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Simulating Sympathetic Detonation of 105-mm Artillery Projectiles with CTH

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and John Starkenberg

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Simulating Sympathetic Detonation of 105-mm Artillery Projectiles with CTH

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Abstract

The CTH code was used to simulate sympathetic detonation experiments conducted using 105-mm projectiles separated by buffers of Plexiglas, rolled homogeneous armor (RHA), and mild steel. Buffer thicknesses near the experimental sympathetic detonation threshold were simulated. No propagation criterion associated with pressure loading was revealed by the results of this study. CTH computations were also made to confirm the presence of finite rise-time or "ramp" waves in the acceptor explosive (previously observed in Lagrangian computations) with layered buffers of Plexiglas and steel. The CTH results show more structure in the ramp wave and shorter rise times than those previously obtained. The History Variable Reactive Burn (HVRB) explosive initiation model in the CTH code was exercised in simulations of similar configurations. These simulations showed that initiation may occur during propagation of the incident shock wave through the acceptor or after its reflection from the casing at the back of the acceptor. Predicted buffer thicknesses required to prevent sympathetic detonation are much less than those determined in the experiments, indicating that mechanisms in addition to shock initiation contribute to sympathetic detonation.

TABLE OF CONTENTS

	<u>Page</u>
LIST OF FIGURES	v
LIST OF TABLES	vii
1. INTRODUCTION	1
2. DESCRIPTION OF CTH	1
3. BRIEF DESCRIPTION OF THE EXPERIMENTS	2
4. CTH SIMULATION OF THE EXPERIMENTS	2
5. COMPARISON OF CTH AND STEALTH COMPUTATIONS	4
6. HVRB PREDICTIONS OF SYMPATHETIC DETONATION	5
7. SUMMARY AND CONCLUSIONS	5
8. REFERENCES	27
DISTRIBUTION LIST	29
REPORT DOCUMENTATION PAGE	33

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LIST OF FIGURES

<u>Figure</u>	<u>Page</u>
1. Experimental arrangement used by Boyle	7
2. 2-D CTH simulation	9
3. 76-mm Plexiglas buffer: contour plot sequence	10
4. 76-mm Plexiglas buffer: pressure history	11
5. 76-mm Plexiglas buffer: impulse history	12
6. Plexiglas and mild steel: comparison of pressure contours	13
7. Plexiglas and mild steel: comparison of pressure and impulse histories	14
8. Mild steel and RHA: comparison of pressure contours at the experimental threshold	15
9. Mild steel and RHA: comparison of pressure and impulse histories at the experimental threshold	16
10. Mild steel and RHA: comparison of pressure contours at the same buffer thickness	17
11. Mild steel and RHA: comparison of pressure and impulse histories at the same buffer thickness	18
12. Results of the STEALTH sympathetic detonation simulation with layered buffers .	20
13. Results of the CTH sympathetic detonation simulation with layered buffers	21
14. Unbuffered configuration with 12.7-mm separation: pressure and reaction variable contours	22
15. 6.4-mm Steel buffer in direct contact with donor and acceptor munitions: pressure and reaction variable contours	23
16. 6.4-mm Plexiglas buffer centered in 12.7-mm space: pressure and reaction variable contours	24

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LIST OF TABLES

<u>Table</u>	<u>Page</u>
1. Experimental Results	8
2. Computed Pressure and Impulse at the Experimental Thresholds	19
3. Sympathetic Detonation Predictions for the Contact Configuration	25
4. HVRB Results for 12.7-mm Munition-to-Munition Separation Computations ...	26

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1. INTRODUCTION

Sympathetic detonation of munitions occurs when a detonating munition (the donor) initiates detonation in a neighboring munition (the acceptor). Shock due to casing impact is the primary propagation mechanism for unshielded munitions at close range, while at longer range, fragment penetration is the primary mechanism. Shielding (buffers) between munitions reduces the incidence of sympathetic detonation by reducing shock stimulus and impeding fragments.

The present study employed the CTH code (Hertel et al. 1993) and focused on three objectives. The first was to determine if any similarities in pressure-loading exist when using CTH to simulate buffered sympathetic detonation experiments with buffer thicknesses near the sympathetic detonation threshold, as determined in experiments. The second objective was to confirm the presence of finite rise-time or "ramp" waves in the acceptor explosive previously observed using the nonreactive Lagrangian code STEALTH (Electric Power Research Institute 1981). The third objective was to exercise a CTH reactive model within the acceptor explosive.

2. DESCRIPTION OF CTH

The continuum mechanics solver CTH is an ongoing project of the Sandia National Laboratory. It is intended to provide capabilities for modeling dynamics of multidimensional systems with multiple materials, large deformations and strong shock waves. Finite-difference analogs of the Lagrangian equations of momentum and energy conservation are employed with continuous rezoning to construct Eulerian differencing. Shock and detonation waves are treated using the method of artificial viscosity. CTH makes use of analytic (Mie-Gruneisen, JWL, etc.) and tabular (Sesame) equations of state as well as modern constitutive models (Johnson-Cook, Zerilli-Armstrong) including fracture (void insertion). In addition, there are three reaction models (Programmed Burn, CJ Volume Burn and History Variable Reactive Burn [HVRB]) and two porosity models. A variety of plots of computed results can be produced. These options provide an opportunity to treat complex material behavior including melting, vaporization, solid phase transitions, chemical reaction, and electronic excitation and ionization.

3. BRIEF DESCRIPTION OF THE EXPERIMENTS

The experimental arrangement (Boyle 1995) is illustrated in Figure 1. Both the donor and the acceptor munitions were 105-mm projectiles. In each experiment, the donor was filled with Composition B and the acceptor with pentolite. Each donor was initiated at a point on the side farthest from the acceptor, halfway between its top and bottom. Potted carbon gauges and steel witness plates were used to record the results. Buffer materials included polyethylene, mild steel, and rolled homogeneous armor (RHA). All buffers were 203 mm wide and 510 mm high. The thickness of the buffers was varied in order to determine a sympathetic detonation threshold.

The experimental results are summarized in Table 1. The "GOs" represent configurations in which sympathetic detonation of the acceptor occurred, while the "NOGOs" indicate that sympathetic detonation did not occur. Threshold ranges obtained from these results determined the buffer thicknesses we simulated computationally.

4. CTH SIMULATION OF THE EXPERIMENTS

The 2-D CTH simulation (representing the cross-sectional plane in which the donor is initiated) is illustrated in Figure 2. The primary effect of simulating a 3-D experiment in 2-D is to decrease the rate of decay of spherically divergent waves to that of cylindrically divergent waves. This produces somewhat higher stimulus levels in the 2-D case. The experiments were simulated with buffer thicknesses near the sympathetic detonation threshold for each buffer material. The dimensions were consistent with M1 105-mm projectiles. Casings were 10-mm-thick mild steel. The donor munition was filled with Composition B, modeled using a JWL equation of state for detonation products. The acceptor fill was "inert" pentolite, represented by a JWL equation of state with estimated constants. The donor munition was initiated at the side farthest from the acceptor using the programmed burn model. All buffers were 203 mm wide. Plexiglas was substituted for polyethylene, which was used as a buffer material in some of the original experiments. The buffer thicknesses were 70 mm and 76 mm for the Plexiglas buffers, 32 mm and

38 mm for the mild-steel buffers, and 38 mm and 51 mm for the RHA buffers. In addition to the threshold computations, a computation was made with a 38-mm-thick RHA buffer to enable direct comparison with the mild-steel computation at the same thickness.

Figure 3 shows a sequence of pressure contour plots for the Plexiglas buffer. The programmed burn detonation can be seen propagating across the donor munition in the first frame, while subsequent frames illustrate a shock wave propagating through the buffer and casing of the acceptor and into the acceptor explosive. The buffer is nearly obliterated and the acceptor is significantly deformed at late times. A crack can be seen in the casing at the back of the acceptor in the last frame. Figures 4 and 5 illustrate pressure and impulse history plots, respectively, from the same computation, taken at a point just inside the acceptor casing. The loading consists of an initial pulse about 40 μ s wide, followed by significant late-time reverberations. The impulse history plot indicates that about half the ultimate impulse delivered is associated with the reverberations.

Figure 6 is a comparison of pressure contour plots for the Plexiglas buffer with similar plots for a mild-steel buffer. The shock arrives at the acceptor explosive 15 μ s sooner in the mild-steel buffer simulation, due to the smaller thickness of and higher wave speed in the steel. Otherwise, the results from both the Plexiglas and mild-steel buffer simulations appear similar. At late times, some cracking on the front of the acceptor near the center can be observed with the steel buffer and acceptor casing, but no cracking is seen at the back of the casing. As illustrated in Figure 7, significant differences in pressure-loading are indicated in the pressure and impulse history plots. With the mild-steel buffer, the initial pulse is higher and narrower and the late-time pressures remain insignificant. Thus, though the impulse associated with the initial pulse is higher with the mild-steel buffer, the ultimate impulse is higher with the Plexiglas buffer.

Figure 8 illustrates a comparison of pressure contour plots for the 38-mm mild-steel buffer and the 51-mm RHA buffer. With the RHA buffer, a more definite cracking response can be seen in the acceptor casing on the side near the buffer, but otherwise the results appear similar. A

comparison of the pressure and impulse history plots of the RHA and mild-steel buffers, as shown in Figure 9, reveals no significant differences except that the pressures are somewhat higher and the ultimate impulse is significantly higher with the mild-steel buffer.

Figure 10 shows a comparison of pressure contour plots between a 38-mm RHA buffer and a 38-mm mild-steel buffer. With the buffer thicknesses equal, the RHA shows greater resistance to deformation and cracks clearly at late times. The pressure and impulse history plots are similar, as shown in Figure 11. The initial peak pressure is slightly higher and the ultimate impulse is somewhat lower with the RHA buffer.

The pressure and impulse results at the experimental threshold are summarized in Table 2. The impulse at the end of the first pulse, as well as the ultimate impulse (defined as the value at 250 μ s) is included. As shown in the table, the peak pressure is the same for Plexiglas and RHA, but higher for mild steel. The first-pulse impulse is different for all three buffer materials. The ultimate impulse values are similar for Plexiglas and mild steel, but lower for RHA.

5. COMPARISON OF CTH AND STEALTH COMPUTATIONS

CTH computations were performed to compare with the results obtained in a previous sympathetic detonation study, which used the nonreactive Lagrangian code STEALTH (Starkenberget al. 1987). In the STEALTH study, ramp waves as long as 25 μ s were observed in the acceptor explosive when layered buffers were used between munitions. In one case, the layered buffers consisted of 10 mm of Plexiglas sandwiched between two 10-mm layers of steel. Figures 12 and 13 show pressure waveforms produced in the acceptor munition in STEALTH and CTH simulations of the same configuration. The results obtained with CTH show more structure in the ramp wave and shorter rise-times than those obtained with STEALTH.

6. HVRB PREDICTIONS OF SYMPATHETIC DETONATION

The HVRB explosive initiation model (Kerley 1992) was exercised in two series of CTH simulations. In one series, the donor and acceptor were in direct contact with the buffer. In the other, the donor and acceptor were separated by a fixed 12.7-mm space, and the buffer was centered in that space. In both series, the acceptors were filled with reactive Composition B, and buffer thicknesses were decreased until sympathetic detonation occurred.

Figure 14 shows a sequence of pressure and reaction variable contour plots for unbuffered projectiles separated by a 12.7-mm space. Pressure contours are shown on the right side, and reaction variable contours are shown on the left side of each plot. In this case, initiation of the acceptor occurs as the incident shock wave propagates through it.

A sequence of contour plots for a 6.4-mm-thick steel buffer in direct contact with the donor and acceptor munitions is shown in Figure 15. This illustrates a configuration that does not produce sympathetic detonation.

Figure 16 shows a sequence of pressure and reaction variable contour plots for a 6.4-mm Plexiglas buffer centered in a 12.7-mm space. Initiation of the acceptor occurs after reflection of the shock wave at 55 μ s.

The results obtained in the HVRB simulations are summarized in Tables 3 and 4. In all cases, the buffer thicknesses required to prevent sympathetic detonation are less than those required in the experiments.

7. SUMMARY AND CONCLUSIONS

We simulated sympathetic detonation experiments with buffers at the threshold thickness. No propagation criterion associated with pressure-loading was revealed by the results of this study.

Buffers may prevent sympathetic detonation by influencing other aspects of the loading in addition to pressure. We observed that low-impedance Plexiglas buffers tend to spread out the pressure-loading over a longer period of time, while the high-strength steel and RHA buffers reduce deformation and damage.

When layered buffers are used, the results obtained with CTH show more structure in the ramp wave and shorter rise-times than those previously obtained with STEALTH. The response of explosives to ramp waves is not well understood, but it has been observed to be less violent than to a shock wave of the same strength.

Simulations with the HVRB explosive initiation model show that shock initiation may occur during propagation of the incident shock wave through the acceptor or after its reflection from the casing at the back of the acceptor. Buffers required to prevent sympathetic detonation in the computations were much thinner than those required in the experiments. This is another indication that mechanisms in addition to shock initiation contribute to sympathetic detonation. These results contrast sharply with those obtained in an earlier study using the Forest Fire initiation model and the 2DE code (Starkenbergh, Huang, and Arbuckle 1984). In that study, no buffer that could prevent sympathetic detonation of Composite B-filled 105-mm projectiles was found.

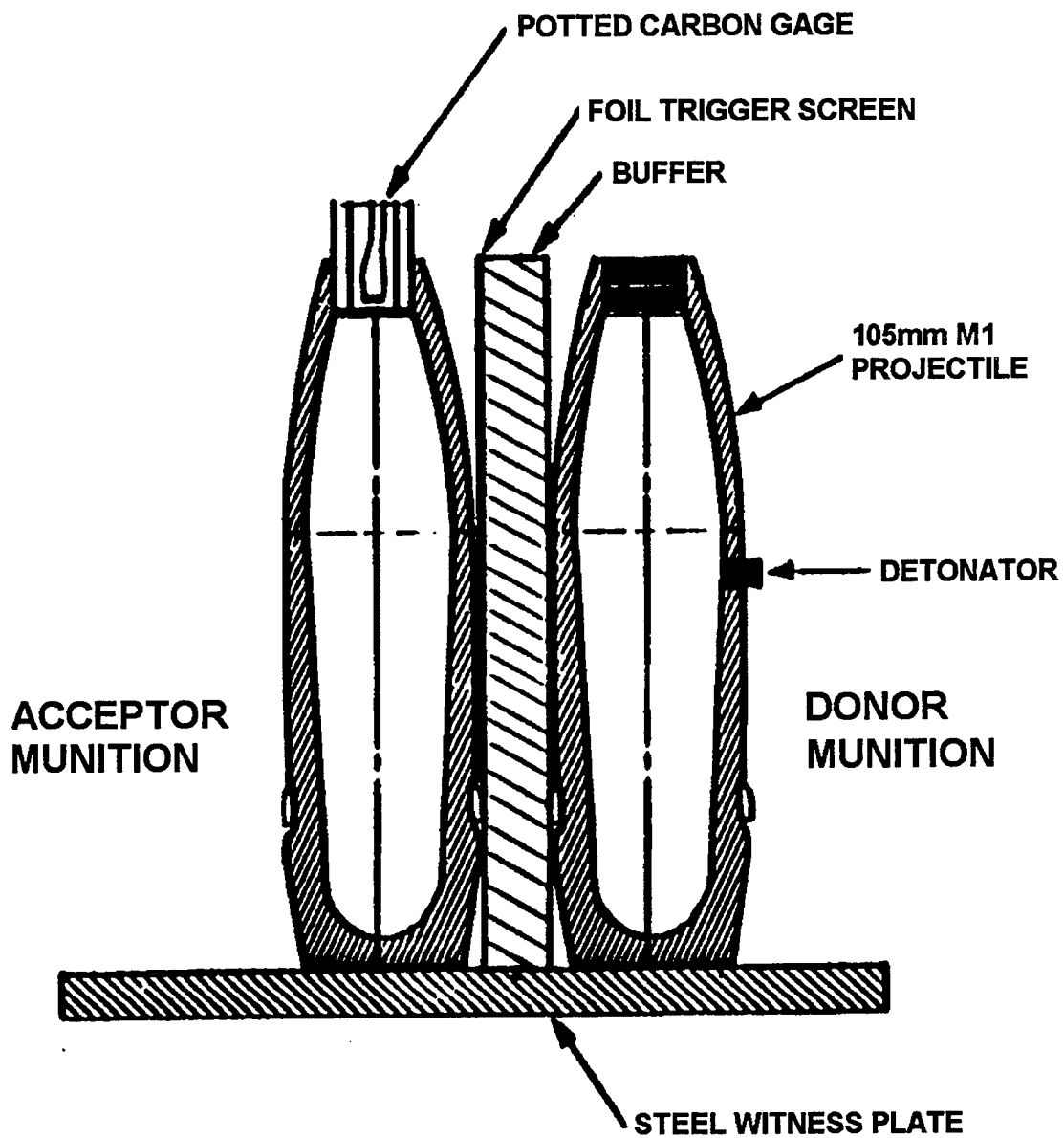


Figure 1. Experimental arrangement used by Boyle.

Table 1. Experimental Results

MATERIAL	THICKNESS (mm)	RESULT
MILD STEEL	<38 38 38 >38	4 GOs NOGO NOGO 3 NOGOs
RHA	<51 51 51 >51	2 GOs GO NOGO 3 NOGOs
POLYETHYLENE	<70 70 70 76 76 76 >76	5 GOs GO NOGO GO NOGO NOGO 3 NOGOs

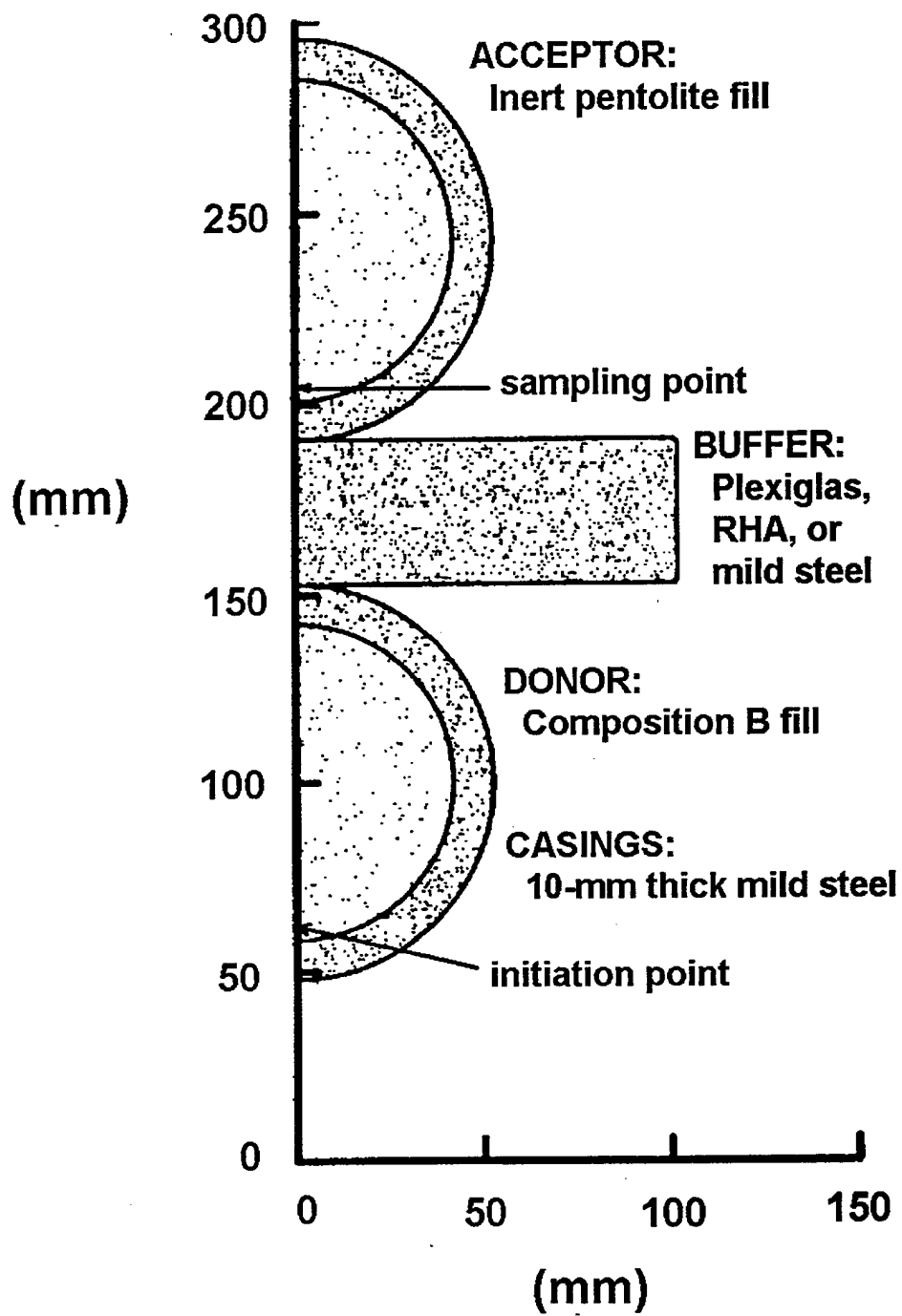


Figure 2. 2-D CTH Simulation.

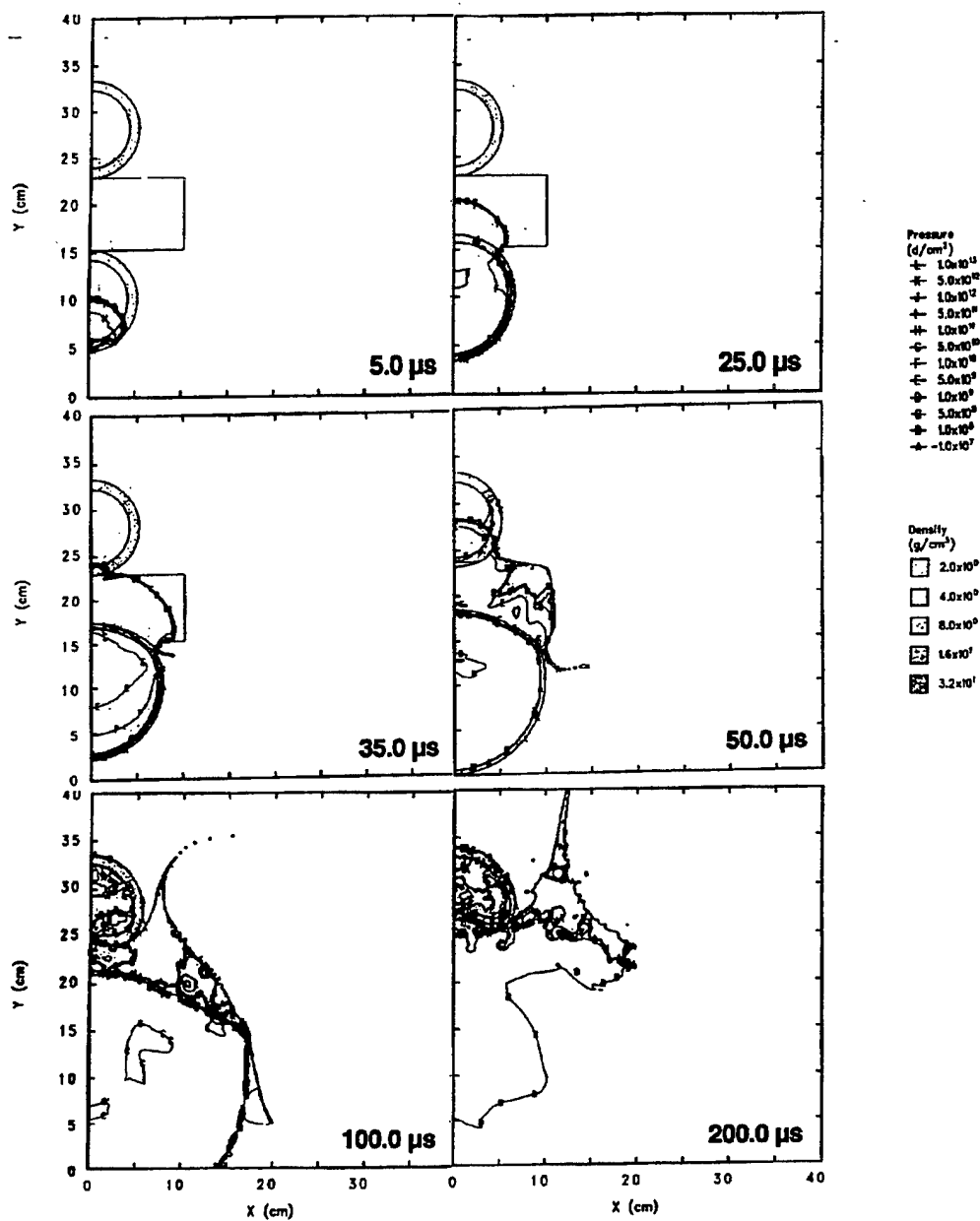


Figure 3. 76-mm Plexiglas buffer: contour plot sequence.

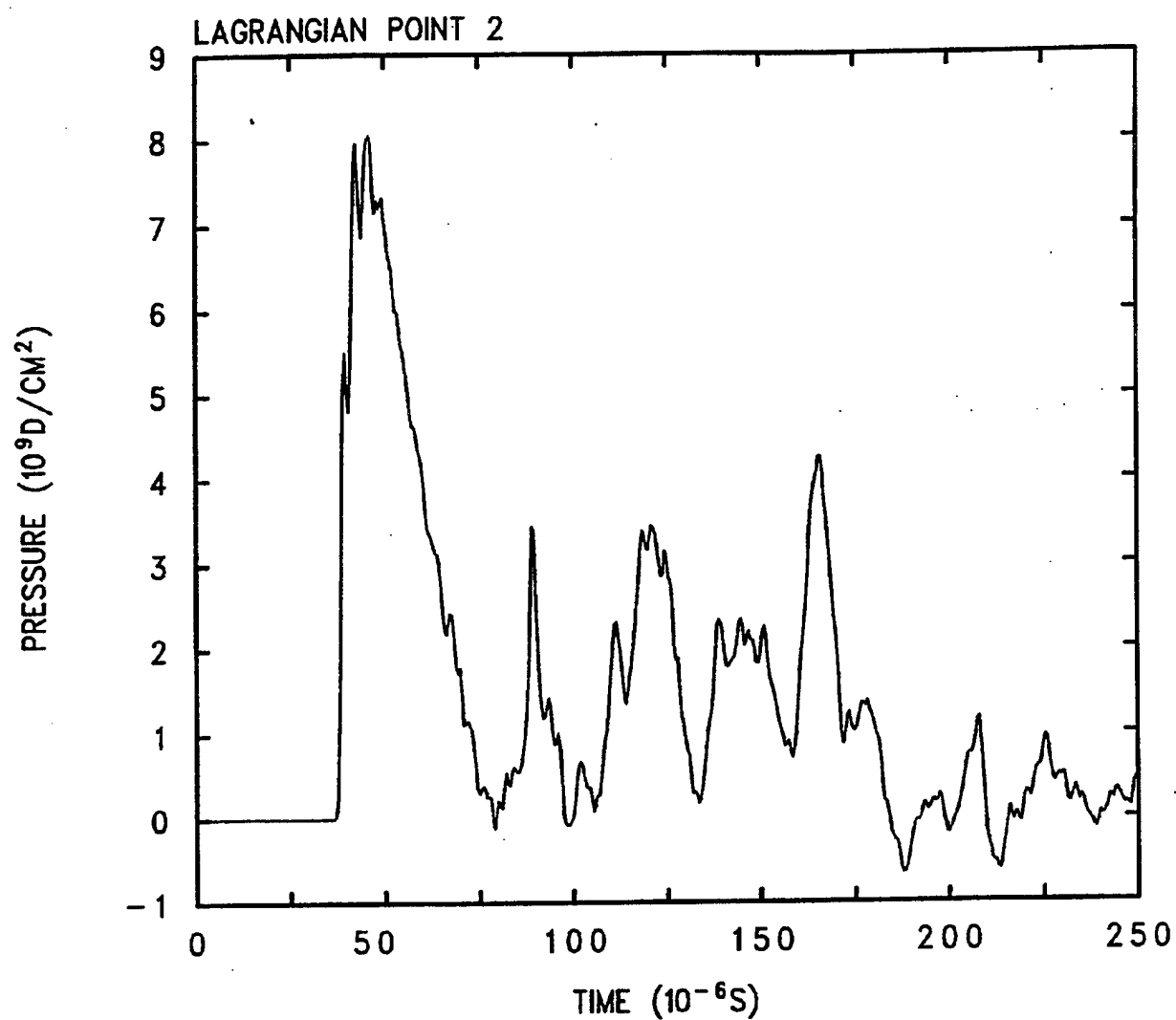


Figure 4. 76-mm Plexiglas buffer: pressure history.

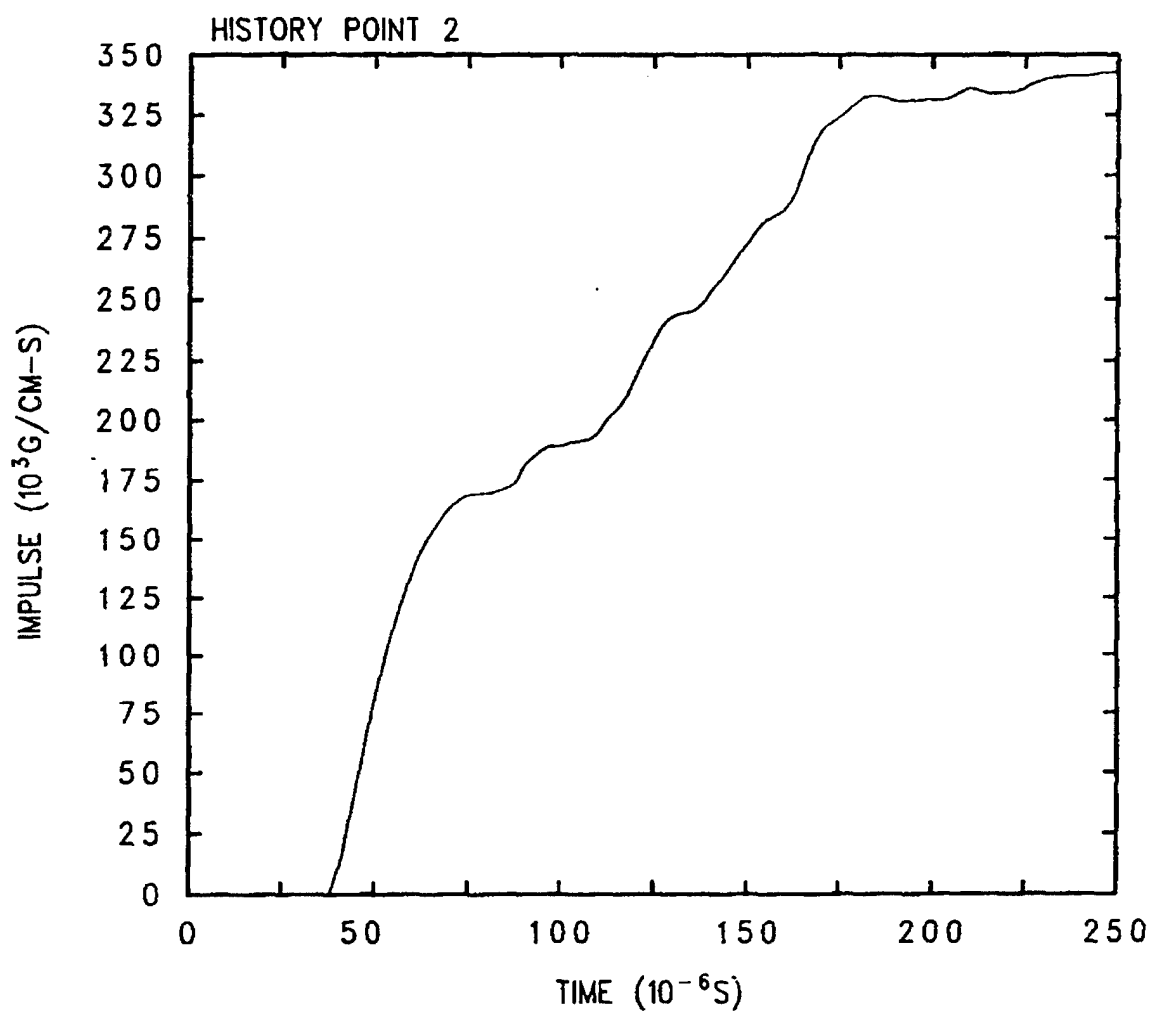


Figure 5. 76-mm Plexiglas buffer: impulse history.

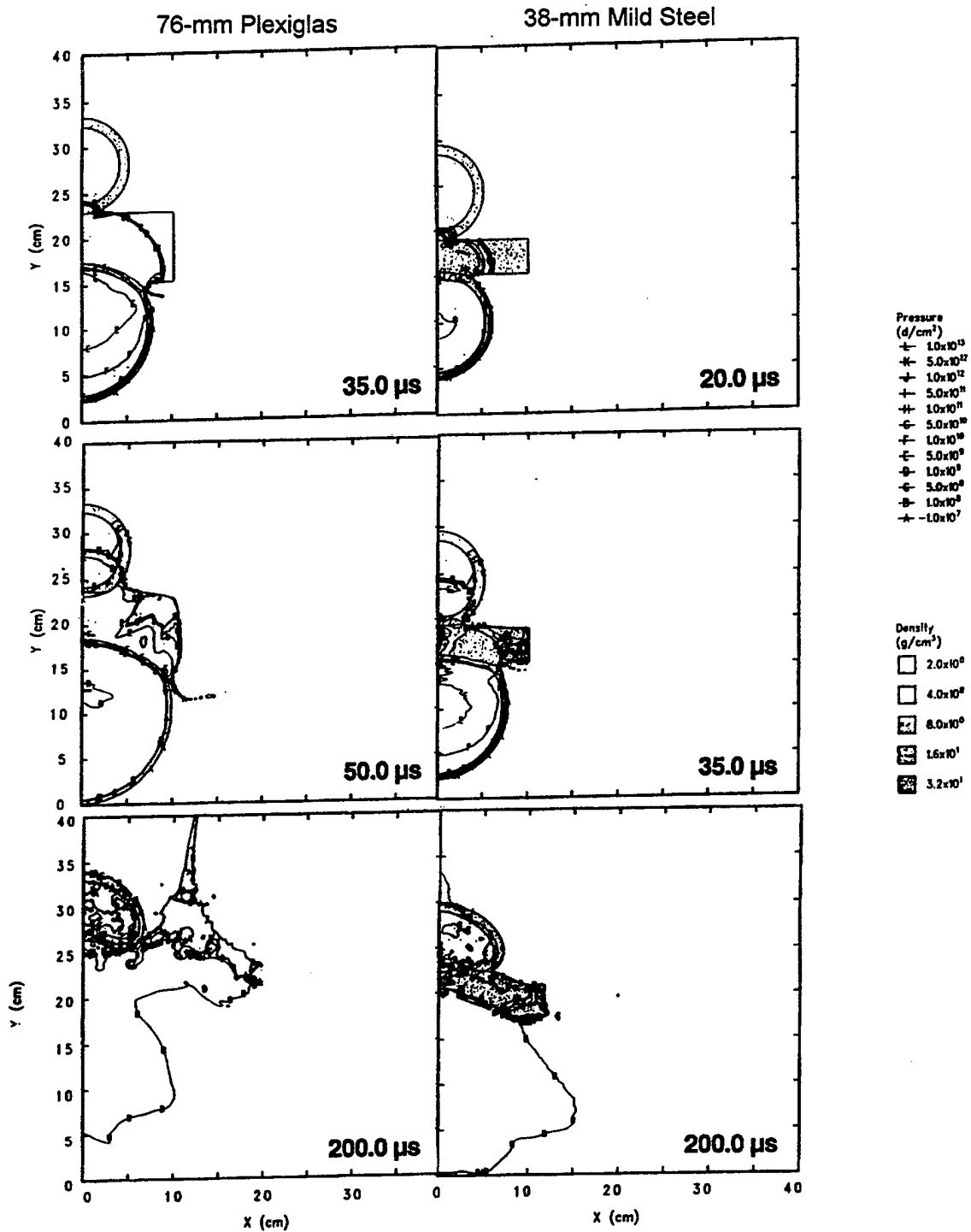


Figure 6. Plexiglas and mild steel: comparison of pressure contours.

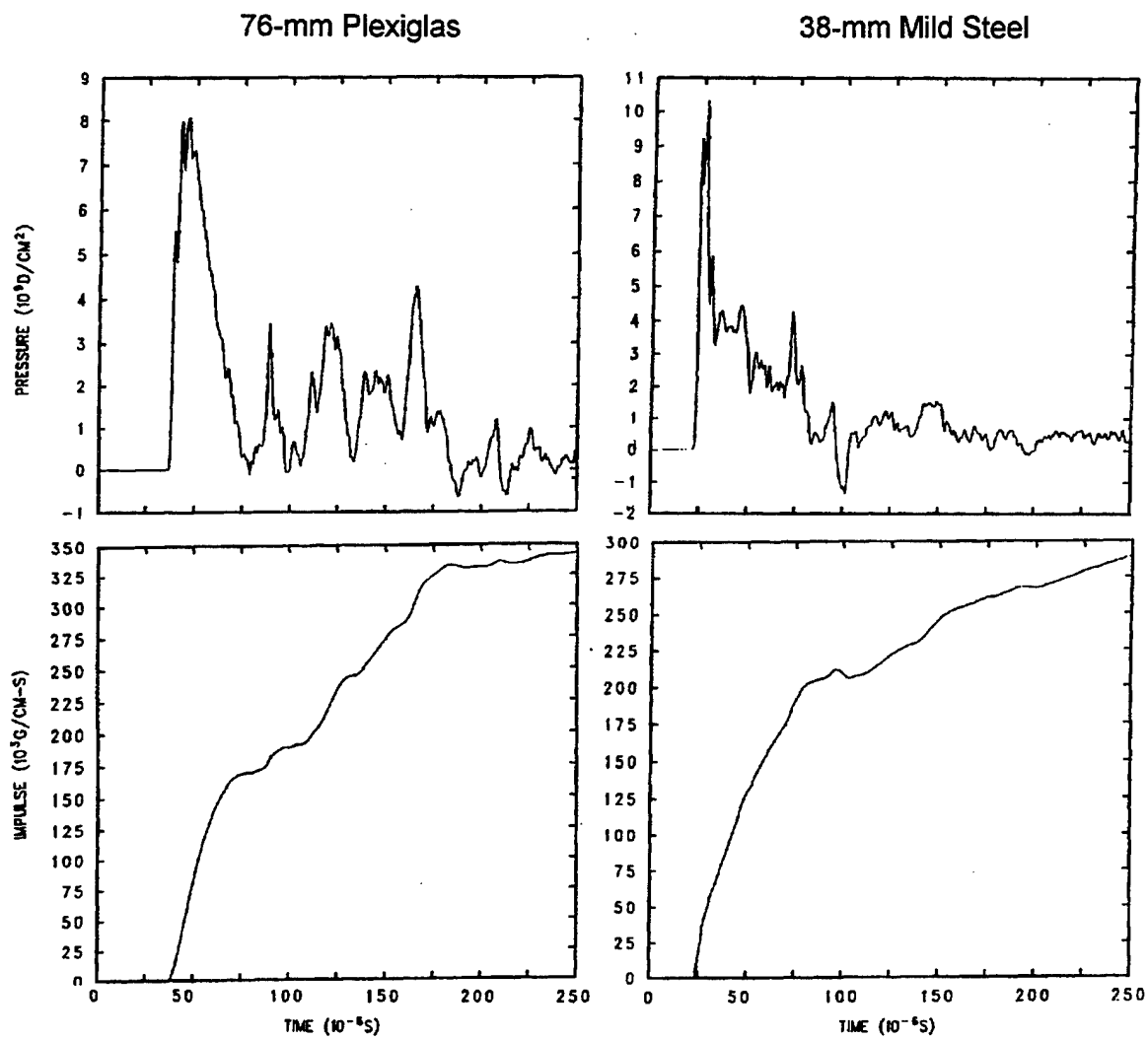


Figure 7. Plexiglas and mild steel: comparison of pressure and impulse histories.

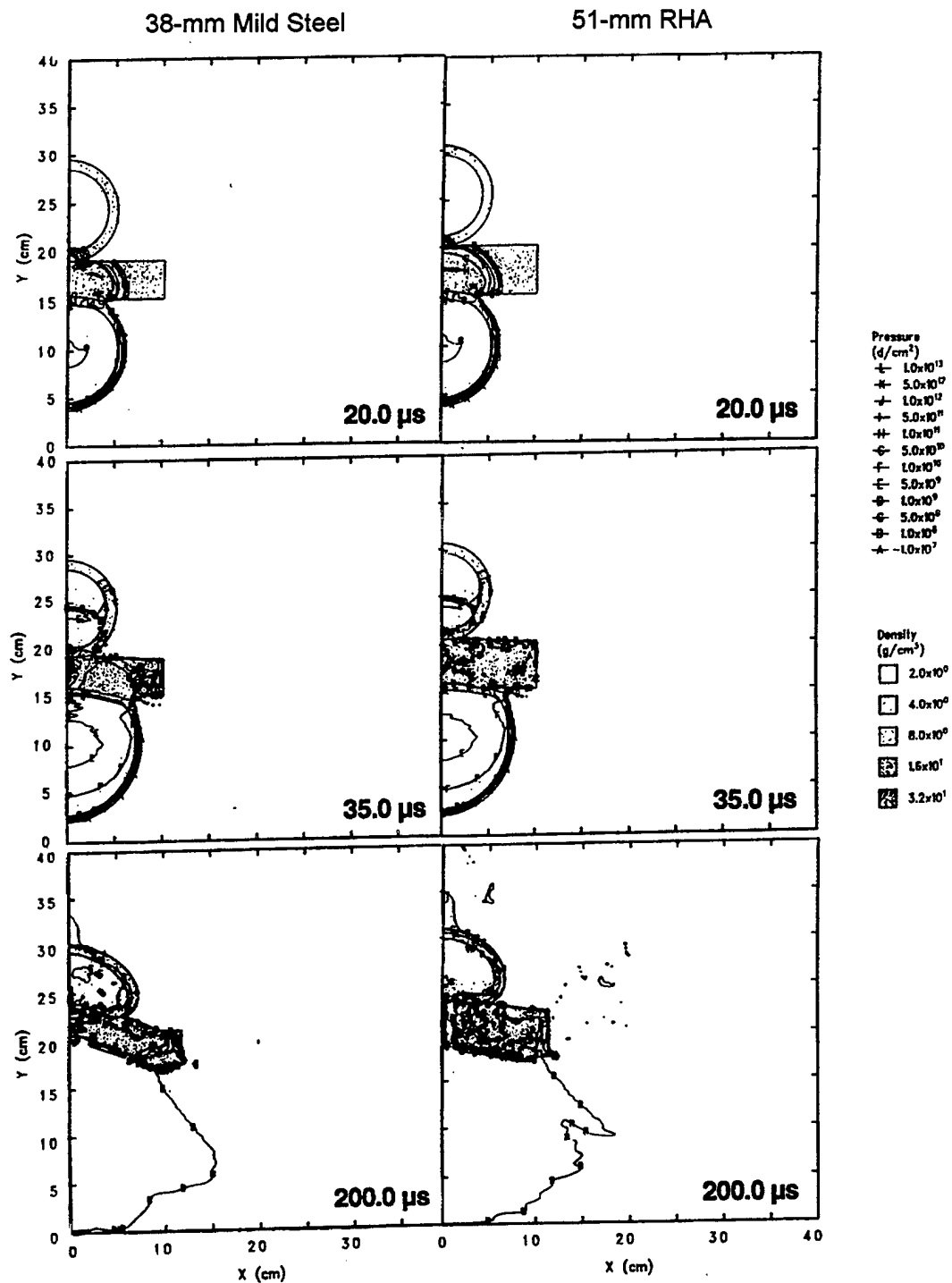


Figure 8. Mild steel and RHA: comparison of pressure contours at the experimental threshold.

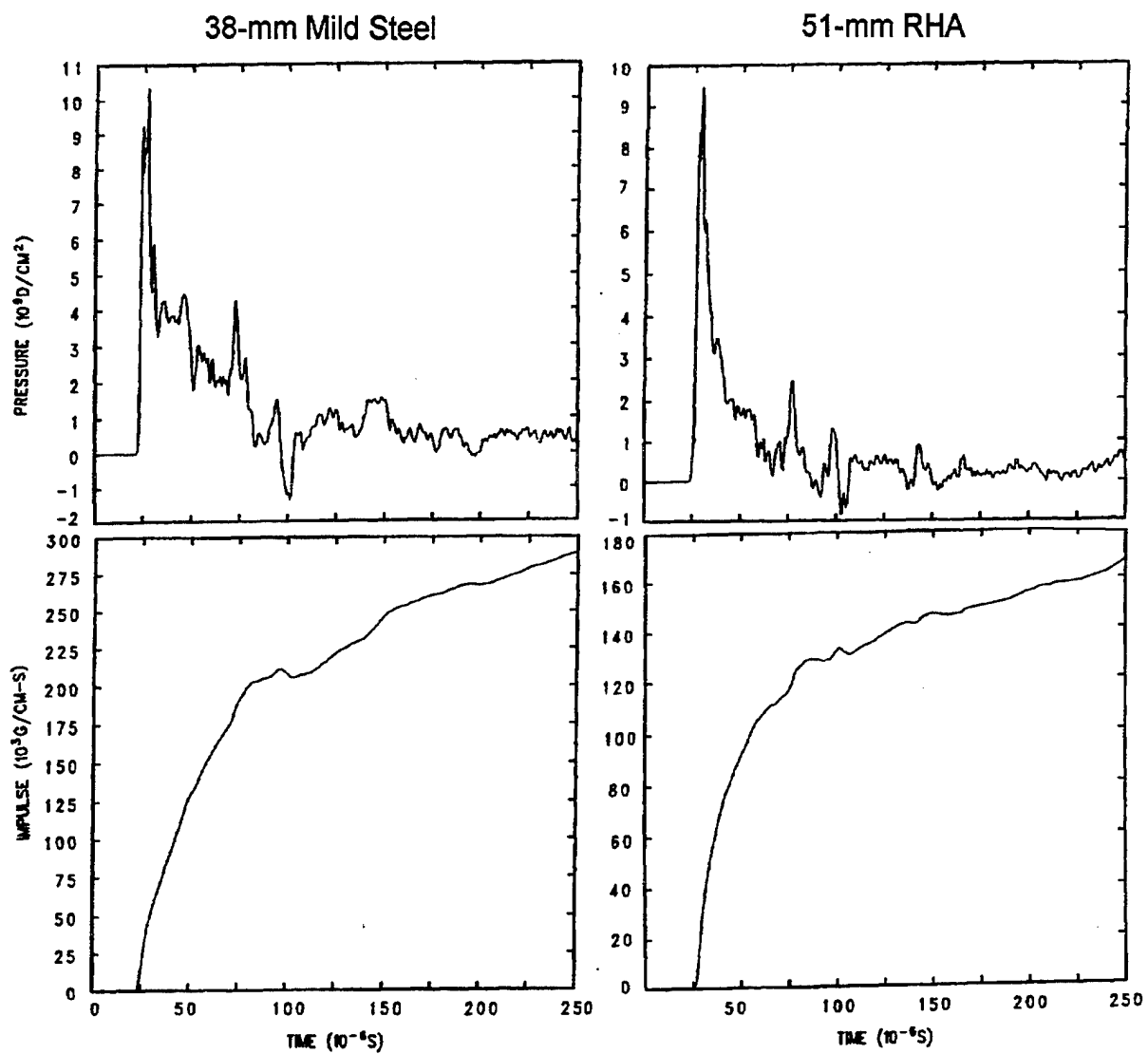


Figure 9. Mild steel and RHA: comparison of pressure and impulse histories at the experimental threshold.

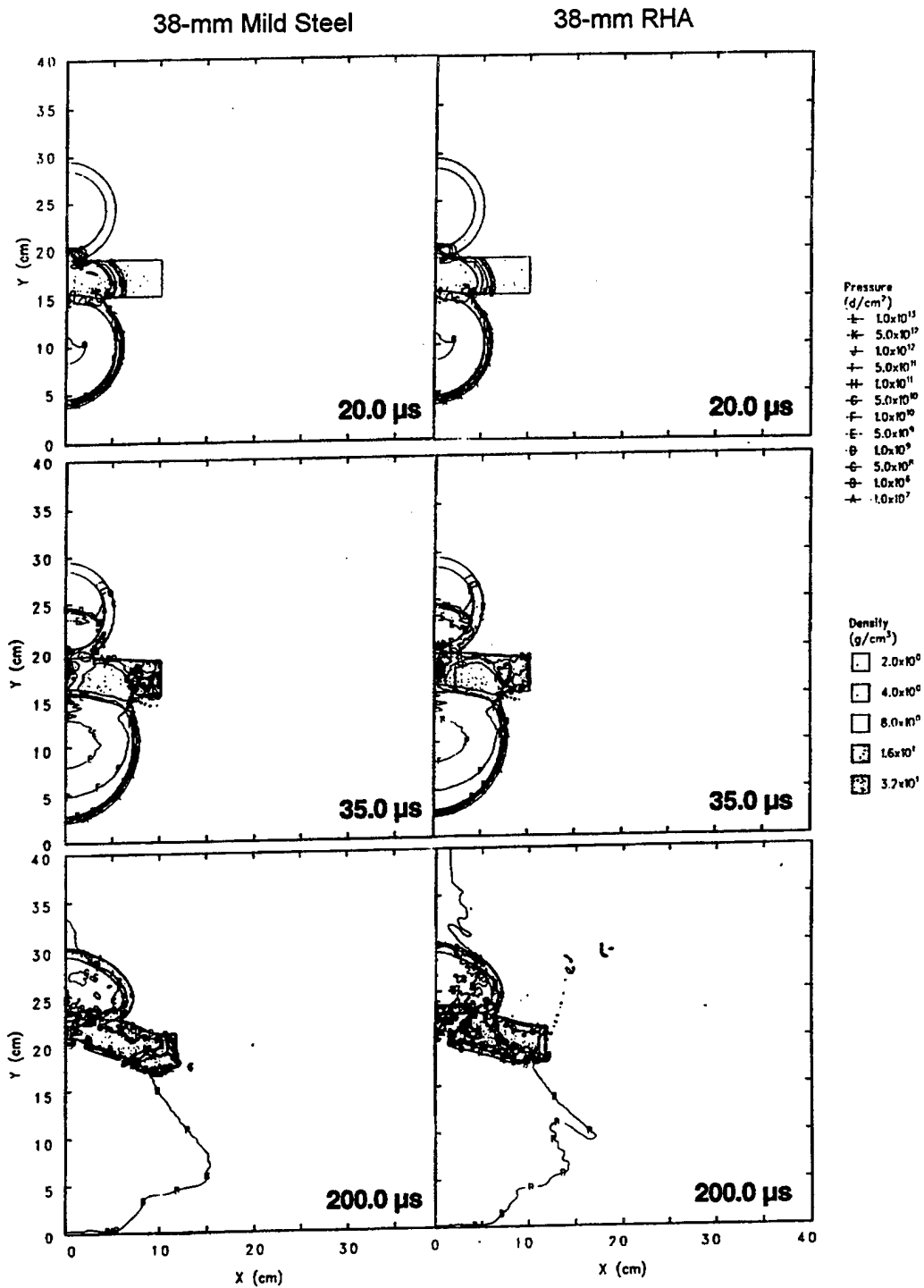


Figure 10. Mild steel and RHA: comparison of pressure contours at the same buffer thickness.

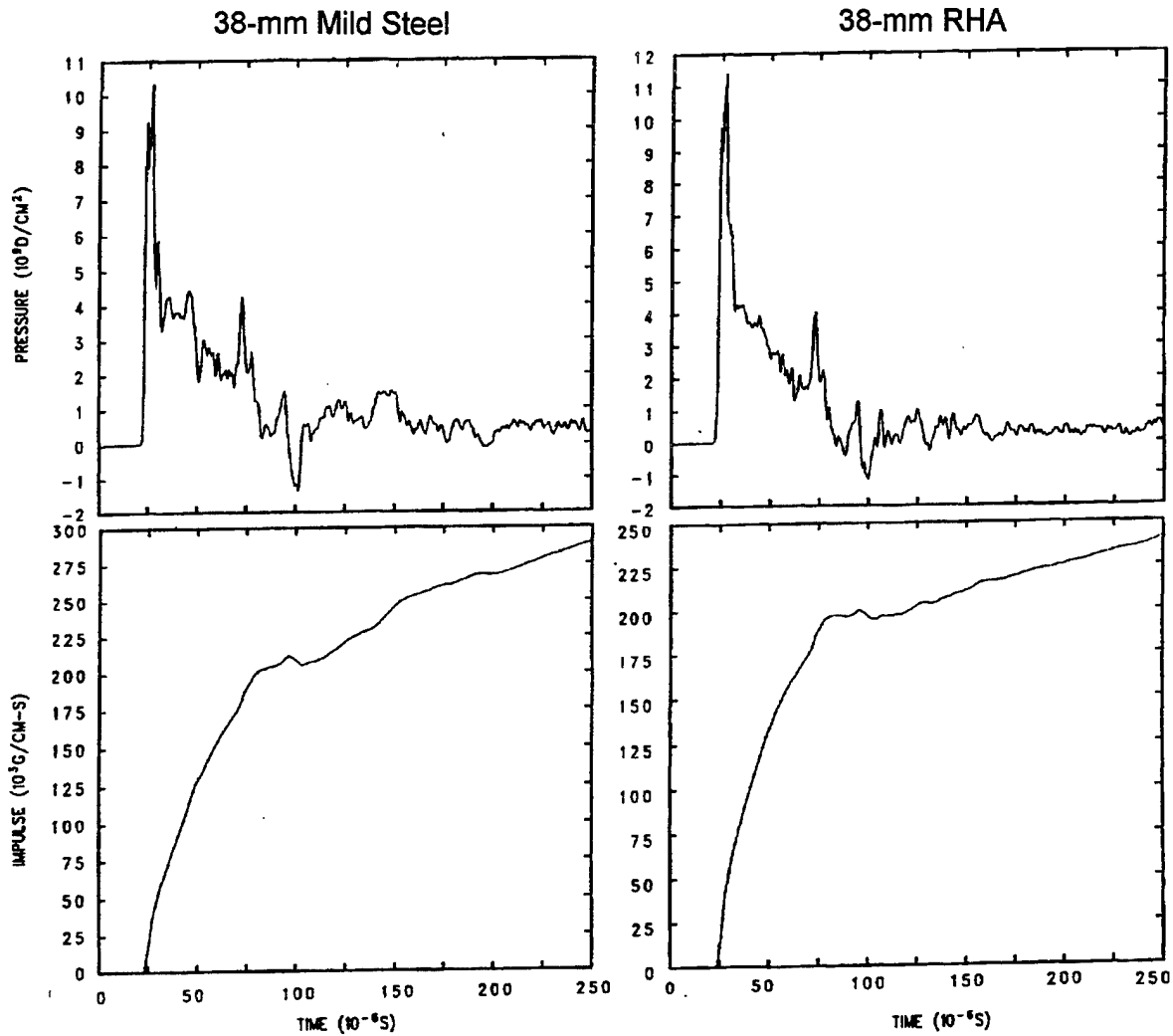


Figure 11. Mild steel and RHA: comparison of pressure and impulse histories at the same buffer thickness.

Table 2. Computed Pressure and Impulse at the Experimental Thresholds

BUFFER MATERIAL	BUFFER THICKNESS (mm)	PEAK PRESSURE (GPa)	FIRST-PULSE IMPULSE (kPa•s)	ULTIMATE IMPULSE (kPa•s)
PLEXIGLAS	70	0.94	17.6	36.0
	76	0.81	16.9	34.2
MILD STEEL	32	1.22	24.7	35.1
	38	1.28	20.3	28.8
RHA	51	0.94	12.9	16.8

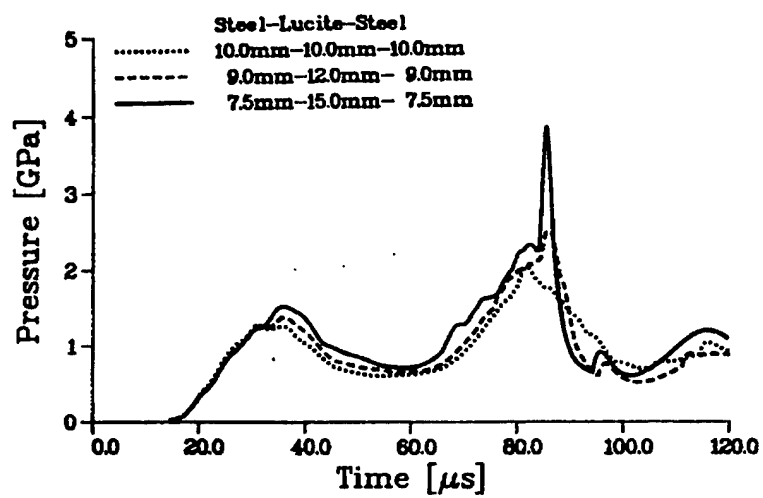
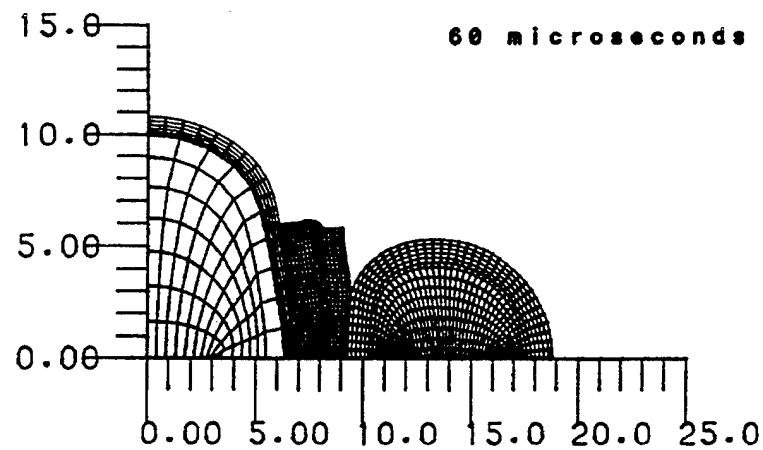


Figure 12. Results of the STEALTH sympathetic detonation simulation with layered buffers.

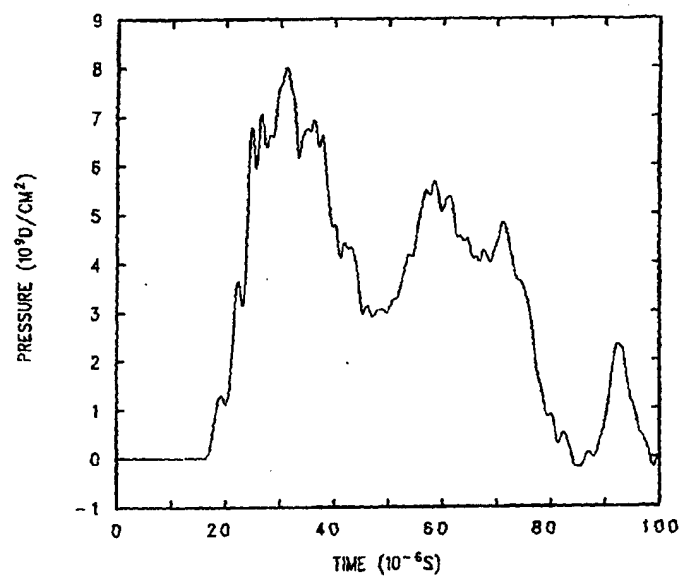
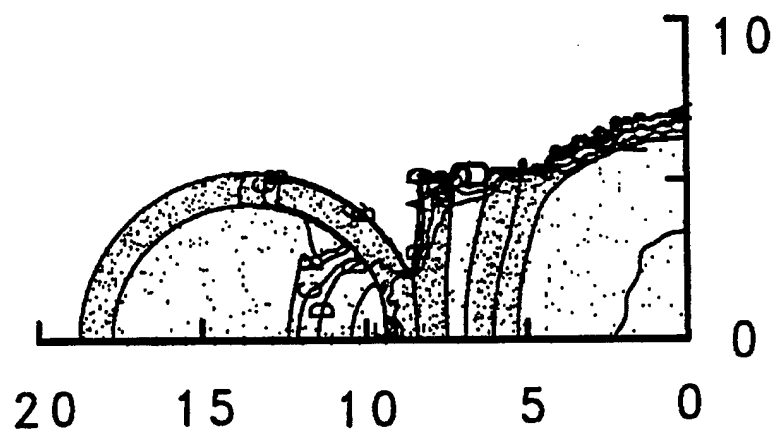


Figure 13. Results of the CTH sympathetic detonation simulation with layered buffers.

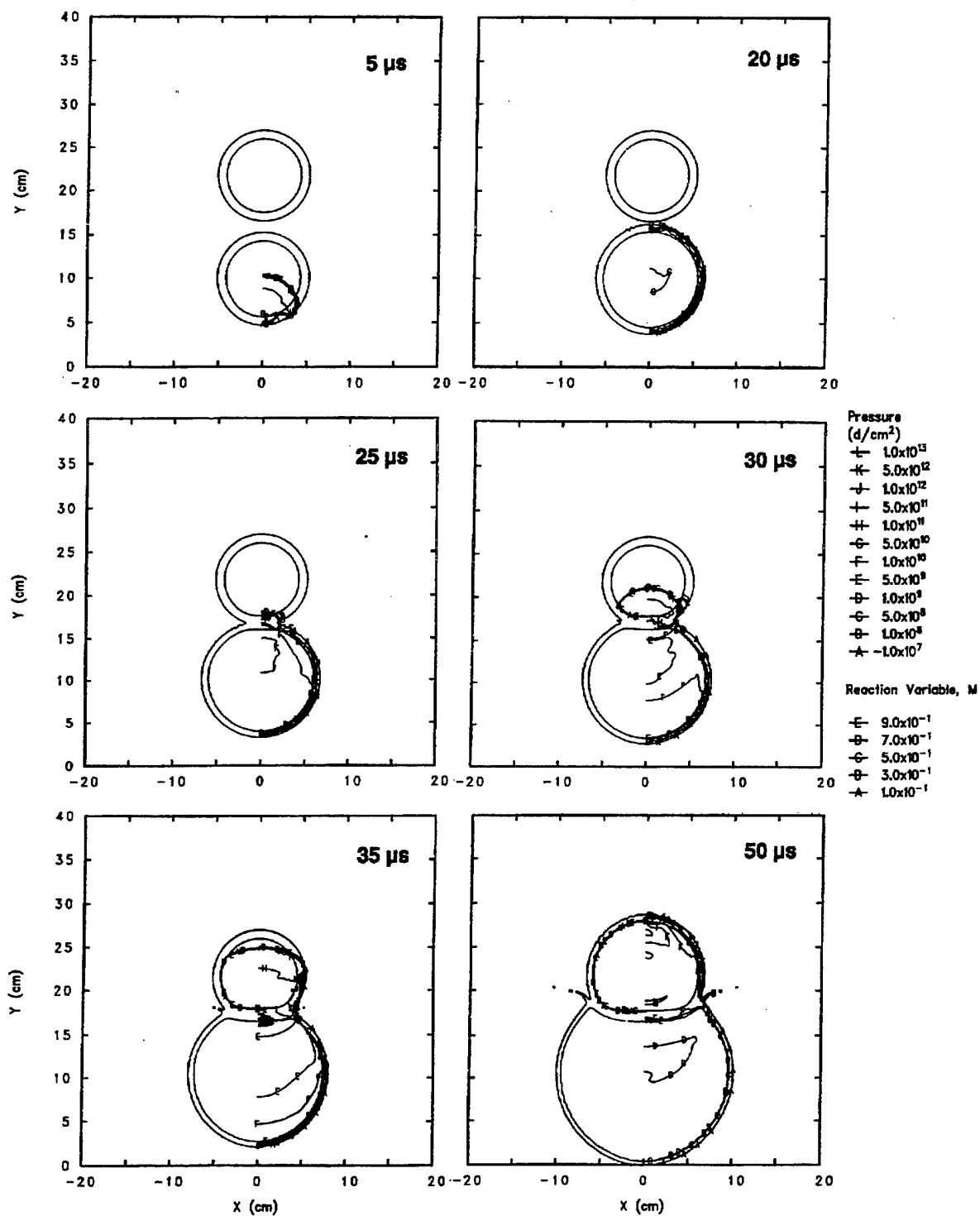


Figure 14. Unbuffered configuration with 12.7-mm separation: pressure and reaction variable contours.

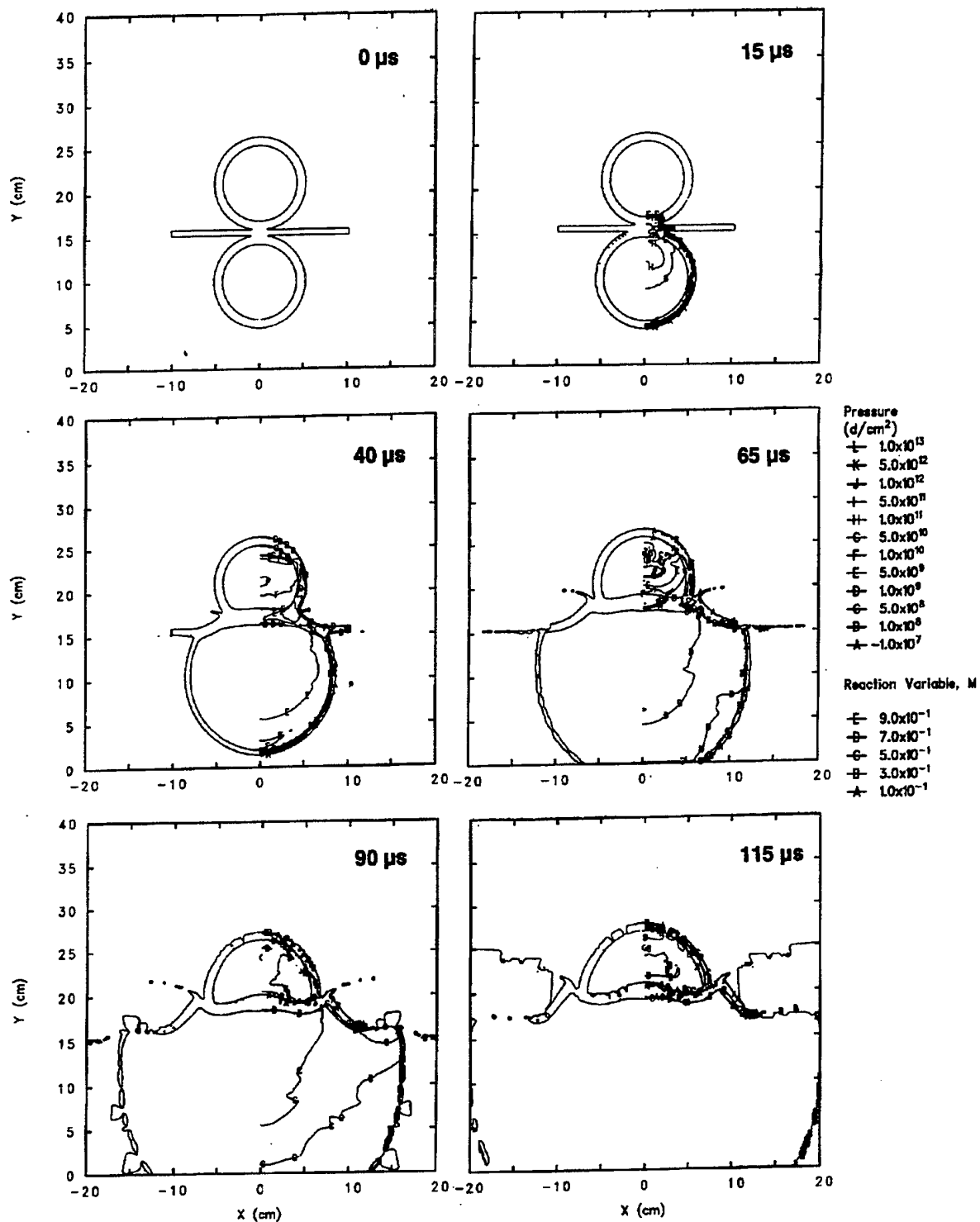


Figure 15. 6.4-mm Steel buffer in direct contact with donor and acceptor munitions: pressure and reaction variable contours.

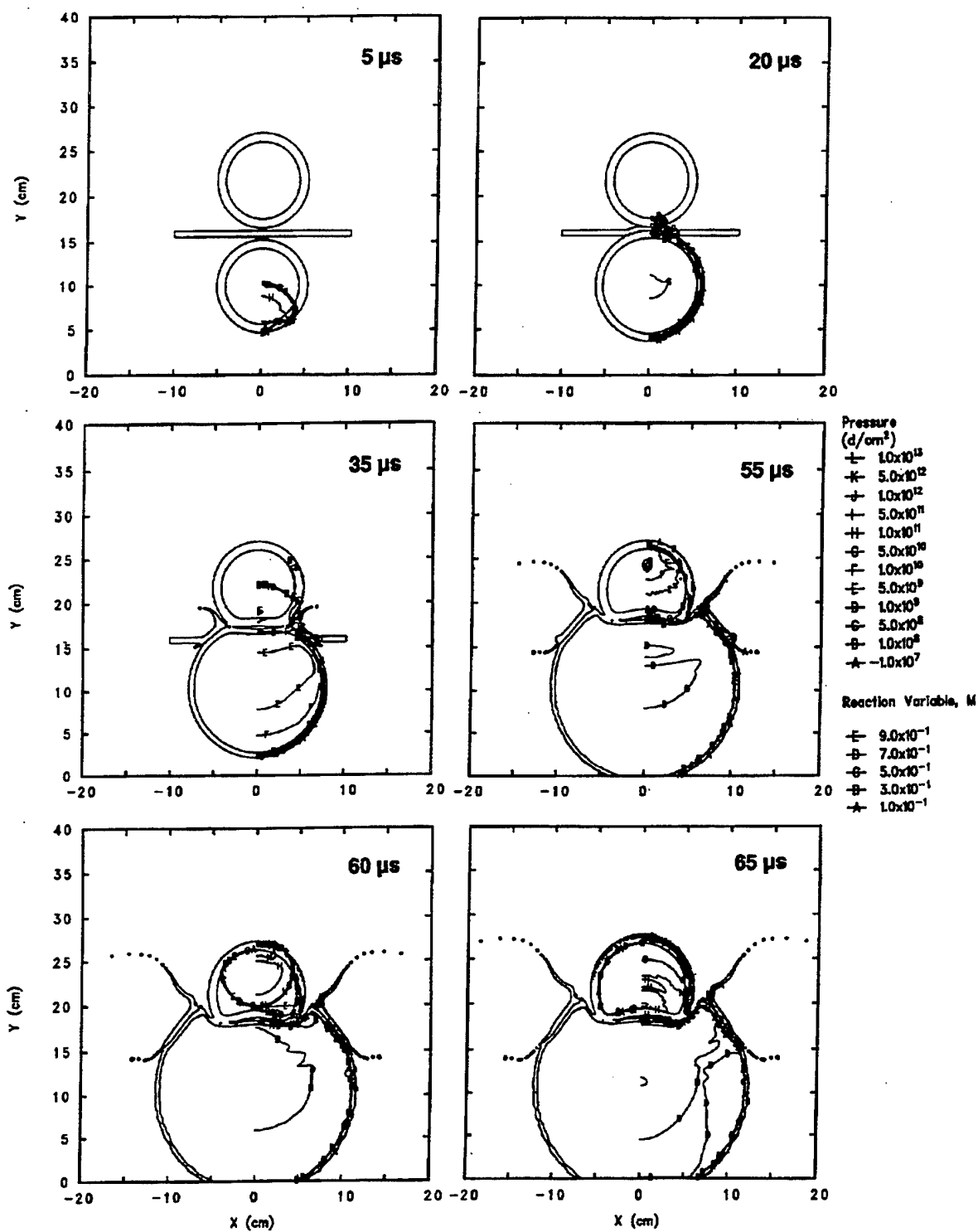


Figure 16. 6.4-mm Plexiglas buffer centered in 12.7-mm space: pressure and reaction variable contours.

Table 3. Sympathetic Detonation Predictions for the Contact Configurations

BUFFER THICKNESS (mm)	STEEL	PLEXIGLAS	AIR
3.2	GO (reflected wave, ~45 μ s)	GO (reflected wave, ~50 μ s)	
6.4	NOGO	NOGO	GO (incident wave, ~23 μ s)
12.7		NOGO	GO (incident wave, ~27 μ s)

Table 4. HVRB Results for 12.7-mm Munition-to-munition Separation Computations.

BUFFER THICKNESS (mm)	STEEL	PLEXIGLAS	AIR
1.6	GO (incident wave, ~30 μ s)	GO (incident wave, ~25 μ s)	
3.2	NOGO	GO (incident wave, ~25 μ s)	
6.4	NOGO	GO (reflected wave, ~55 μ s)	
12.7			GO (incident wave, ~27 μ s)

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13. ABSTRACT (Maximum 200 words) The CTH code was used to simulate sympathetic detonation experiments conducted using 105-mm projectiles separated by buffers of Plexiglas, rolled homogeneous armor (RHA), and mild steel. Buffer thicknesses near the experimental sympathetic detonation threshold were simulated. No propagation criterion associated with pressure loading was revealed by the results of this study. CTH computations were also made to confirm the presence of finite rise-time or "ramp" waves in the acceptor explosive (previously observed in Lagrangian computations) with layered buffers of Plexiglas and steel. The CTH results show more structure in the ramp wave and shorter rise times than those previously obtained. The History Variable Reactive Burn (HVRB) explosive initiation model in the CTH code was exercised in simulations of similar configurations. These simulations showed that initiation may occur during propagation of the incident shock wave through the acceptor or after its reflection from the casing at the back of the acceptor. Predicted buffer thicknesses required to prevent sympathetic detonation are much less than those determined in the experiments, indicating that mechanisms in addition to shock initiation contribute to sympathetic detonation.				
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