SHOCK WAVE RESPONSE OF YTTERBIUM GAUGES UPTO 20 KBARS*

Satish C. Gupta, M. R. Williams, and Y. M. Gupta

Shock Dynamics Laboratory
Washington State University
Department of Physics
Pullman, Washington 99164-2814

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INTRODUCTION

In this report we have compiled the results of our dynamic loading and unloading experiments on ytterbium foils. The Yb foils were oriented parallel and perpendicular to the shock front. These dynamic experiments have served as the basis of our analytic work on ytterbium. These results provide information for the Yb foils without the complications introduced by using a gauge package. We have taken special care to characterize the foils and used an experimental configuration that can be easily analyzed. The results presented here will be of interest to others who may wish to analyze these data or to those workers who may want to know the experimental results in detail to compare with their own results. This report may be viewed as an Appendix to our paper to be published in the Journal of Applied Physics (1).

The information presented here is intended to be complete as far as the experimental assembly and results are concerned. No attempt is made to analyze the data in this report.

SUMMARY OF EXPERIMENTS AND RESULTS

The gauges were cut into a four terminal configurations from 50 μm (nominal thickness) ytterbium sheets (2) and embedded in a PMMA matrix (Fig. 1). The embedding was done by machining closely matching grooves in the PMMA, gluing the gauges into the grooves using Hysol 815 adhesive (3), lapping the surfaces so that the gauges were flushed with the PMMA surfaces, and then gluing the other PMMA plates on these surfaces. The embedded gauges had two orientaions--one parallel to the shock front and the other perpendicular to the shock front.

The experiments were performed using the 2 1/2 inch gas gun at our laboratory. PMMA was used as the impactor material and the impactor thickness was chosen to permit complete unloading of the longitudinal stress in the matrix at the gauge site. The duration of the square wave stress pulses were in the 1.5 - 2.0 μs range. The longitudinal stresses in the targets were obtained from experimental stress-particle velocity data for PMMA (4).

The gauge signal recording system used was similar to that used by Keough (5) (Fig. 2A). A constant current power supply (Pulsar Model 301) was used. Figure 2B shows the recording system for measuring low resistance change signals. This circuit generates higher current through the gauge, resulting in higher voltage signals. We used this system for the shots at 1.25 and 1.85 kbar.

A representative record showing voltage developed across the gauge is given in Fig. 3a. This record can be reduced to the one showing gauge resistance change as a function of time (Fig. 3b).

For each gauge in all the shots a dual beam oscilloscope was used to register the gauge records--one beam registered the voltage versus time profile and the other registered the voltage change (due to stress) as a function of time. In the Appendix, we have given details for all the shock experiments and experimentally measured profiles.

From the resistance change profiles we determined the peak resistance change ratio $(\delta R)/(R_o)$ and the residual resistance change ratio $(\delta R)/(R_o)$ corresponding to a given peak longitudinal stress. This procedure is used for both longitudinally and laterally oriented gauges. The experimental data are summarized in Table I. The plots of $(\delta R)/(R_o)$ as a function of longitudinal stress for both orientations show that $(\delta R)/(R_o)\big|_{peak}$ values increase parabolically with peak longitudinal matrix stress above 2 kbar; and, as expected, the $(\delta R)/(R_o)\big|_{peak}$ values for longitudinal gauges lie higher than those for lateral gauges.

But, below 2 kbar the resistance change is higher for lateral gauges, although the lateral matrix stress is lower than the longitudinal stress (Fig. 4). This result is contrary to the empirical usage of the gauges, and confirms theoretical prediction (6).

Initially, the residual resistance change for both orientations increases with the peak loading stresses (Fig. 5). These resistance values however, saturate at about 8.5 kbar for longitudinal gauges and at about 11.6 kbar for the lateral gauge.

Acknowledgements

We thank B. Johnson for his assistance in preparing this report.

REFERNCES

1. Gupta, S. C. and Gupta, Y. M. (to be published).

2. These ytterbium sheets were supplied by Research Chemical Corporation, Phoenix, Arizona.

3. The mechanical impedance of Hysol 815 is very close to that of PMMA.

4. Barker, L. M. and Hollanbach, R. E., J. Appl. Physics 41, 4208 (1970).

5. Keough, D. D., Stanford Reserarch Institute Report, AD 839983 (1968).

6. Gupta, Y. M., J. Appl. Physics (Oct. 1983).

TABLE I SUMMARY OF EXPERIMENTAL DATA

SHOT NO.	PEAK STRESS	Longitudinal Gauge		Lateral Gauge	
		$\delta R/R_o\|_{peak}$	$\delta R/R_o\|_{residual}$	$\delta R/R_o\|_{peak}$	$\delta R/R_o\|_{residual}$
82504	5.4	0.37			
82506	6.5	0.53	0.09		
83505	11.5	1.11	0.15	0.66	0.23
83510	8.4	0.74	0.15		
83511	1.85	0.092	0.033	0.098	0.023
83512	1.25	0.042	0.010	0.072	0.014
83521	3.6	0.23	0.060	0.17	0.045
83522	15.1	1.62	0.15	1.06	0.22
83525	7.4	0.62	0.12	0.38	0.11
83526	18.4	2.15	1.31[a]	1.53	0.78[a]

[a]In this experiment fused silica impactor was used; $\delta R/R_o|_{res.}$ values for this experiment correspond to the first unloading step.

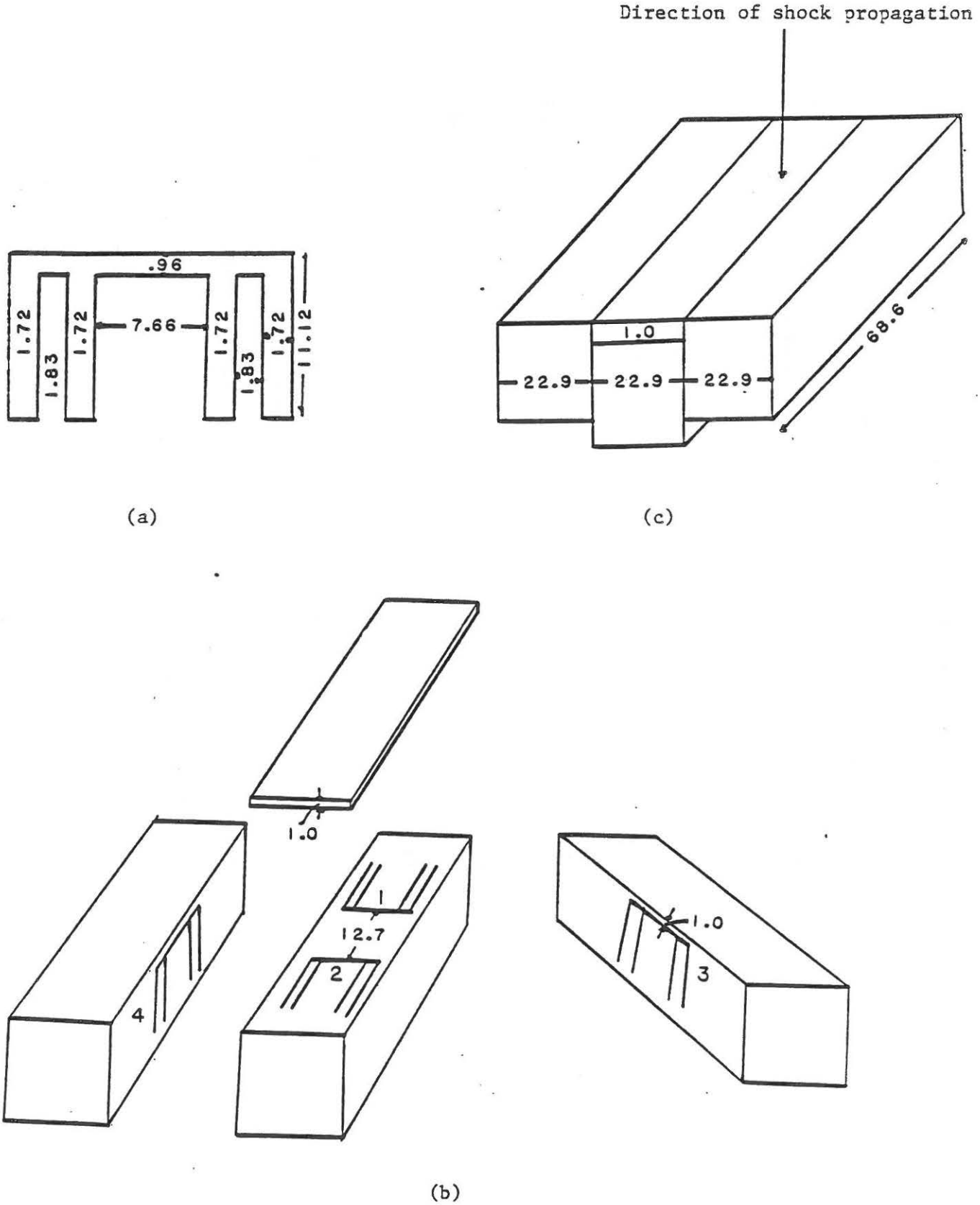
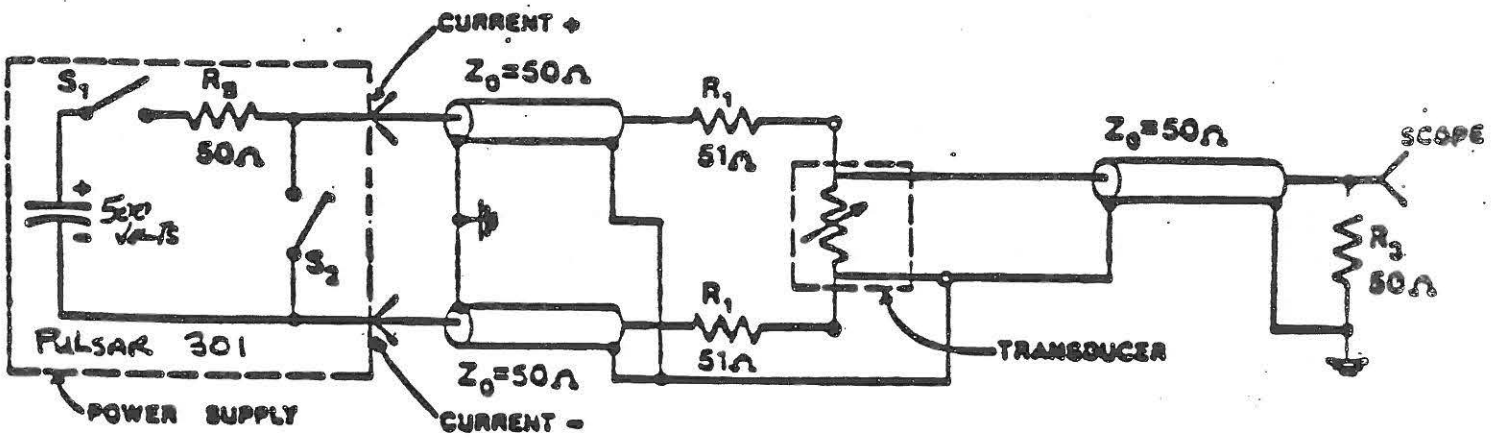


Fig. 1. Schematic view of the PMMA matrix containing the gauges.

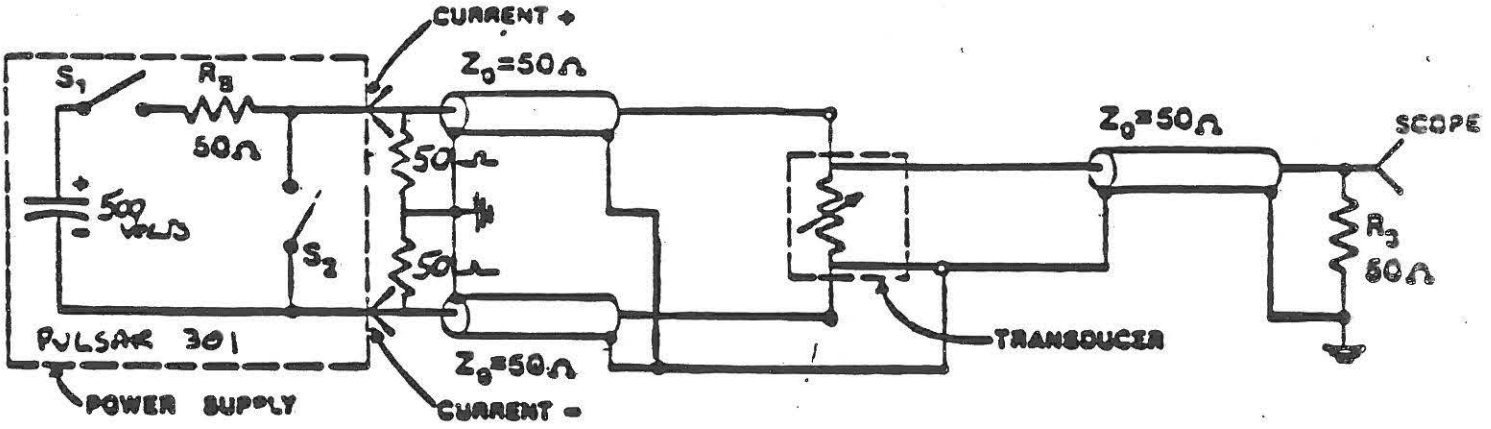
(a) dimensions of the typical ytterbium gauge.

(b) for longitudinal gauges, labeled 1 and 2, the gauge surface is parallal to shock front; for lateral gauges, labeled 3 and 4, the gauge surface is perpendicular to the shock front.

(c) final PMMA assembly.

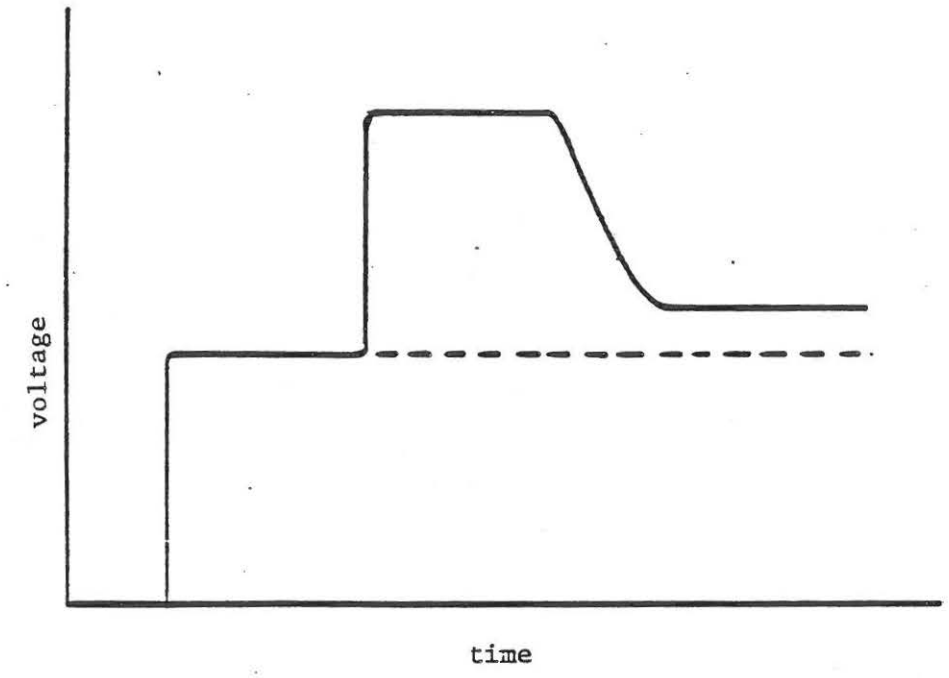


(a)

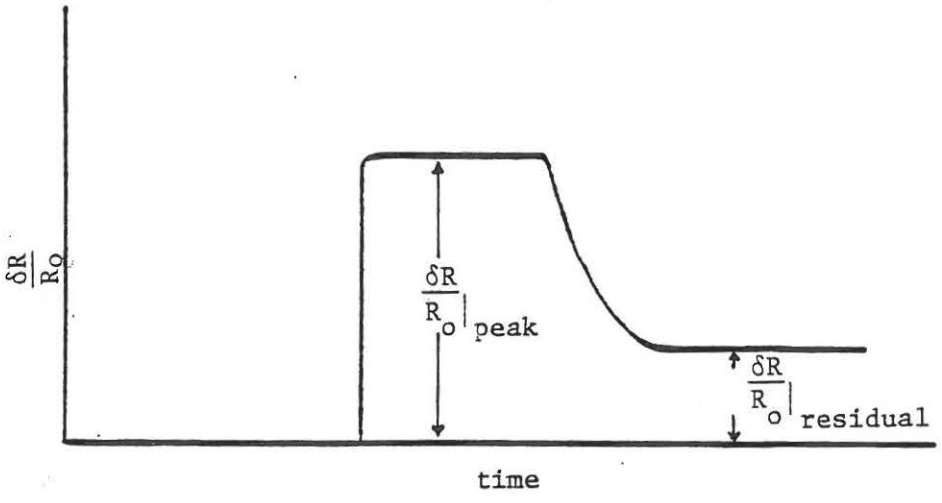


(b)

Fig. 2. Electrical circuit for gauge signal recording system.



(a)



(b)

Fig. 3. (a) A representative gauge voltage versus time record.
(b) The corresponding resistance change ratio versus time record.

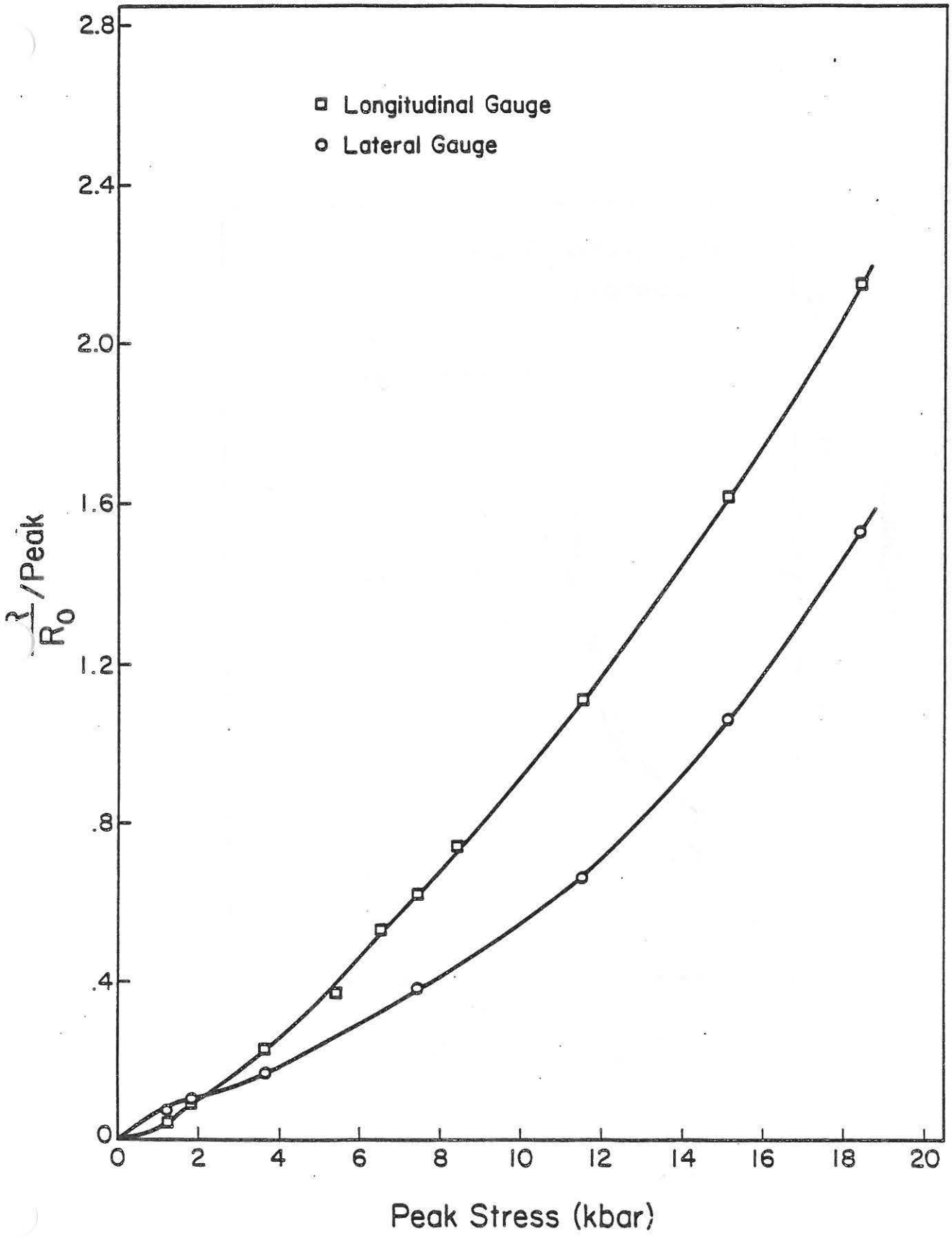


Fig. 4. $\frac{\delta R}{R_o}\Big|_{peak}$ versus peak longitudinal stress.

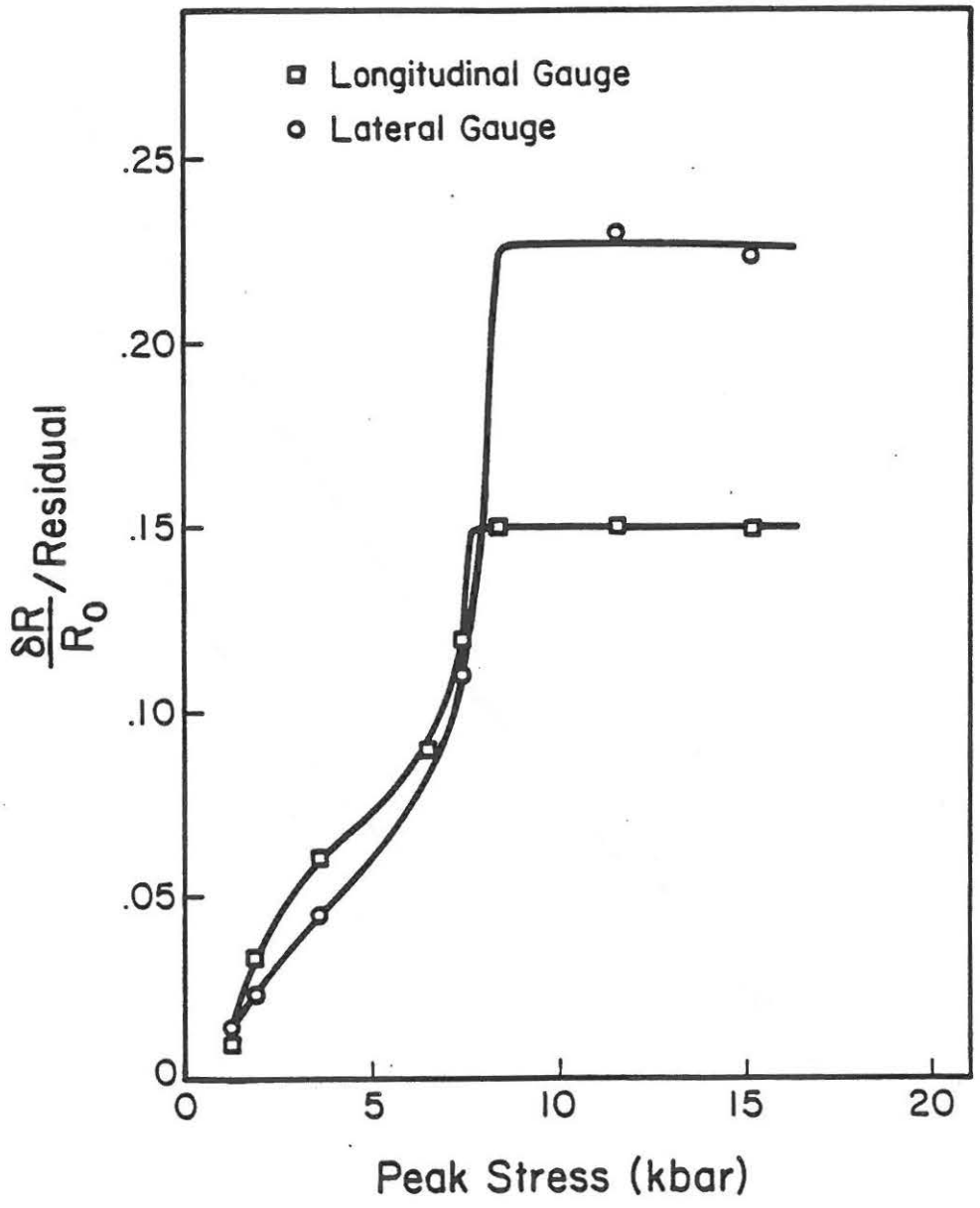


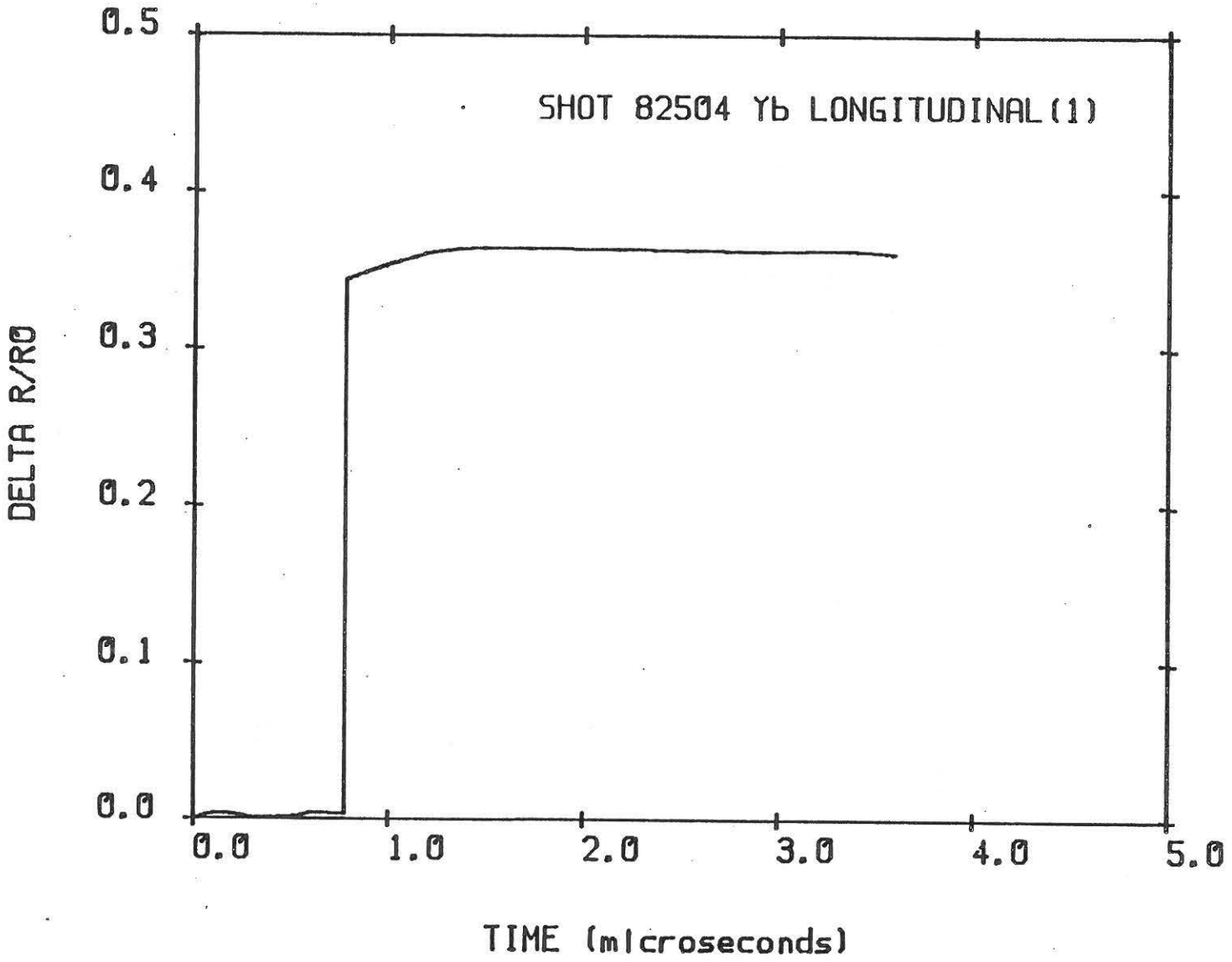
Fig. 5. $\left.\frac{\delta R}{R_o}\right|_{residual}$ versus peak longitudinal stress.

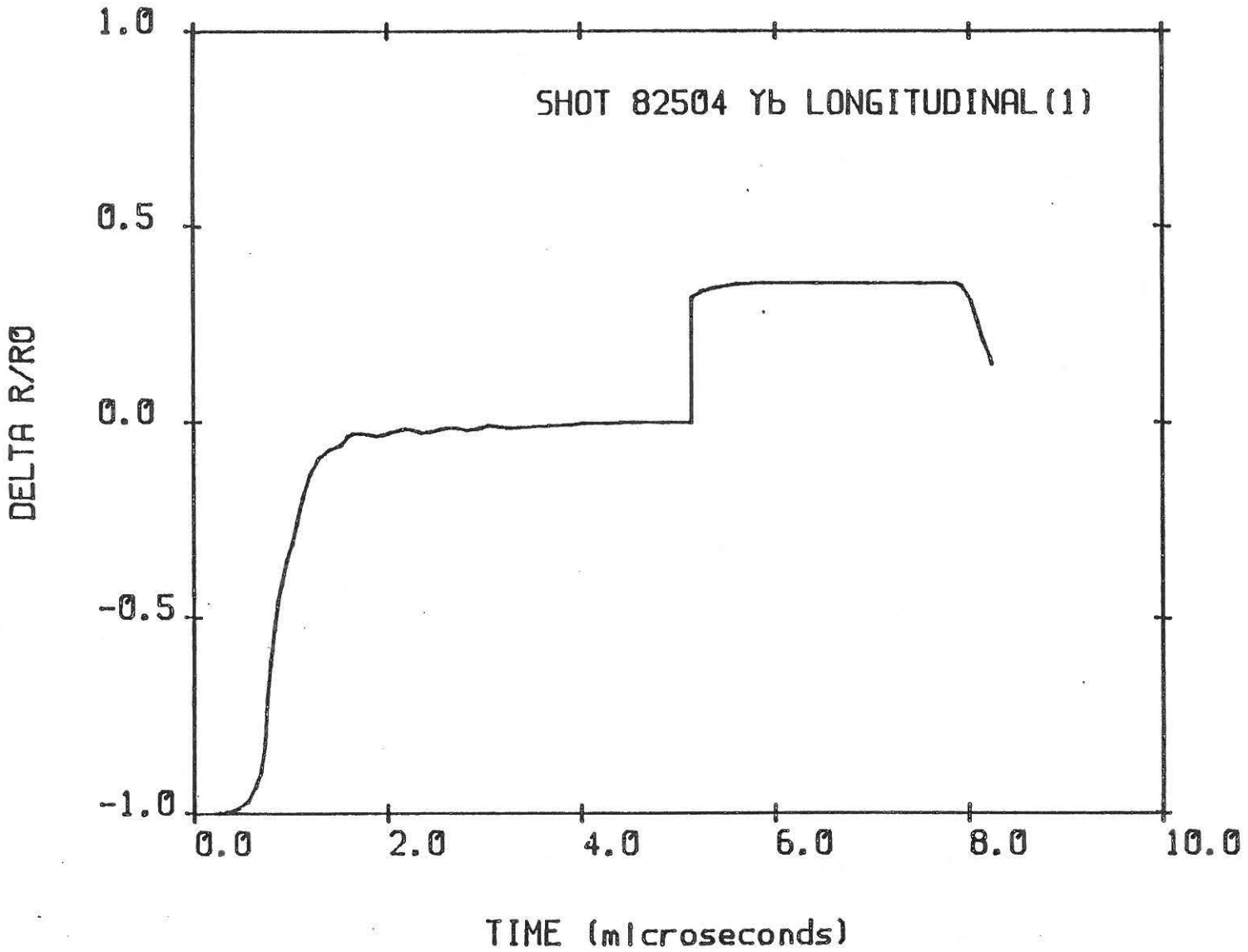
APPENDIX

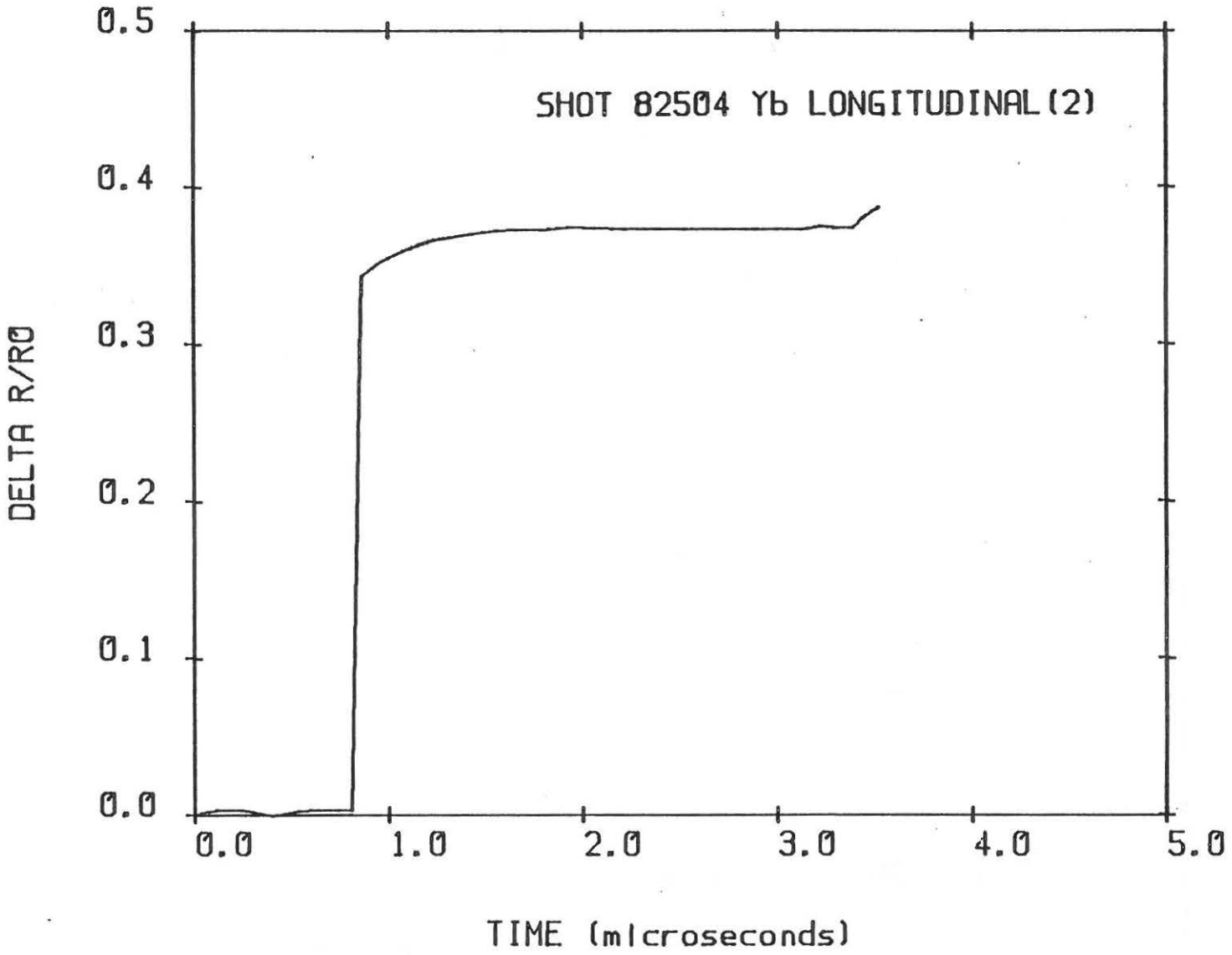
In this appendix we give the details of each experiment and the experimentally measured profiles.

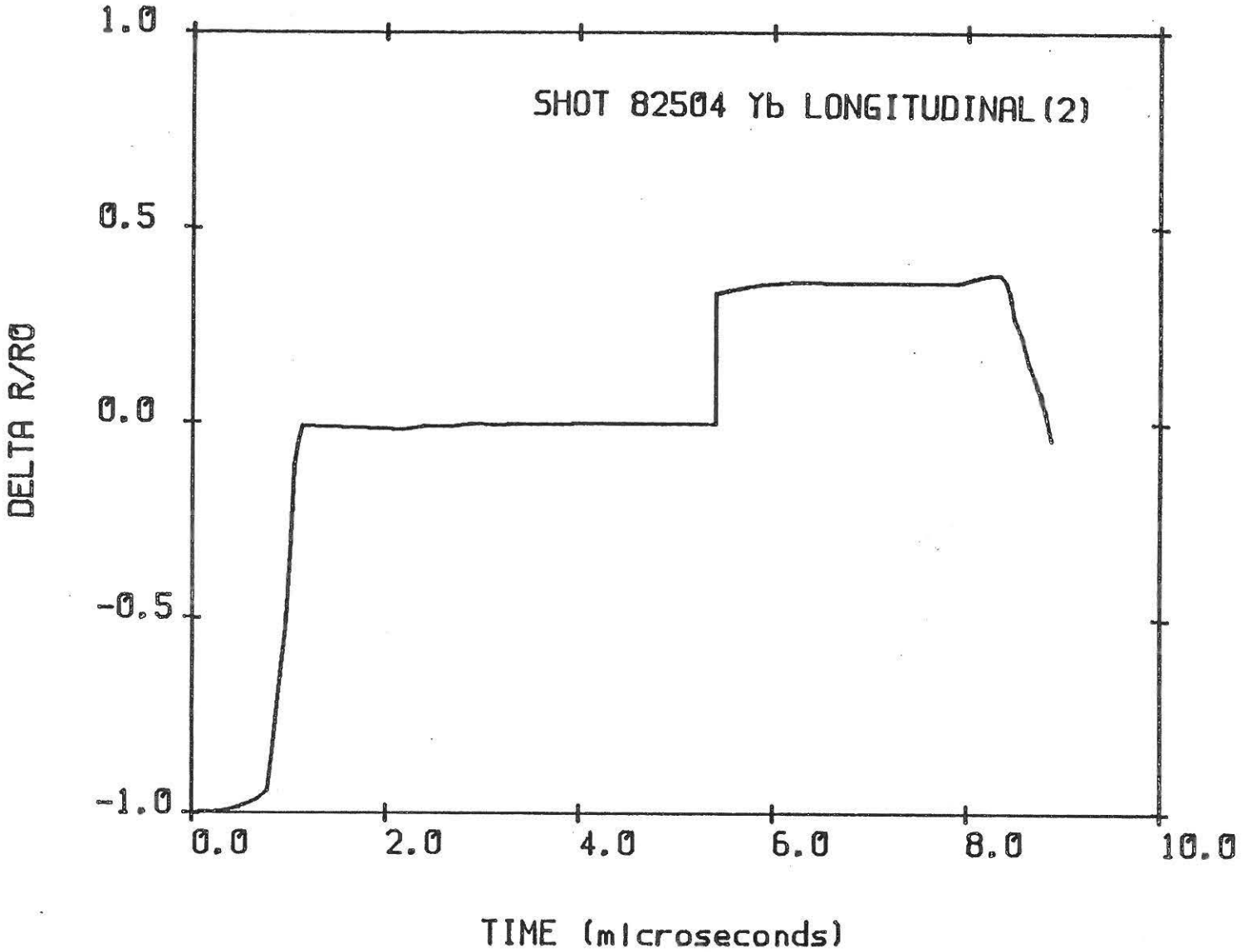
For each experiment we have given a table listing the important experimental parameters. Following the table are given the plots of measured resistance change profiles for every gauge. In these plots the term "longitudinal gauge" refers to the gauge oriented parallel to the shock front and the term "lateral gauge" refers to the gauge oriented perpendicular to the shock front.

Shot Number:	82-504
Projectile Velocity:	0.296 mm/μs
Shock Stress:	5.4 kbar
Impactor Material:	PMMA
Impactor thickness:	5.08 mm
Gauge Depth in PMMA Matrix:	5.57 mm
Gauges Embedded in PMMA Matrix:	Two longitudinal ytterbium gauges
Remarks:	Unloading response could not be recorded.

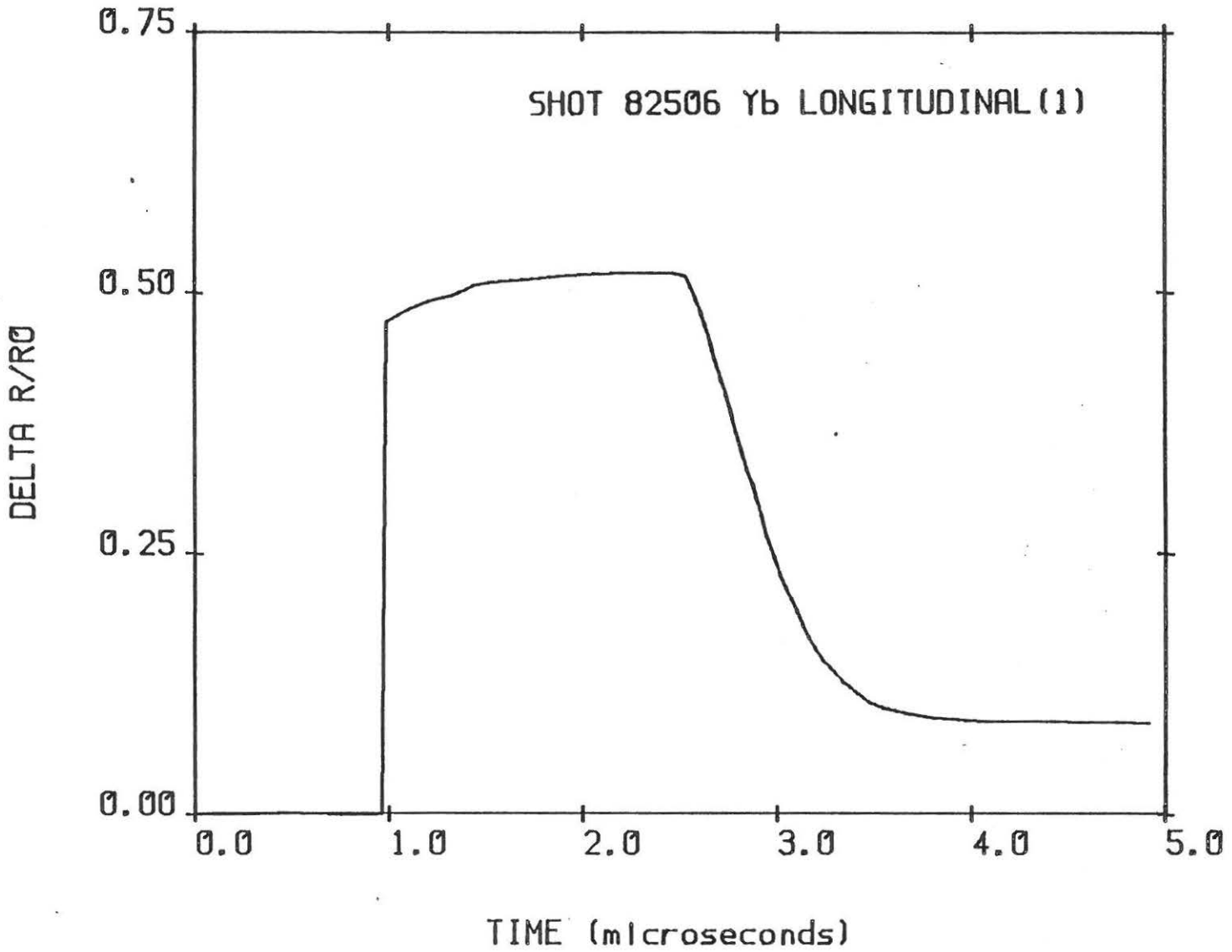

SHOT 82504 Yb LONGITUDINAL(1)
DELTA R/R0
0.5
0.4
0.3
0.2
0.1
0.0
0.0
1.0
2.0
3.0
4.0
5.0
TIME (microseconds)

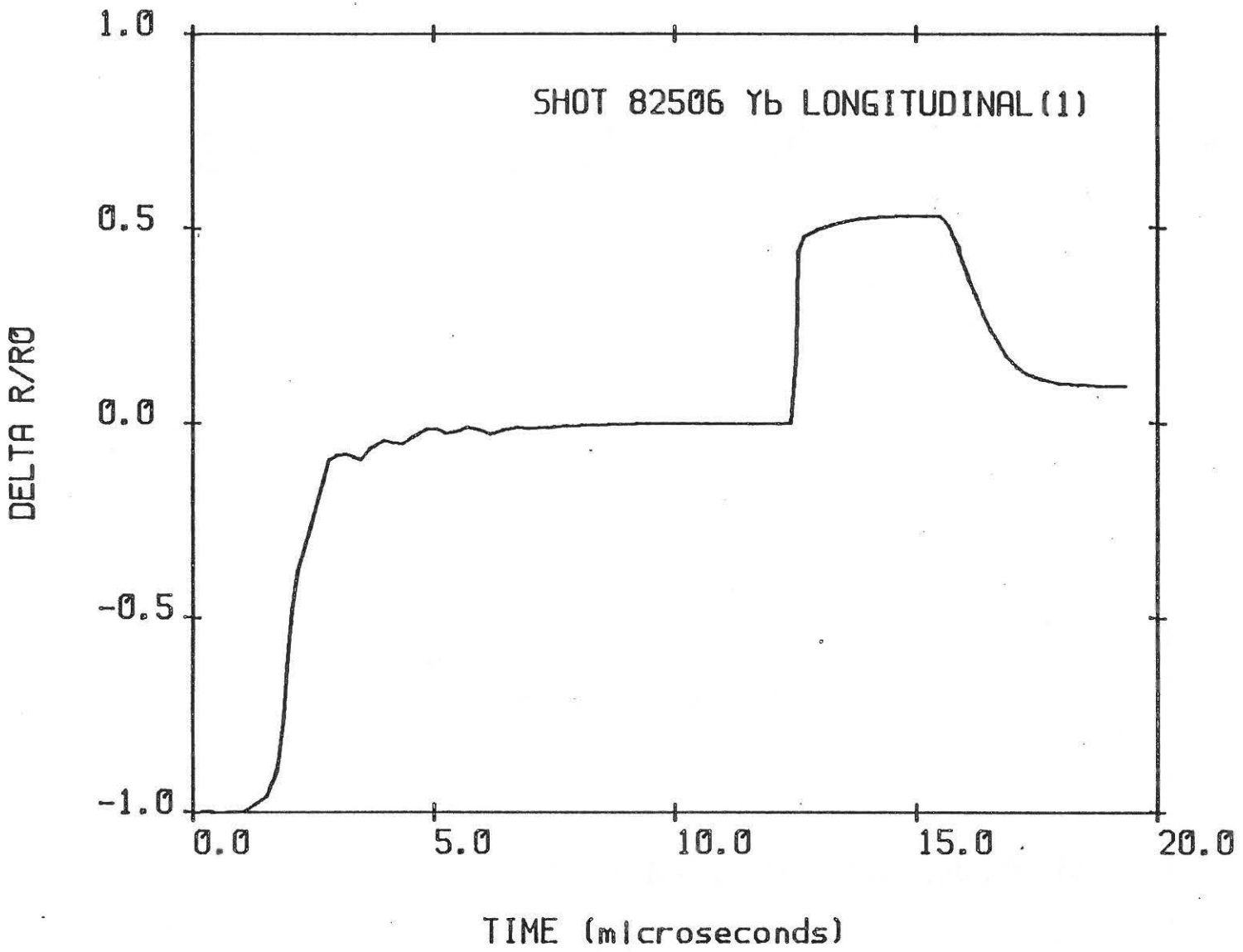

SHOT 82504 Yb LONGITUDINAL(1)
1.0
0.5
0.0
-0.5
-1.0
DELTA R/R0
0.0
2.0
4.0
6.0
8.0
10.0
TIME (microseconds)

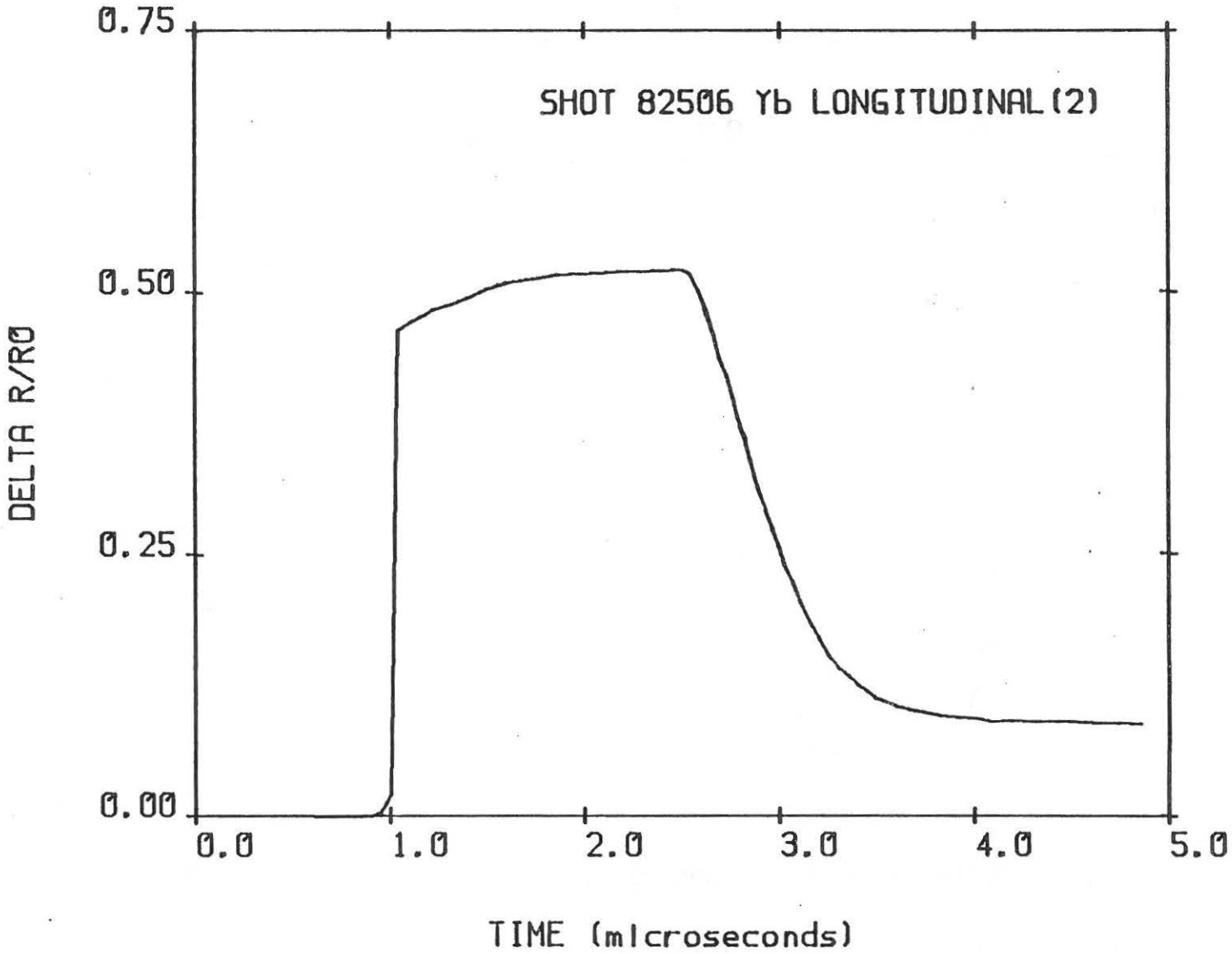

SHOT 82504 Yb LONGITUDINAL(2)
DELTA R/R0
0.5
0.4
0.3
0.2
0.1
0.0
0.0
1.0
2.0
3.0
4.0
5.0
TIME (microseconds)

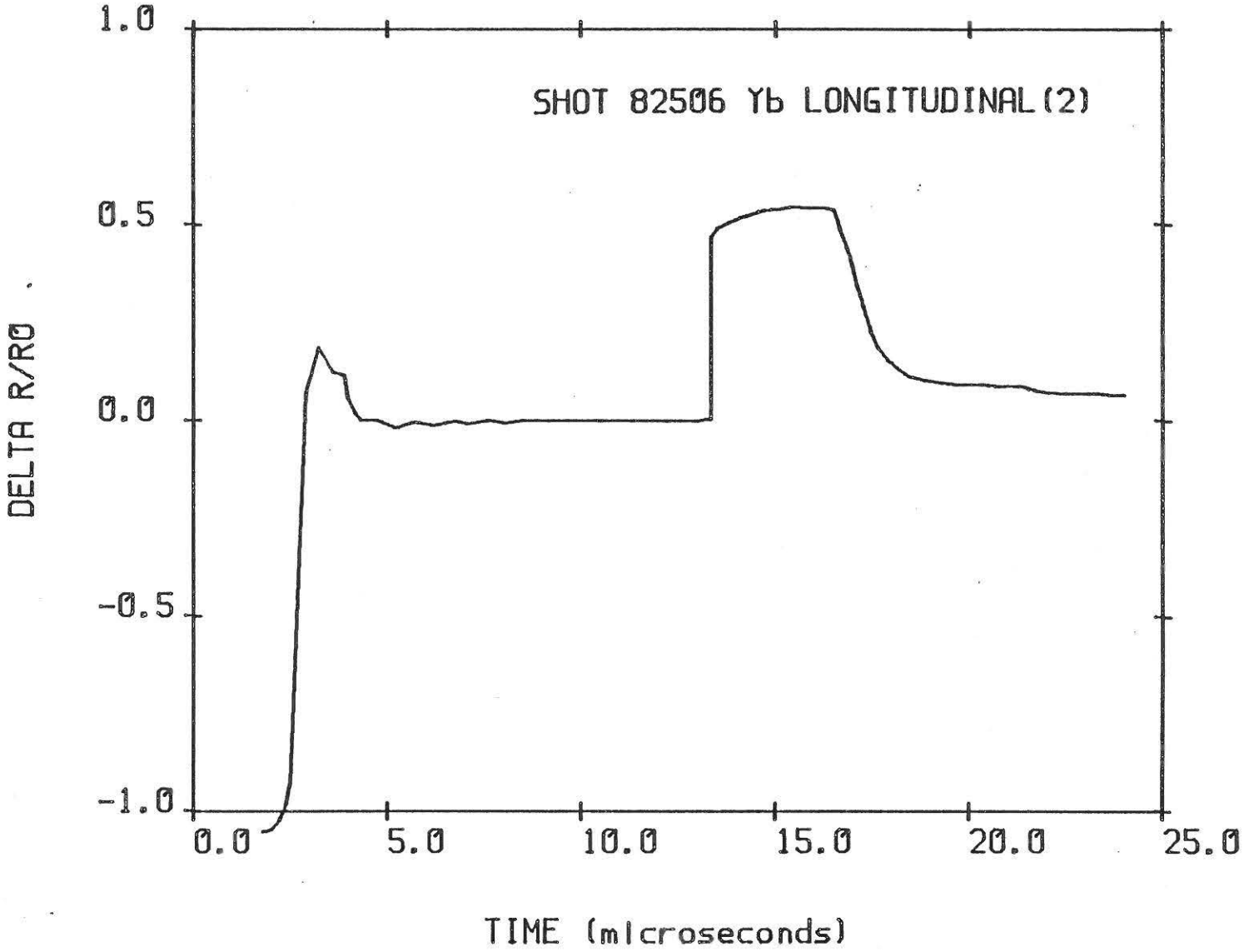

SHOT 82504 Yb LONGITUDINAL(2)
1.0
0.5
0.0
-0.5
-1.0
DELTA R/R0
0.0
2.0
4.0
6.0
8.0
10.0
TIME (microseconds)

Shot Number:	82-506
Projectile Velocity:	0.352 mm/μsec
Shock Stress:	6.5 kbar
Impactor Material:	PMMA
Impactor Thickness:	3.02 mm
Gauge Depth in PMMA Matrix:	6.44 mm
Gauges Embedded in PMMA Matrix:	Two longitudinal ytterbium gauges
Remarks:	The results from two gauges agreed within 0.2%. The viscoelastic effect in PMMA was observed. To reduce the effect of viscoelasticity on the resistance change profile of the gauges, it is better to bring the gauges closer to the impact surface.

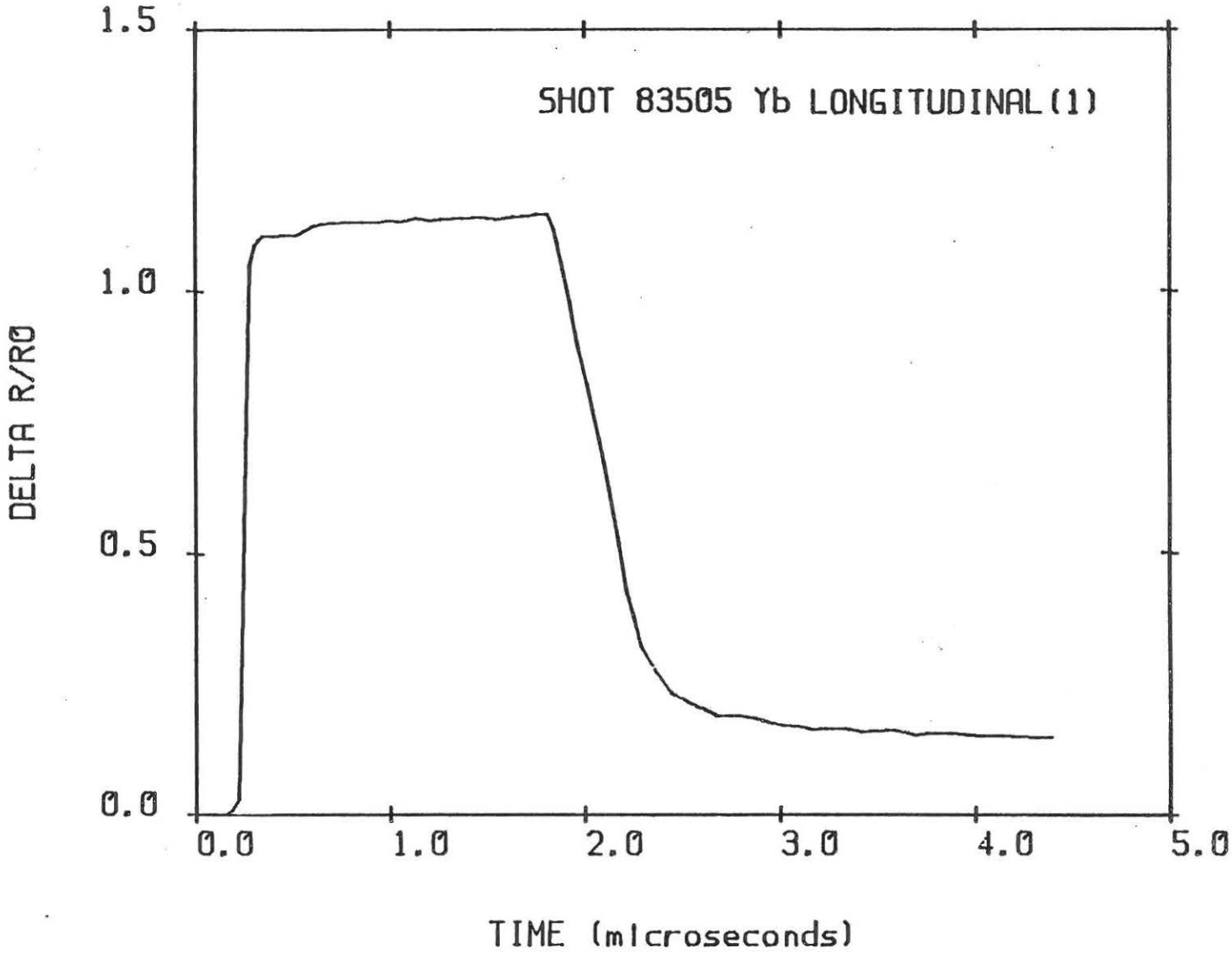

SHOT 82506 Yb LONGITUDINAL(1)
0.75
0.50
0.25
0.00
DELTA R/R0
0.0
1.0
2.0
3.0
4.0
5.0
TIME (microseconds)

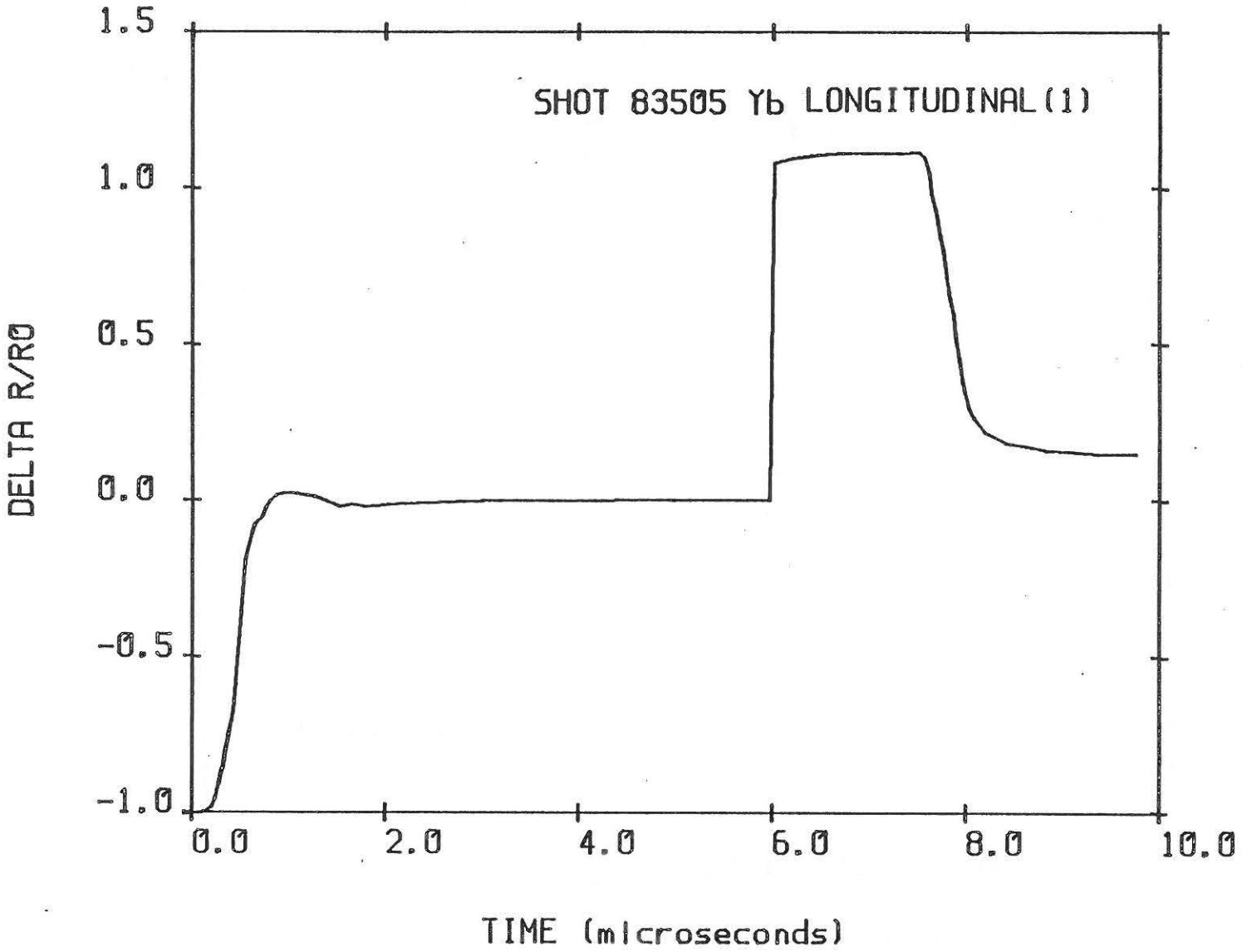

SHOT 82506 Yb LONGITUDINAL(1)
1.0
0.5
0.0
-0.5
-1.0
DELTA R/R0
0.0
5.0
10.0
15.0
20.0
TIME (microseconds)

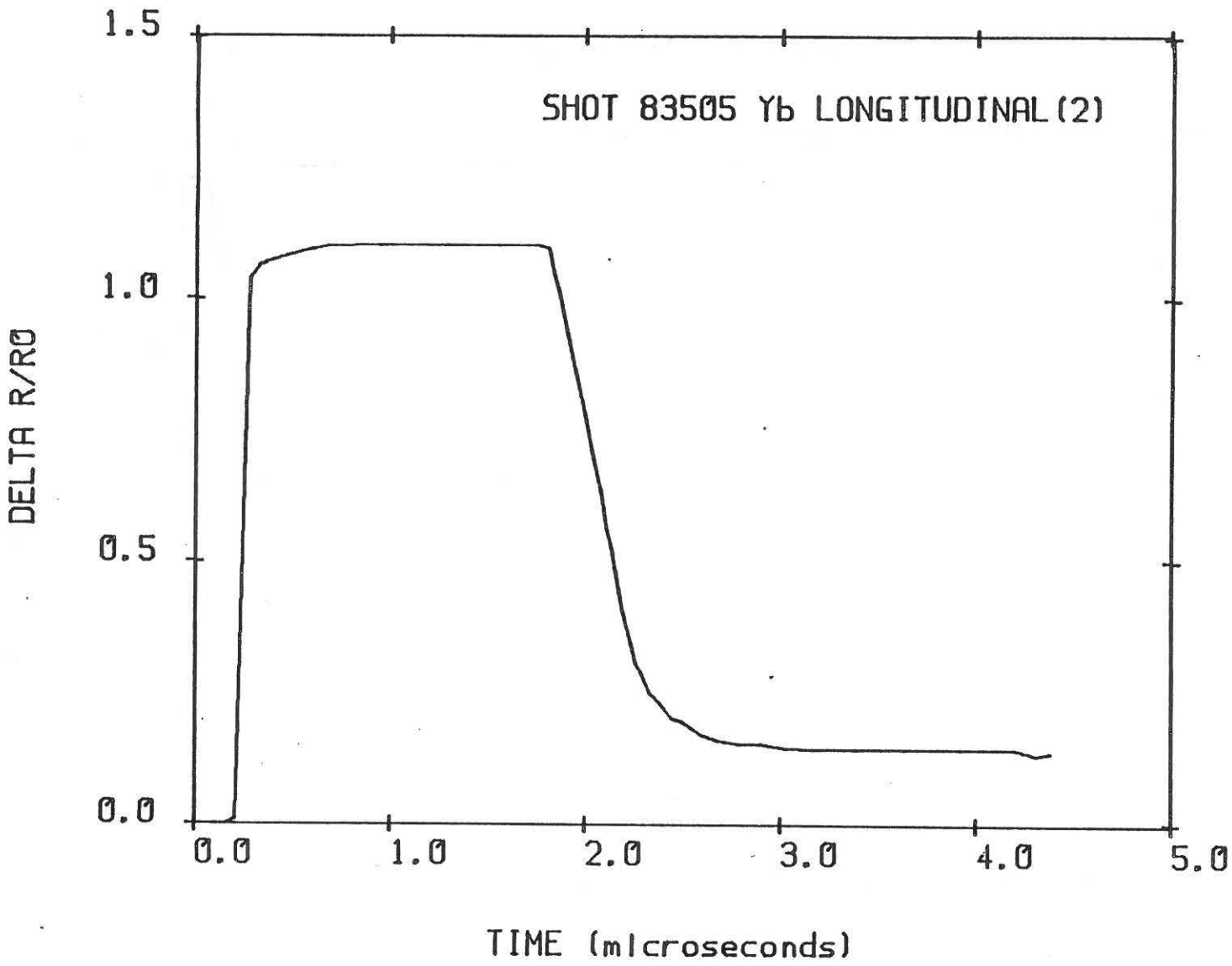

SHOT 82506 Yb LONGITUDINAL(2)
0.75
0.50
0.25
0.00
DELTA R/RØ
0.0
1.0
2.0
3.0
4.0
5.0
TIME (microseconds)

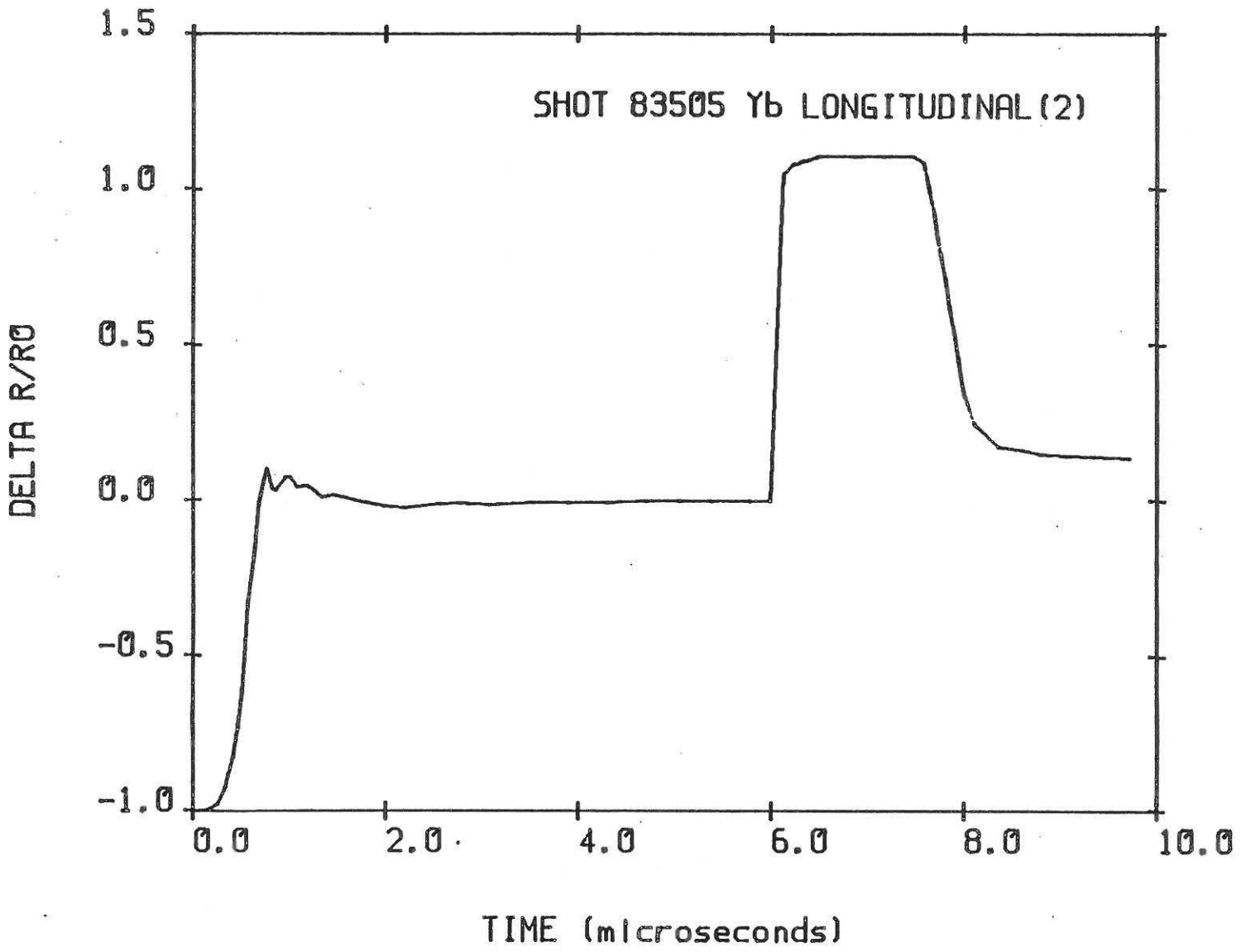

SHOT 82506 Yb LONGITUDINAL(2)
1.0
0.5
0.0
-0.5
-1.0
DELTA R/R0
0.0
5.0
10.0
15.0
20.0
25.0
TIME (microseconds)

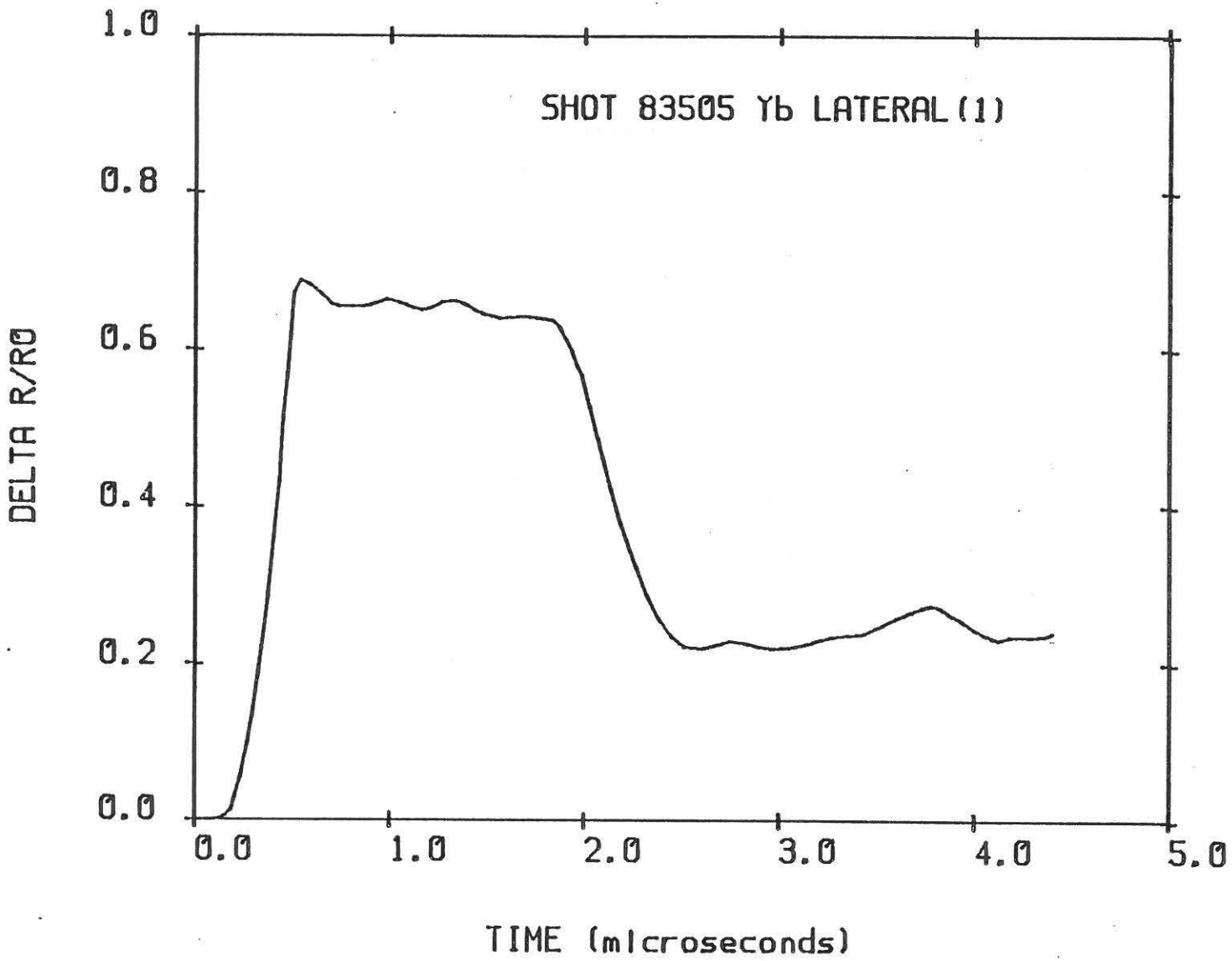
Shot Number:	83-505
Projectile Velocity:	0.615 mm/μsec
Shock Stress:	11.5 kbar
Impactor Material:	PMMA
Impactor Thickness:	2.99 mm
Gauge Depth in PMMA Matrix:	0.5 mm for lateral gauges
	0.96 for longitudinal gauges
Gauges Embedded in PMMA Matrix:	4 ytterbium gauges—
	2 longitudinal and 2 lateral
Remarks:	For one of the gauges (longitudinal) the length of the leads was reduced to 7.4 mm as compared to 13.7 mm for other gauges. We found that the lead length has no effect on gauge response.

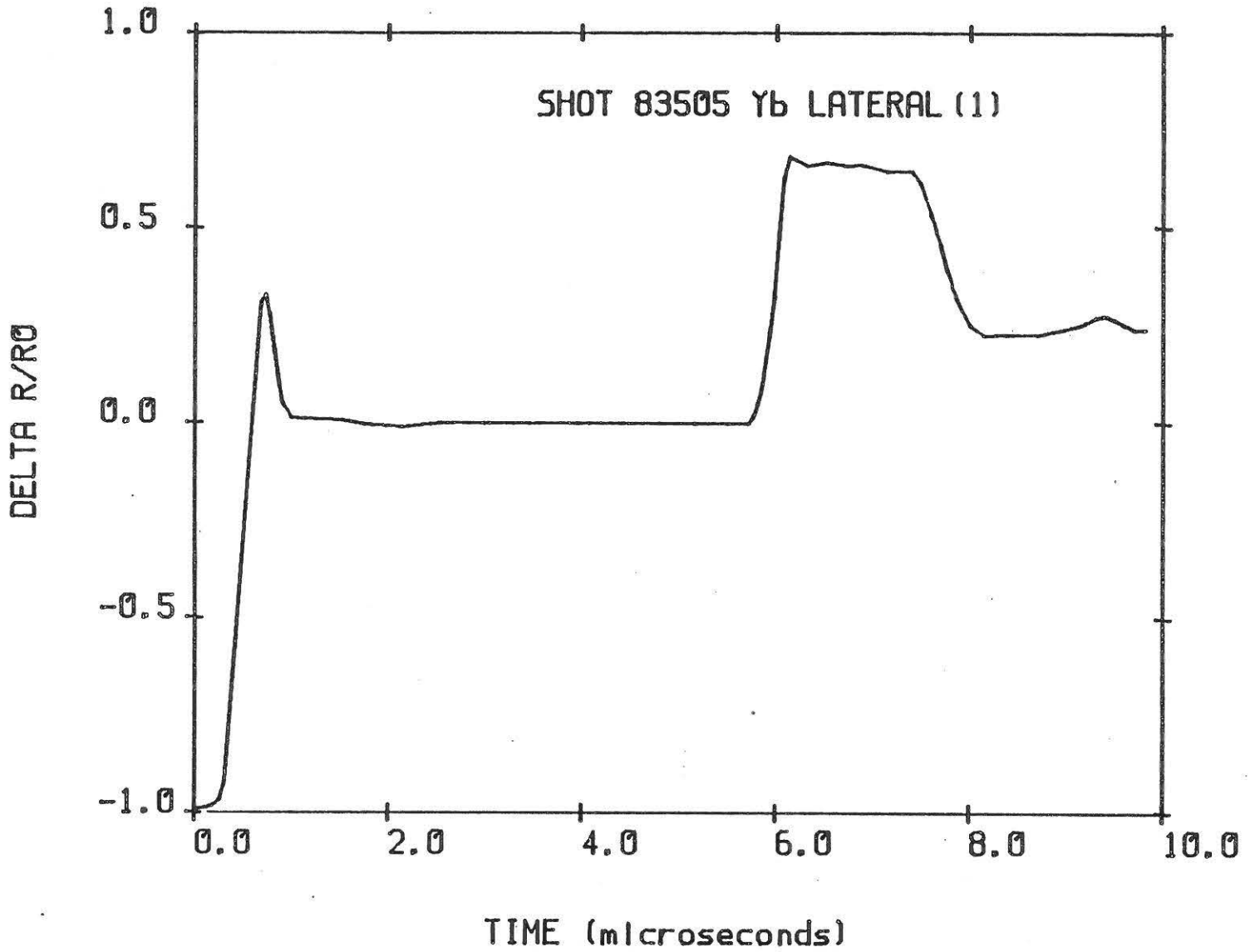

SHOT 83505 Yb LONGITUDINAL(1)
DELTA R/R0
1.5
1.0
0.5
0.0
0.0
1.0
2.0
3.0
4.0
5.0
TIME (microseconds)

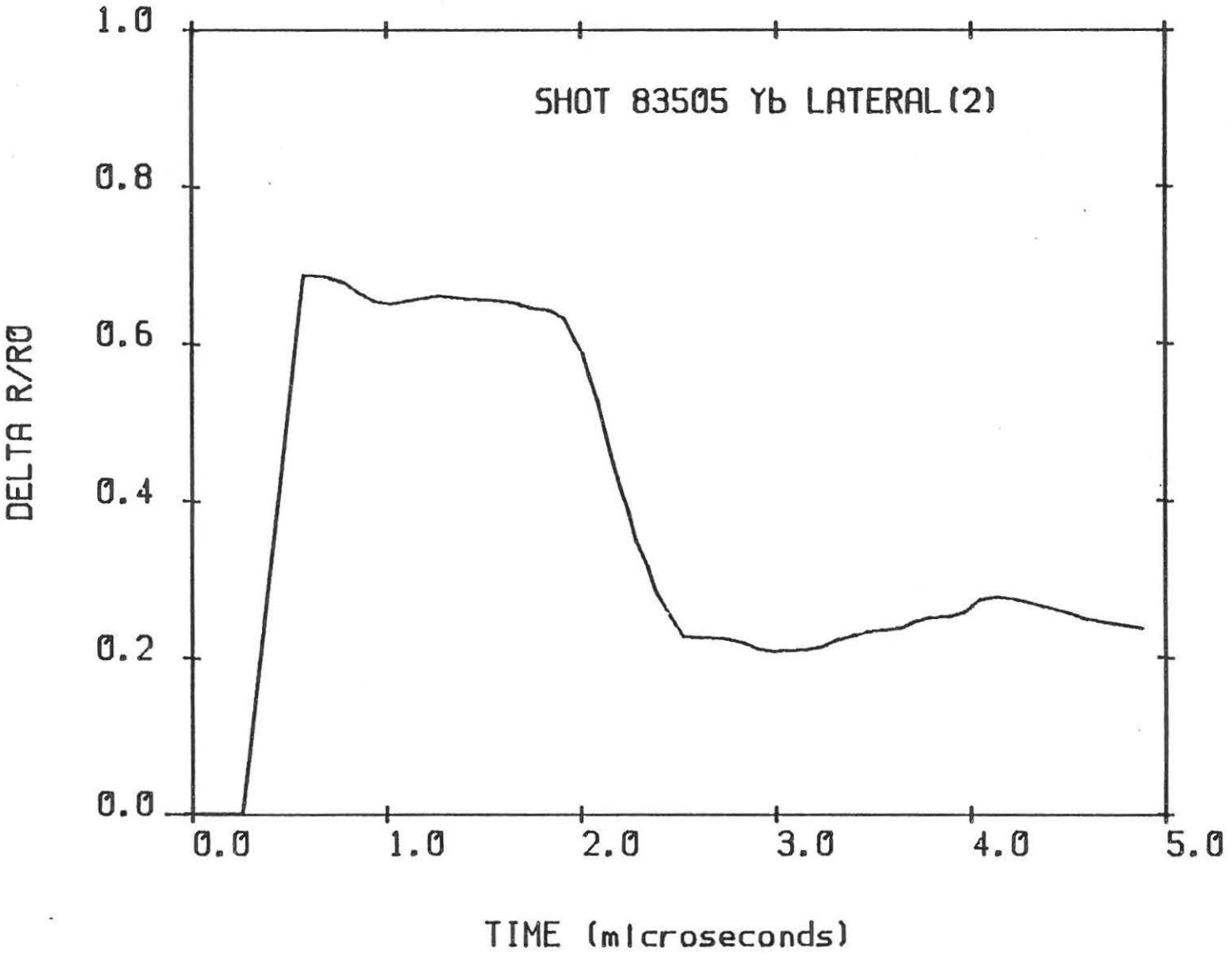

SHOT 83505 Yb LONGITUDINAL(1)
1.5
1.0
0.5
0.0
-0.5
-1.0
DELTA R/R0
0.0
2.0
4.0
6.0
8.0
10.0
TIME (microseconds)

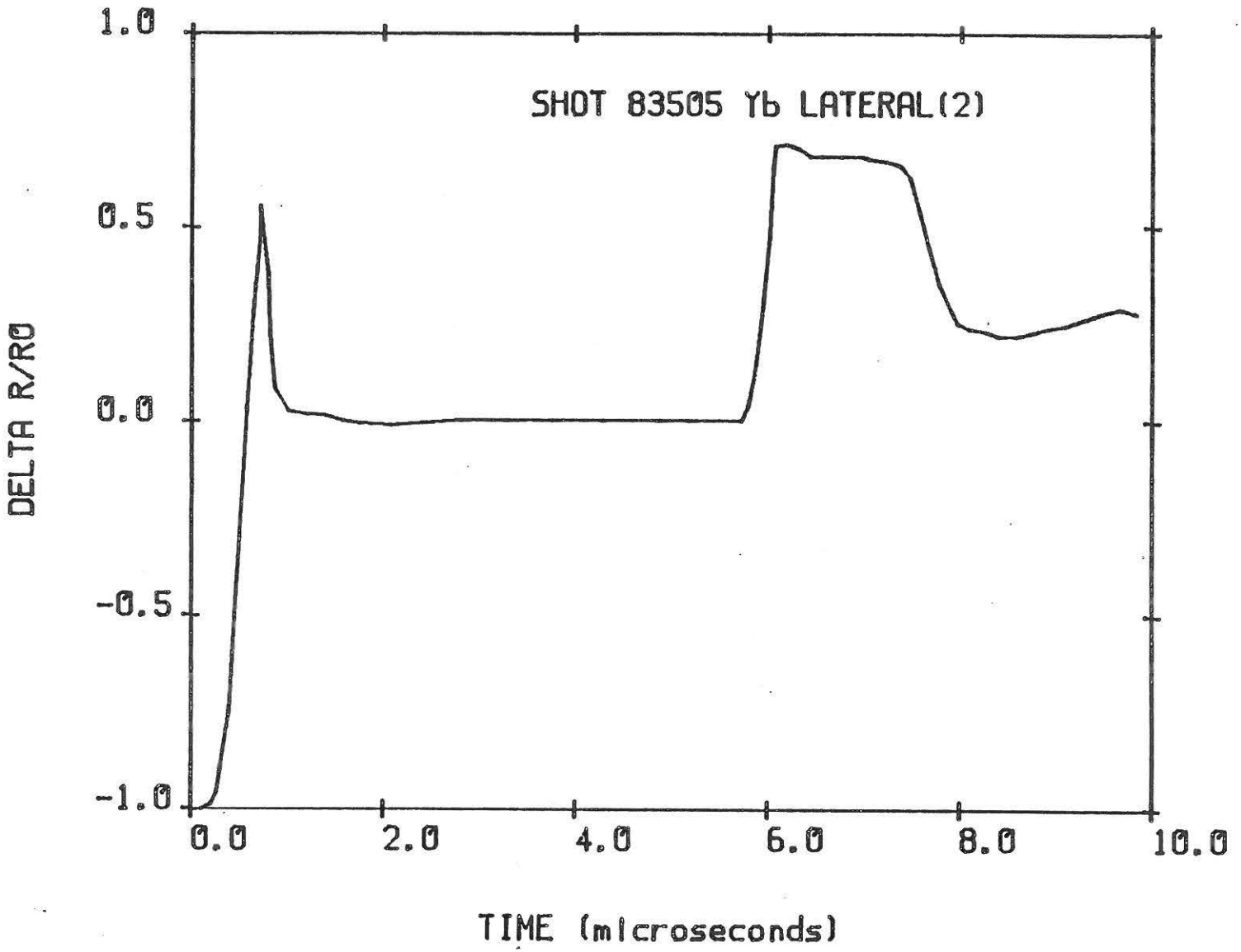

SHOT 83505 Yb LONGITUDINAL(2)
DELTA R/R0
1.5
1.0
0.5
0.0
0.0
1.0
2.0
3.0
4.0
5.0
TIME (microseconds)


SHOT 83505 Yb LONGITUDINAL(2)
DELTA R/R0
1.5
1.0
0.5
0.0
-0.5
-1.0
0.0
2.0
4.0
6.0
8.0
10.0
TIME (microseconds)

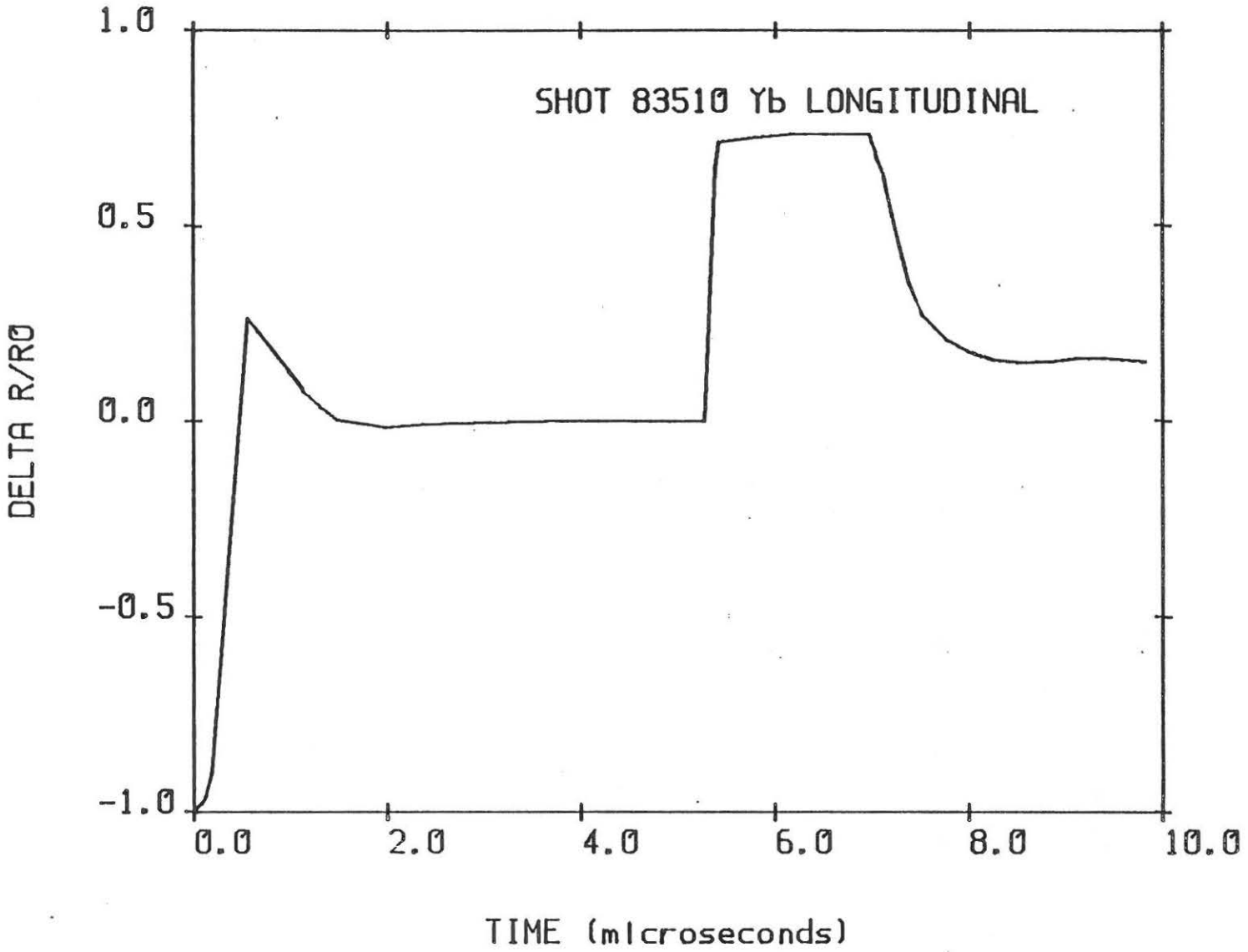

SHOT 83505 Yb LATERAL (1)
DELTA R/R0
1.0
0.8
0.6
0.4
0.2
0.0
0.0
1.0
2.0
3.0
4.0
5.0
TIME (microseconds)

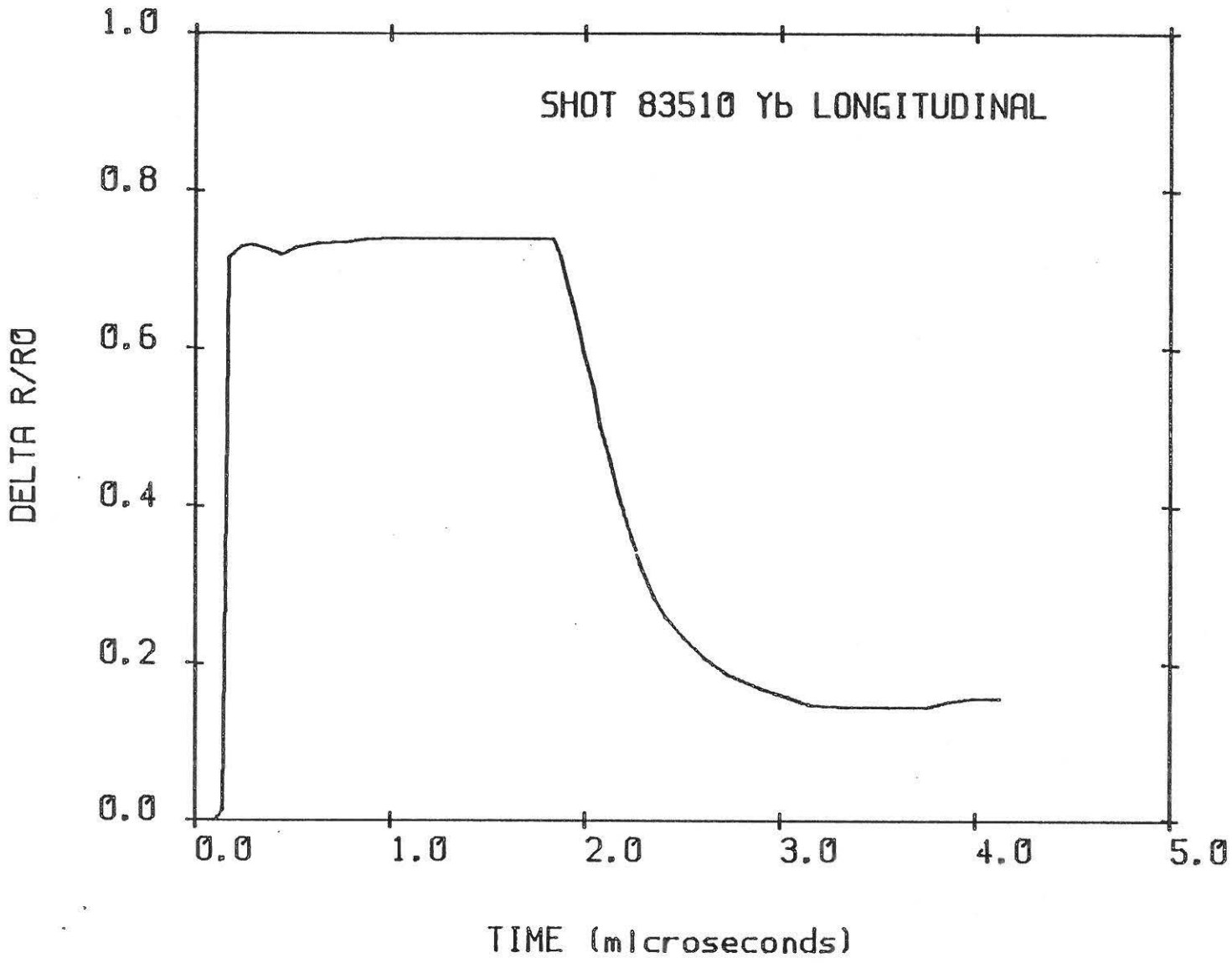

SHOT 83505 Yb LATERAL (1)
1.0
0.5
0.0
-0.5
-1.0
DELTA R/R0
0.0
2.0
4.0
6.0
8.0
10.0
TIME (microseconds)

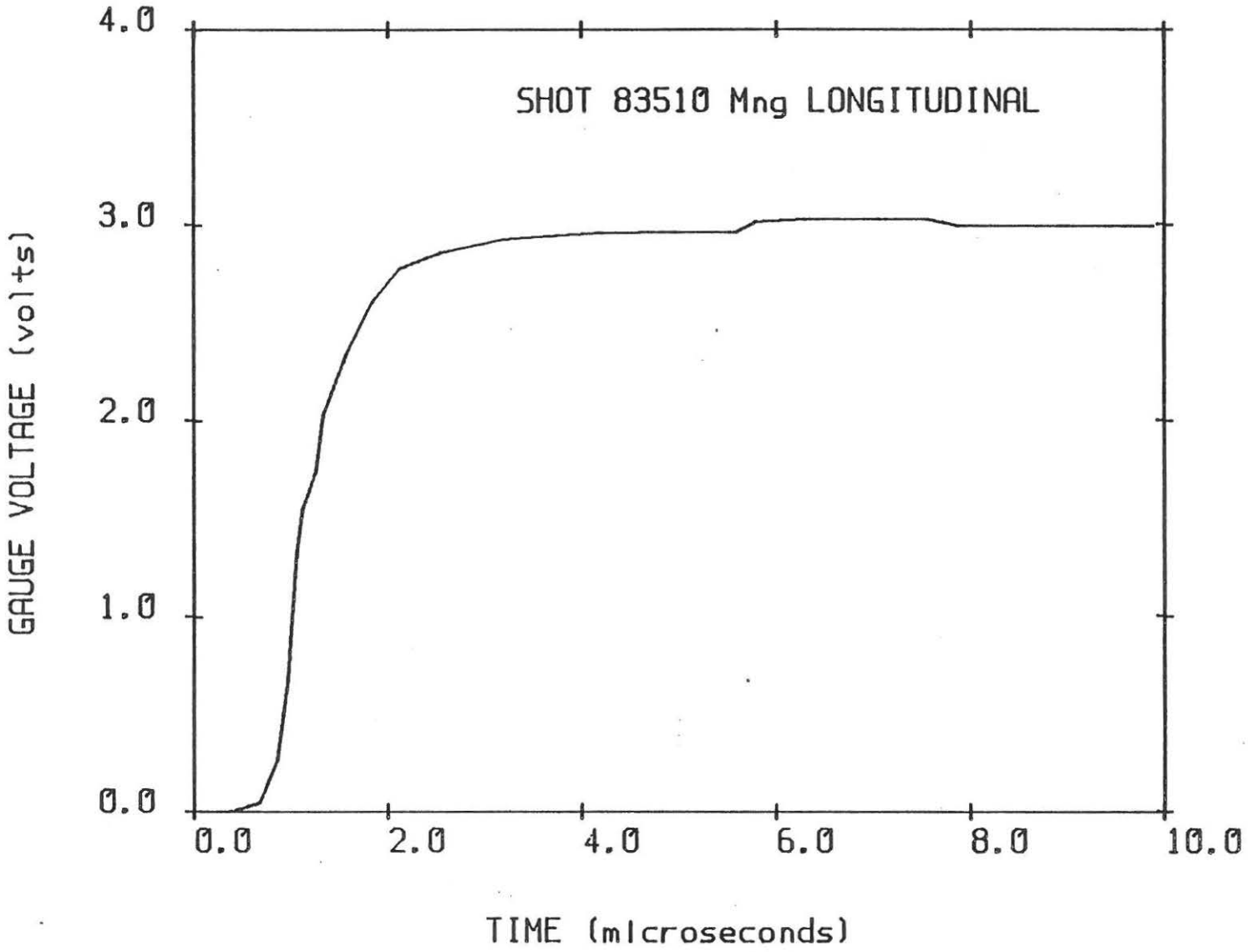

SHOT 83505 Yb LATERAL(2)
DELTA R/R0
1.0
0.8
0.6
0.4
0.2
0.0
0.0
1.0
2.0
3.0
4.0
5.0
TIME (microseconds)

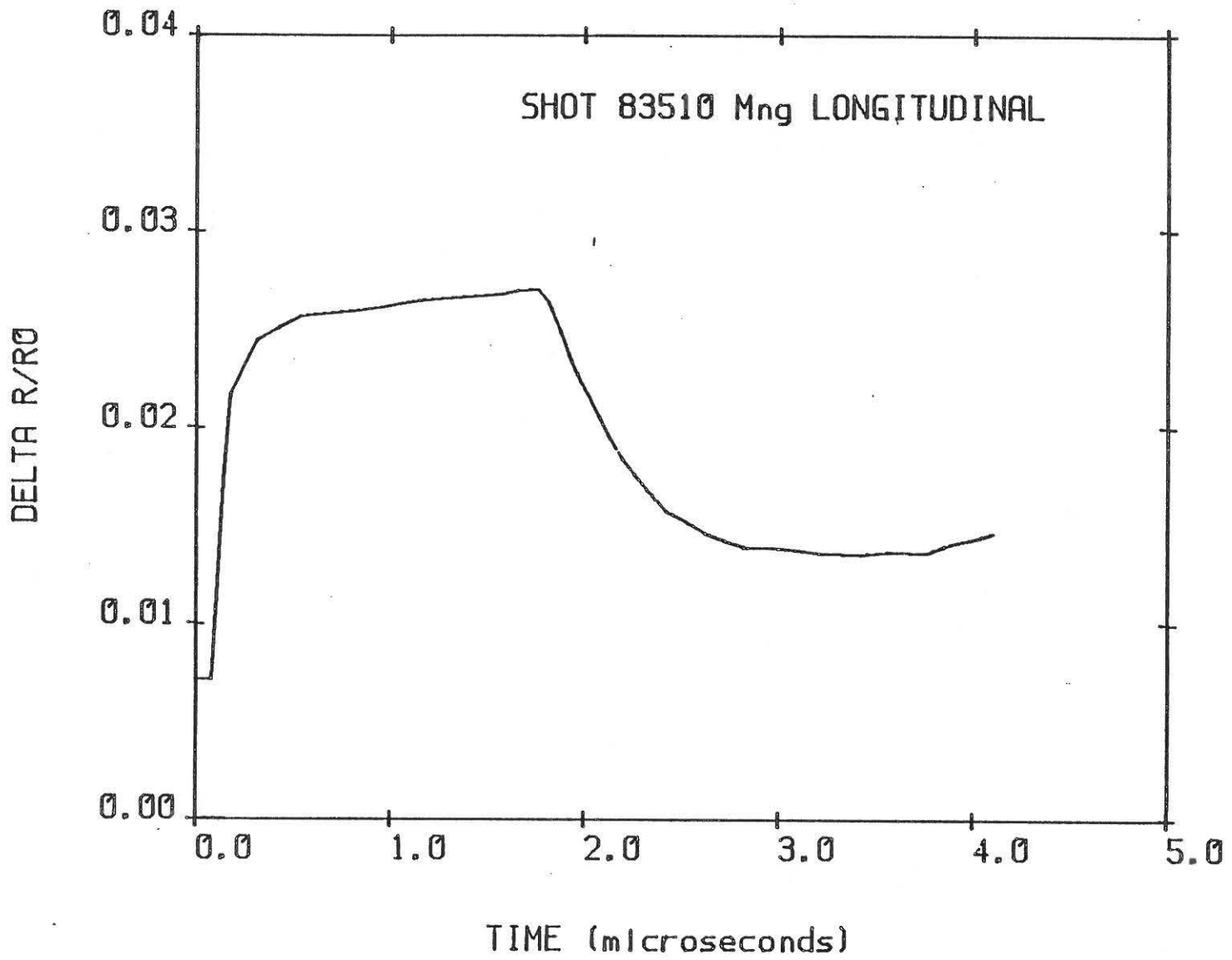

SHOT 83505 Yb LATERAL(2)
1.0
0.5
0.0
-0.5
-1.0
DELTA R/R0
0.0
2.0
4.0
6.0
8.0
10.0
TIME (microseconds)

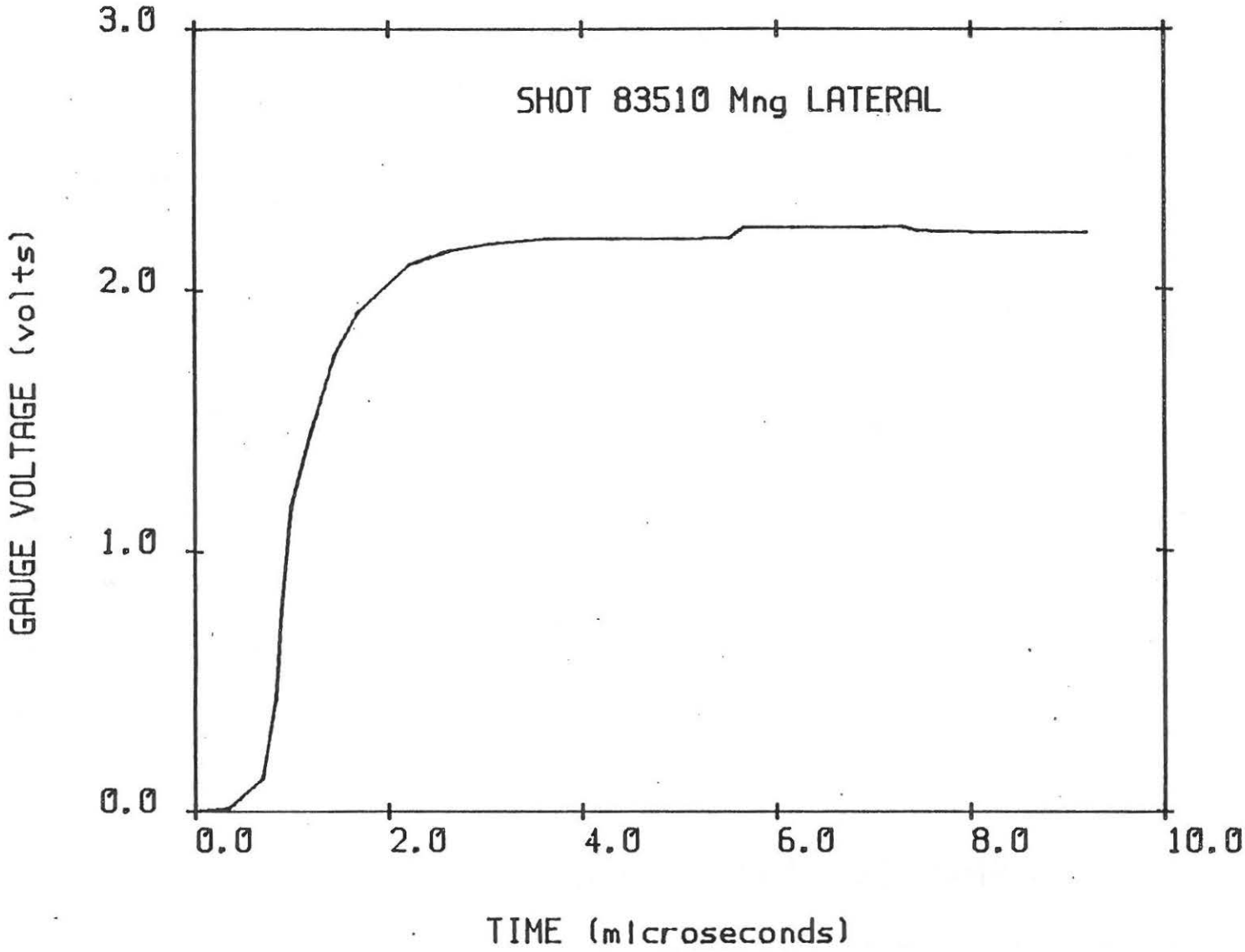
Shot Number:	83-510
Projectile Velocity:	0.45 mm/μs
Shock Stress:	8.4 kbar
Impactor Material:	PMMA
Impactor Thickness	2.95 mm
Gauge Depth in PMMA Matrix	0.96 for longitudinal gauge 1.0 for lateral gauge.
Gauges Embedded in PMMA Matrix:	4 gauges one longitudinal ytterbium, one lateral ytterbium; one longitudinal manganin and one lateral manganin
Remarks:	We did not obtain resistance change profiles for lateral Yb gauge because power supply did not work.

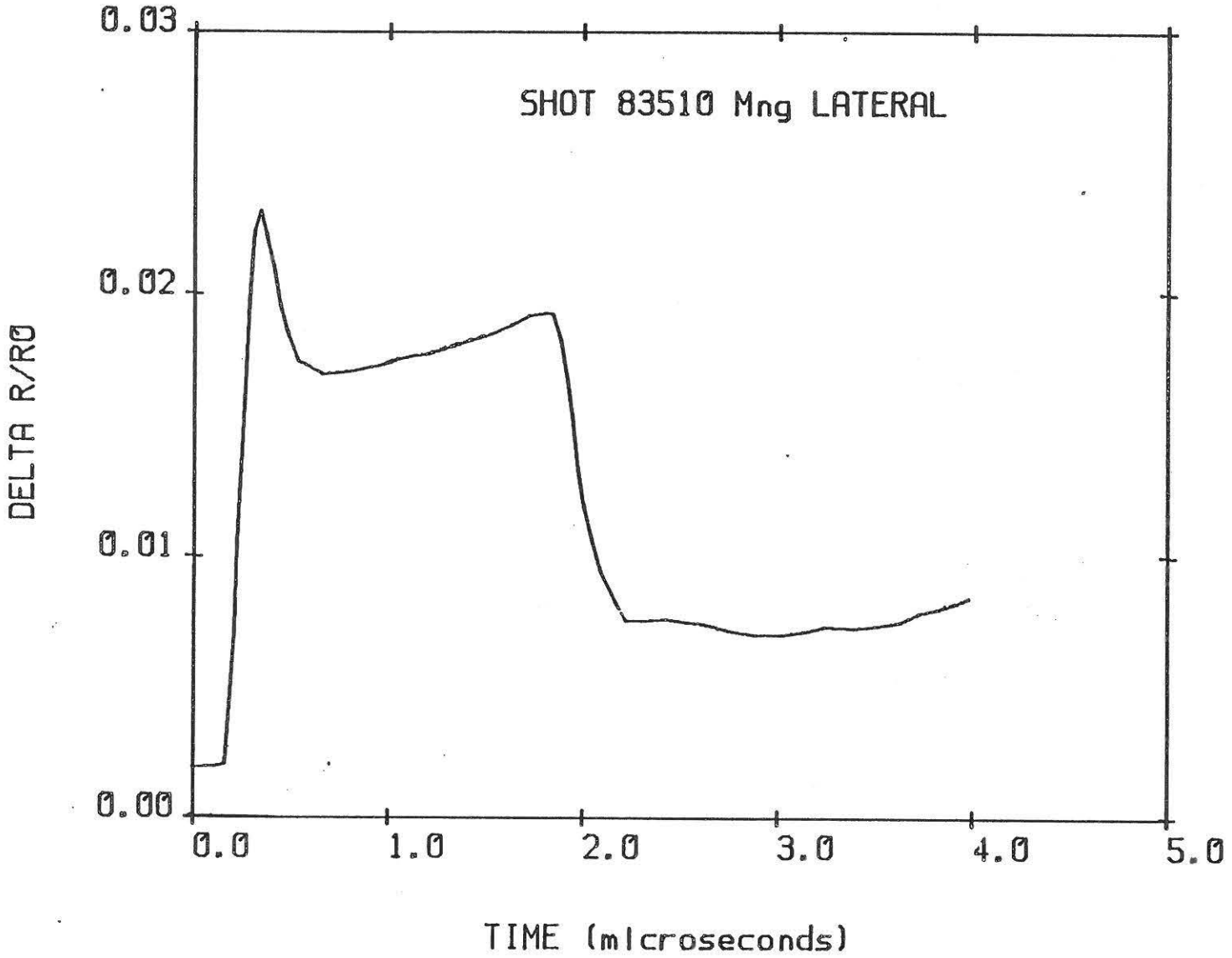

SHOT 83510 Yb LONGITUDINAL
1.0
0.5
0.0
-0.5
-1.0
DELTA R/R0
0.0
2.0
4.0
6.0
8.0
10.0
TIME (microseconds)


SHOT 83510 Yb LONGITUDINAL
DELTA R/R0
1.0
0.8
0.6
0.4
0.2
0.0
0.0
1.0
2.0
3.0
4.0
5.0
TIME (microseconds)

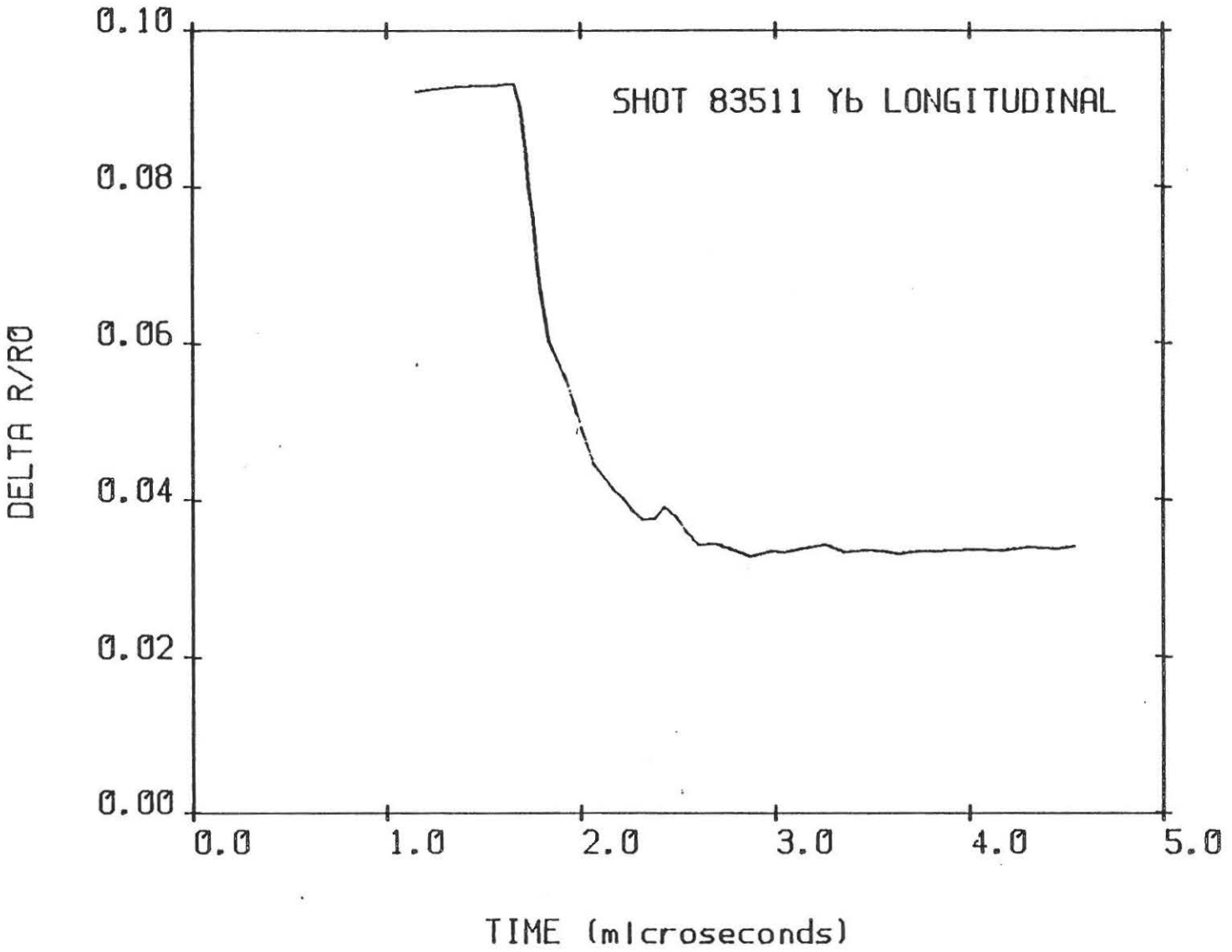

SHOT 83510 Mng LONGITUDINAL
GAUGE VOLTAGE (volts)
4.0
3.0
2.0
1.0
0.0
0.0
2.0
4.0
6.0
8.0
10.0
TIME (microseconds)

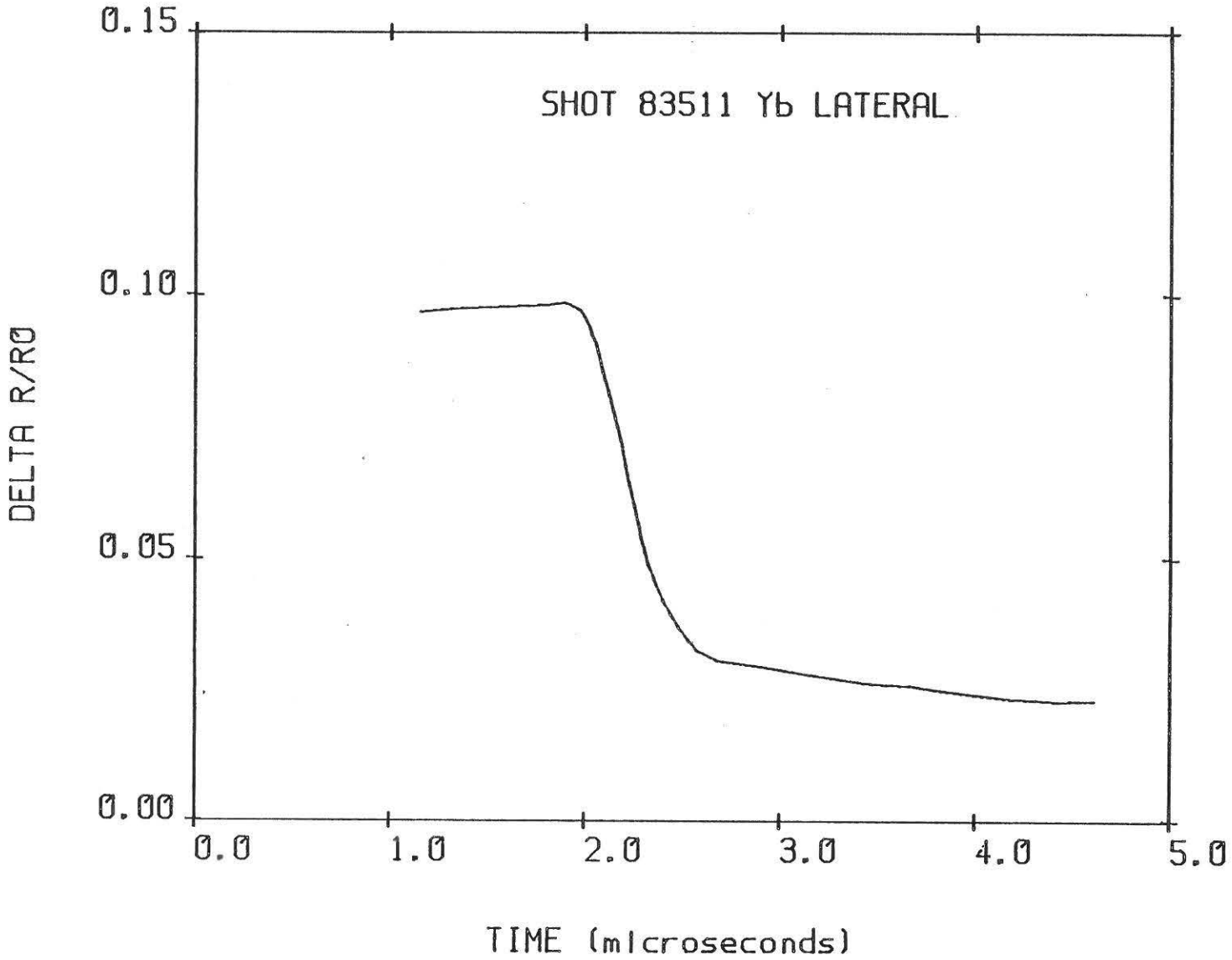

SHOT 83510 Mng LONGITUDINAL
DELTA R/R0
0.04
0.03
0.02
0.01
0.00
0.0
1.0
2.0
3.0
4.0
5.0
TIME (microseconds)


SHOT 83510 Mng LATERAL
GAUGE VOLTAGE (volts)
3.0
2.0
1.0
0.0
0.0
2.0
4.0
6.0
8.0
10.0
TIME (microseconds)

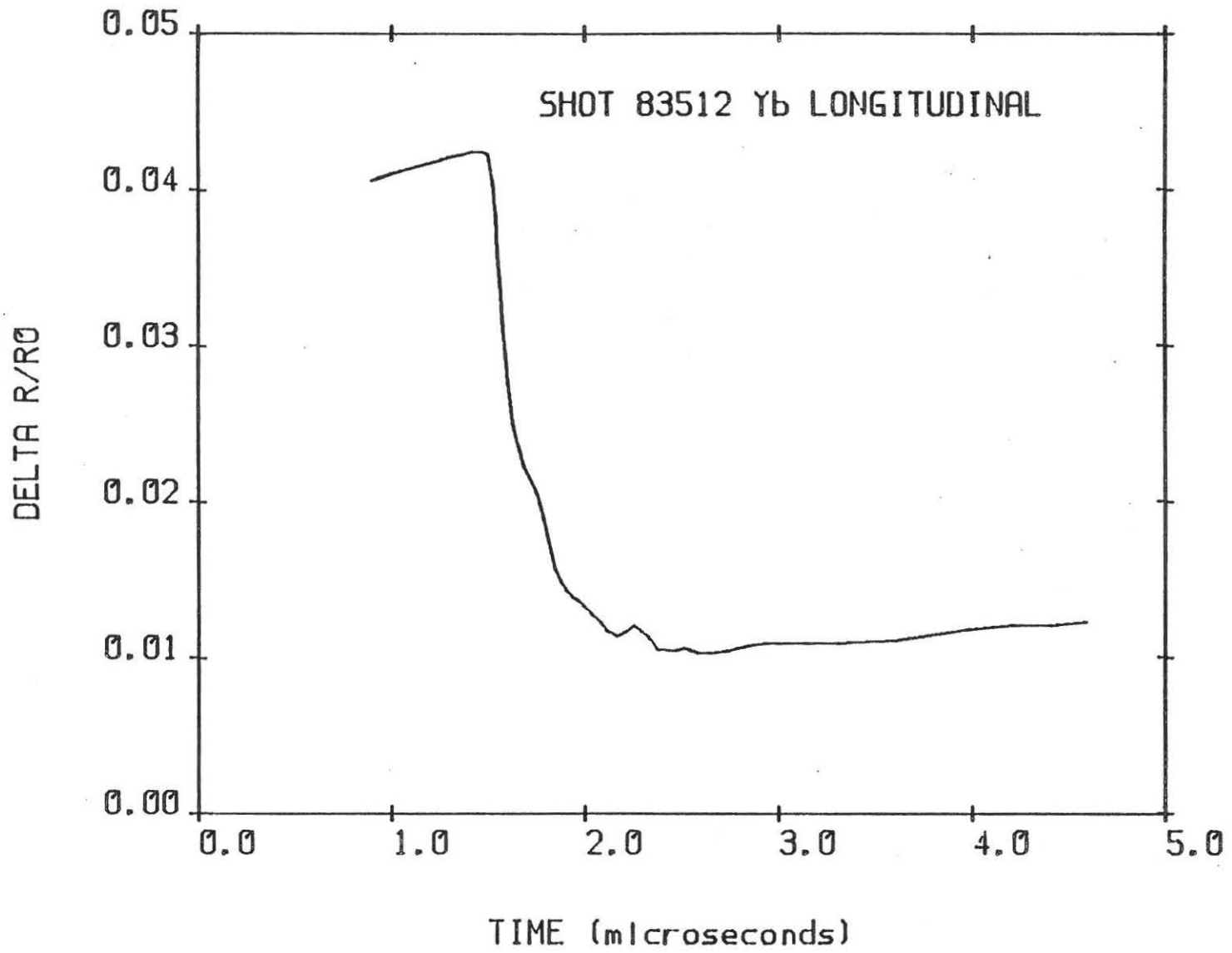

SHOT 83510 Mng LATERAL
0.03
0.02
0.01
0.00
DELTA R/R0
0.0
1.0
2.0
3.0
4.0
5.0
TIME (microseconds)

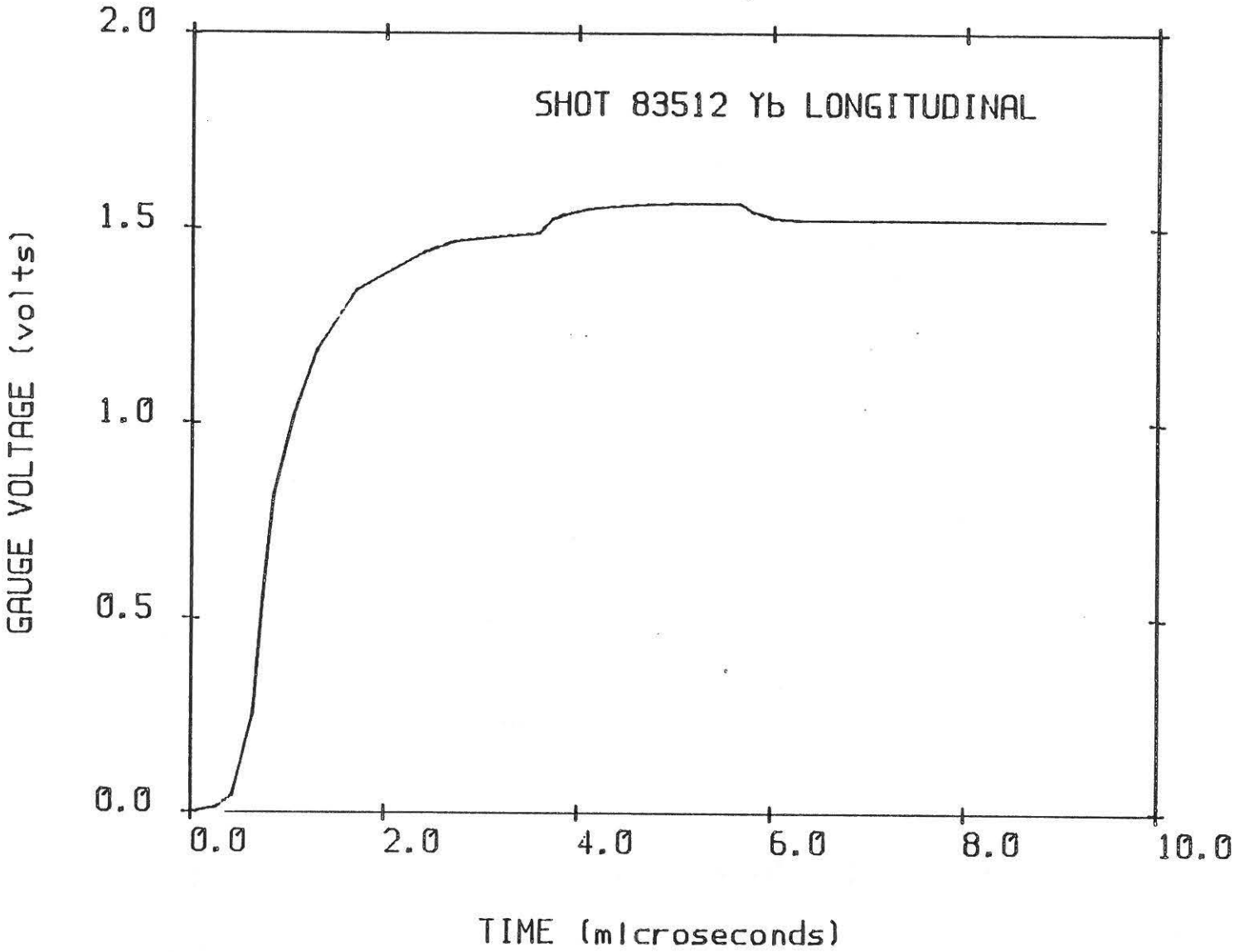
Shot Number:	83-511
Projectile Velocity:	0.114 mm/μs
Shock Stress:	1.85 kbar
Impactor Material:	PMMA
Impactor Thickness:	2.95 mm
Gauge Depth in PMMA Matrix:	0.99 mm for longitudinal gauge 1.0 mm for lateral gauge
Gauge Embedded in PMMA Matrix:	One longitudinal ytterbium and one lateral ytterbium
Remarks:	Current source giving a higher current (∿ 9 amps) was used for these gauges; the electrical circuit is shown in Fig. 2b.

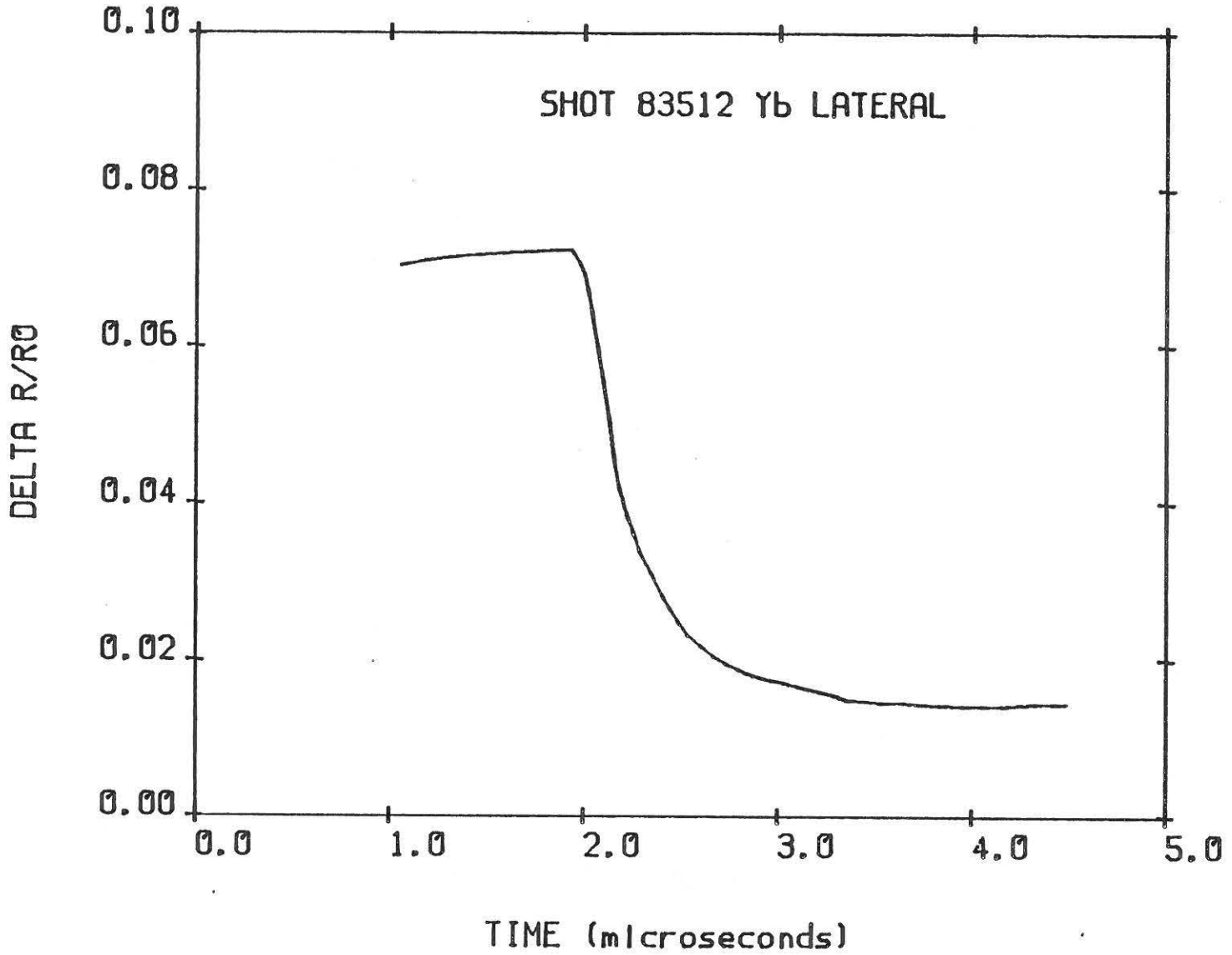

SHOT 83511 Yb LONGITUDINAL
DELTA R/R0
0.10
0.08
0.06
0.04
0.02
0.00
0.0
1.0
2.0
3.0
4.0
5.0
TIME (microseconds)

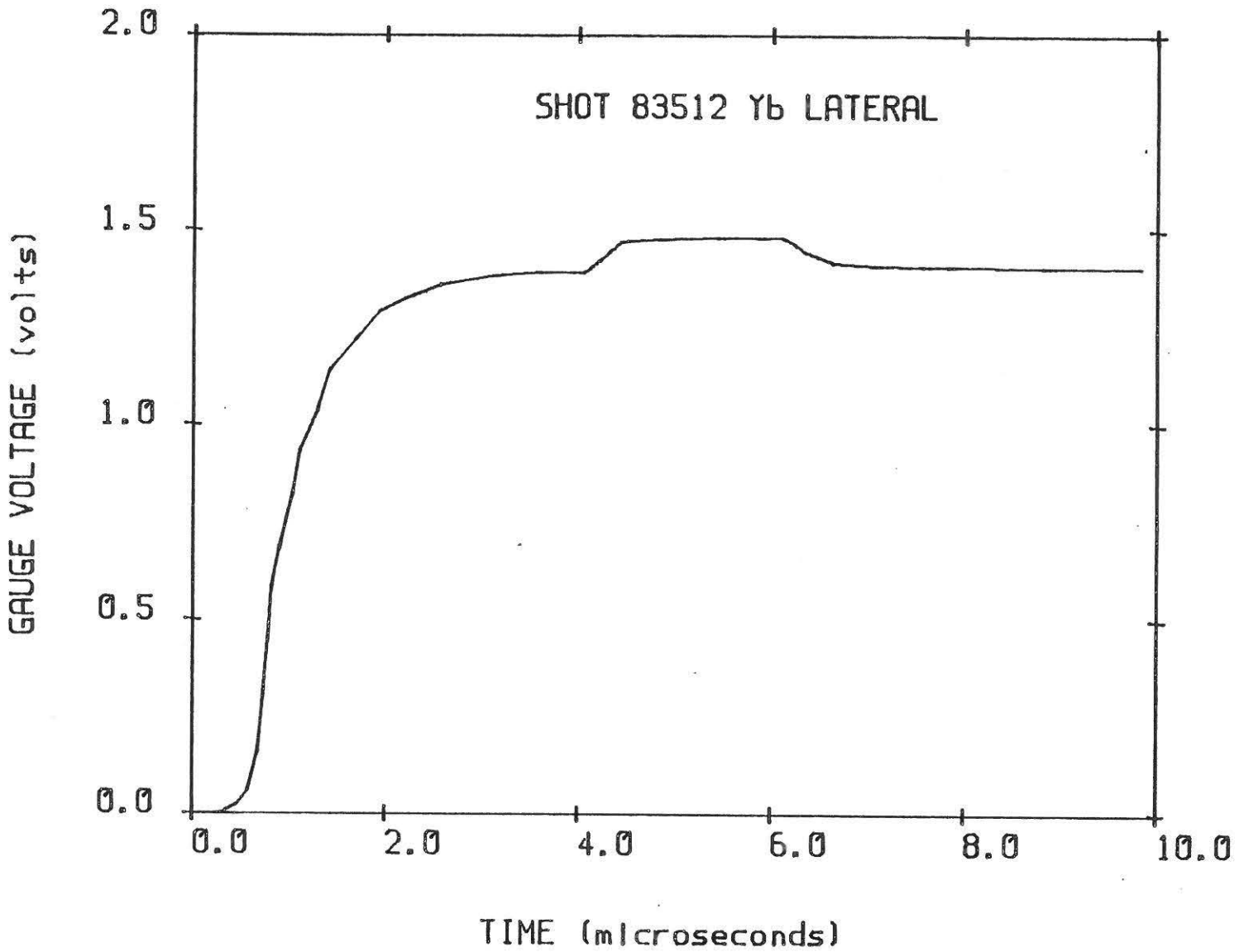

SHOT 83511 Yb LATERAL
0.15
0.10
0.05
0.00
DELTA R/R0
0.0
1.0
2.0
3.0
4.0
5.0
TIME (microseconds)

Shot Number:	83-512
Projectile Velocity:	0.074 mm/μsec
Shock Stress:	1.25 kbar
Impactor Material:	PMMA
Impactor Thickness:	2.95 mm
Gauge Depth in PMMA matrix:	1.0 mm
Gauges Embedded in PMMA Matrix:	one lateral ytterbium and one longitudinal ytterbium
Remarks:	Current source giving a higher current (∿ 9 amps) was used for these gauges. Electrical circuit is shown in Fig. 2b. Width of the gauges was .48 mm (compared to about 1 mm for the gauges in other shots).

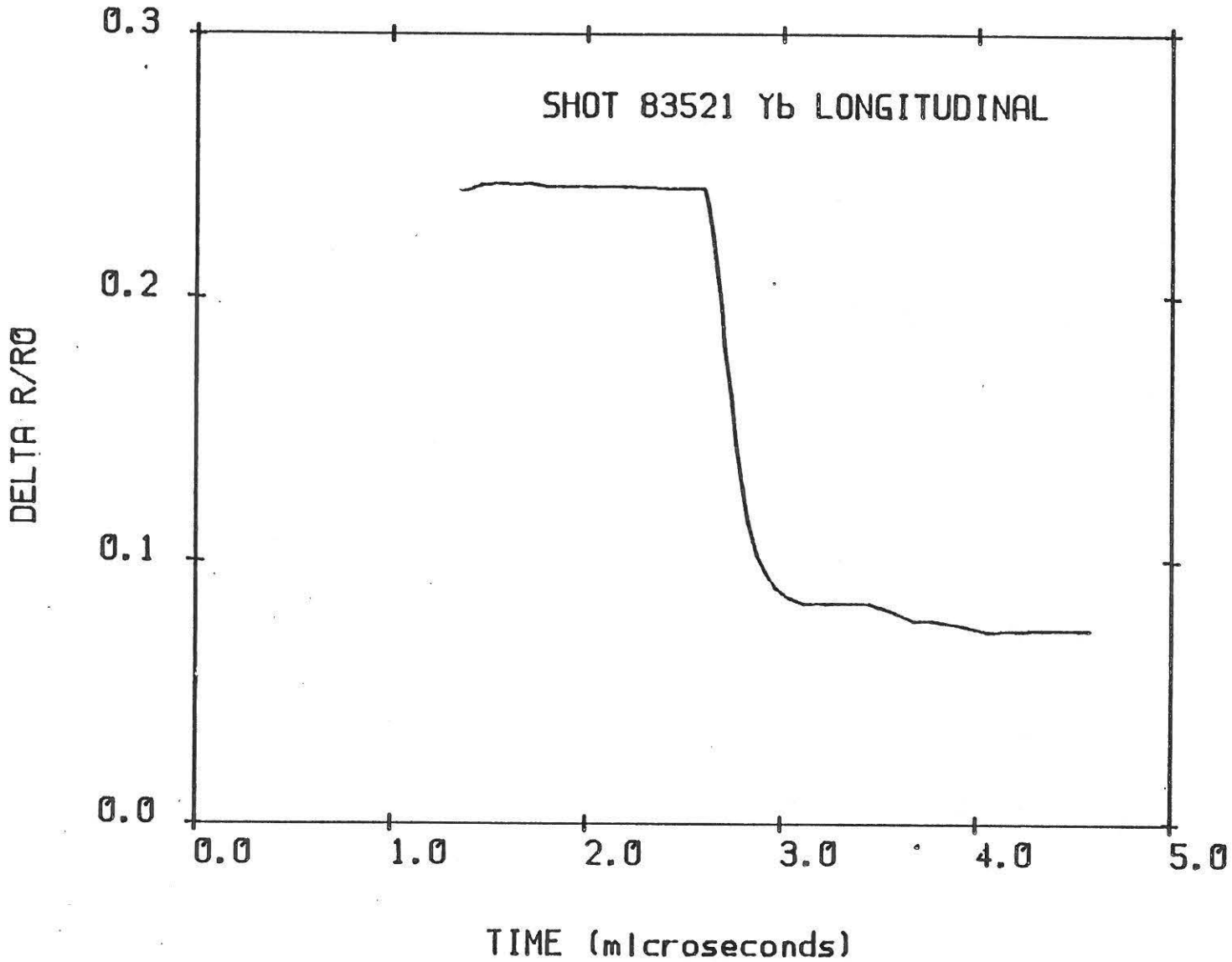

SHOT 83512 Yb LONGITUDINAL
DELTA R/R0
0.05
0.04
0.03
0.02
0.01
0.00
0.0
1.0
2.0
3.0
4.0
5.0
TIME (microseconds)

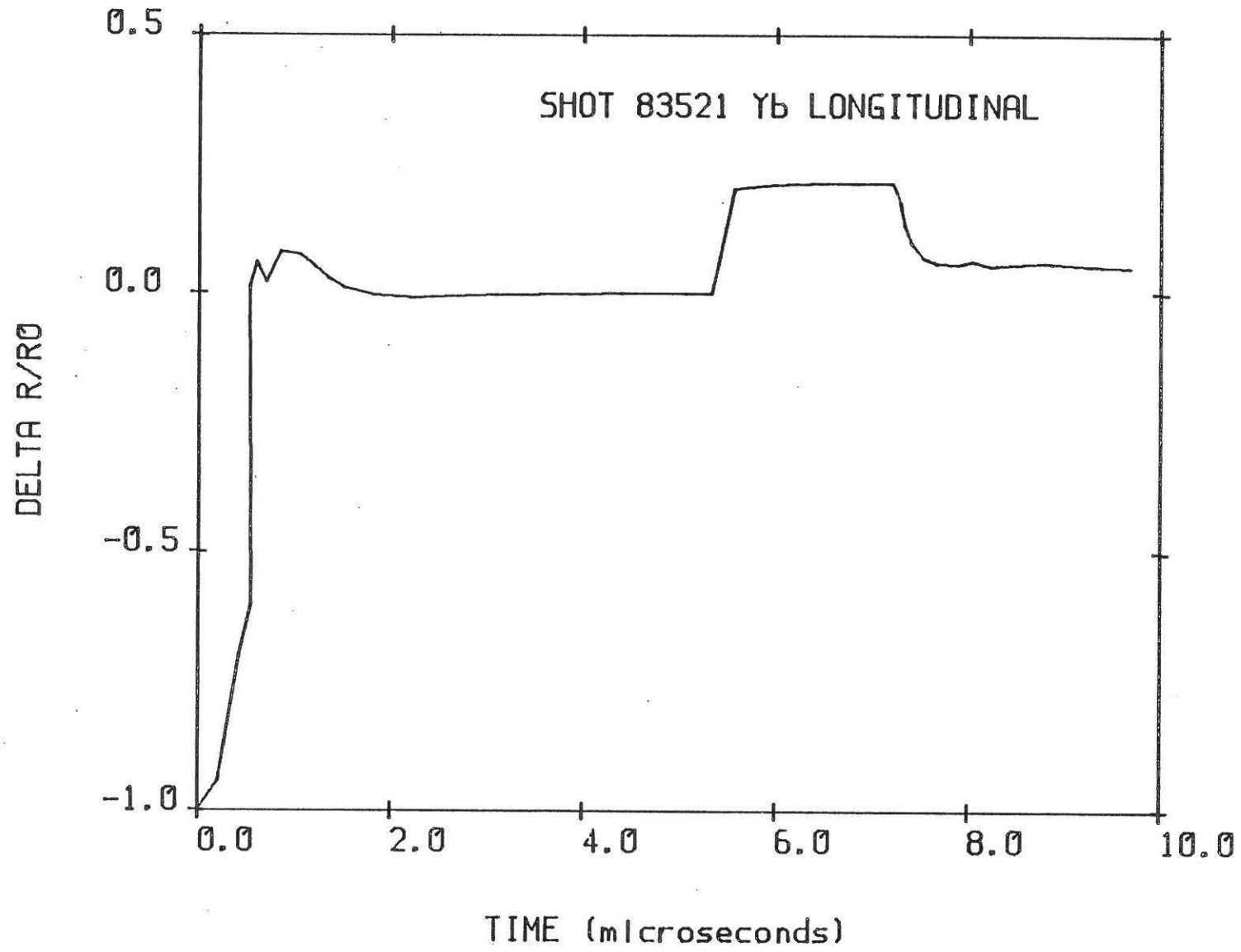

SHOT 83512 Yb LONGITUDINAL
GAUGE VOLTAGE (volts)
2.0
1.5
1.0
0.5
0.0
0.0
2.0
4.0
6.0
8.0
10.0
TIME (microseconds)

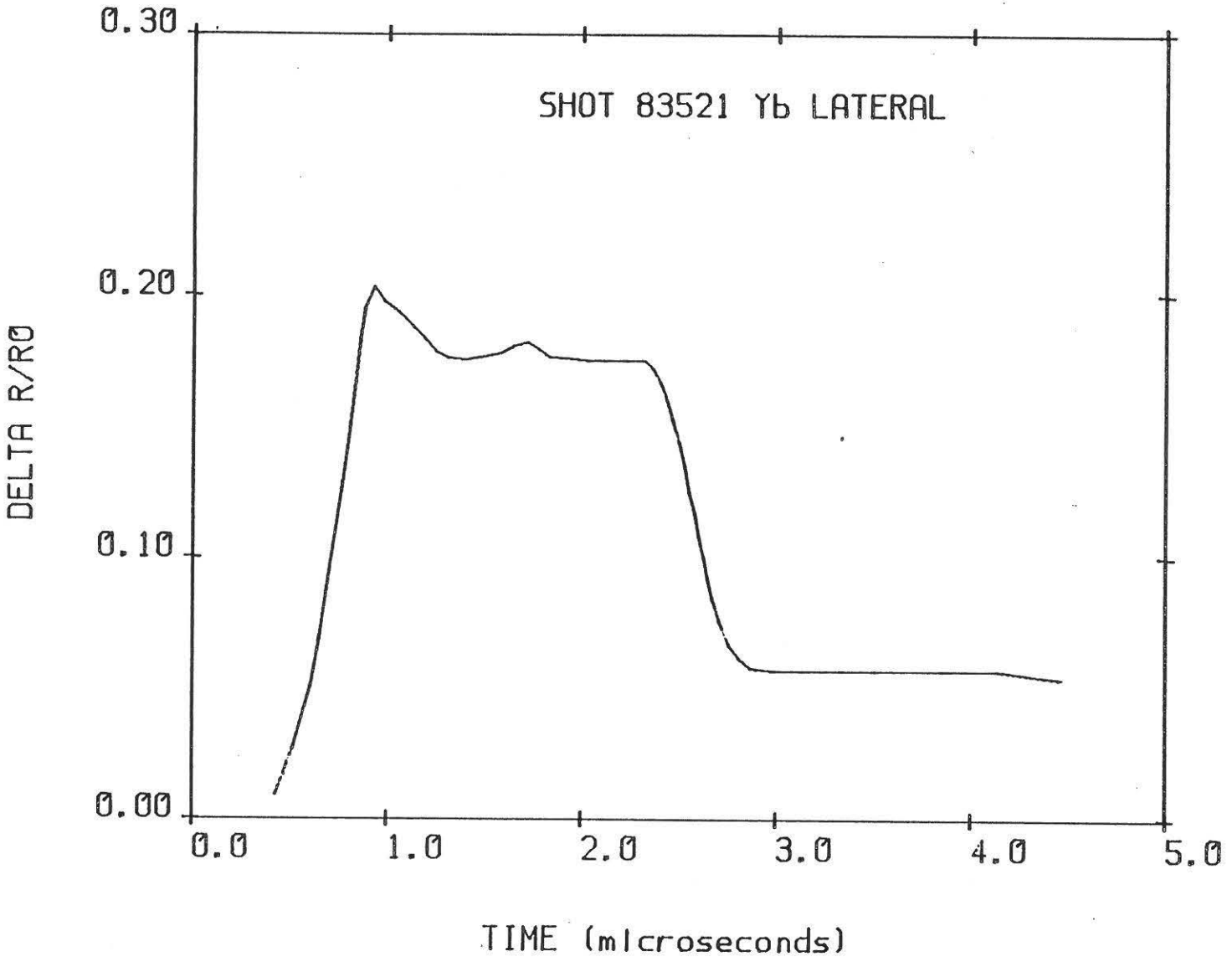

SHOT 83512 Yb LATERAL
0.10
0.08
0.06
0.04
0.02
0.00
DELTA R/R0
0.0
1.0
2.0
3.0
4.0
5.0
TIME (microseconds)

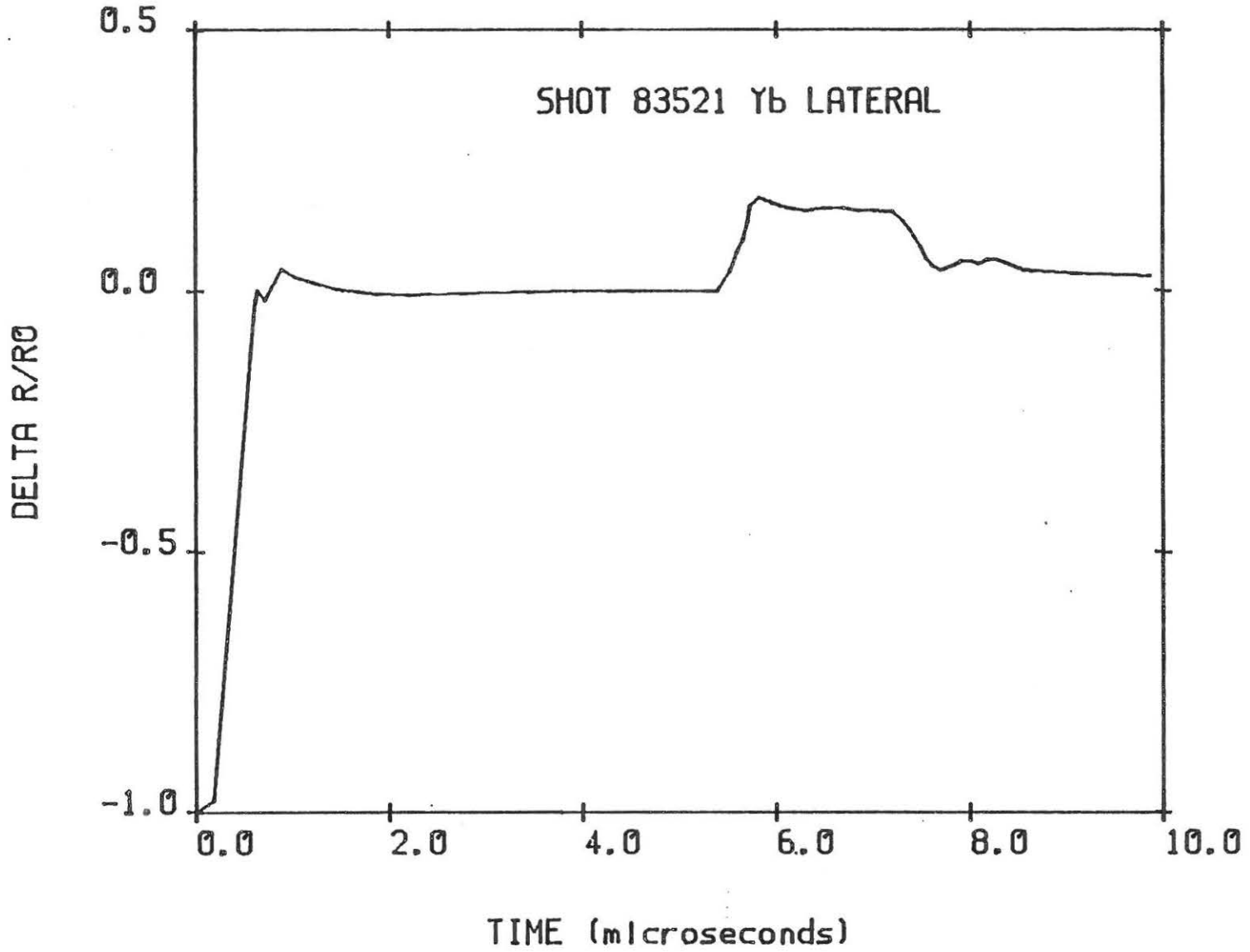

SHOT 83512 Yb LATERAL
GAUGE VOLTAGE (volts)
2.0
1.5
1.0
0.5
0.0
0.0
2.0
4.0
6.0
8.0
10.0
TIME (microseconds)

Shot Number:	83-521
Projectile Velocity:	0.202 mm/μs
Shock Stress:	3.6 kbar
Impactor Material:	PMMA
Impactor Thickness:	2.95 mm
Gauge Depth in PMMA Matrix:	1.0 mm
Gauges Embedded in PMMA Matrix:	2 gauges one lateral and one longitudinal ytterbium.


SHOT 83521 Yb LONGITUDINAL
DELTA R/R0
0.3
0.2
0.1
0.0
0.0
1.0
2.0
3.0
4.0
5.0
TIME (microseconds)

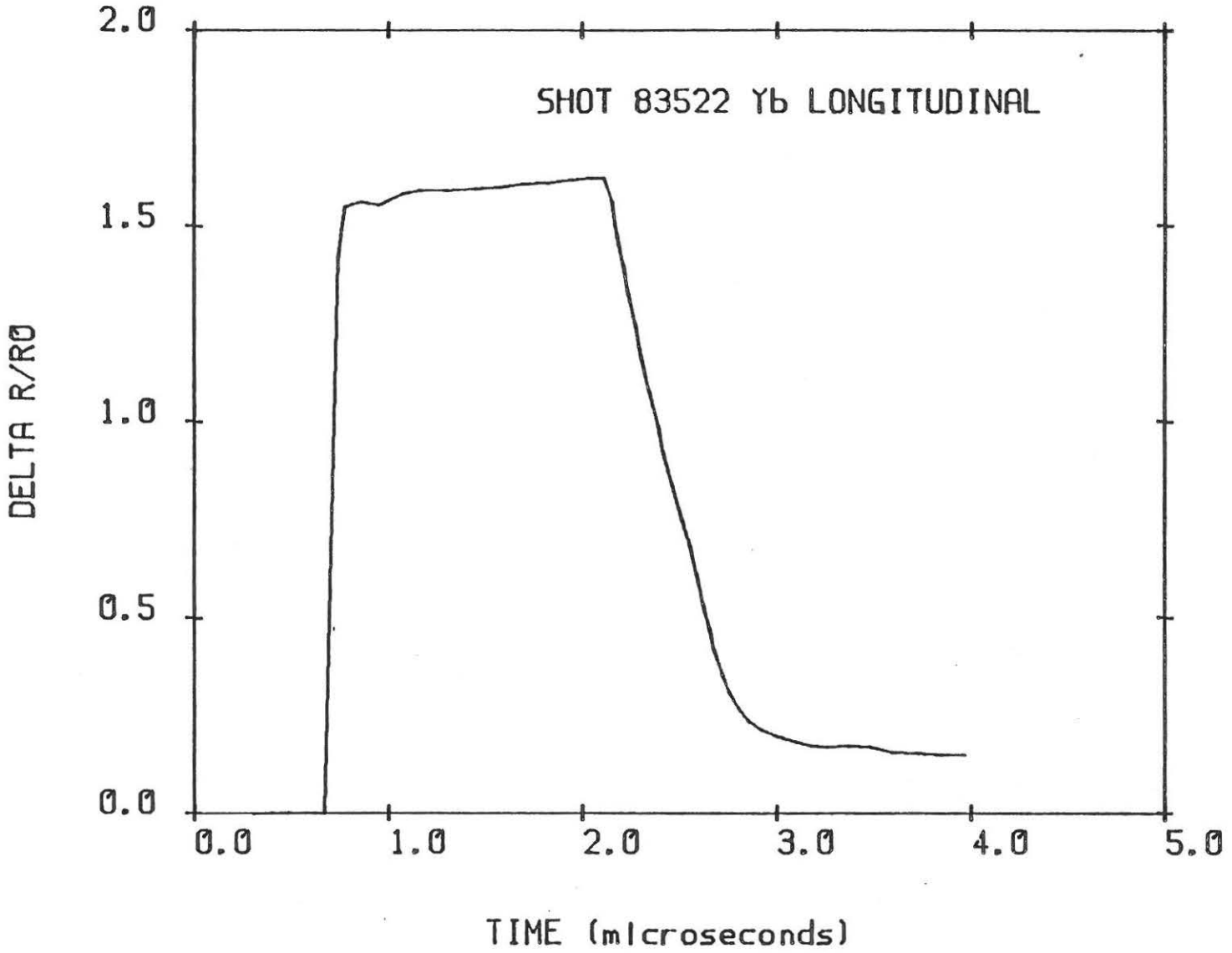

SHOT 83521 Yb LONGITUDINAL
0.5
0.0
-0.5
-1.0
DELTA R/R0
0.0
2.0
4.0
6.0
8.0
10.0
TIME (microseconds)

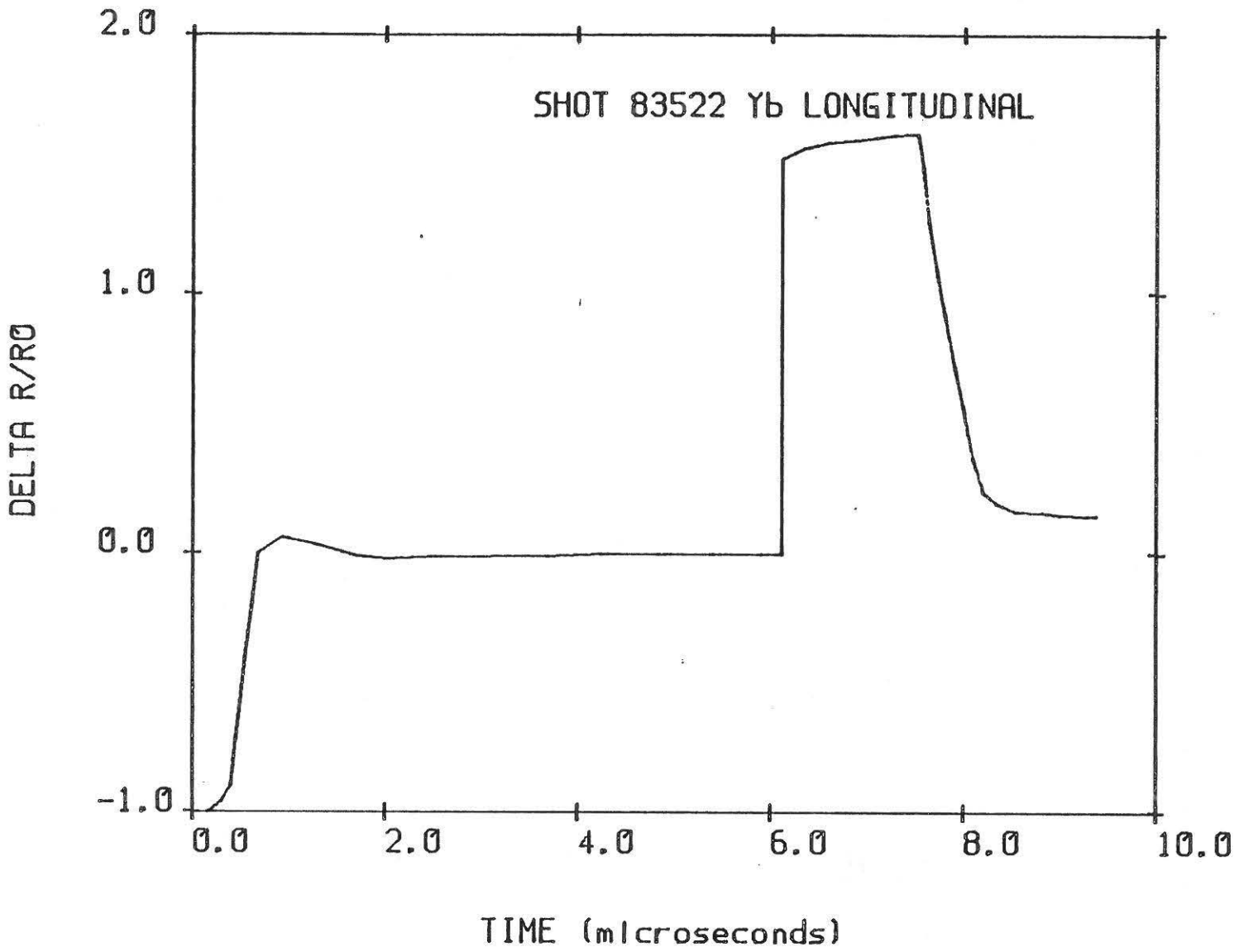

SHOT 83521 Yb LATERAL
0.30
0.20
0.10
0.00
DELTA R/R0
0.0
1.0
2.0
3.0
4.0
5.0
TIME (microseconds)

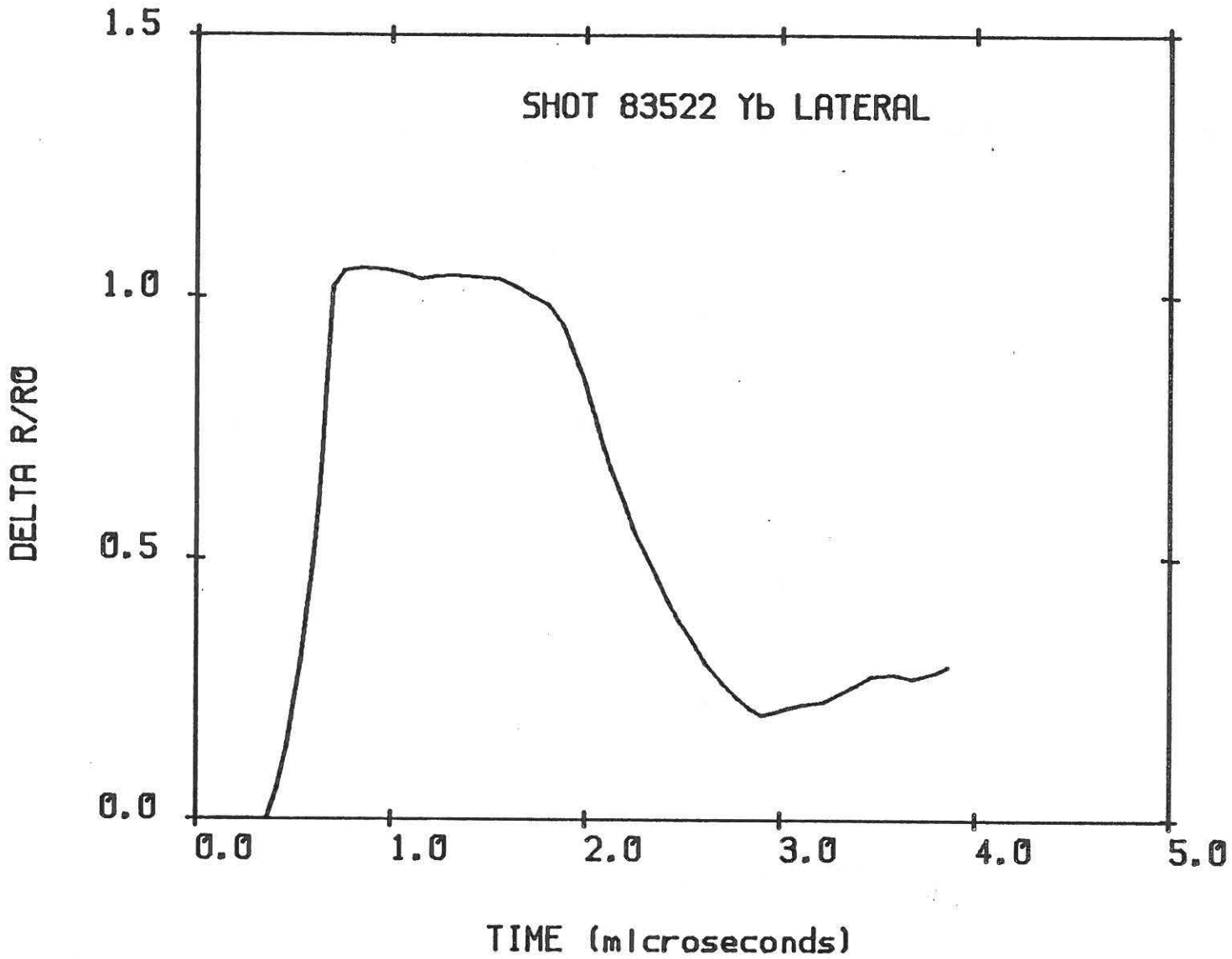

SHOT 83521 Yb LATERAL
0.5
0.0
-0.5
-1.0
DELTA R/R0
0.0
2.0
4.0
6.0
8.0
10.0
TIME (microseconds)

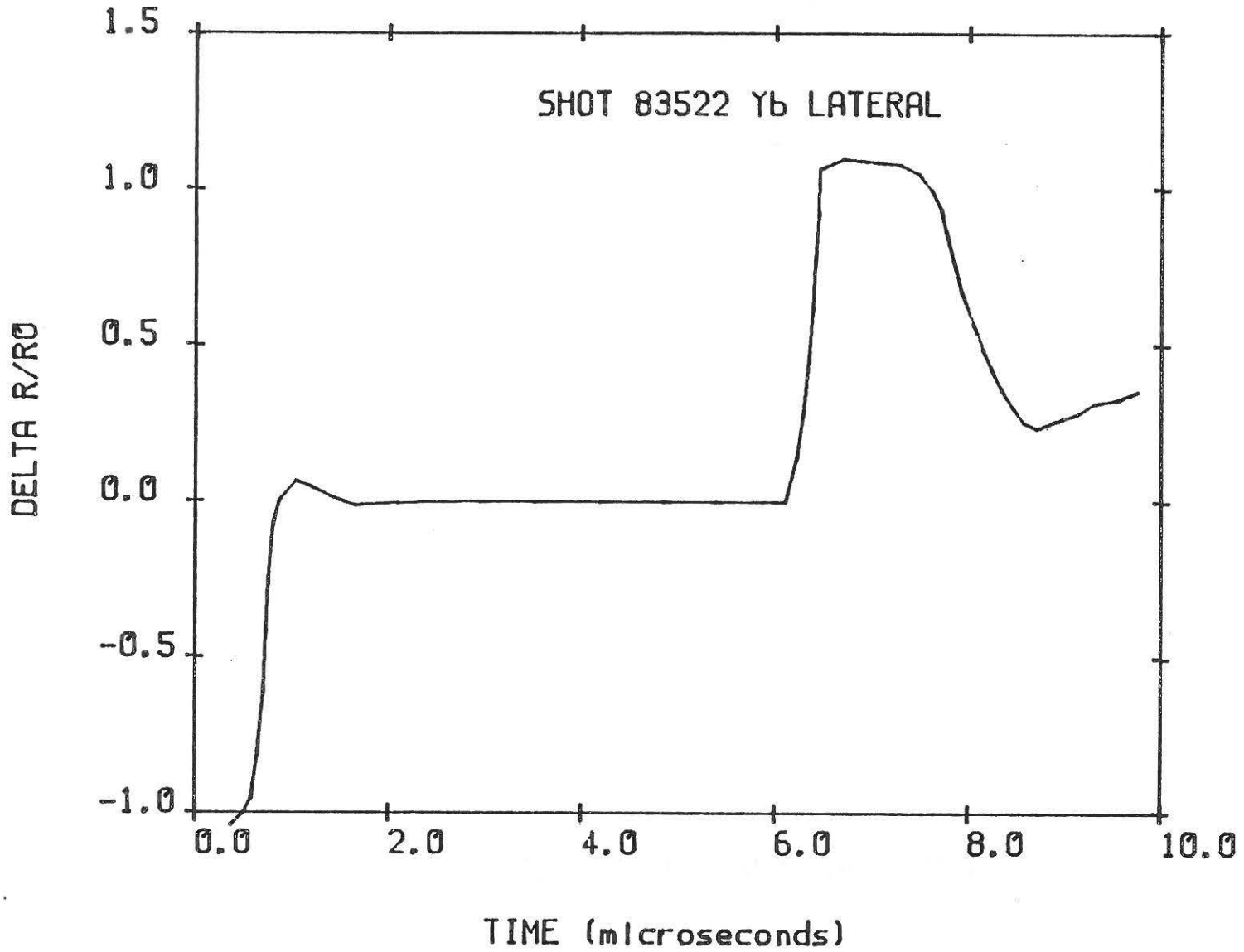
Shot Number:	83-522
Projectile Velocity:	0.788 mm/μs
Shock Stress:	15.1 kbar
Impactor Material:	PMMA
Impactor Thickness:	2.84 mm
Gauge Depth in PMMA Matrix:	1.01 mm
Gauges Embedded in PMMA Matrix:	4 gauges one longitudinal and one lateral ytterbium; one longitudinal and on lateral manganin

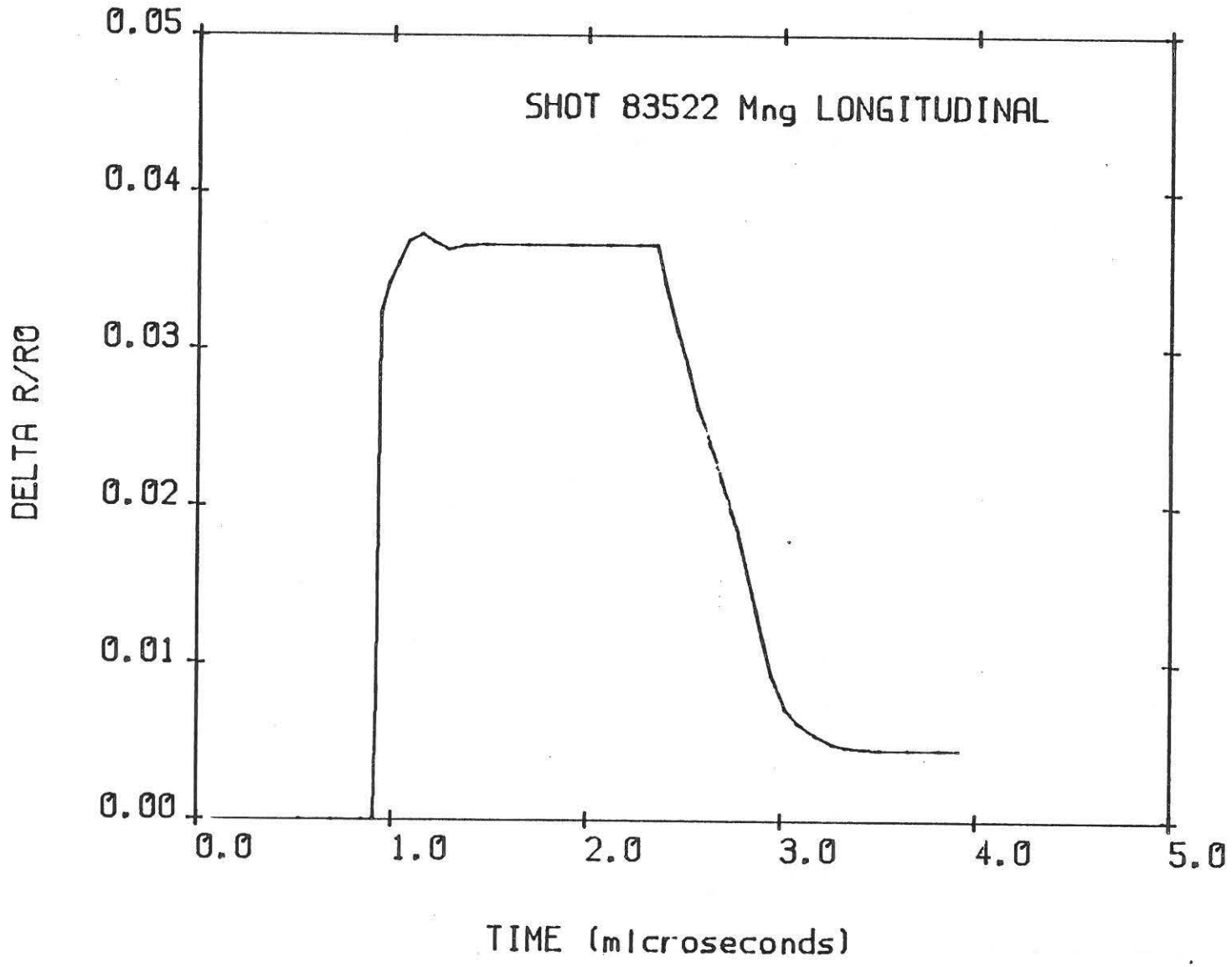
Remarks:

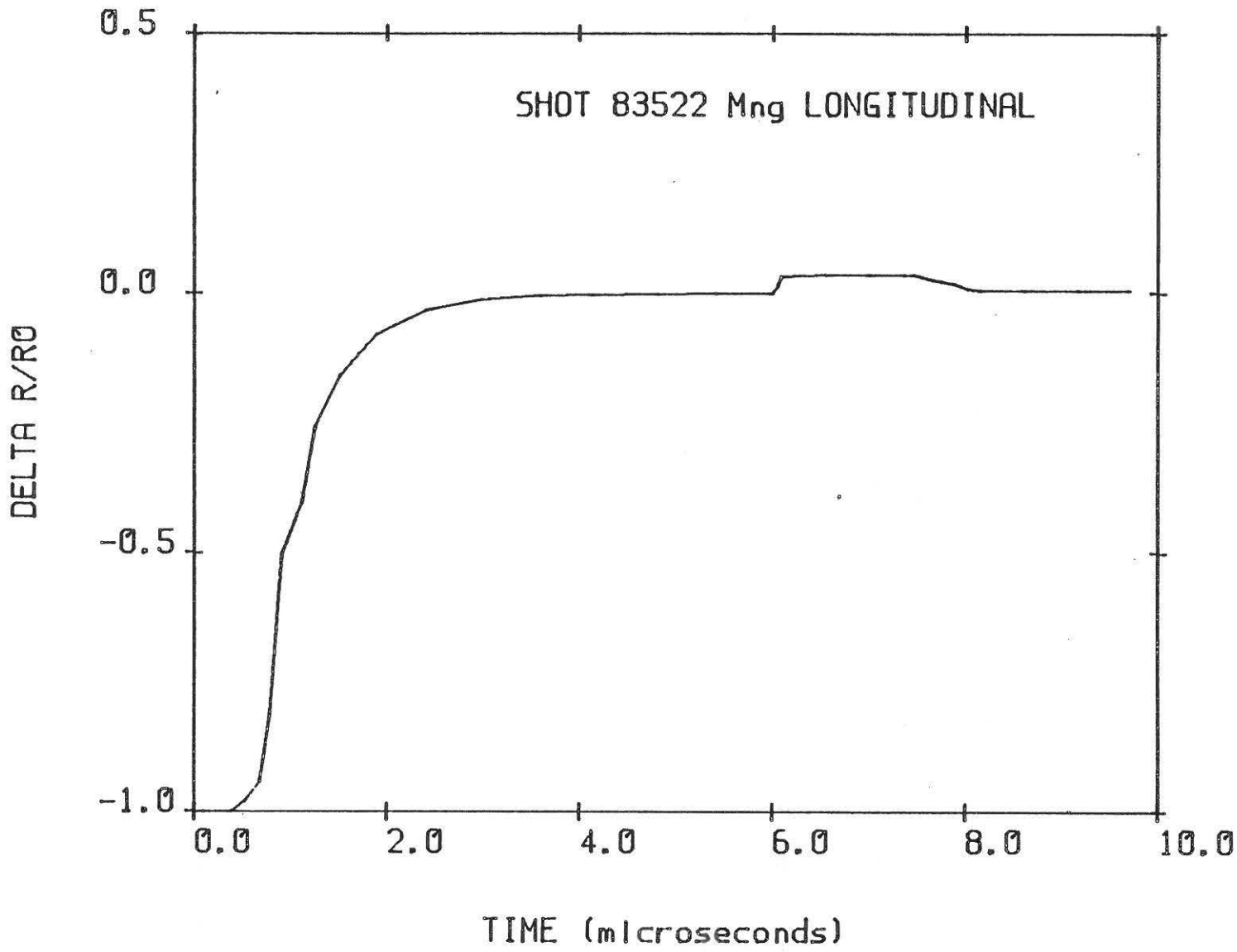

SHOT 83522 Yb LONGITUDINAL
DELTA R/R0
2.0
1.5
1.0
0.5
0.0
0.0
1.0
2.0
3.0
4.0
5.0
TIME (microseconds)

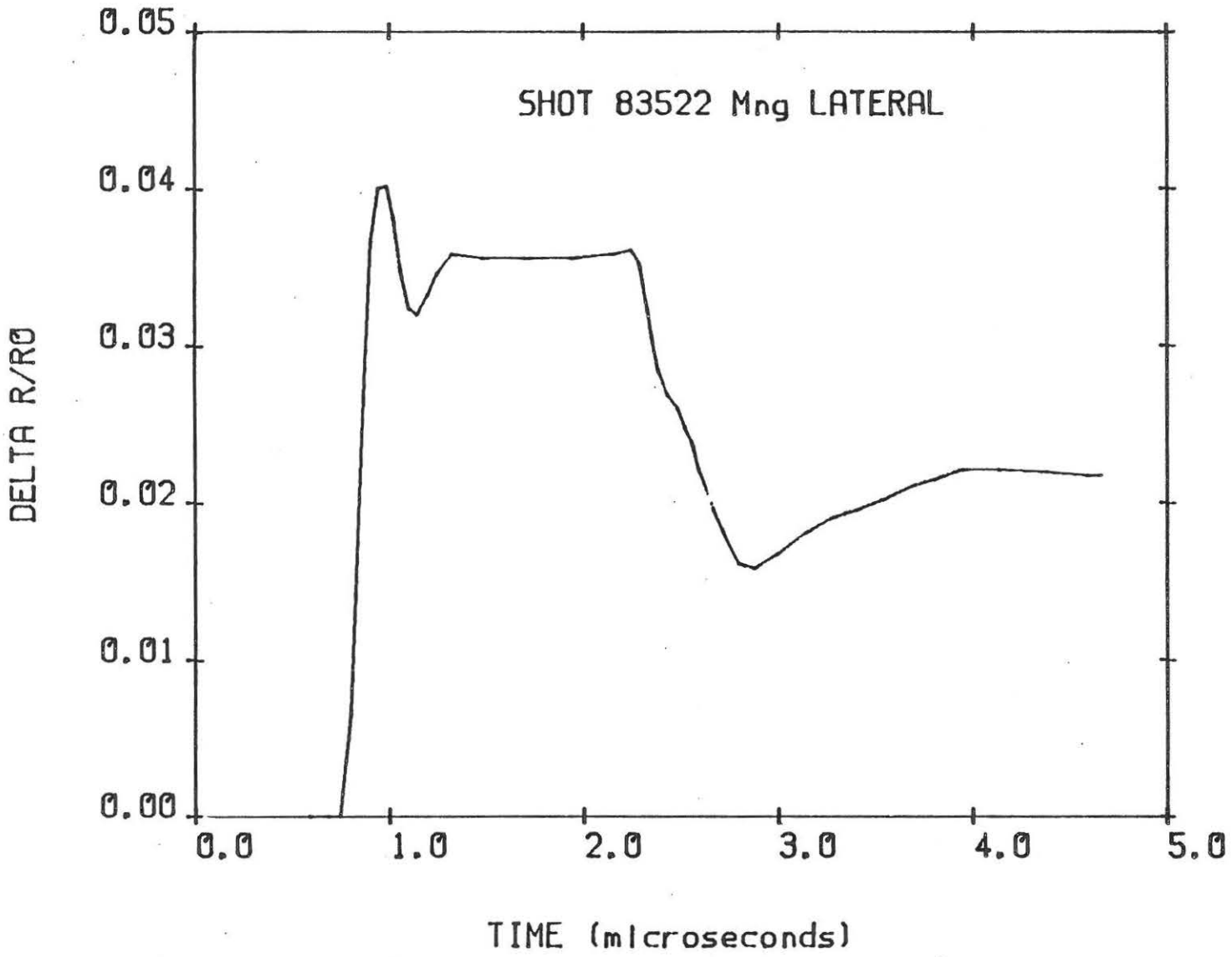

SHOT 83522 Yb LONGITUDINAL
2.0
1.0
0.0
-1.0
DELTA R/R0
0.0
2.0
4.0
6.0
8.0
10.0
TIME (microseconds)

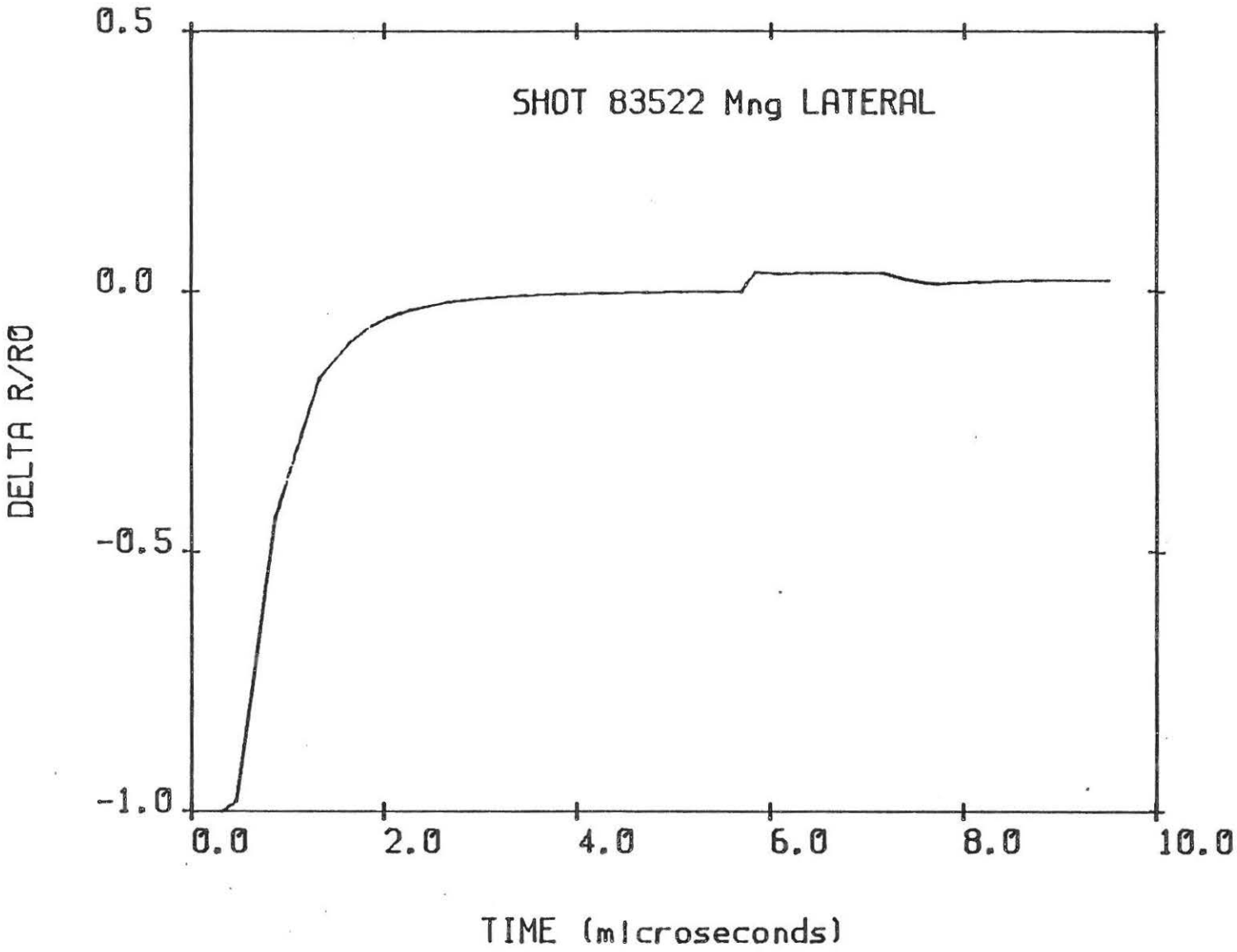

SHOT 83522 Yb LATERAL
DELTA R/R0
1.5
1.0
0.5
0.0
0.0
1.0
2.0
3.0
4.0
5.0
TIME (microseconds)


SHOT 83522 Yb LATERAL
1.5
1.0
0.5
0.0
-0.5
-1.0
DELTA R/R0
0.0
2.0
4.0
6.0
8.0
10.0
TIME (microseconds)


SHOT 83522 Mng LONGITUDINAL
DELTA R/R0
0.05
0.04
0.03
0.02
0.01
0.00
0.0
1.0
2.0
3.0
4.0
5.0
TIME (microseconds)

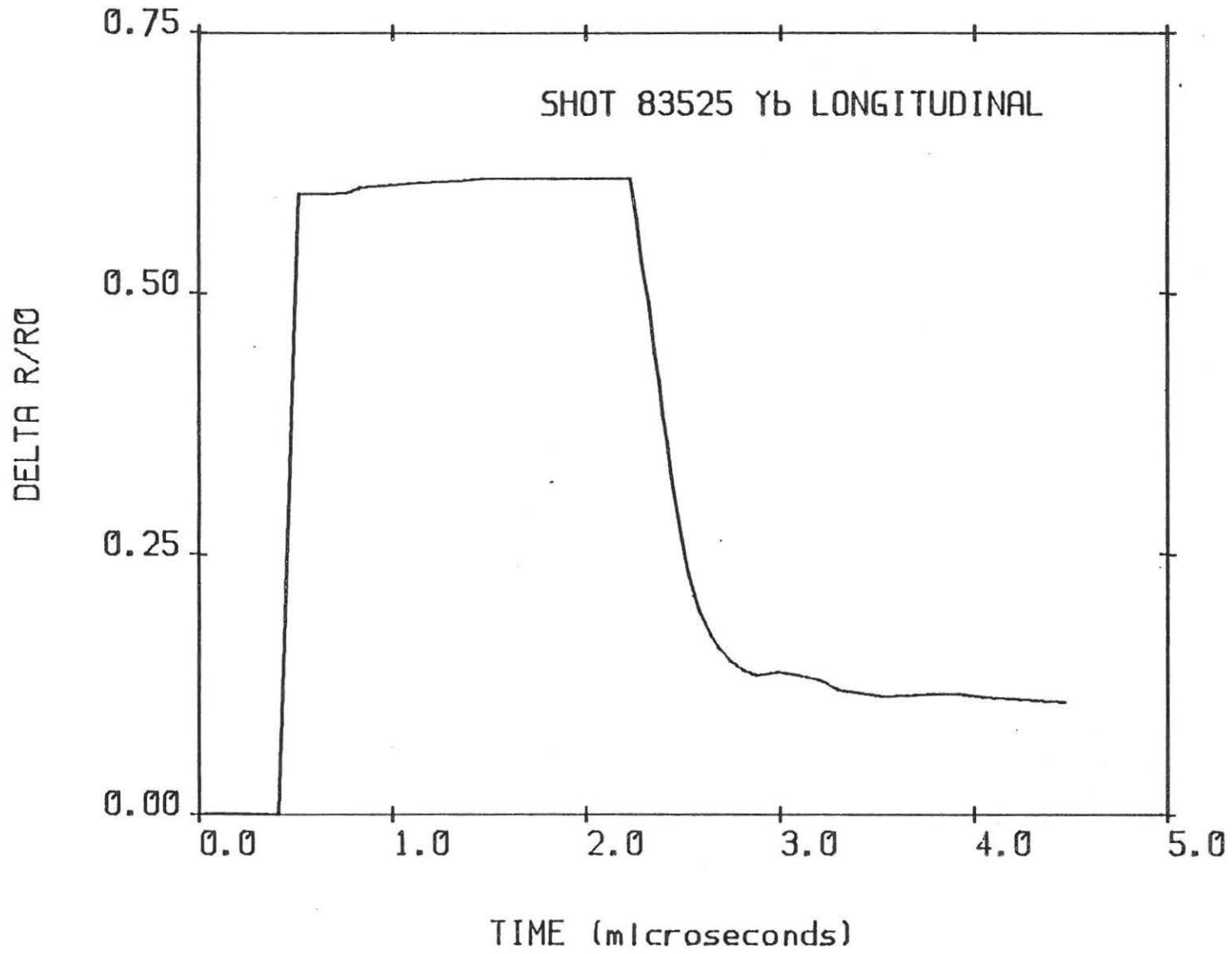

SHOT 83522 Mng LONGITUDINAL
0.5
0.0
-0.5
-1.0
DELTA R/R0
0.0
2.0
4.0
6.0
8.0
10.0
TIME (microseconds)

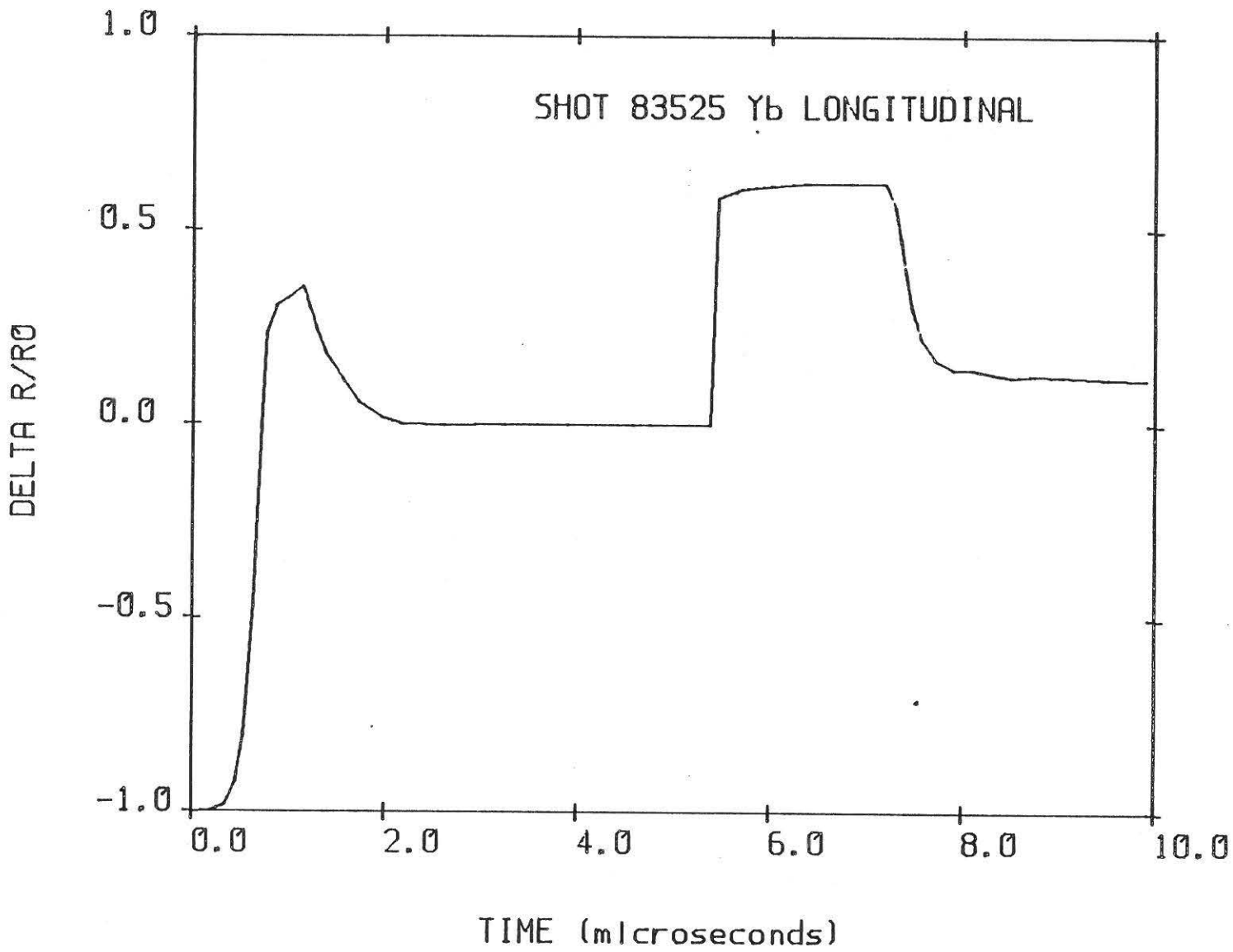

SHOT 83522 Mng LATERAL
0.05
0.04
0.03
0.02
0.01
0.00
DELTA R/R0
0.0
1.0
2.0
3.0
4.0
5.0
TIME (microseconds)

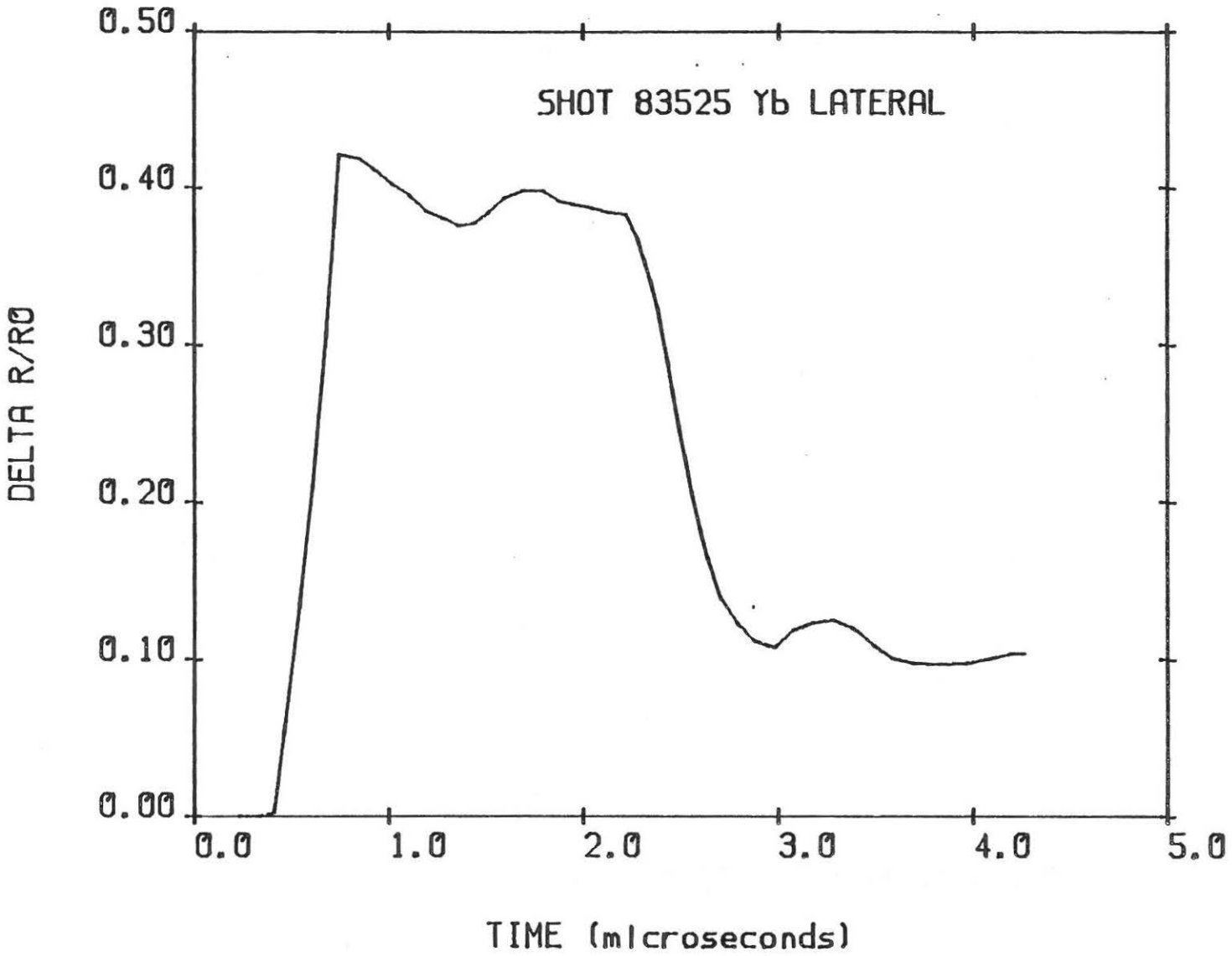

SHOT 83522 Mng LATERAL
0.5
0.0
-0.5
-1.0
DELTA R/R0
0.0
2.0
4.0
6.0
8.0
10.0
TIME (microseconds)

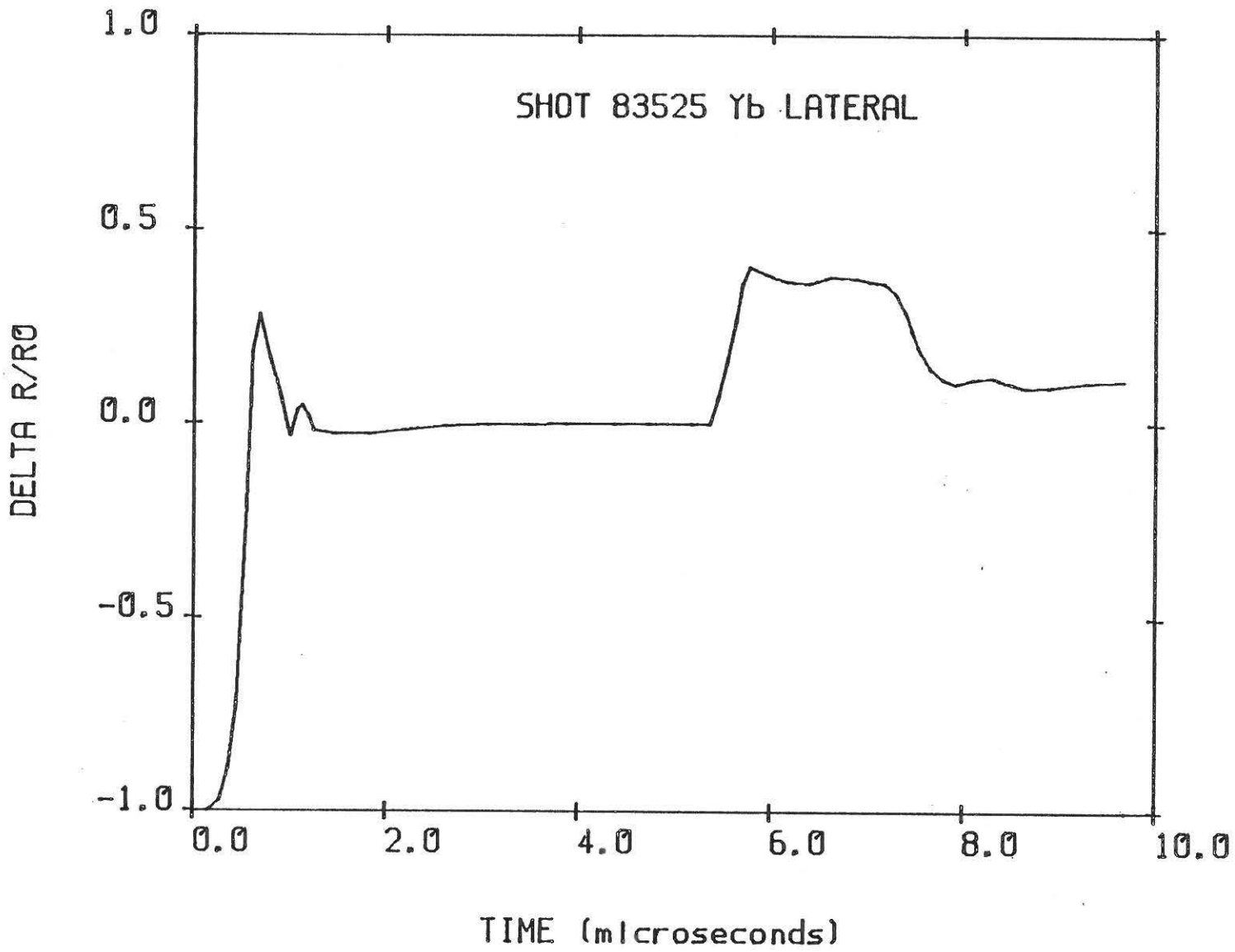
Shot Number:	83-525
Projectile Velocity:	0.398 mm/μs
Shock Stress:	7.4 kbar
Impactor Material:	PMMA
Impactor Thickness:	3.048 mm
Gauge Depth in PMMA Matrix:	0.955 mm
Gauges Embedded in PMMA Matrix:	4 gauges one longitudinal and one lateral ytterbium; one longitudinal and one lateral manganin.

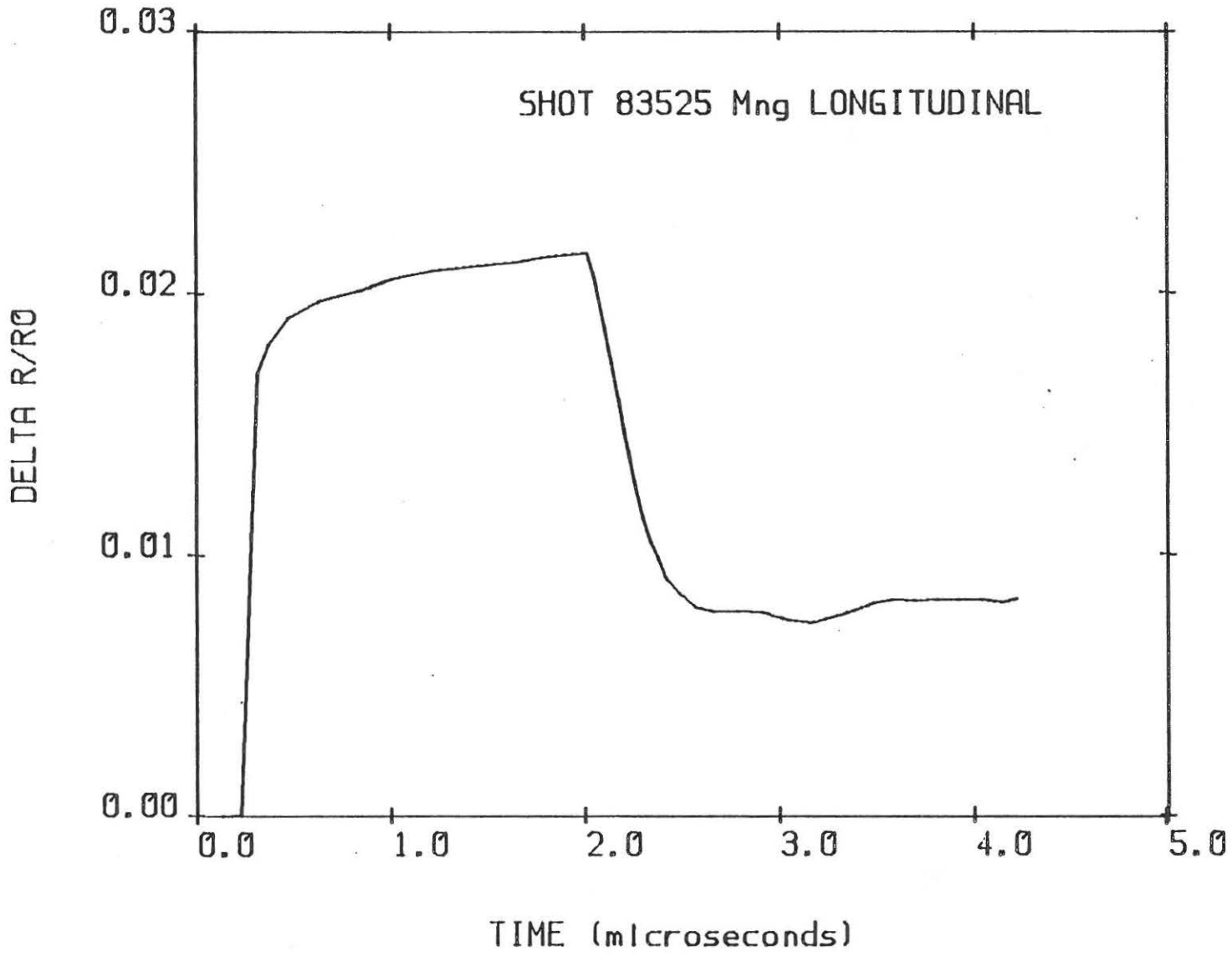
Remarks:

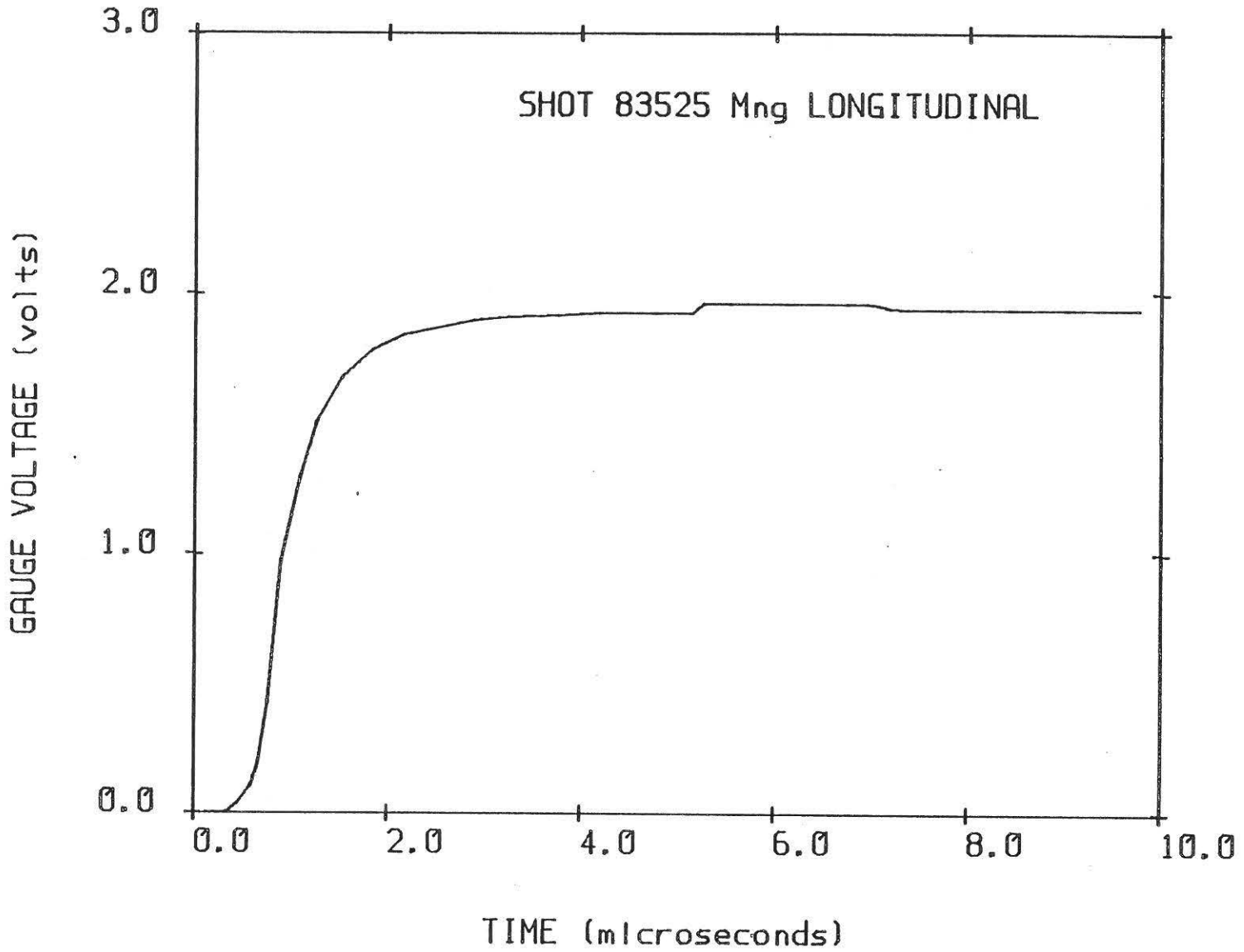

SHOT 83525 Yb LONGITUDINAL
0.75
0.50
0.25
0.00
DELTA R/R0
0.0
1.0
2.0
3.0
4.0
5.0
TIME (microseconds)

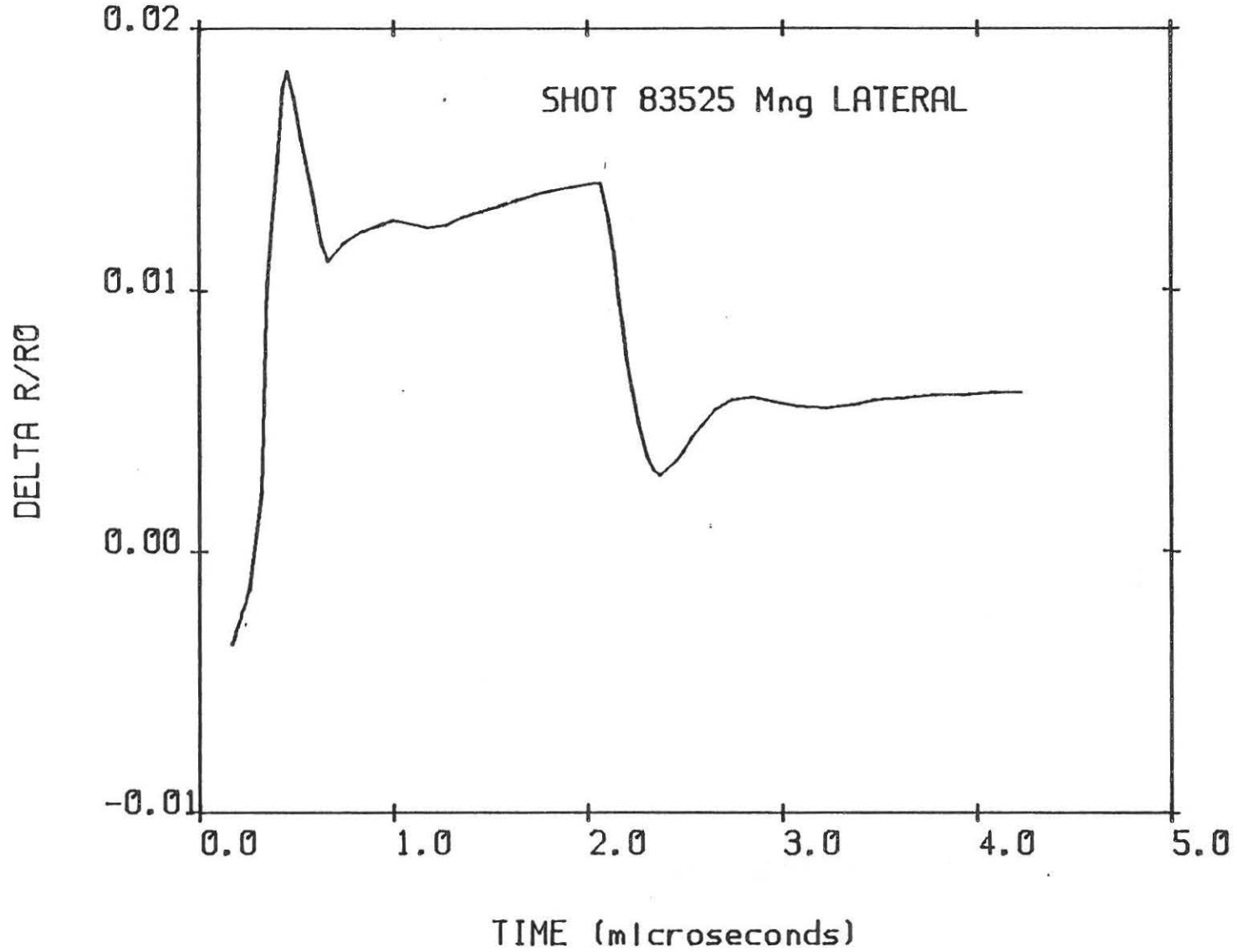

SHOT 83525 Yb LONGITUDINAL
1.0
0.5
0.0
-0.5
-1.0
DELTA R/R0
0.0
2.0
4.0
6.0
8.0
10.0
TIME (microseconds)

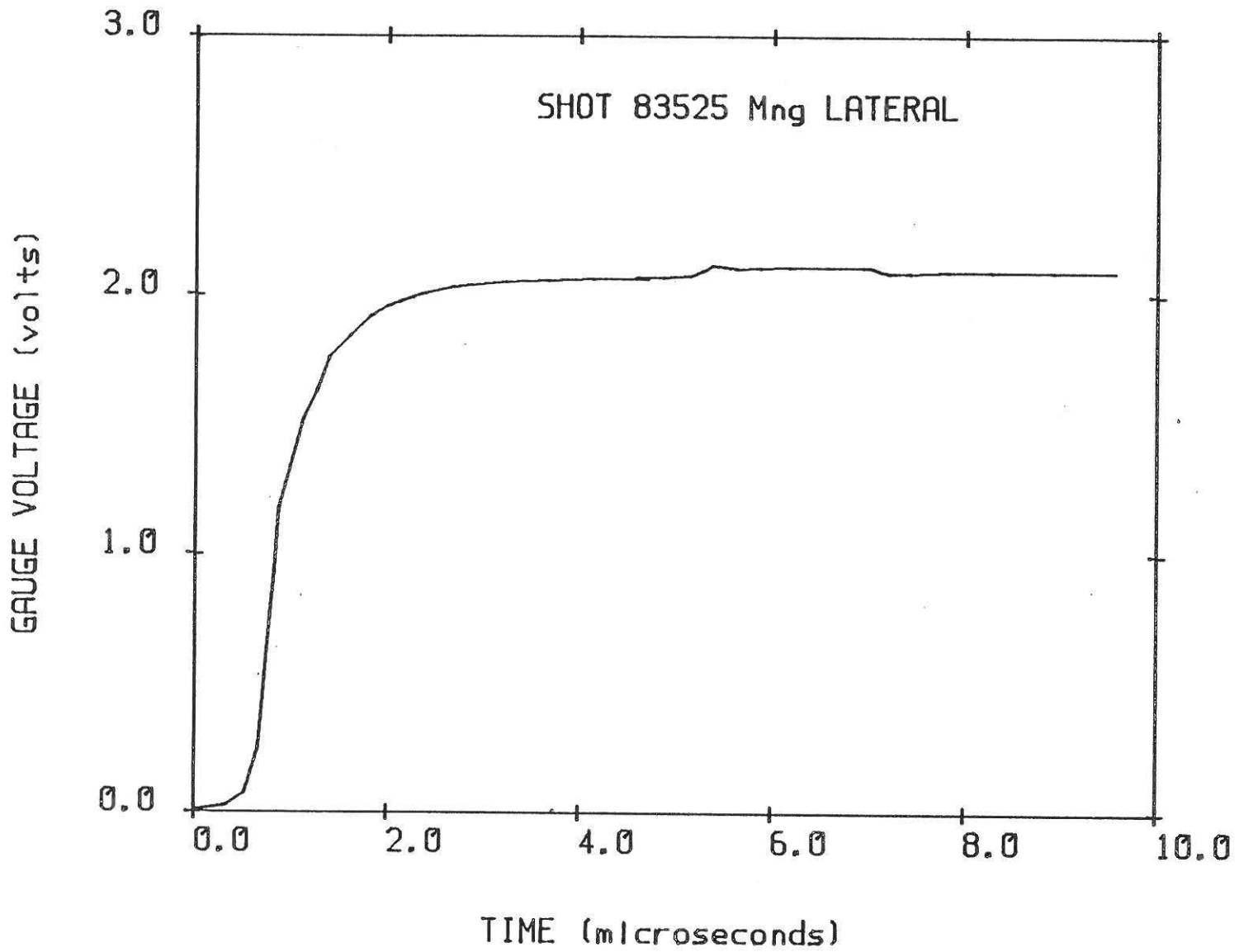

SHOT 83525 Yb LATERAL
0.50
0.40
0.30
0.20
0.10
0.00
DELTA R/R0
0.0
1.0
2.0
3.0
4.0
5.0
TIME (microseconds)


SHOT 83525 Yb LATERAL
1.0
0.5
0.0
-0.5
-1.0
DELTA R/R0
0.0
2.0
4.0
6.0
8.0
10.0
TIME (microseconds)

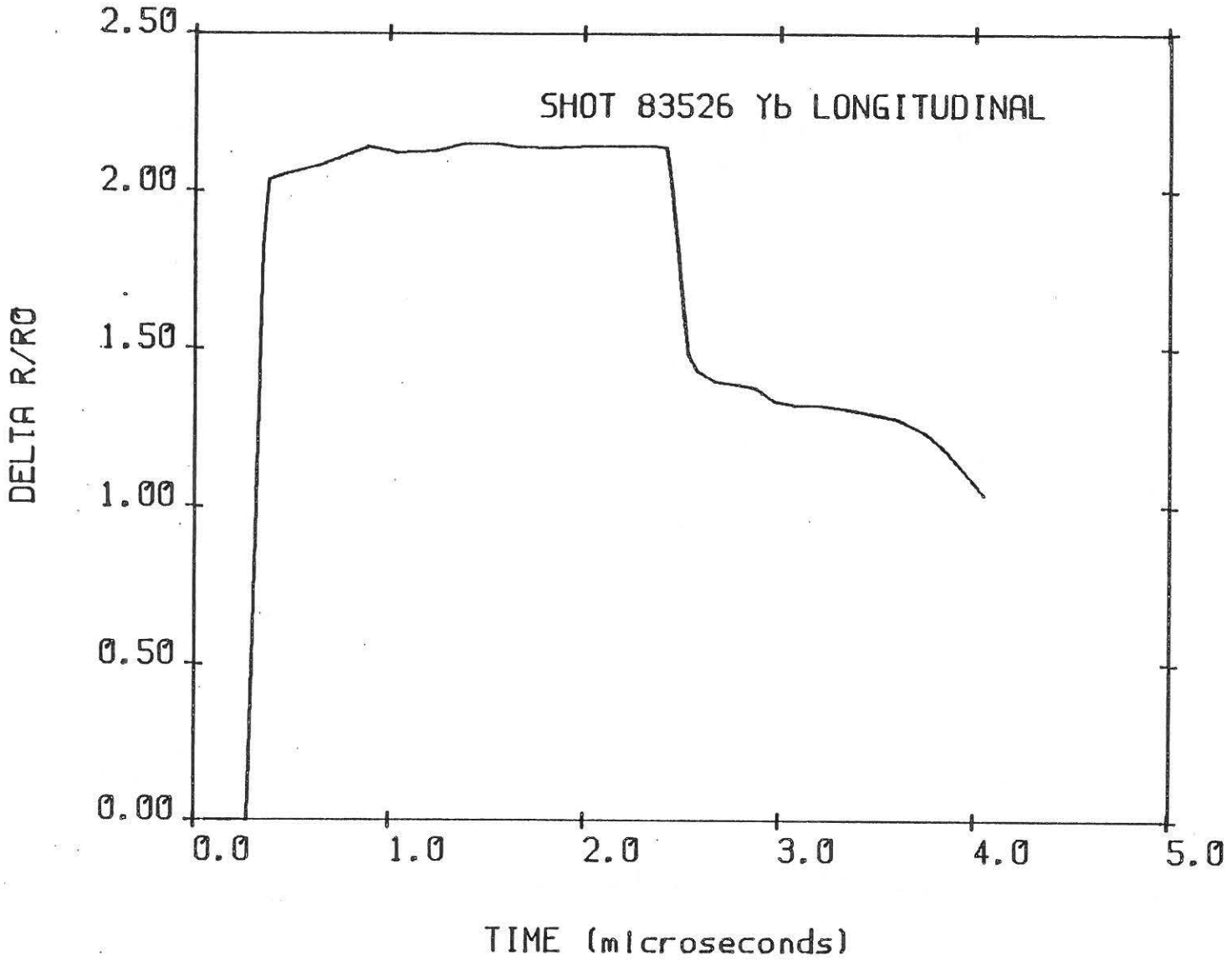

SHOT 83525 Mng LONGITUDINAL
DELTA R/R0
0.03
0.02
0.01
0.00
0.0
1.0
2.0
3.0
4.0
5.0
TIME (microseconds)

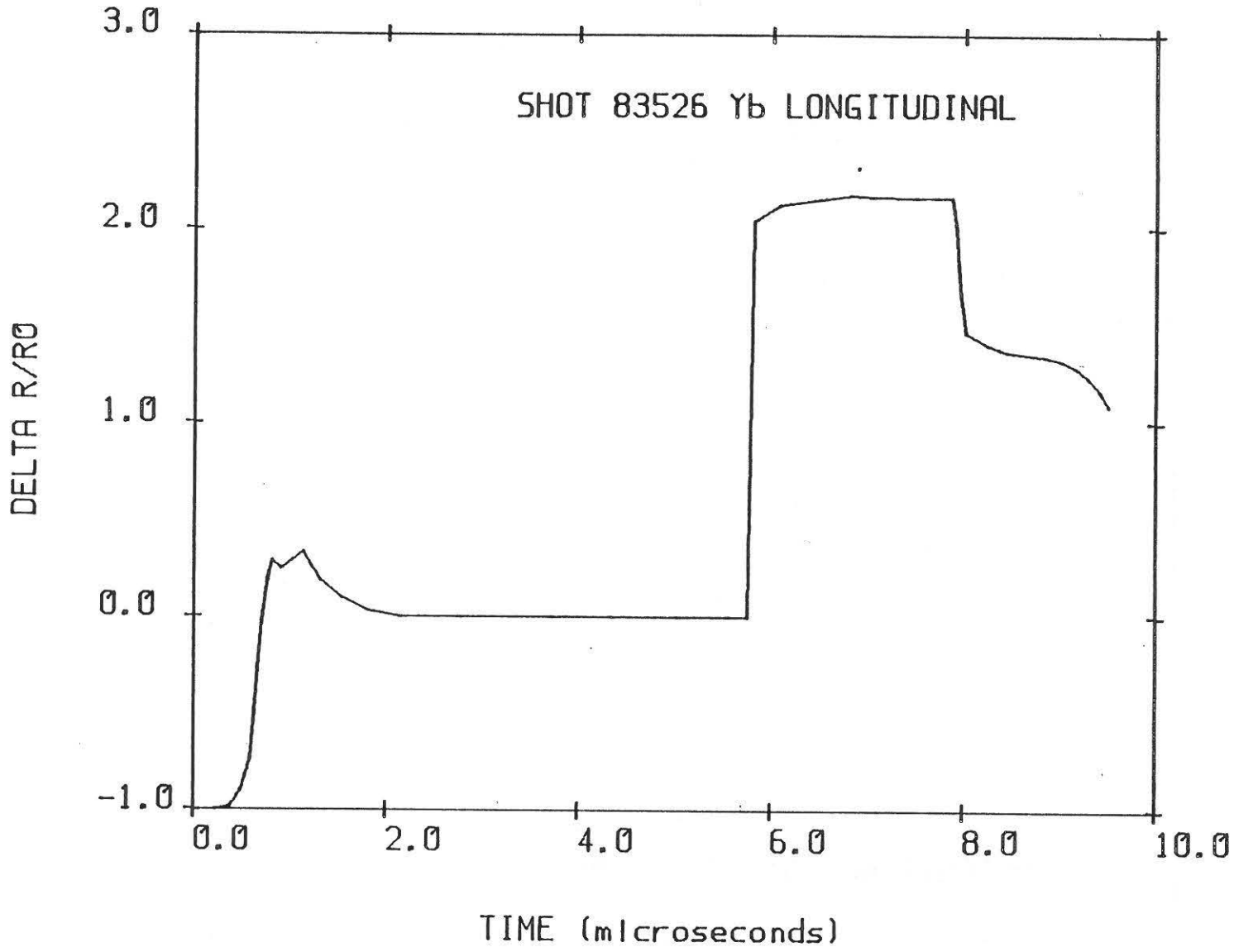

SHOT 83525 Mng LONGITUDINAL
GAUGE VOLTAGE (volts)
3.0
2.0
1.0
0.0
0.0
2.0
4.0
6.0
8.0
10.0
TIME (microseconds)

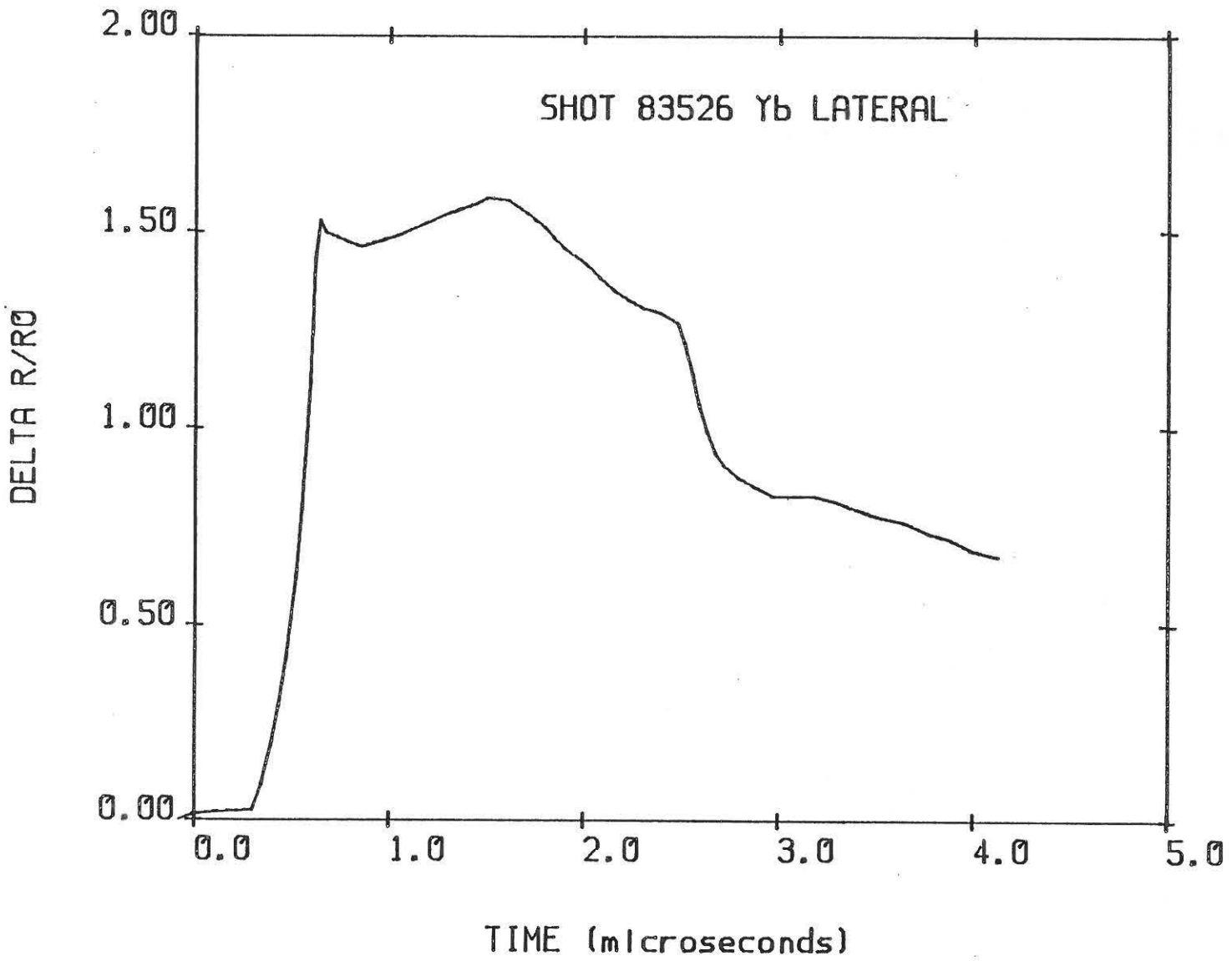

SHOT 83525 Mng LATERAL
0.02
0.01
0.00
-0.01
DELTA R/R0
0.0
1.0
2.0
3.0
4.0
5.0
TIME (microseconds)

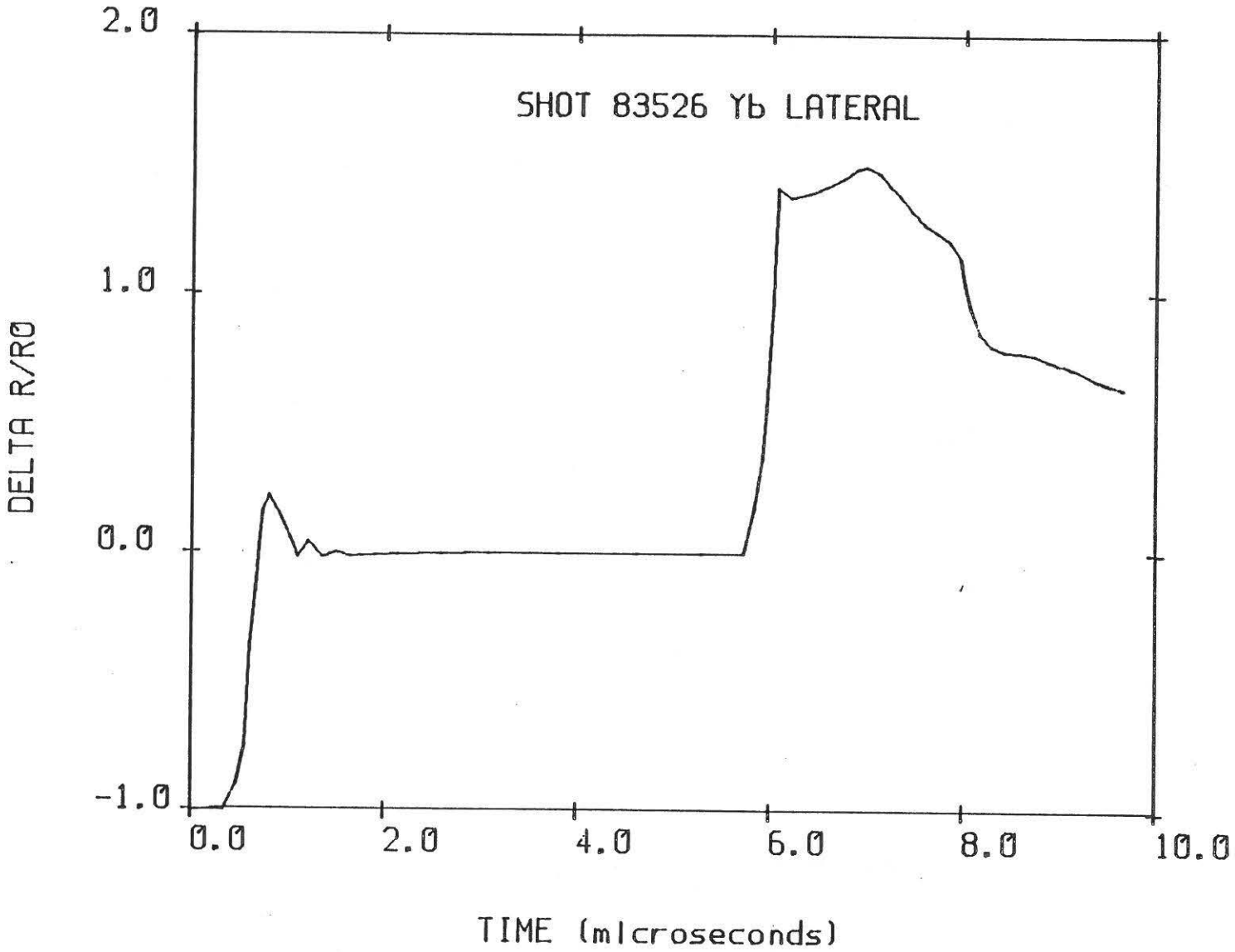

SHOT 83525 Mng LATERAL
GAUGE VOLTAGE (volts)
3.0
2.0
1.0
0.0
0.0
2.0
4.0
6.0
8.0
10.0
TIME (microseconds)

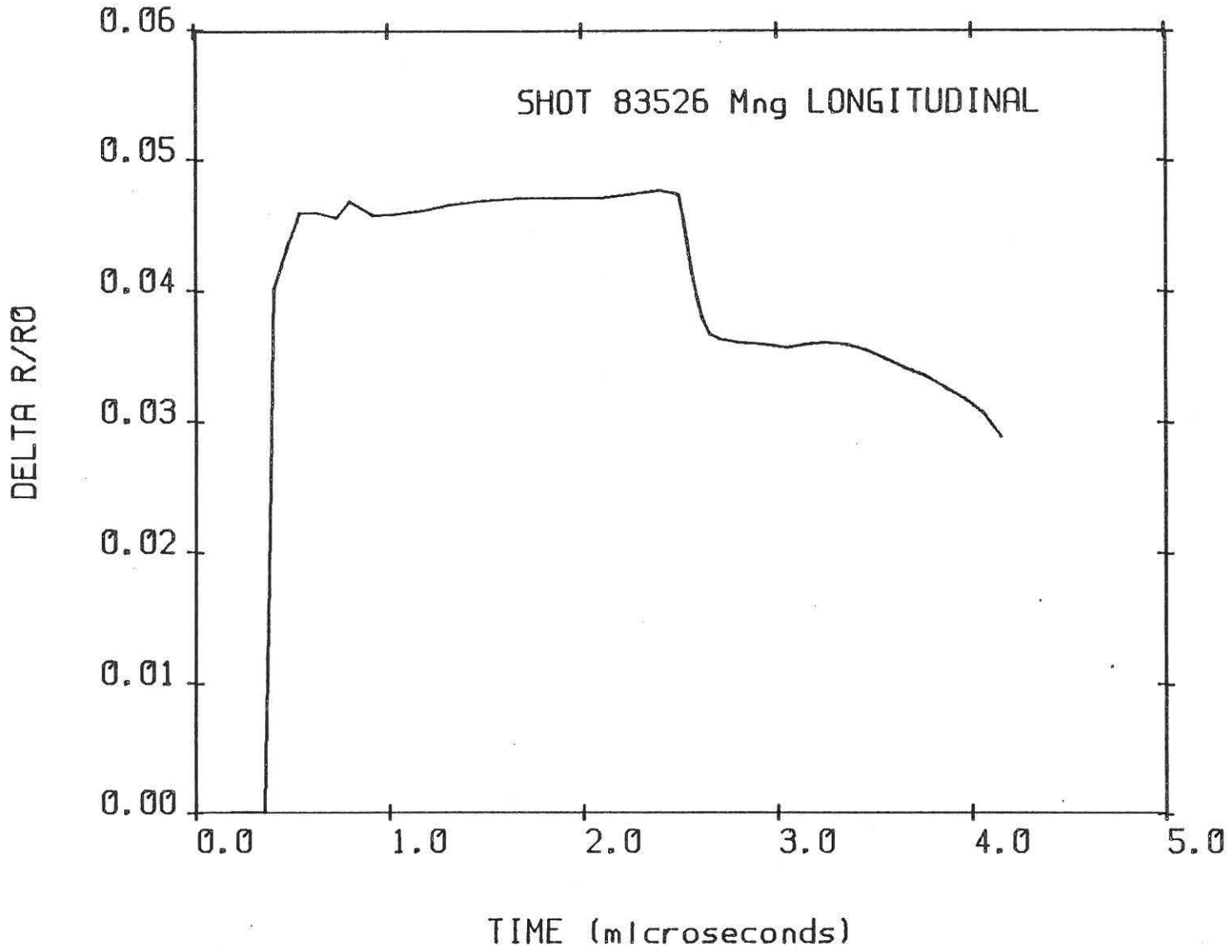
Shot Number:	83-526
Projectile Velocity:	0.605 mm/μs
Shock Stress:	18.4 kbar
Impactor Material:	Fused silica
Impactor Thickness:	6.35 mm
Gauge Depth in PMMA Matrix:	0.96 mm
Gauges Embedded in PMMA Matrix:	4 gauges one longitudinal and one lateral ytterbium; one longitudinal and one lateral manganin.
Remarks:	This experiment was designed to study step unloading response of the gauges. Only one step could be observed before the gauge was brokent by rarefaction waves from the edges.

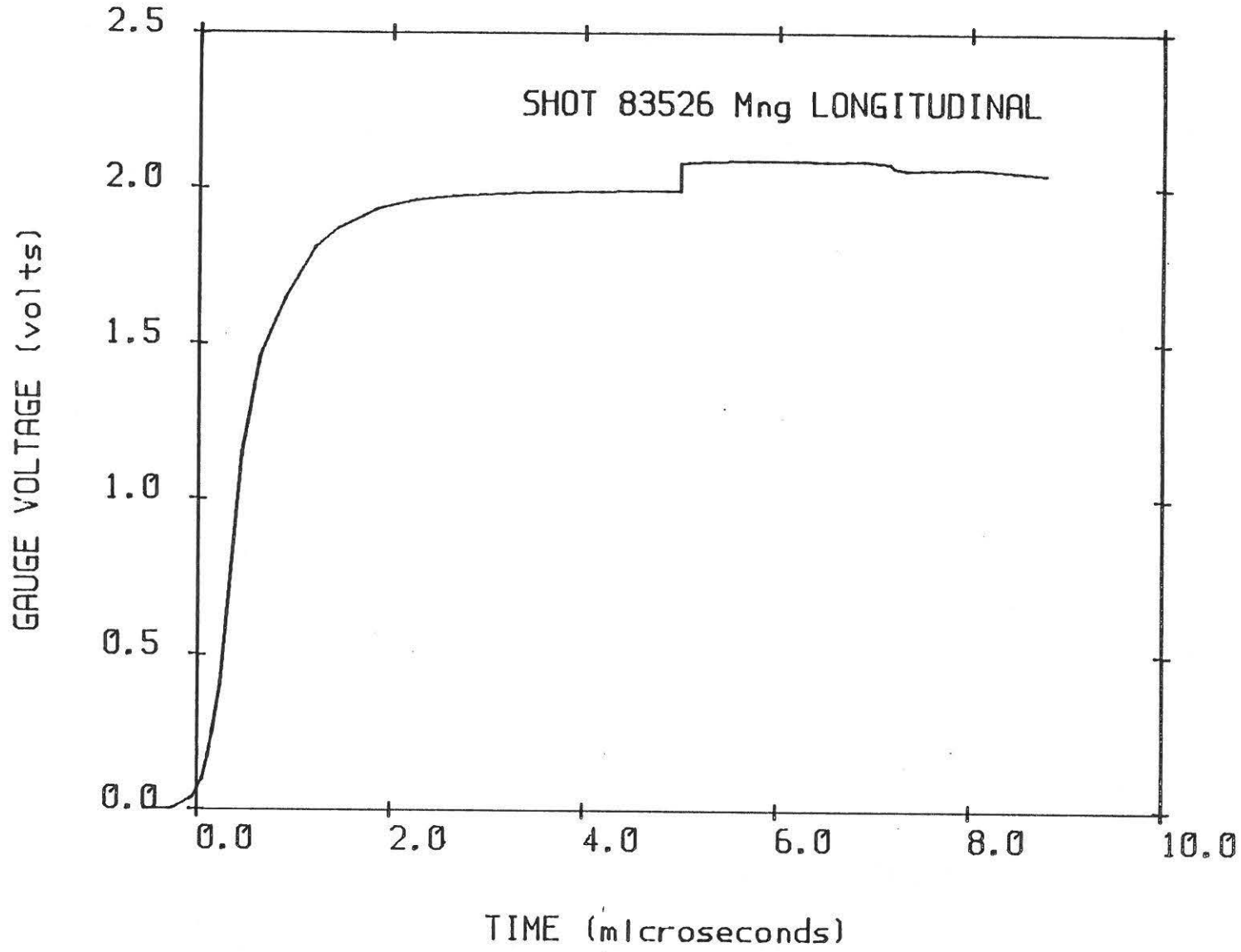

SHOT 83526 Yb LONGITUDINAL
DELTA R/R0
2.50
2.00
1.50
1.00
0.50
0.00
0.0
1.0
2.0
3.0
4.0
5.0
TIME (microseconds)

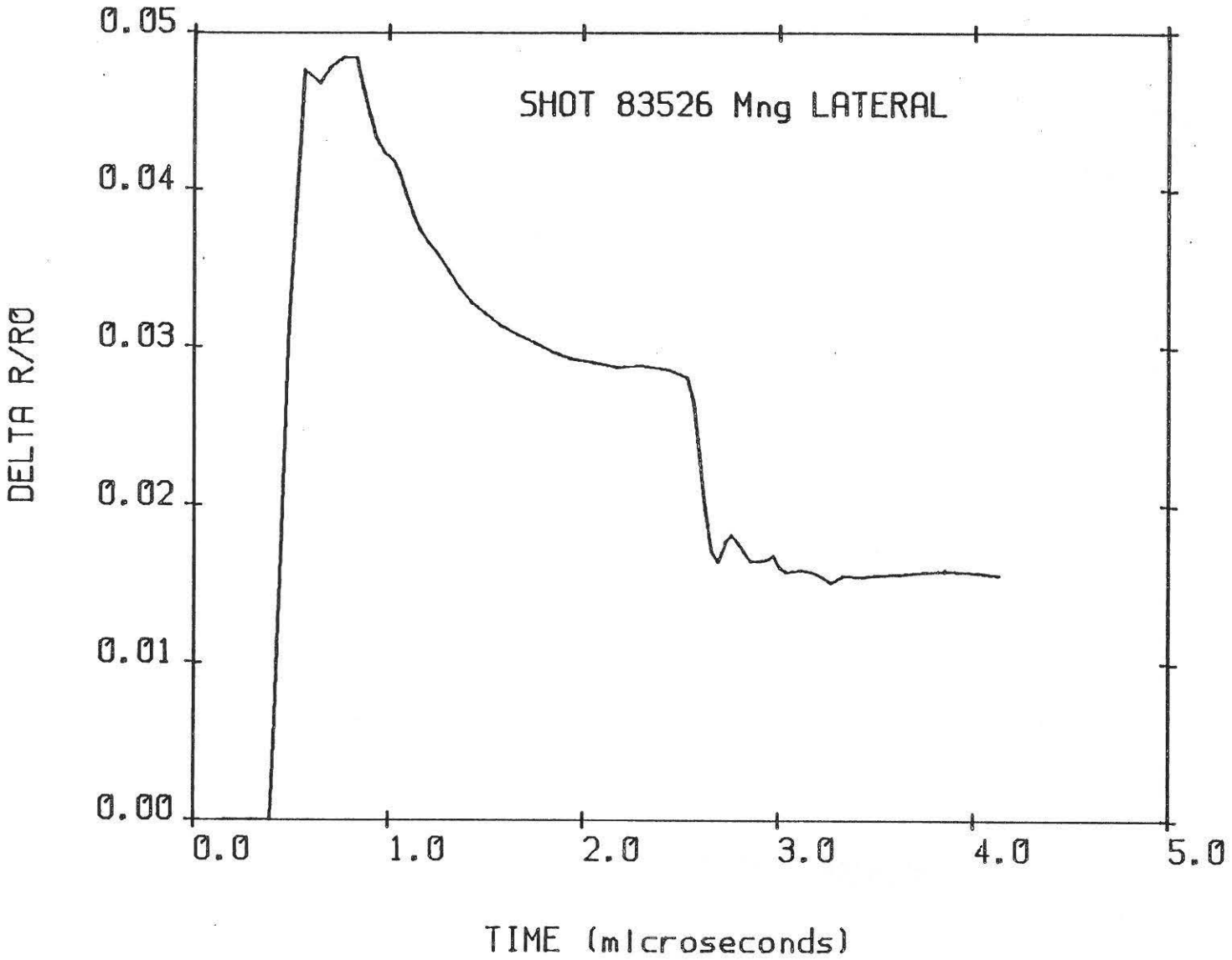

SHOT 83526 Yb LONGITUDINAL
3.0
2.0
1.0
0.0
-1.0
DELTA R/R0
0.0
2.0
4.0
6.0
8.0
10.0
TIME (microseconds)

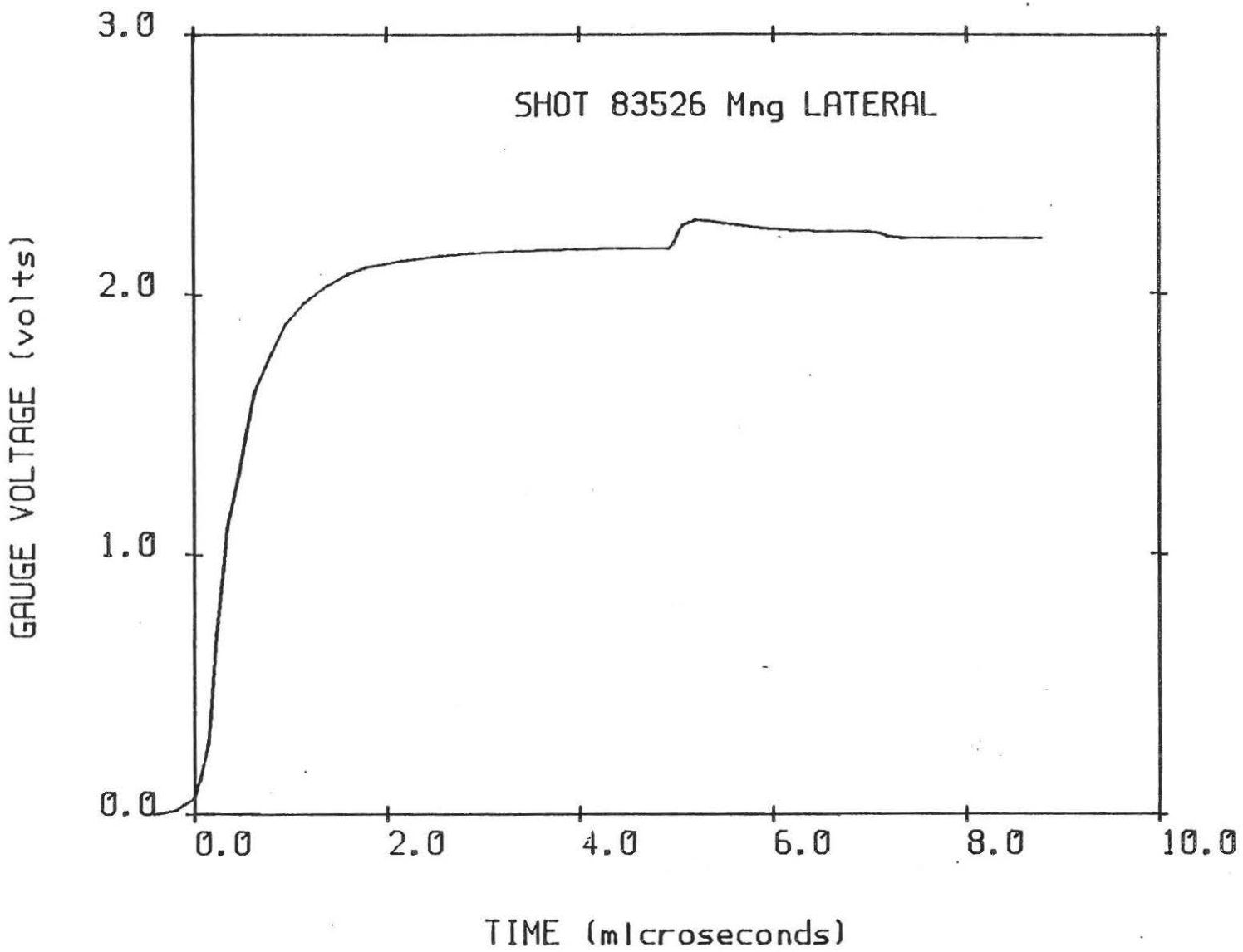

SHOT 83526 Yb LATERAL
2.00
1.50
1.00
0.50
0.00
DELTA R/R0
0.0
1.0
2.0
3.0
4.0
5.0
TIME (microseconds)

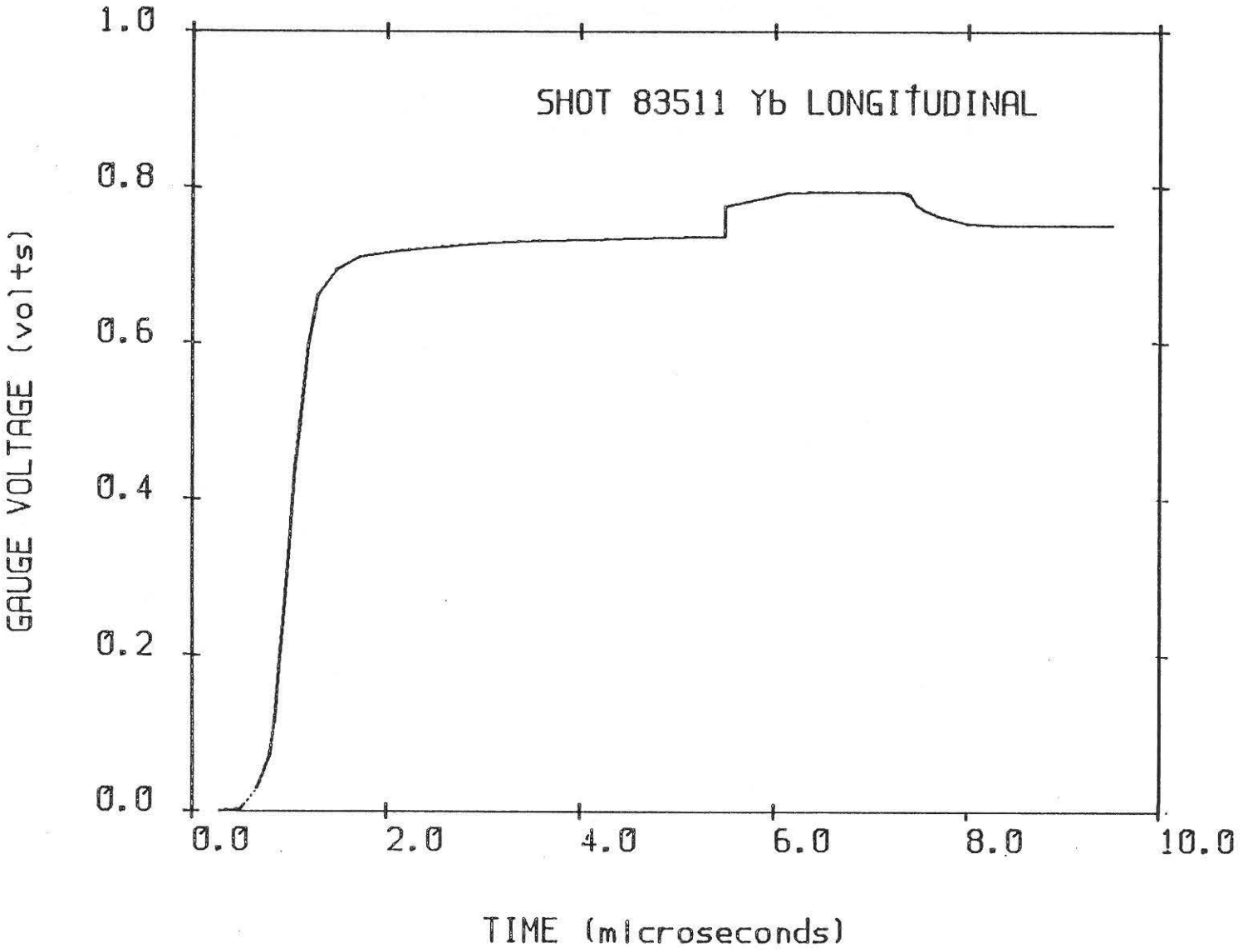

SHOT 83526 Yb LATERAL
2.0
1.0
0.0
-1.0
DELTA R/R0
0.0
2.0
4.0
6.0
8.0
10.0
TIME (microseconds)

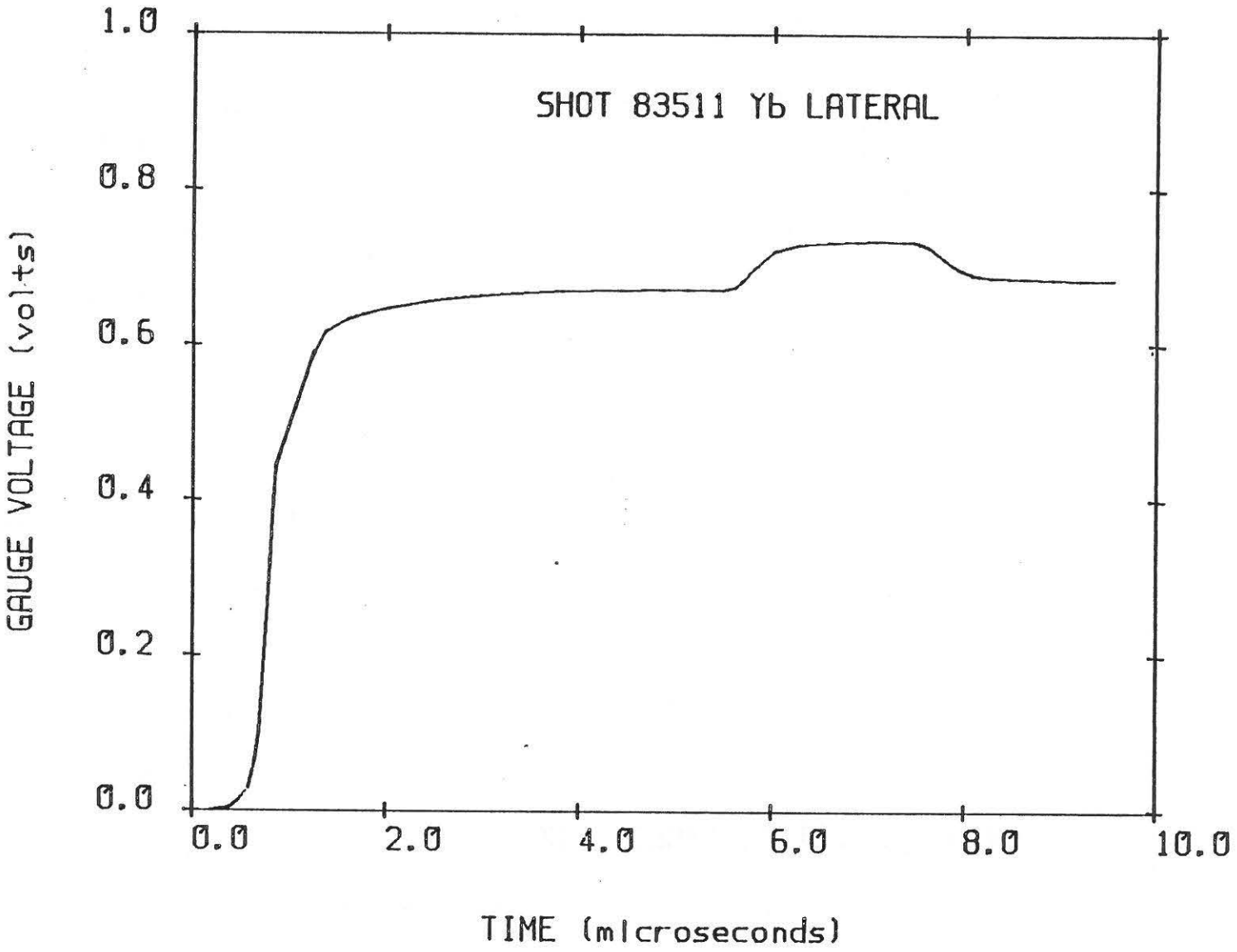

SHOT 83526 Mng LONGITUDINAL
DELTA R/R0
0.06
0.05
0.04
0.03
0.02
0.01
0.00
0.0
1.0
2.0
3.0
4.0
5.0
TIME (microseconds)


SHOT 83526 Mng LONGITUDINAL
GAUGE VOLTAGE (volts)
2.5
2.0
1.5
1.0
0.5
0.0
0.0
2.0
4.0
6.0
8.0
10.0
TIME (microseconds)


SHOT 83526 Mng LATERAL
0.05
0.04
0.03
0.02
0.01
0.00
DELTA R/R0
0.0
1.0
2.0
3.0
4.0
5.0
TIME (microseconds)


SHOT 83526 Mng LATERAL
GAUGE VOLTAGE (volts)
3.0
2.0
1.0
0.0
0.0
2.0
4.0
6.0
8.0
10.0
TIME (microseconds)


SHOT 83511 Yb LONGITUDINAL
GAUGE VOLTAGE (volts)
1.0
0.8
0.6
0.4
0.2
0.0
0.0
2.0
4.0
6.0
8.0
10.0
TIME (microseconds)


SHOT 83511 Yb LATERAL
GAUGE VOLTAGE (volts)
1.0
0.8
0.6
0.4
0.2
0.0
0.0
2.0
4.0
6.0
8.0
10.0
TIME (microseconds)