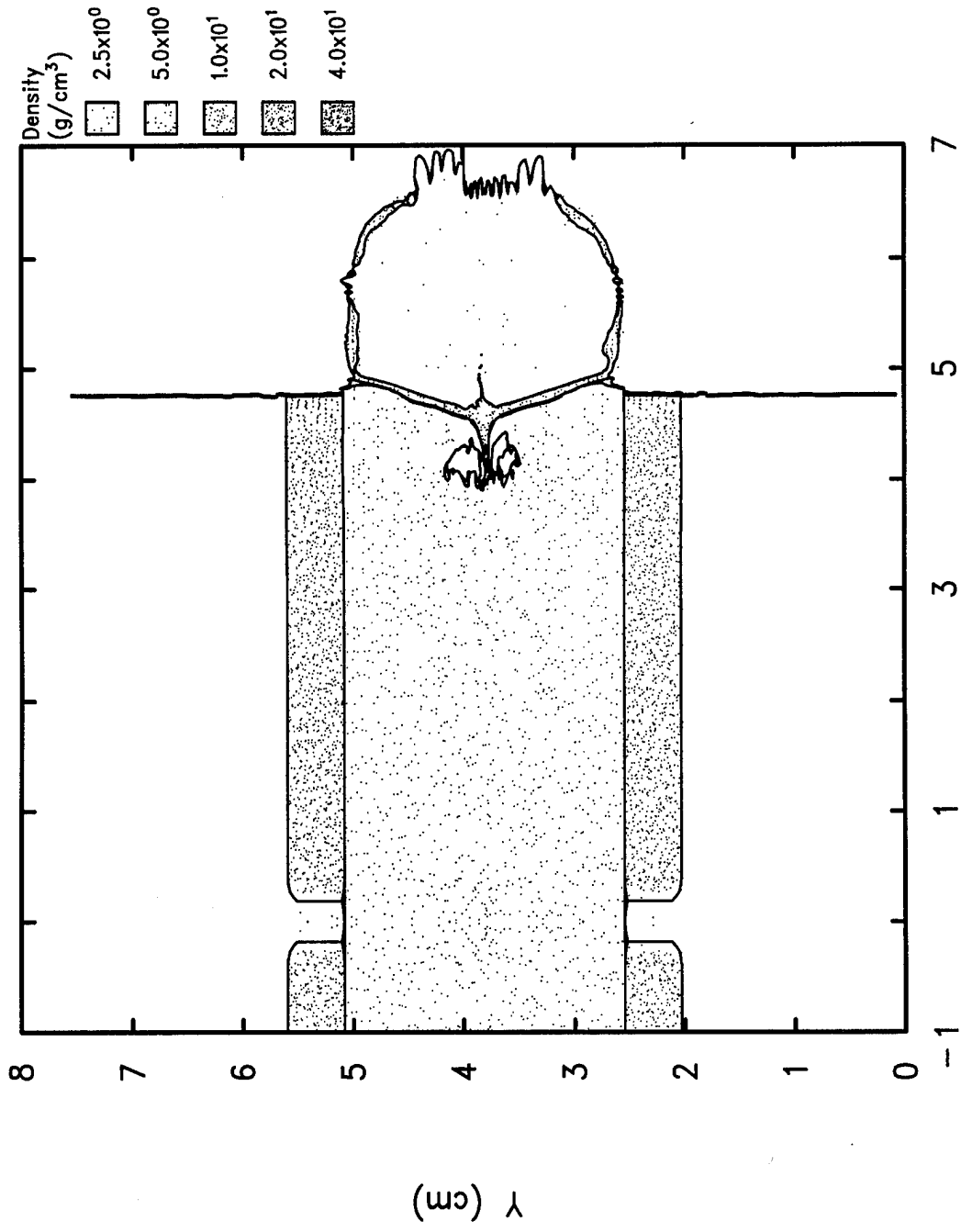
AYJAMT 1/26/95 00:39:35 CTH 6832 Time=2.48073x10⁻⁵



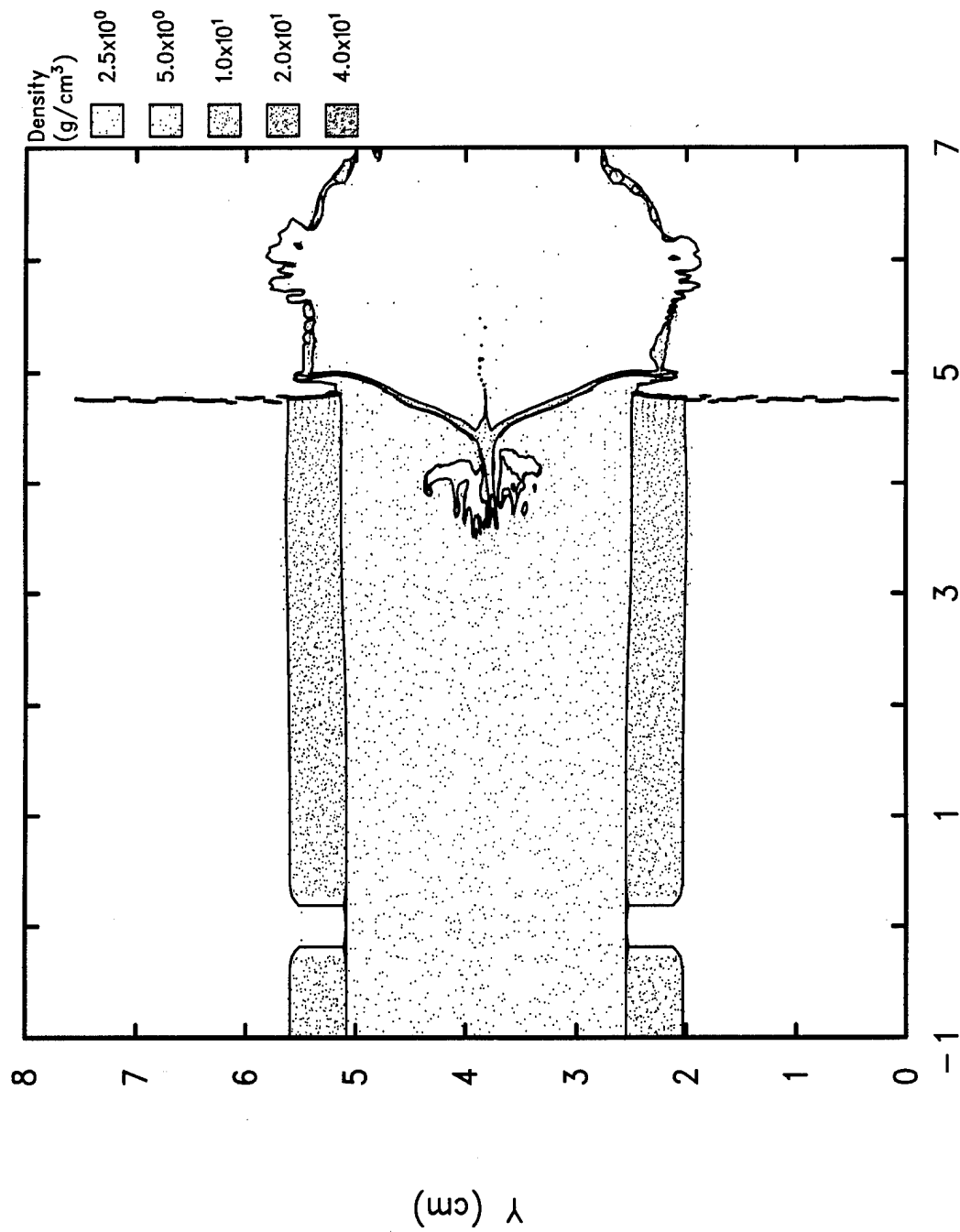
2DC Block 1
 2d-cth--mmp simulation of NEOD Phase III LSC detonation
 AXNATN G 1/24/95 13:08:27 CTH 0 Time=0.



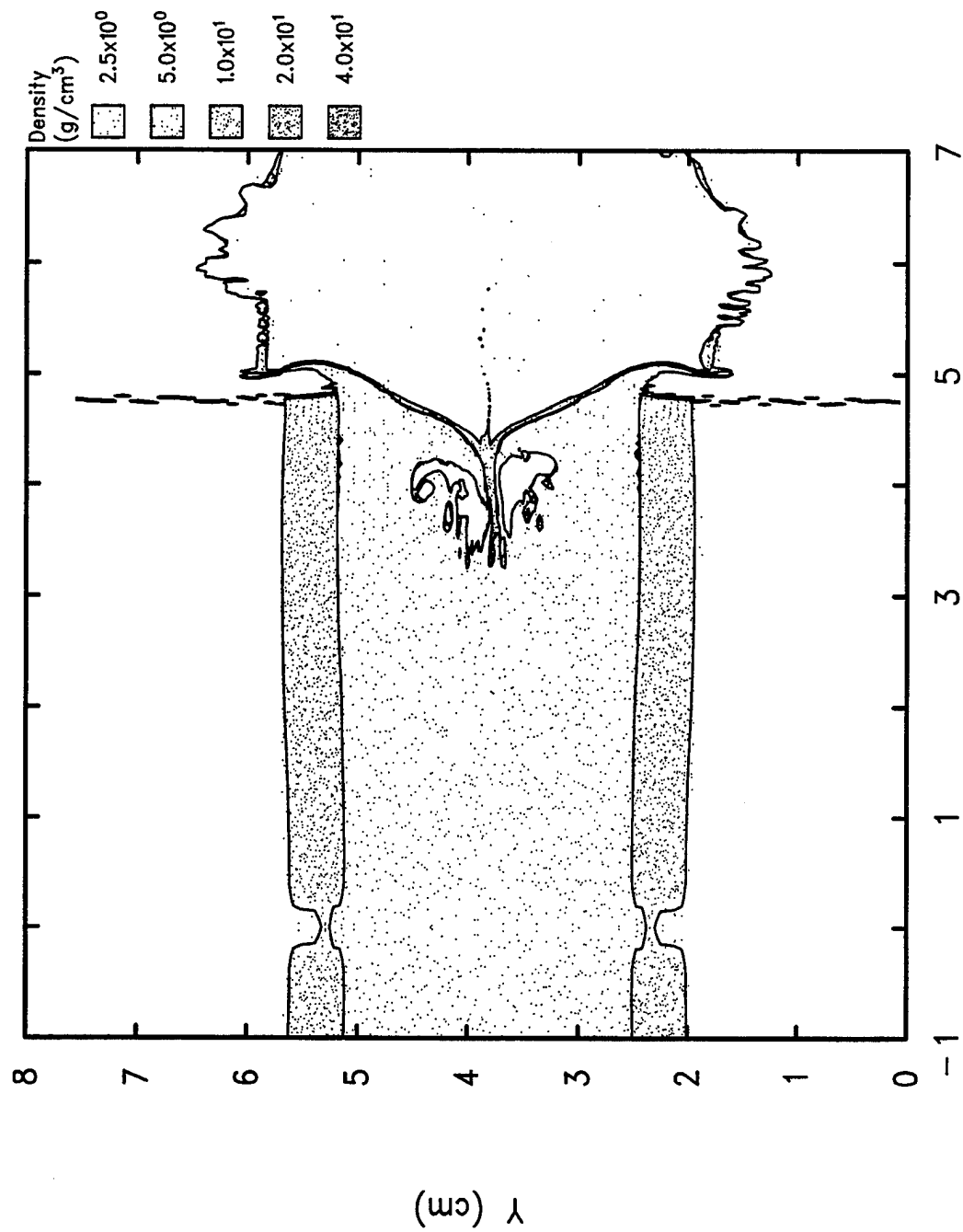
2DC Block 1
 2d-cth-mmp simulation of NEOD Phase III LSC detonation
 AXNCTT 1/24/95 19:45:27 CTH 1513 Time=5.00175x10⁻⁶



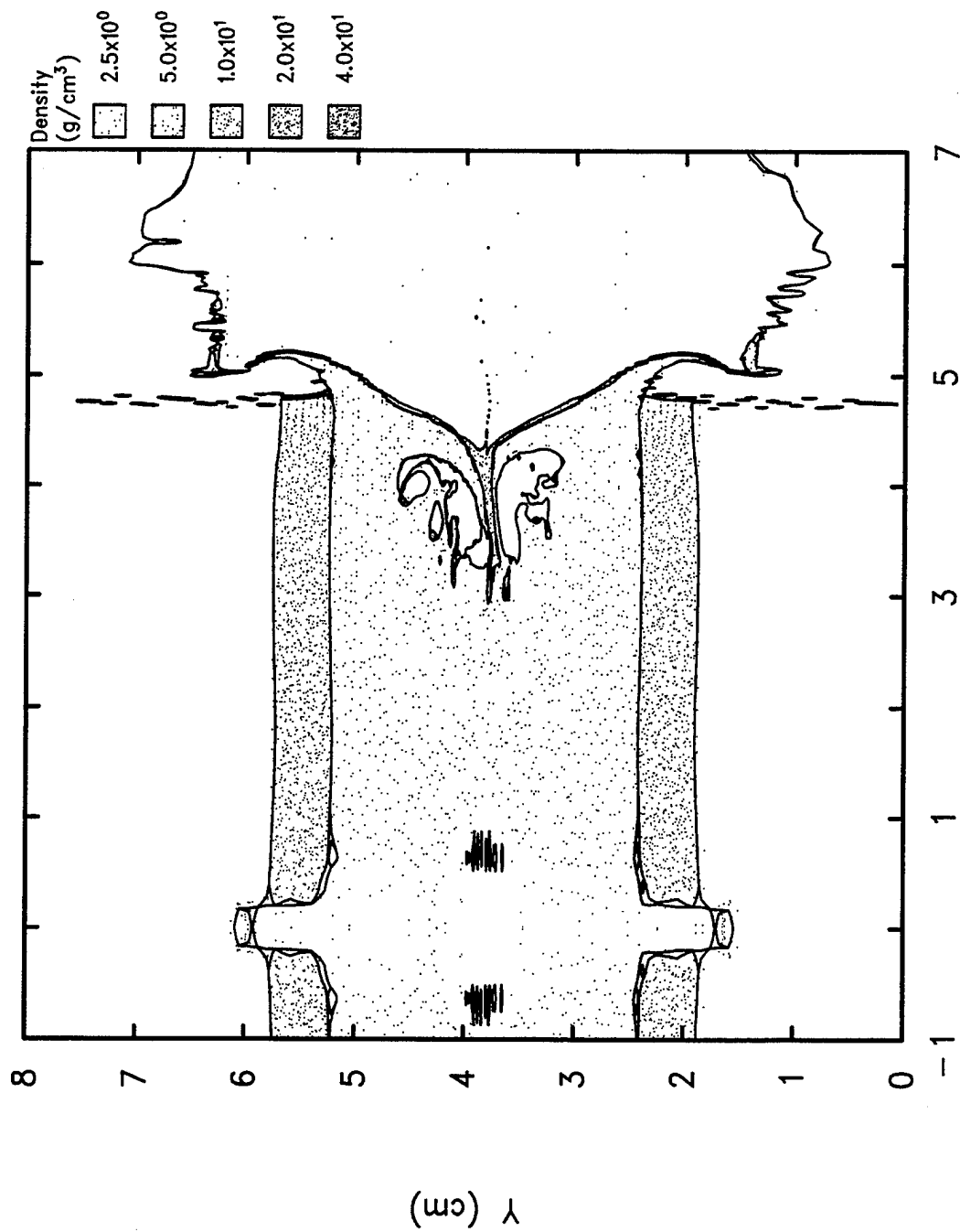
2DC Block 1
 2d-cth-mmp simulation of NEOD Phase III LSC detonation
 AXNCTT 1/25/95 01:34:57 CTH 2900 Time=1.00036x10⁻⁵



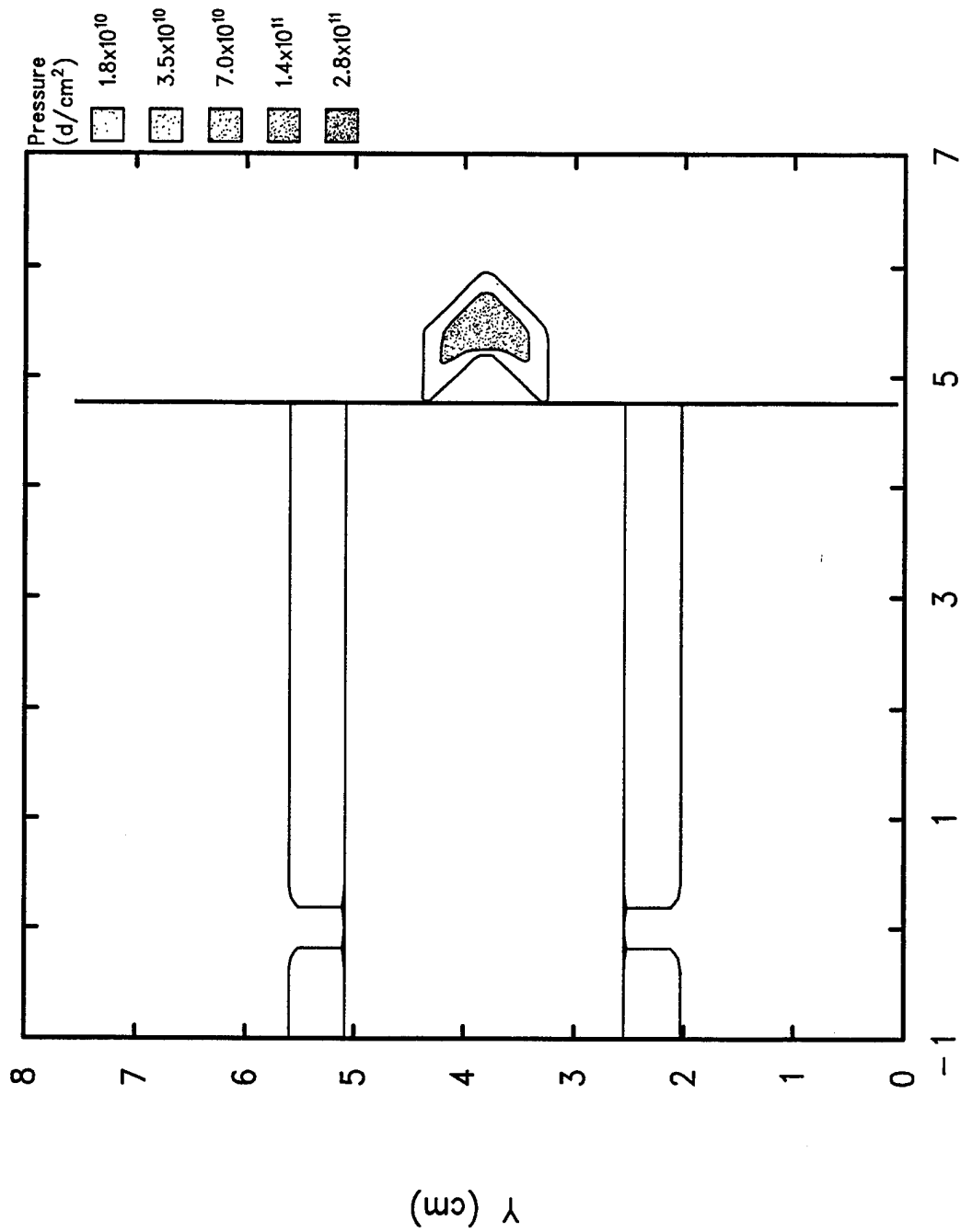
2DC Block 1
 2d-cth-mmp simulation of NEOD Phase III LSC detonation
 AYJAMT 1/25/95 10:03:14 CTH 4258 Time=1.50031x10⁻⁵



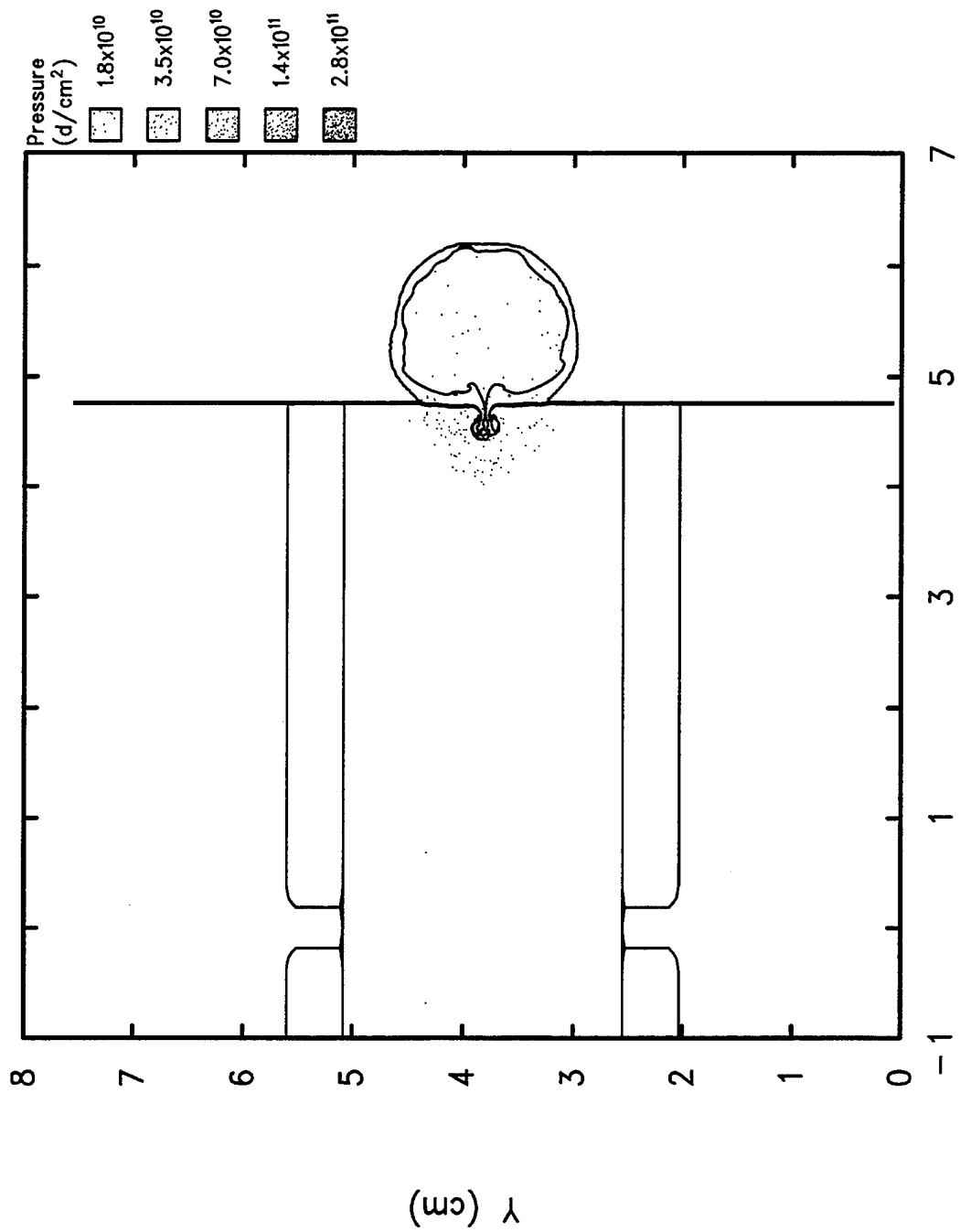
2DC Block 1
 2d-cth-mmp simulation of NEOD Phase III LSC defonation
 AYJAMT 1/25/95 18:13:15 CTH 5577 Time=2.00004x10⁻⁵



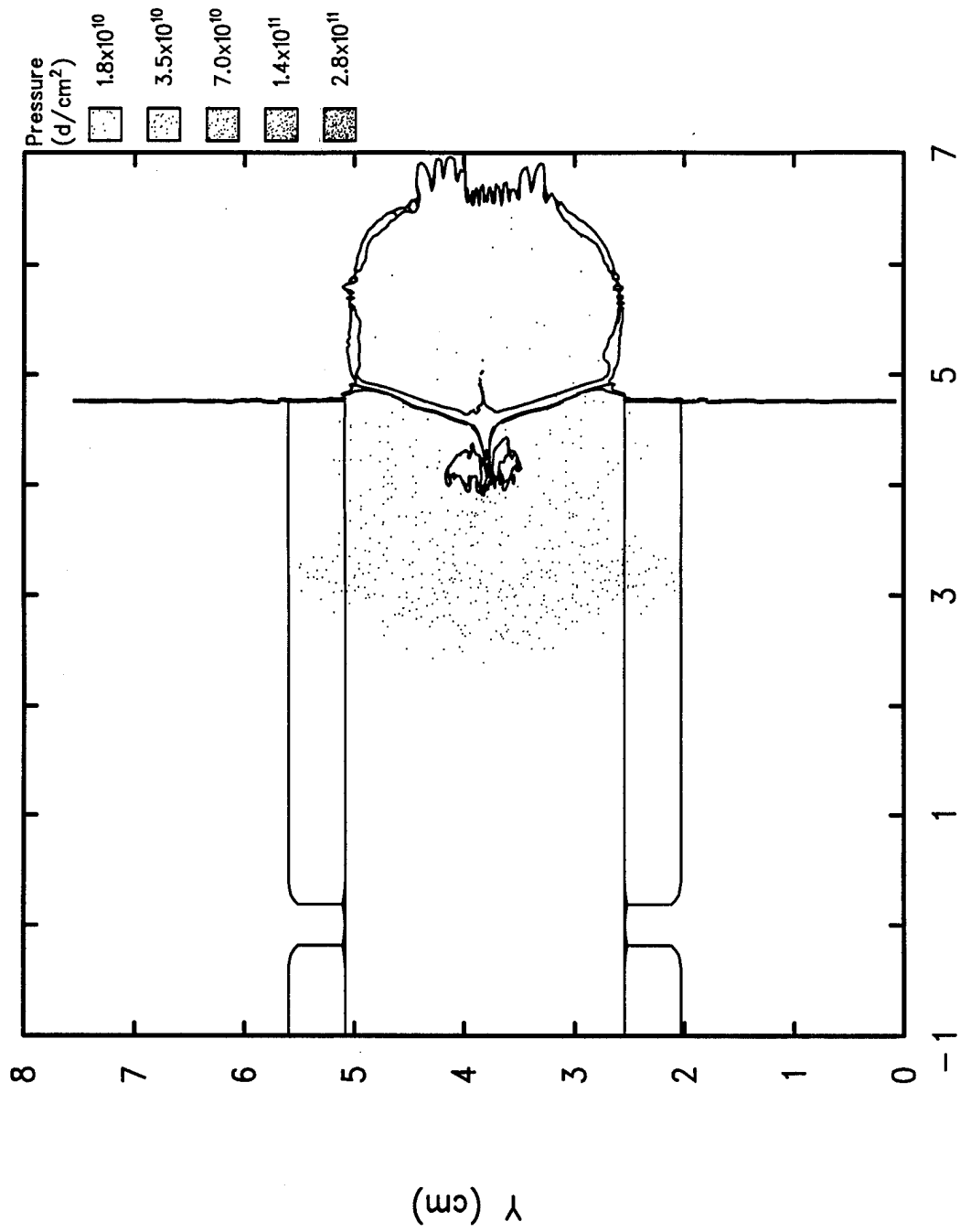
2DC Block 1 X (cm)
 2d-cth-mmp simulation of NEOD Phase III LSC detonation
 AYJAMT 1/26/95 00:39:35 CTH 6832 Time=2.48073x10⁻⁵



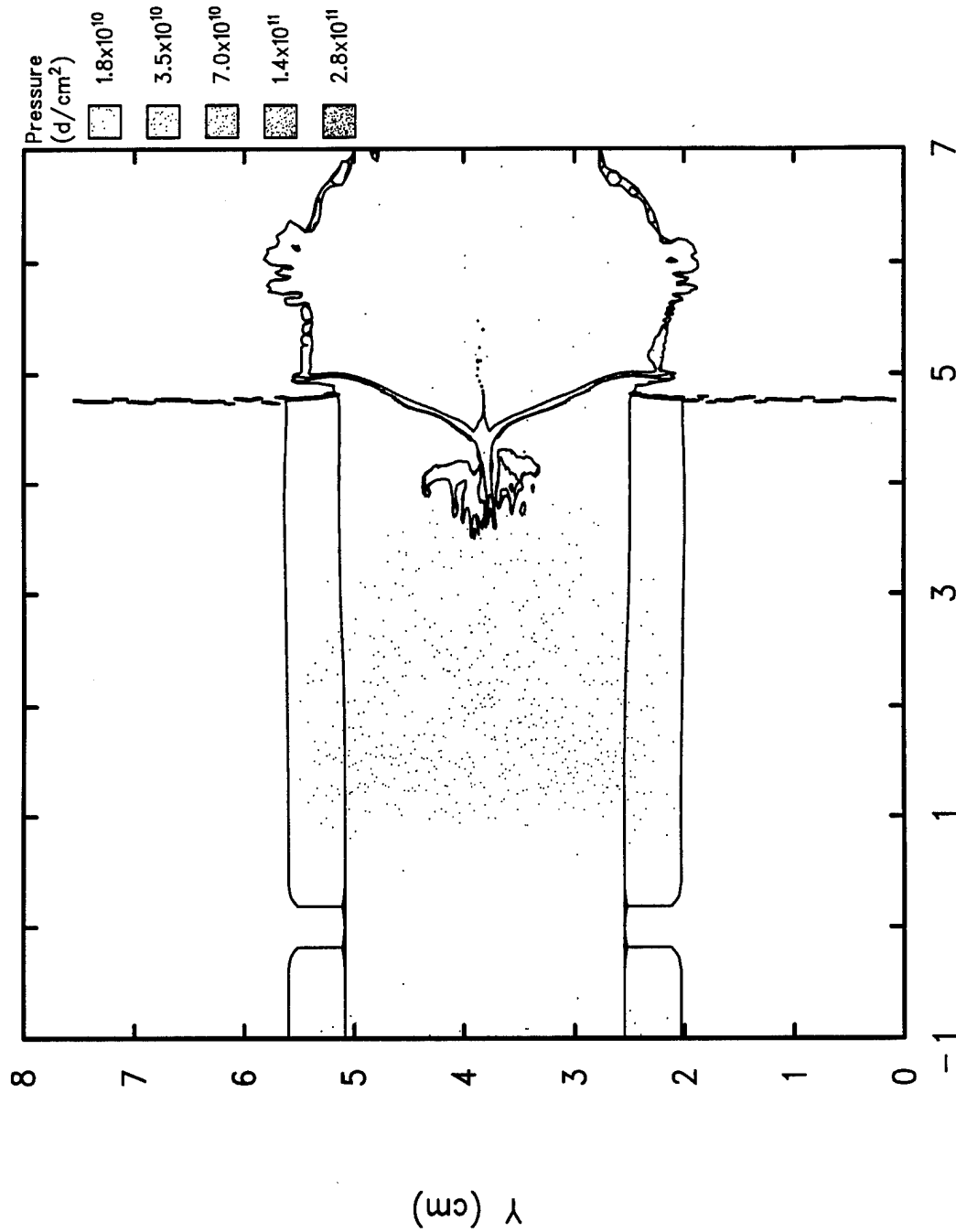
2DC Block 1
 2d-cth-mmp simulation of NEOD Phase III LSC detonation
 AXNATN G 1/24/95 13:08:27 CTH 0 Time=0.



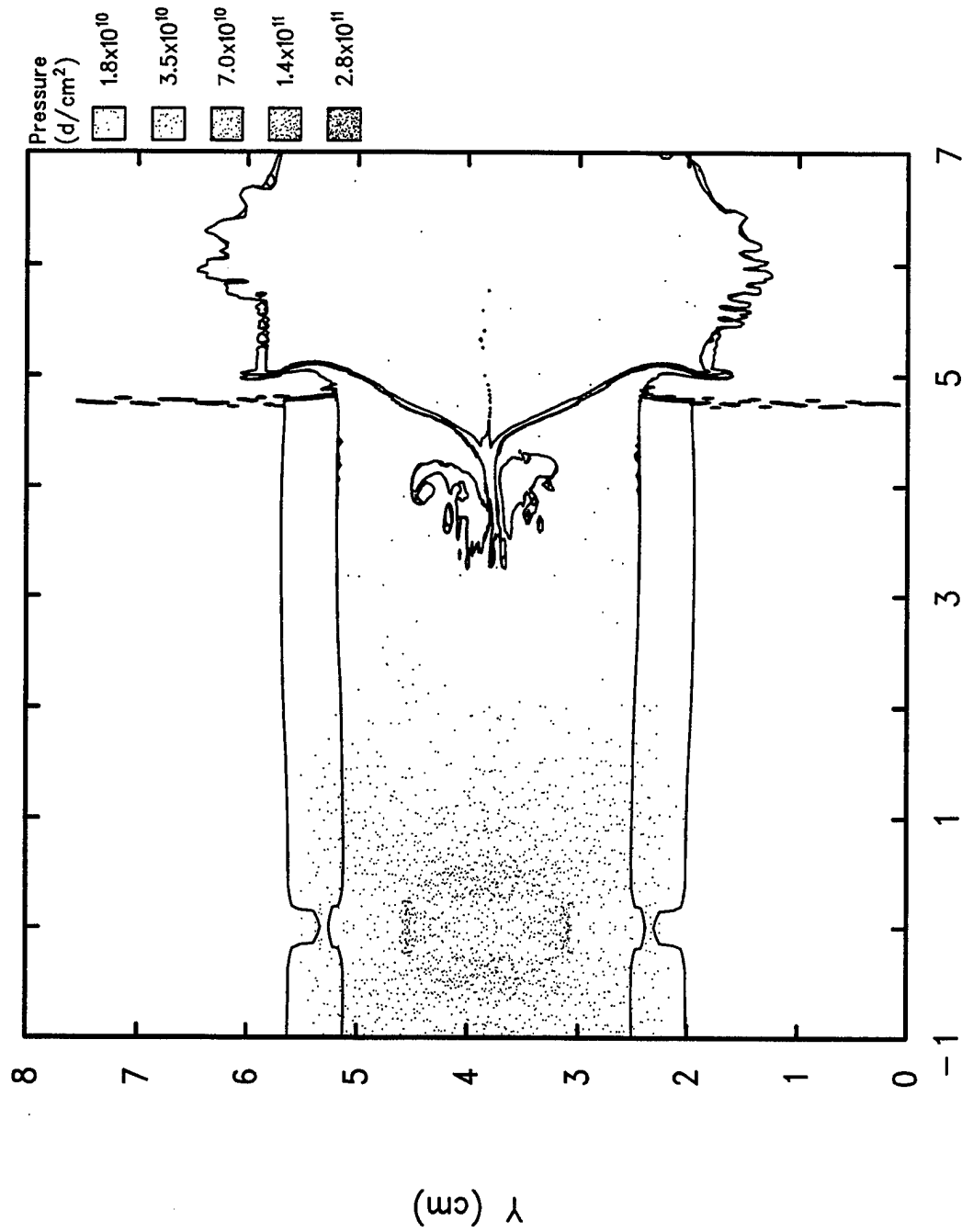
2DC Block 1
 2d-cth-mmp simulation of NEOD Phase III LSC detonation
 AXNCTT 1/24/95 19:45:27 CTH 1513 Time=5.00175x10⁻⁶



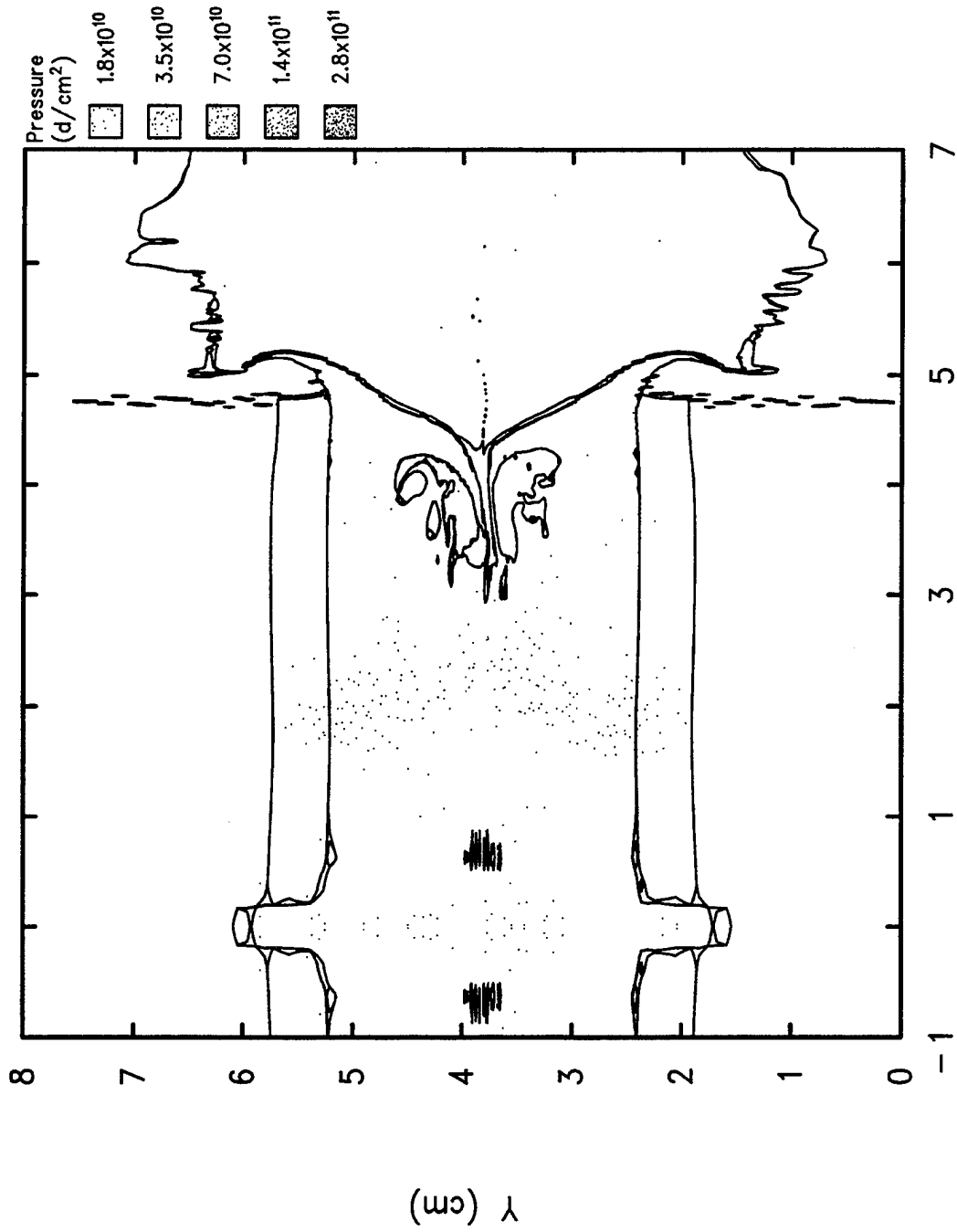
2DC Block 1
 2d-cth-mmmp simulation of NEOD Phase III LSC detonation
 AXNCTT 1/25/95 01:34:57 CTH 2900 Time=1.00036x10⁻⁵



2DC Block 1
 2d-cth-mmp simulation of NEOD Phase III LSC detonation
 AYJAMT 1/25/95 10:03:14 CTH 4258 Time=1.50031x10⁻⁵



2DC Block 1
 2d-cth-mmp simulation of NEOD Phase III LSC defonation
 AYJAMT 1/25/95 18:13:15 CTH 5577 Time=2.00004x10⁻⁵

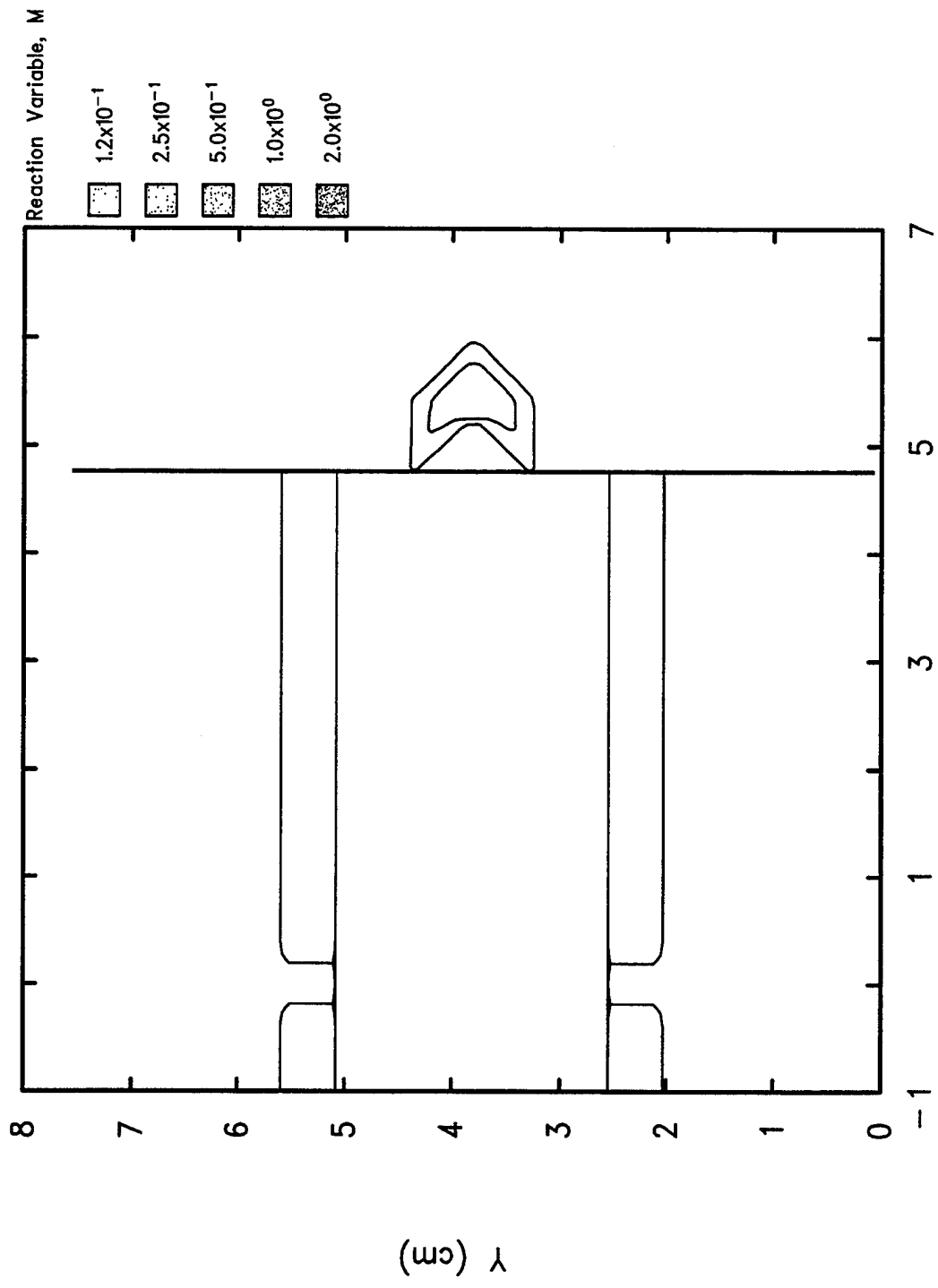


2DC Block 1

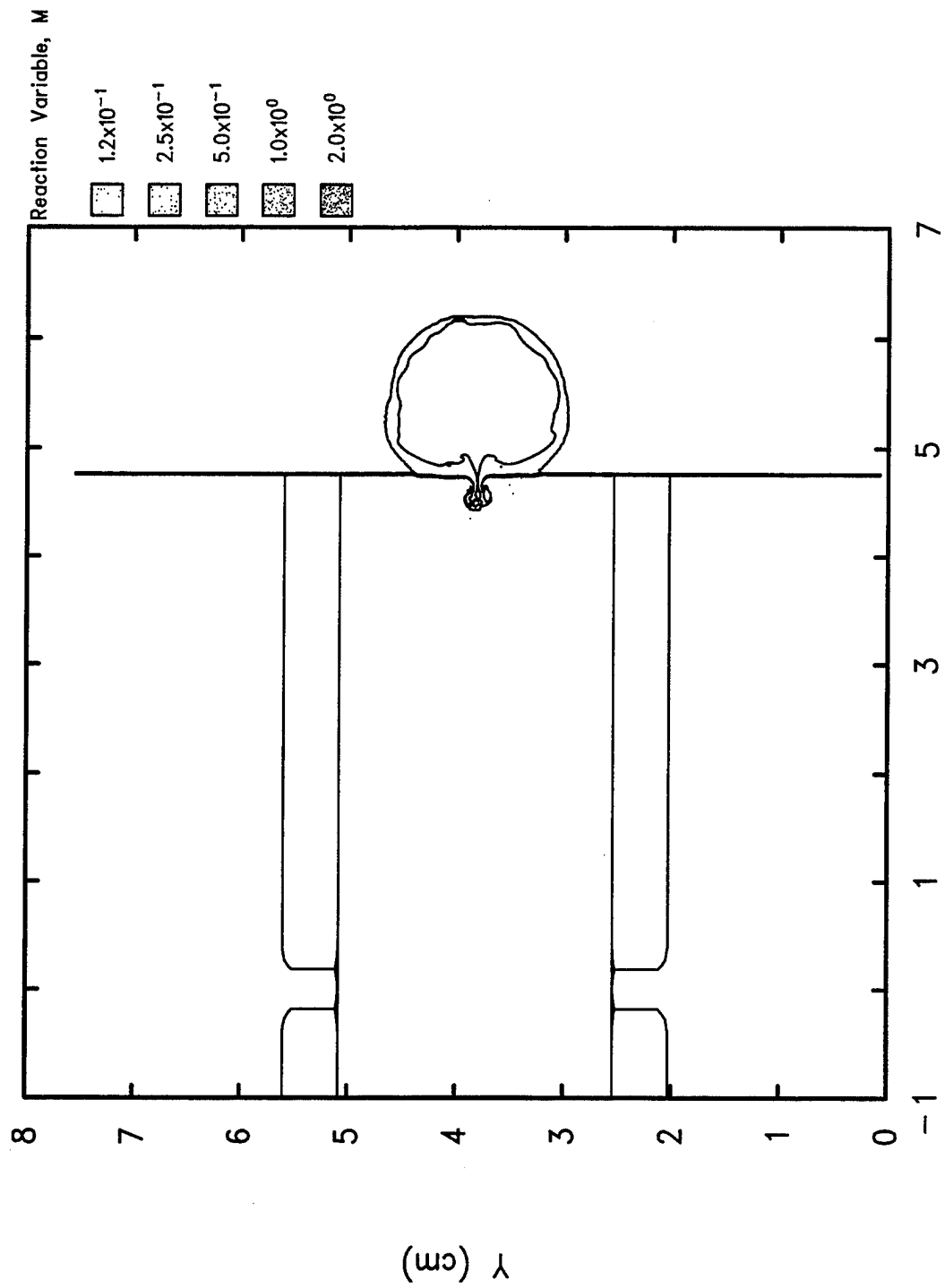
X (cm)

2d-cth-mmp simulation of NEOD Phase III LSC detonation

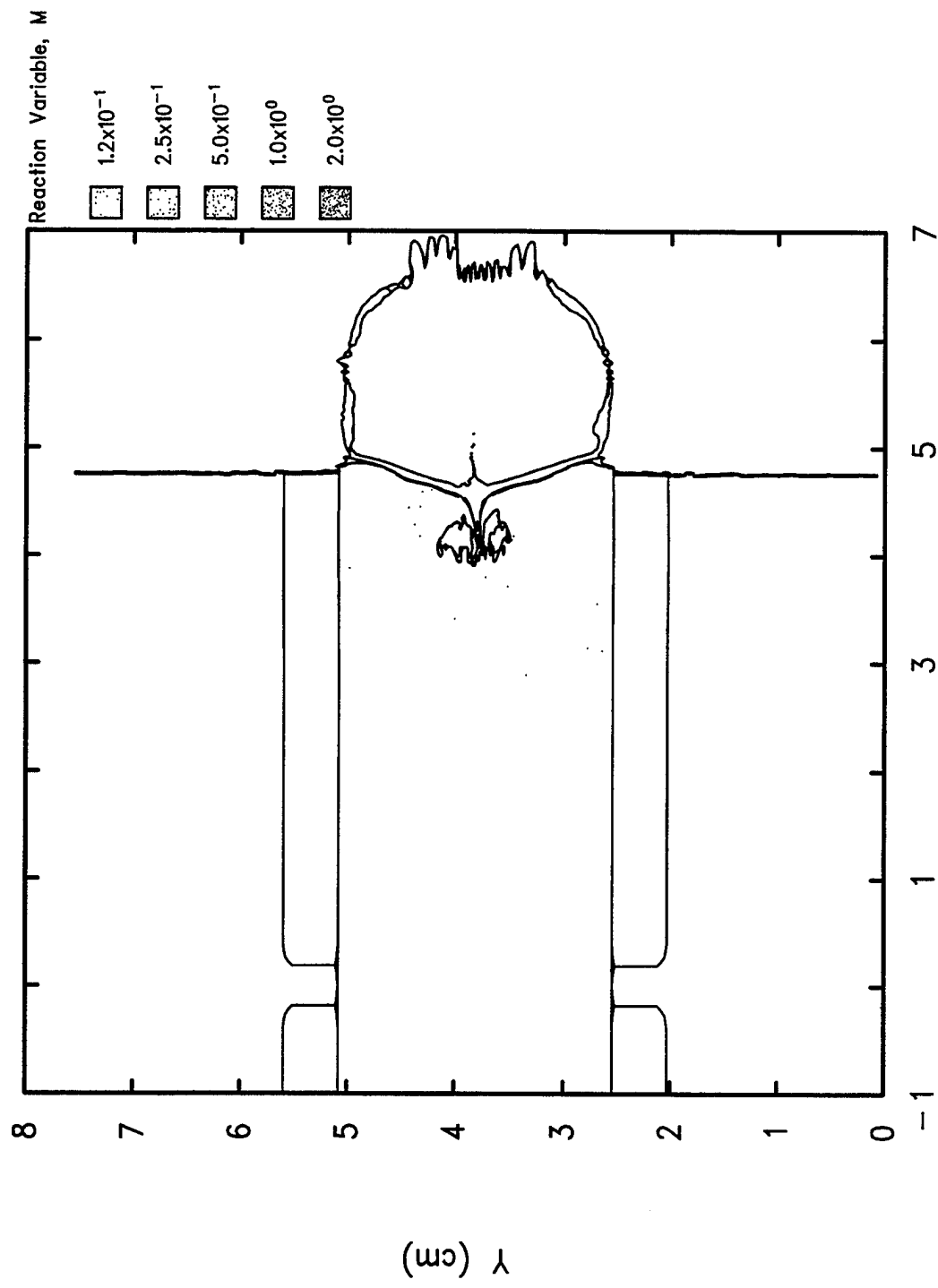
AYJAMT 1/26/95 00:39:35 CTH 6832 Time=2.48073x10⁻⁵



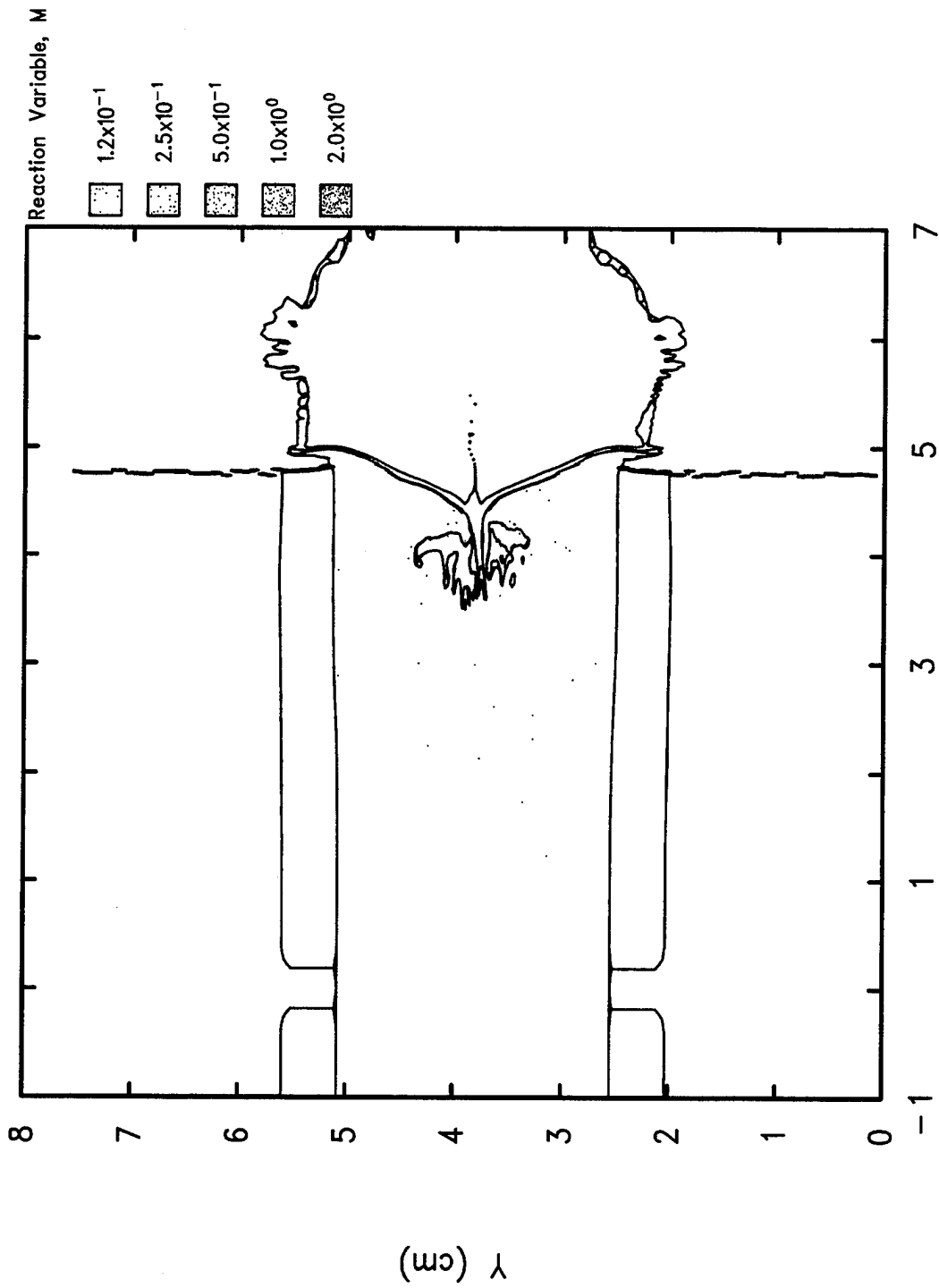
2DC Block 1
 2d-cth-mmp simulation of NEOD Phase III LSC detonation
 AXNATN G 1/24/95 13:08:27 CTH 0 Time=0.



2DC Block 1
 2d-cth-mmp simulation of NEOD Phase III LSC detonation
 AXNCTT 1/24/95 19:45:27 CTH 1513 Time=5.00175x10⁻⁶



2DC Block 1
 2d-cth-mmp simulation of NEOD Phase III LSC detonation
 AXNCTT 1/25/95 01:34:57 CTH 2900 Time=1.00036x10⁻⁵

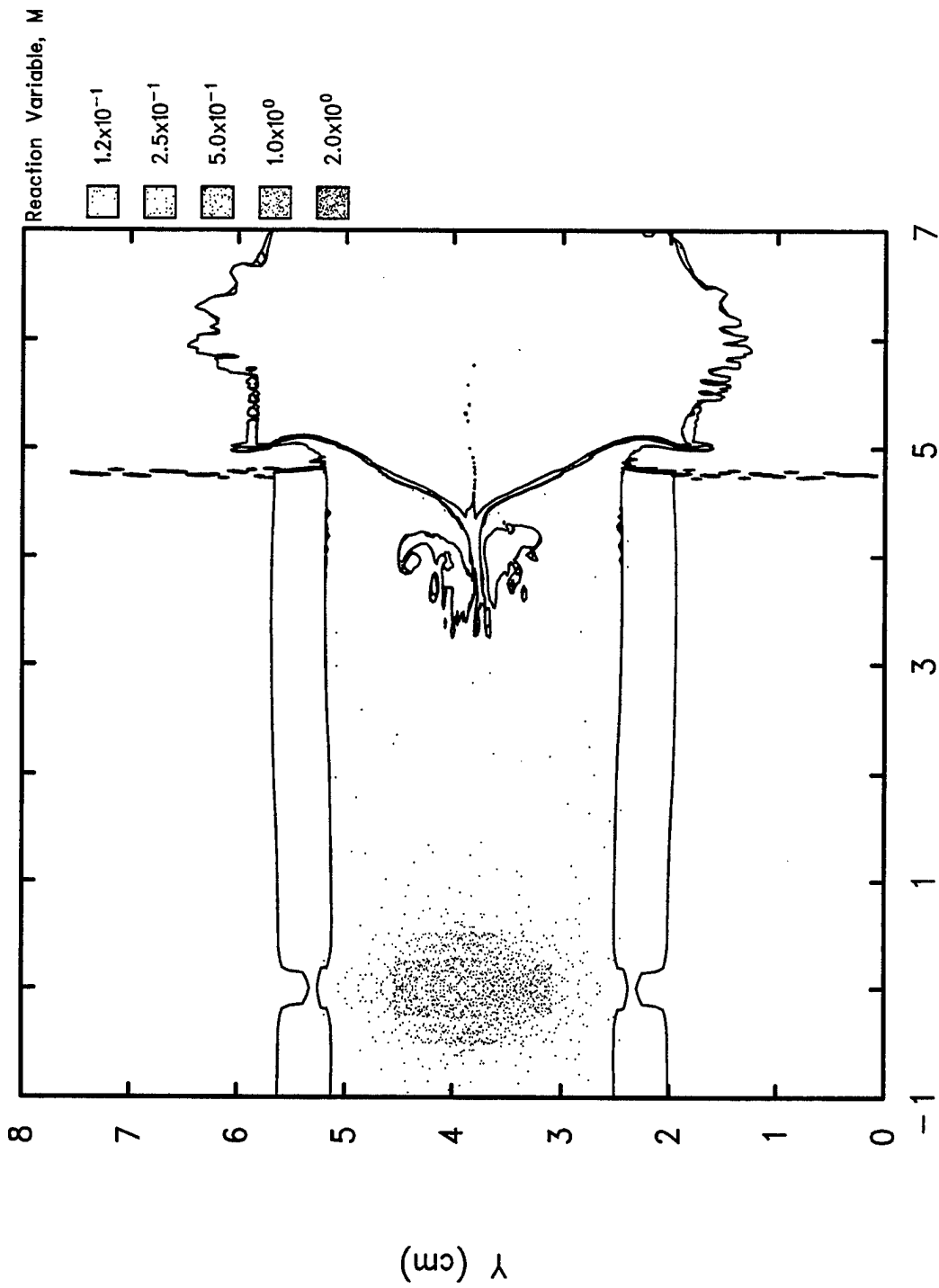


2DC Block 1

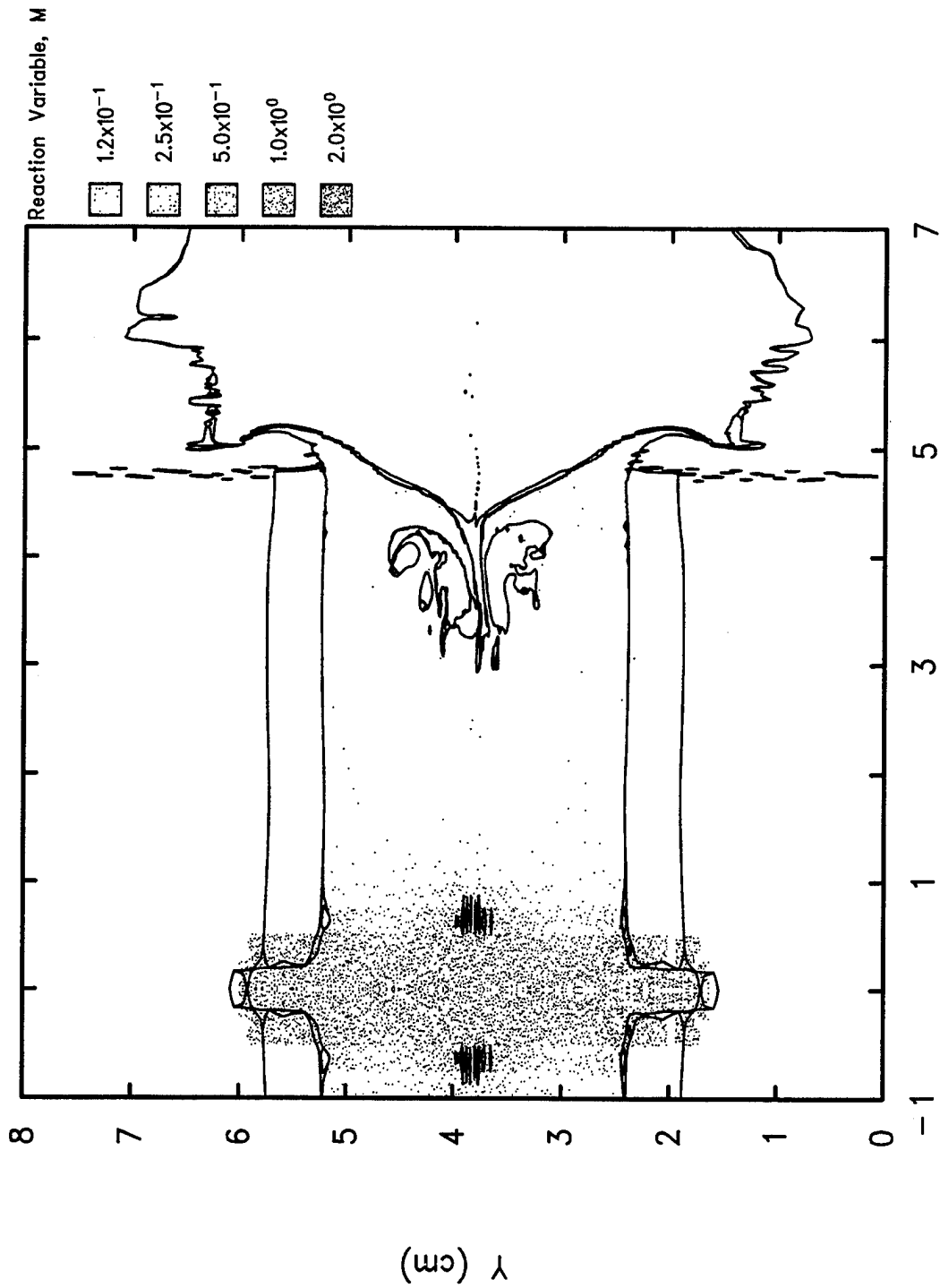
X (cm)

2d-cth-mmp simulation of NEOD Phase III LSC detonation

AYJAMT 1/25/95 10:03:14 CTH 4258 Time=1.50031x10⁻⁵



2DC Block 1
 2d-cth-mmp simulation of NEOD Phase III LSC detonation
 AYJAMT 1/25/95 18:13:15 CTH 5577 Time=2.00004x10⁻⁵



2DC Block 1 X (cm)
 2d-cth--mmp simulation of NEOD Phase III LSC detonation
 AYJAMT 1/26/95 00:39:35 CTH 6832 Time=2.48073x10⁻⁵

APPENDIX C:
LX-14 SIMULATION INPUT DECK

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```

*
*eor*cgenin
*
2d-cth-mmp simulation of NEOD Phase III LSC detonation
*
control
ep
mmp
endcontrol
*
mesh
block geometry 2dc type e
x0=0.0
x1 n=70 w=4.747 dxl=0.0055
x2 n=3 w=0.0155 rat=1
x3 n=110 w=1.252 dxf=0.0055
x4 n=17 w=1.5 dxf=0.021
endx
y0=0.0
y1 dyf 0.15 dyl 0.05 w 2.54
y2 dyf 0.05 dyl 0.0055 w 1.27
y3 dyf 0.0055 dyl 0.05 w 1.27
y4 dyf 0.05 dyl 0.15 w 2.54
endy
xact=4.76,5.95
yact=3.24,4.40
endblock
endmesh
*
insertion of material
block 1
*
package 'AL Case - 1'
material 1
numsub 50
pressure 1.0e6
insert box
x1 4.747 x2 4.76250
y1 0.000 y2 15.24000
endinsert
endpackage
*
package 'HE Patty - 1'
material 2
numsub 50
pressure 1.0e6

```

```
insert box
  x1 0.000  x2 4.74700
  y1 2.540  y2 5.08000
endinsert
endpackage
```

*

```
package 'HE LSC - 1'
```

```
material 3
```

```
numsub 50
```

- * G. Kerley told me (12/1/94) that RDX @ $\rho=1.70$ g/cc detonates at
- * $T=3560\text{K}=0.30678\text{eV}$; $P_0=13.8\text{GPa}$. This calculation was done with BCAT
- * or PANDA. Specifying the insert at this temp is equivalent to
- * detonating the whole mass at time=0.

```
temperature 0.30678
```

```
insert uds
```

```
point 5.24615 3.81328
point 5.24615 3.77718
point 5.24615 3.71811
point 5.23957 3.66561
point 5.21983 3.60982
point 5.20009 3.56716
point 5.16719 3.51465
point 5.14087 3.46543
point 5.13758 3.44902
point 5.14416 3.42933
point 5.15403 3.41948
point 5.17706 3.41292
point 5.20338 3.41620
point 5.25273 3.41620
point 5.30538 3.41620
point 5.35473 3.41620
point 5.39421 3.42276
point 5.42382 3.43589
point 5.44685 3.45230
point 5.48304 3.48183
point 5.52253 3.51465
point 5.56859 3.56388
point 5.63768 3.63607
point 5.69361 3.69186
point 5.73639 3.73452
point 5.75284 3.75749
point 5.75613 3.77390
point 5.75942 3.80344
point 5.75613 3.82969
point 5.75613 3.84938
point 5.72652 3.88548
point 5.67058 3.95111
```

point 5.61465 4.00362
point 5.51595 4.10535
point 5.45672 4.15457
point 5.43040 4.17755
point 5.40737 4.19395
point 5.37118 4.20052
point 5.29551 4.21364
point 5.20667 4.22021
point 5.16390 4.22021
point 5.13429 4.22021
point 5.12113 4.21036
point 5.11784 4.19724
point 5.12113 4.18411
point 5.13100 4.17098
point 5.14087 4.14473
point 5.15732 4.11191
point 5.18035 4.07253
point 5.20338 4.03643
point 5.22641 3.99377
point 5.23628 3.95439
point 5.23957 3.91173
point 5.24286 3.87563
point 5.24286 3.83625
point 5.24615 3.81656

endinsert

endpackage

package 'Lead LSC - 1'

material 4

numsub 50

pressure 1.0e6

insert uds

point 5.19022 3.81000
point 5.19351 3.79031
point 5.19351 3.76078
point 5.18693 3.74437
point 5.17706 3.73452
point 5.13100 3.68202
point 5.06519 3.60982
point 4.93359 3.47527
point 4.80527 3.34401
point 4.77895 3.31775
point 4.77237 3.31119
point 4.76579 3.29478
point 4.76579 3.27509
point 4.77237 3.25868
point 4.78553 3.24556
point 4.80198 3.24227

point	4.82172	3.24227
point	4.87437	3.24227
point	5.12113	3.24556
point	5.29880	3.24227
point	5.33828	3.24556
point	5.39092	3.25212
point	5.43369	3.26196
point	5.46659	3.28494
point	5.52911	3.34072
point	5.66071	3.47199
point	5.79232	3.60326
point	5.91405	3.72468
point	5.93051	3.75093
point	5.94038	3.77390
point	5.94696	3.79359
point	5.94696	3.81656
point	5.94367	3.83625
point	5.93380	3.85266
point	5.92392	3.86579
point	5.89760	3.89532
point	5.83838	3.95767
point	5.76600	4.02659
point	5.70348	4.08894
point	5.63439	4.15457
point	5.55872	4.23333
point	5.46988	4.33178
point	5.45014	4.35147
point	5.43369	4.36788
point	5.41395	4.37444
point	5.38763	4.37773
point	5.30867	4.38101
point	5.20009	4.38101
point	5.03229	4.38429
point	4.84804	4.38757
point	4.80198	4.39085
point	4.78224	4.38101
point	4.77237	4.37116
point	4.76908	4.35804
point	4.76908	4.34819
point	4.77237	4.33178
point	4.78224	4.31537
point	4.81843	4.27928
point	4.88424	4.21036
point	4.95991	4.12504
point	5.05203	4.02987
point	5.11126	3.96424
point	5.15403	3.92486

```

point 5.17377 3.89204
point 5.18693 3.86579
point 5.19022 3.83953
point 5.19022 3.81656
endinsert
endpackage
*
package 'Cu Damper - Bottom'
material 5
numsub 50
pressure 1.0e6
insert box
  x1 0.258  x2 4.747
  y1 2.032  y2 2.540
endinsert
endpackage
*
package 'Cu Damper - Top'
material 5
numsub 50
pressure 1.0e6
insert box
  x1 0.258  x2 4.747
  y1 5.080  y2 5.588
endinsert
endpackage
*
endblock
endinsertion
*
eos
*
* Aluminum Mie-Grüneisen
mat1 mgrun eos=7075-t6_al feos=/b/scheffle/cth/MGR_data'
  ro=2.804  cs=0.5200E6 s=1.360  go=2.20  cv=1.07E11
*
* LX-14 Patty
* Parameters estimated to be roughly halfway between RDX and TNT.
* RP and R0 made identical per advice of G. Kerley, to avoid bug.
MAT2 SESAME EOS=8231 FEOS=/b/scheffle/cth/sesame'
  RP=1.850 R0=1.850 CS=2.9E5 S=2.0 G0=1.0 CV=1.35E11
  TYP=2.0 PR=8.8E10 ZR=2.36 MR=1.5 PI=0.5E10
  RMAX=5.0 RMIN=0.01 TMAX=5.0 PT=1.0E13
** CEQ(I),I=1,40
** 8.2310E+03 0.0000E+00 1.0000E+00 1.8500E+00 2.5680E-02
** 0.0000E+00 1.9166E+06 1.0000E+00 1.3500E+11 1.0000E-02
** 5.0000E+00 6.6667E-01 3.3333E-01 2.0000E-01 1.8889E-01

```

```

** 3.4120E+00 -1.7943E+12 4.2272E+12 1.3500E+09 2.0000E+00
** 5.0000E+00 1.5000E+00 2.3600E+00 8.8000E+10 6.8497E+10
** 2.9000E+05 2.0000E+00 5.0000E+09 1.8500E+00 1.2459E+01
** 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
** 0.0000E+00 0.0000E+00 0.0000E+00 5.1450E+01 1.0004E+02
*
* CH-6 (RDX=HMX) HE as LSC charge
mat3 SESAME EOS=8012 FEOS='/b/scheffle/cth/sesame'
  RP=1.70 R0=1.70
*
* Lead (6% Antimony) Mie-Gru (modified from Library data)
mat4 mgrun eos=lead_s feos='/b/scheffle/cth/MGR_data'
  ro=10.9 cs=0.2006E6 s=1.429 go=2.74 cv=1.5512E10
* Copper Mie-Grüneisen
mat5 mgrun eos=copper feos='/b/scheffle/cth/MGR_data'
  ro=8.930 cs=3.940E5 s=1.489 go=1.99 cv=4.56E10
endeos
*
* heburn option not needed, with predetonated sesame option
**heburn
**endheburn
epdata
  vpsave
* Library 7075-T6 Al.
  matep 1 steinberg-guinan='7075-T6_ALUMINUM' fvp='/b/scheffle/cth/VP_data'
    poisson 0.16
  r0st=2.804 tm0st=0.105127 atmst=1.70 gm0st=2.20
  ast=6.52E-12 bst=7.148680 nst=0.10 c1st=0.00
  c2st=0.00 g0st=0.267E+12 btst=965.0 eist=0.00 ypst=0.00
  ukst=0.00 ysmst=0.00 yast=0.00 y0st=4.2E+09 ymst=8.1E+09
* Library Lead
  matep 4 steinberg-guinan='LEAD' fvp='/b/scheffle/cth/VP_data'
    poisson 0.43
  r0st=11.34 tm0st=0.065489 atmst=2.20 gm0st=2.74
  ast=11.63E-12 bst=13.461800 nst=0.52 c1st=0.00
  c2st=0.00 g0st=8.6E+10 btst=110.0 eist=0.00 ypst=0.00
  ukst=0.00 ysmst=0.00 yast=0.00 y0st=8.0E+07 ymst=1.0E+09
*
  matep 5 steinberg-guinan='COPPER' fvp='/b/scheffle/cth/VP_data'
    poisson 0.32
  r0st=8.93 tm0st=0.154244 atmst=1.50 gm0st=2.02
  ast=2.83E-12 bst=4.375085 nst=0.45 c1st=0.00
  c2st=0.00 g0st=0.477E+12 btst=36.0 eist=0.00 ypst=0.00
  ukst=0.00 ysmst=0.00 yast=0.00 y0st=1.2E+09 ymst=6.4E+09
*
  mix 3
endep

```

```

*
*
*eor*cthin
*
2d-cth-mmp NEOD Phase III LSC detonation
*
control
  tstop=40.e-6
*  cpshift=900.
*  rdumpf=3600
*  ntbad 1000000
endcontrol
restart
  cycle=0
*  file='rs04h'
  newfile=all
endrestart
*
cellthermo
  mmp
endcell
*
convct
  convect=1
  nofrag=2
  interface=high
endc
*
discard
  material 3 density -0.01 pressure 5.0e6 ton 7.0e-6
endd
*
edit
  shortt
    tim=0. dt=10000.
  ends
  longt
    tim=0. dt=10000.
  endl
  plott
    time=0. dtfreq=5.0e-6
  endp
endedit
*
mindt
  time=0. dtmin=1.0e-13
endm

```

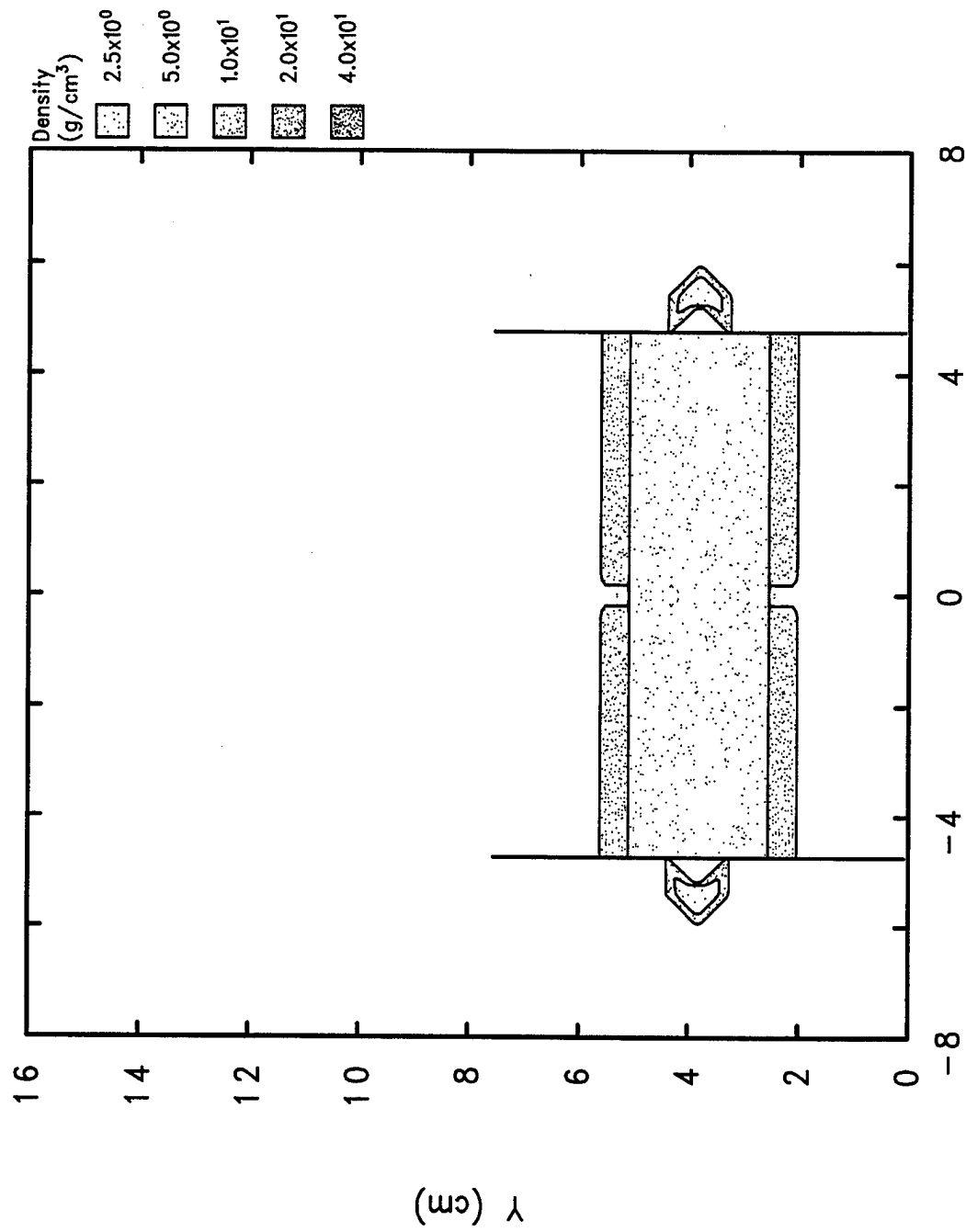
```

*
fracts
  stress
  pfrac1=-8.1E9
  pfrac3=-1.0E9
  pfmix =-5.0E6
  pvoid=-5.0E6
endf
*
boundary
  bhydro
  block=1
  bxbot 0
  bxtop 2
  bybot 2
  bytop 2
  endb
  endh
endb
*
*eor*ptin
*
units cgsev
*
nlegend=off
*
time,0.0e-6,rest
color table 4
units cgsk
limits x=-8.0,8.0,1 y=0.0,16.0,1
*flegend=b
flegend=d
*2dplot,materials,mirror
2dplot,dots=density=10.,mirror,if
limits x=-1.0,7.0,1 y=0.0,8.0,1
*rbands, b1=1e9, b2=1e11, c1=236, c2=256, skip=2
*2dplot,materials
2dplot,dots=density=10.,mirror,if
nlegend=on
*2dplot bands=pressure, mirror, if
bands=1e9, 5e9, 1e10, 2e10, 4e10, 5e10, 6e10, 8e10, 1e11
2dplot dots=pressure=7e10 mirror if
*rbands, b1=0.0, b2=0.1, c1=236, c2=256, skip=2
*2dplot bands=hvb2, mirror if
bands=0.0, 0.01, 0.02, 0.03, 0.04, 0.05, 0.06, 0.07, 0.08, 0.09, 0.10
2dplot dots=hvb2=.50 mirror if

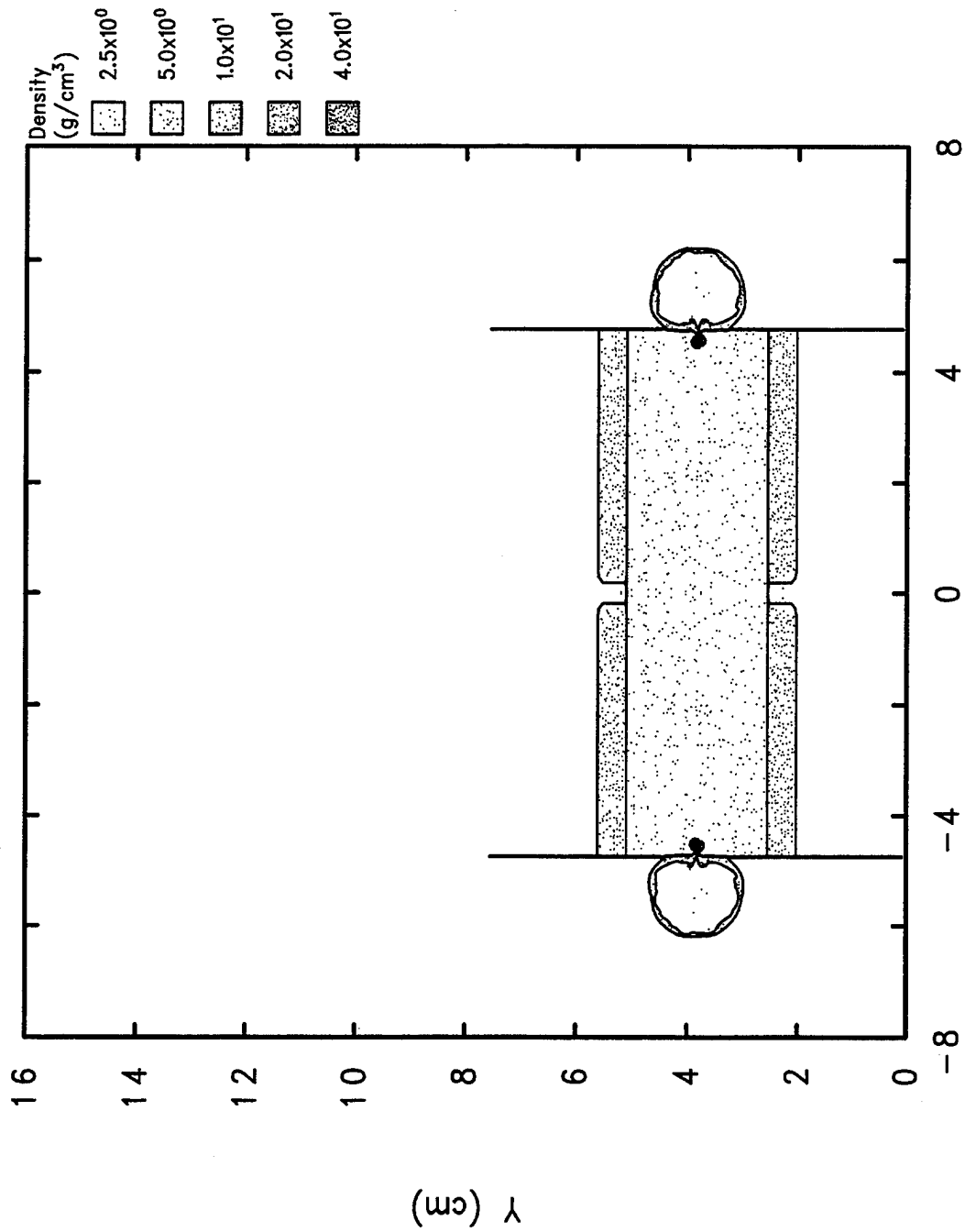
```

APPENDIX D:
LX-14 COMPUTATIONAL RESULTS

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2DC Block 1
 2d-cth-mmp simulation of NEOD Phase III LSC detonation
 CTKCZY G 3/20/95 10:33:46 CTH 0 Time=0.

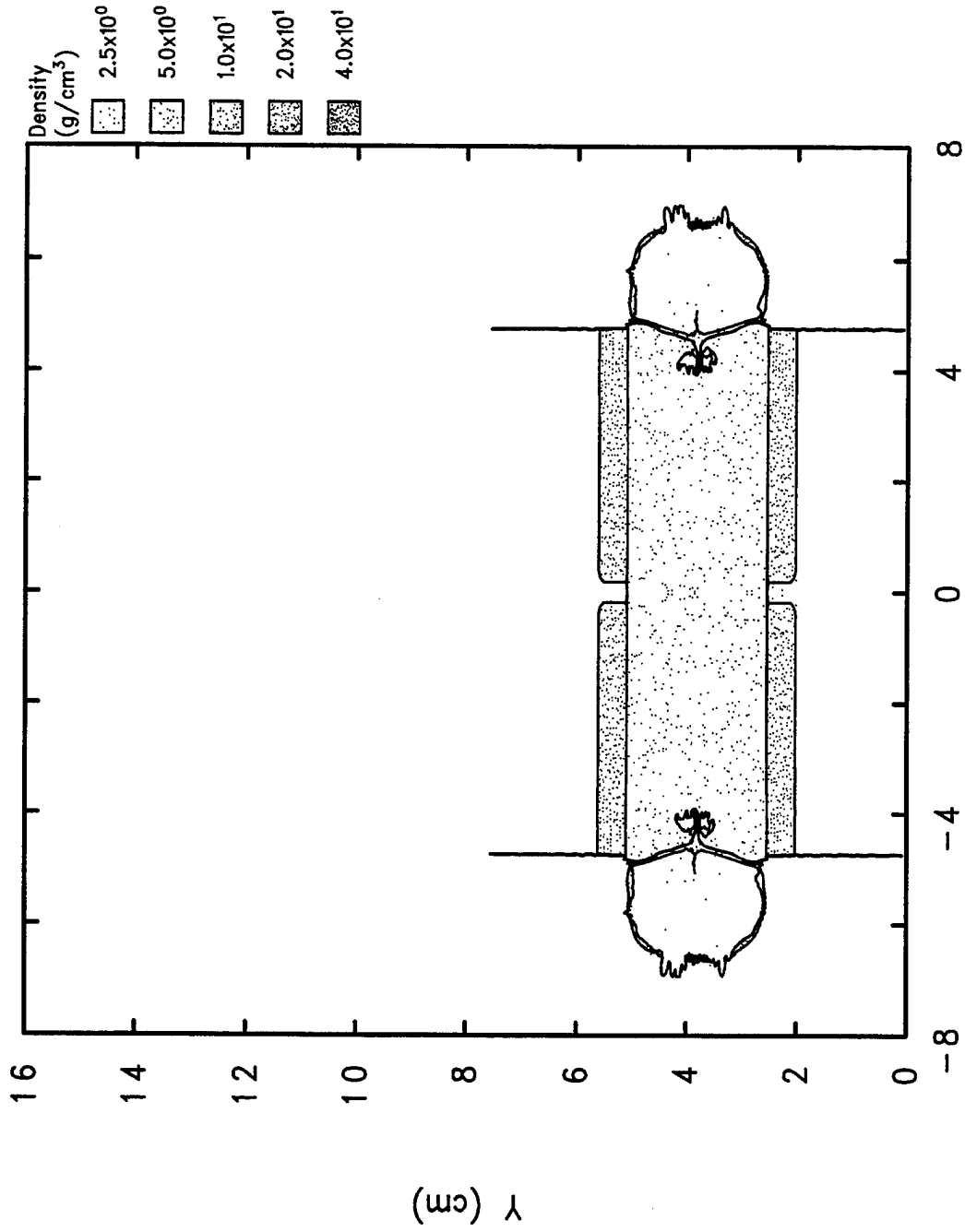


2DC Block 1

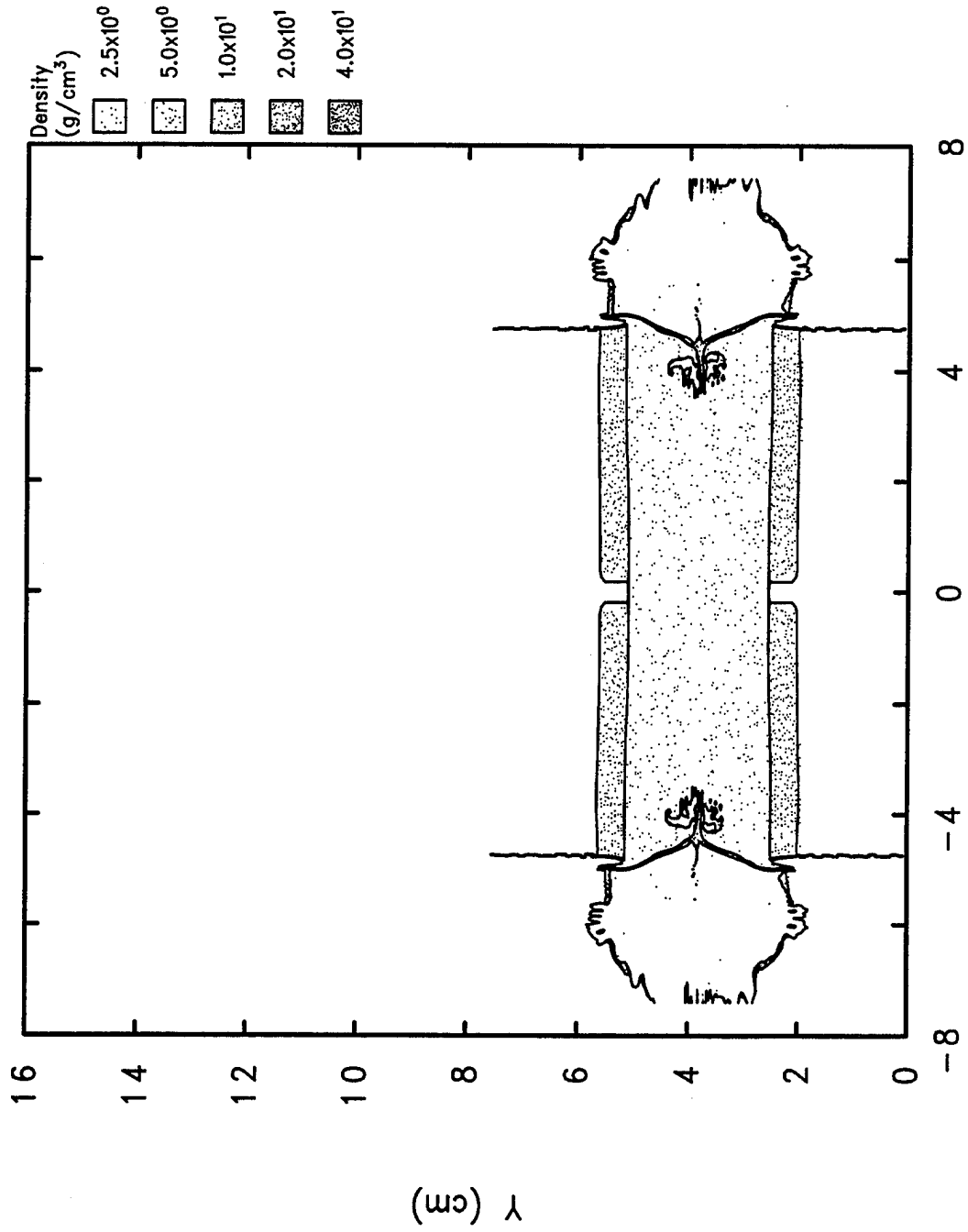
X (cm)

2d-cth-mmp simulation of NEOD Phase III LSC detonation

CTKDUK 3/21/95 09:46:33 CTH 1519 Time=5.00316x10⁻⁶



2DC Block 1
 2d-cth-mmp simulation of NEOD Phase III LSC detonation
 CTKDUK 3/25/95 13:31:40 CTH 2904 Time=1.0002x10⁻⁵

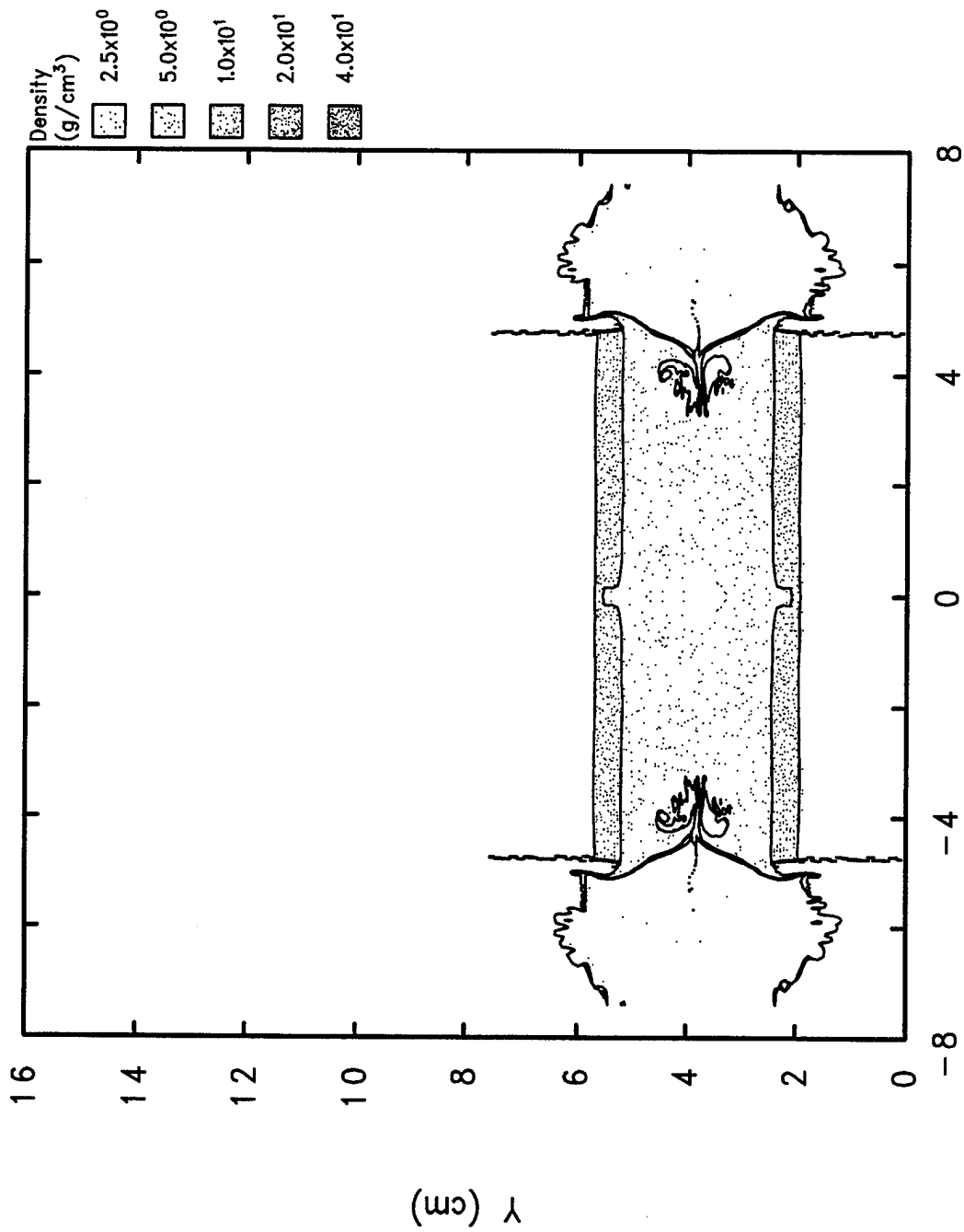


2DC Block 1

X (cm)

2d-cth-mmp simulation of NEOD Phase III LSC detonation

CTKDUK 3/27/95 03:19:28 CTH 4247 Time=1.50014x10⁻⁵

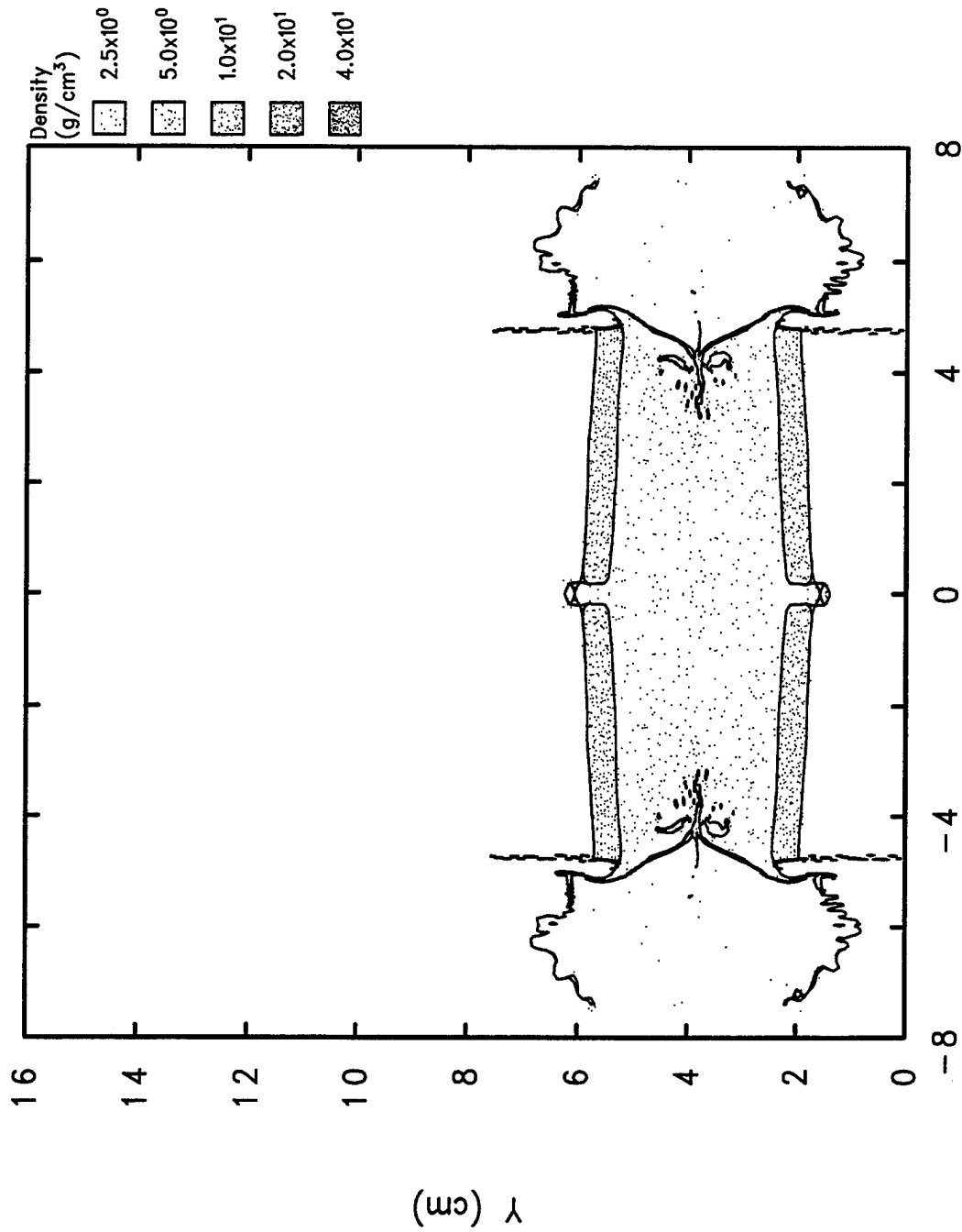


2DC Block 1

X (cm)

2d-cth-mmp simulation of NEOD Phase III LSC detonation

CTKDUK 3/28/95 11:40:25 CTH 5557 Time=2.00005x10⁻⁵

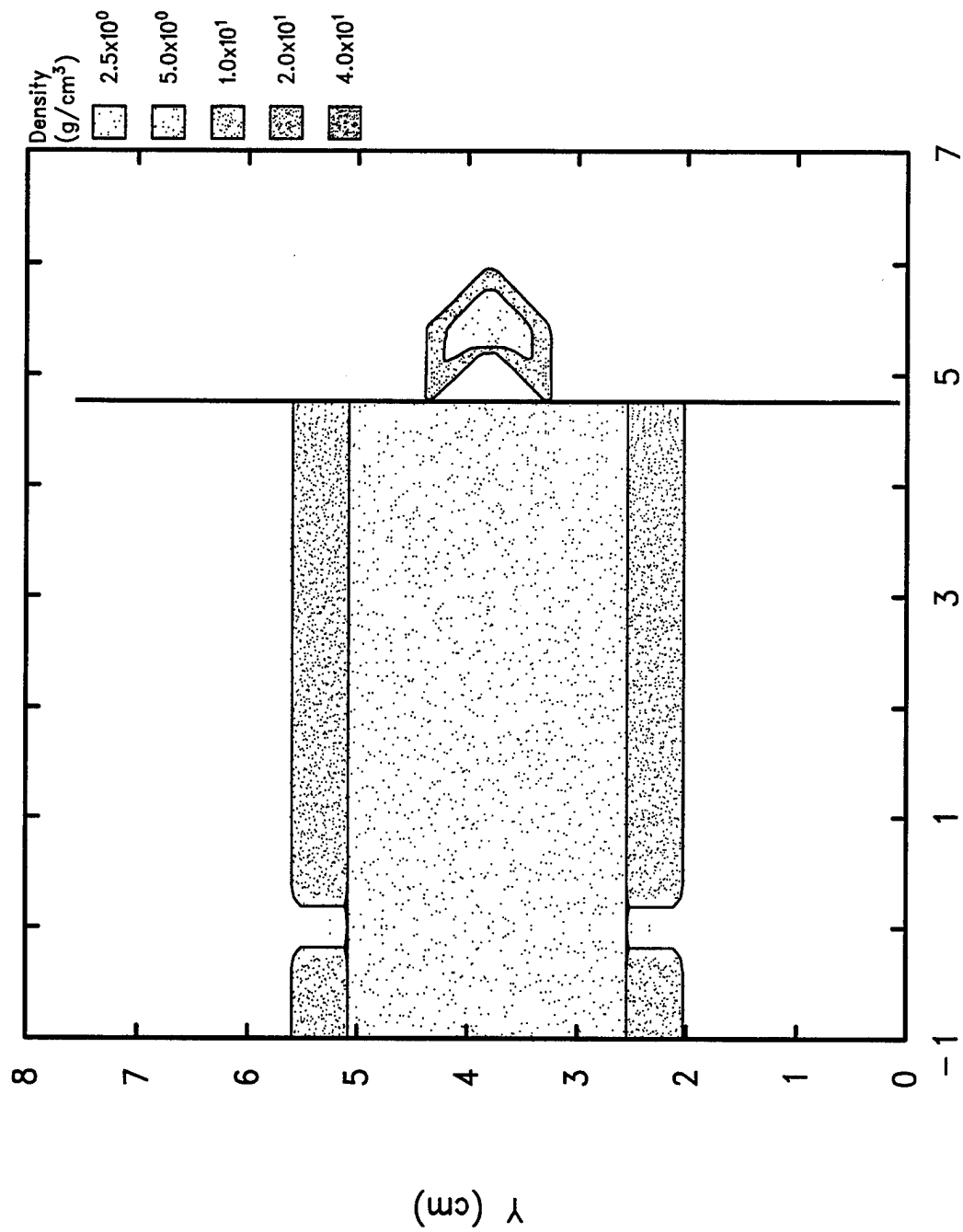


2DC Block 1

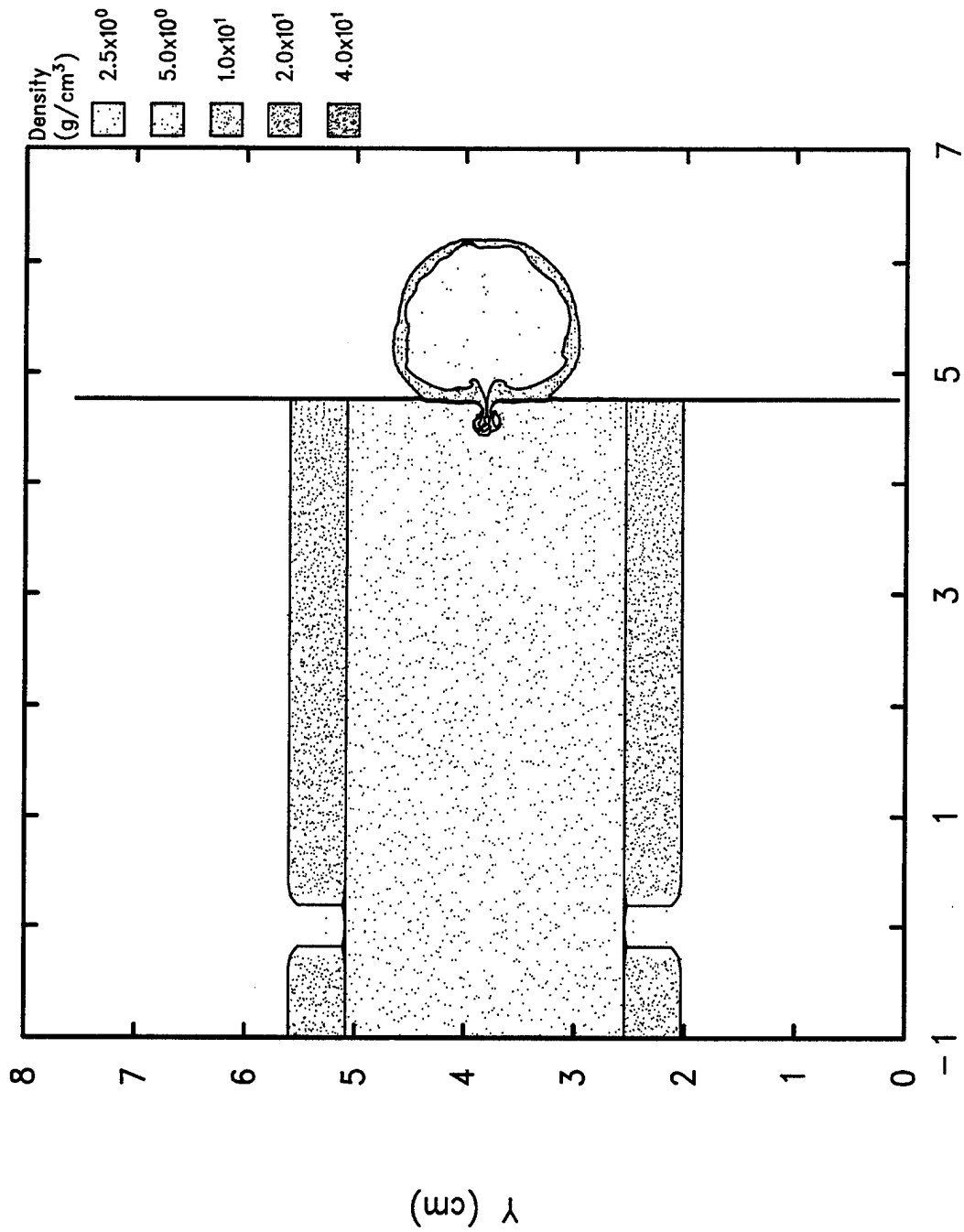
X (cm)

2d-cth-mmp simulation of NEOD Phase III LSC detonation

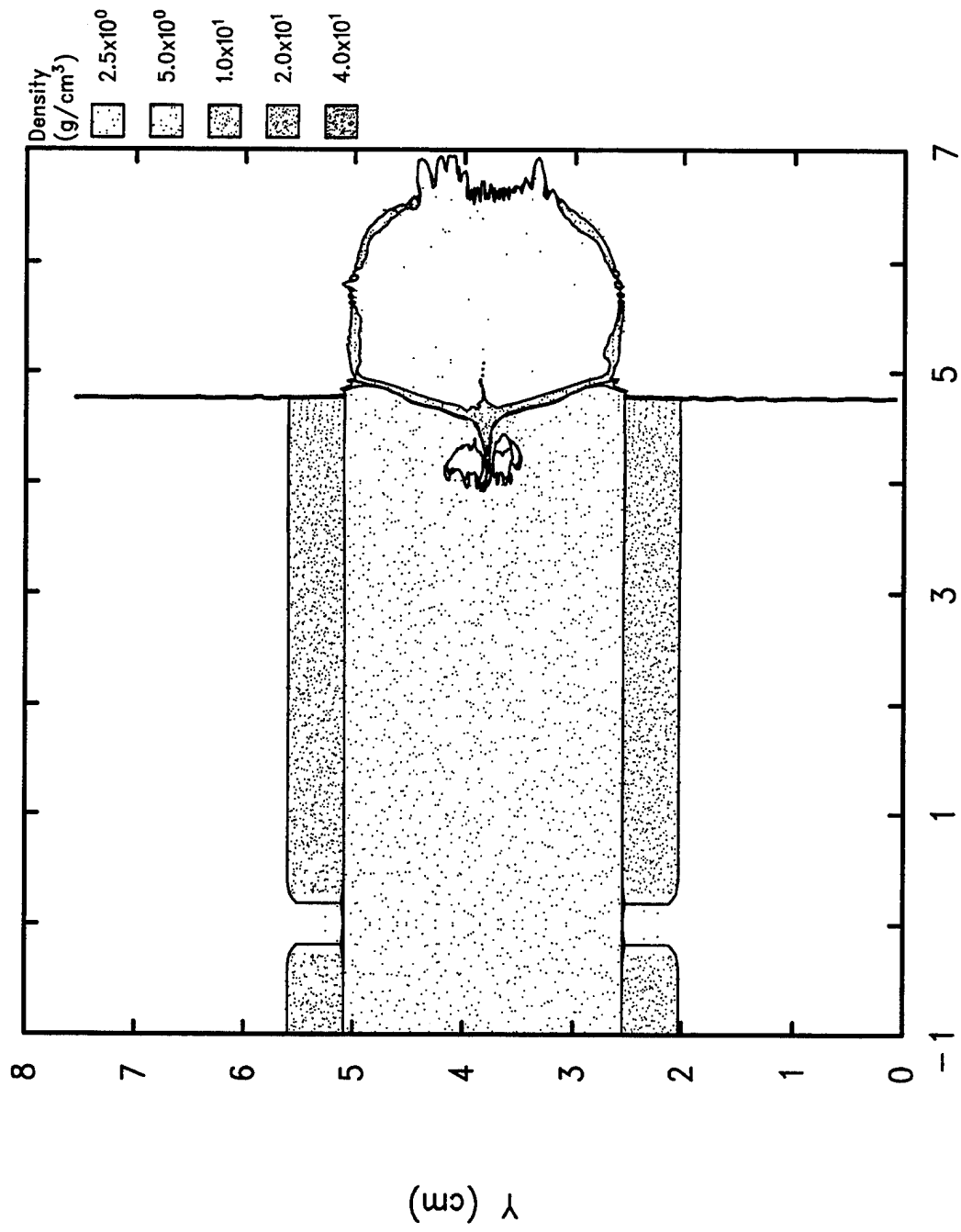
CTKDUK 4/03/95 01:39:30 CTH 12656 Time=2.27859x10⁻⁵



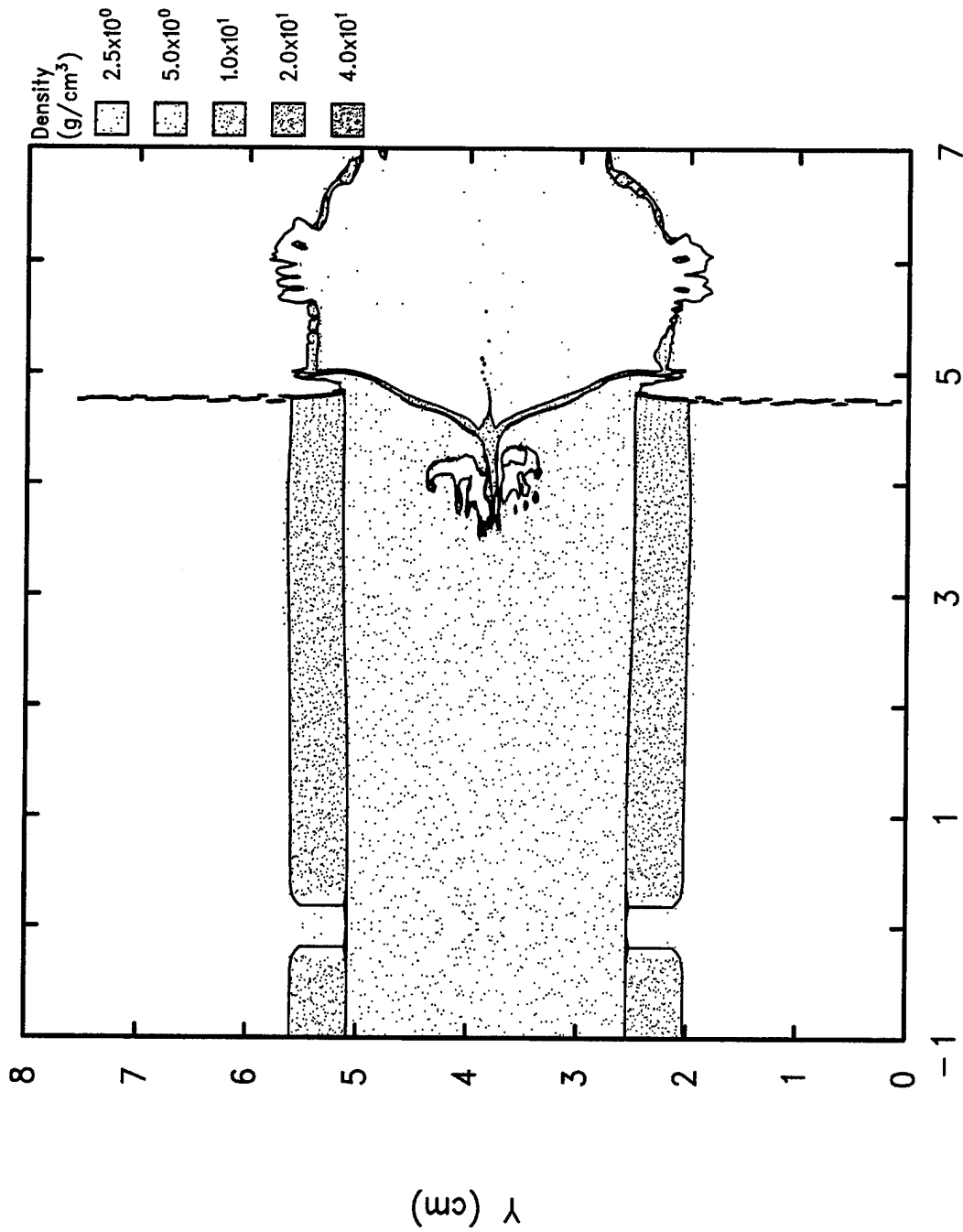
2DC Block 1
 2d-cth-mmp simulation of NEOD Phase III LSC detonation
 CTKCZY G 3/20/95 10:33:46 CTH 0 Time=0.



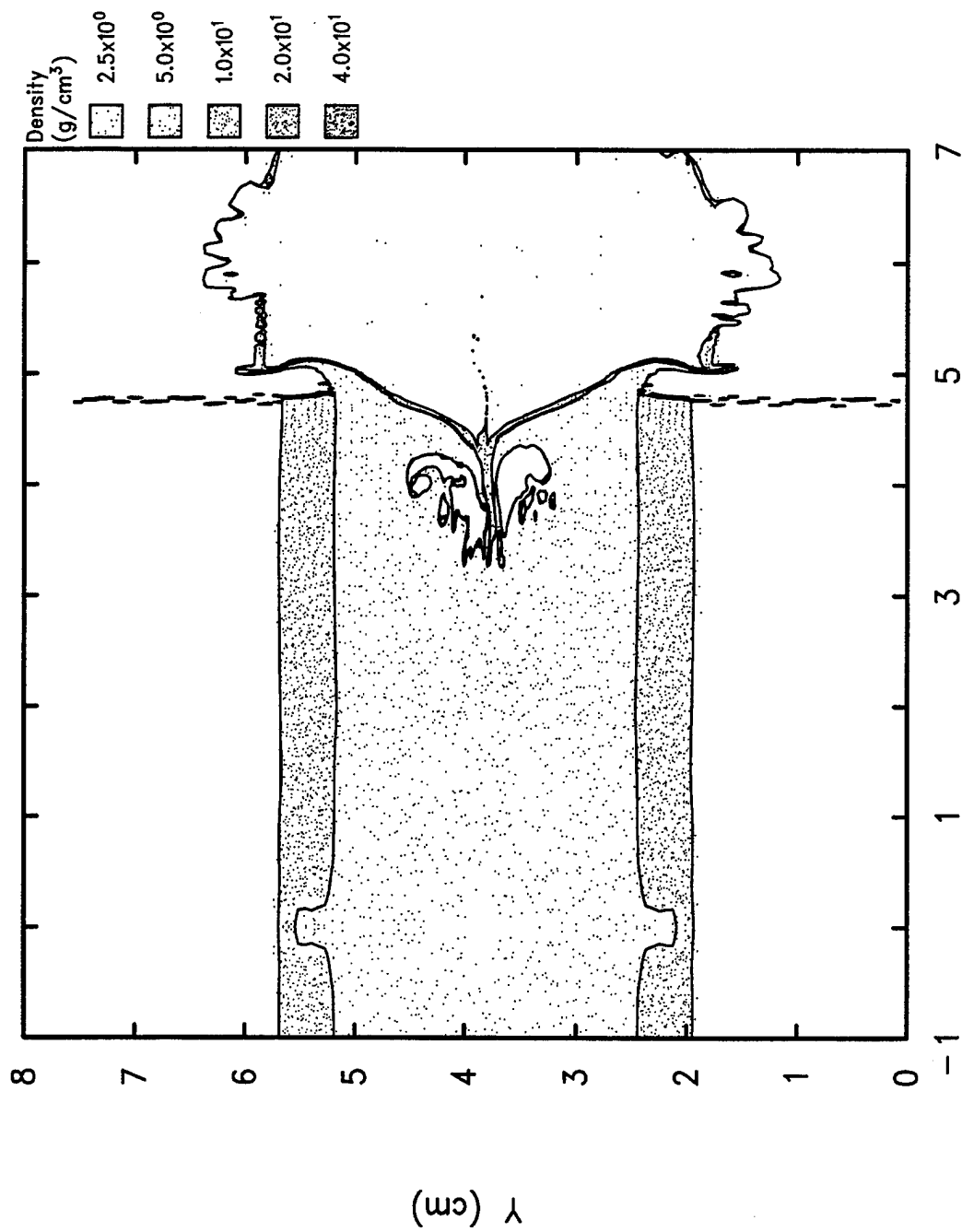
2DC Block 1
 2d-cth-mmp simulation of NEOD Phase III LSC detonation
 CTKDUK 3/21/95 09:46:33 CTH 1519 Time=5.00316x10⁻⁶



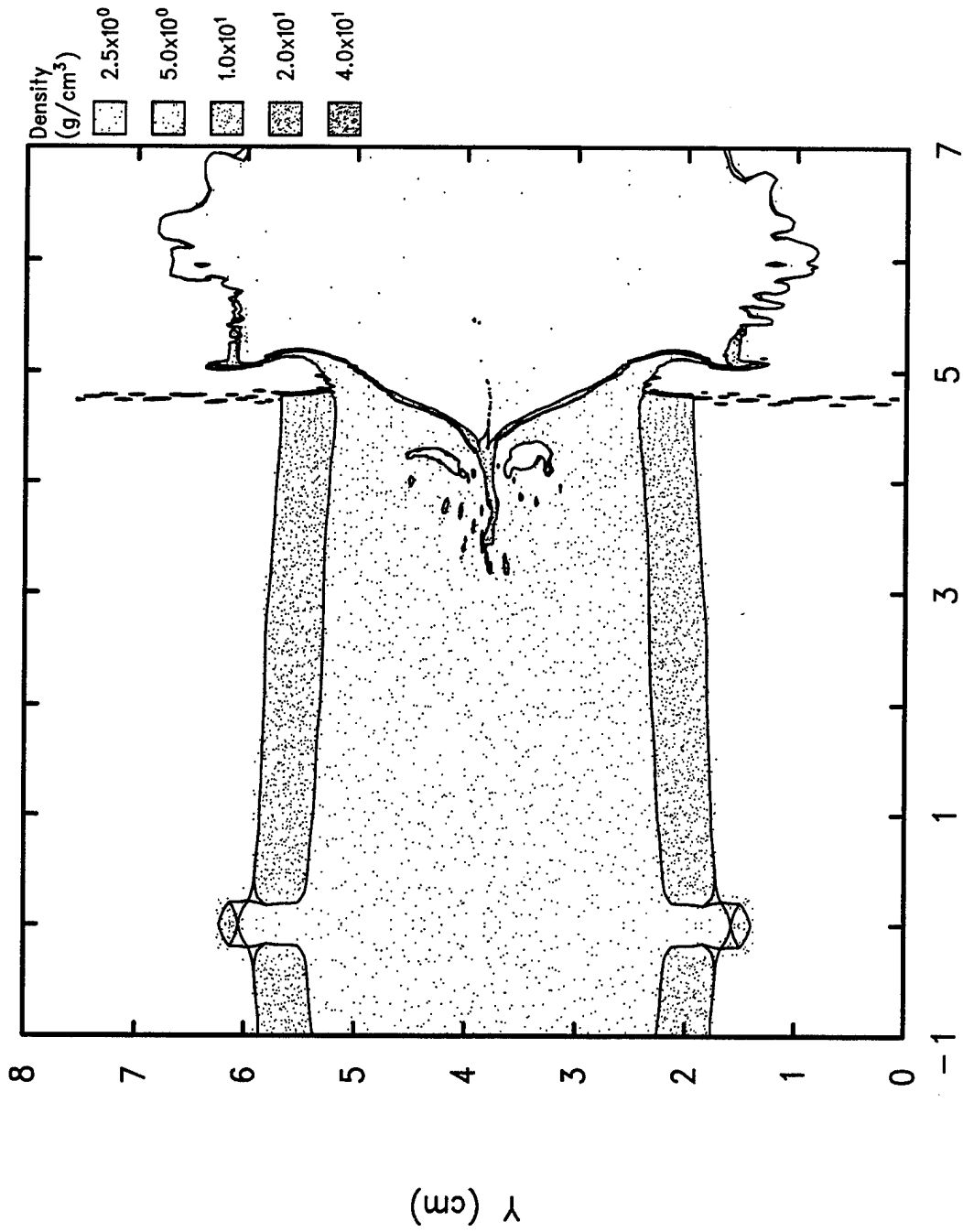
2DC Block 1
 2d-cth-mmp simulation of NEOD Phase III LSC detonation
 CTKDUK 3/25/95 13:31:40 CTH 2904 Time=1.0002x10⁻⁵



2DC Block 1
 2d-cfh-mmp simulation of NEOD Phase III LSC detonation
 CTKDUK 3/27/95 03:19:28 CTH 4247 Time=1.50014x10⁻⁵



2DC Block 1
 2d-cih-mmp simulation of NEOD Phase III LSC detonation
 CTKDUK 3/28/95 11:40:25 CTH 5557 Time=2.00005x10⁻⁵

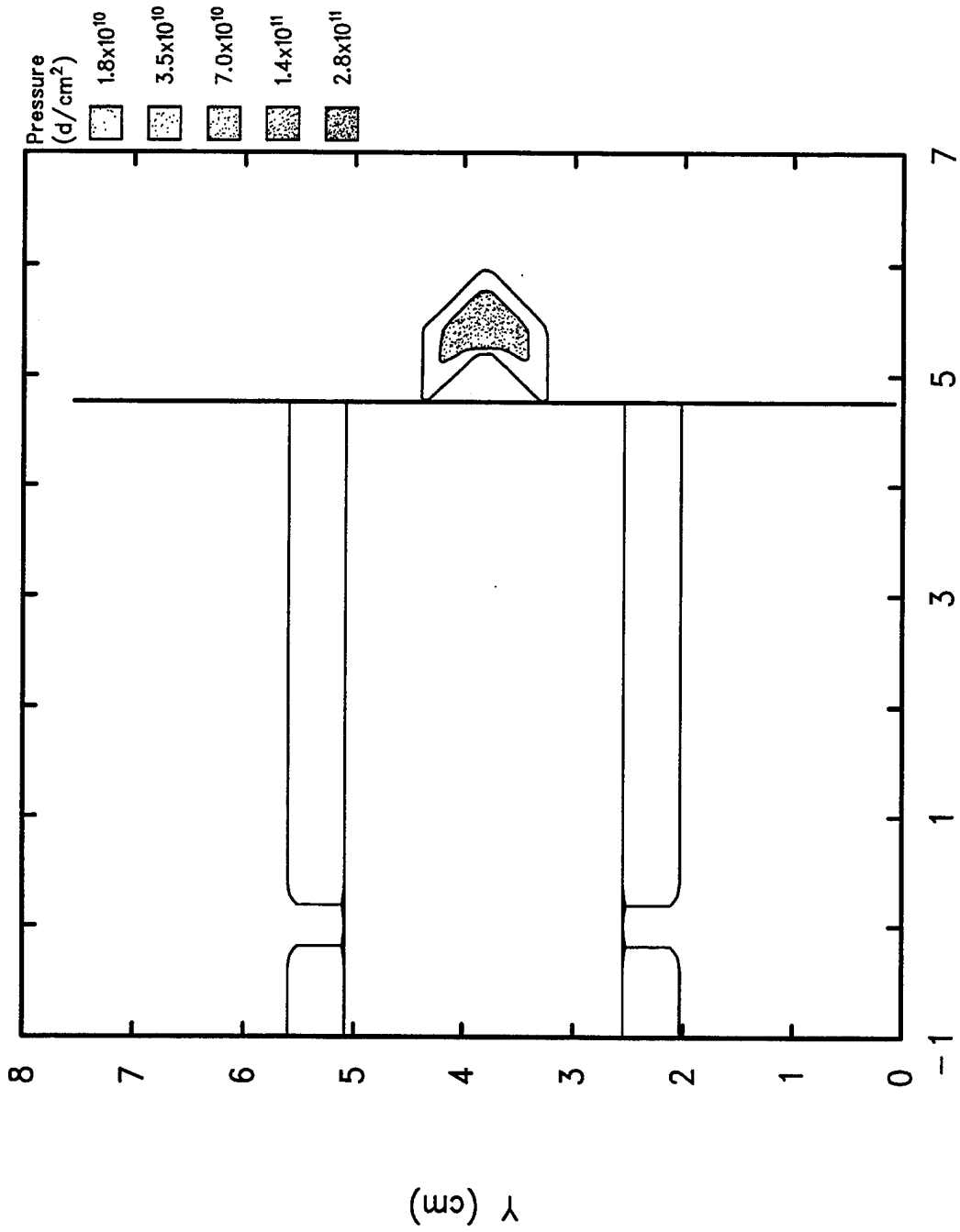


2DC Block 1

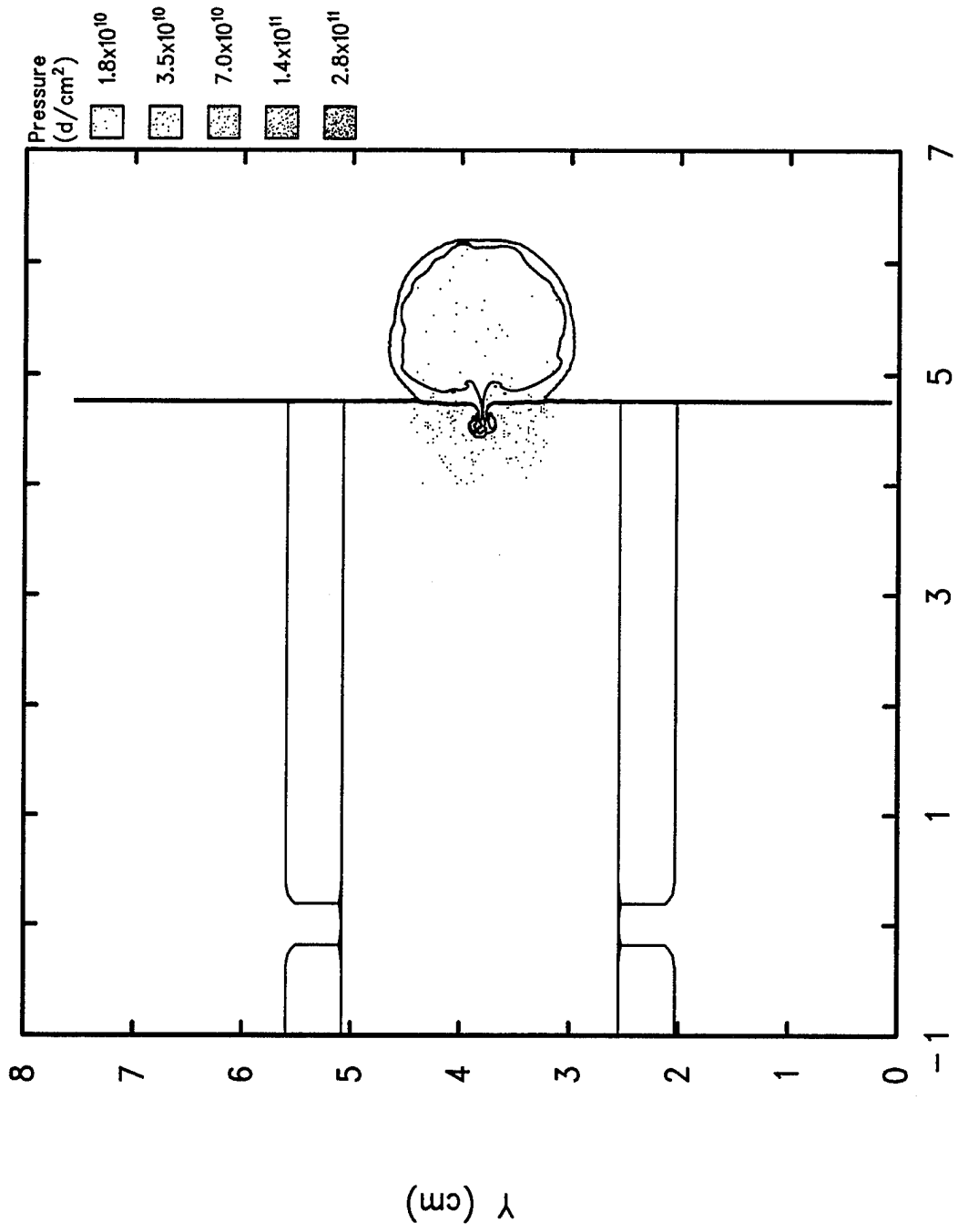
X (cm)

2d-cth-mmp simulation of NEOD Phase III LSC detonation

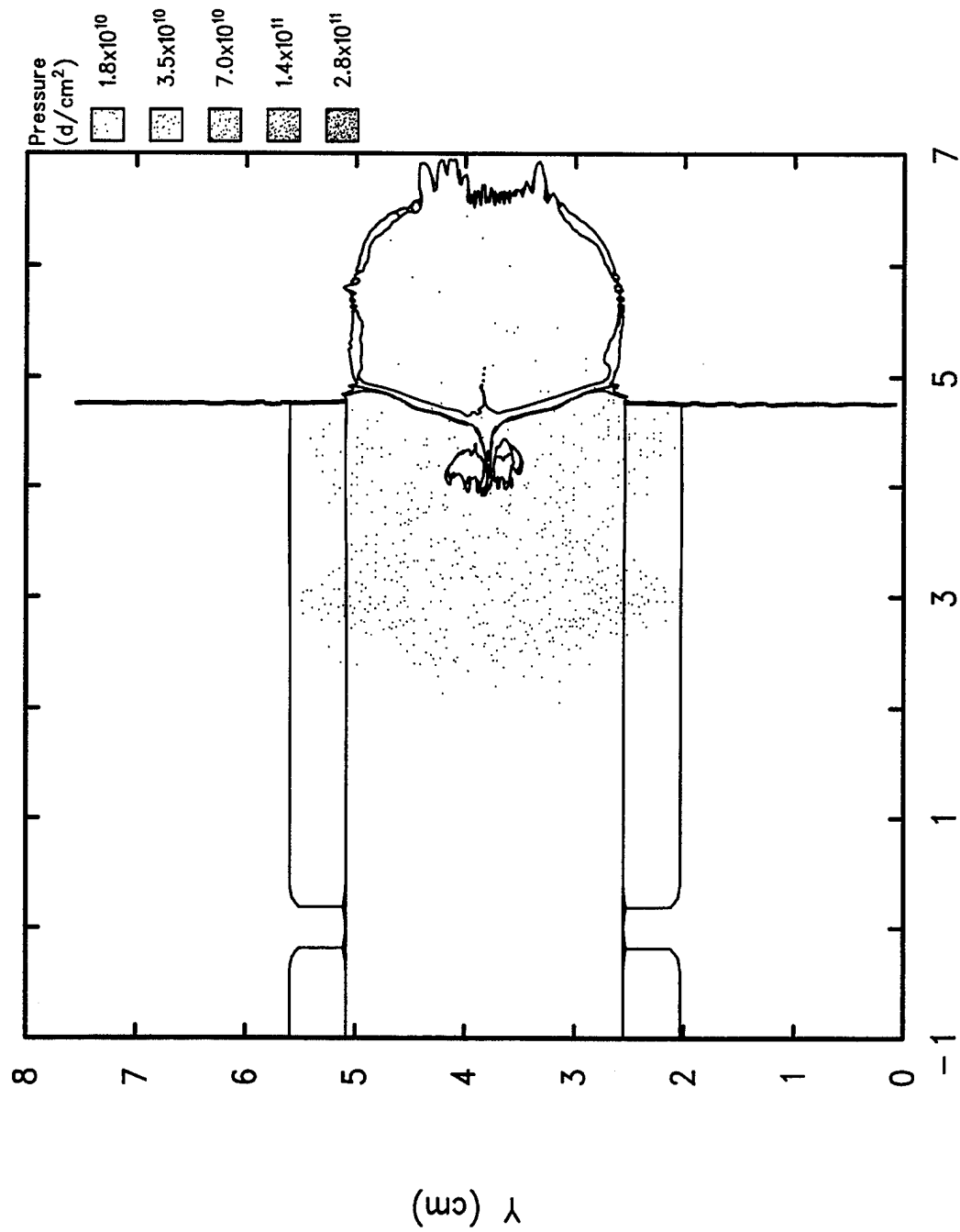
CTKDUK 4/03/95 01:39:30 CTH 12656 Time=2.27859x10⁻⁵



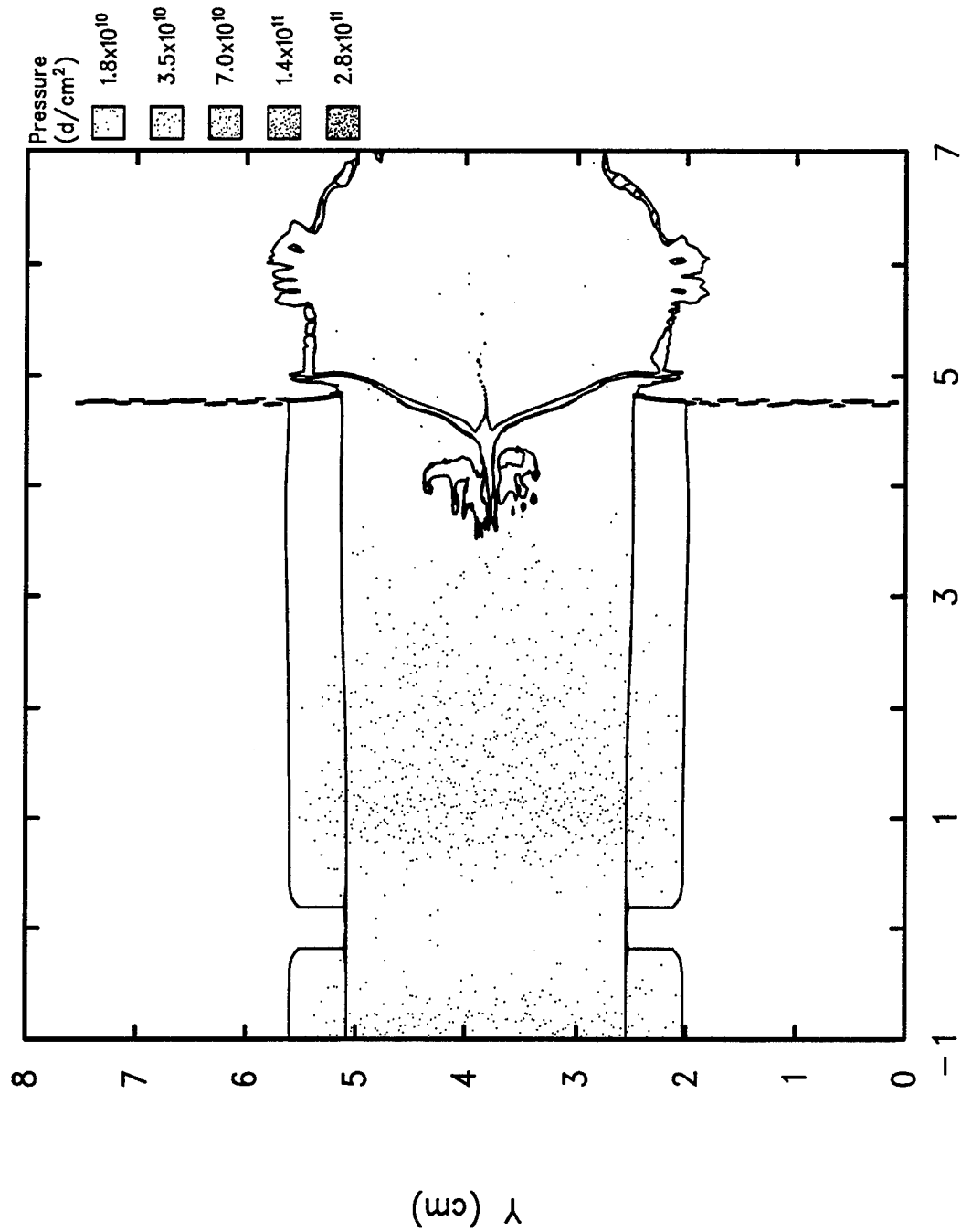
2DC Block 1
 2d-cth--mmp simulation of NEOD Phase III LSC detonation
 CTKCZY G 3/20/95 10:33:46 CTH 0 Time=0.



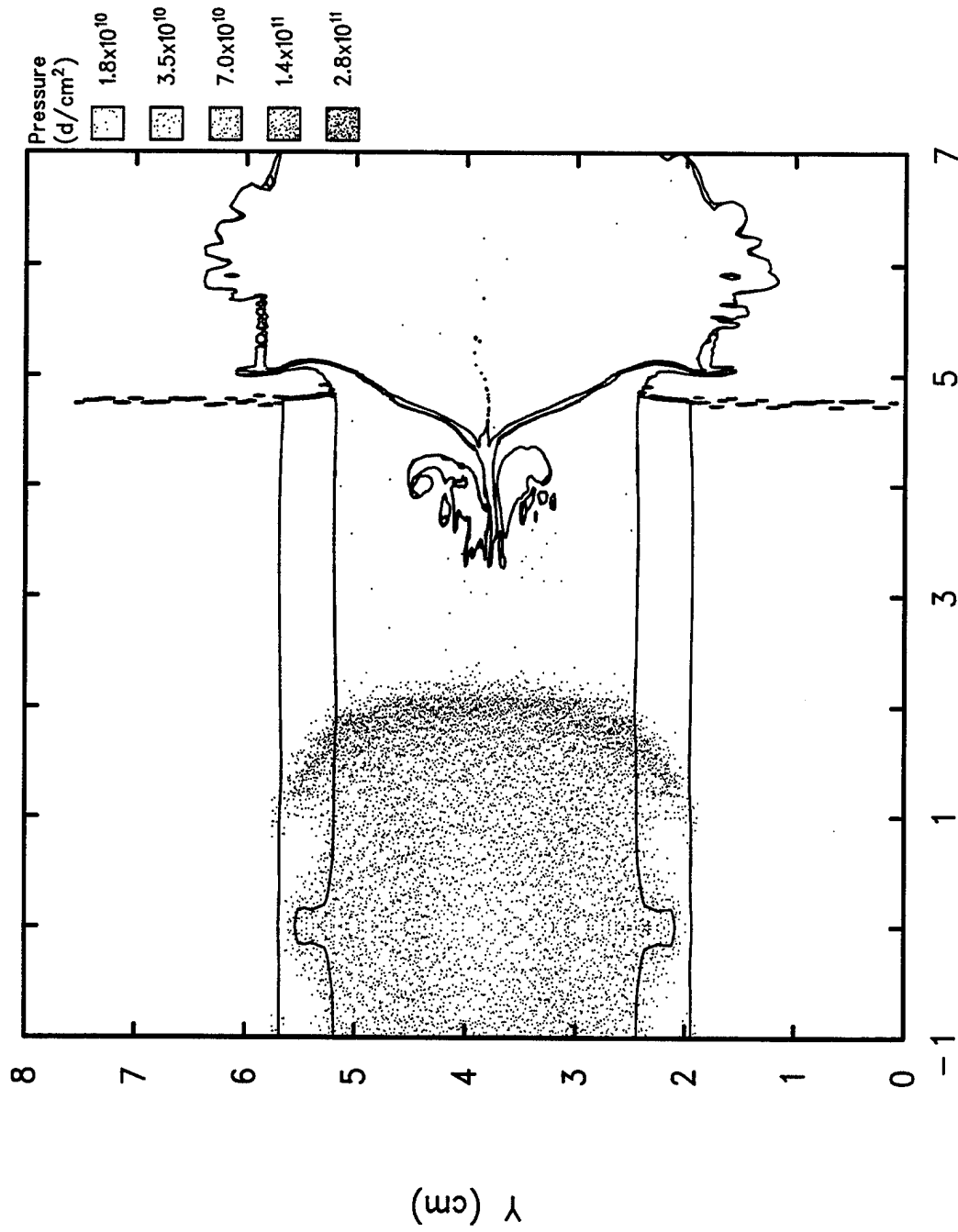
2DC Block 1
 2d-cth-mmp simulation of NEOD Phase III LSC detonation
 CTKDUK 3/21/95 09:46:33 CTH 1519 Time=5.00316x10⁻⁶



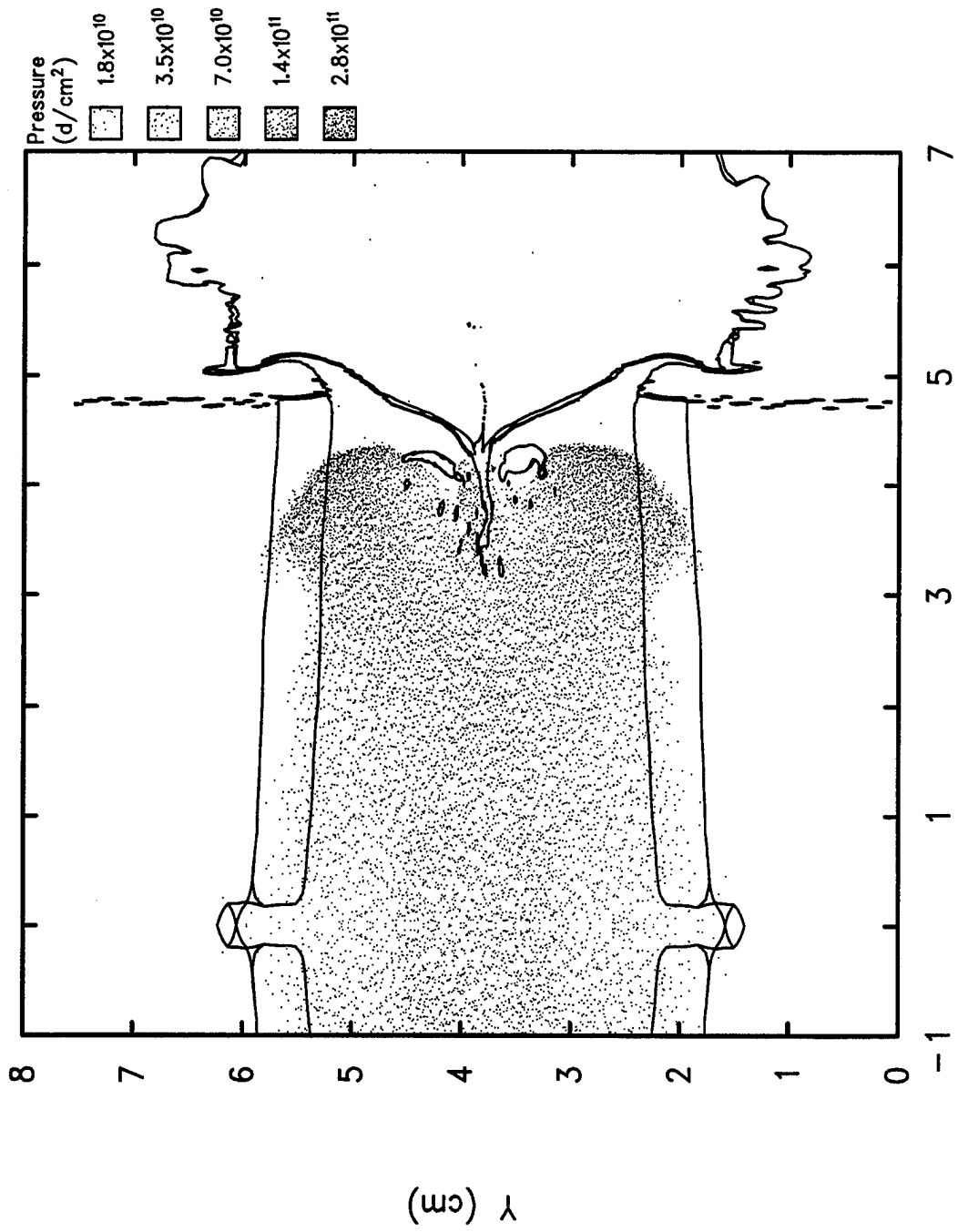
2DC Block 1
 2d-cth-mmp simulation of NEOD Phase III LSC detonation
 CTKDUK 3/25/95 13:31:40 CTH 2904 Time=1.0002x10⁻⁵



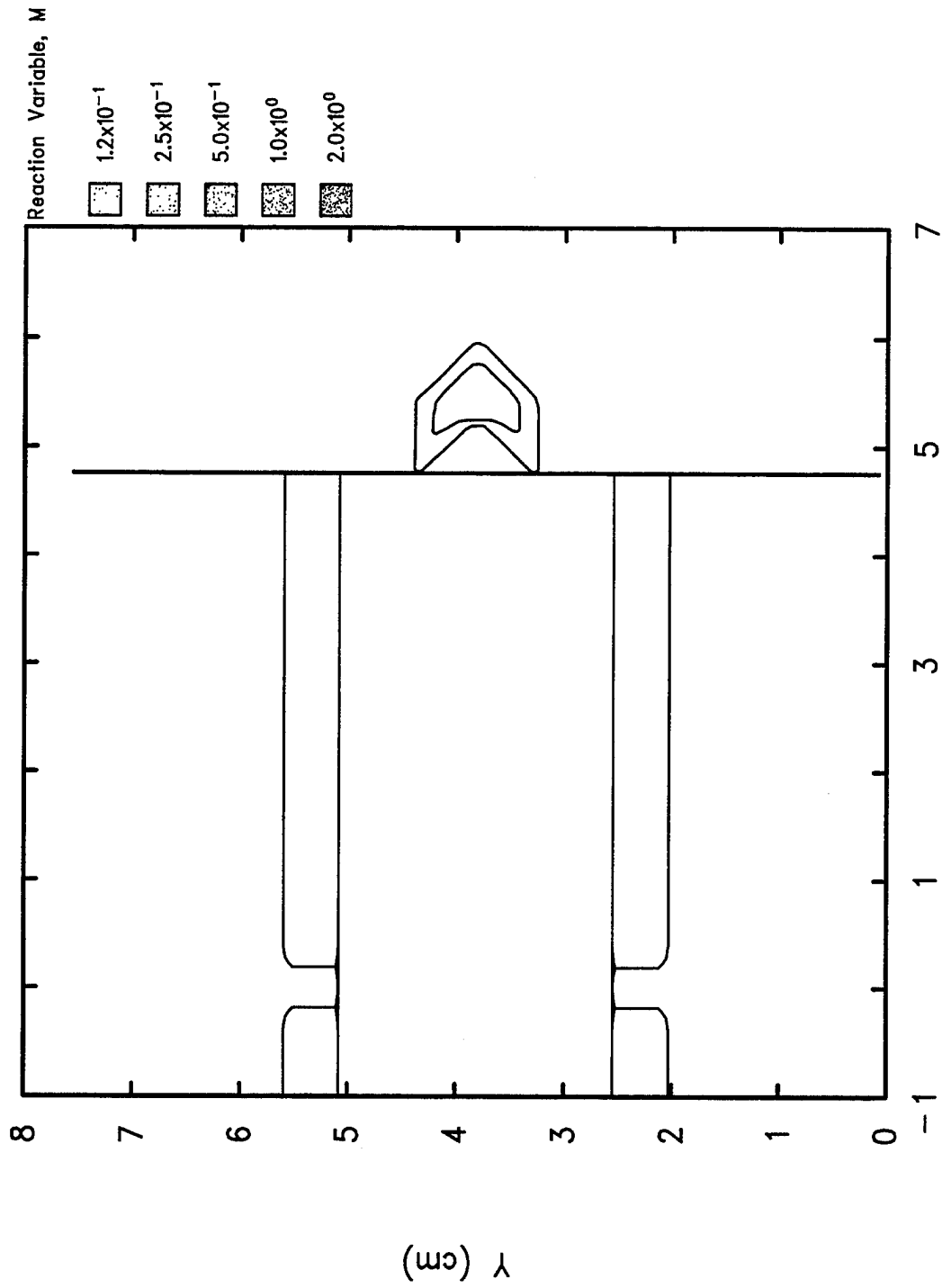
2DC Block 1
 2d-cth-mmp simulation of NEOD Phase III LSC detonation
 CTKDUK 3/27/95 03:19:28 CTH 4247 Time=1.50014x10⁻⁵



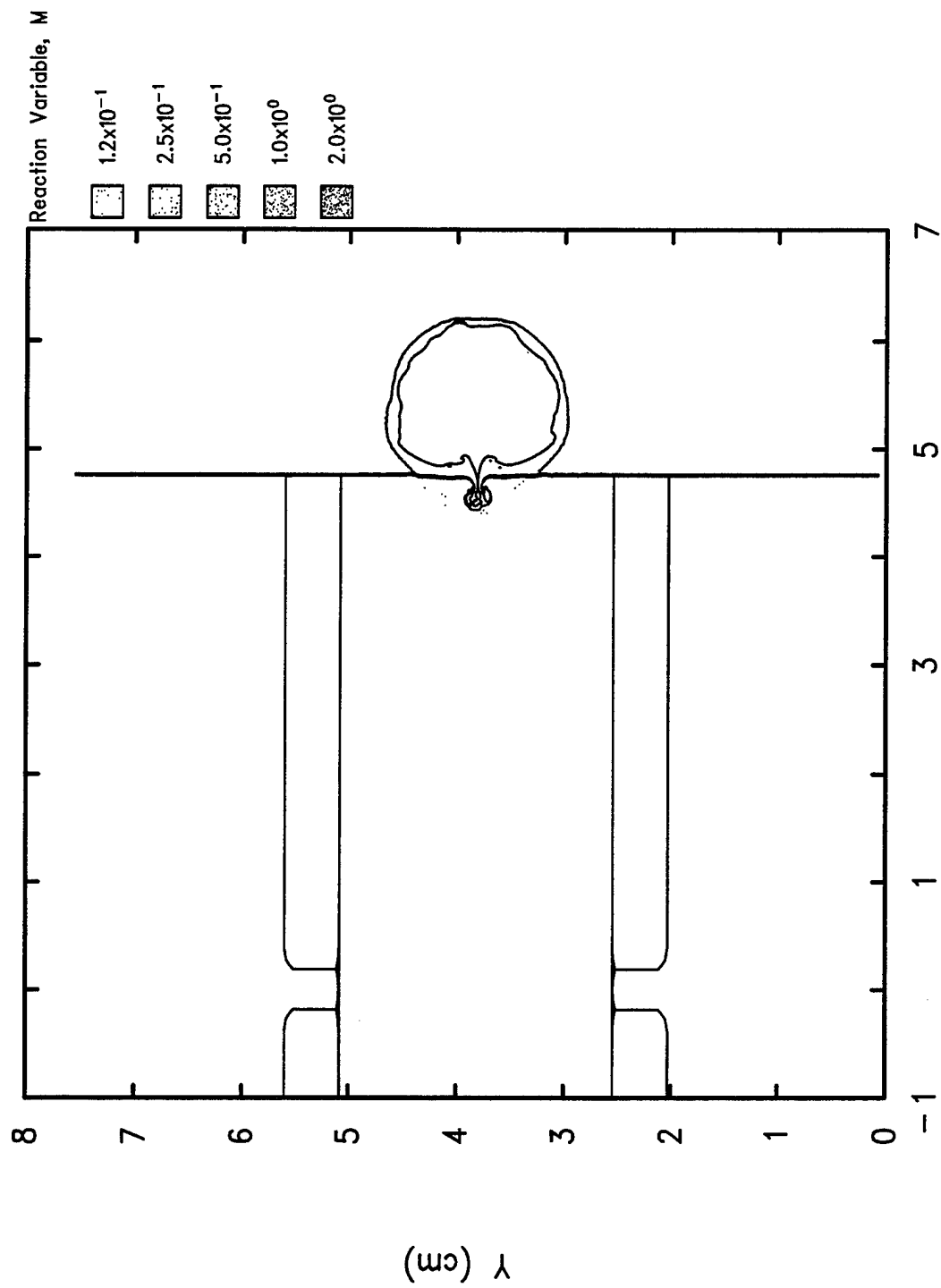
2DC Block 1 X (cm)
 2d-cth-mmp simulation of NEOD Phase III LSC detonation
 CTKDUK 3/28/95 11:40:25 CTH 5557 Time=2.00005x10⁻⁵



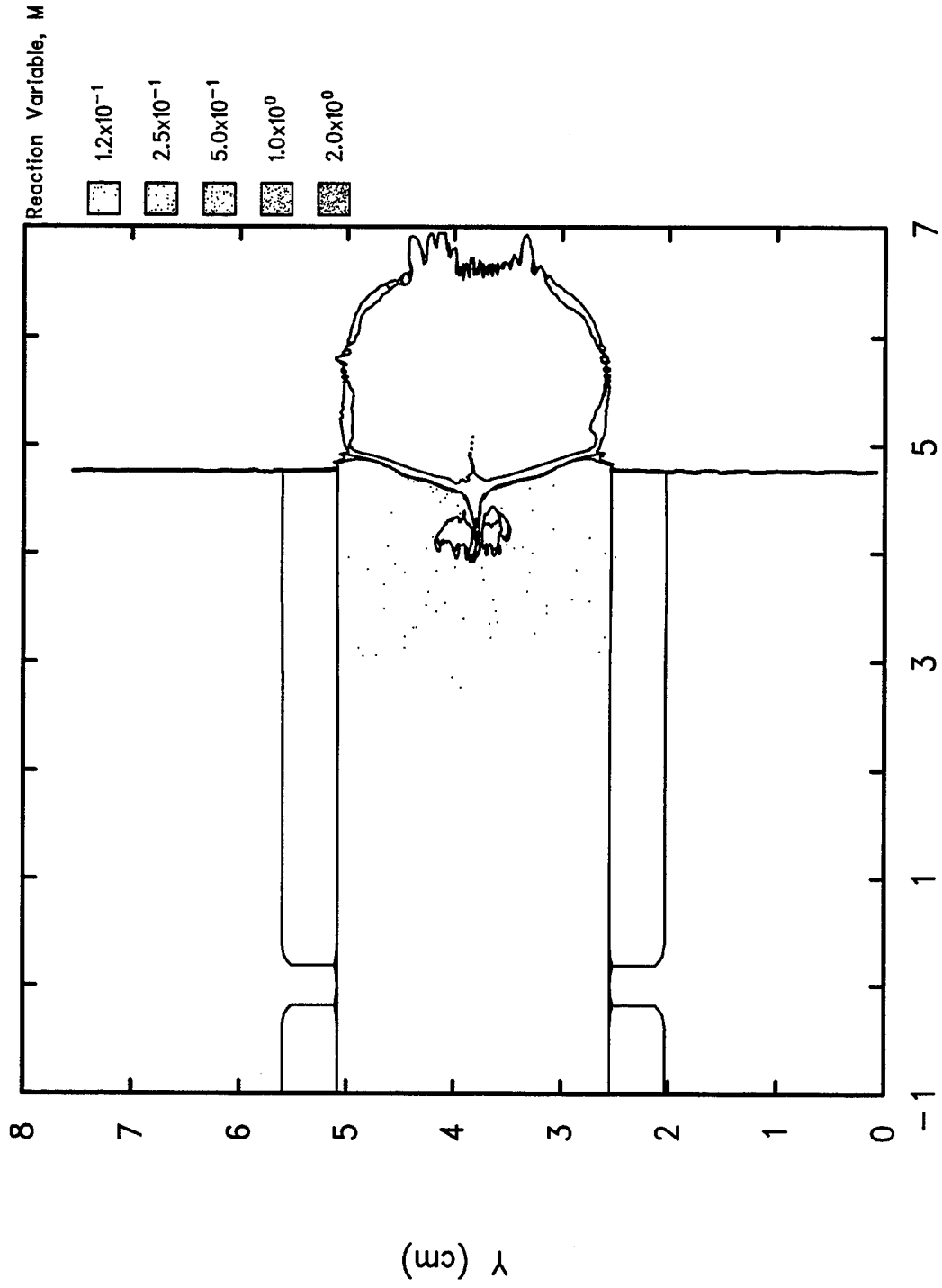
2DC Block 1 X (cm)
 2d-cth-mmp simulation of NEOD Phase III LSC detonation
 CTKDUK 4/03/95 01:39:30 CTH 12656 Time=2.27859x10⁻⁵



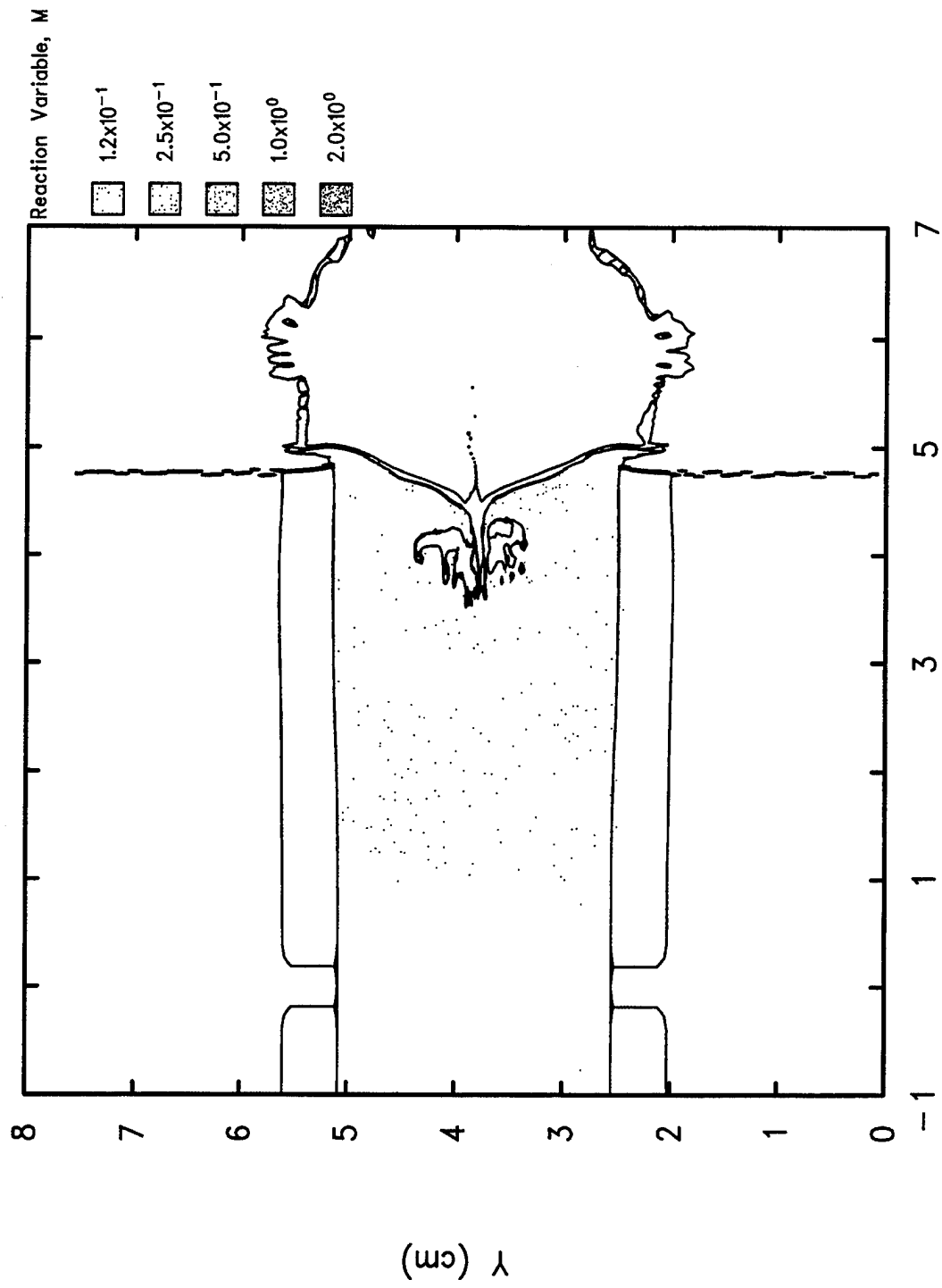
2DC Block 1
 2d-cth-mmp simulation of NEOD Phase III LSC detonation
 CTKCZY G 3/20/95 10:33:46 CTH 0 Time=0.



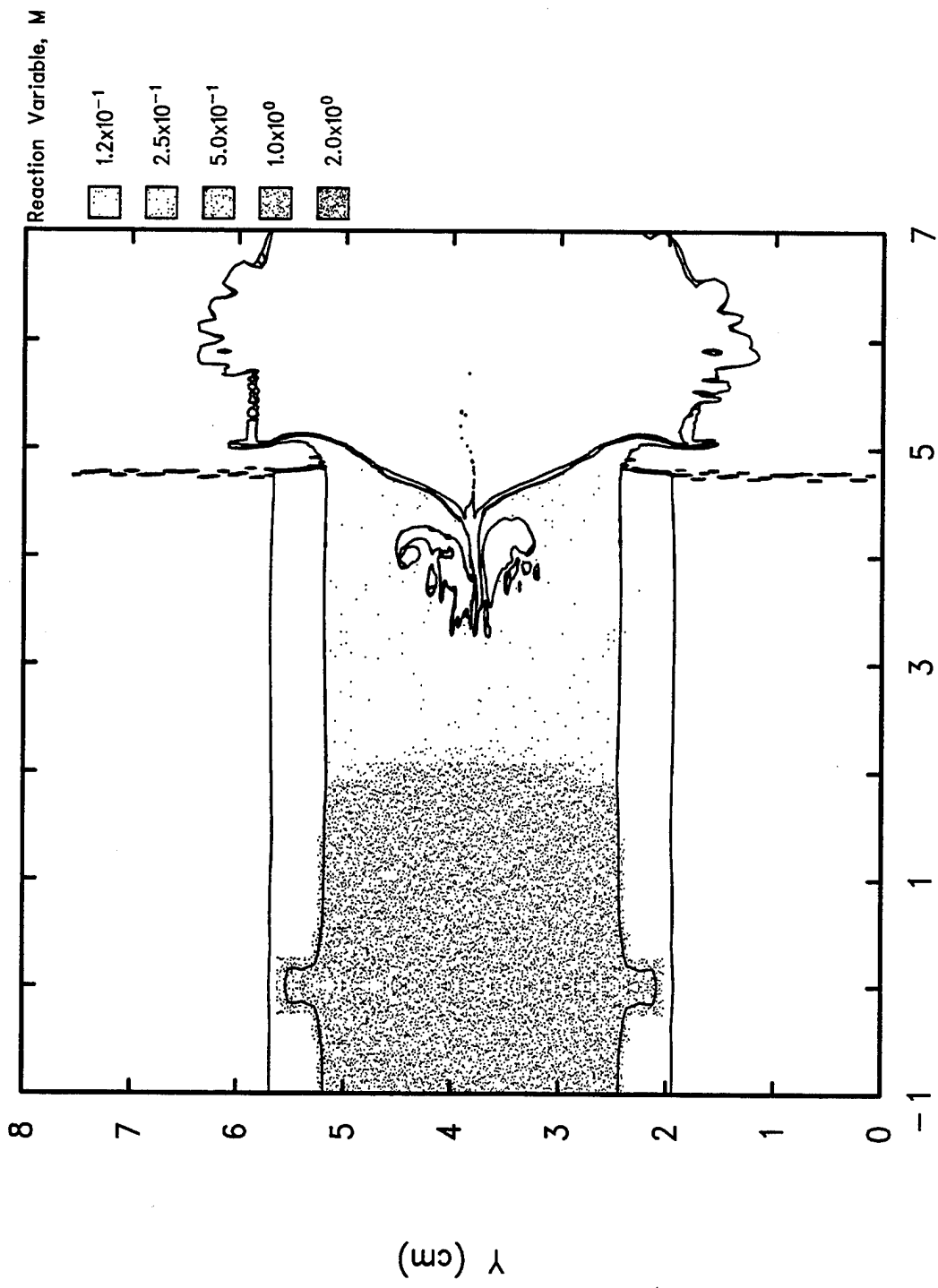
2DC Block 1
 2d-cth-mmp simulation of NEOD Phase III LSC detonation
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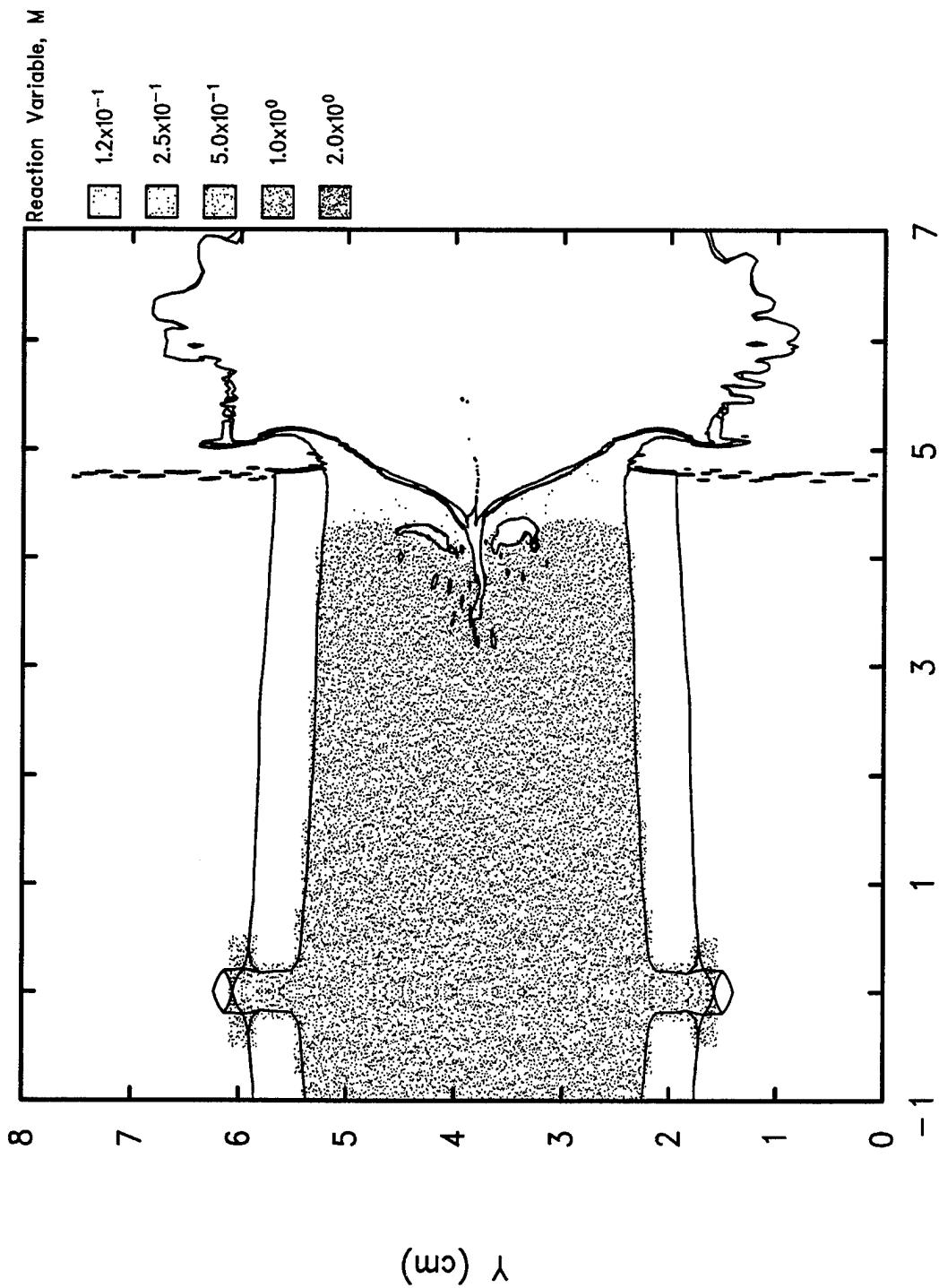
2DC Block 1
 2d-cth-mmp simulation of NEOD Phase III LSC detonation
 CTKDUK 3/25/95 13:31:40 CTH 2904 Time=1.0002x10⁻⁵



2DC Block 1
 2d-cth-mmp simulation of NEOD Phase III LSC detonation
 CTKDUK 3/27/95 03:19:28 CTH 4247 Time=1.50014x10⁻⁵



2DC Block 1
 2d-cth-mmp simulation of NEOD Phase III LSC detonation
 CTKDUK 3/28/95 11:40:25 CTH 5557 Time=2.00005x10⁻⁵



2DC Block 1
 2d-cth-mmp simulation of NEOD Phase III LSC detonation
 CTKDUK 4/03/95 01:39:30 CTH 12656 Time=2.27859x10⁻⁵

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