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TITLE: SM-2 Post-Test Analysis of the Effect of Material Strain Rates

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1.0 INTRODUCTION

This report provides the analyses of two REXCO-HEP models of the SRI SM-2 1/20 scale CRBR. The difference between the two models is in the material properties of the reactor vessel wall and the reactor core barrel. In one model the effects of strain rate on the stress-strain curve are not included, while in the other model the effects of strain rate are included. The results of the analyses are included in this report.

2.0 DISCUSSION

A comparison of the SRI SM-2 scale model test results (Ref. 1) and the REXCO-HEP SM-2 model predictions (Ref. 2) shows discrepancies in the vessel and core barrel maximum strains. As a result, an investigation was made of the REXCO-HEP computer model of SM-2. The following model changes were incorporated:

- 1) The calibrated P-V source term (Figure 1) was used instead of the early predicted P-V source term.
- 2) Head stiffness was taken from the updated SM-3 model (Ref. 3). The original SM-2 model used a scaled-down version of the full-scale REXCO-HEP model of the CRBR.
- 3) The water level was changed from 60.1027 cm to 63.2844 cm.
- 4) The air gap between the water surface and the reactor head was changed from 3.4735 cm to 3.4290 cm.
- 5) For the lead shot - water region, the bulk modulus was changed from 1.6195×10^{10} dyne/cm² to 2.647×10^{10} dyne/cm² and the pressure derivative of the bulk modulus was changed from 6.749 to 8.51.
- 6) For the core barrel strain of 0.05 cm/cm, the stress was changed from 2.3448×10^9 dyne/cm² to 2.3793×10^9 dyne/cm².

These changes were made with the objective of making the analysis more consistent with the as-tested materials and source term properties of

the SRI SM-2 model. Figure 2 shows the REXCO-HEP model along with the instrument locations for the SRI test model.

To analyze the effects of strain rate on the REXCO-HEP results, two analyses were performed. The first analysis, SM-2, 8-15-77, used stress-strain curves for a strain rate of 0.001 in/in/sec for the vessel and core barrel. The second analysis, SM-2, 8-17-77, used stress strain curves for a strain rate of 100 in/in/sec. The stress-strain curves are shown in Figures 3 and 4 (Ref. 4).

The strain rate of 100 in/in/sec is closer to what was experienced in the SM-2. The REXCO-HEP input is shown for SM-2, 8-15-77 and SM-2, 8-17-77 in Table A-1 and Table A-2 respectively.

The results of the analyses are summarized in Table 1 and show that the stronger core barrel contributes to more energy being directed upward toward the reactor head. Also, the maximum core barrel strain was reduced from 8.1% to 6.4%. The stronger vessel wall contributed to reducing the maximum vessel wall strain from 5.2% to 4.7%.

Detailed plots of the two analyses are given in Figures 5 through 64.

3.0 CONCLUSION

A comparison of the results of the two analyses shows a sensitivity to vessel wall and core barrel strain rate effects. In changing from 0.001 in/in/sec material properties to 100. in/in/sec material properties, the positive axial kinetic energy increased while core barrel and vessel wall strains were reduced.

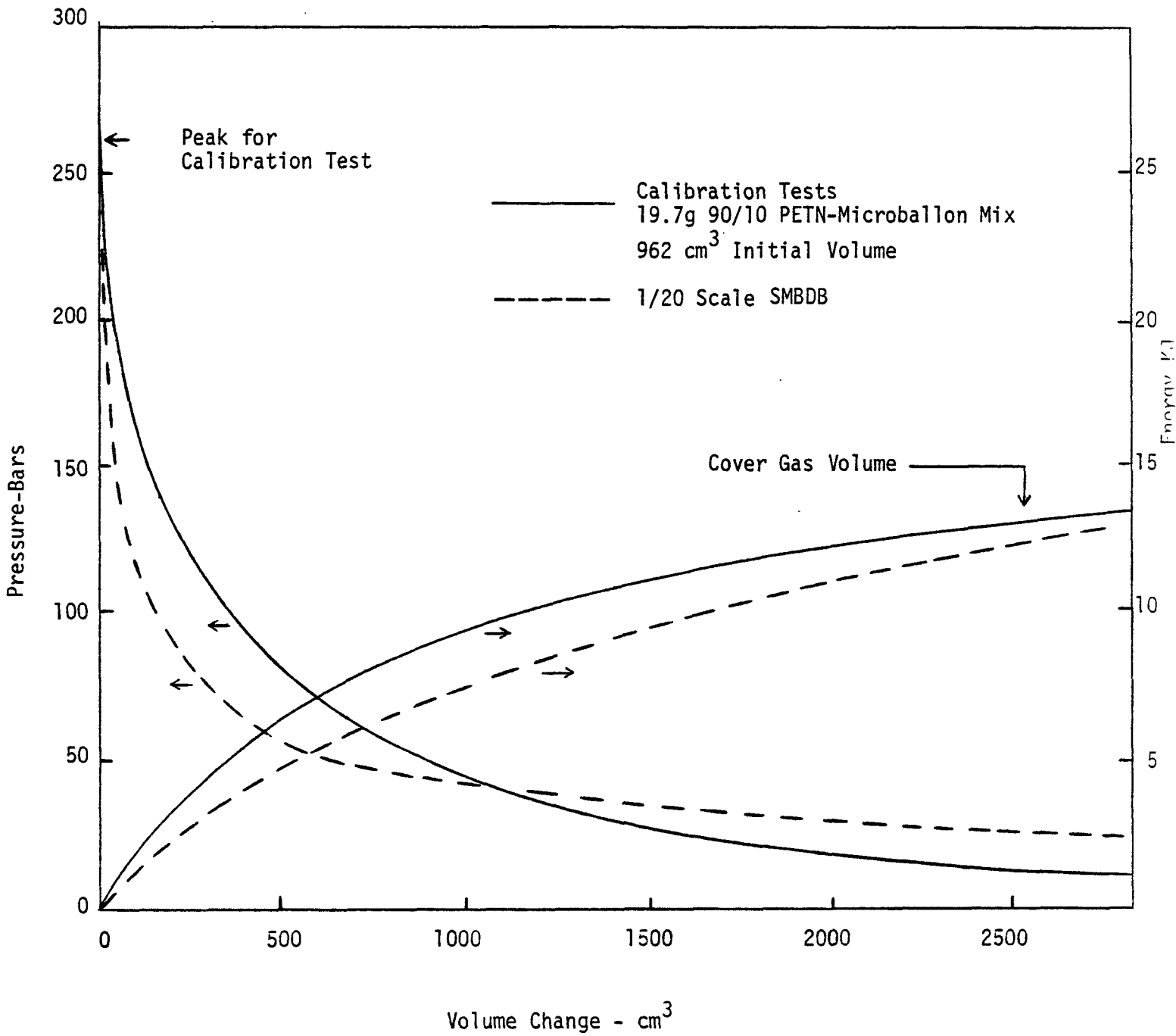
Although both of the REXCO-HEP results are in better agreement with the SRI SM-2 test results, the core barrel strains (6.4% for the REXCO-HEP analysis and 1.3% for the SRI test) are quite different. The test model

uses segmented steel rings to represent the core radial shielding and blanket while REXCO-HEP models this region as a hydrodynamic material (the segmented steel rings can not be modeled in REXCO-HEP). This difference may account for the difference in core barrel strains. The stacked segments have frictional forces between them that may reduce the amount of force on the core barrel, thus reducing the magnitude of the core barrel strain.

Table 1

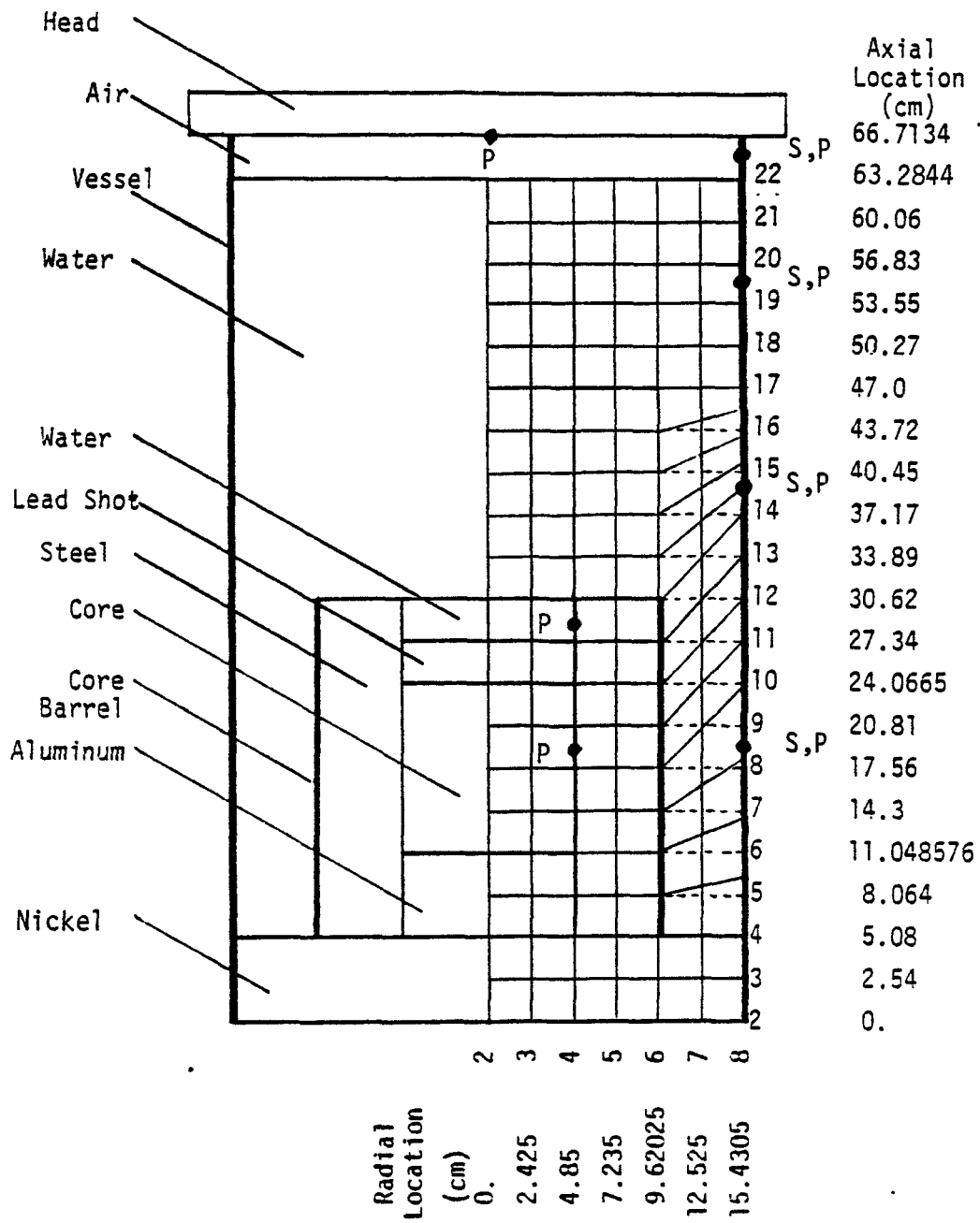
Summary of Post-Test Analysis for SM-2

	<u>SM-2, 8-15-77</u> <u>Strain Rate = 0.001/sec</u>	<u>SM-2, 8-17-77</u> <u>Strain Rate = 100.0/sec</u>
Maximum Radial Kinetic Energy	2.9 x 10 ¹⁰ erg 0.5 msec	2.2 x 10 ¹⁰ erg 0.4 msec
Maximum Positive Axial Kinetic Energy	5.3 x 10 ¹⁰ erg 3.2 msec	6.1 x 10 ¹⁰ erg 3.0 msec
Maximum Slug Velocity	1.8 x 10 ³ cm/sec 3.2 msec	1.9 x 10 ³ cm/sec 2.9 msec
Maximum Slug Force	1.7 x 10 ¹¹ dyne 3.3 msec	1.7 x 10 ¹¹ dyne 3.0 msec
Maximum Head Total Energy	1.1 x 10 ⁹ erg 3.4 msec	1.1 x 10 ⁹ erg 3.1 msec
Maximum Vessel Strain	5.2 % 4.4 msec .80 cm	4.7 % 3.9 msec .73 cm
Maximum Core Barrel Strain	8.1 % 1.2 msec .78 cm	6.4 % 1.1 msec .62 cm



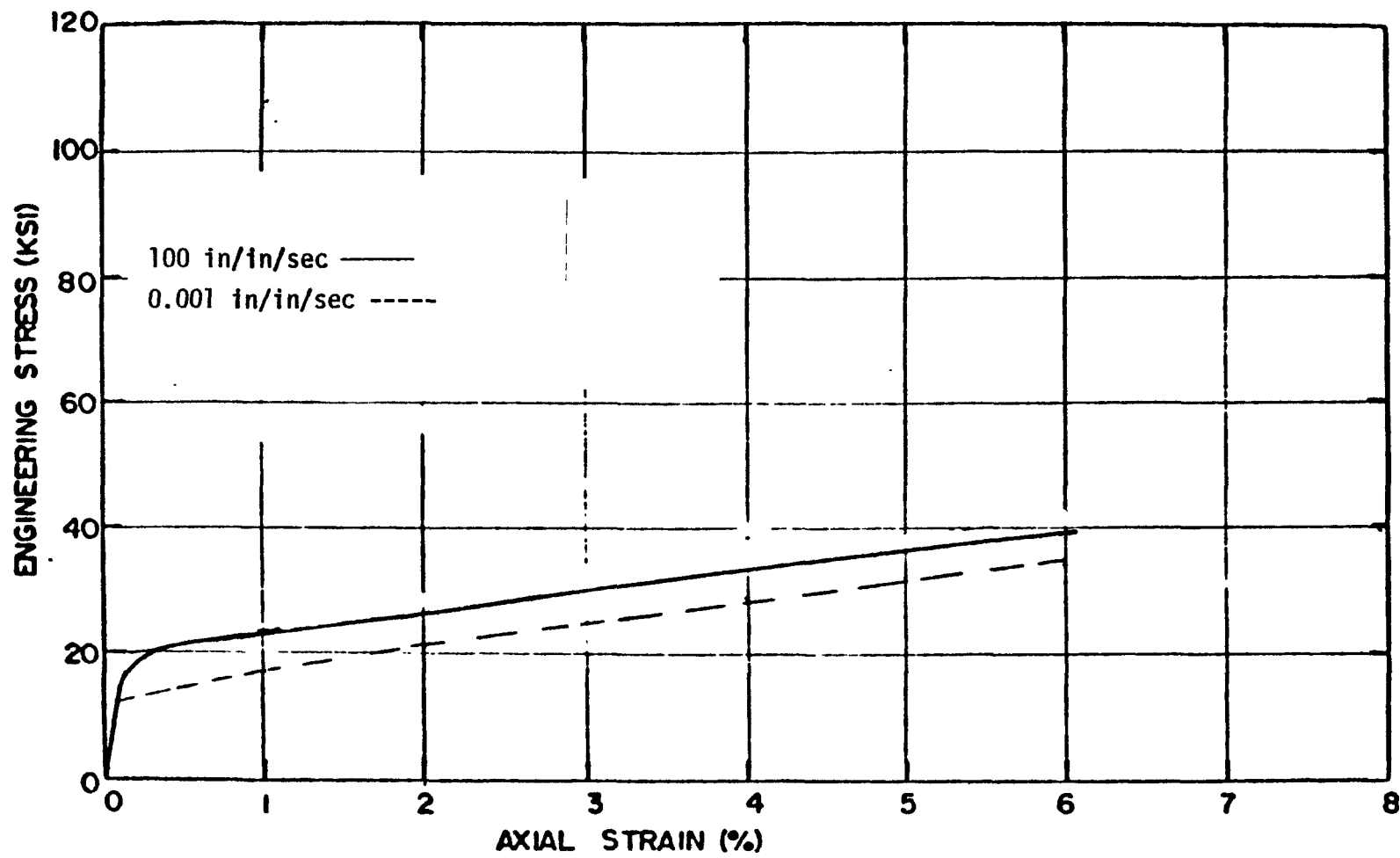
Pressure-Volume and Energy Curves
 for 1/20 Scale SMBDB and SM-2 Calibration Test

Figure 1



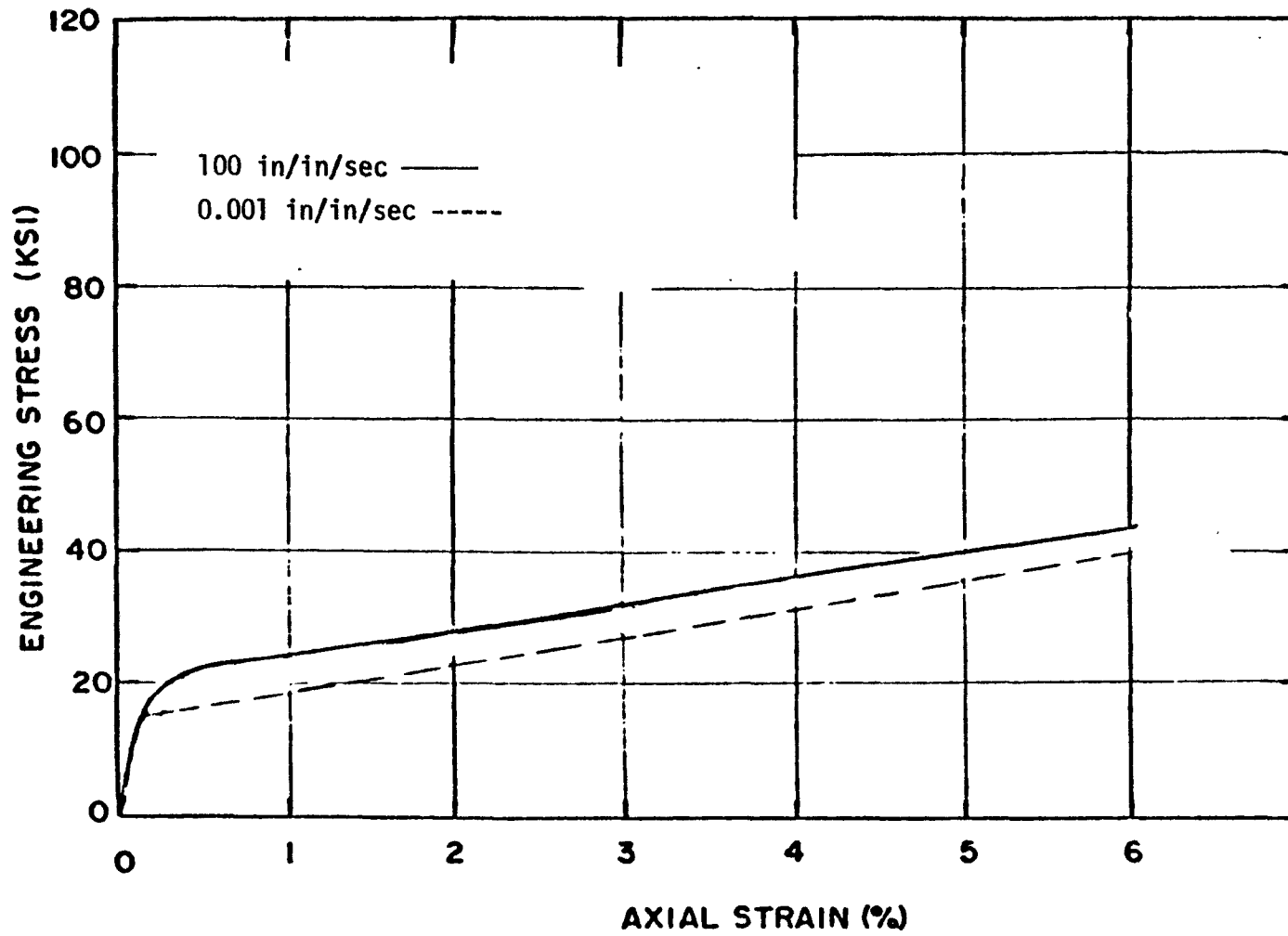
Note: S and P show locations of Strain and Pressure Gauges

Figure 2 SM-2 REXCO Model



Vessel Wall Stress-Strain Curve

Figure 3



Core Barrel Stress-Strain Curve

Figure 4

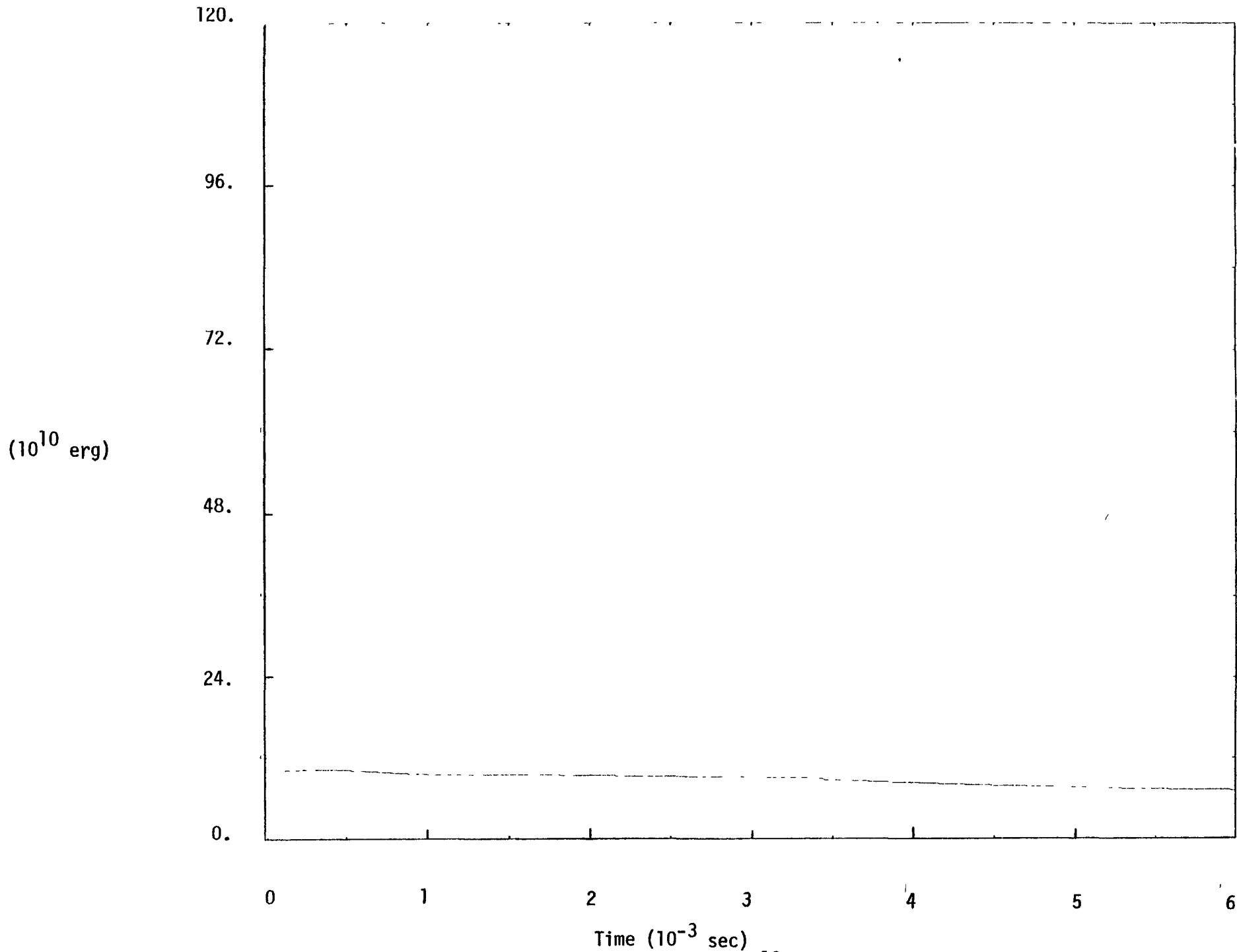


Figure 5 Total Energy (10^{10} erg) SM-2, 8-15-77

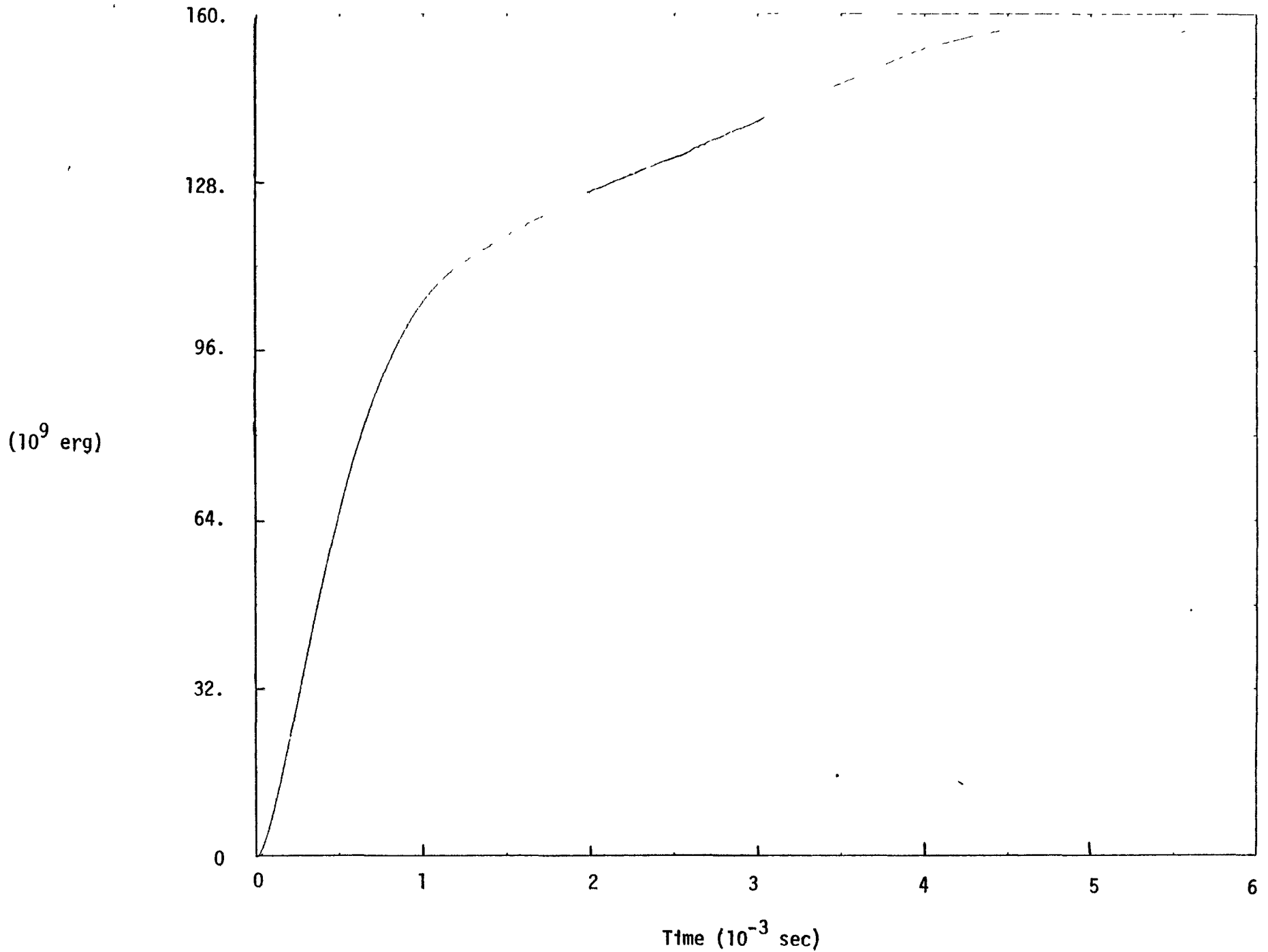


Figure 6 Core Release Energy (10^9 erg) SM-2, 8-15-77

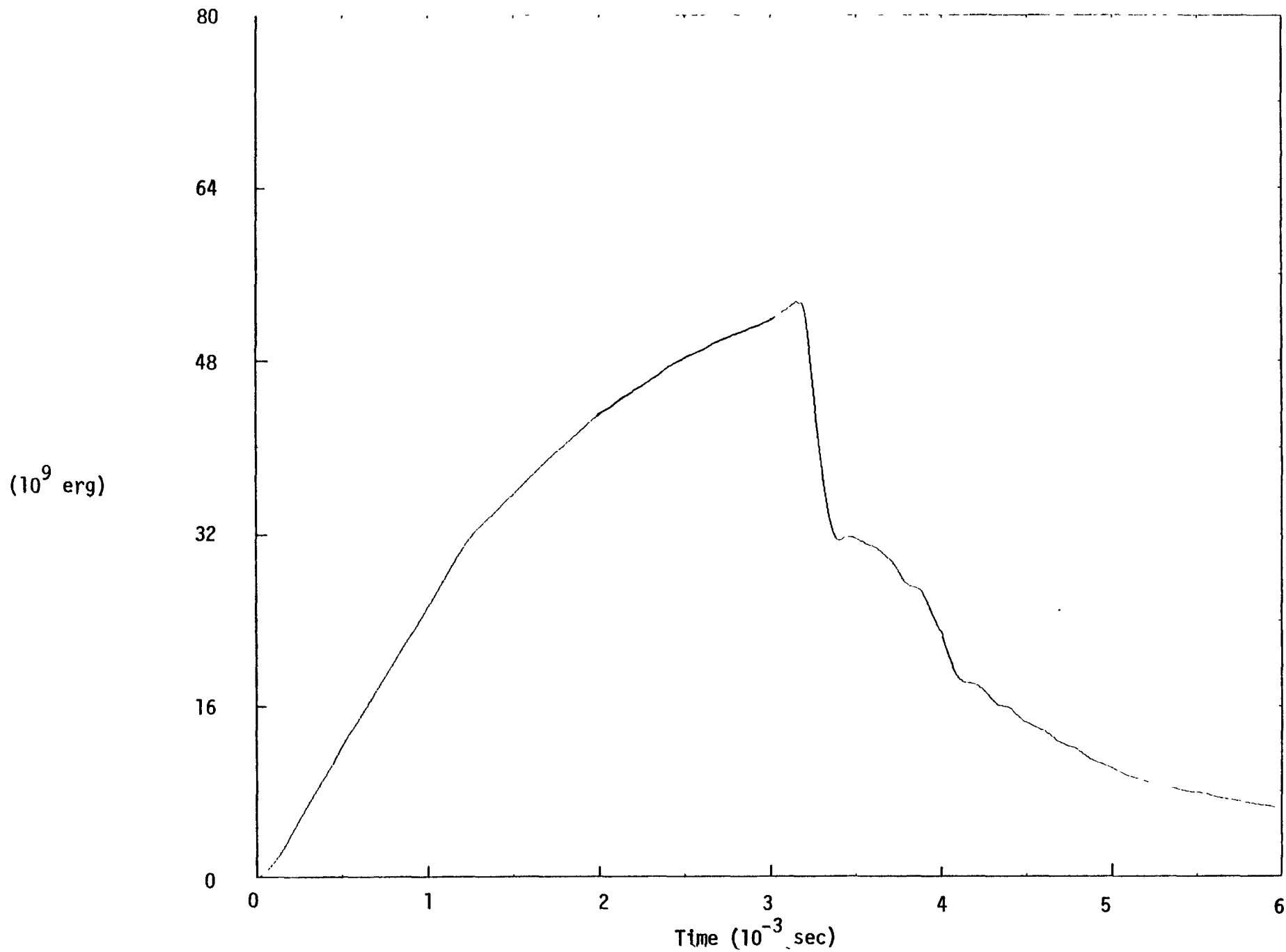


Figure 7 Positive Axial Kinetic Energy (10^9 erg) SM-2, 8-15-77

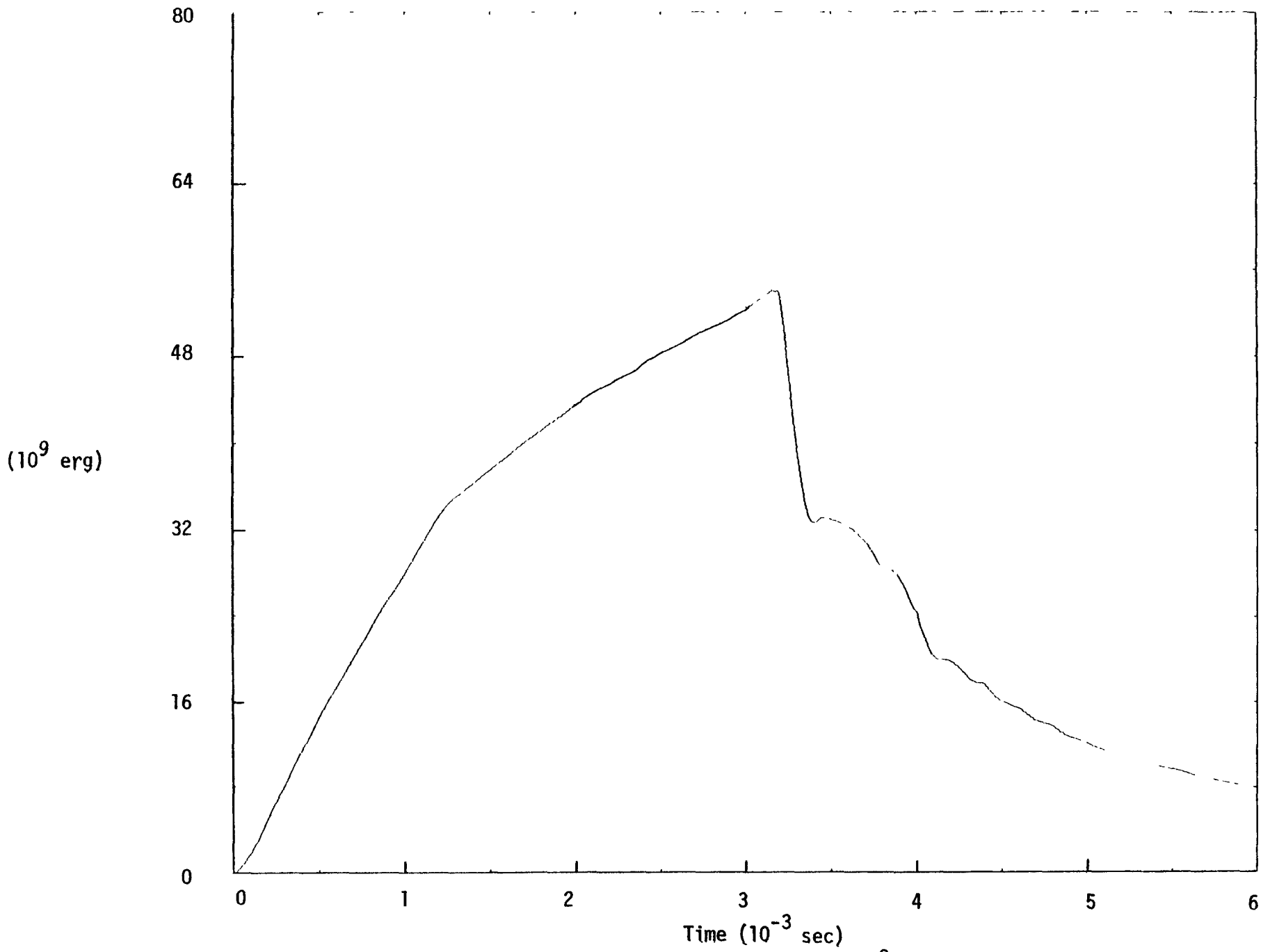


Figure 8 Total Axial Kinetic Energy (10^9 erg) SM-2, 8-15-77

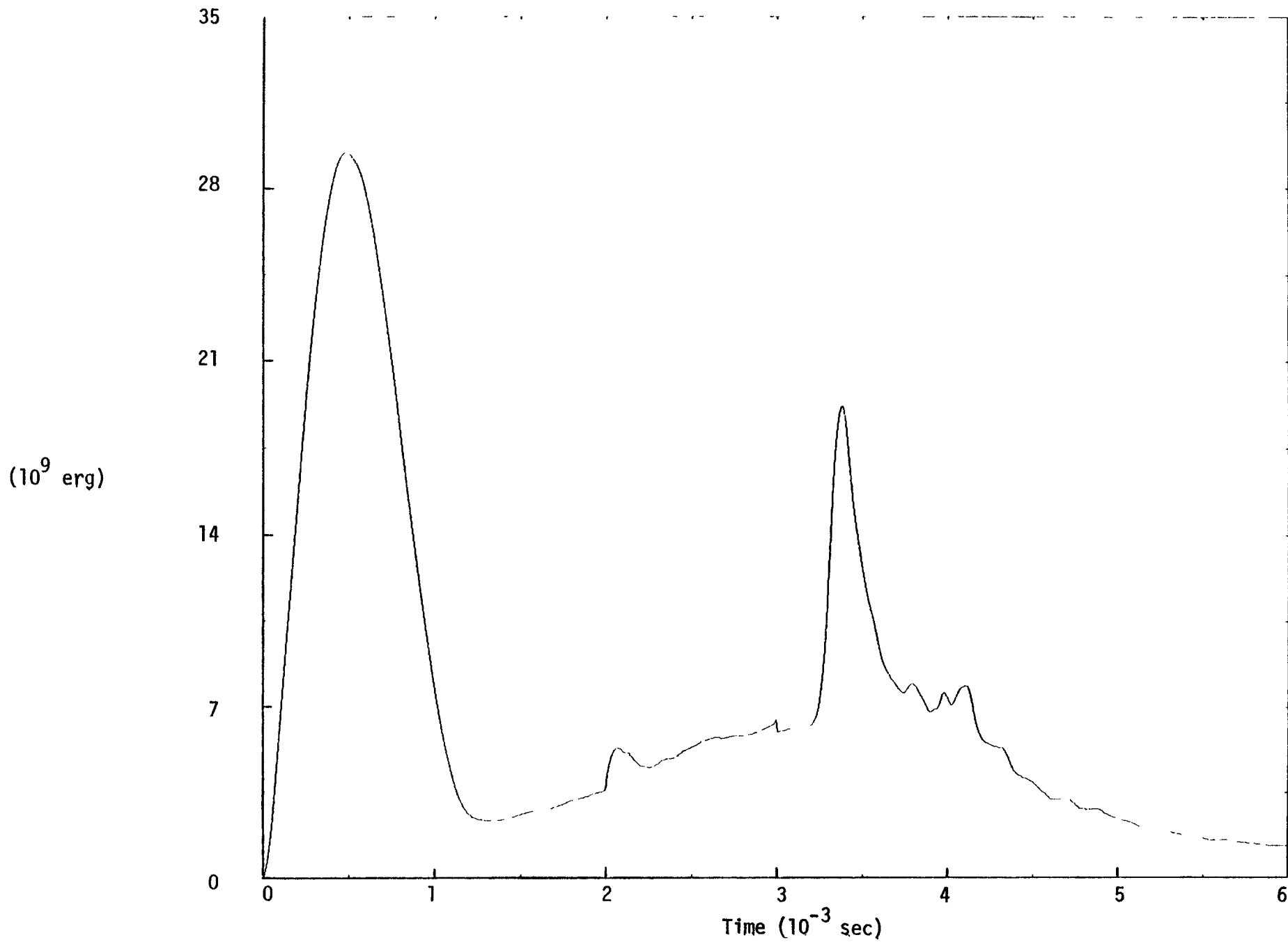


Figure 9 Total Radial Kinetic Energy (10^9 erg) SM-2, 8-15-77

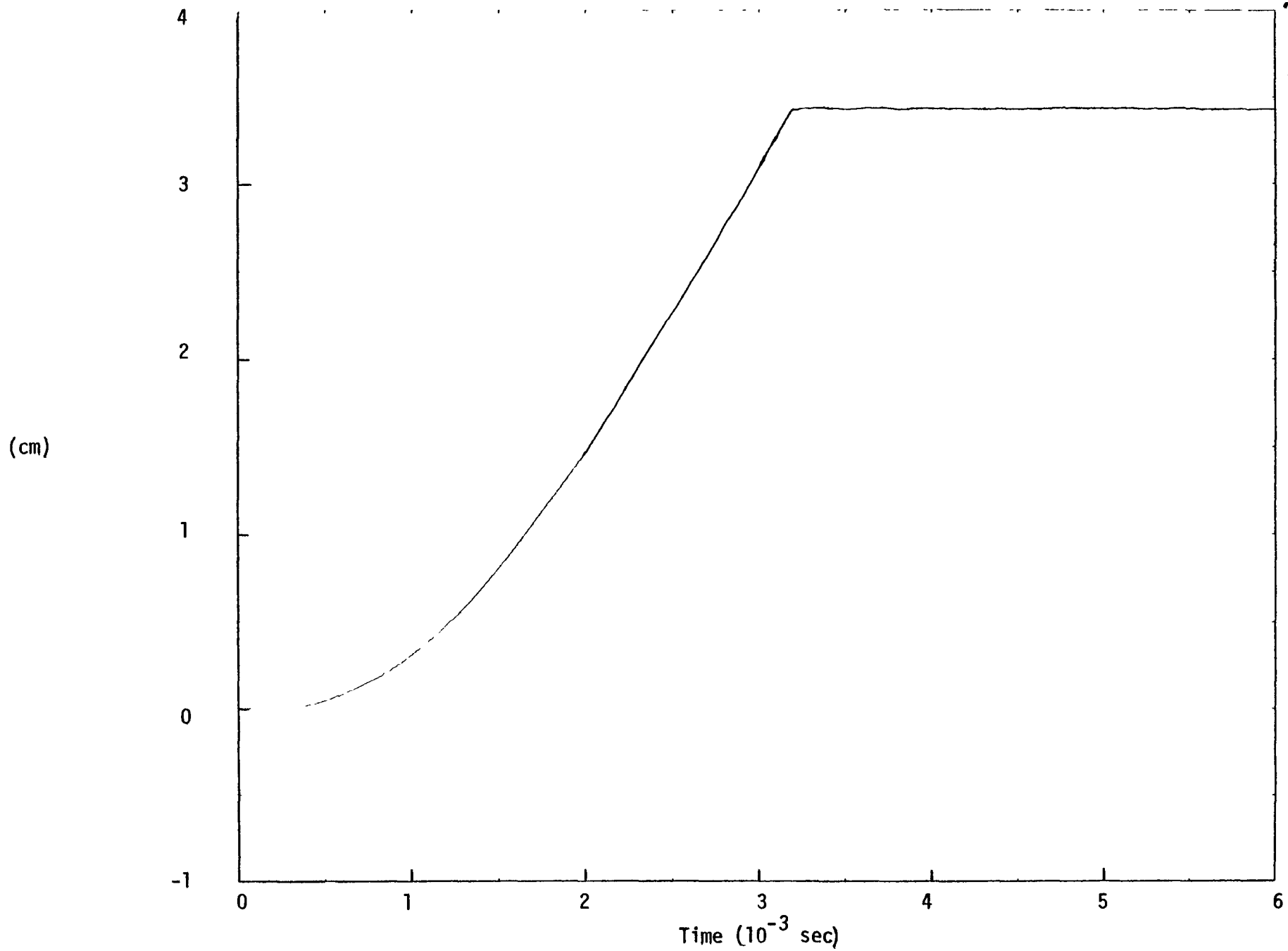


Figure 10 Average Surface Displacement (cm) SM-2, 8-15-77

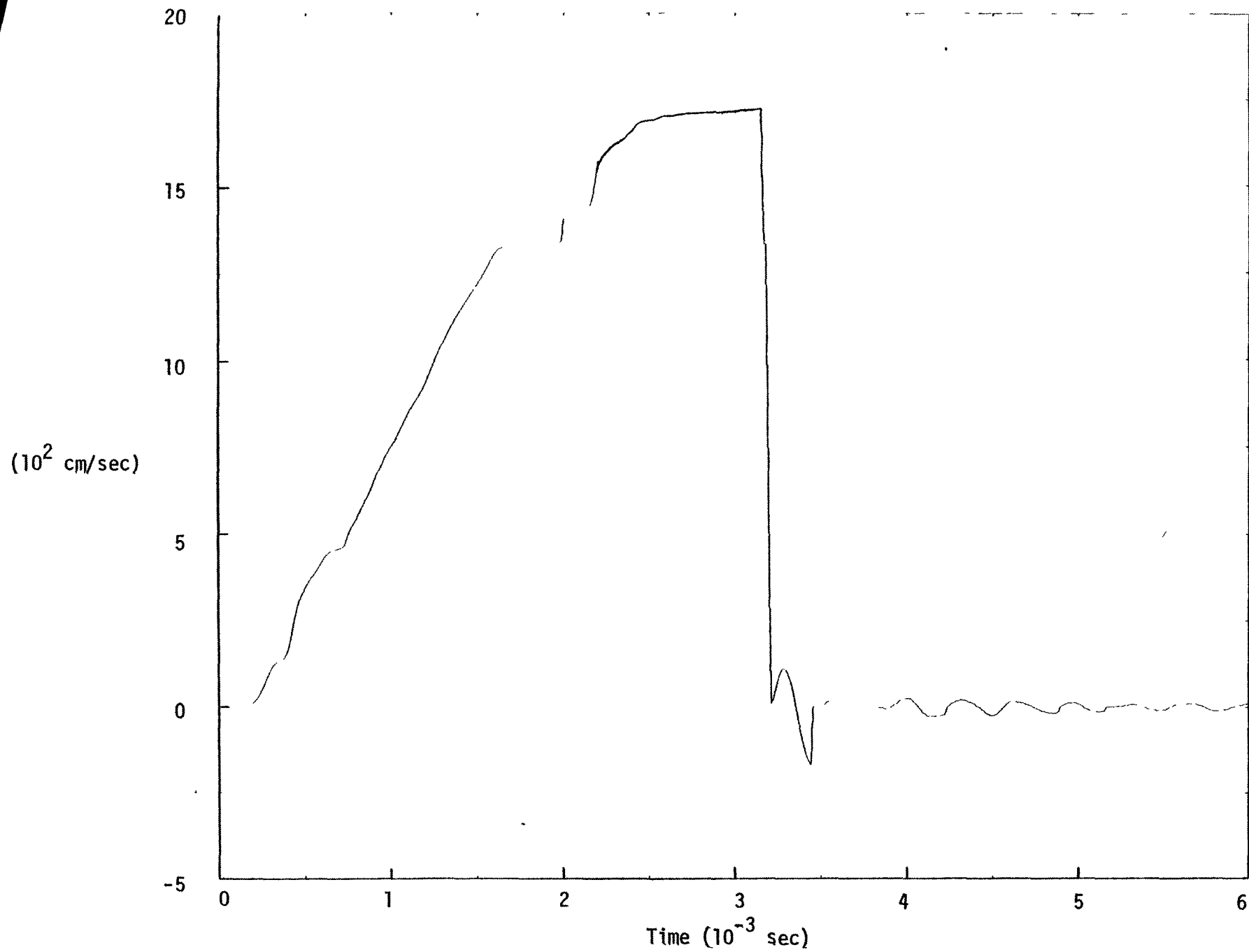


Figure 11 Average Surface Velocity (10^2 cm/sec) SM-2, 8-15-77

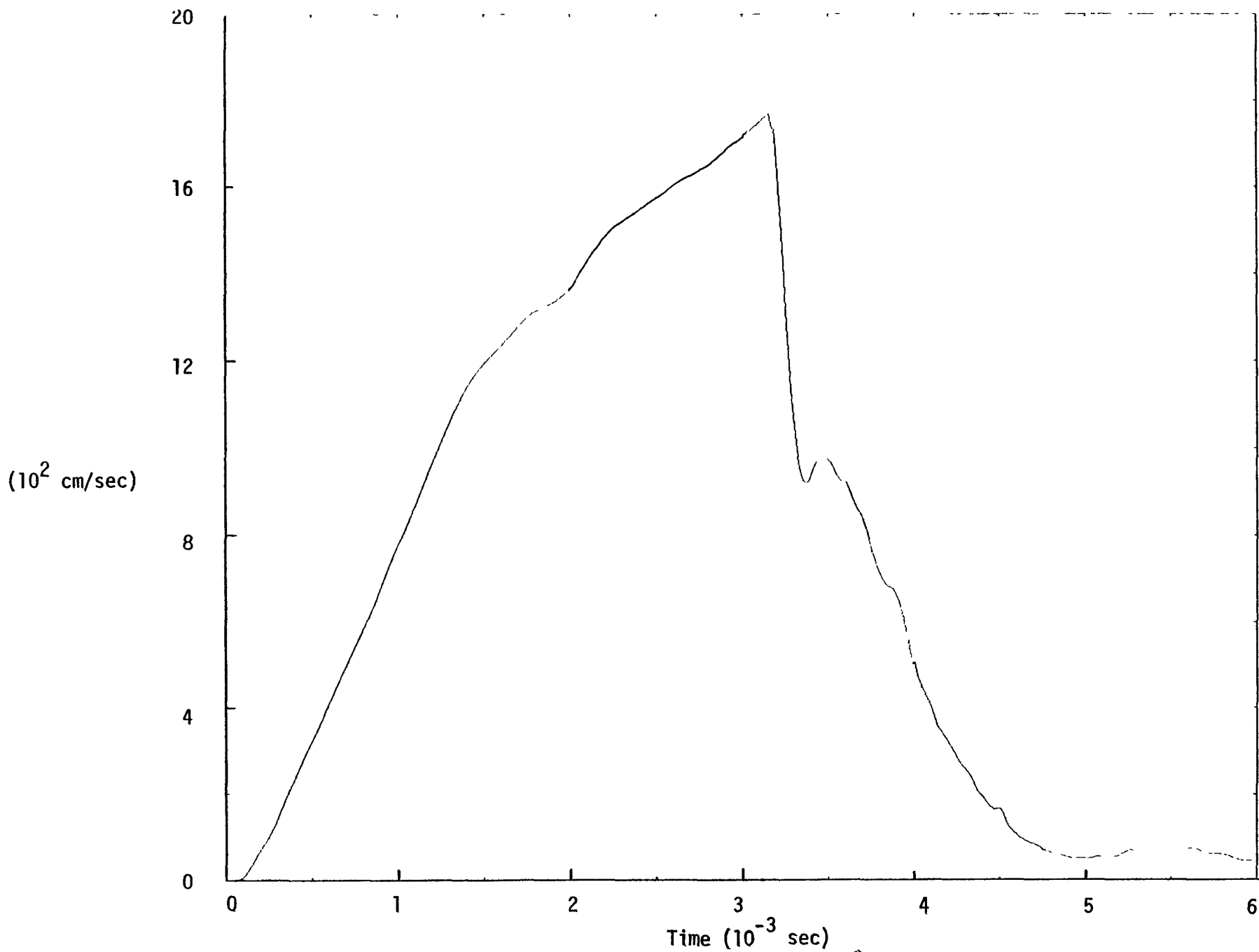


Figure 12 Average Slug Velocity (10^2 cm/sec) SM-2, 8-15-77

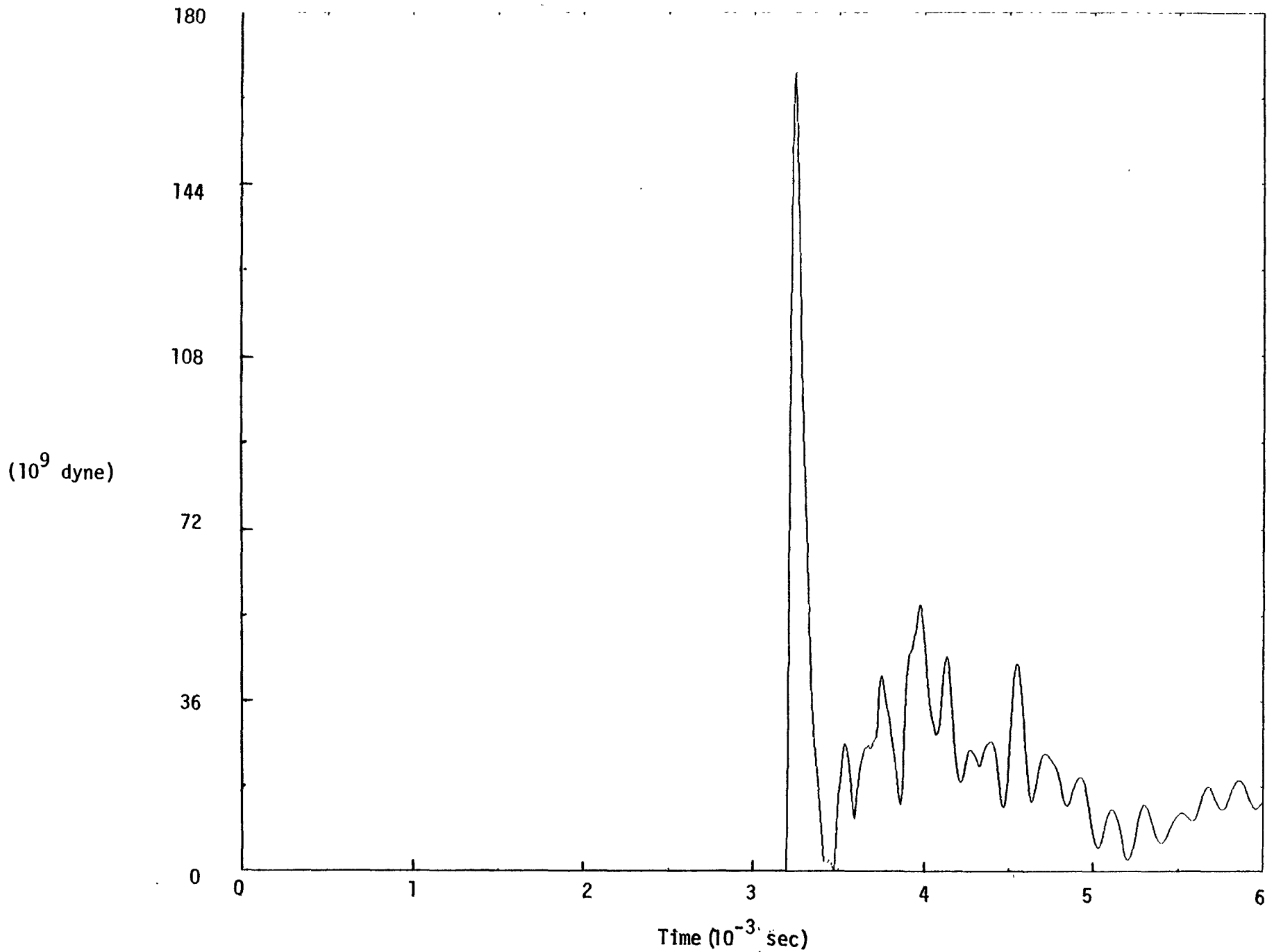


Figure 13 Slug Force (10⁹ dyne) SM-2, 8-15-77

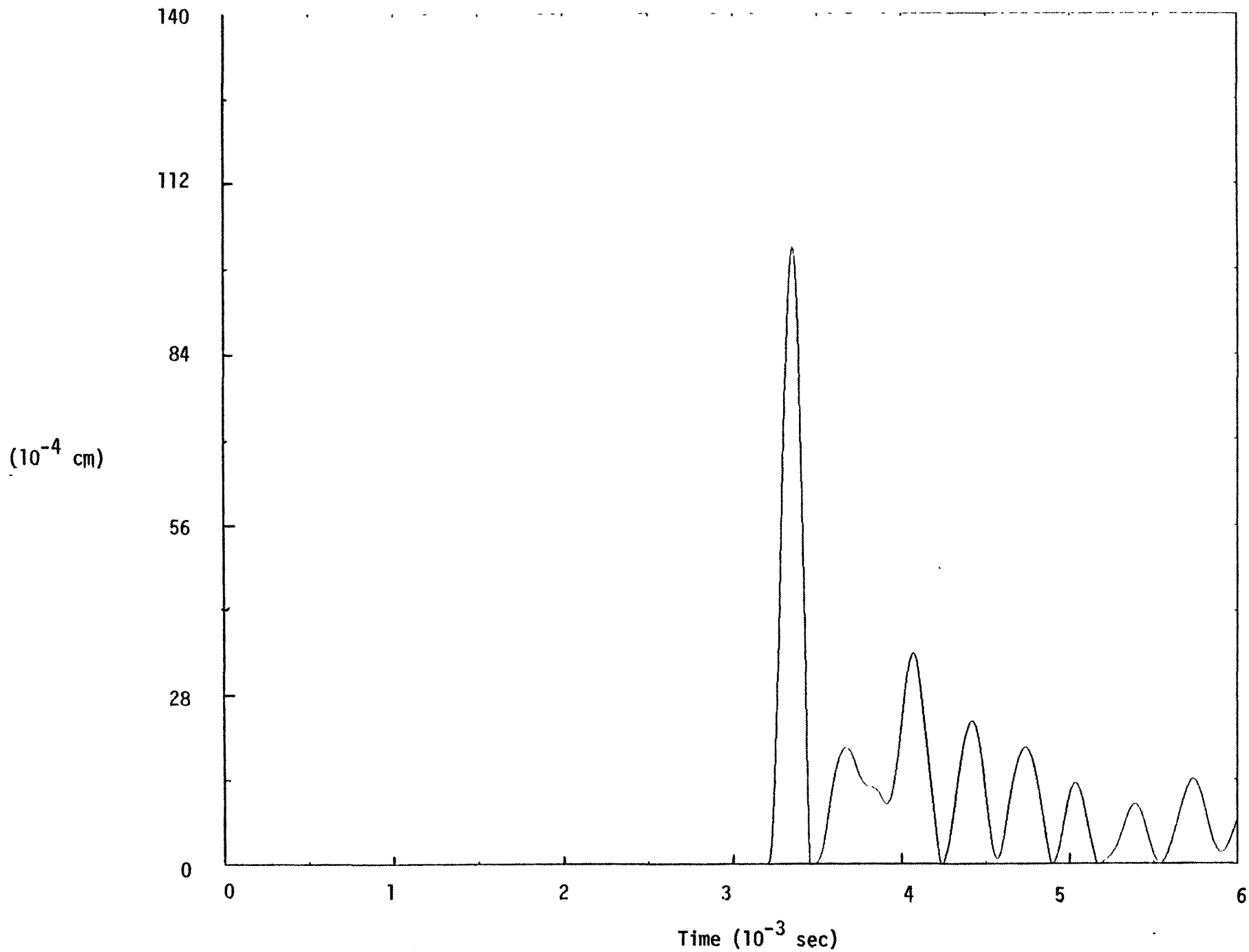


Figure 14 Reactor Head Displacement (10^{-4} cm) SM-2, 8-15-77

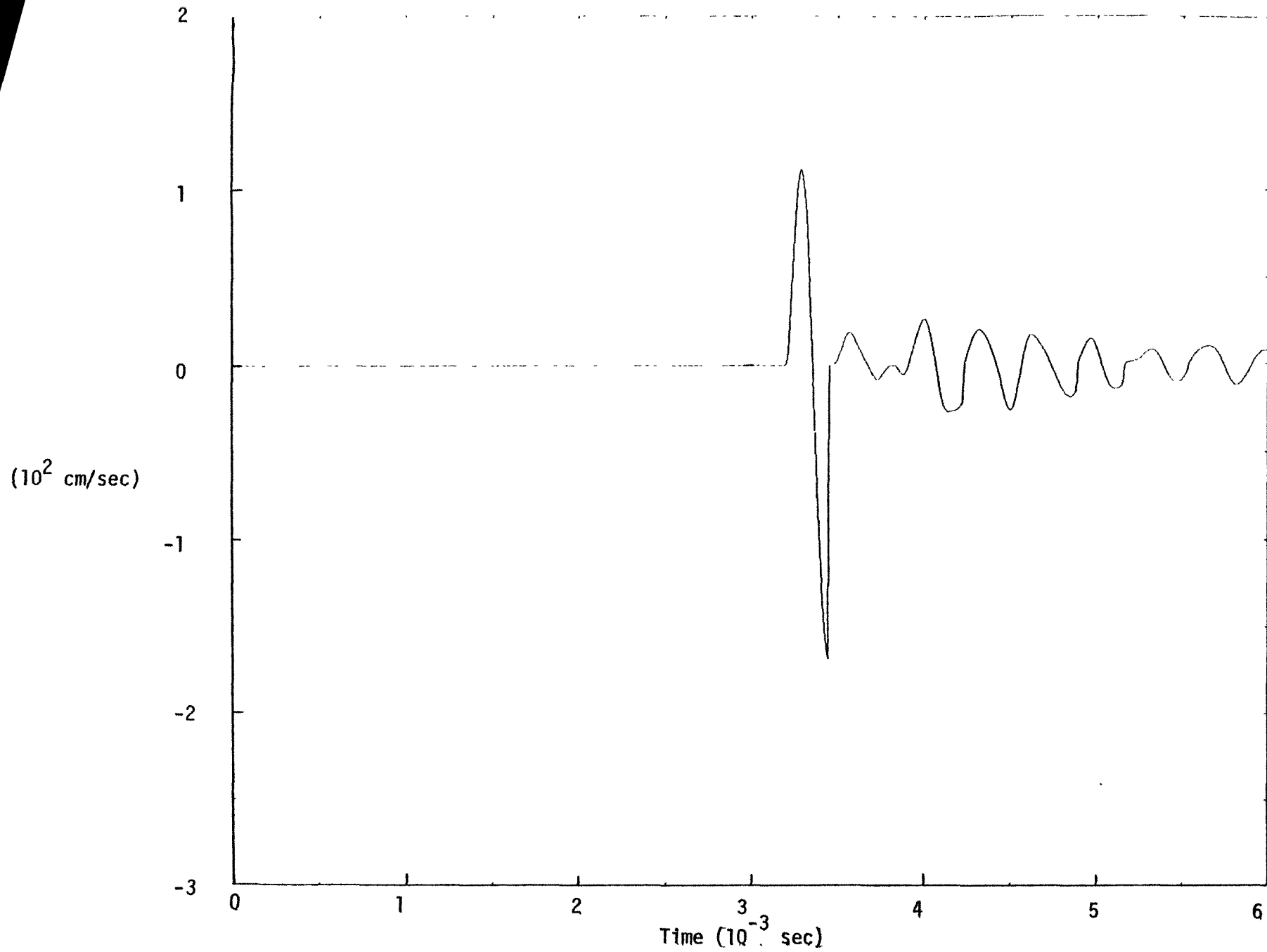


Figure 15 Reactor Head Velocity (10^2 cm/sec) SM-2, 8-15-77

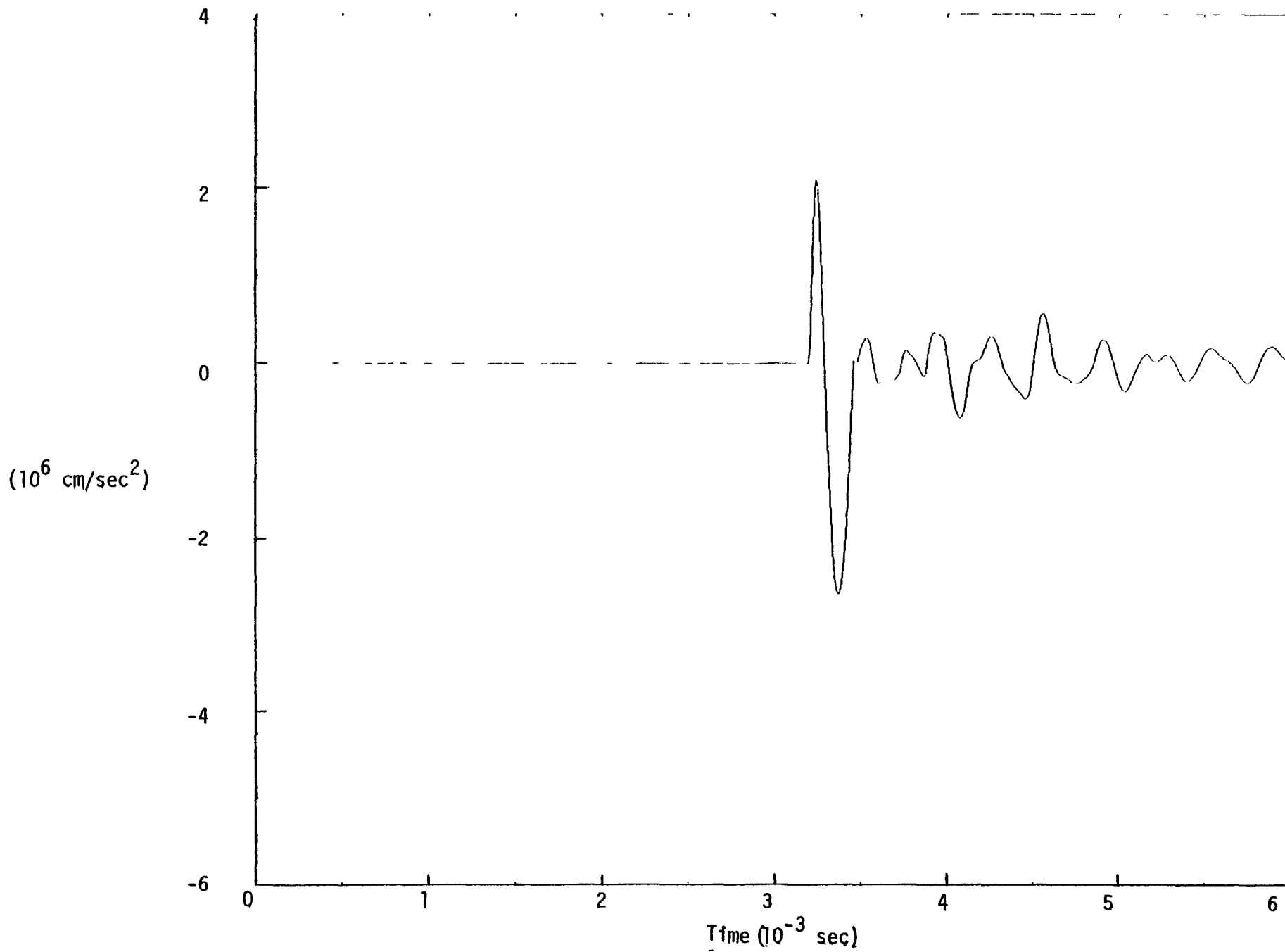


Figure 16 Reactor Head Acceleration (10^6 cm/sec^2) SM-2, 8-15-77

(10⁸ erg)

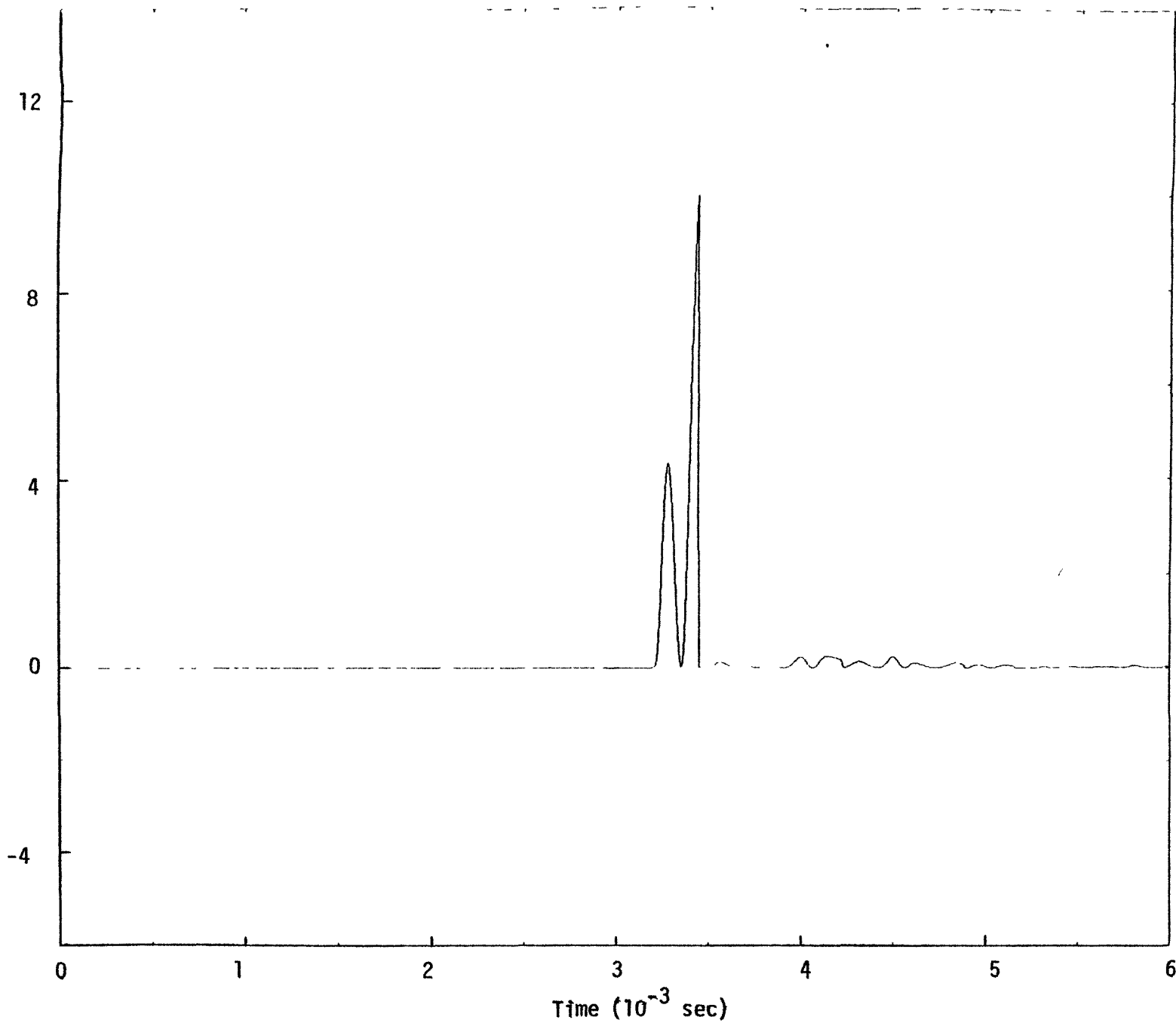


Figure 17 Reactor Head Kinetic Energy (10⁸ erg) SM-2, 8-15-77

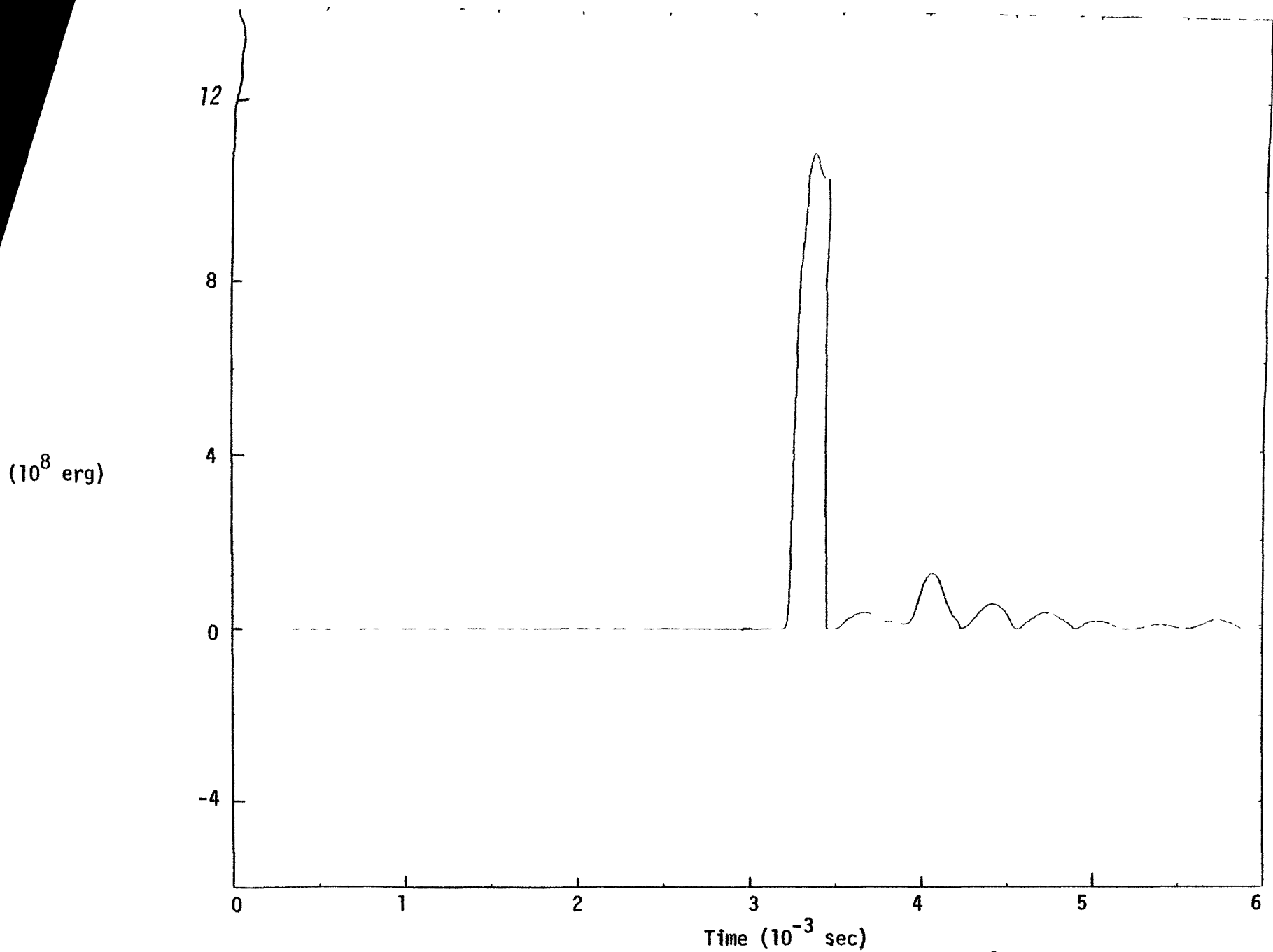


Figure 18 Total Reactor Head Energy (10^8 erg) SM-2, 8-15-77

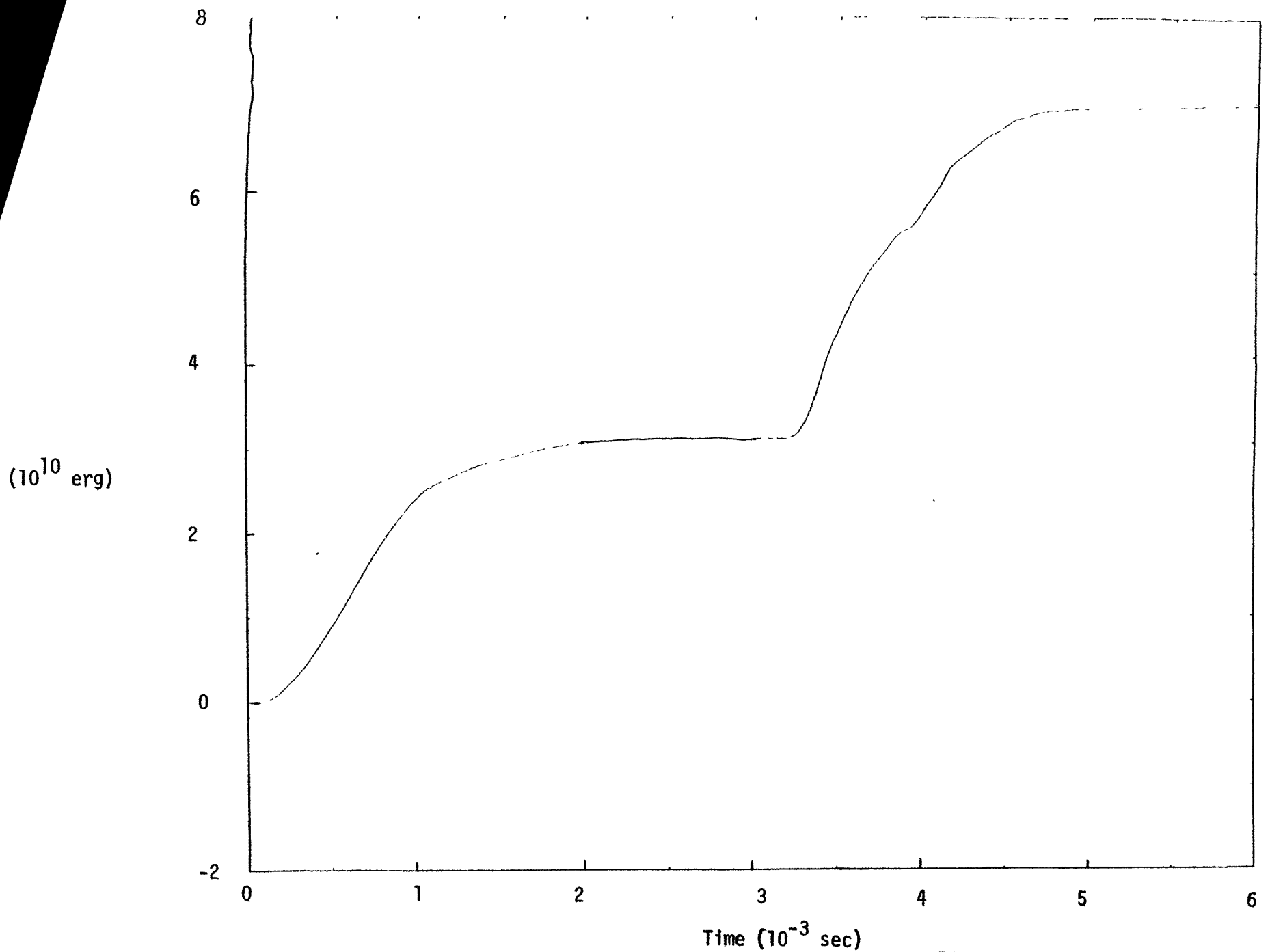


Figure 19 Reactor Vessel Strain Energy (10^{10} erg) SM-2, 8-15-77

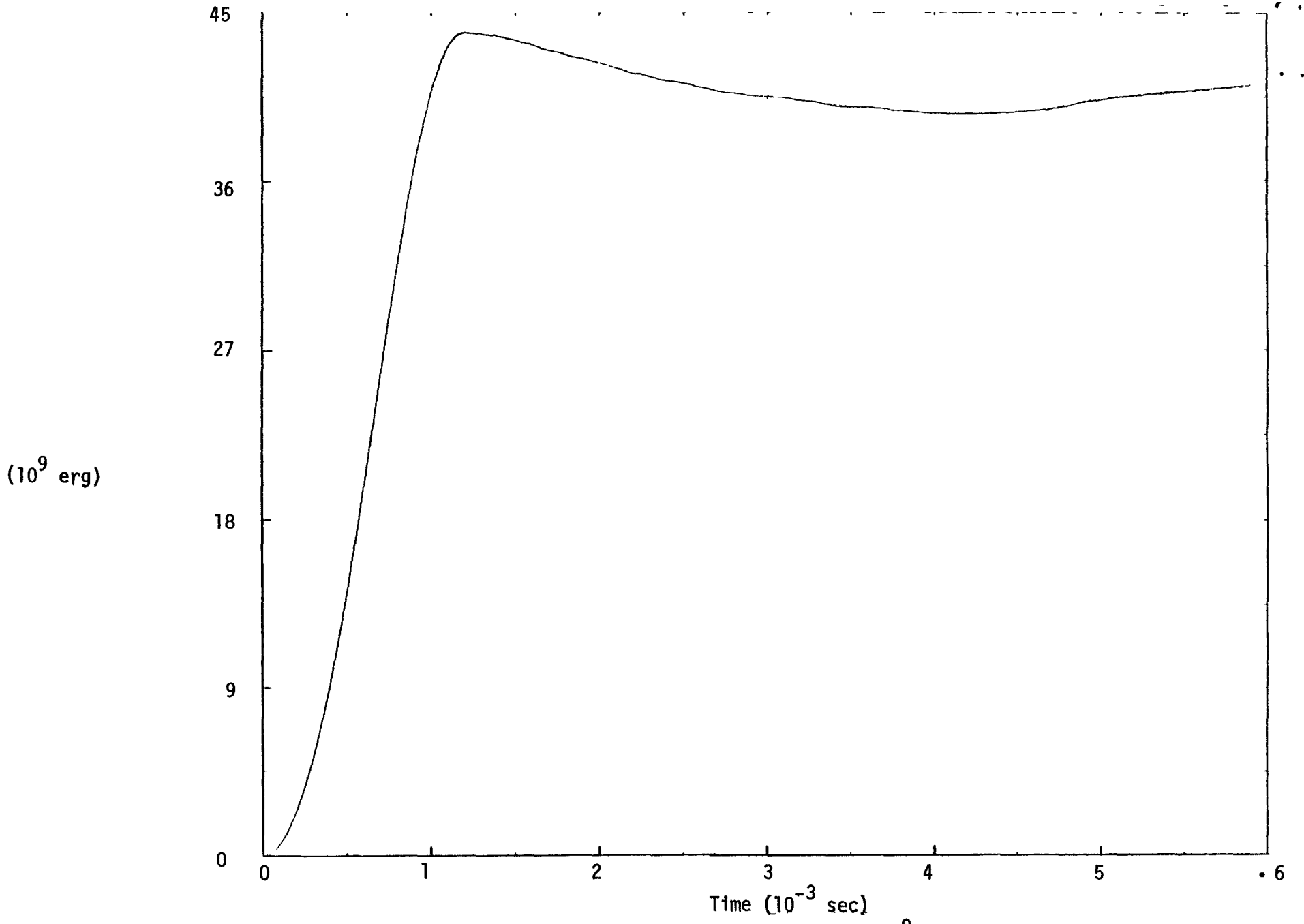


Figure 20 Core Barrel Strain Energy (10^9 erg) SM-2, 8-15-77

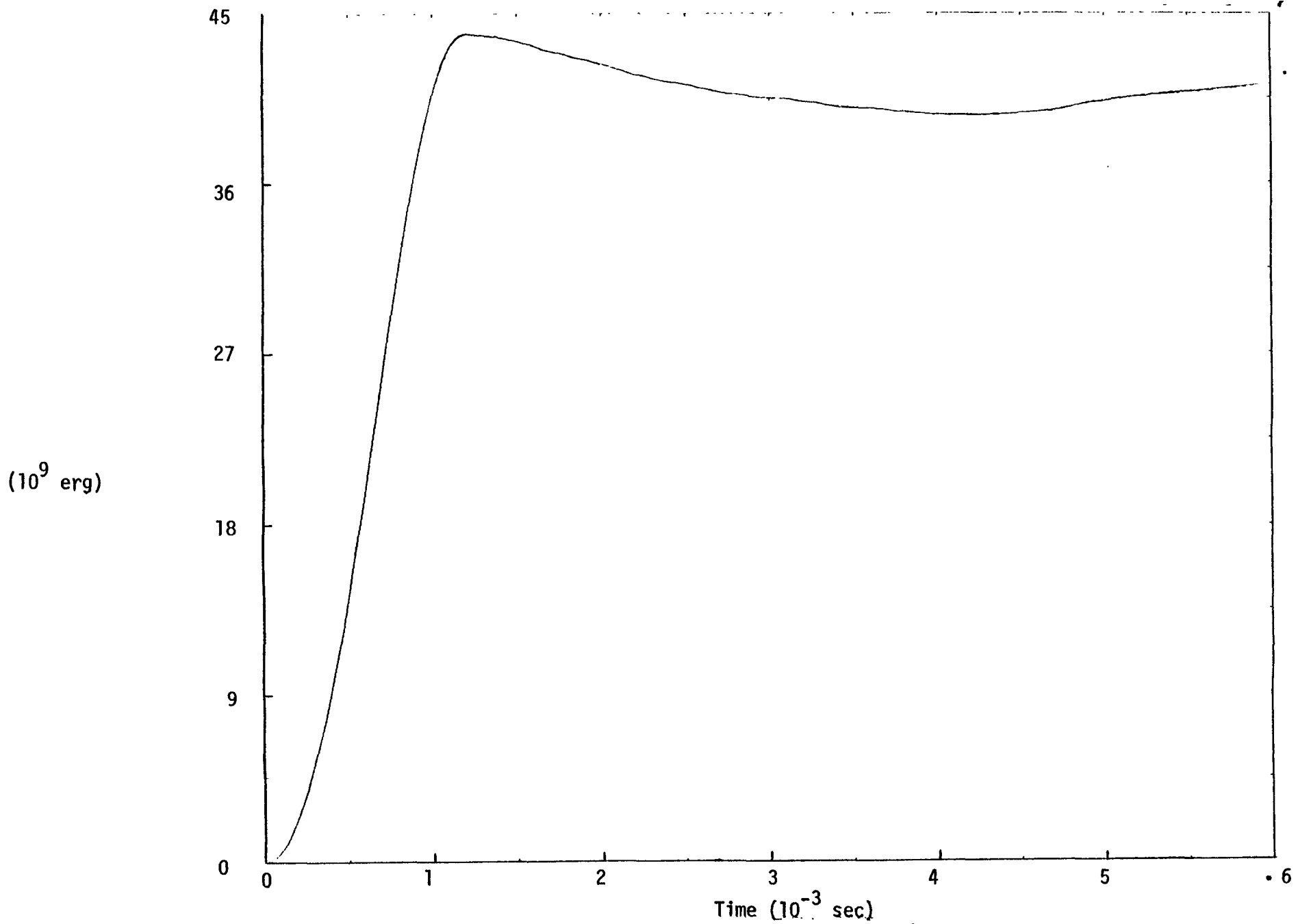


Figure 20 Core Barrel Strain Energy (10^9 erg) SM-2, 8-15-77

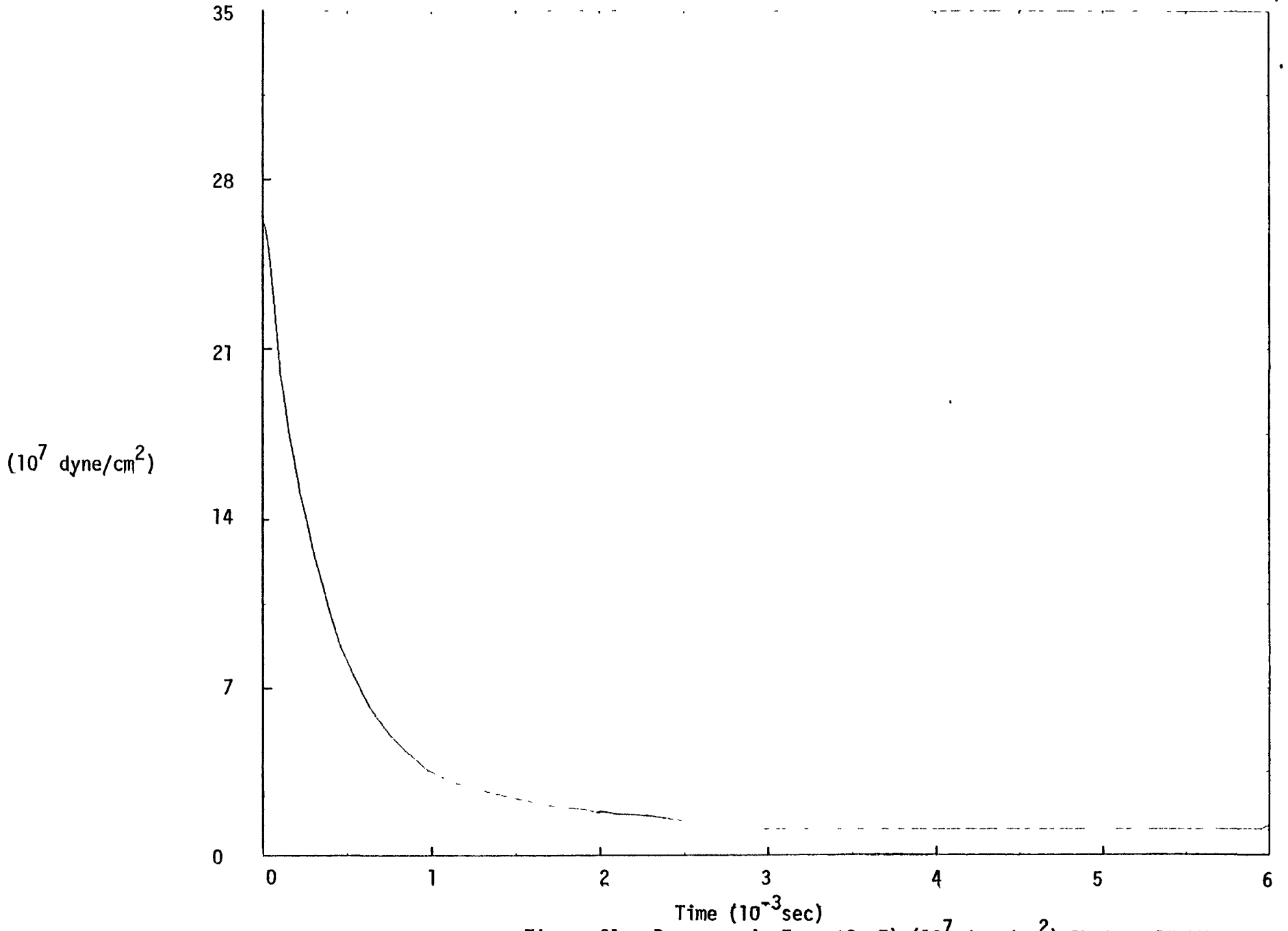


Figure 21 Pressure in Zone (2, 7) (10^7 dyne/cm^2) SM-2, 8-15-77

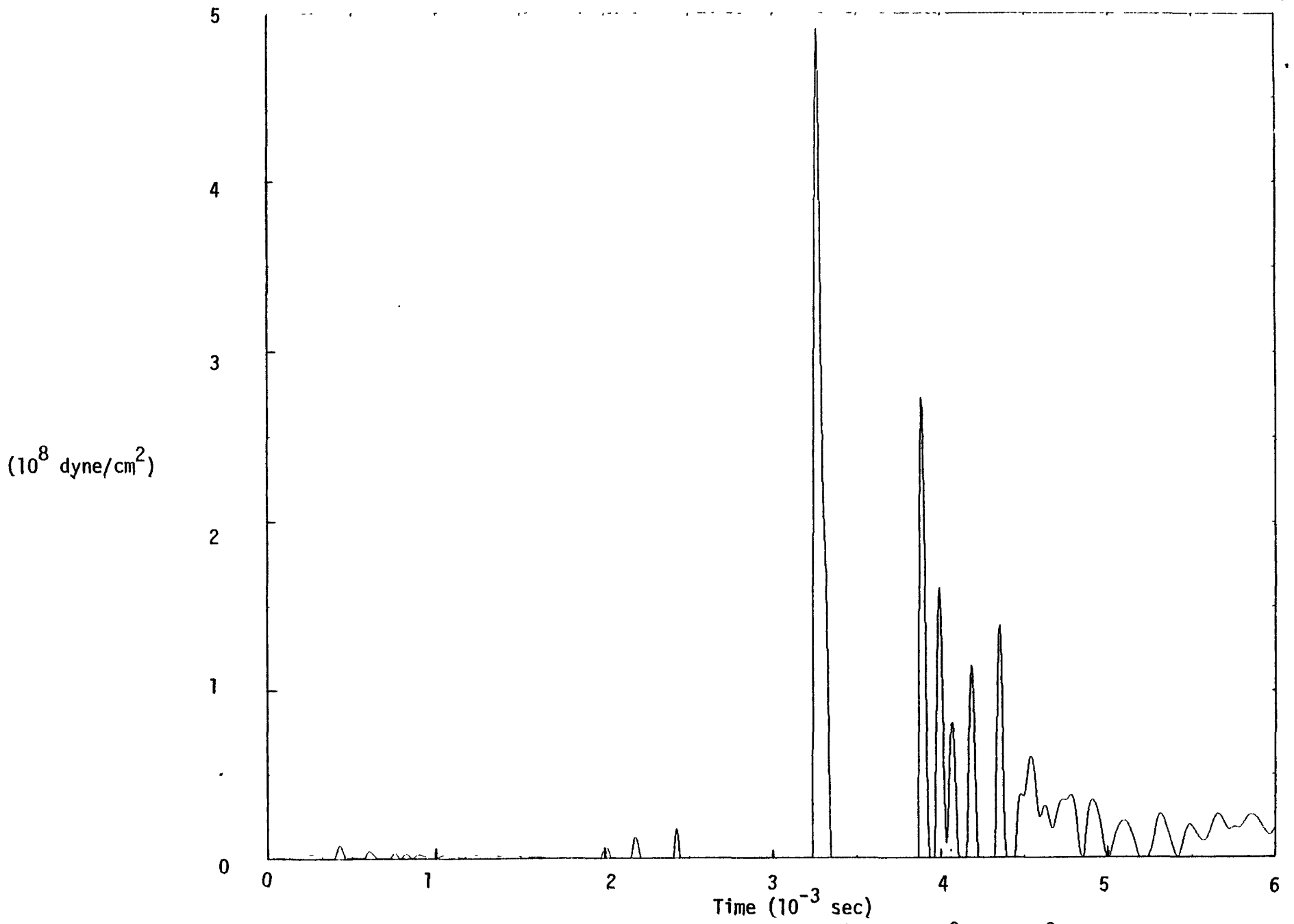


Figure 22 Pressure in zone (2, 21) (10^8 dyne/cm²) SM-2, 8-15-77

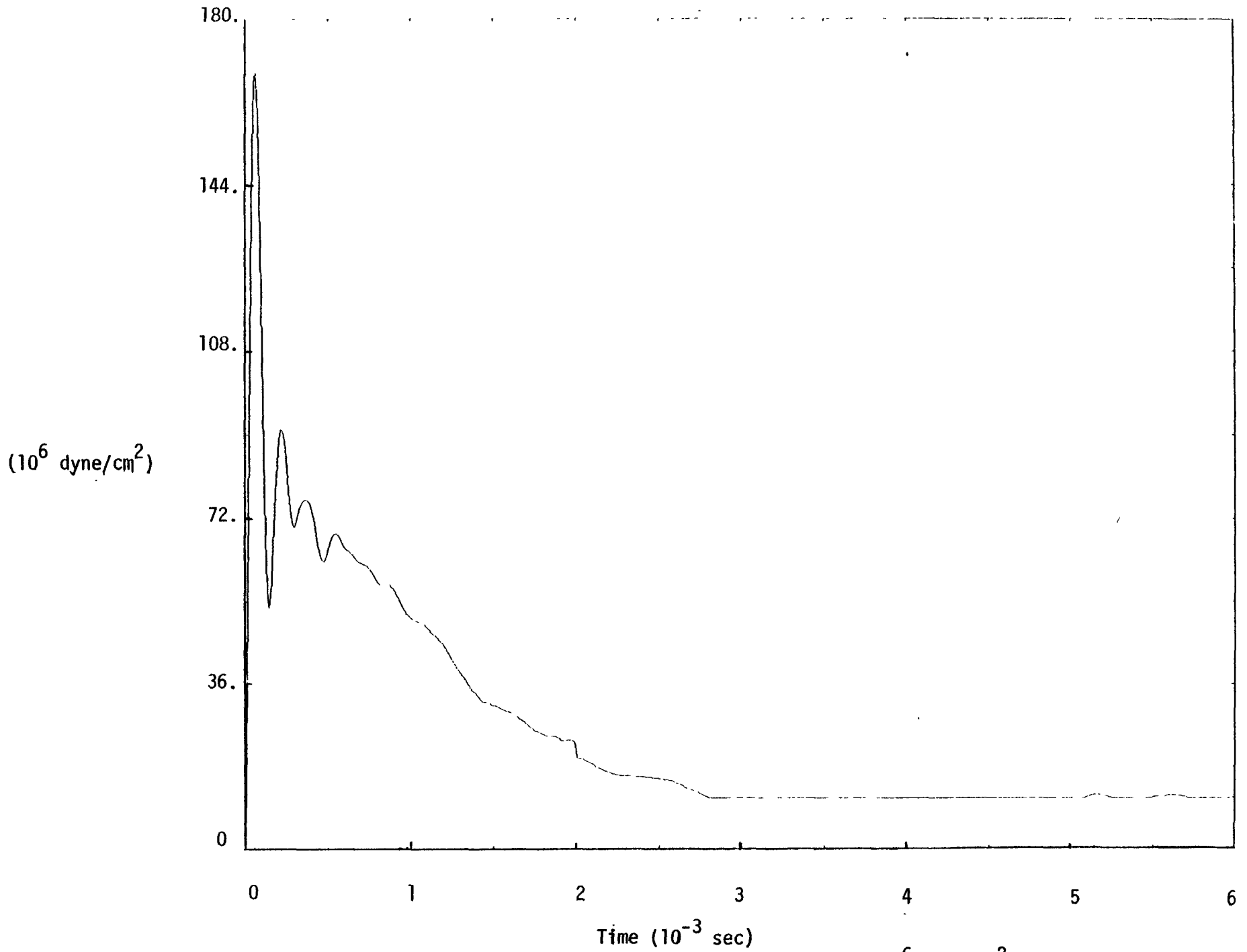


Figure 23 Pressure in Zone (3, 10) (10^6 dyne/cm²) SM-2, 8-15-77

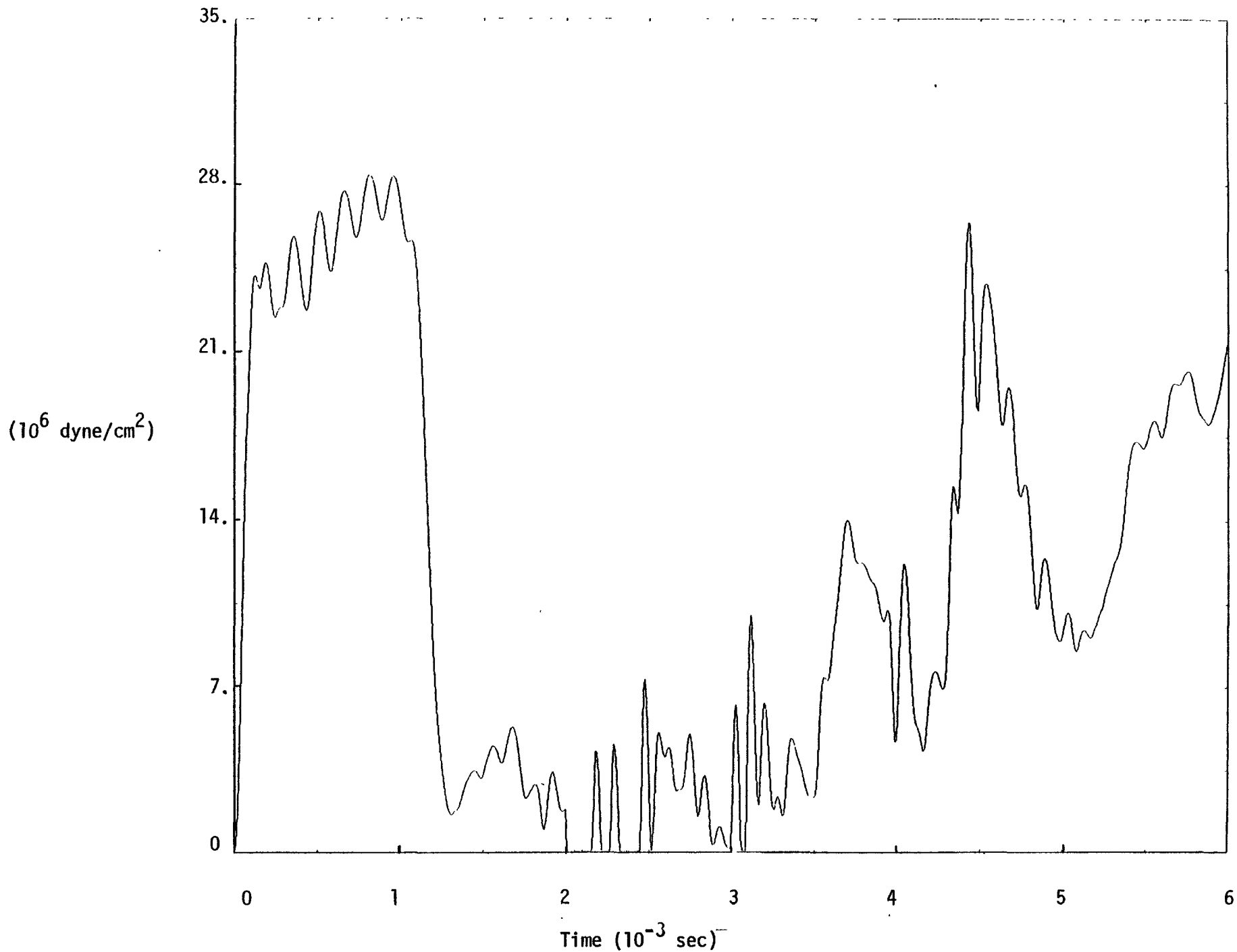


Figure 24 Pressure in Zone (7, 17) ST-2, 8-15-77

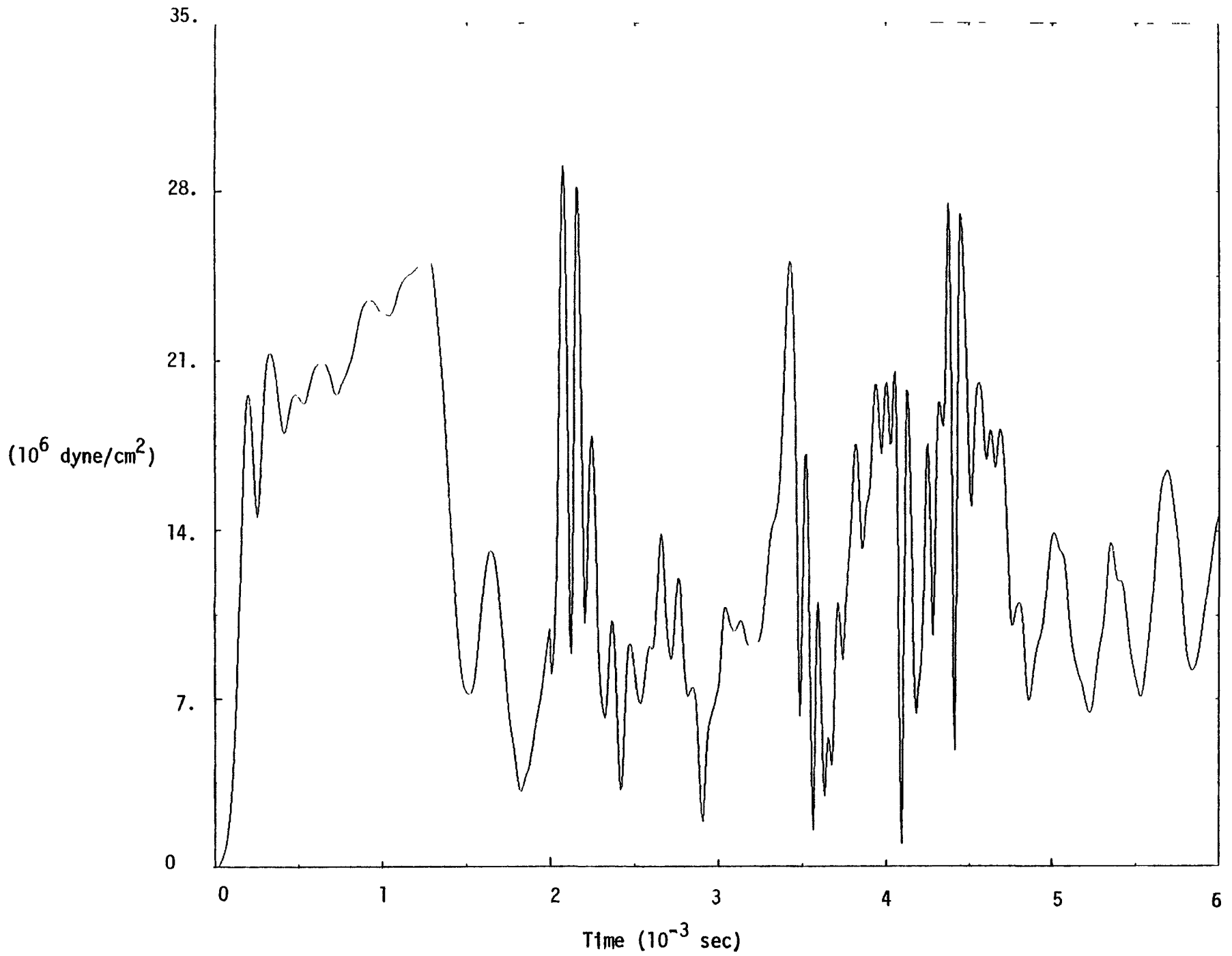


Figure 25 Pressure in Zone (7, 12) SM-2, 8-15-77

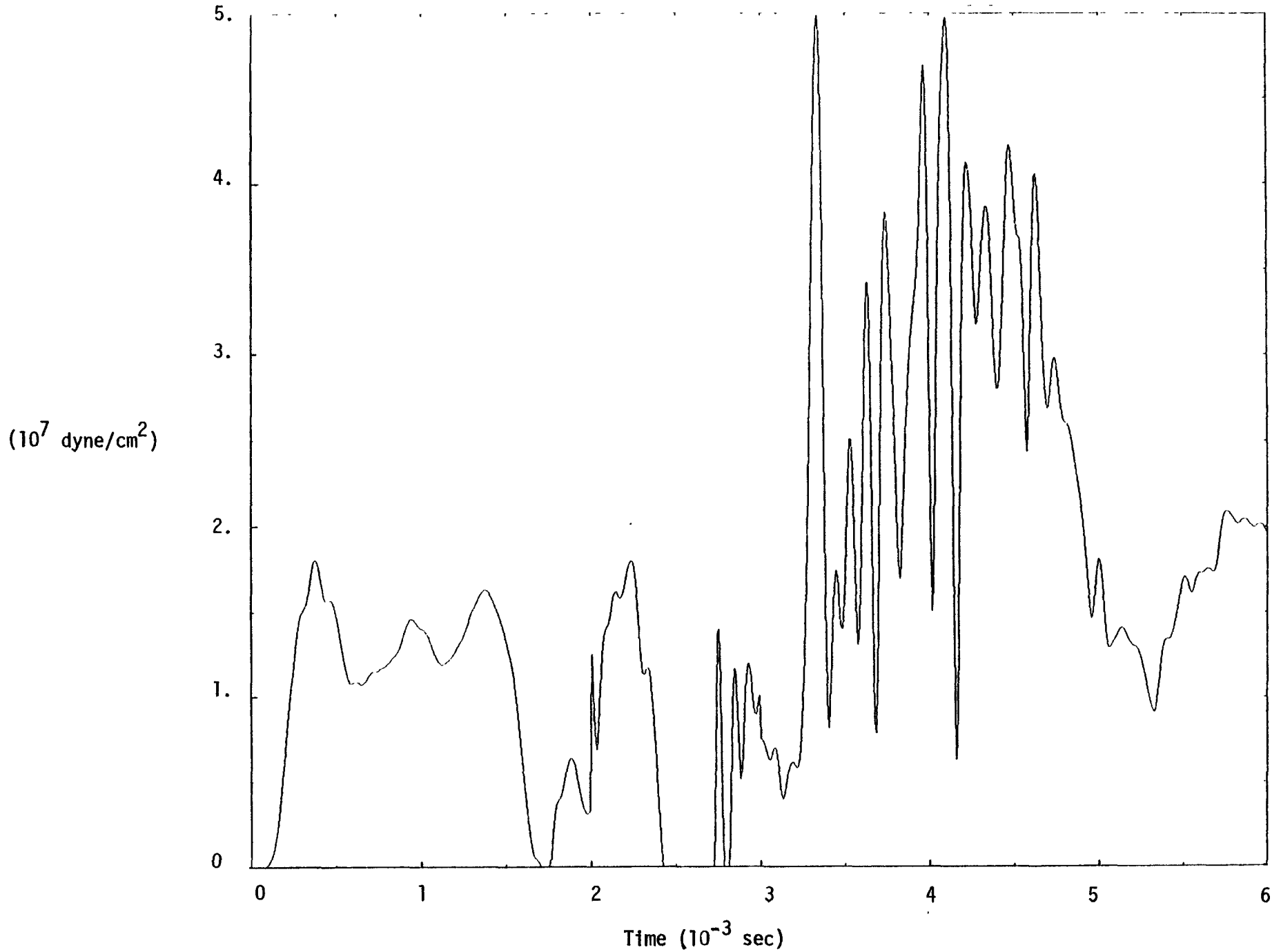


Figure 26 Pressure in Zone (7, 17) SM-2, 8-15-77

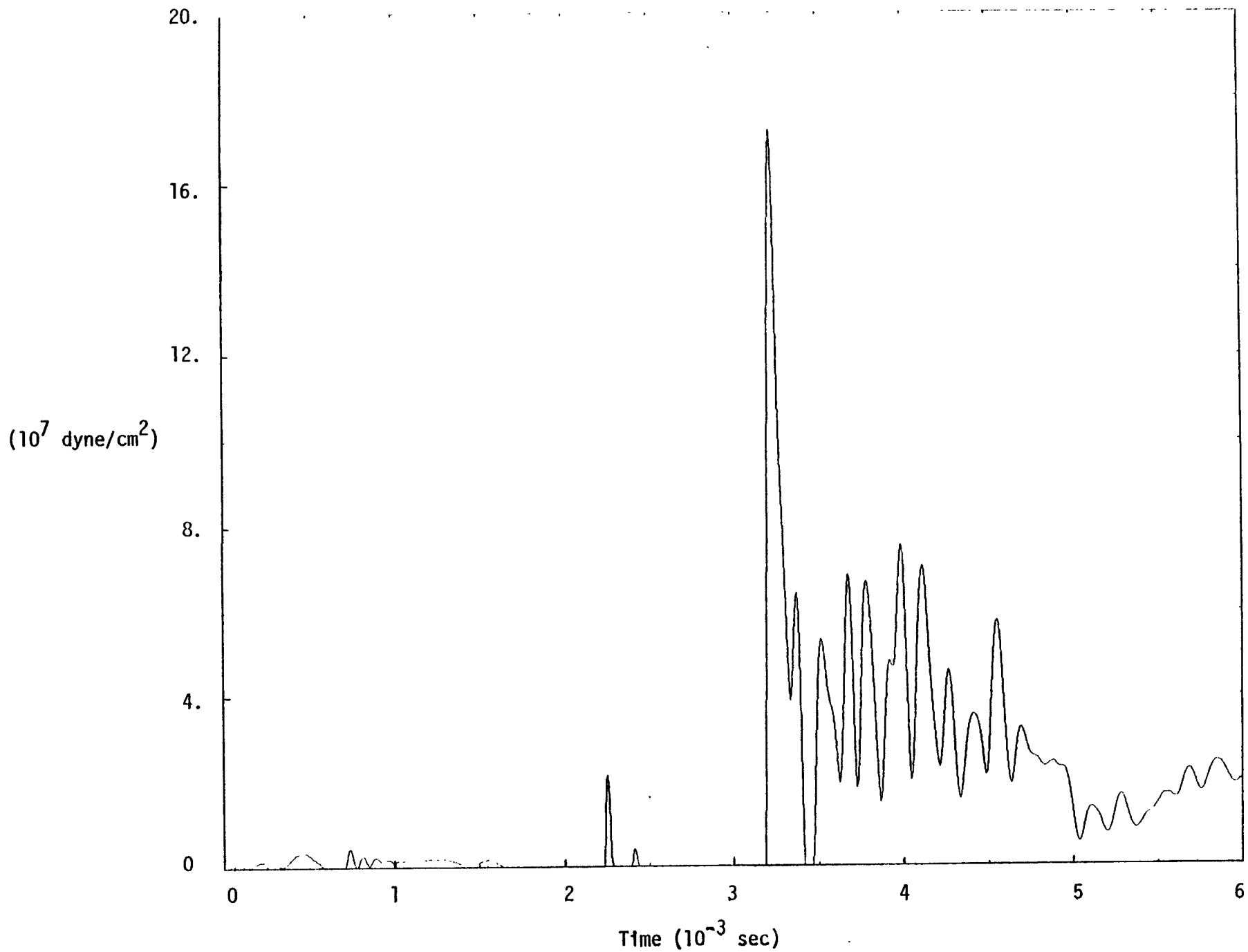


Figure 27 Pressure in Zone (7, 21) SM-2, 8-15-77

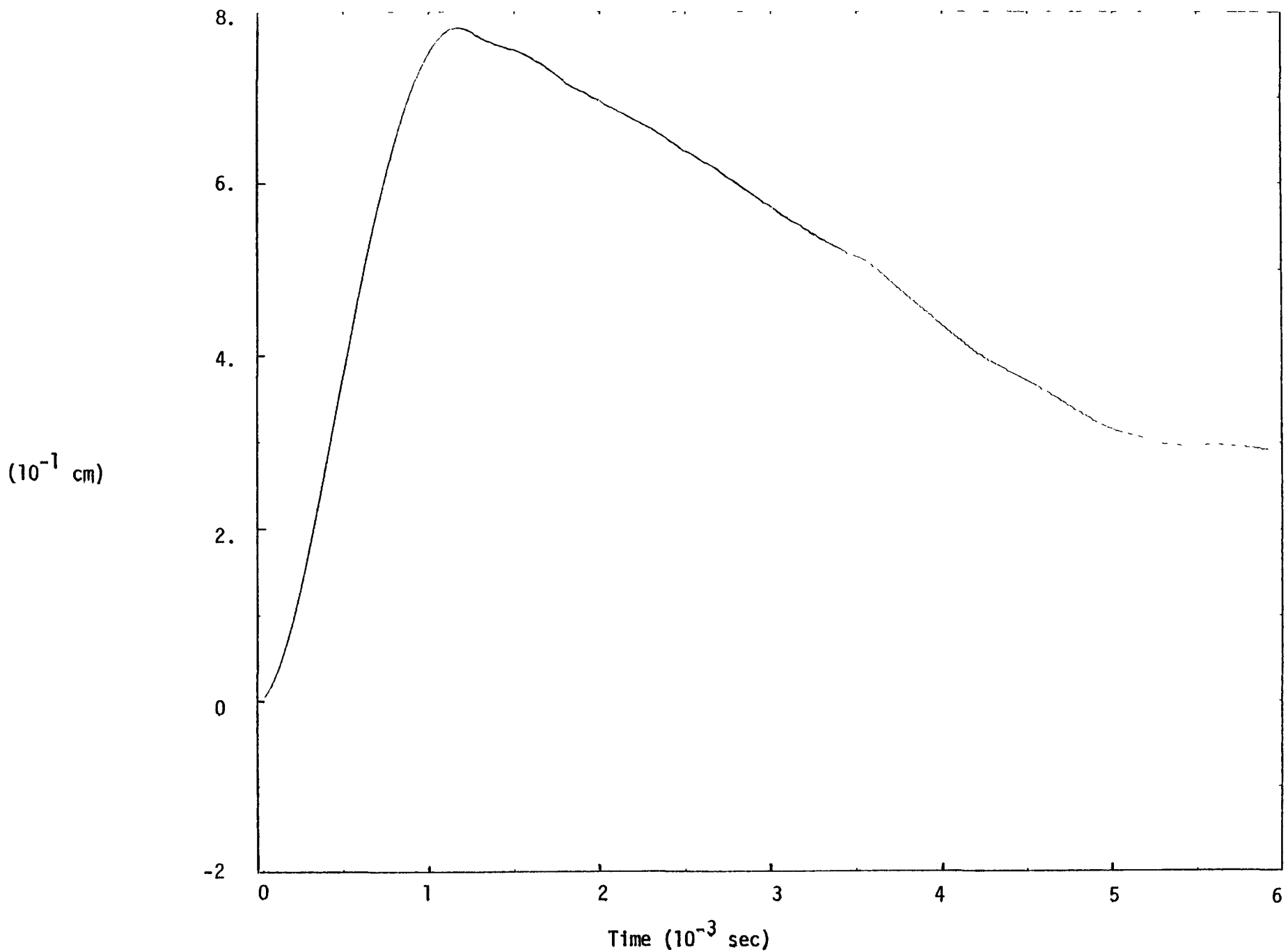


Figure 28 Radial Displacement of Mesh Point (6, 7) (10^{-1} cm)
SM-2, 8-15-77

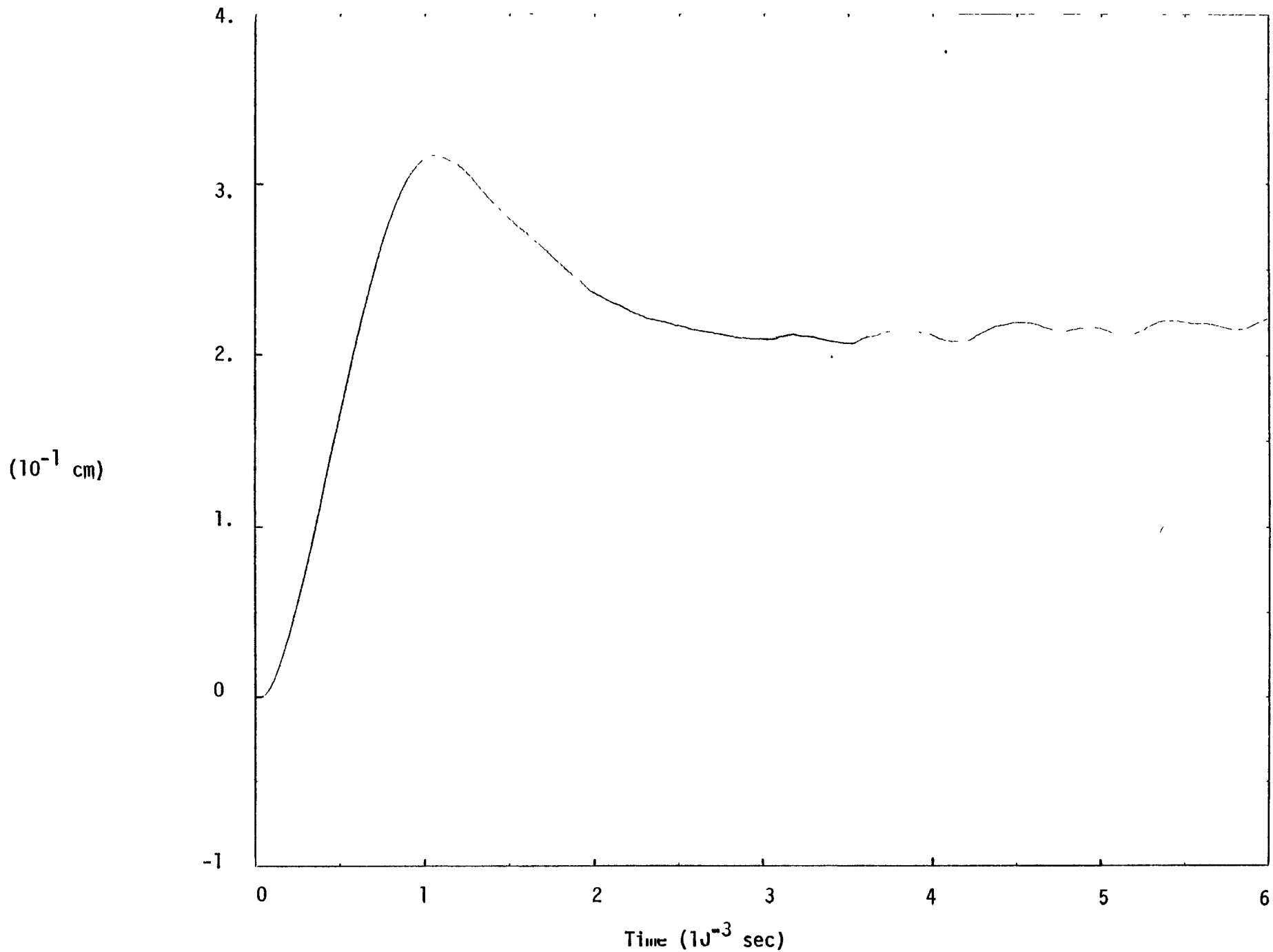


Figure 29 Radial Displacement of Mesh Point (8, 7) (10^{-1} cm)
SM-2, 8-15-77

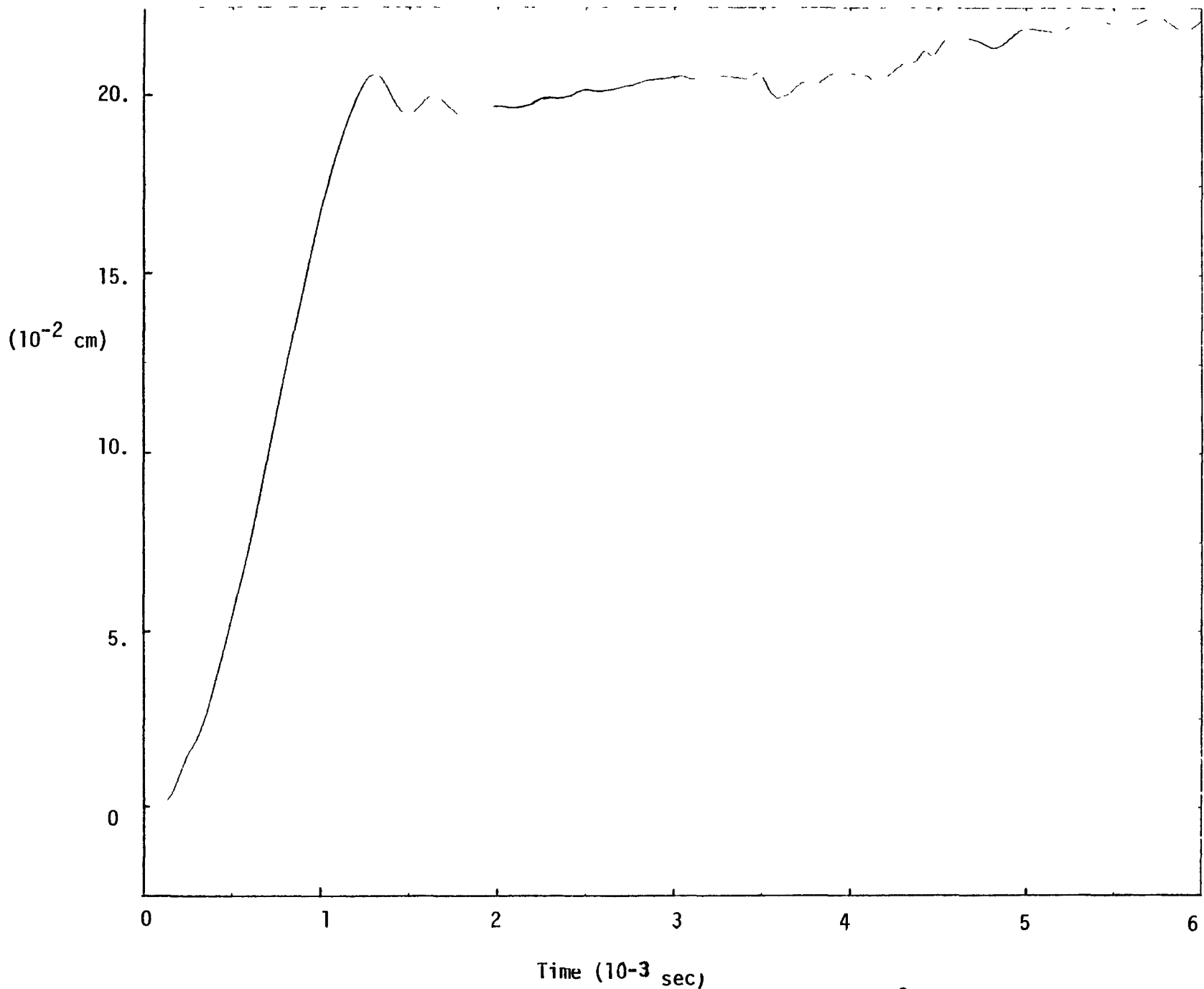


Figure 30 Radial Displacement of Mesh Point (8, 12) (10^{-2} cm) SM-2, 8-15-77

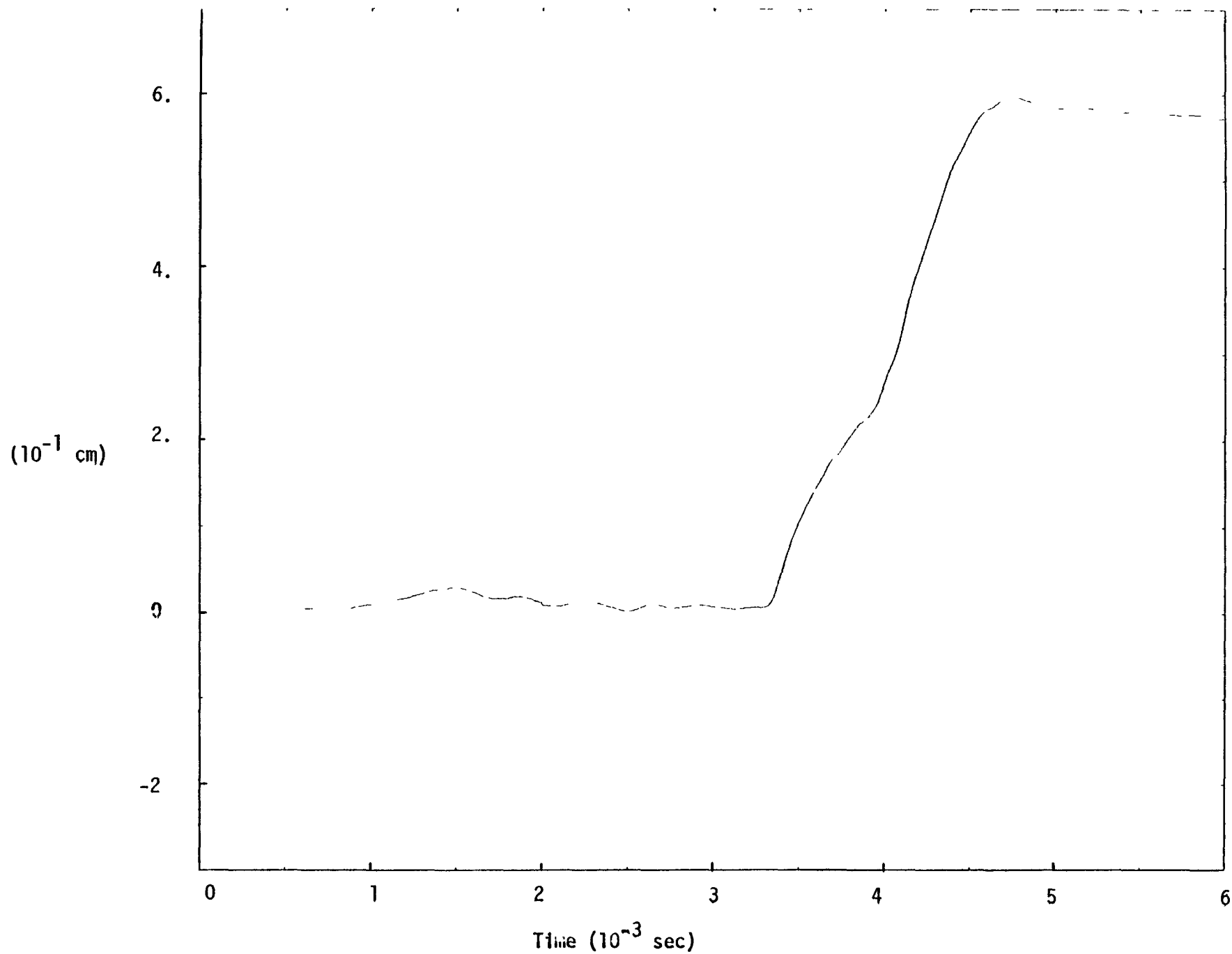


Figure 31 Radial Displacement of Mesh Point (8, 17) (10^{-1} cm) SM-2, 8-15-77

(10⁻¹ cm)

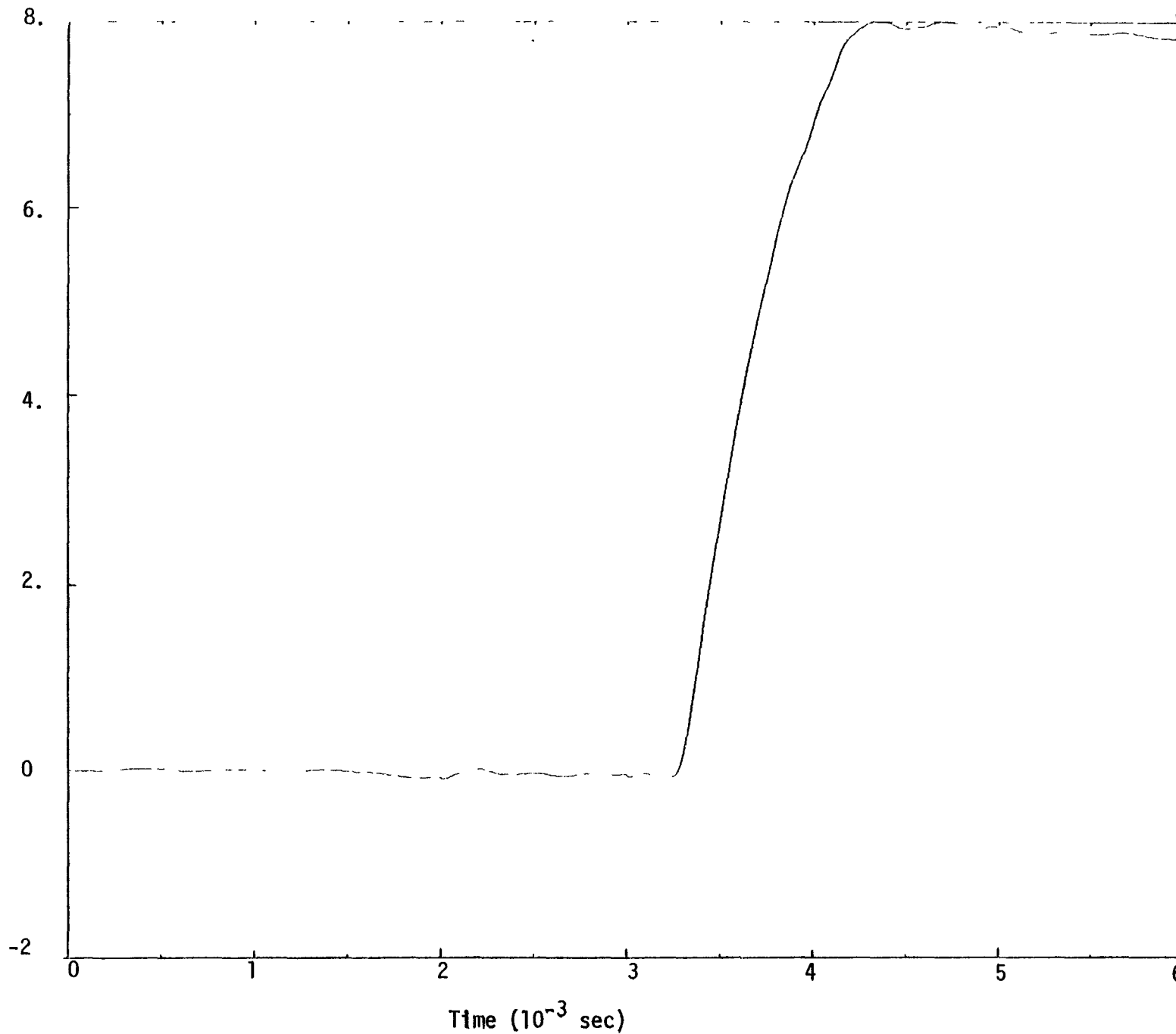


Figure 32 Radial Displacement of Mesh Point (8, 19) (10⁻¹ cm) SM-2, 8-15-77

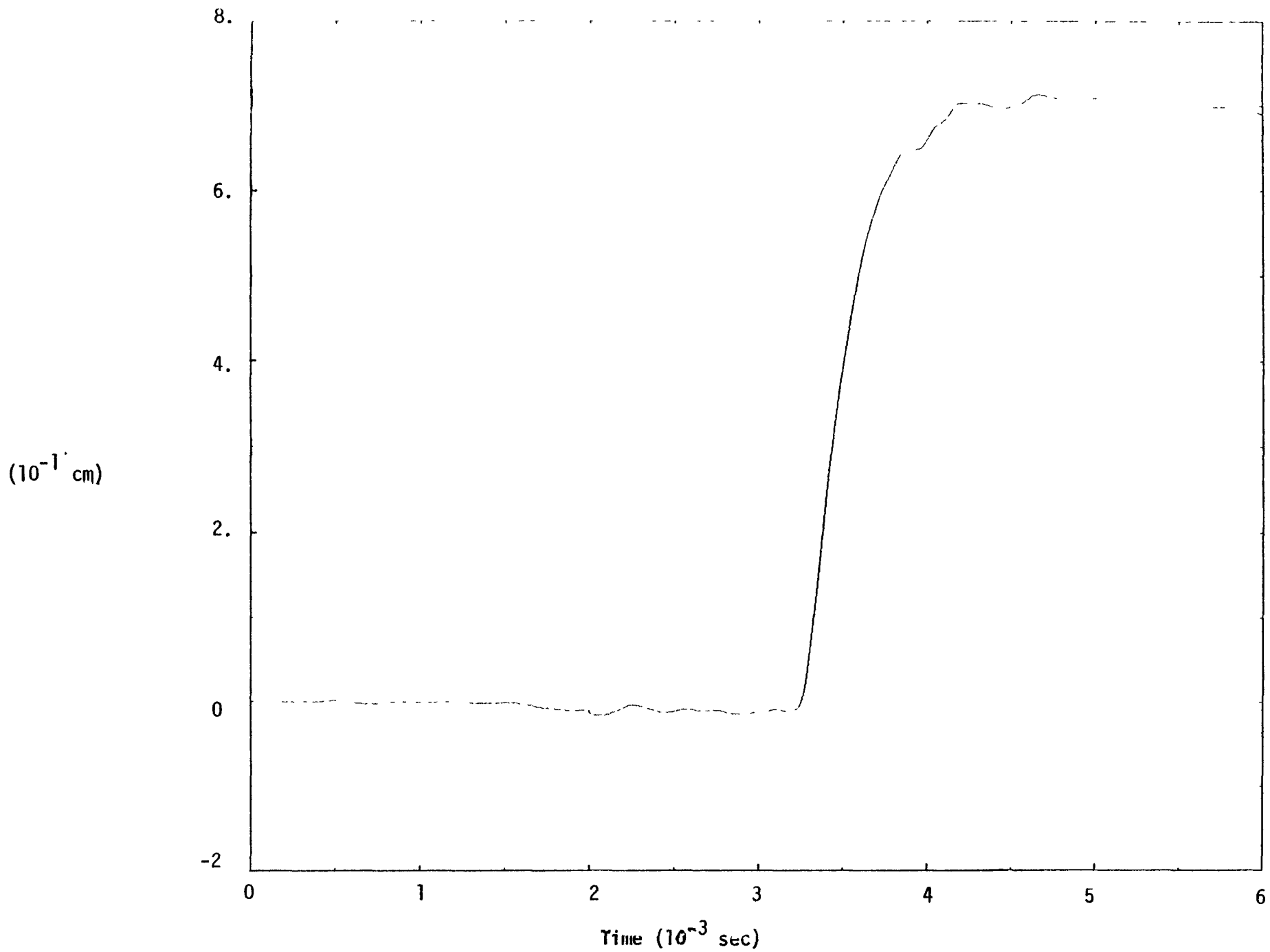


Figure 33 Radial Displacement of Mesh Point (8,20) (10^{-1} cm) SM-2, 8-15-77

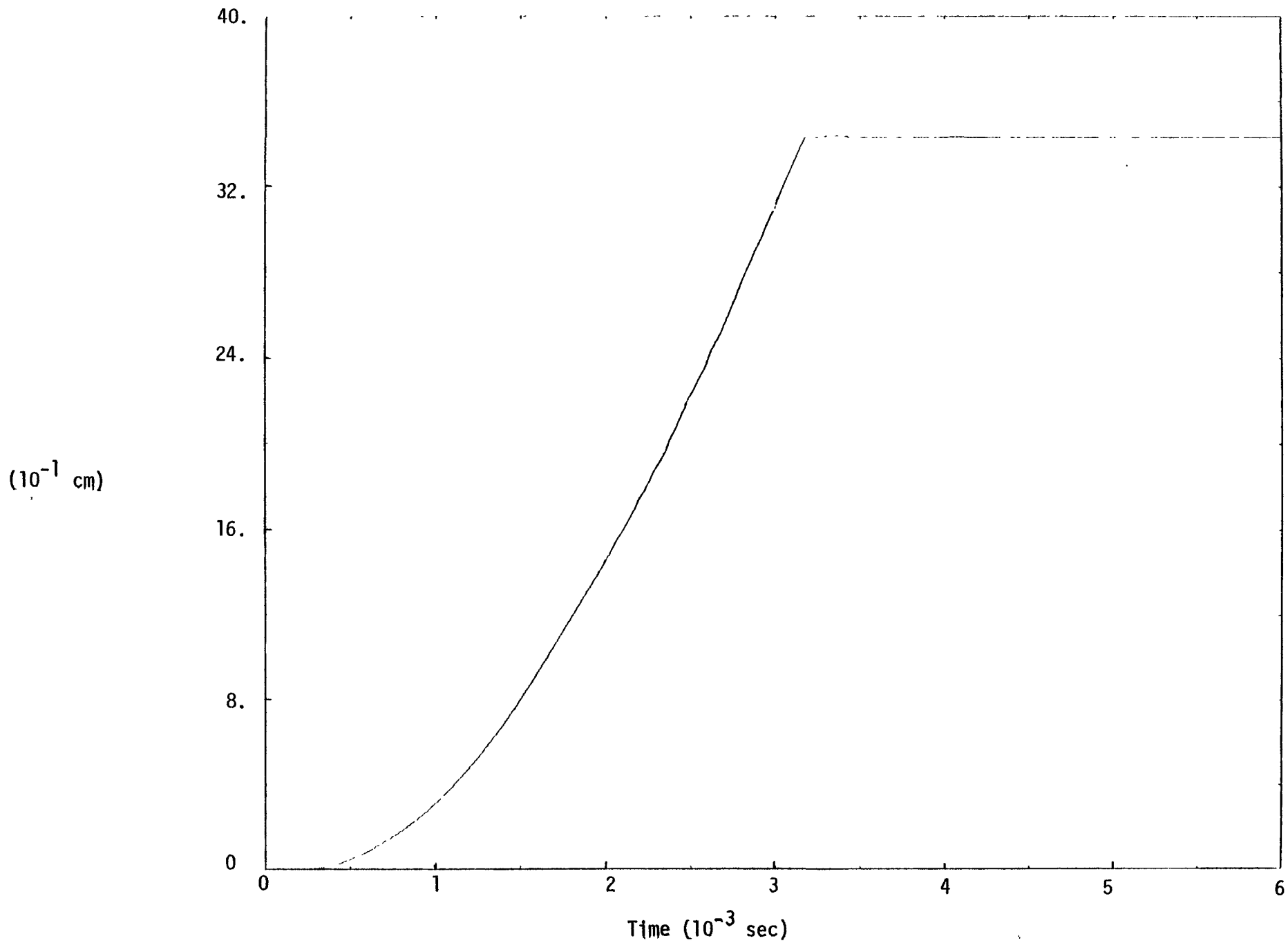


Figure 34 Axial Displacement of Mesh Point (3, 22) (10^{-1} cm) SM-2, 8-15-77

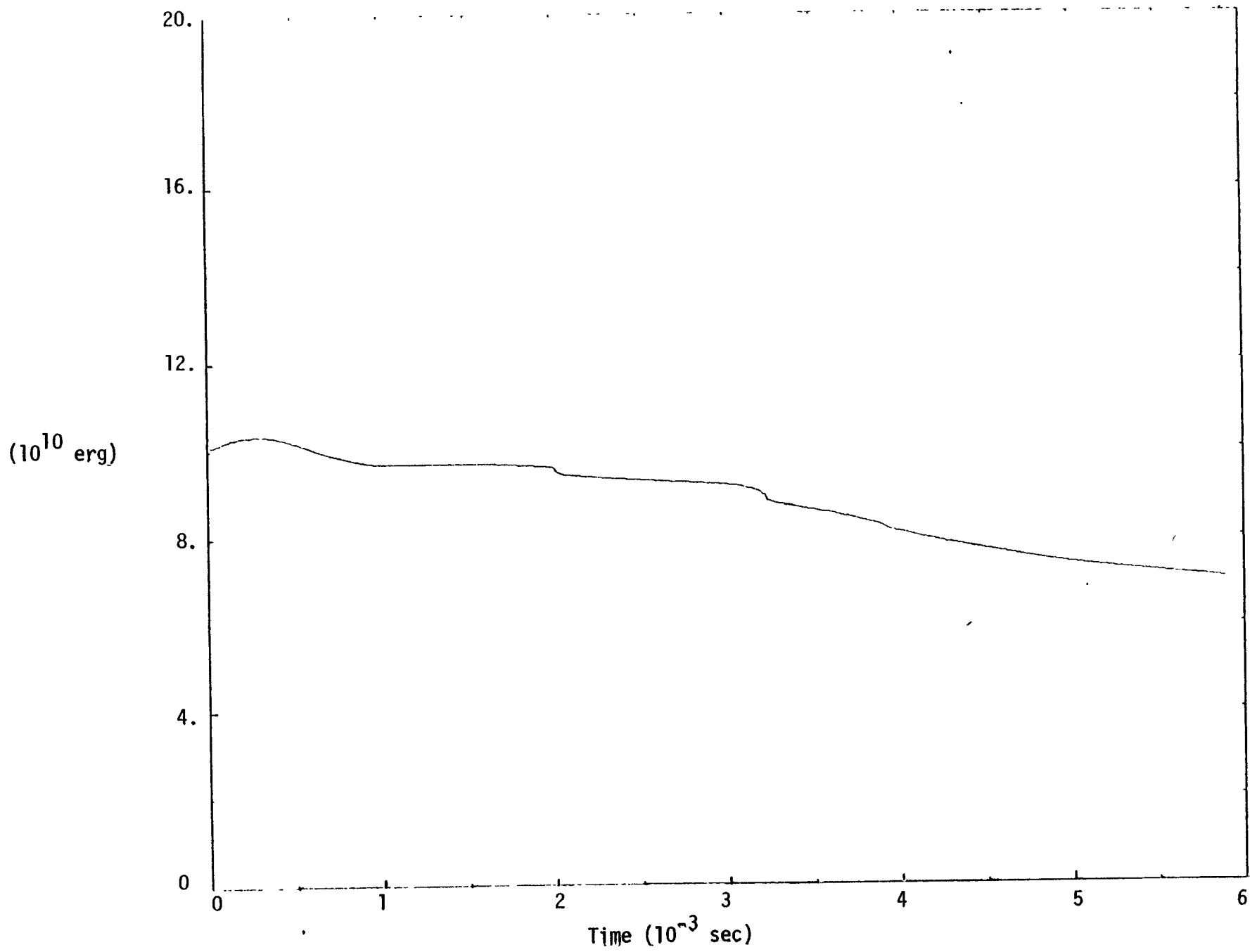


Figure 35 Total Energy (10^{10} erg) SM-2, 8-17-77

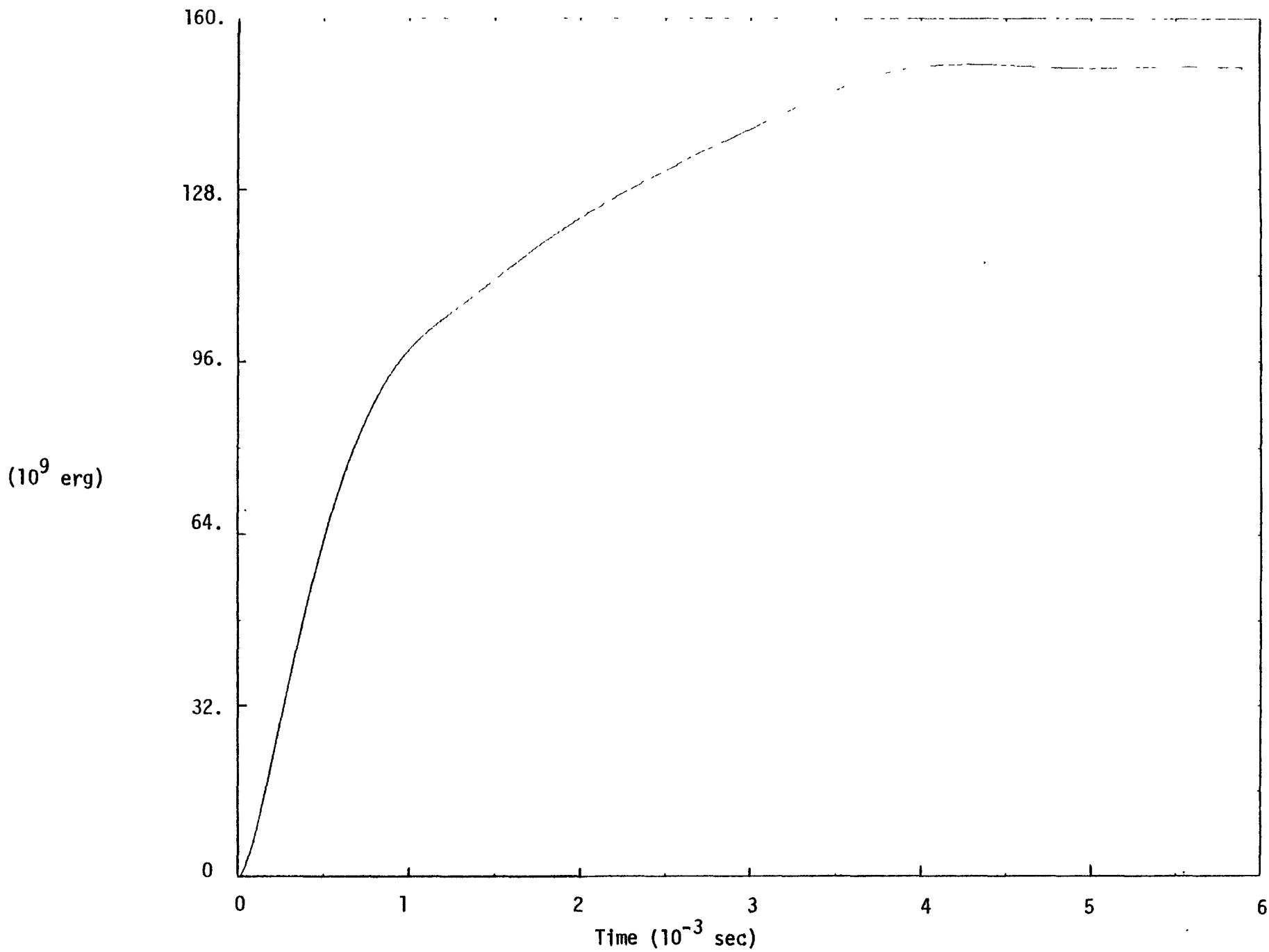


Figure 36 Core Released Energy (10^9 erg) SM-2, 8-17-77

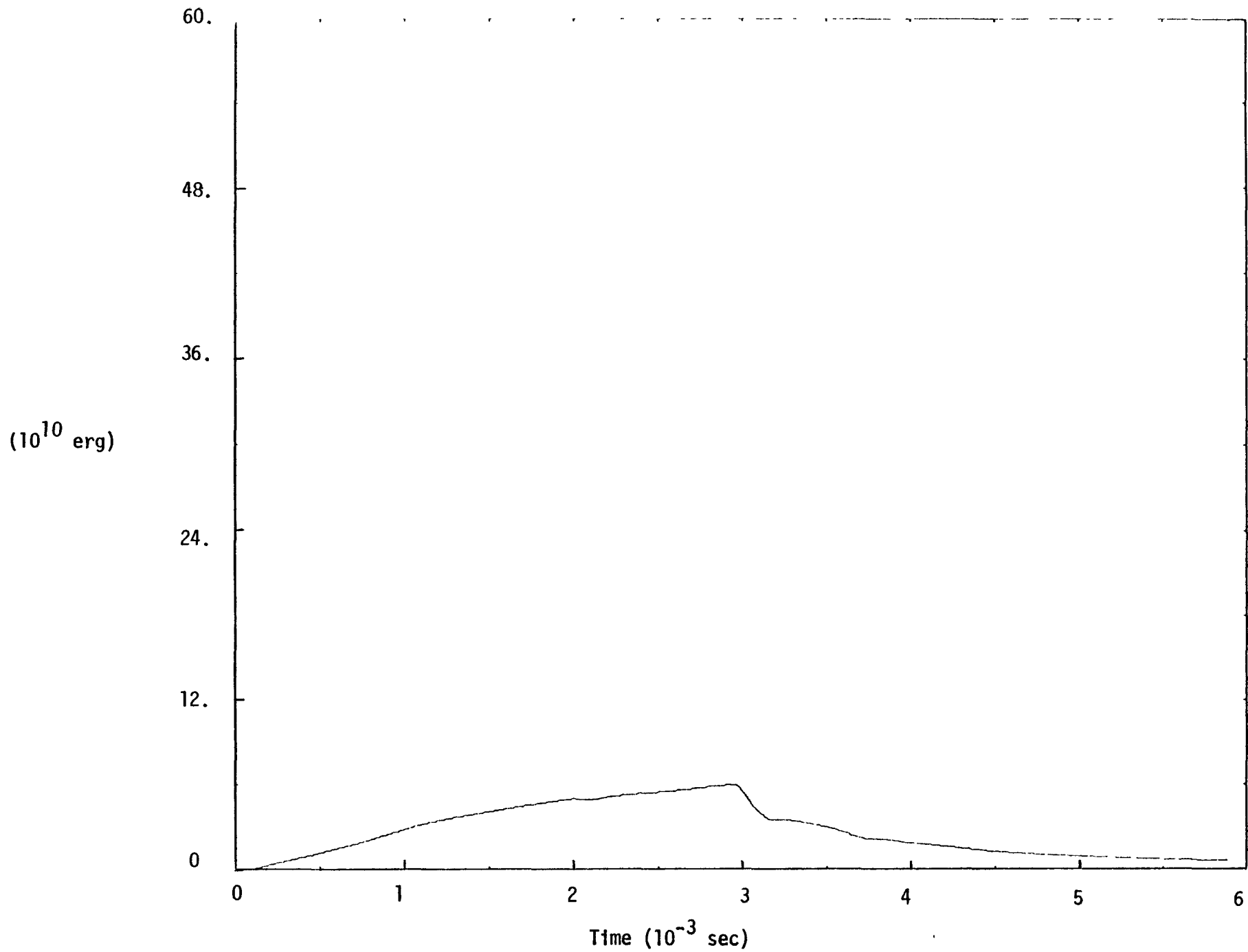


Figure 37 Positive Axial Kinetic Energy (10^{10} erg) SM-2, 8-17-77

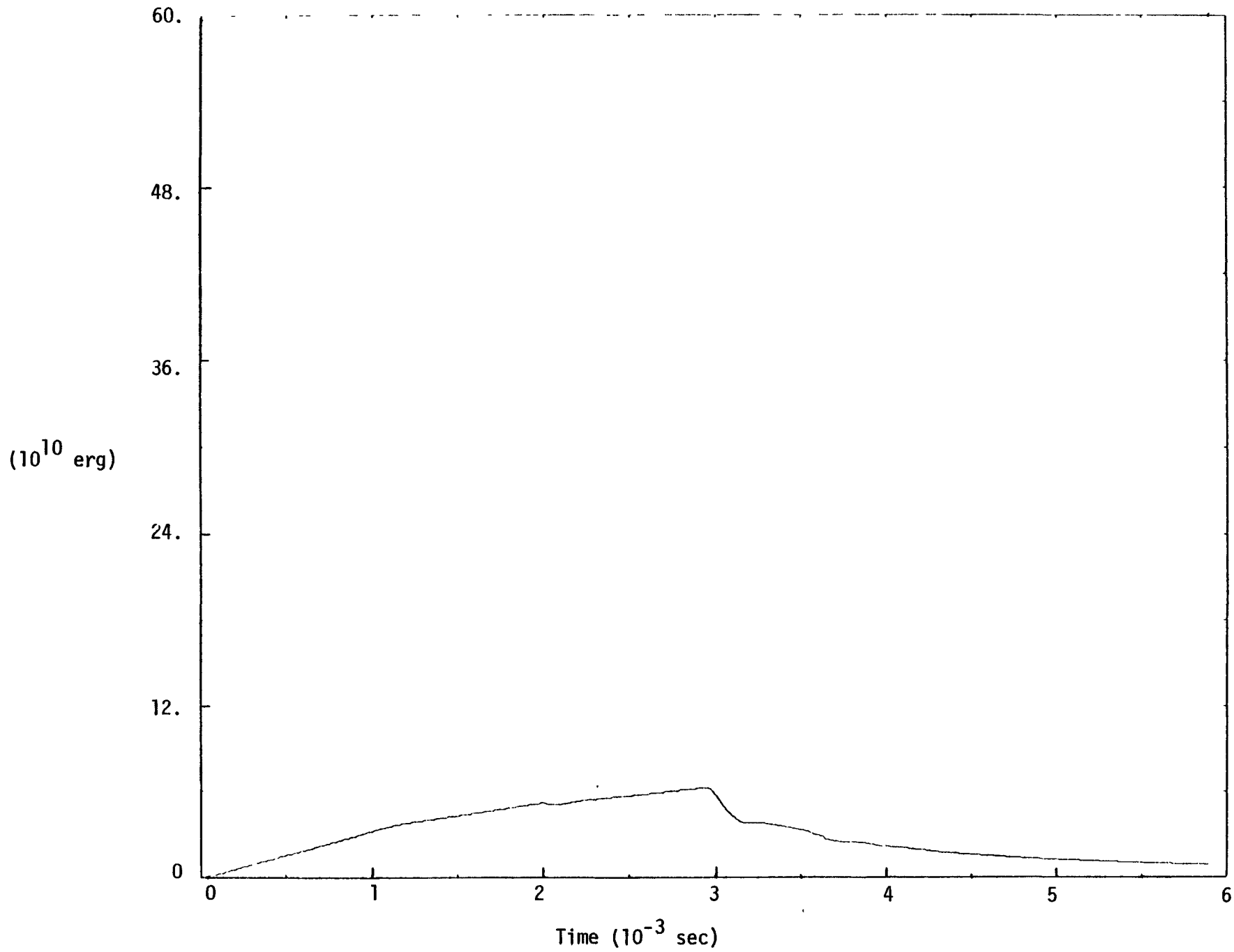


Figure 38 Total Axial Kinetic Energy (10^{10} erg) SM-2, 8-17-77

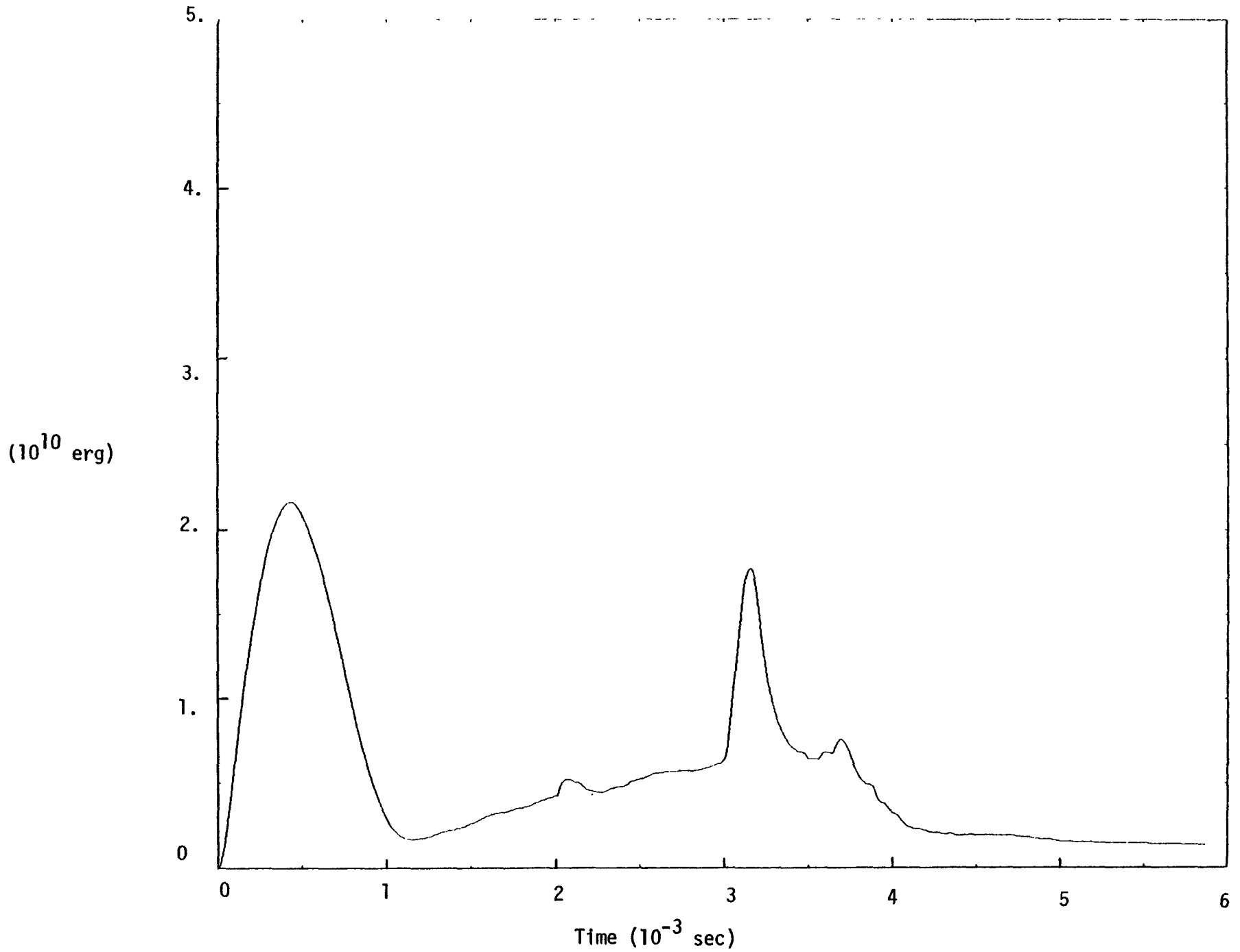


Figure 39 Total Radial Kinetic Energy (10^{10} erg) SM-2, 8-17-77

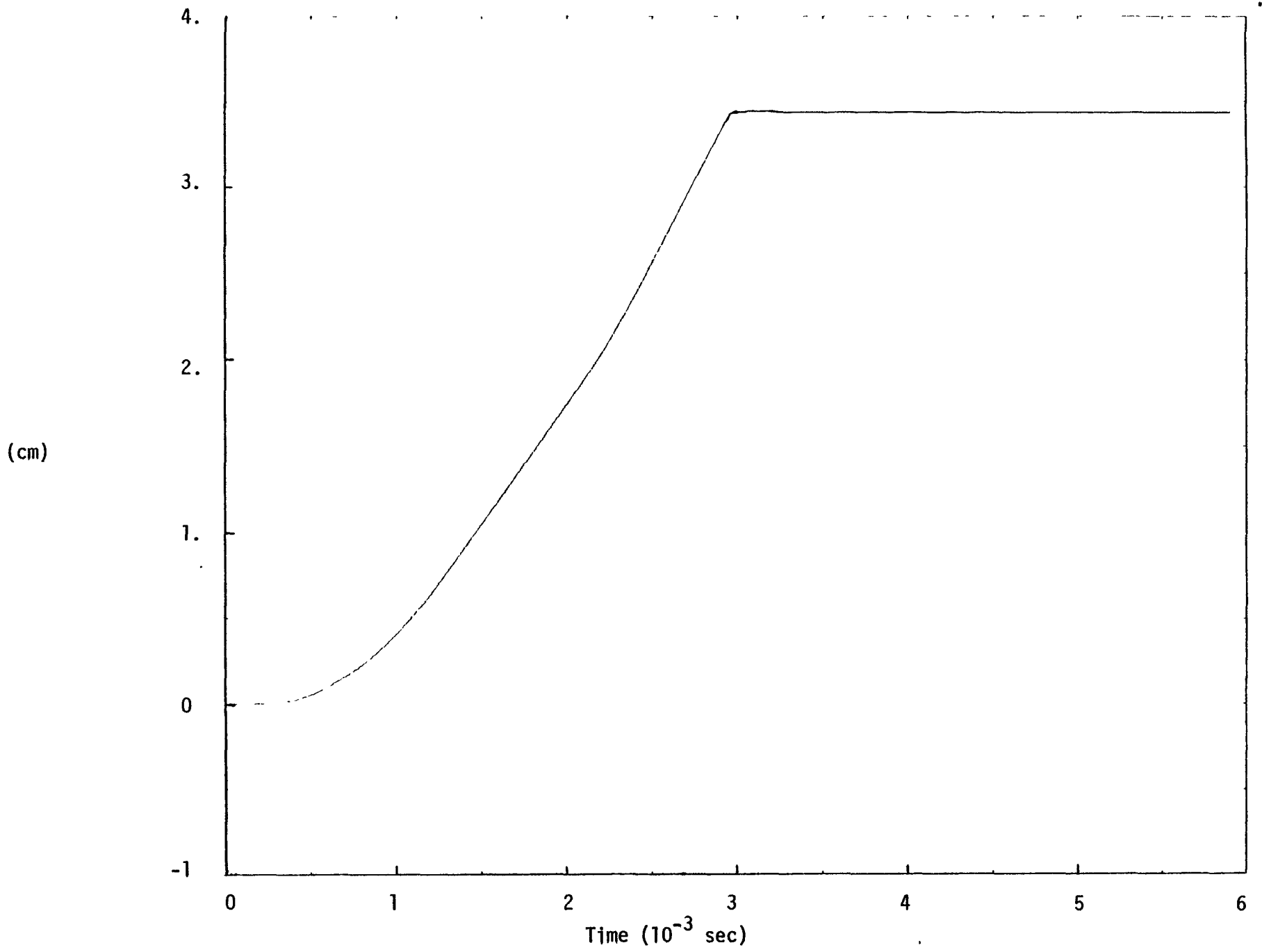


Figure 40 Average Surface Displacement (cm) SM-2, 8-17-77

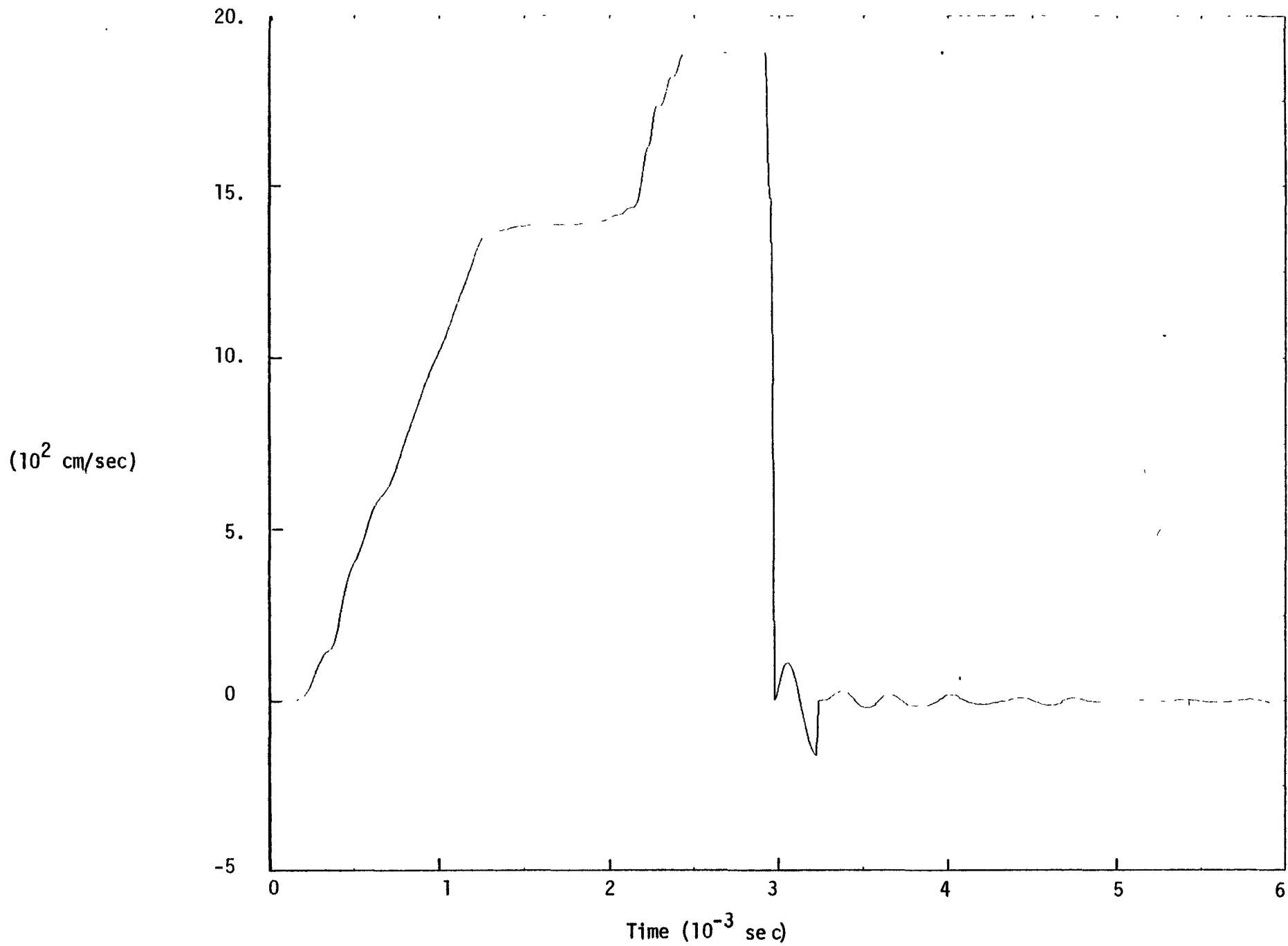


Figure 41 Average Surface Velocity (10^2 cm/sec) SM-2, 8-17-77

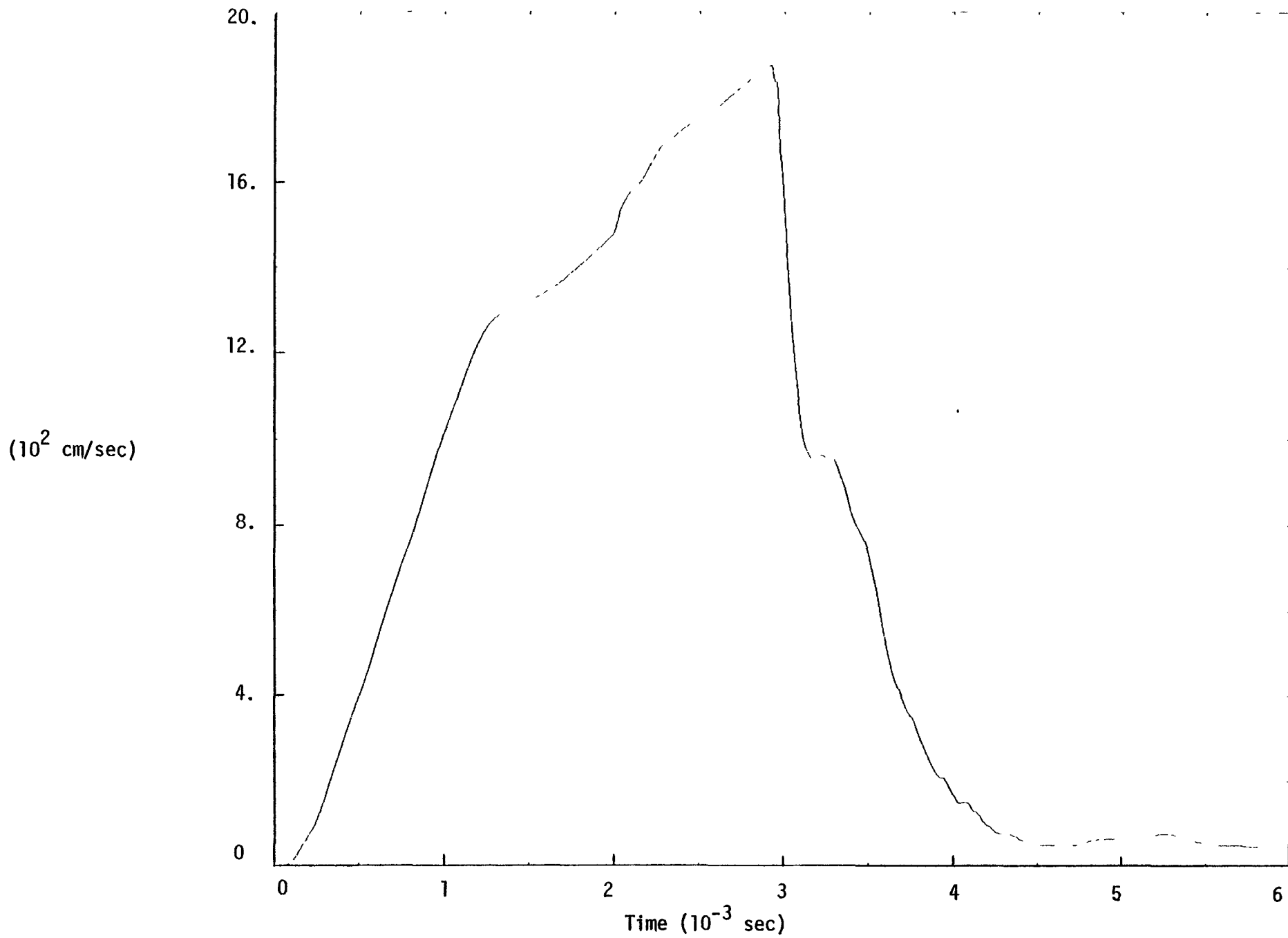


Figure 42 Average Slua Velocity (10^2 cm/sec) SM-2, 8-17-77

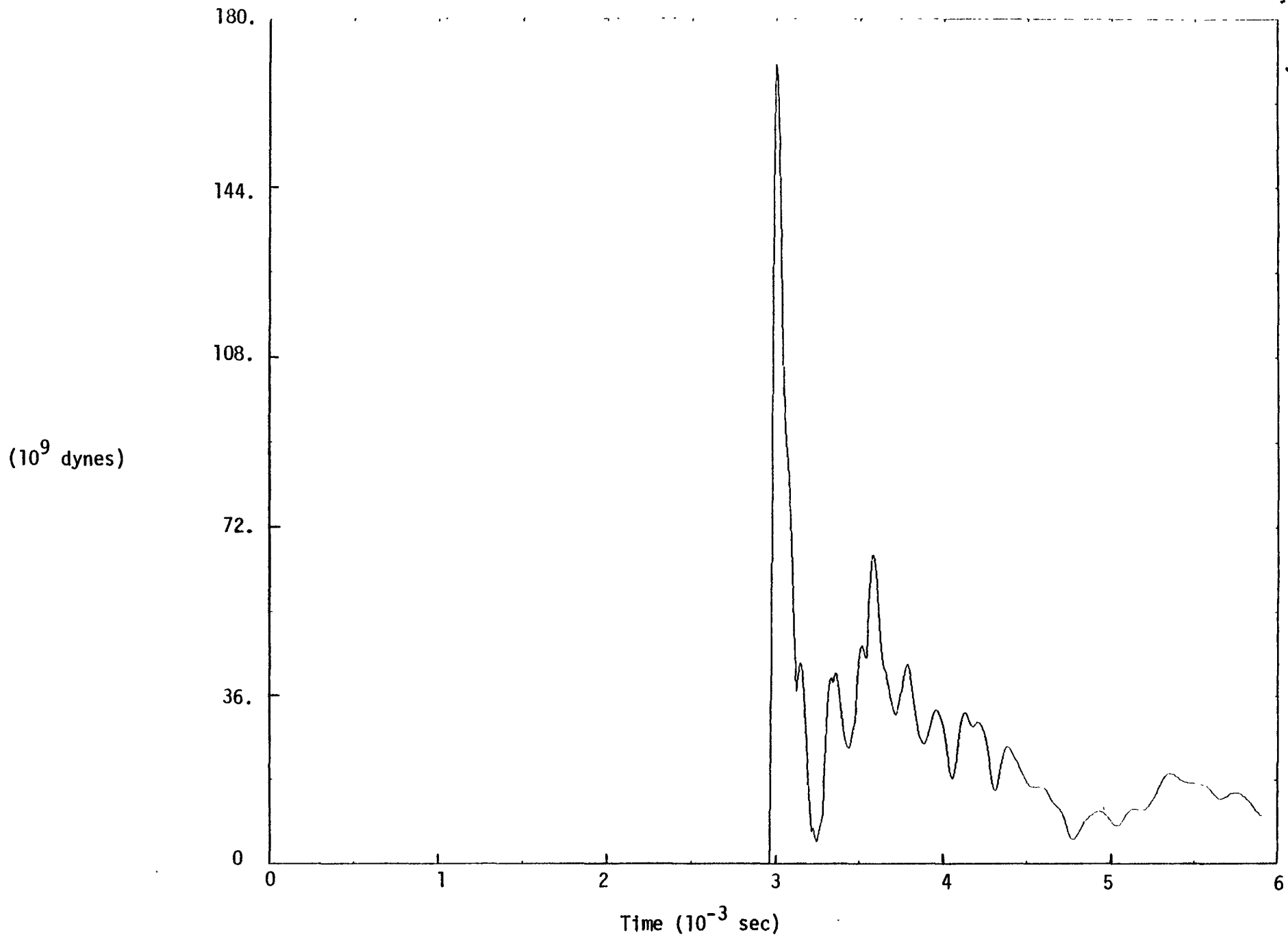


Figure 43 Slug Force (10^9 dynes) SM-2, 8-17-77

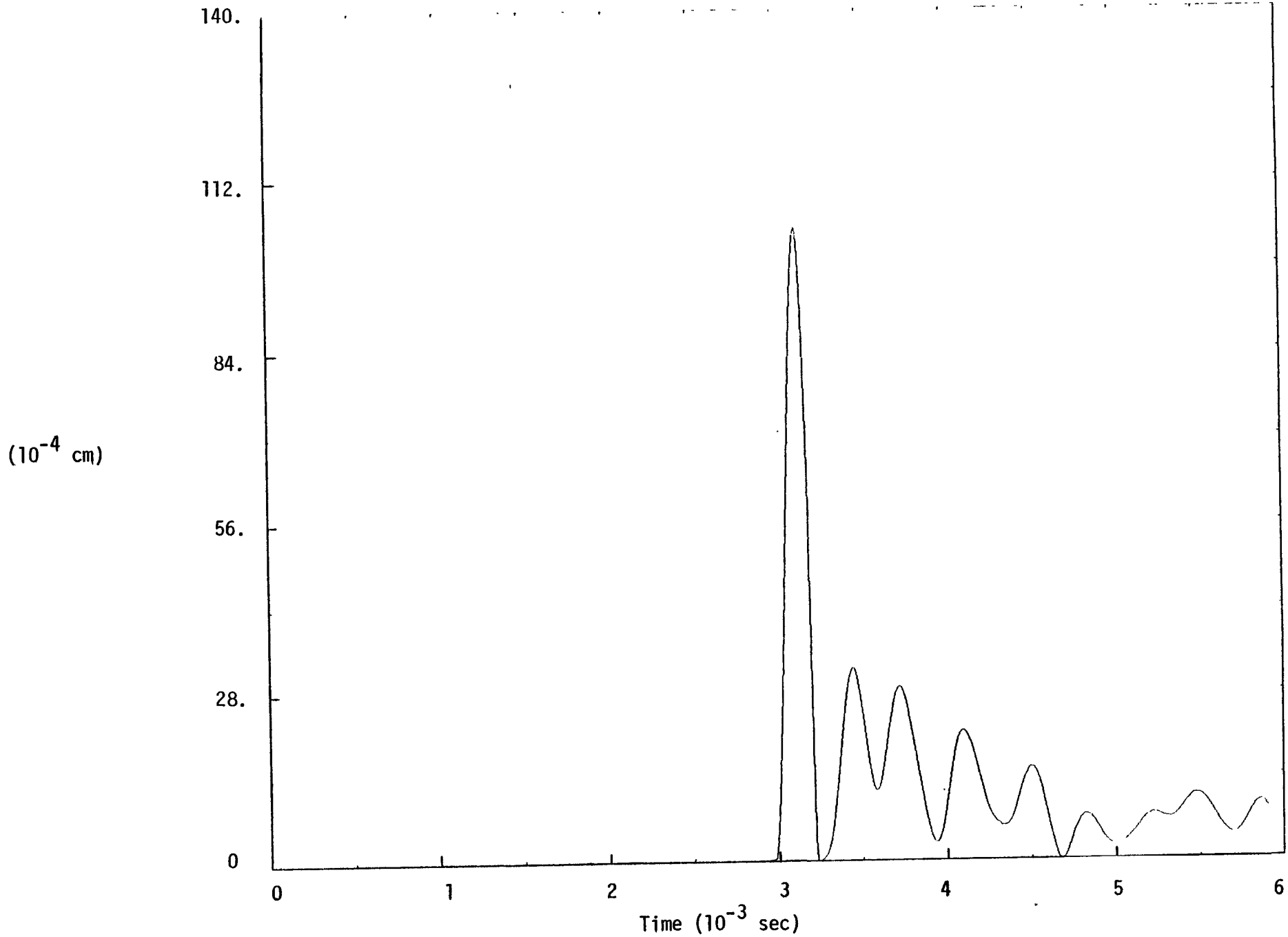


Figure 44 Reactor Head Displacement (10^{-4} cm) SM-2, 8-17-77

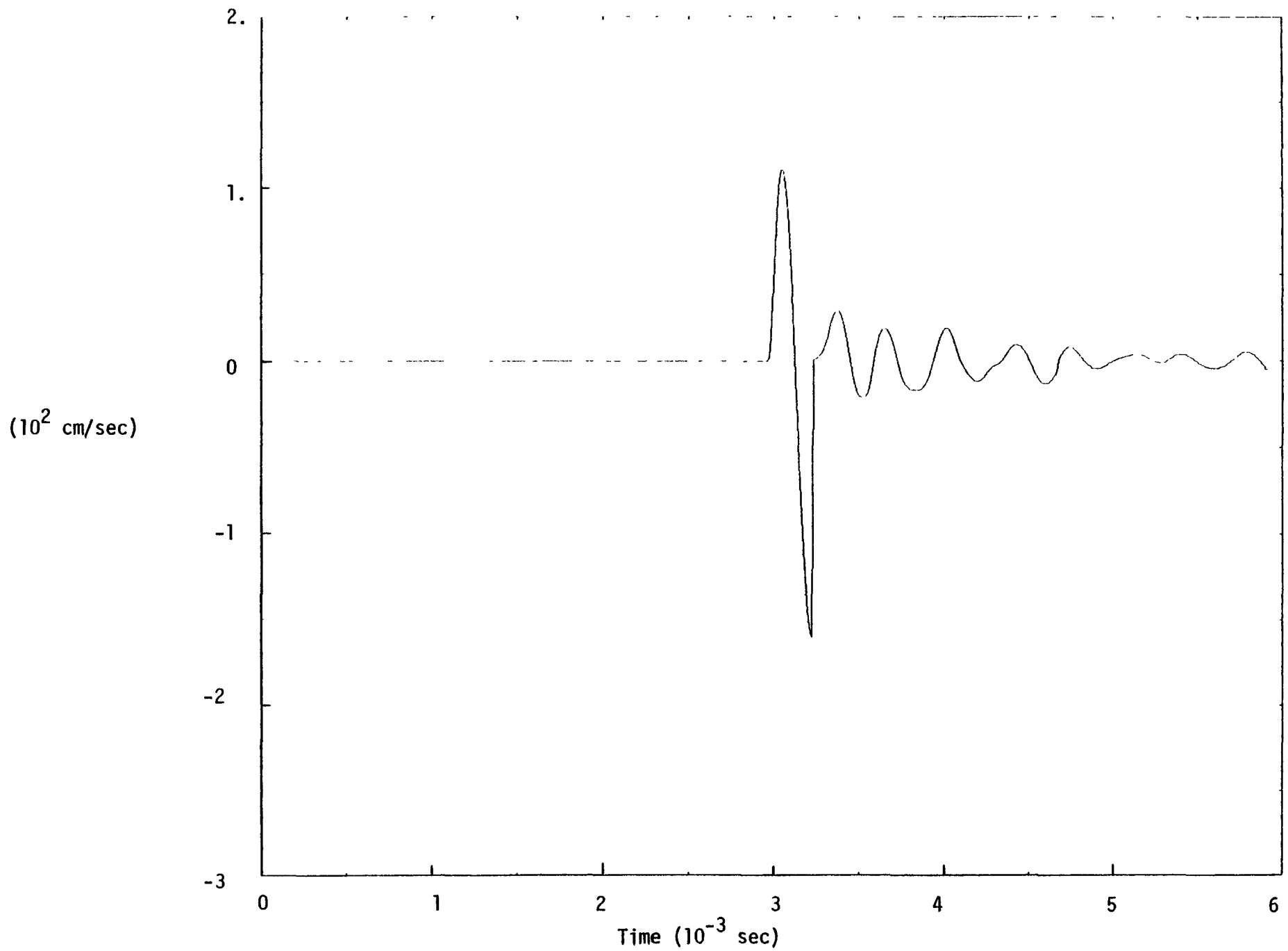


Figure 45 Reactor Head Velocity (10^2 cm/sec) SM-2, 8-17-77

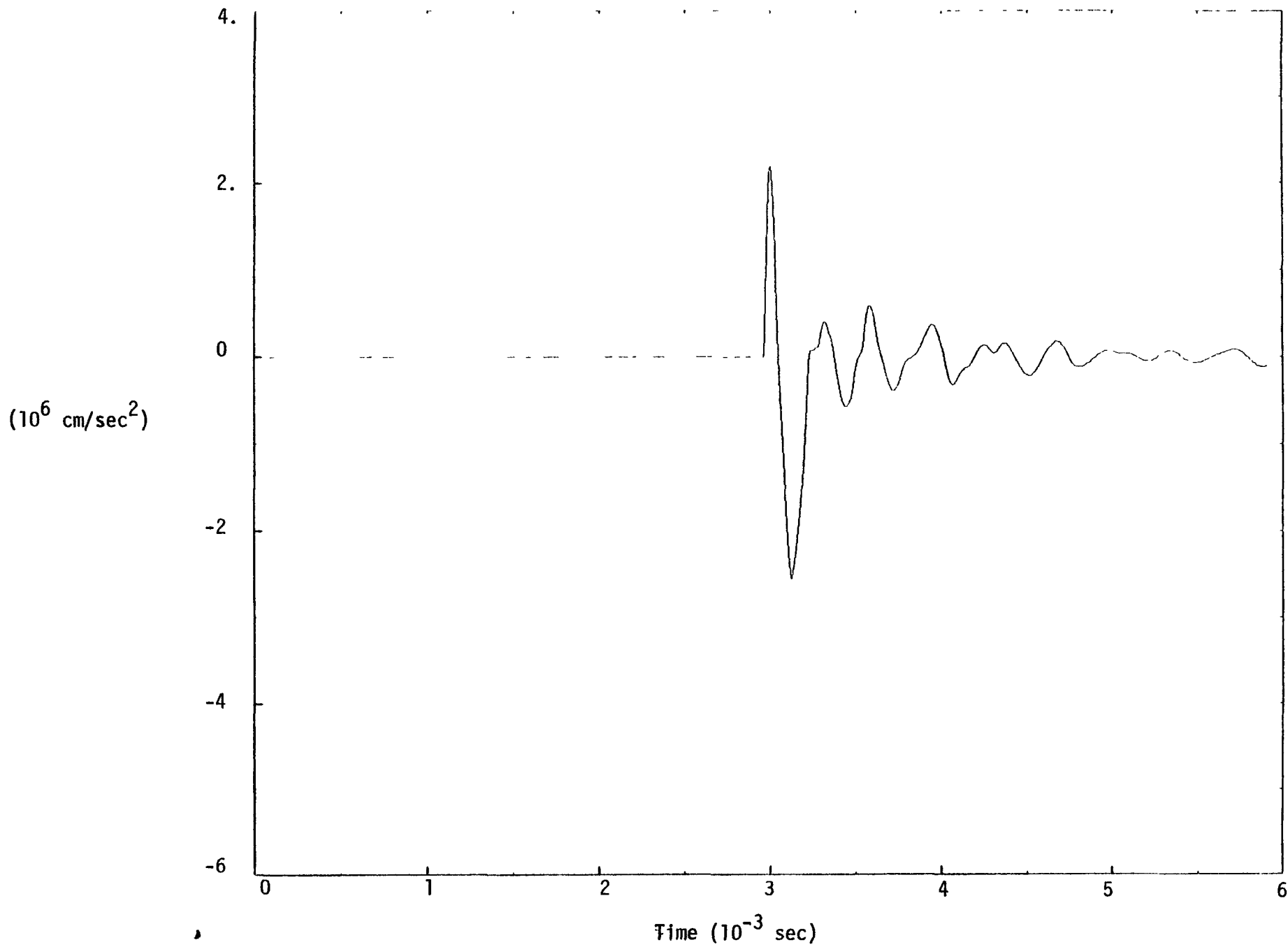


Figure 46 Reactor Head Acceleration (10^6 cm/sec^2) SM-2, 8-17-77

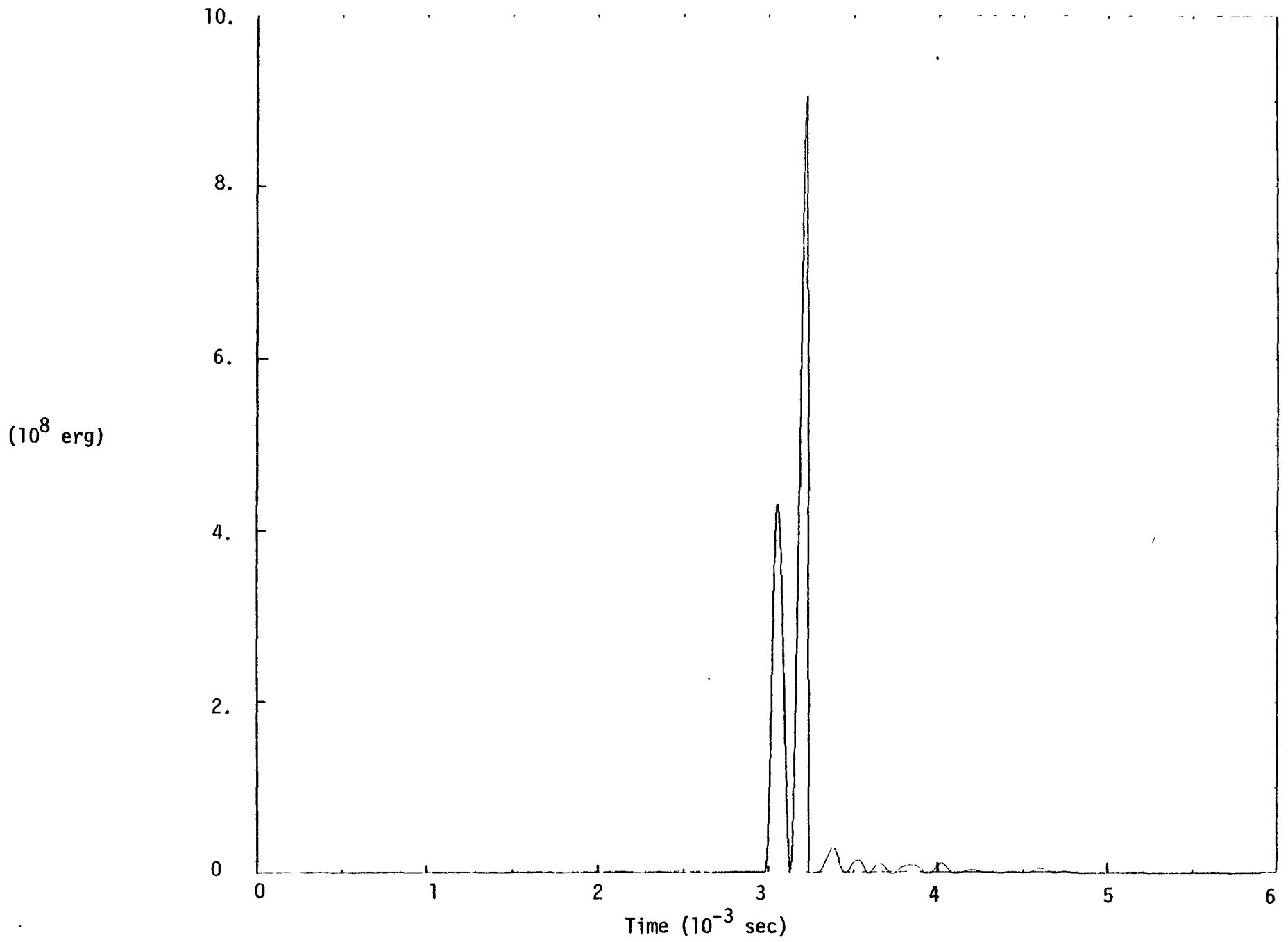


Figure 47 Reactor Head Kinetic Energy (10^8 erg) SM-2, 8-17-77

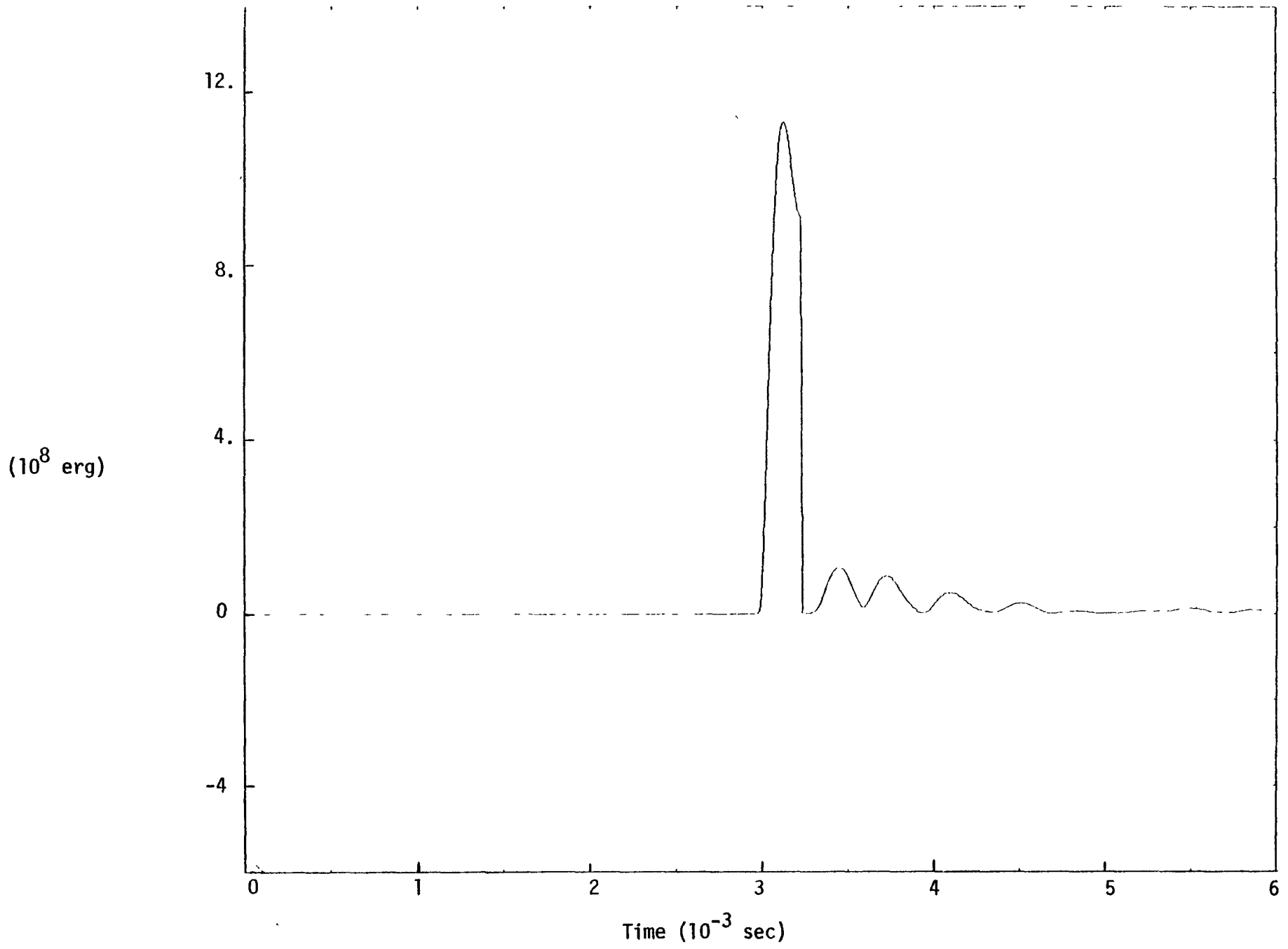


Figure 48 Total Reactor Head Energy (10^8 erg) SM-2, 8-17-77

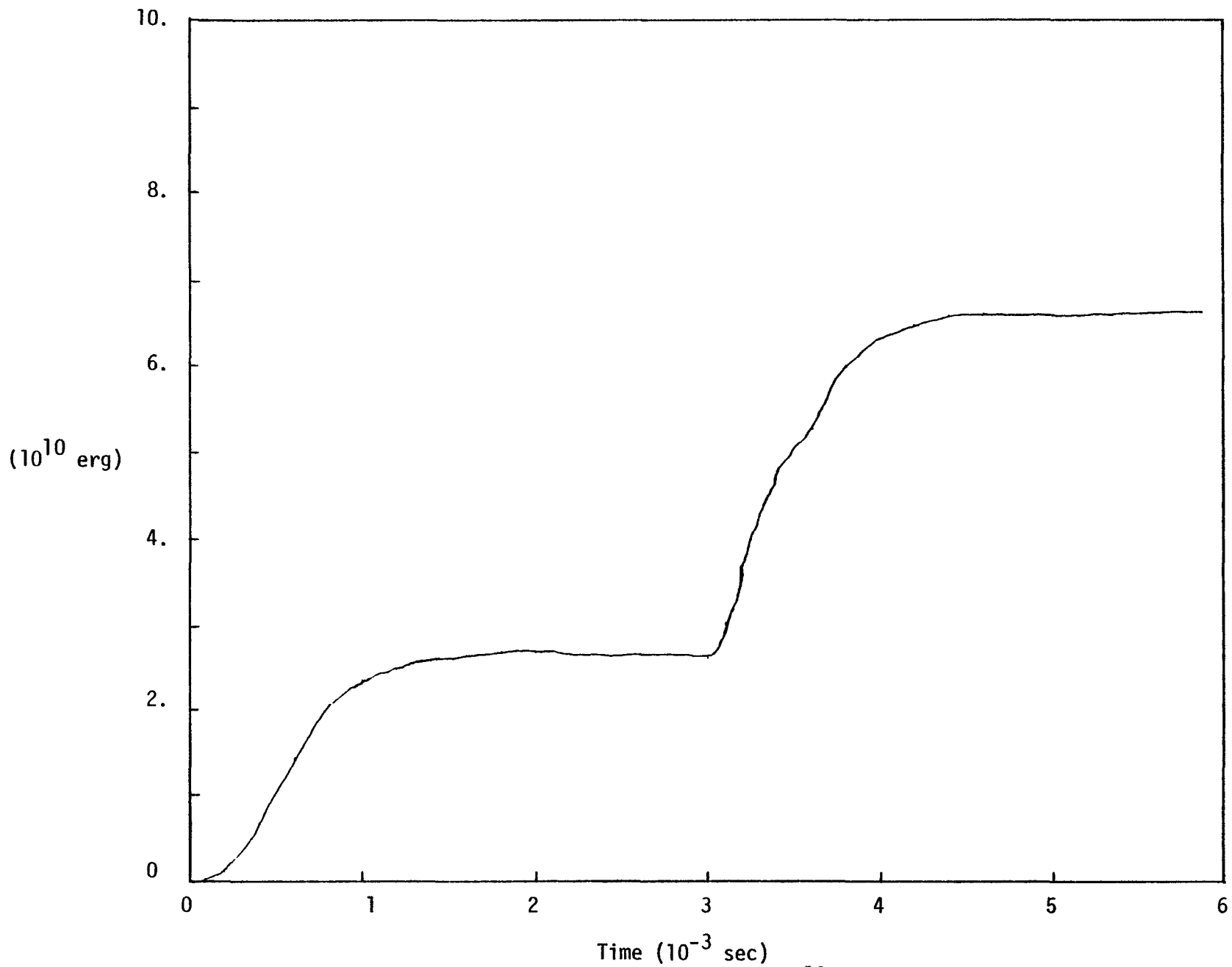


Figure 49 Vessel Strain Energy (10^{10} erg) SM-2, 8-17-77

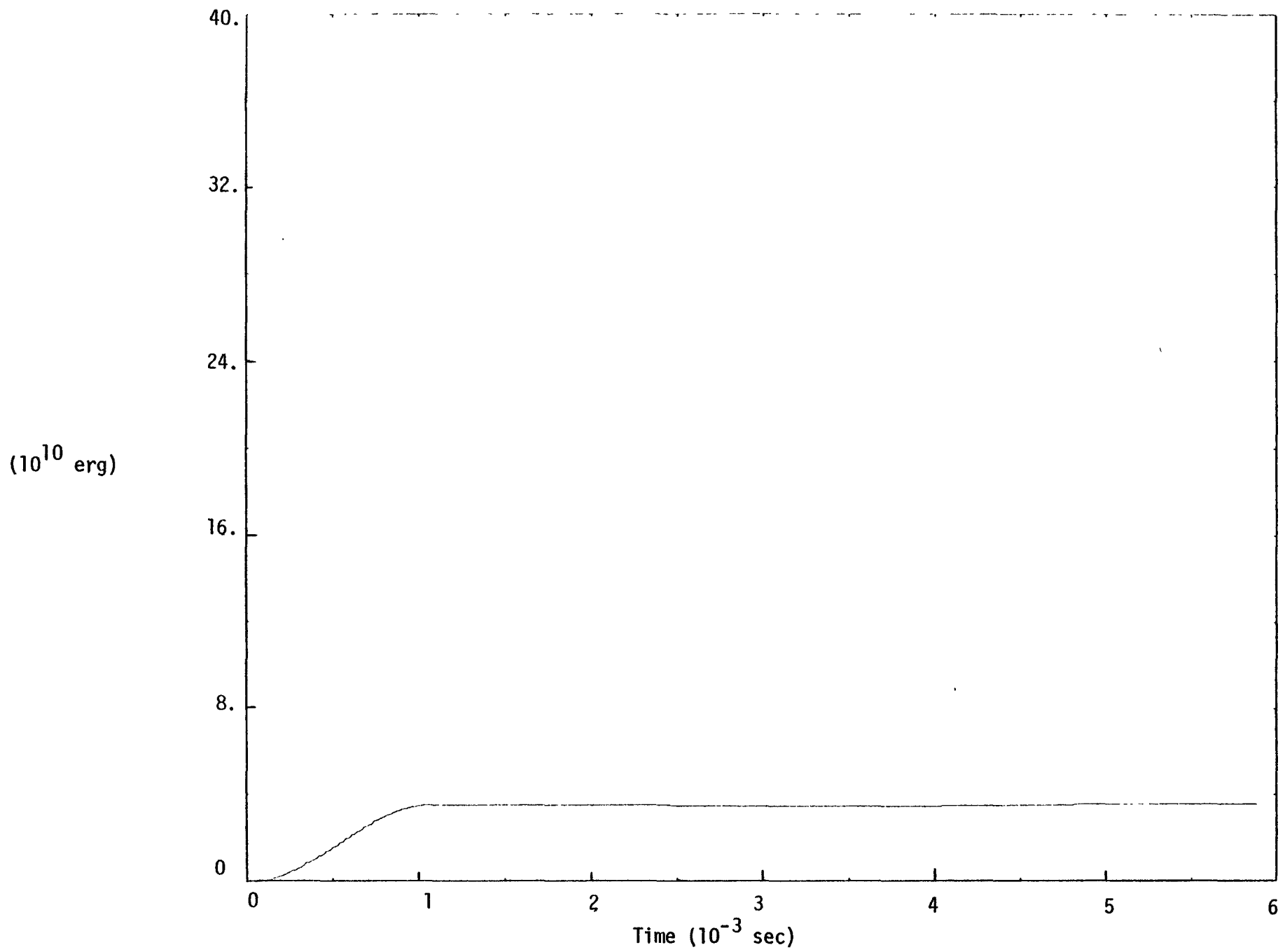


Figure 50 Core Barrel Strain Energy (10^{10} erg) SM-2, 8-17-77

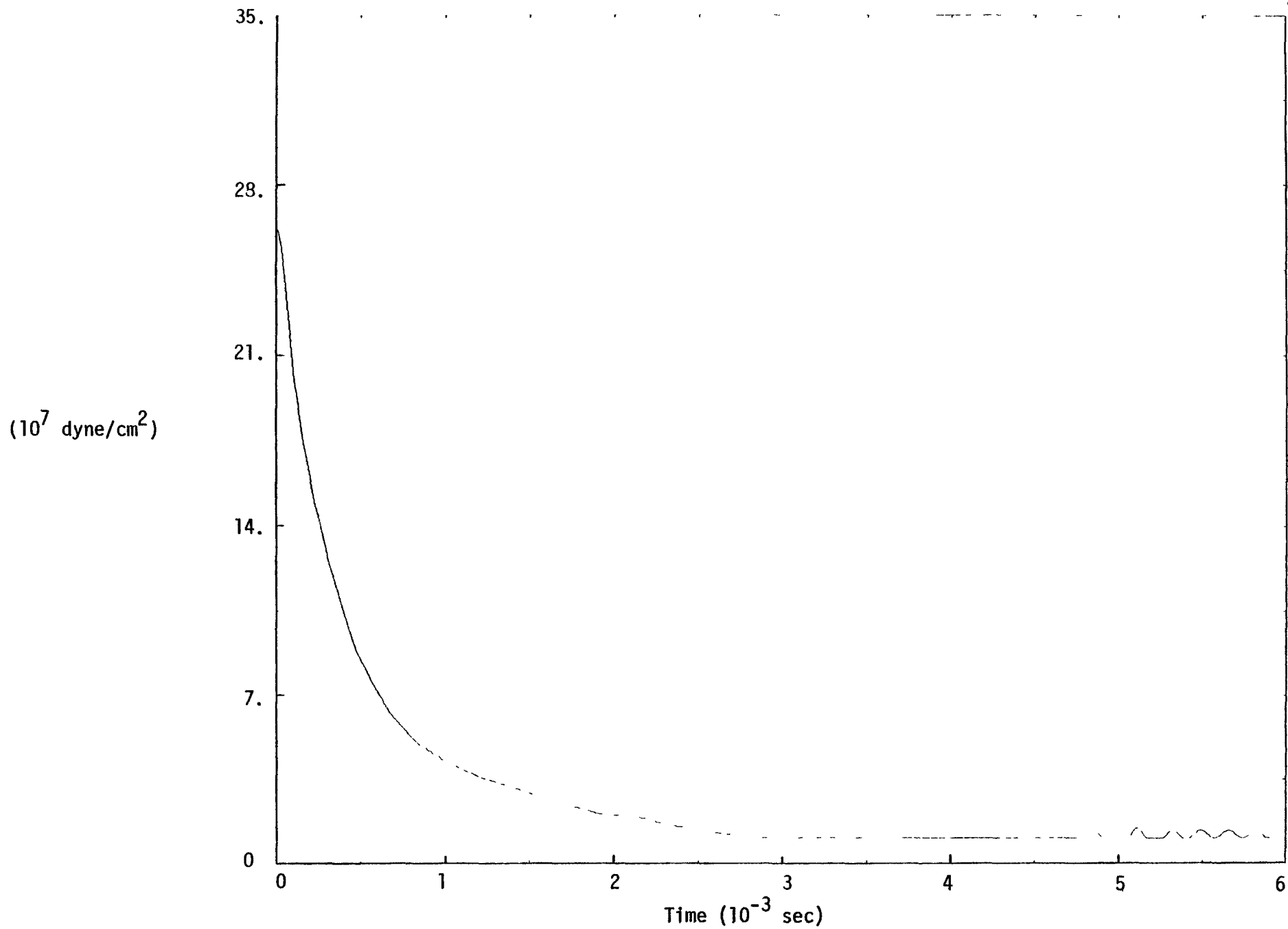


Figure 51 Pressure in Zone (2, 7) (10^7 dyne/cm²) SM-2, 8-17-77

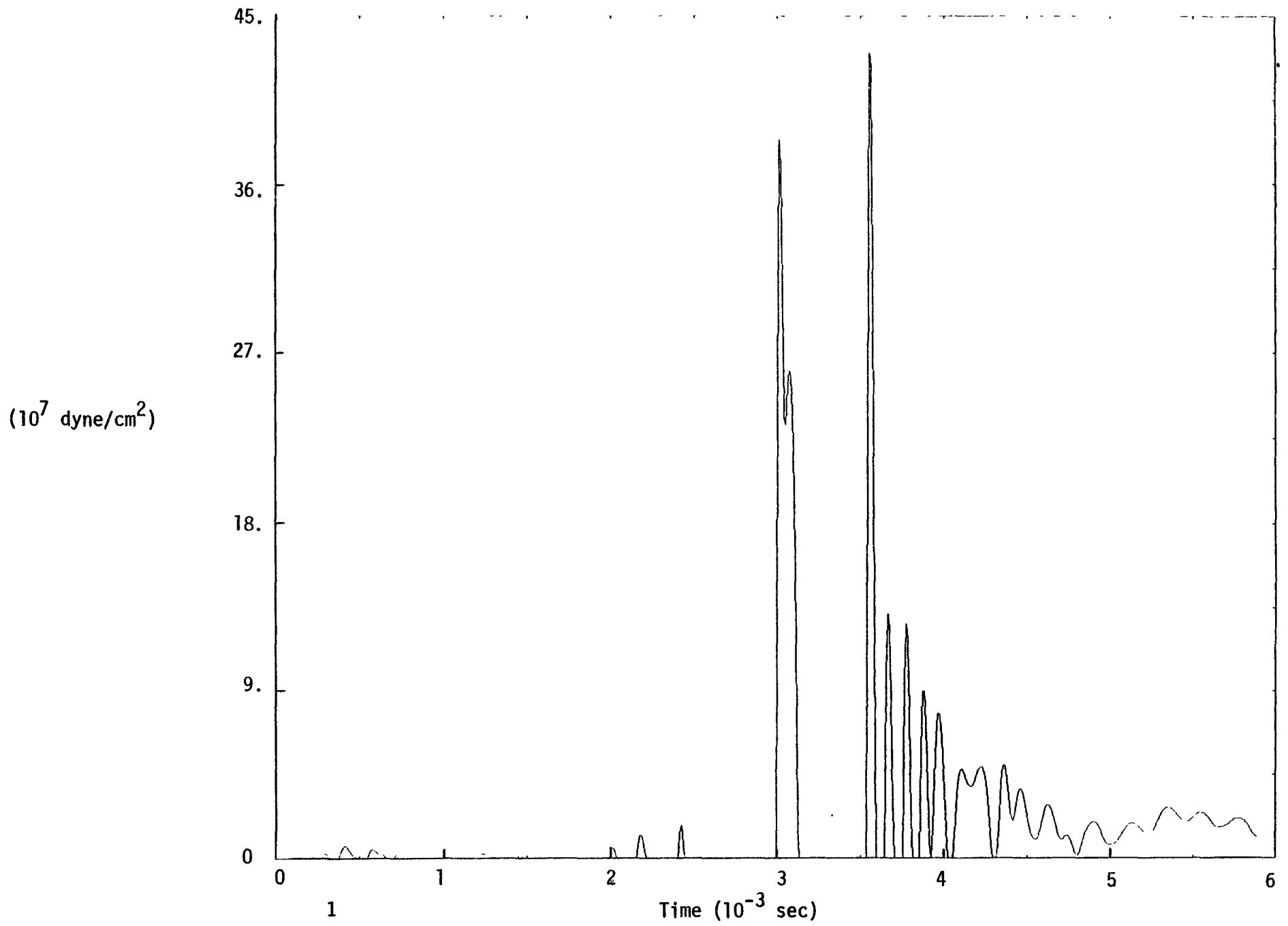


Figure 52 Pressure in Zone (2, 21) (10^7 dyne/cm^2) SM-2, 8-17-77

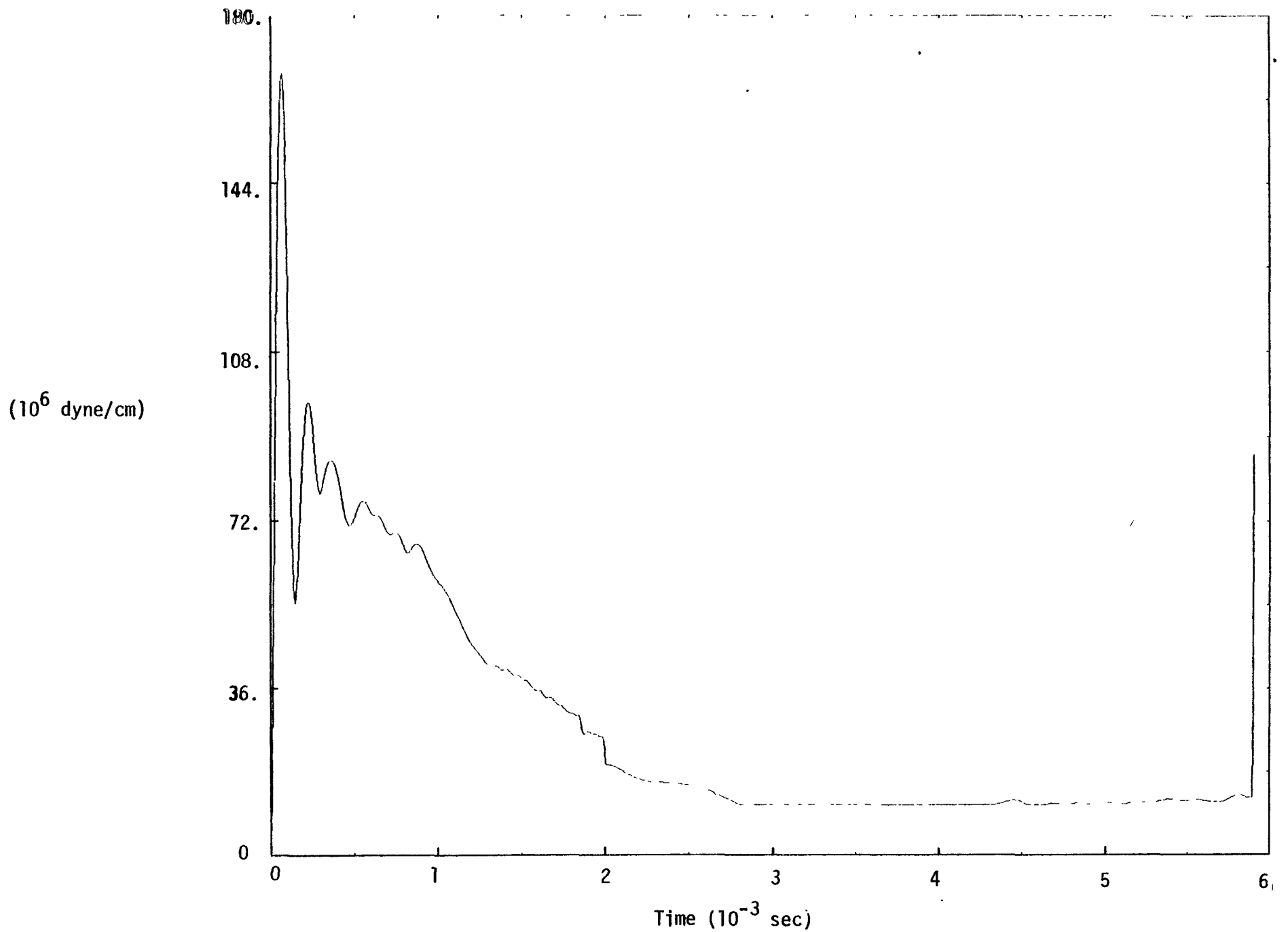


Figure 53 Pressure in Zone (3, 10) (10⁶ dyne/cm) Sm-2, 8-17-77

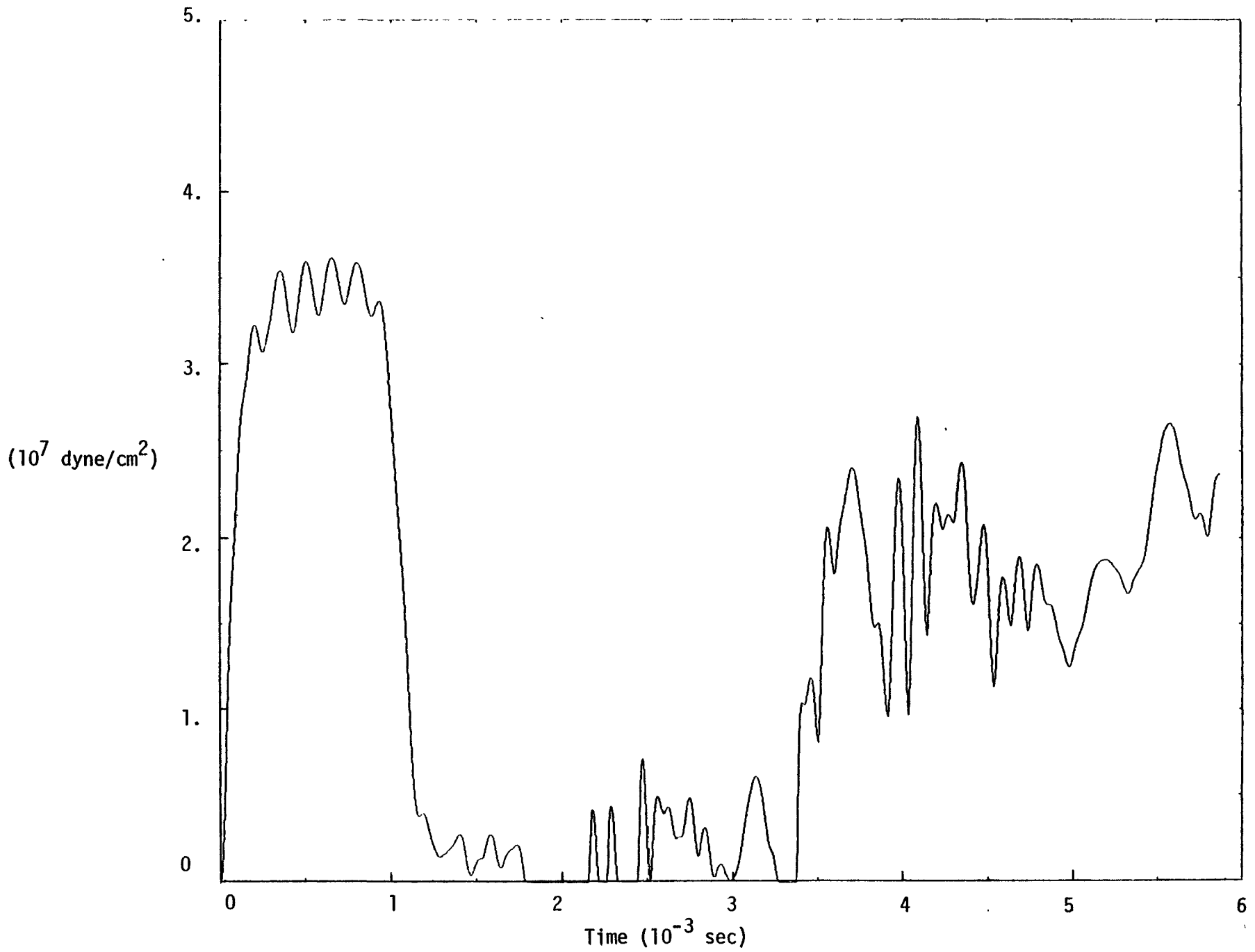


Figure 54 Pressure in Zone (7, 7) (10^7 dyne/cm²) SM-2, 8-17-77

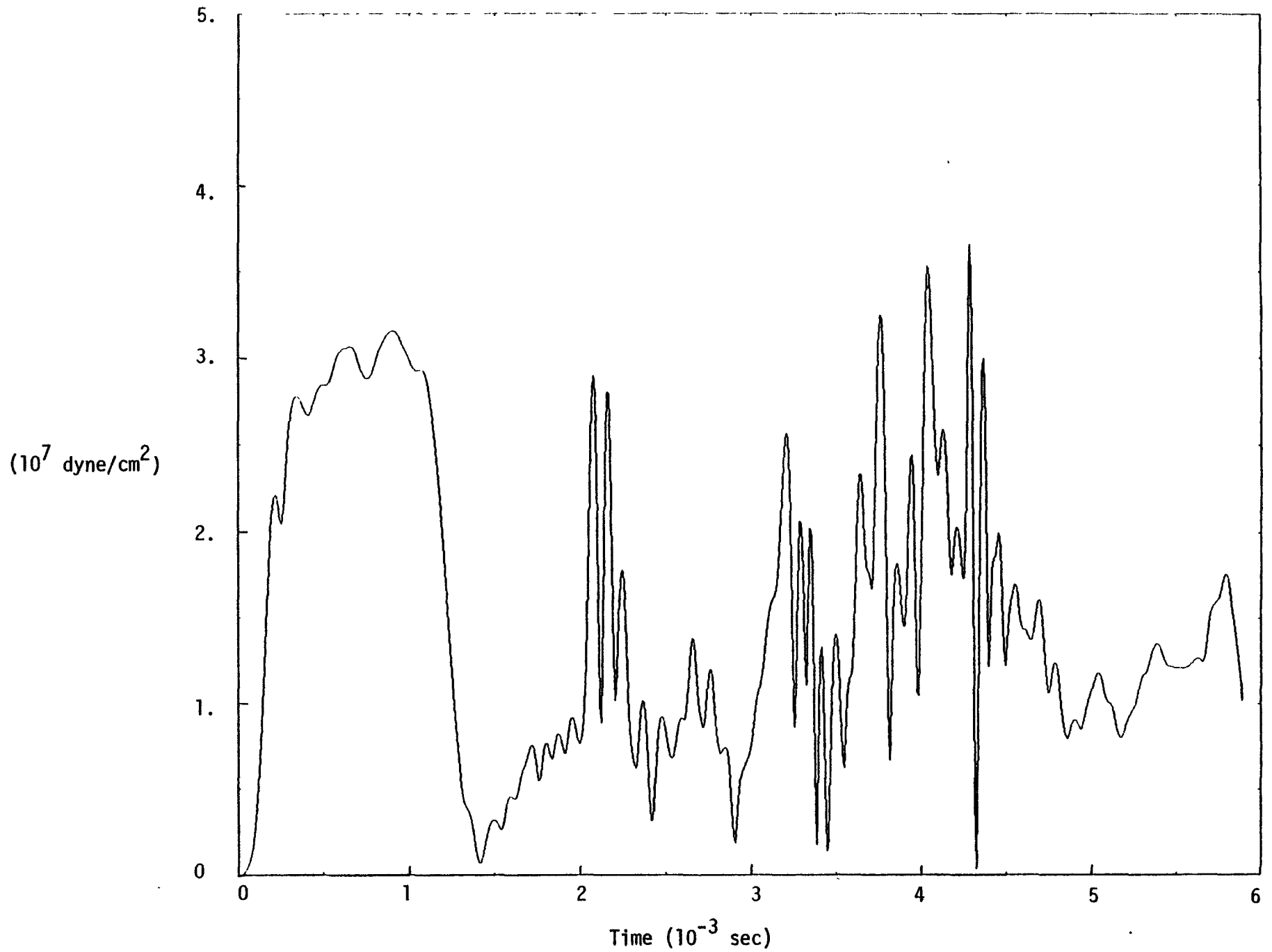


Figure 55 Pressure in Zone (7, 12) (10^7 dyne/cm²) SM-2, 8-17-77

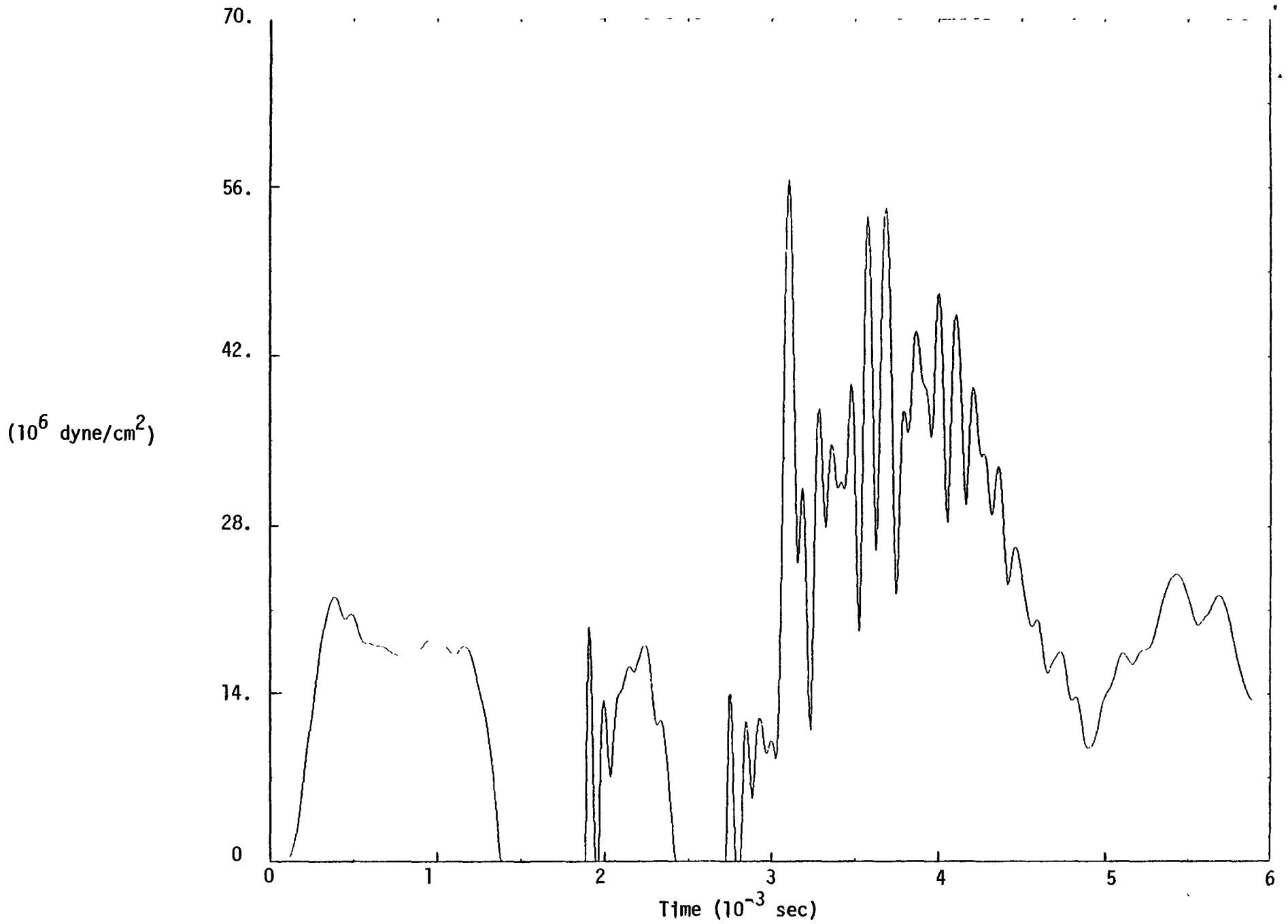


Figure 56 Pressure in Zone (7, 17) (10^6 dyne/cm²) SM-2, 8-17-77

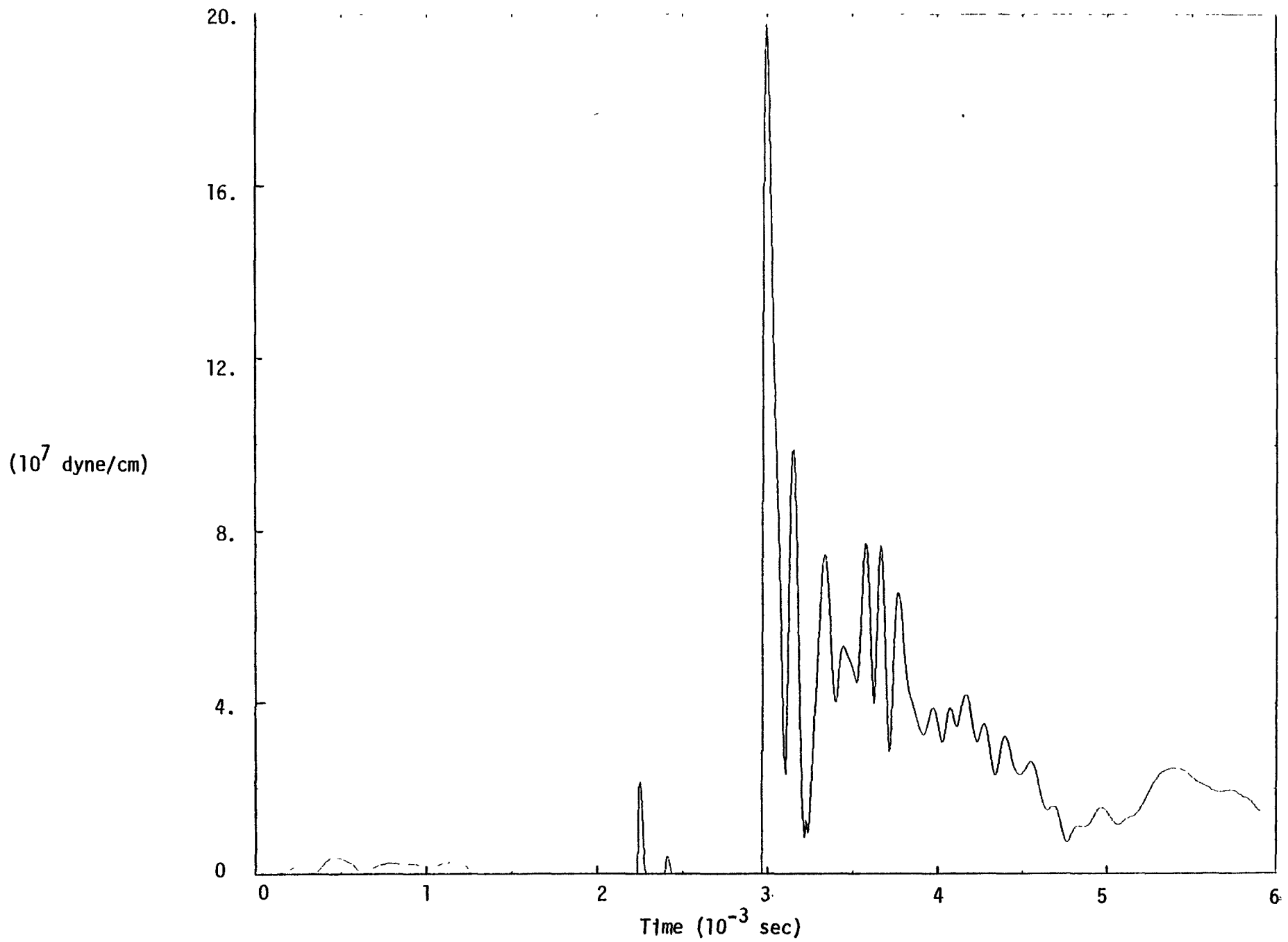


Figure 57 Pressure in Zone (7, 21) (10^7 dyne/cm) SM-2, 8-17-77

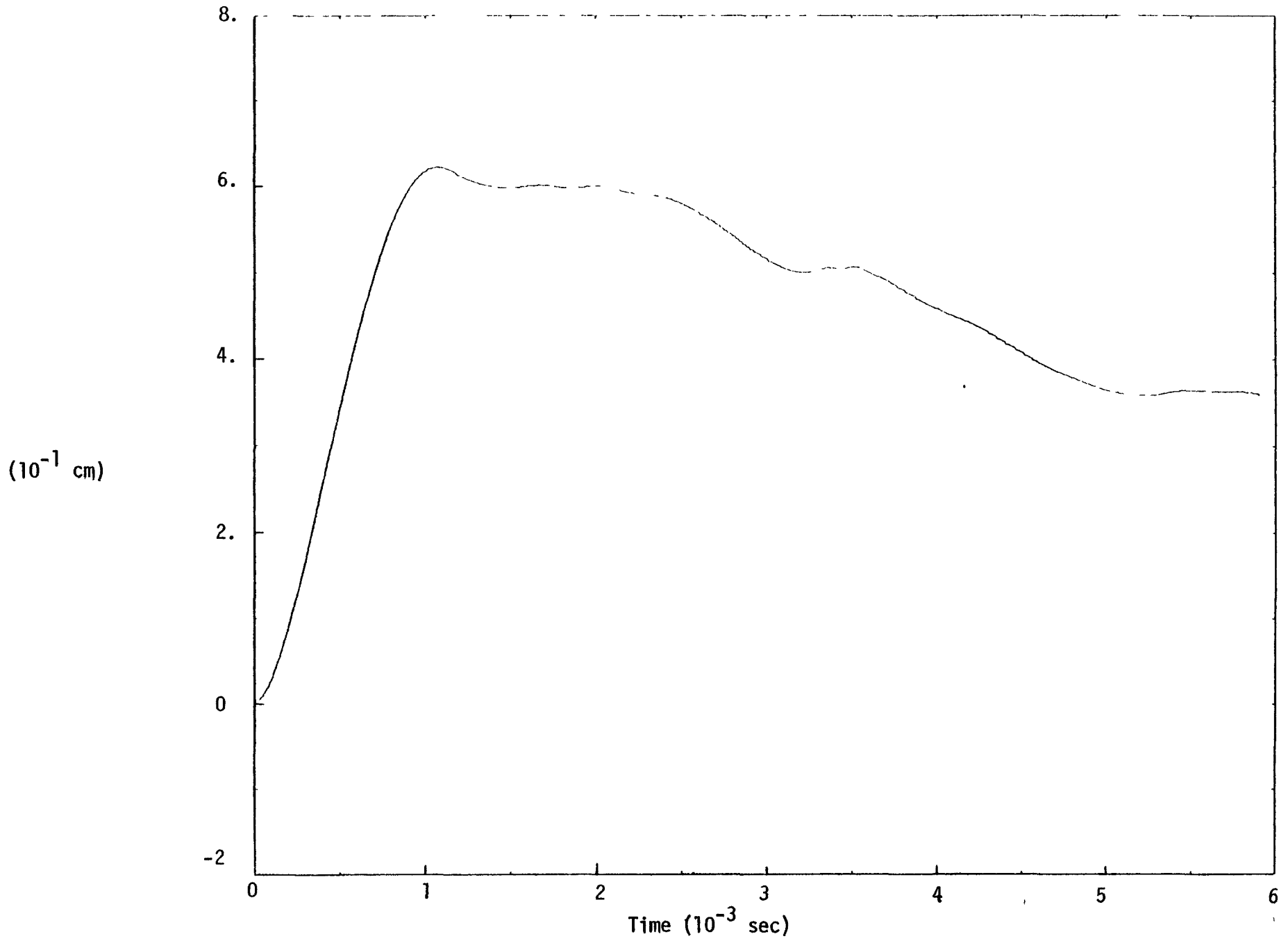


Figure 58 Radial Displacement of Mesh Point (6, 7) (10^{-1} cm) SM-2, 8-17-77

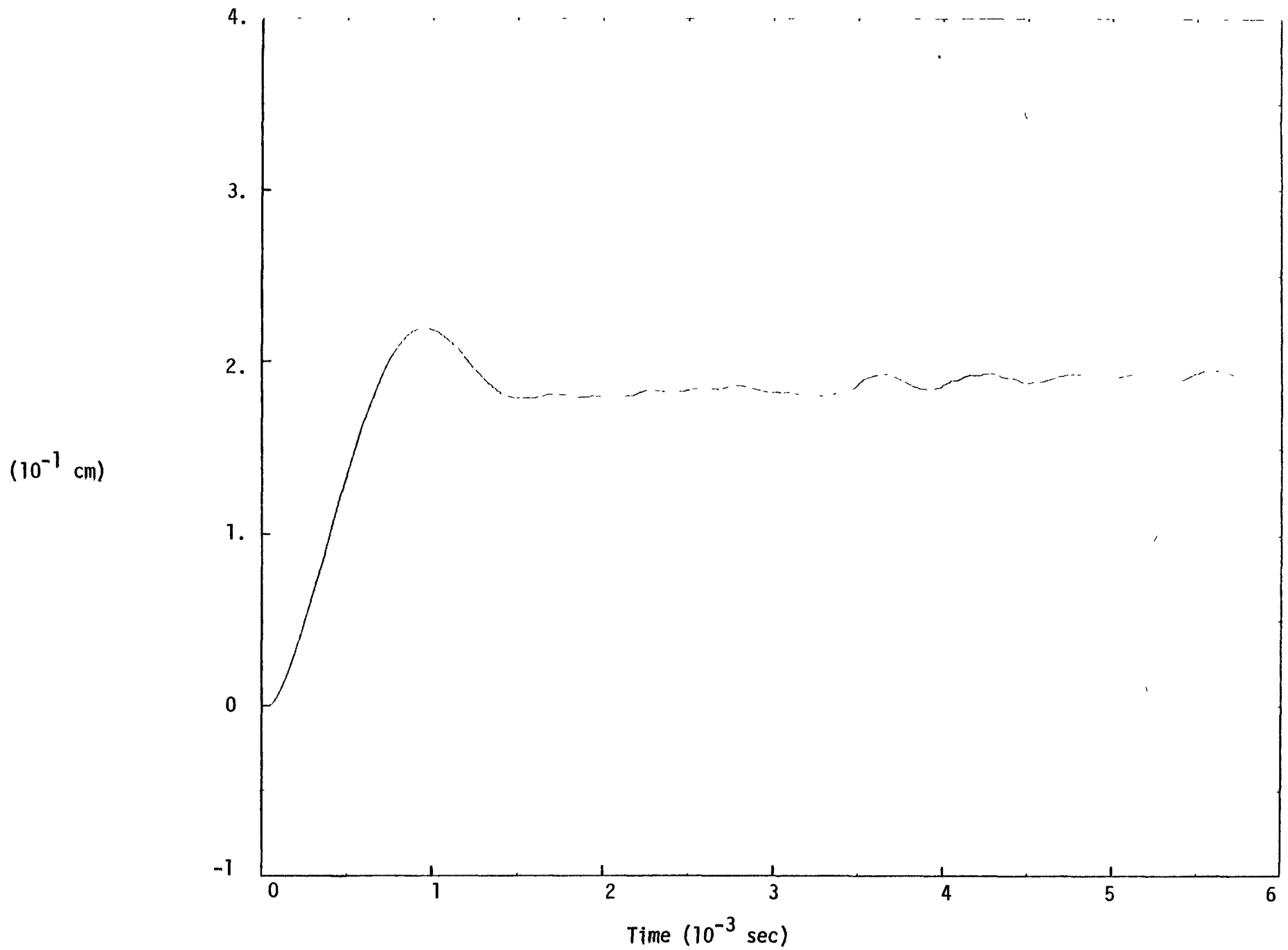
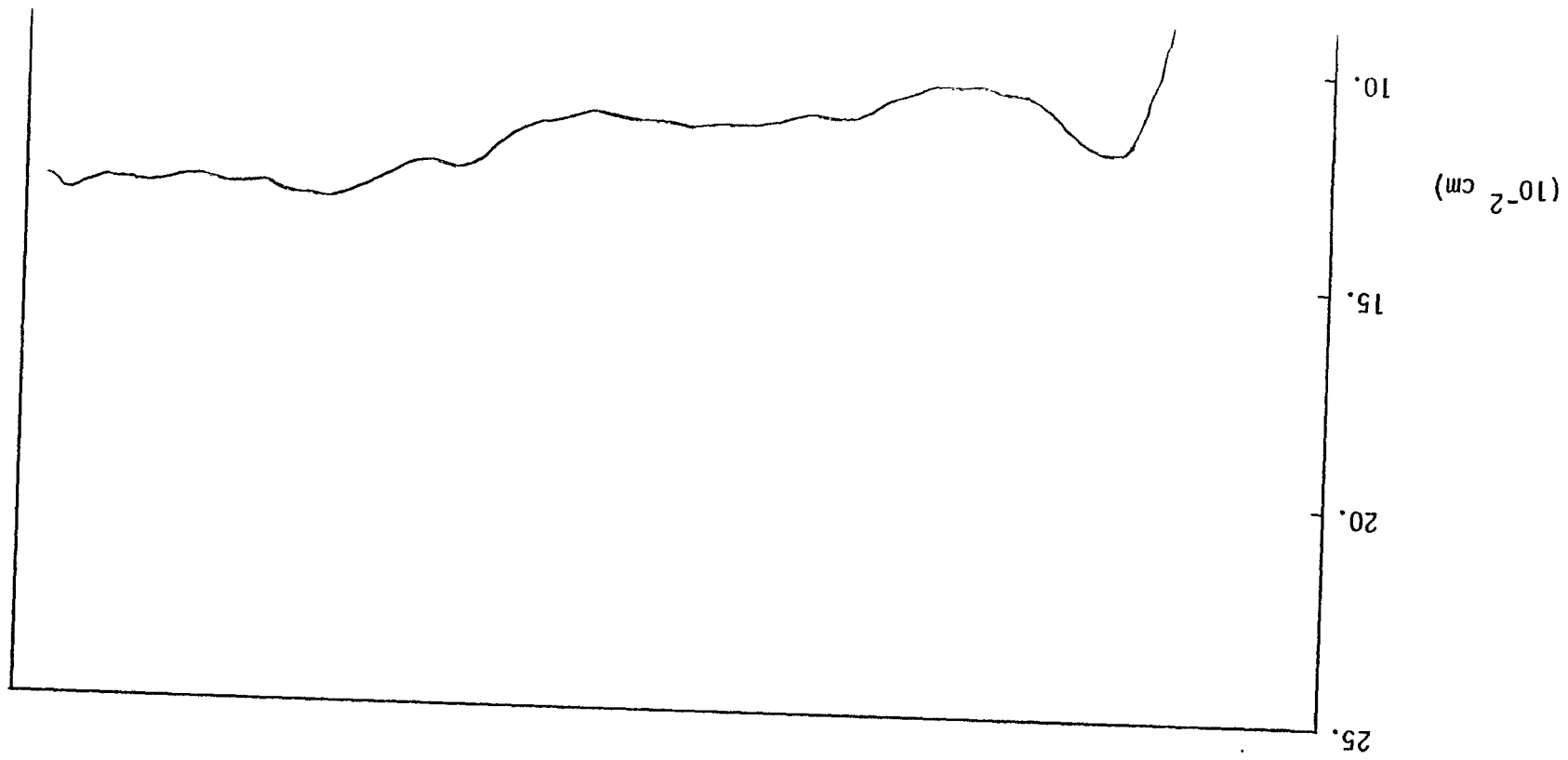


Figure 59 Radial Displacement of Mesh Point (8, 7) (10^{-1} cm) SM-2, 8-17-77



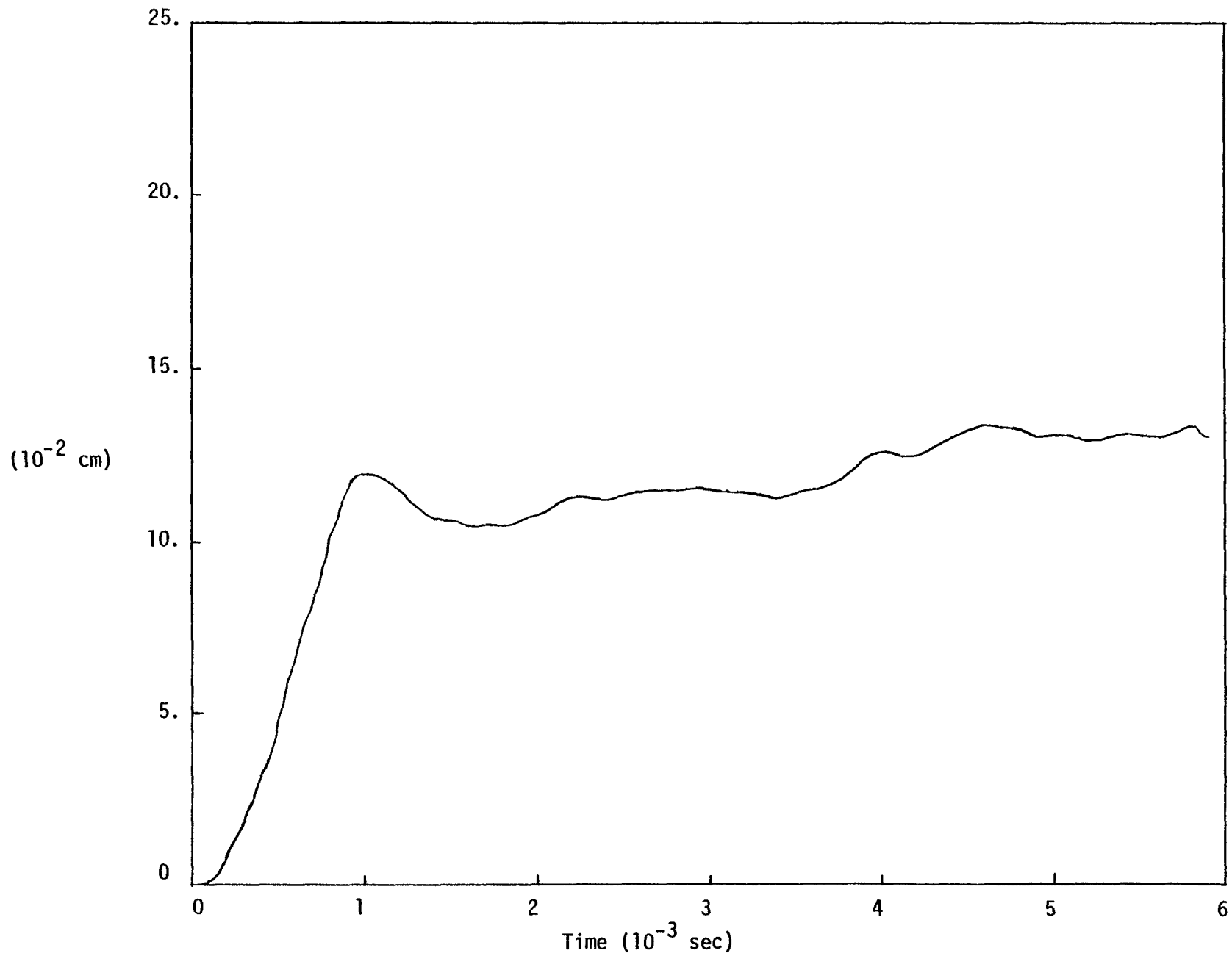


Figure 60 Radial Displacement of Mesh Point (8, 12) (10^{-2} cm) SM-2, 8-17-77

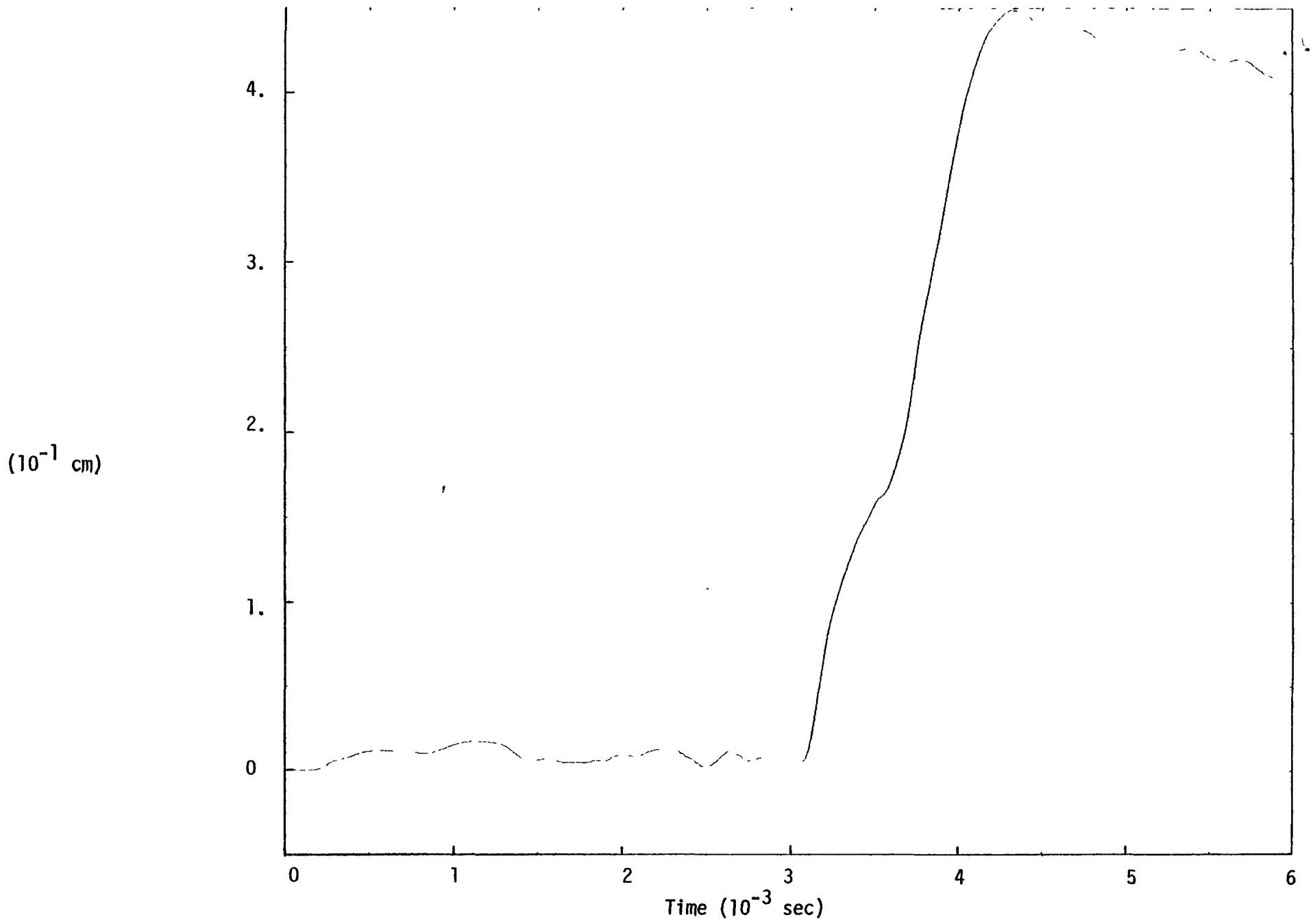


Figure 61 Radial Displacement of Mesh Point (8, 17) (10^{-1} cm) SM-2, 8-17-77

(10^{-1} cm)

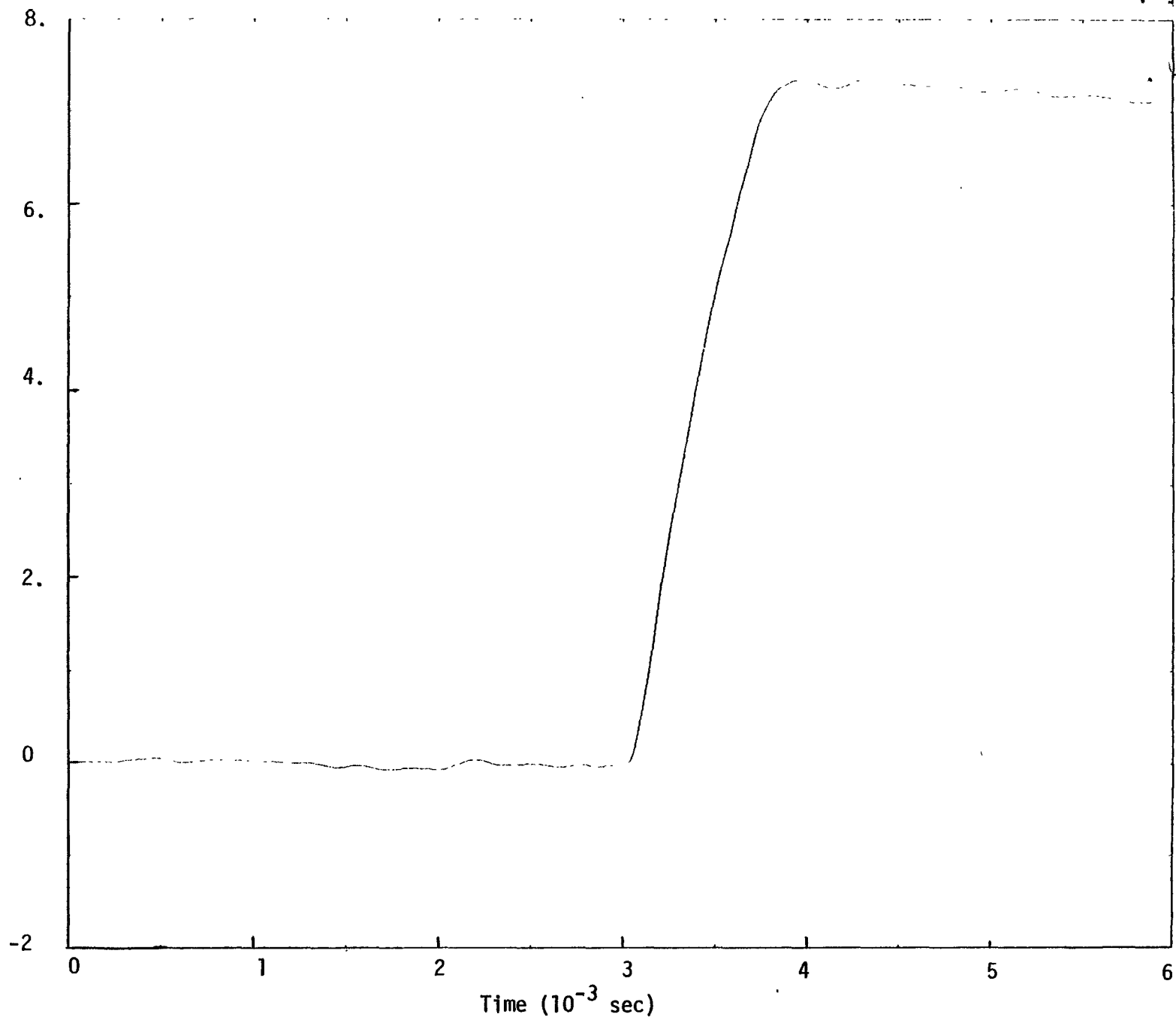


Figure 62 Radial Displacement of Mesh Point (8, 19) (10^{-1} cm) SM-2, 8-17-77

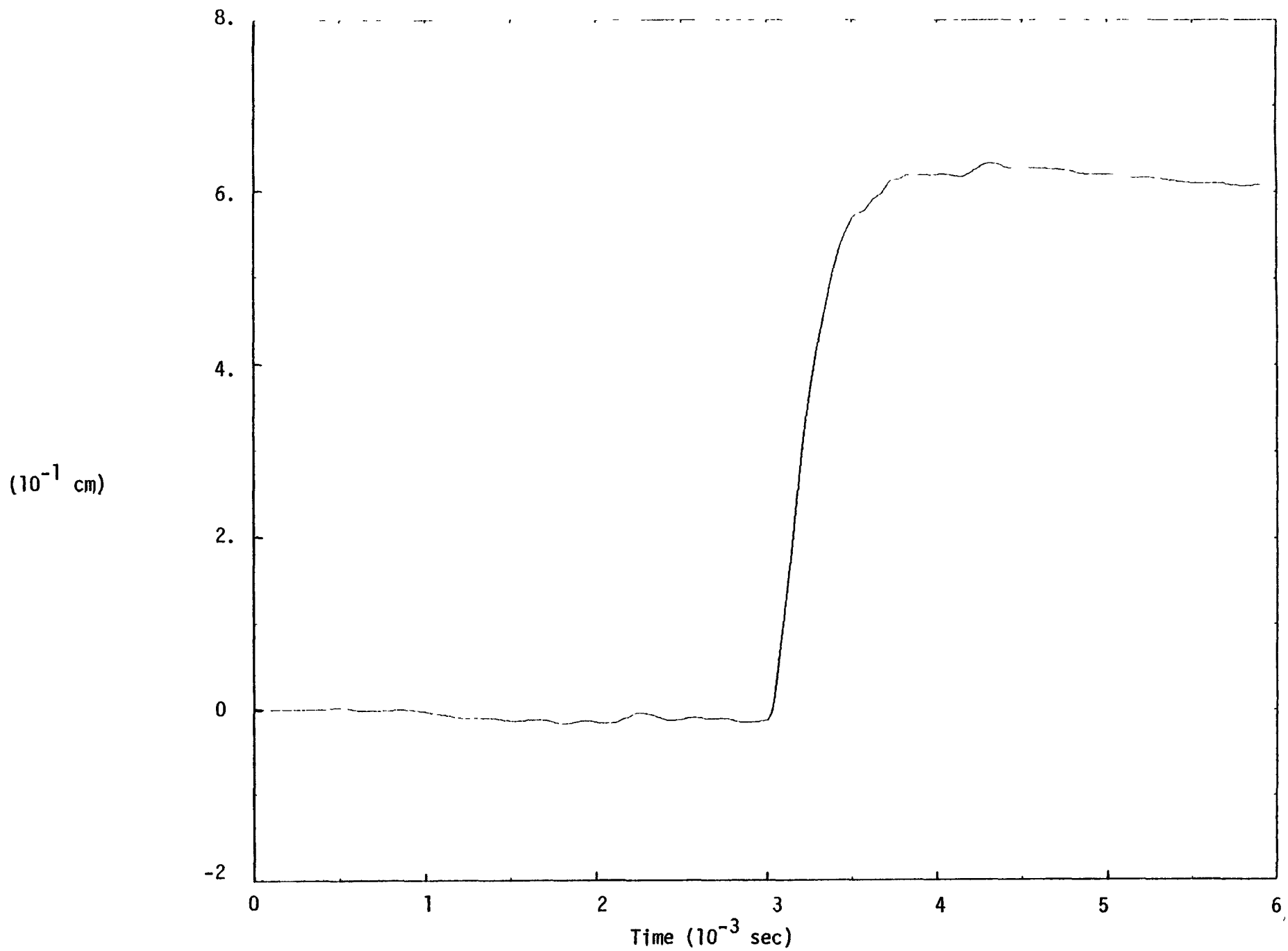


Figure 63 Radial Displacement of Mesh Point (8, 20) (10^{-1} cm) SM-2, 8-17-77

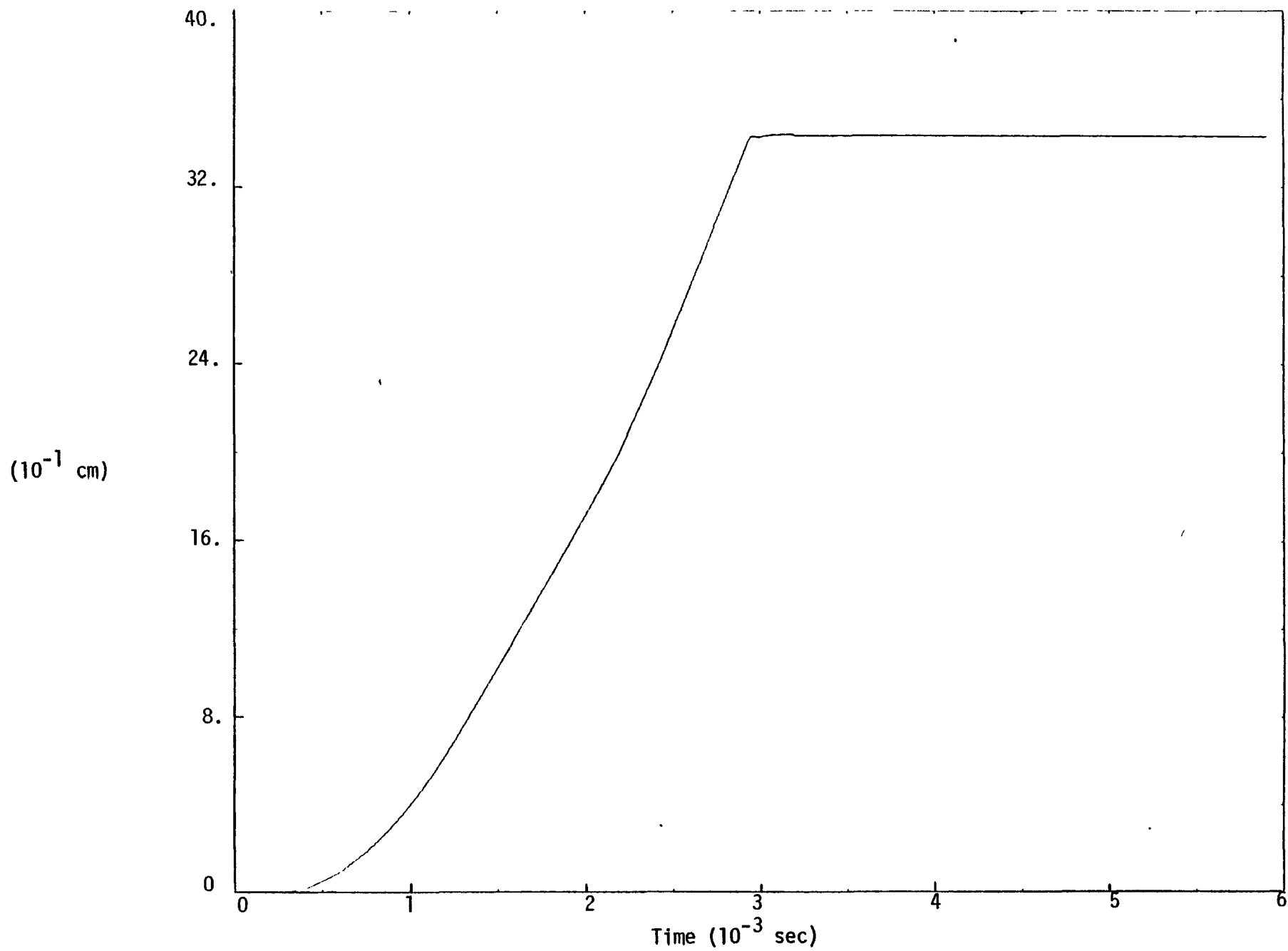


Figure 64 Axial Displacement of Mesh Point (3, 22) (10^{-1} cm) SM-2, 8-17-77

References

1. Letter, D. J. Cagliostro (SRI) to Alan Christie (LRM), "Preliminary Results of 1/20 - Scale CRBR Vessel Experiments SM-2 to SM-4", dated July 5, 1977.
2. Letter XL-596-70167, K. Hikido (GE) to W. M. Jacobi (LRM), "SRI Model SM-2 Pre-Test Analysis Report", dated February 17, 1977.
3. Letter XL-596-70247, K. Hikido (GE) to W. M. Jacobi (LRM), "Additional SRI Model SM-3 Pre-Test Analysis Report", dated April 18, 1977.
4. Letter, D. J. Cagliostro (SRI) to E. C. Chang (GE), "Stress-Strain Curves for Nickel 200", dated May 11, 1977.

Appendix A

REXCO HEP Input Listings

for SM-2 Post-Test Analysis

Table A-1 (Continued)

.4	9	LEAD SHOT AND WATER XBLANKET	0.	0.	6.	0.	0.
8.51		2.8104E9	2.87929	0.	0.	0.	0.
1.2		.2	0.	0.	.1		
2.87929		2.647E10	8.51				
10		STEEL (SHIELD)					
4.		3.2068E116	.9369492	0.	6.	0.	0.
1.2		.2	0.	0.	.1		
6.9369492		1.2827E12	4.				
11		ALUMINUM					
5.		1.3793E11	2.768	0.	6.		
1.2		.2	0.	0.	.1		
2.768		6.8966E11	5.				
7	5	12.525	8.73	0.	99823	0.	0.
7	6	12.525	12.37	0.	99823	0.	0.
7	7	12.525	16.15	0.	99823	0.	0.
7	8	12.525	19.93	0.	99823	0.	0.
7	9	12.525	23.71	0.	99823	0.	0.
7	10	12.525	26.97	0.	99823	0.	0.
7	11	12.525	30.24	0.	99823	0.	0.
7	12	12.525	33.52	0.	99823	0.	0.
7	13	12.525	36.22	0.	99823	0.	0.
7	14	12.525	38.91	0.	99823	0.	0.
7	15	12.525	41.61	0.	99823	0.	0.
7	16	12.525	44.30	0.	99823	0.	0.
8	5	15.4305	9.39	0.	99823	0.	0.
8	6	15.4305	13.70	0.	99823	0.	0.
8	7	15.4305	18.00	0.	99823	0.	0.
8	8	15.4305	22.31	0.	99823	0.	0.
8	9	15.4305	26.62	0.	99823	0.	0.
8	10	15.4305	29.88	0.	99823	0.	0.
8	11	15.4305	33.15	0.	99823	0.	0.
8	12	15.4305	36.43	0.	99823	0.	0.
8	13	15.4305	38.54	0.	99823	0.	0.
8	14	15.4305	40.66	0.	99823	0.	0.
8	15	15.4305	42.77	0.	99823	0.	0.
8	16	15.4305	44.89	0.	99823	0.	0.
1		7	0.70622.31		0.	2	7
0.		2	4.12E11	.01978	18.	8	1
1		8	66.7134	8	1.22	1	8
2		2	1	50	.00	0.30266	8.7567
8		2	2	01	.00	0.254	0.
6		4					
10		0.	0.	6	13	0.	6
6	12	0.	6	14	0.	6	15
6	18	0.	6	19	0.	6	21
0		0	0.	6	20	0.	0.
8	8861	.36	5	4	.01	1.E09	1.
8	2758F08	.00038	1.9655E09	.04	3.1379E09	.11	4.1034E09
8	8861	.36	5	4	.01	1.E09	1.
9	3103E08	.000428	2.3793E09	.05	3.6551E09	.11	5.E09
0		0					.2

Table A-2

SRI CRAR MODEL POST-TEST ANALYSIS, SM-2, 8-17-77

6	20	2	2	2	.000	1.E-6	1.E-6
500	1000	1	100	50	1	1	1 0000
50							
	1		2		3		4
8	7		8		9		11
	14		15		16		15
2	4	1	2	7	1	3	7
3	11	1	7	7	1	7	17
7	20	1	7	21	1	6	6
6	9	2	6	10	2	6	7
8	18	2	8	19	2	8	21
3	22	3	8	4	3	8	22
	0.	2.425	4.85		7.235	9.62025	12.525
0.		2.54	5.08		8.064	11.048576	14.3
24.0665		27.34	30.62		33.89	37.17	40.45
50.27		53.55	56.83		60.06	63.2844	67.0
7							
2	7	2	21	2			
2	3	6	9	1			
2	7	2	3	3			
2	3	10	10	9			
4	5	4	11	10			
2	3	4	5	11			
.7	8	5	16	0	0.	0.	
9							
1	AIR (CORE VOLUME = 962. CM**3, 19.7 G 90/10 PETN-MICROBALLON MIX)						
1.4		.02048	5.103E09	2.625E08	7.	0.	1.
1.2	.2	0.	0.	.1			
.02048		0.		20.			
.2625	1.	.225	1.02079	.200	1.03950	.175	1.07796
.150	1.14033	.125	1.23909	.100	1.37422	.0875	1.45738
.075	1.58212	.0625	1.72765	.050	1.93555	.0362	2.24740
.030	2.45530	.025	2.66320	.021	2.87110	.019	3.07900
.016	3.28690	.015	3.49480	.013	3.70270	.011	3.91060
2	WATER						
6.915	2.8626E09	.99823	0.	0.	6.	0.	0.
1.2	.2	0.	0.	.1			
.99823	0.	1.9895E10	6.915				
3	STEEL 516GR55 E/P						
4.	3.2068E11	7.856208	0.	0.	6.	.3	0.
3.7793E09	7.6965E11	1.0141E10	1.	0.			
1.2	.2	0.	0.	.1			
7.856208	0.	1.2827E12	4.				
4	STEEL (FLUID)						
4.	3.2068E11	7.856208	0.	0.	6.	0.	0.
1.2	.2	0.	0.	.1			
7.856208	0.	1.2827E12	4.				
6	LEAD (SHIELD)						
6.	.793E06	11.34	0.	0.	6.	0.	0.
1.2	.2	0.	0.	.1			
11.34	0.	4.76E06	6.				
8	AIR (COVER)						
1.4			0.	0.	4.	0.	0.
1.2	.2	0.	0.	.1			

