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BASEBALL IMPACTS TO DUMMY HEADS

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16. Abstract

The heads of two different dummies, the Part 572 and the Hybrid III, were subjected to frontal and lateral impacts from baseballs to determine whether any significant difference may exist between test results due solely to the dummy used. Secondarily, tests were conducted with the HSRI dummy in order to compare these results with a previous test series. Variability related to dummy head construction and impact location is discussed. It was concluded that, for the impact conditions in these tests, i.e., a low mass, high velocity, hard impacting object, there was no significant difference between the Part 572 and Hybrid III dummies in frontal impact, and that the peak acceleration and HIC values obtained in direct hits to the front and side are consistent with our understanding of head tolerance due to direct rigid impact.

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CONTENTS

Introduction

There are many situations in which accidental head injury can occur. Most of these events involve impact conditions that lack definition in terms of object contacted, velocity of contact, and attitude of the body at impact. The striking of a professional baseball batter's head by a pitched ball, however, represents a situation in which there is a demonstrated potential for head injury, such as skull fracture, concussion, and/or more serious brain damage, under narrowly defined conditions, in terms of impactor (ball) weight, velocity range, and distance of impactor travel.

Recognizing this unique situation, UMTRI conducted a series of baseball/head impacts in 1978 using regulation hard balls (5.25 oz) fired from a pitching machine at the HSRI dummy (see Jones and Mohan 1984). The primary purpose of the study was to duplicate a known injury-producing environment with a biomechanically realistic dummy and to compare the resulting head acceleration data with our understanding of human head impact tolerance. Tests included front and side impacts to the unprotected head as well as impacts to helmeted heads, to study the efficacy of various head protection devices. The speed of the baseballs was in the 80- to 100-mph range, and results were reported in terms of peak resultant acceleration and Head Injury Criterion (HIC). Our conclusions from this study were that, for the particular impact conditions simulated, i.e., small, hard, high-velocity impactor, the results were compatible with previous rigid-impact studies that suggest a HIC of 1000 indicates the likelihood of skull fracture and/or concussion.

In the current study, the impact response of the heads of two different dummies, the Part 572 and the Hybrid III, were compared to determine whether any significant difference may exist between test results due solely to the dummy used. Secondarily, tests were conducted with the HSRI dummy in order to compare these results with the previous test series. Both frontal and lateral head impacts were included.

Methodology

Fifty-one successful head impact tests were conducted using the Part 572, Hybrid III, and HSRI dummies in both forehead and temple impact locations. A baseball pitching machine was used to propel the ball at maximum speed toward each dummy head, but only direct hits were counted as successful tests. Each dummy was seated in turn in a wheelchair with its wheels locked and anchored to the ground. Table 1 summarizes the tests in terms of dummy type and impact location.

TABLE 1

SUMMARY OF TEST CONDITIONS

Dummy	Frontal Impacts	Side Impacts
Part 572	10	10
Hybrid III	10	12
HSRI	4	5
TOTAL	24	27

Endevco piezoresistive accelerometers (7264-2000) secured inside the dummy head at the CG site measured the triaxial accelerations. Computer analysis of the accelerations was performed to obtain the resultant acceleration-time histories and HIC values. High-speed movies at 1000 frames per second were taken of the tests with the Part 572 and Hybrid III dummies, but not with the tests of the HSRI dummy.

Test Results

Tables 2 through 7 contain the summary experimental data for all tests. The baseball velocities were derived from analysis of the high-speed films. Peak resultant head acceleration is given along with the HIC interval and finally the HIC value. The triaxial and resultant accelerations plotted versus time are included in the Appendix. The last row of each table gives the average velocity, average peak acceleration, and average HIC value with its calculated standard deviation.

TABLE 2
BASEBALL IMPACT TEST SUMMARY FOR PART 572 DUMMY
FRONTAL HEAD IMPACT

Test Number	Ball Number*	Baseball Velocity (mph)	Peak Head Accel. (G)	HIC Interval (ms)	HIC
84BF13	5-3	81.8	269	0.55	400
84BF14	5-4	86.2	229	0.45	257
84BF15	8-1	87.1	437	0.50	1127
84BF16	8-2	90.8	484	0.45	1399
84BF17	8-3	88.4	537	0.45	1799
84BF18	8-4	91.1	462	0.50	1320
84BF19	13-1	78.8	341	0.50	644
84BF20	13-2	78.7	434	0.50	1164
84BF21	13-3	76.7	295	0.50	459
84BF22	13-4	79.3	381	0.50	831
AVERAGE		83.9	387	0.49	940 SD=502

*The first number refers to the ball number and the second number refers to the pitch number. For example, 1-1 translates to Ball 1, pitch 1 (a new ball), while 5-4 translates to Ball 5, pitch 4.

TABLE 3
BASEBALL IMPACT TEST SUMMARY FOR PART 572 DUMMY
SIDE HEAD IMPACT

Test Number	Ball Number	Baseball Velocity (mph)	Peak Head Accel. (G)	HIC Interval (ms)	HIC
84BS03	3-2	89.30	192	0.60	179
84BS04	6-1	85.2	167	0.60	124
84BS05	6-2	83.2	176	0.60	151
84BS06	6-3	85.7	221	0.60	245
84BS07	4-1	82.9	212	0.55	211
84BS08	4-2	82.9	163	0.60	126
84BS09	4-3	84.0	176	0.60	140
84BS10	4-4	85.2	199	0.55	174
84BS11	5-1	82.0	168	0.60	131
84BS12	5-2	83.3	178	0.65	152
AVERAGE		84.5	185	0.60	163 SD=38

TABLE 4

BASEBALL IMPACT TEST SUMMARY FOR HYBRID III DUMMY
FRONTAL HEAD IMPACT

Test Number	Ball Number	Baseball Velocity (mph)	Peak Head Accel. (G)	HIC Interval (ms)	HIC
84BF23	14-1	83.6	280	0.60	471
84BF24	14-2	82.2	446	0.70	1659
84BF25	15-1	82.0	311	0.55	553
84BF26	15-2	85.2	250	0.60	336
84BF28	16-2	83.9	430	0.50	1156
84BF29	17-1	82.8	292	0.65	589
84BF30	17-2	81.2	263	0.60	391
84BF31	18-1	81.8	385	0.50	896
84BF32	19-1	87.9	438	0.55	1341
84BF33	19-2	85.2	387	0.55	927
AVERAGE		83.6	348	0.58	832 SD=443

TABLE 5

BASEBALL IMPACT TEST SUMMARY FOR HYBRID III DUMMY
SIDE HEAD IMPACT

Test Number	Ball Number	Baseball Velocity (mph)	Peak Head Accel. (G)	HIC Interval (ms)	HIC
84BS34	20-1	85.2	257	0.50	320
84BS35	20-2	88.3	410	0.50	962
84BS36	21-1	81.6	214	0.70	297
84BS37	21-2	81.2	313	0.55	587
84BS40	23-1	87.9	407	0.50	922
84BS41	23-2	85.2	207	1.50	422
84BS42	24-1	84.1	334	0.55	654
84BS43	24-2	80.6	281	0.55	434
84BS44	24-3	81.7	186	0.65	169
84BS45	17-3	85.2	353	0.55	755
84BS46	14-3	83.9	356	0.55	755
84BS47	14-4	85.7	240	0.65	328
AVERAGE		84.4	297	0.65	550 SD=249

TABLE 6

BASEBALL IMPACT TEST SUMMARY FOR HSRI DUMMY
FRONTAL HEAD IMPACT

Test Number	Ball Number*	Baseball Velocity (mph)**	Peak Head Accel. (G)	HIC Interval (ms)	HIC
84BF53			446	1.8	1499
84BF54			324	1.8	777
84BF56			285	1.0	454
84BF57			383	1.8	1282
AVERAGE			359	1.6	1003 SD=411

TABLE 7

BASEBALL IMPACT TEST SUMMARY FOR HSRI DUMMY
SIDE HEAD IMPACT

Test Number	Ball Number*	Baseball Velocity (mph)**	Peak Head Accel. (G)	HIC Interval (ms)	HIC
84BS48			425	2.30	1590
84BS49			425	1.10	1357
84BS50			442	1.80	1694
84BS51			375	1.70	387
84BS52			422	2.35	1896
AVERAGE			418	1.85	1385 SD=496

*Not recorded.

**No high-speed movies were taken of these tests, therefore no velocities could be calculated.

Discussion

This discussion addresses the question of whether there are differences in head response among the three dummies in these impact tests, and, if so, what the sources of these differences might be.

Looking first at frontal impact, Tables 2 and 4 indicate a range of peak acceleration of from 209 to 537 G for the Part 572 dummy and from 250 to 446 G for the Hybrid III. Peak acceleration is a measure of response, whereas HIC, which is a function of both acceleration and time, relates to injury potential and tends to exaggerate variations in response. A brief comment should be made at this point about the wide range of peak Gs and associated HICs within each dummy series. The reasons will be discussed in more detail with reference to the side impact tests, but basically there is a problem with hitting one curved surface with another curved surface. Small changes in impact location are likely to occur from one test to the next, which can result in large changes in the transfer of momentum to the CG of the head.

A statistical analysis (t-test) of the data from the Part 572 and Hybrid III frontal test series indicates that there was no significant difference between the mean values of the peak accelerations ($p>0.35$) or the mean values of the HIC numbers ($p>0.65$). Further, the mean of the HSRI dummy test series fell between those of the other dummies. The peak accelerations and means for all three frontal impact test series are plotted in Figure 1. Although there was a statistically significant difference between the mean HIC intervals of the first two dummies ($p<0.01$), this difference of less than 0.1 ms has no practical significance.

Next we look at Tables 3 and 5 and find an apparent difference between the Part 572 (mean G=185) and Hybrid III (mean G=297) results in the side head-impact condition. The HSRI dummy registered even higher peak accelerations (mean G=418). The peak accelerations and means for the side impact test series are plotted in Figure 2. Two factors are most likely responsible for these differences. One is the head construction differences among the three dummies, and the other is the problem of impact location mentioned above.

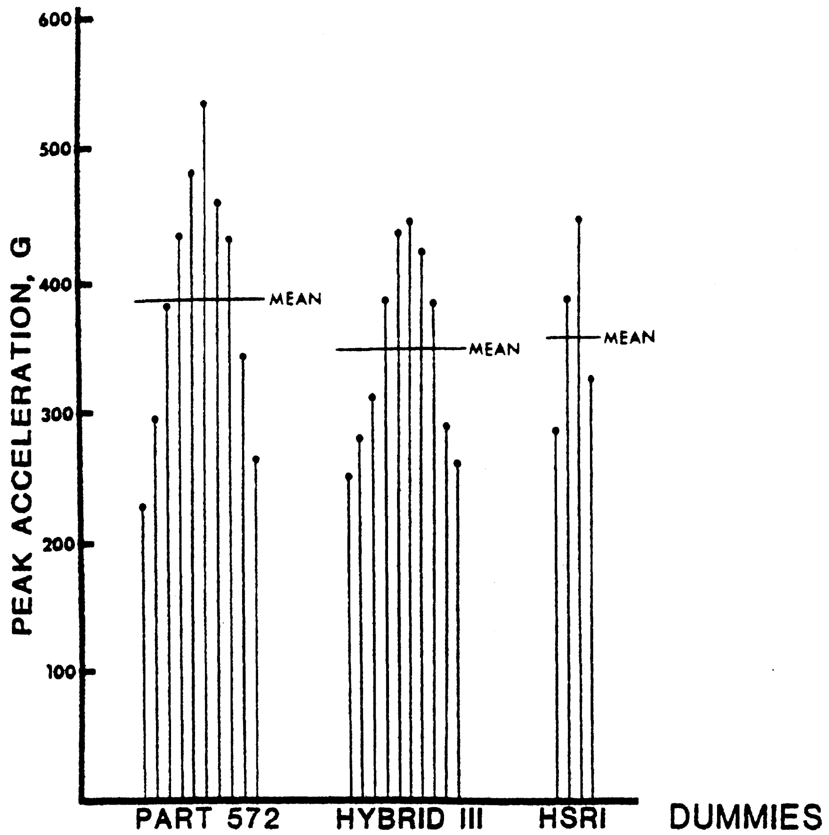


Figure 1. Peak Resultant Acceleration Results, Frontal Head Impacts

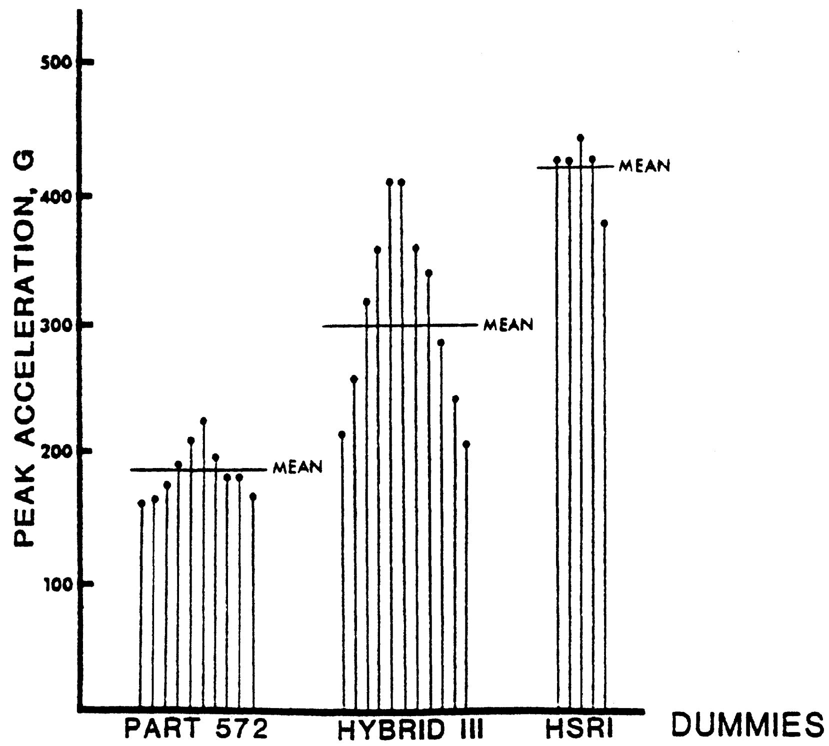


Figure 2. Peak Resultant Acceleration Results, Side Head Impacts

The lateral scalp characteristics and skull structures are different in all three designs. The Part 572 head features a firm, relatively thick (0.3 to 0.4 inch) vinyl scalp over a rigid cast aluminum skull. The Hybrid III head has a thicker (0.41-0.49 inch) soft vinyl scalp over a rigid cast aluminum skull. The HSRI head has a thinner (0.250-0.270 inch) soft urethane scalp over a deformable cast urethane skull, with the skull urethane being harder than the scalp material. The surface geometries of the sides of the head of each dummy differ also. The HSRI dummy head is flatter vertically over a larger area, making a direct hit easier to achieve, while both the Hybrid III and Part 572 heads have a more pronounced curvature, particularly in the upper half. In the case of the Hybrid III and Part 572 dummies, the curvature of the side of the head varies with position strongly enough to cause significantly different responses to impact for small changes in the ball contact point, either up/down or fore/aft. A test in which the only variable would be the material properties of the scalp/skull combination would require very precise control of the impactor path, impact location, and impactor properties.

The side impacts to the head of the Part 572 dummy were the first test series run in the current study. Comparison of points of ball contact for the Part 572 and Hybrid III tests from the film data indicates that the contacts were consistently higher on the head of the Part 572 dummy by about 0.5 to 0.75 inch. This resulted in consistently lower head accelerations due to a decreased transfer of momentum from the ball to the head. Similar impacts occurred in some of the Hybrid III side impact tests with similar results. Other impact sites, however, were more in line with the head center of gravity, and high head accelerations were produced.

Finally, an examination of the HIC intervals listed in Tables 2 through 7 indicates that the durations for the HSRI dummy head are three times as great as those for the other two dummies, while the corresponding average peak acceleration values for frontal head impacts are similar in all three dummies. The head acceleration traces for the HSRI dummy (see Appendix) reveal a marked oscillatory characteristic not found in the traces from the other two dummies. This is most likely due to the unusual mounting arrangement for the accelerometers in the HSRI dummy head. This design uses a cantilevered box structure cast into the skull from the rear. Vibration of this structure, particularly in side impacts, can cause an oscillation in the head acceleration trace. Such an oscillation following the initial impact acceleration spike will cause the HIC function to converge on a longer time interval, thereby producing an erroneously high HIC value. Since the average acceleration values of the Part 572 and Hybrid III dummies bracket the HSRI dummy value, simple linear interpolation of the HIC values would indicate an estimated HIC for a non-oscillating waveform to be 862 for frontal impacts. Using the same reasoning, the side impact data must be extrapolated due to the higher average head acceleration value of the HSRI head (417 G). This results in an estimated non-oscillating waveform HIC value of 1025. Using these estimated values, the average results of the tests for all three dummies are listed in Table 8.

TABLE 8

SUMMARY OF AVERAGE BASEBALL IMPACT TEST RESULTS
FOR ALL DUMMIES

Dummy	Frontal Head Impact		Head Side Impact	
	Peak Accel. (G)	HIC	Peak Accel. (G)	HIC
Part 572	386.8	940	185.2	163
Hybrid III	348.3	832	296.7	550
HSRI	359.0	862*	417.9	1025*

*Estimated.

Conclusion

For the impact conditions in these tests, i.e., a low mass, high velocity, hard impacting object, there was no significant difference between the Part 572 and Hybrid III dummies in frontal impact. For side impact, when a direct transfer of the momentum of a ball occurs, the results from both the Hybrid III and HSRI dummies indicate that baseball impacts to a batter's temple area are capable of producing 400-G accelerations with associated HIC values near 1000. These values are consistent with our understanding of head impact tolerance due to direct rigid impact, as are the values from the frontal head impact tests with all three dummies.

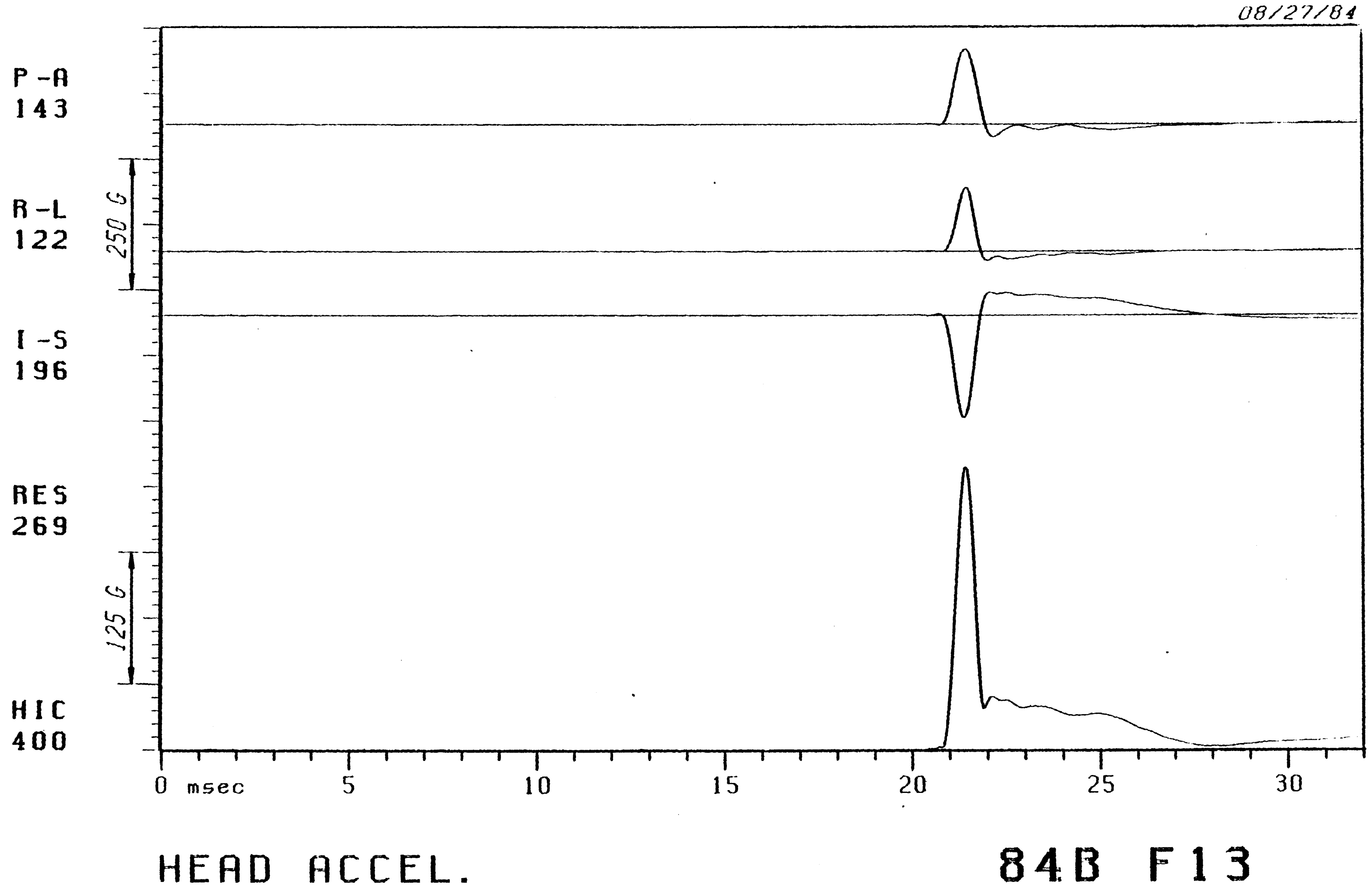
Reference

Jones, I.S.; and Mohan, D. (1984) Head impact tolerance: Correlation between dummy impacts and actual head injuries. Insurance Institute for Highway Safety, Washington, D.C.

APPENDIX

Dummy Head Acceleration Data

Part 572 Dummy Results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HEAD ACCEL.
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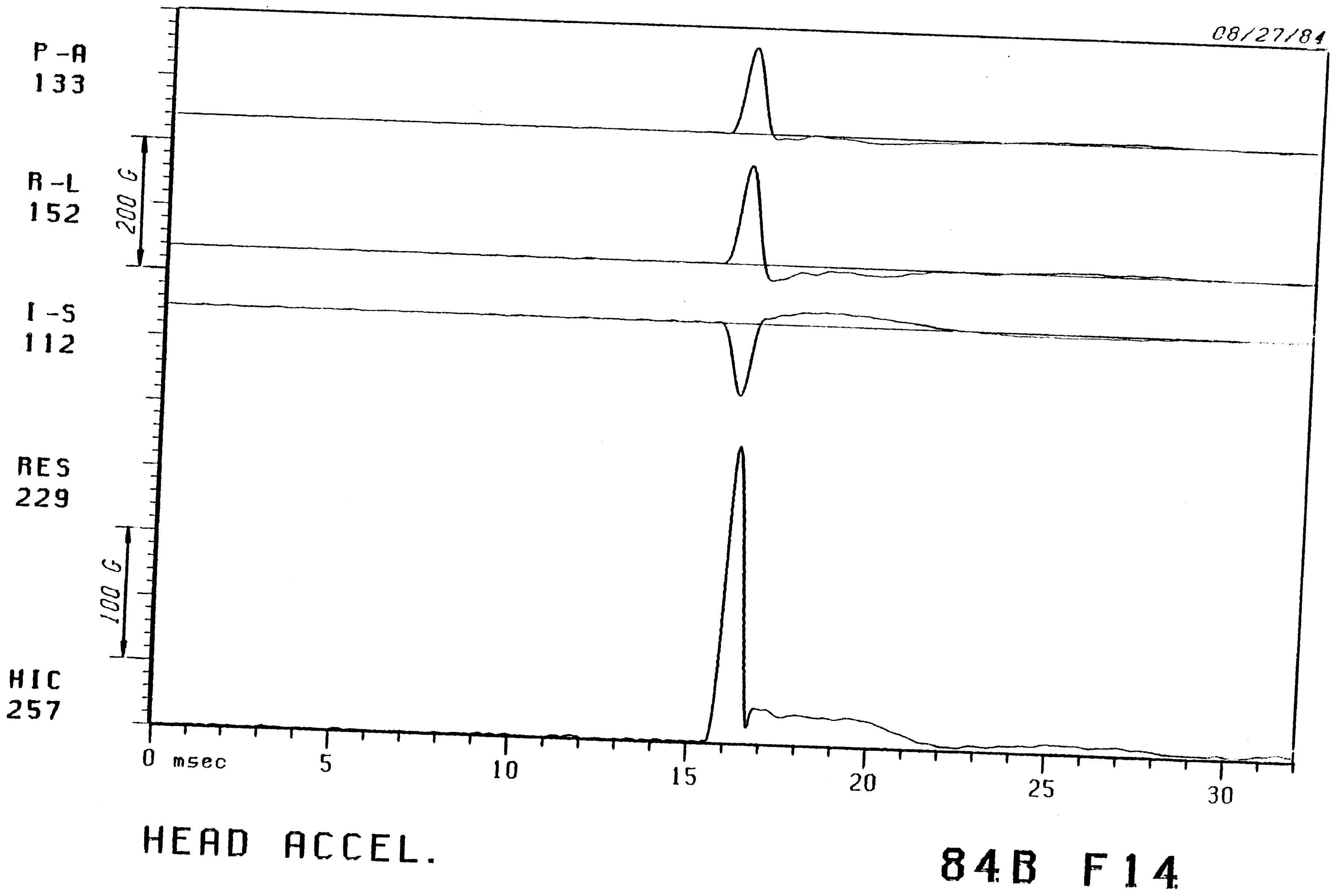
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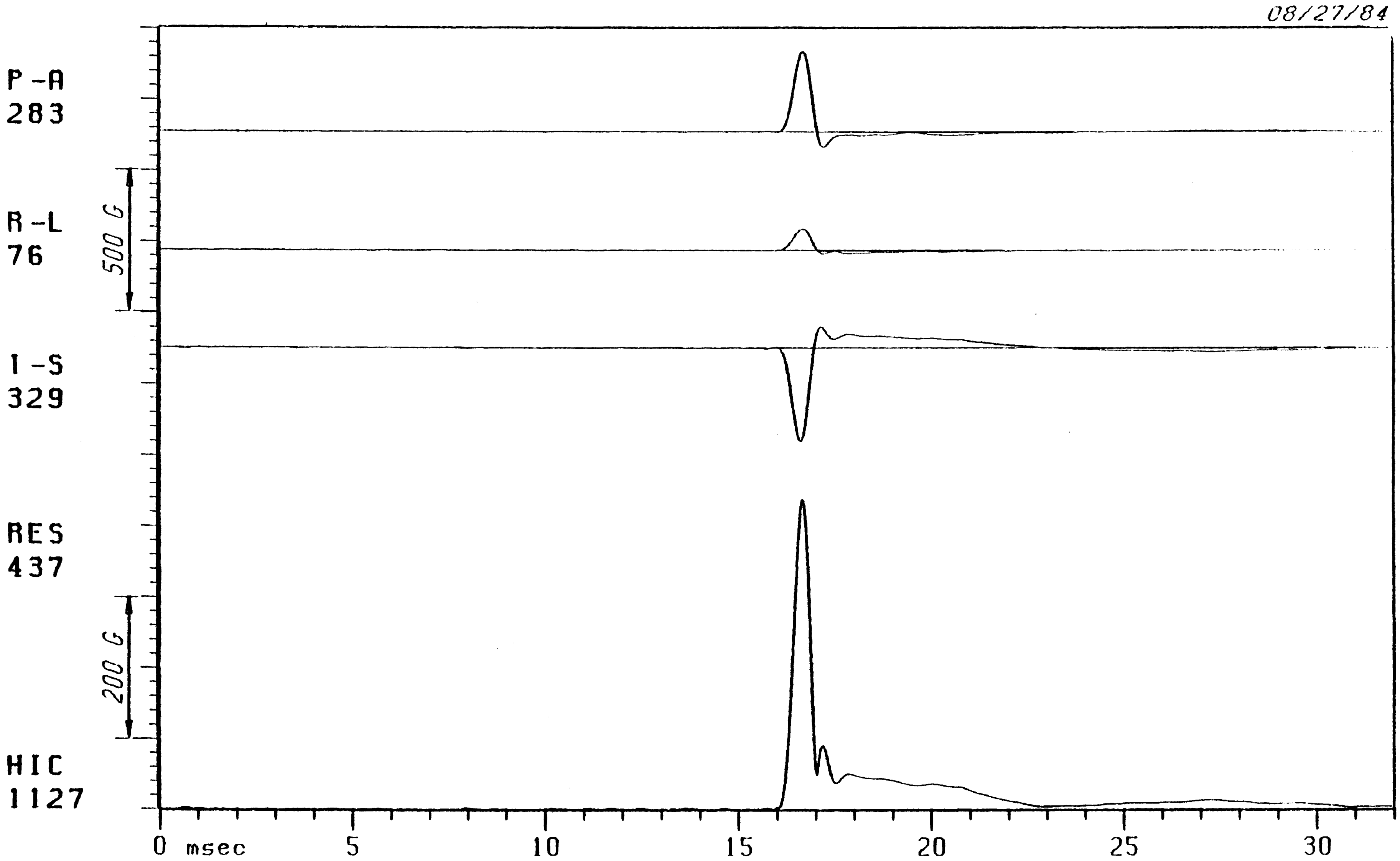

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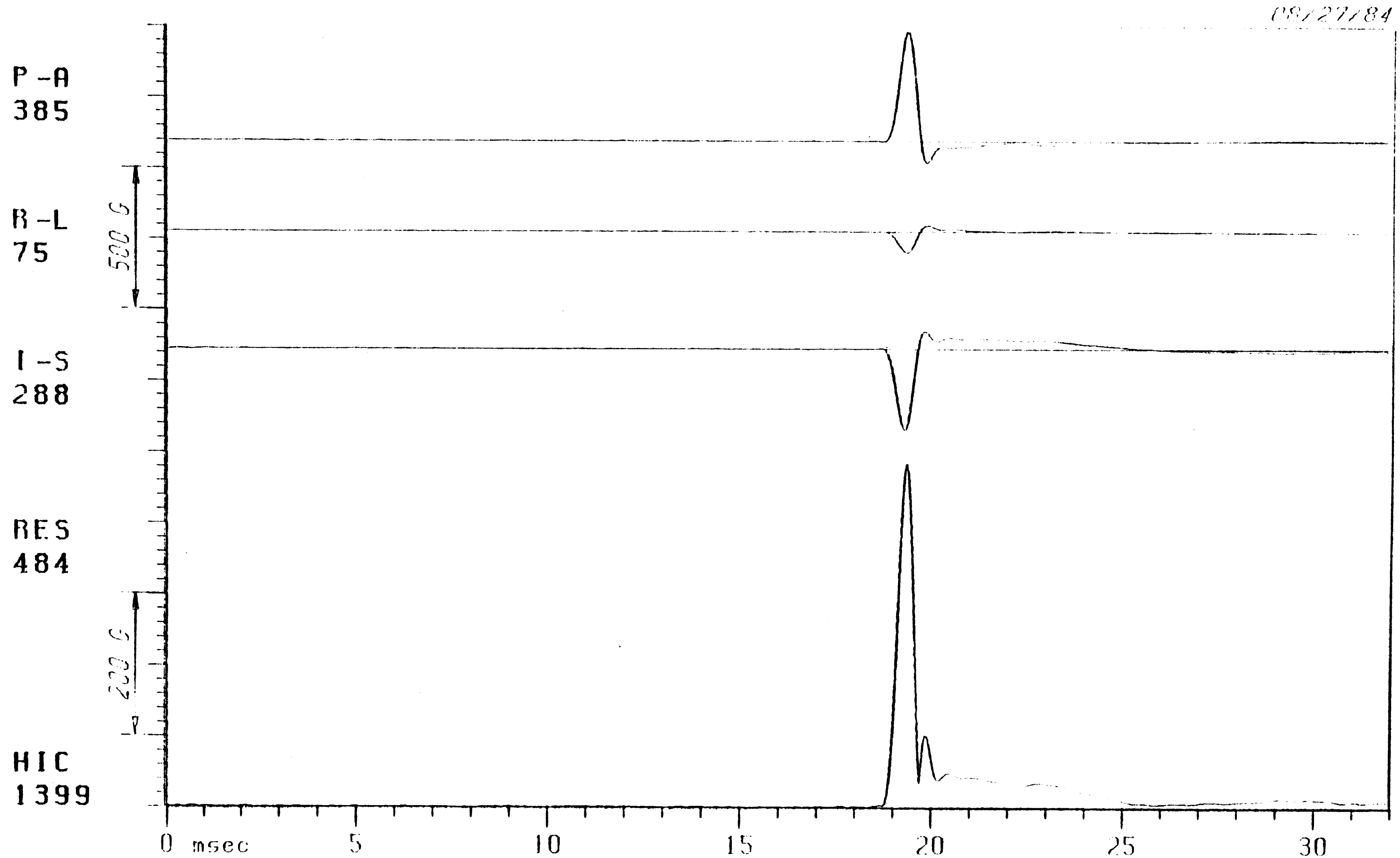

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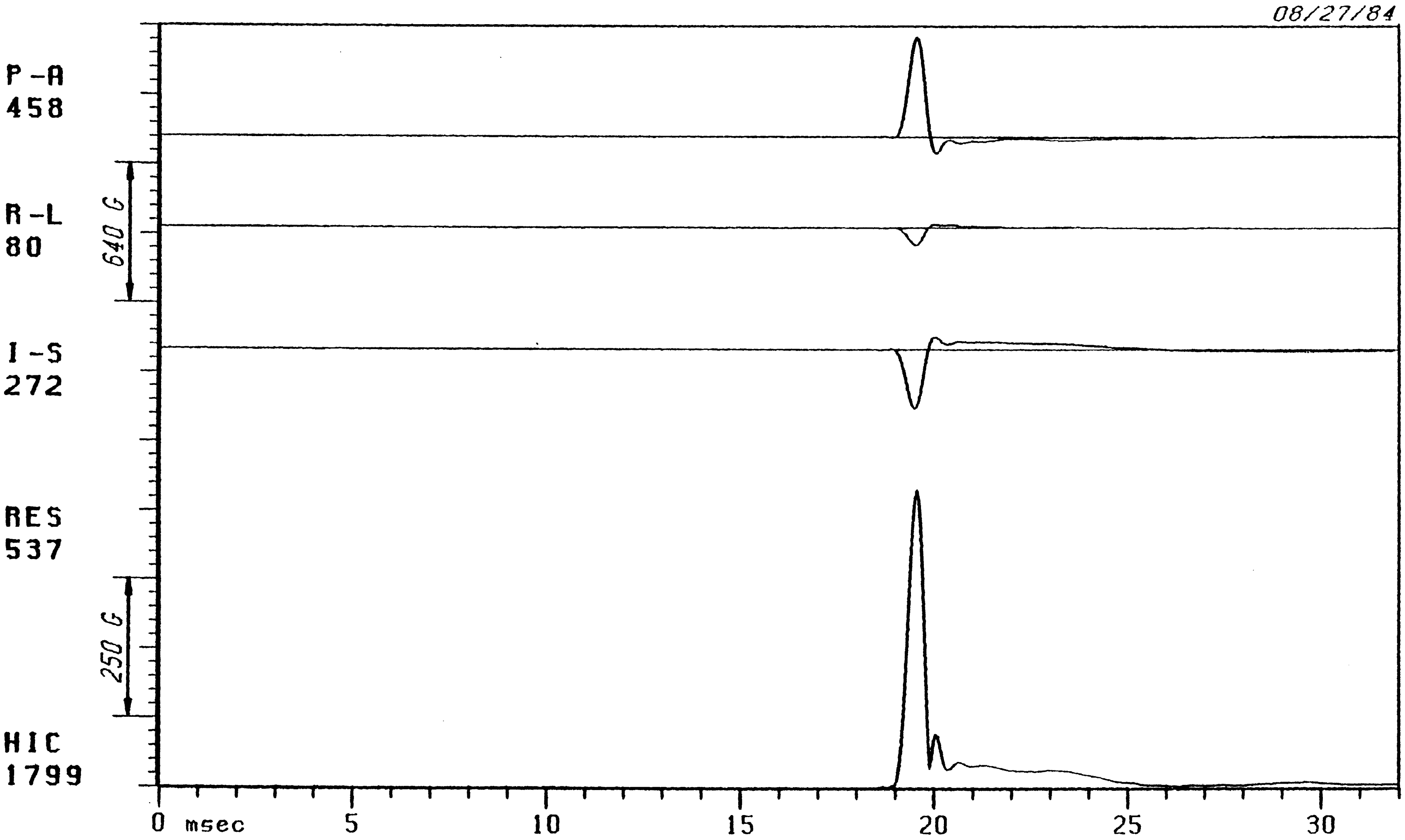

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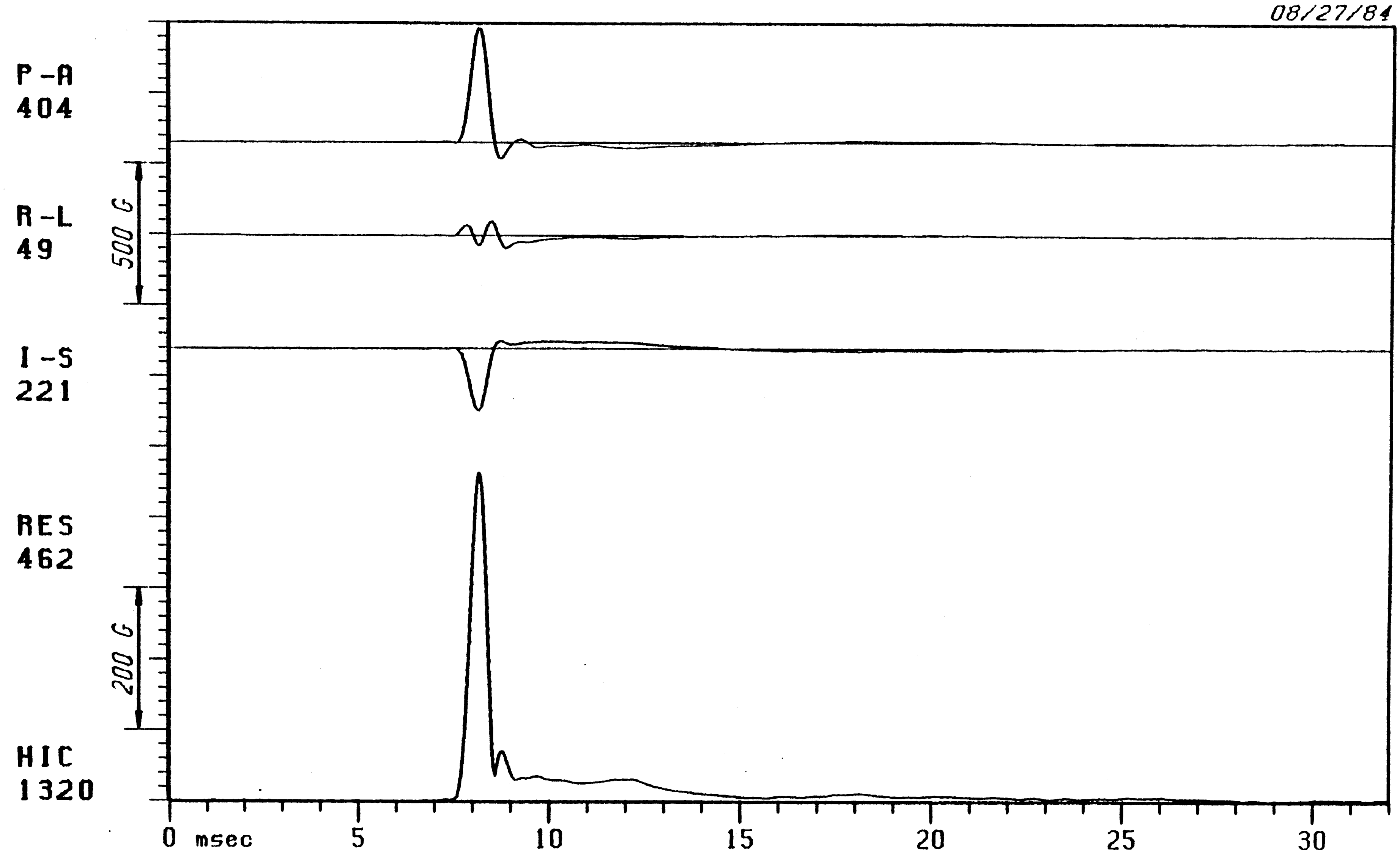

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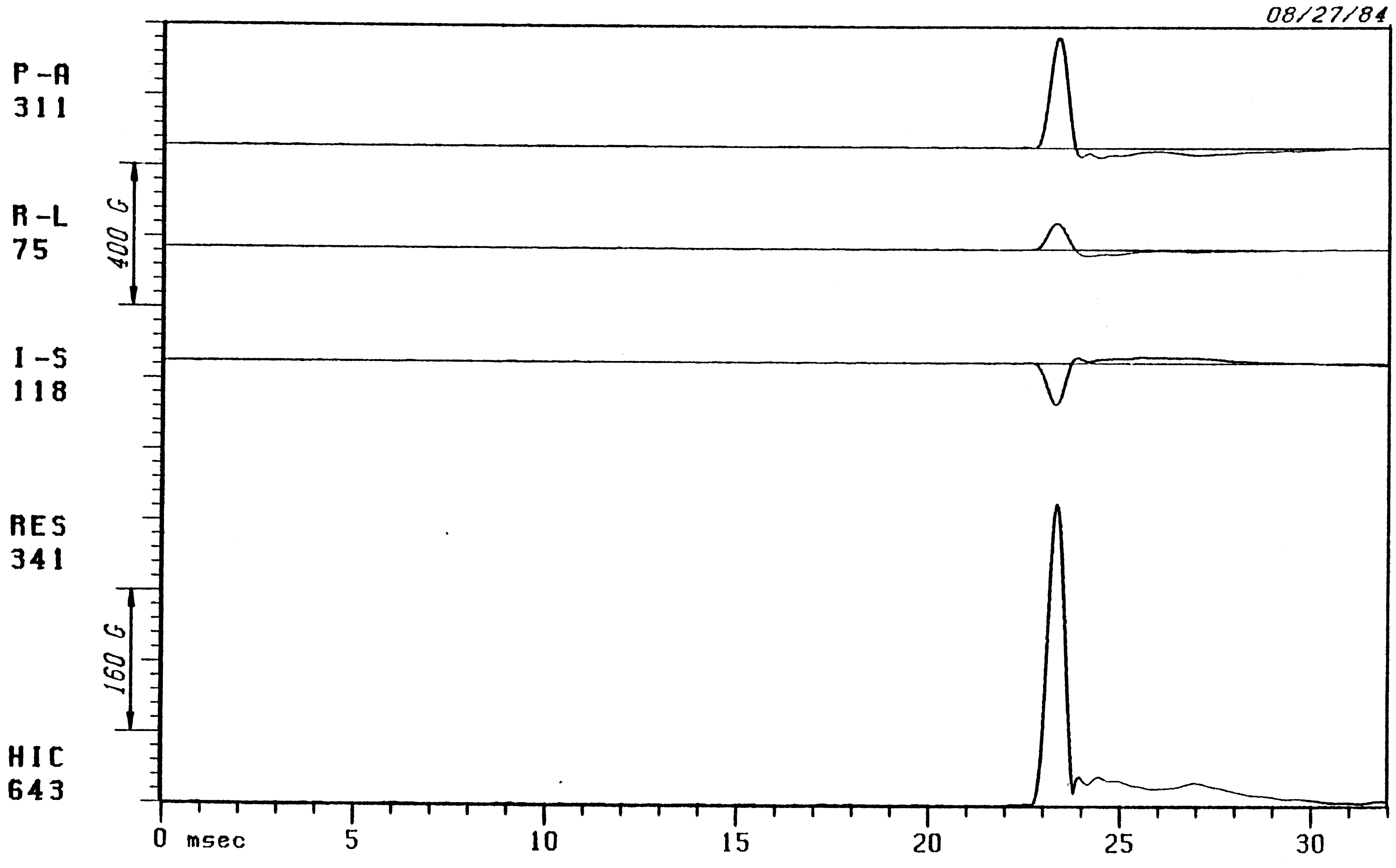

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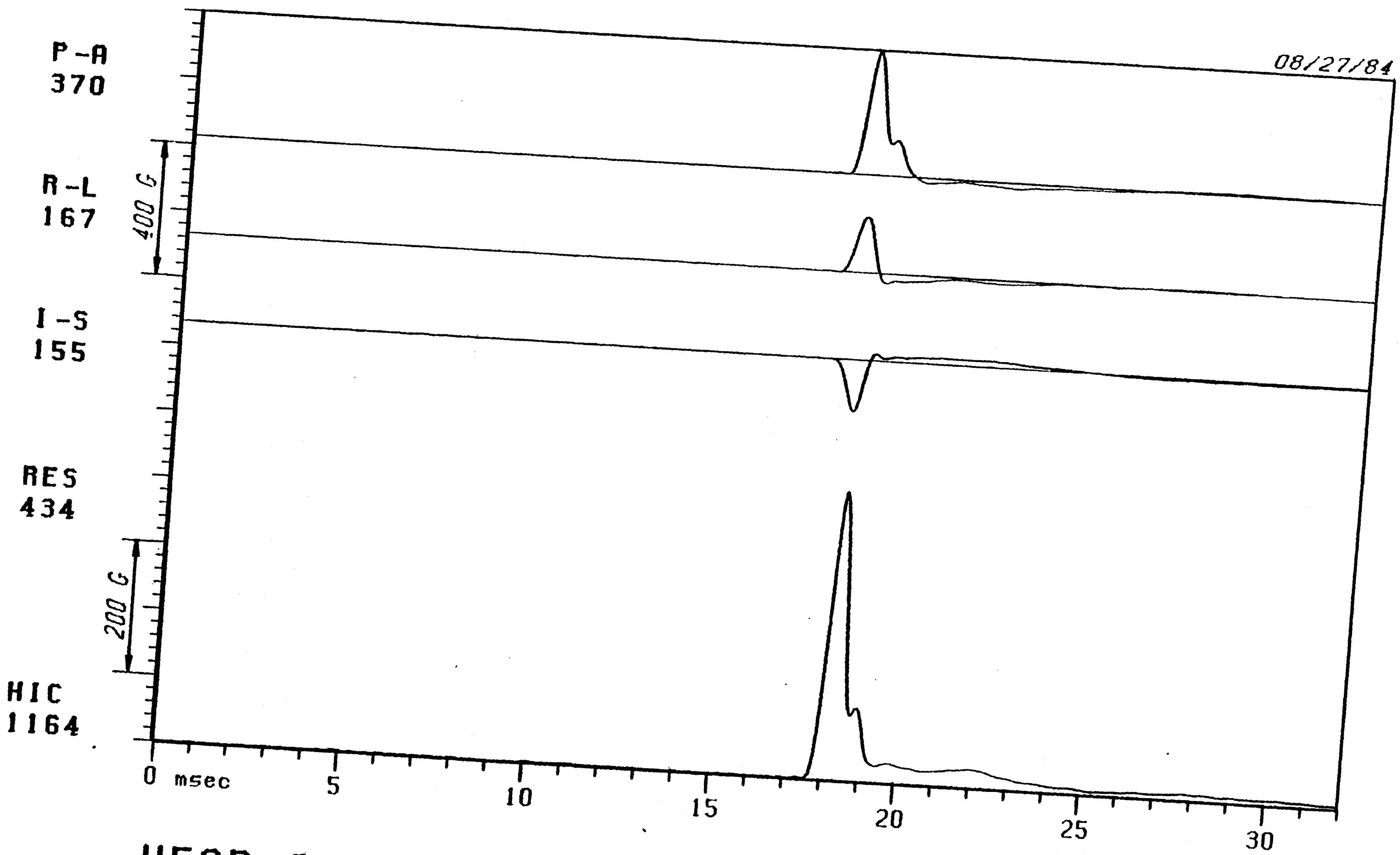

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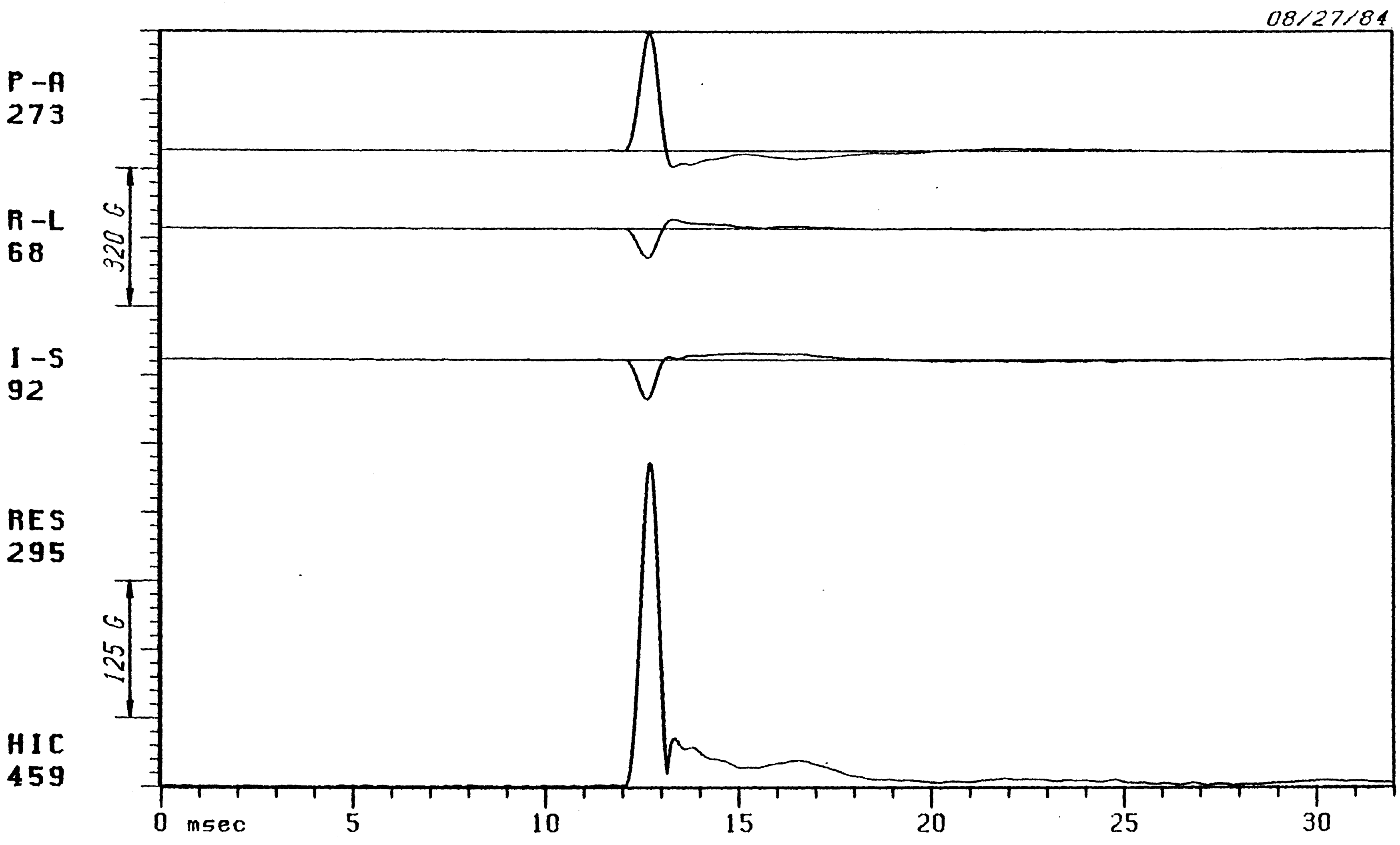

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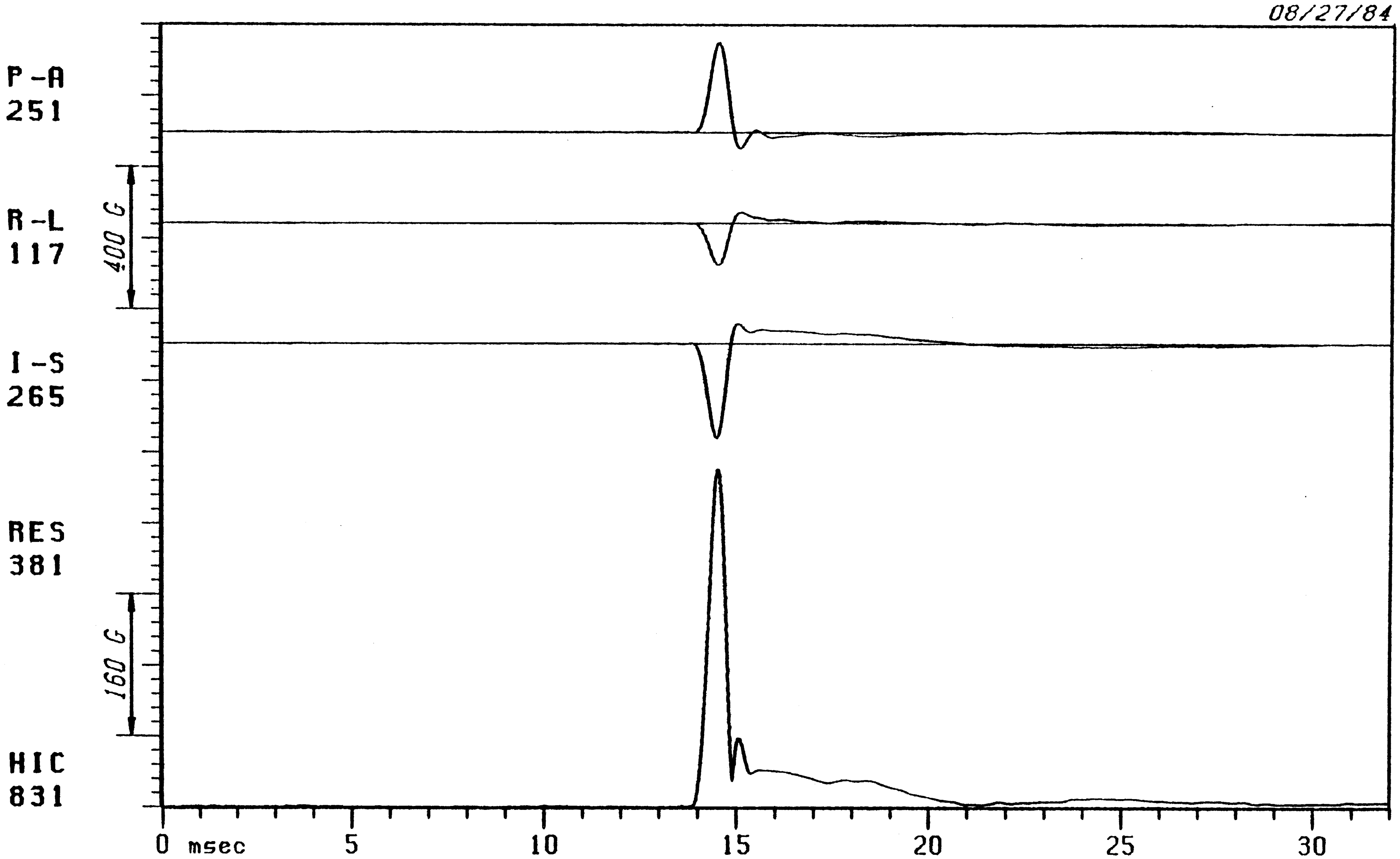

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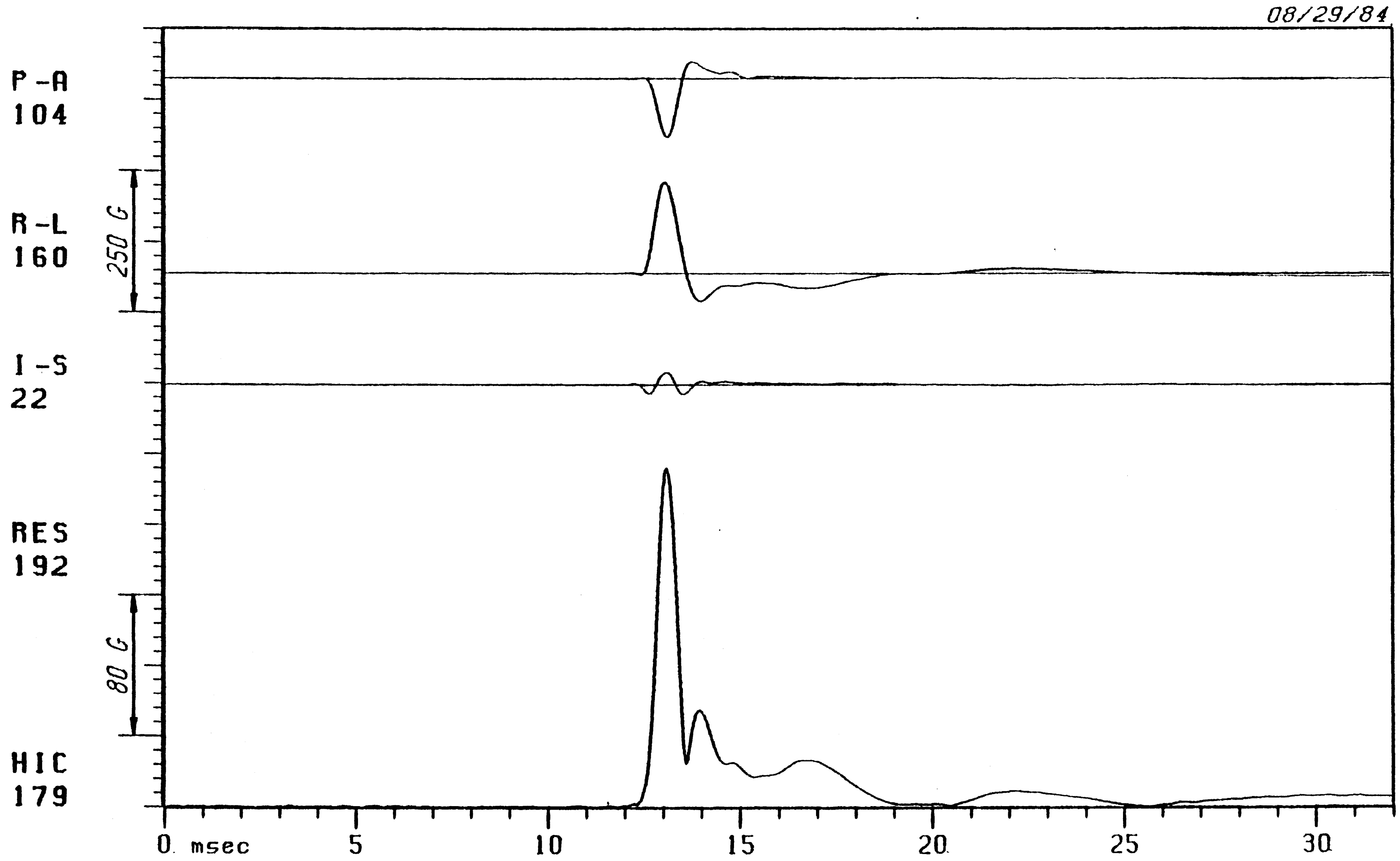

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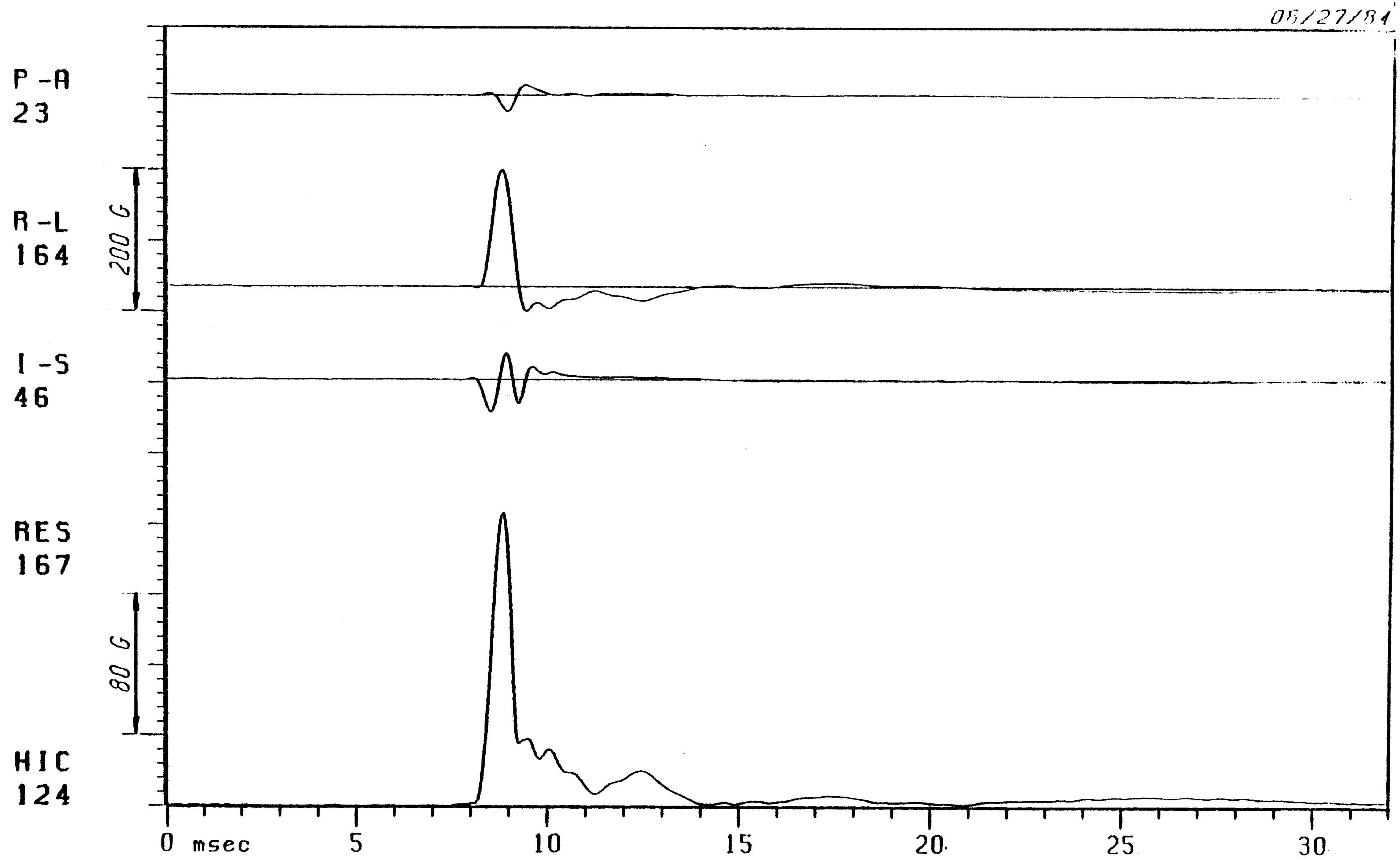

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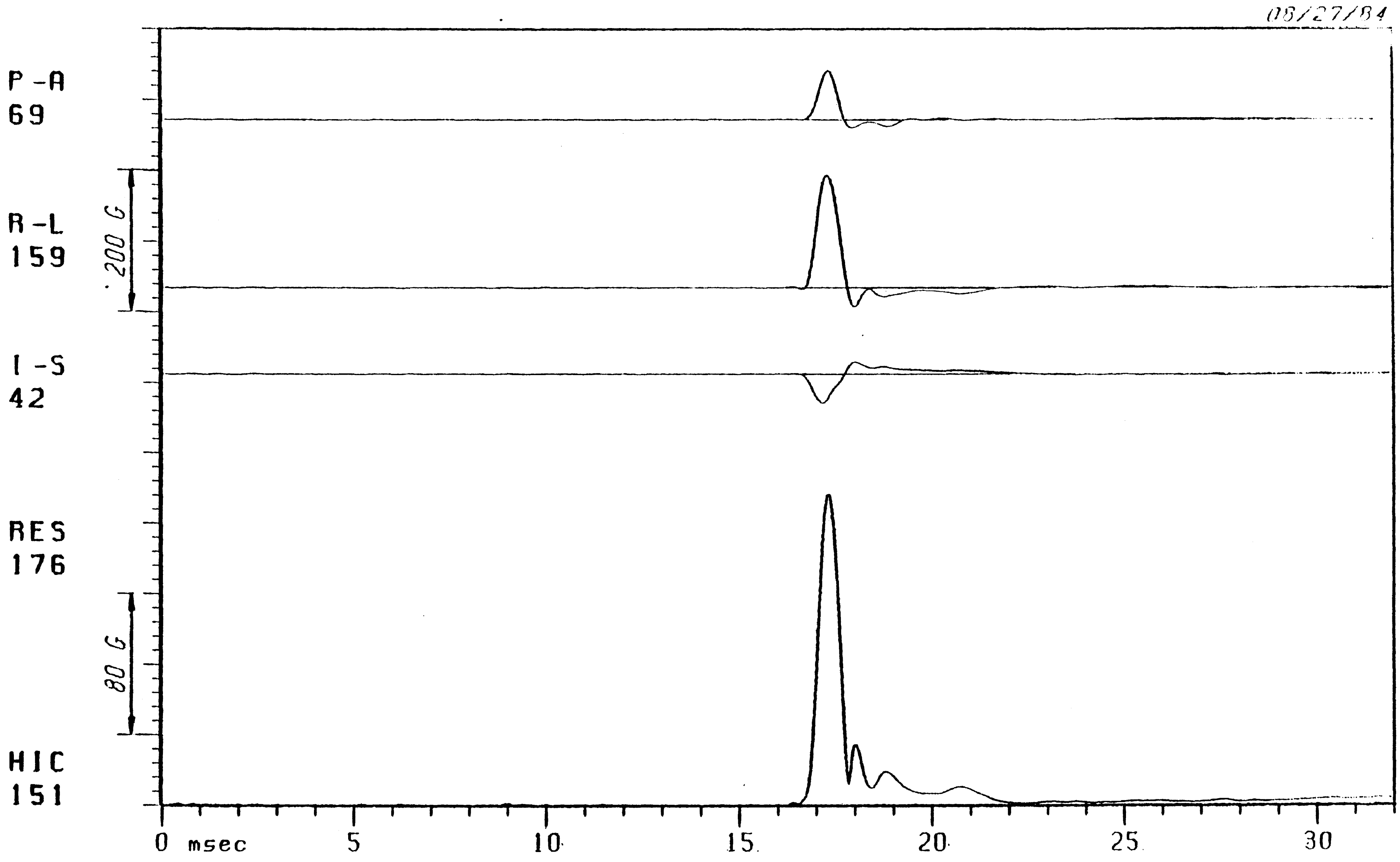

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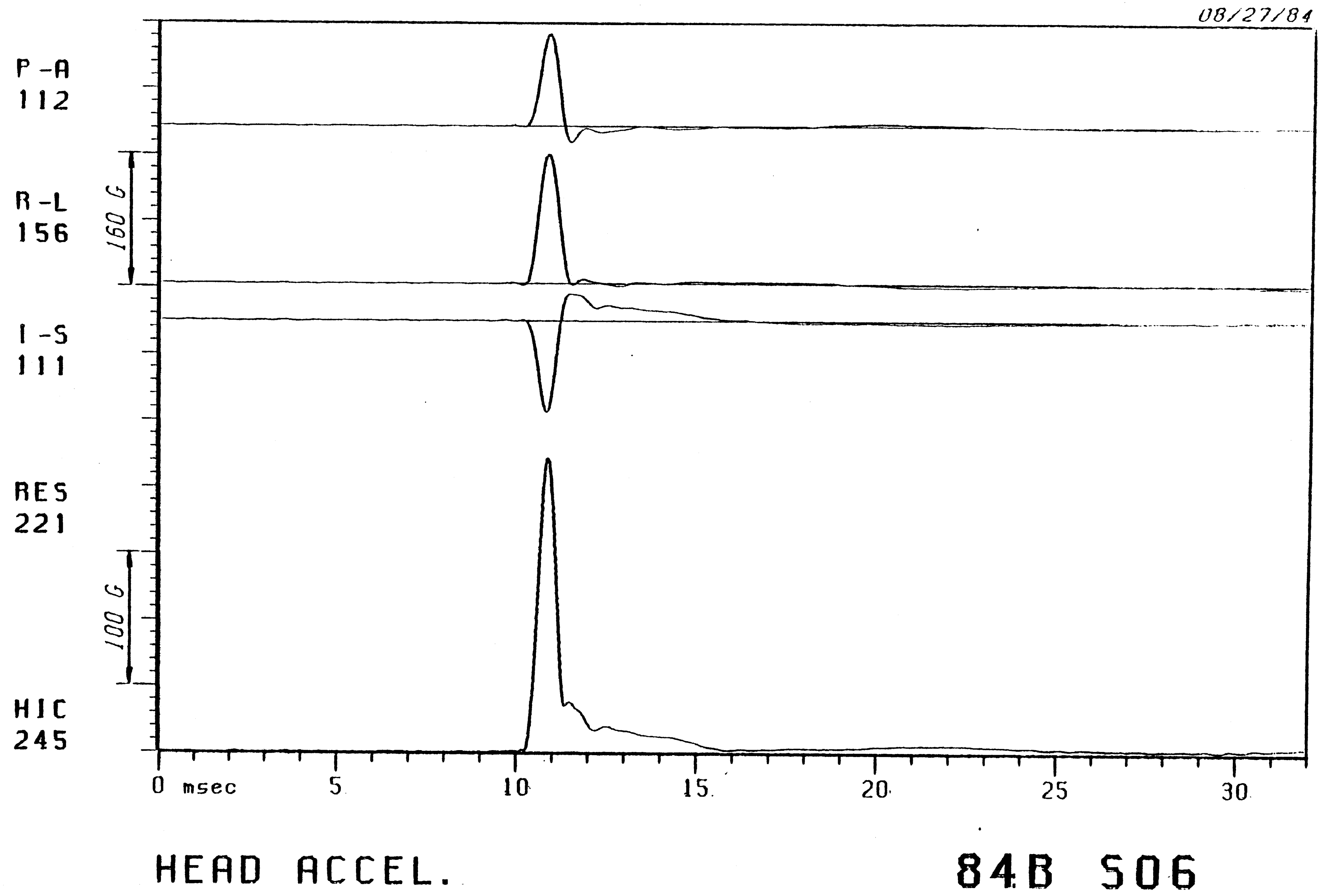
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I-S
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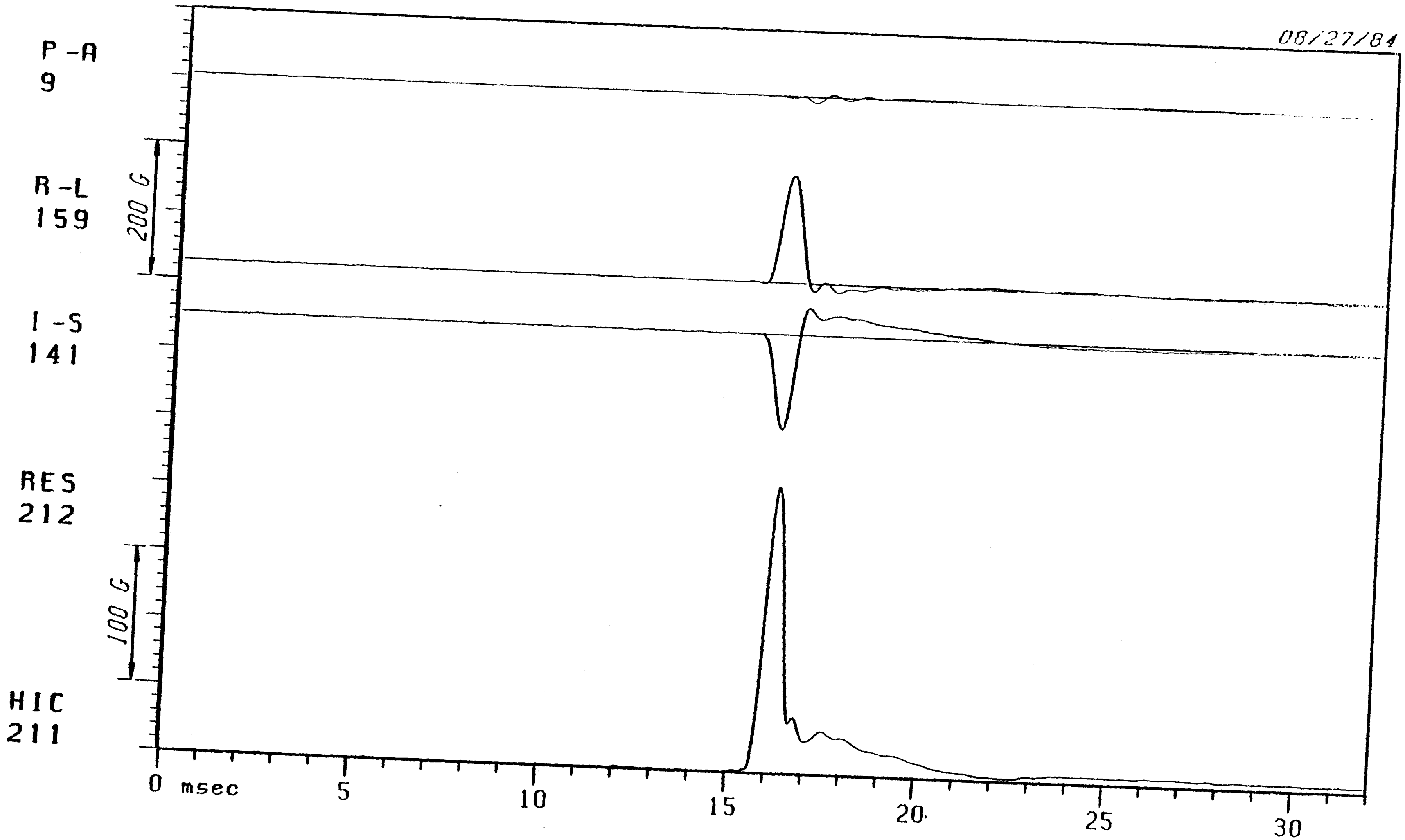

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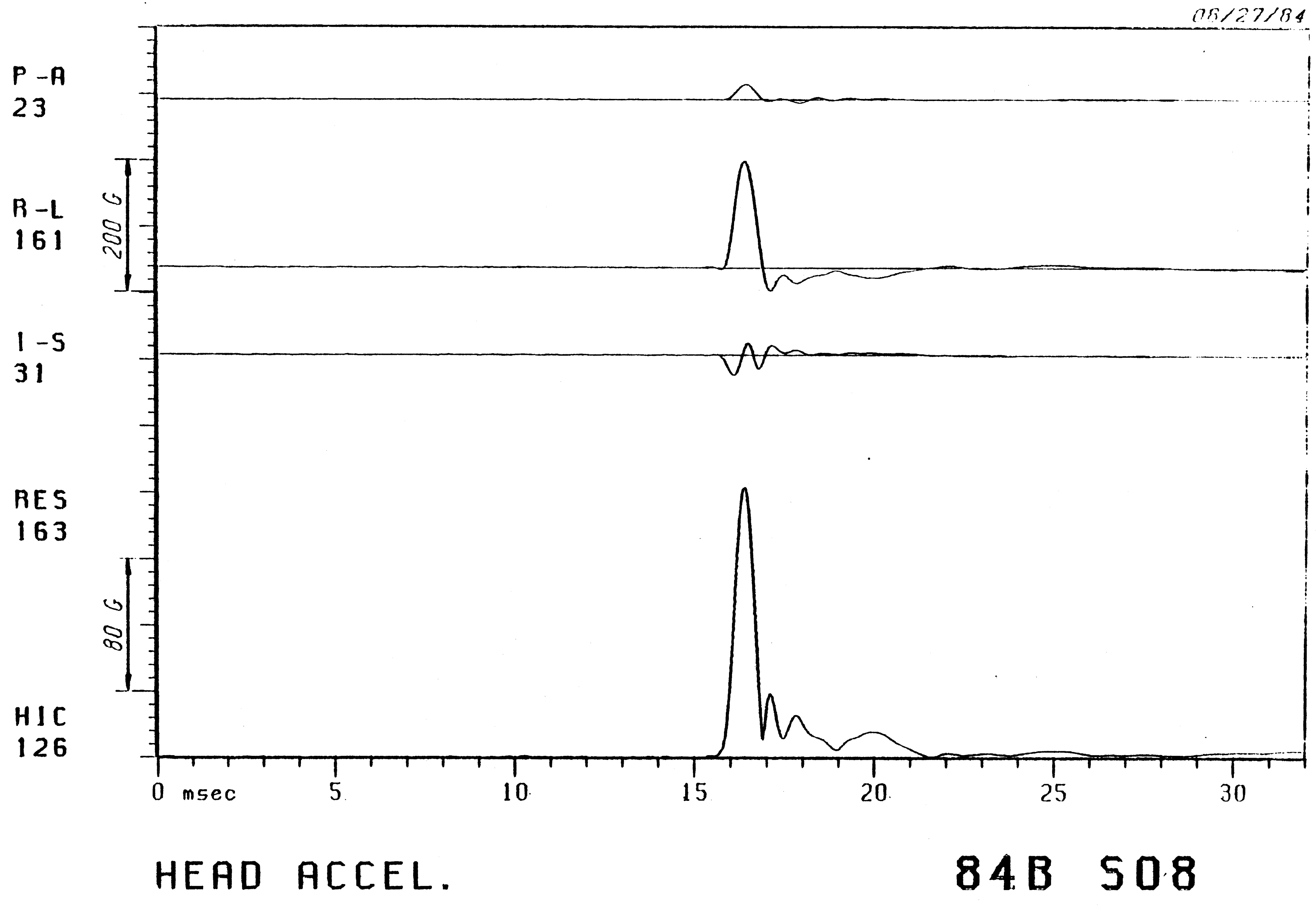
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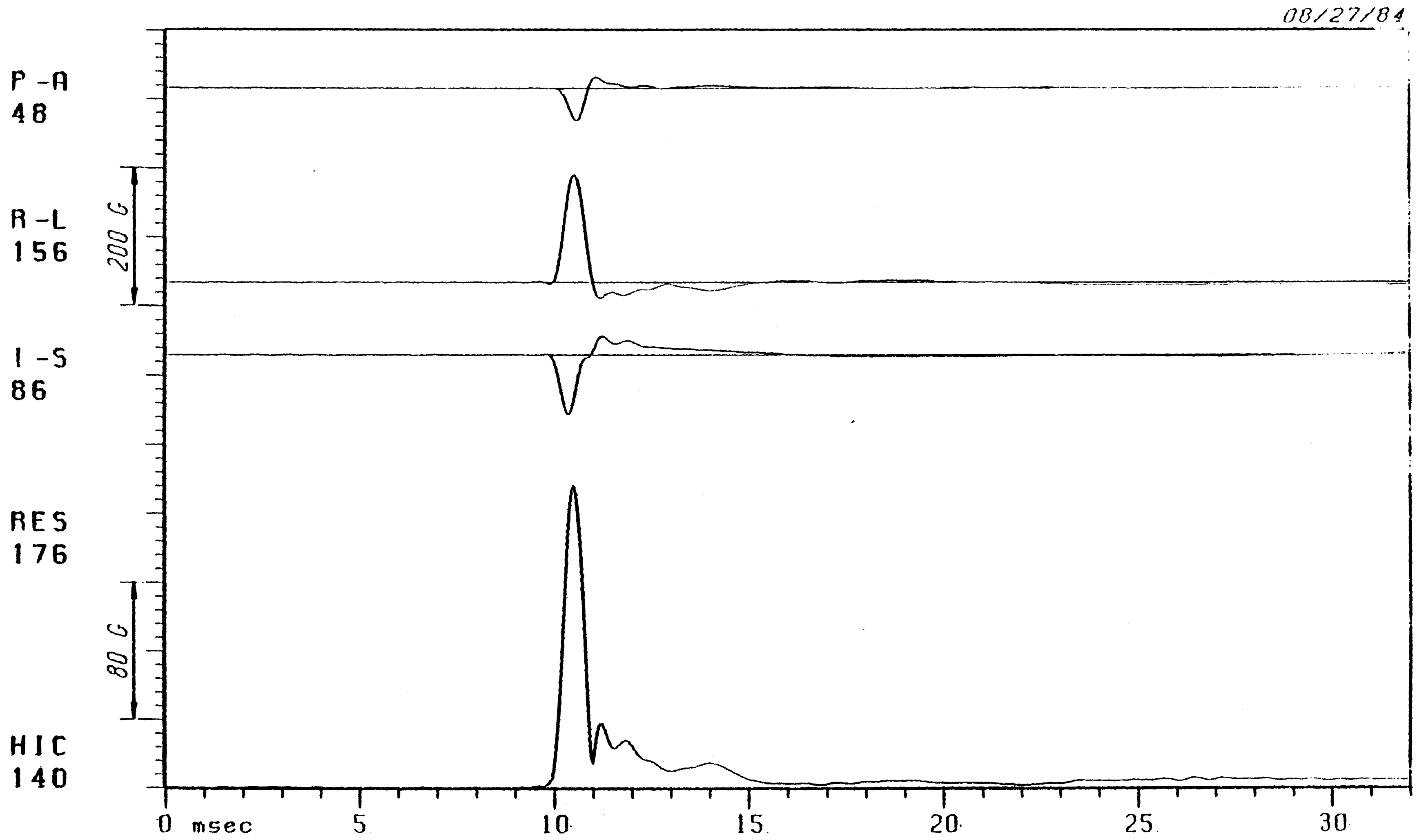

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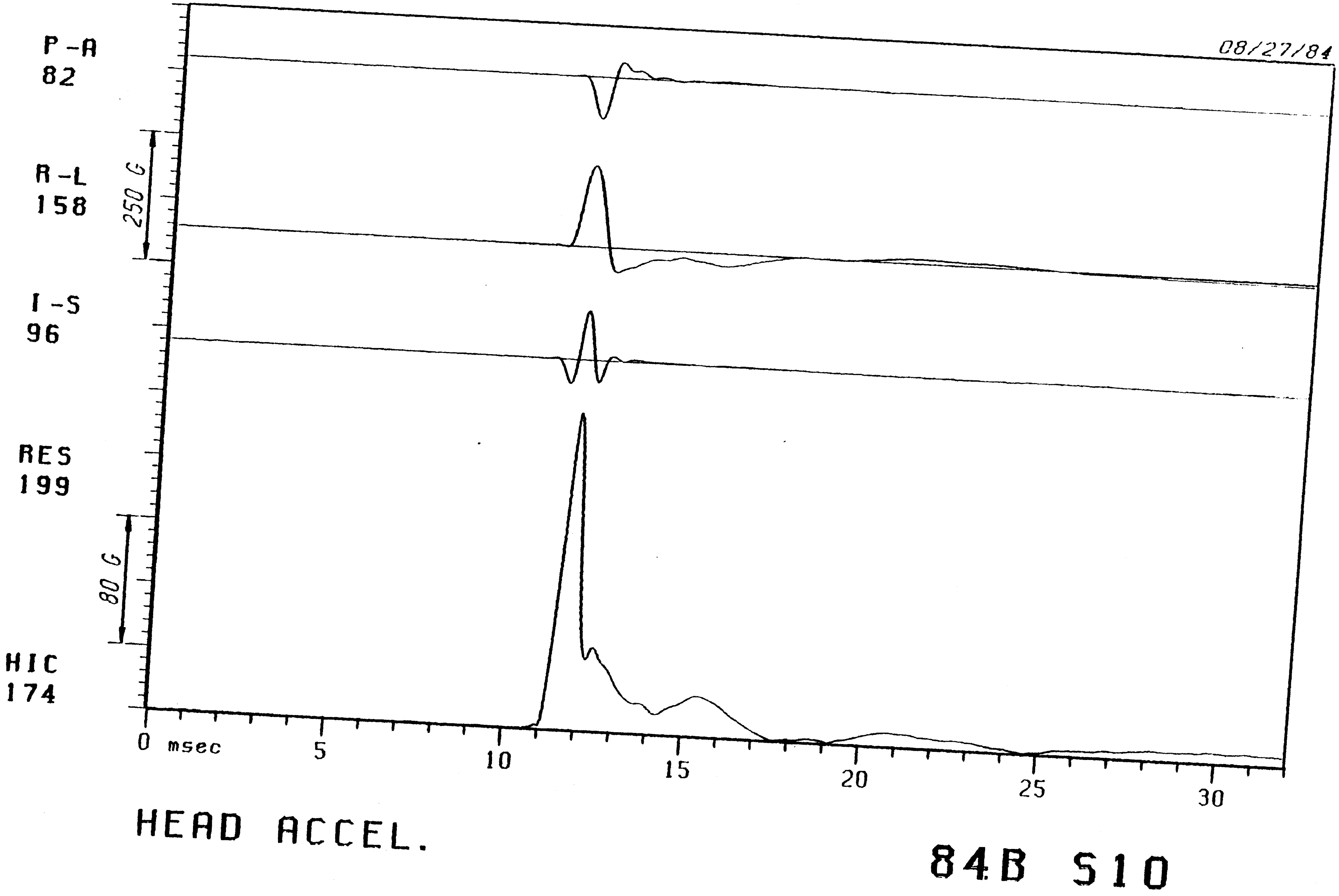
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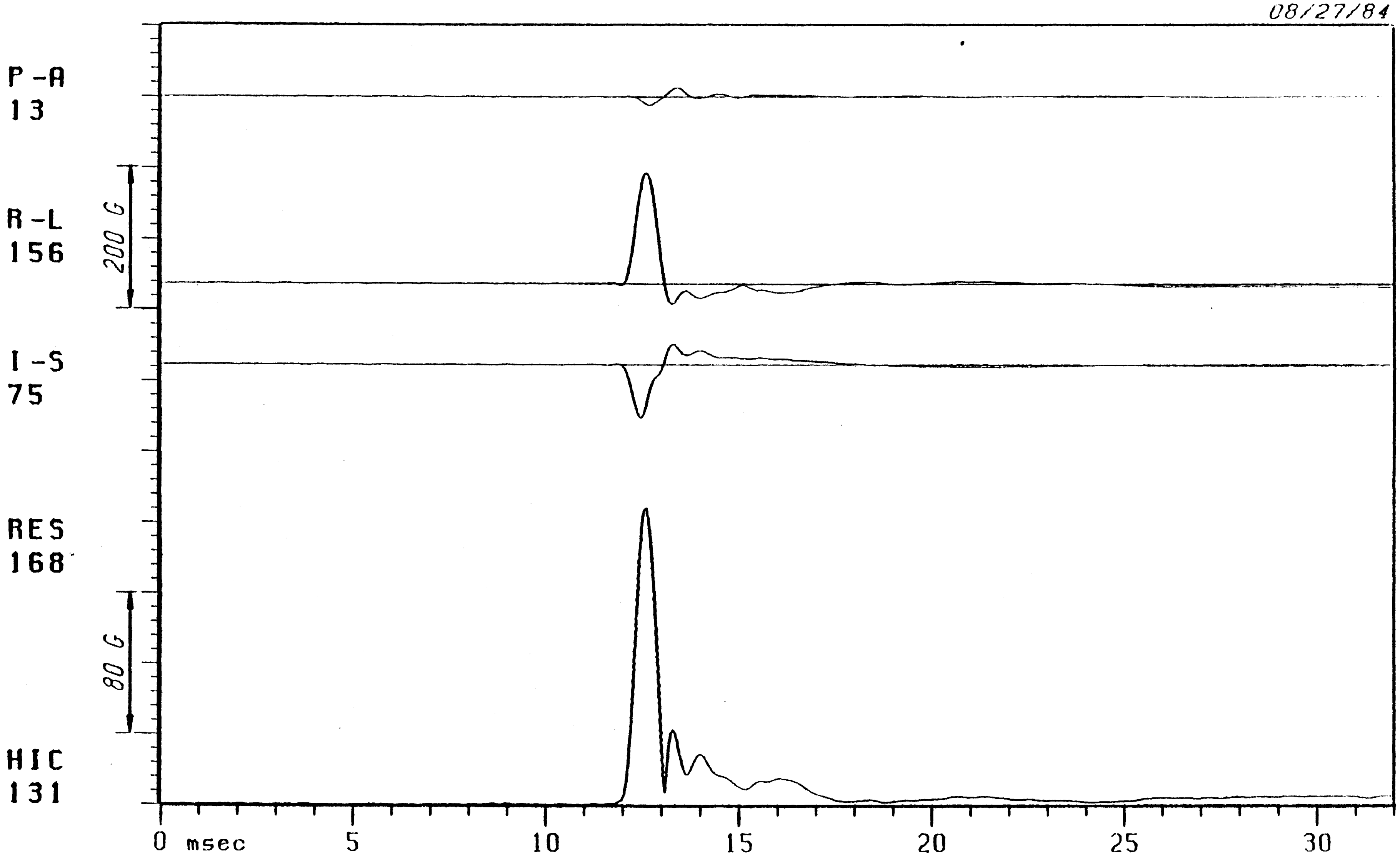

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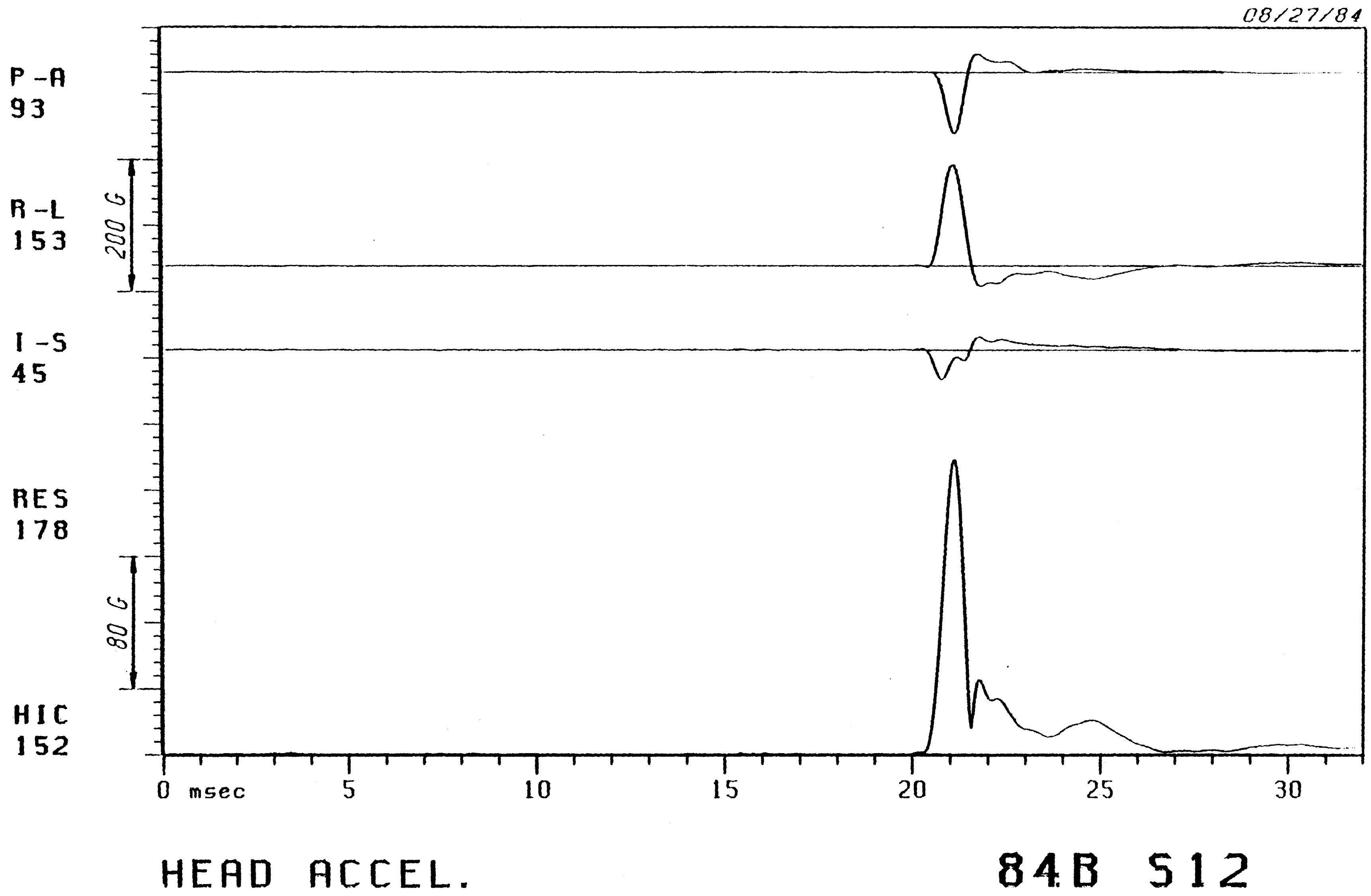
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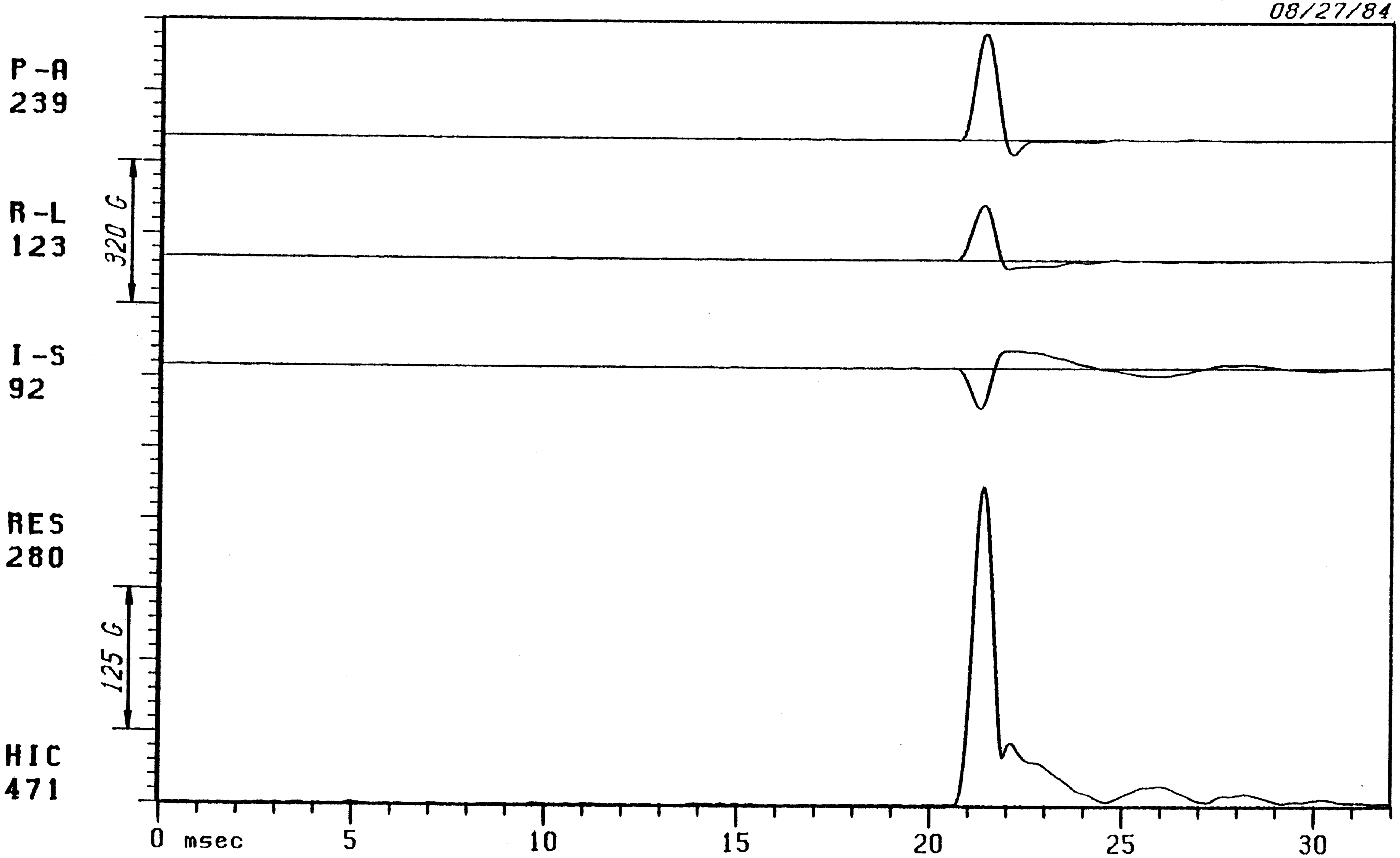
Hybrid III Dummy Results



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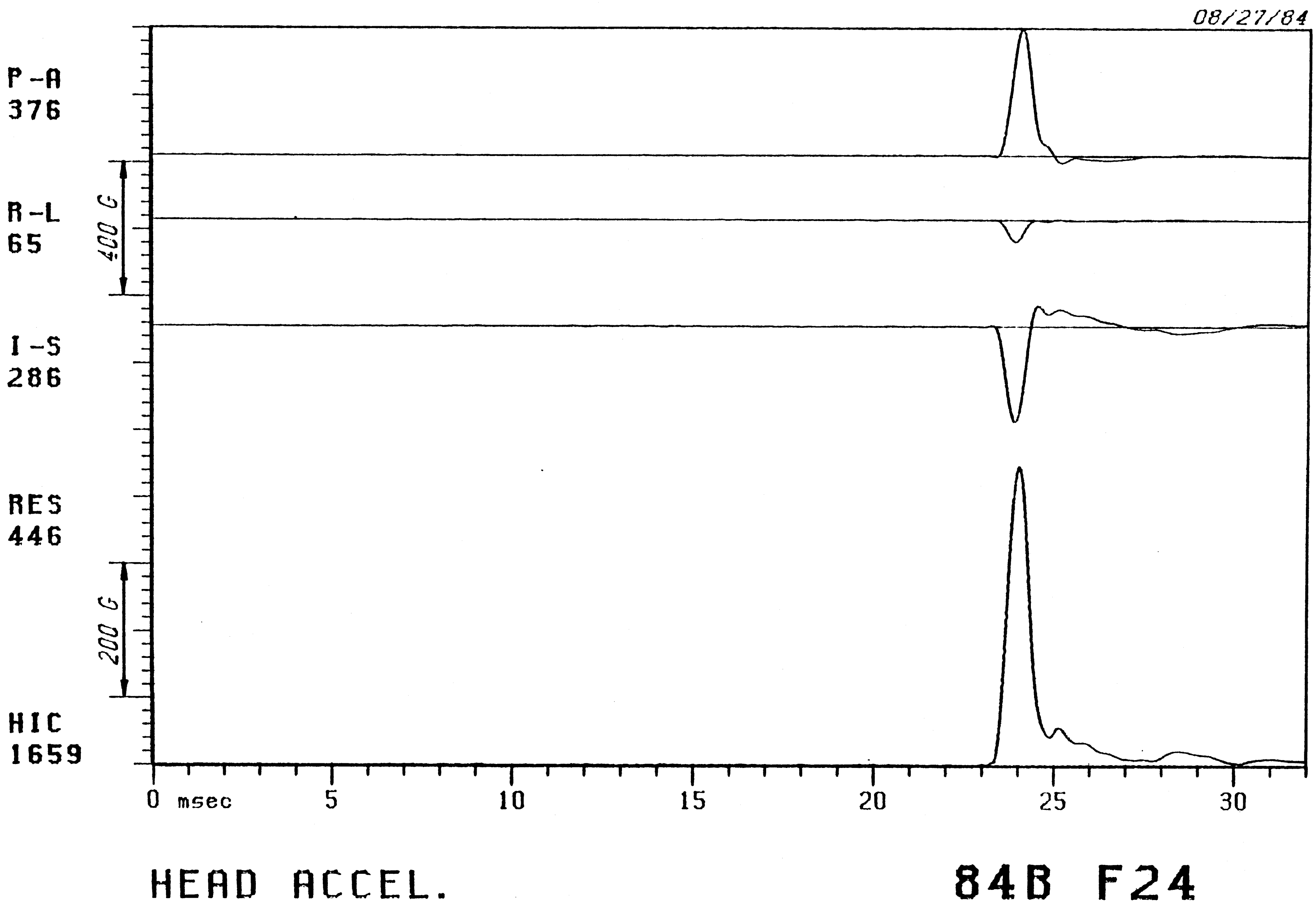
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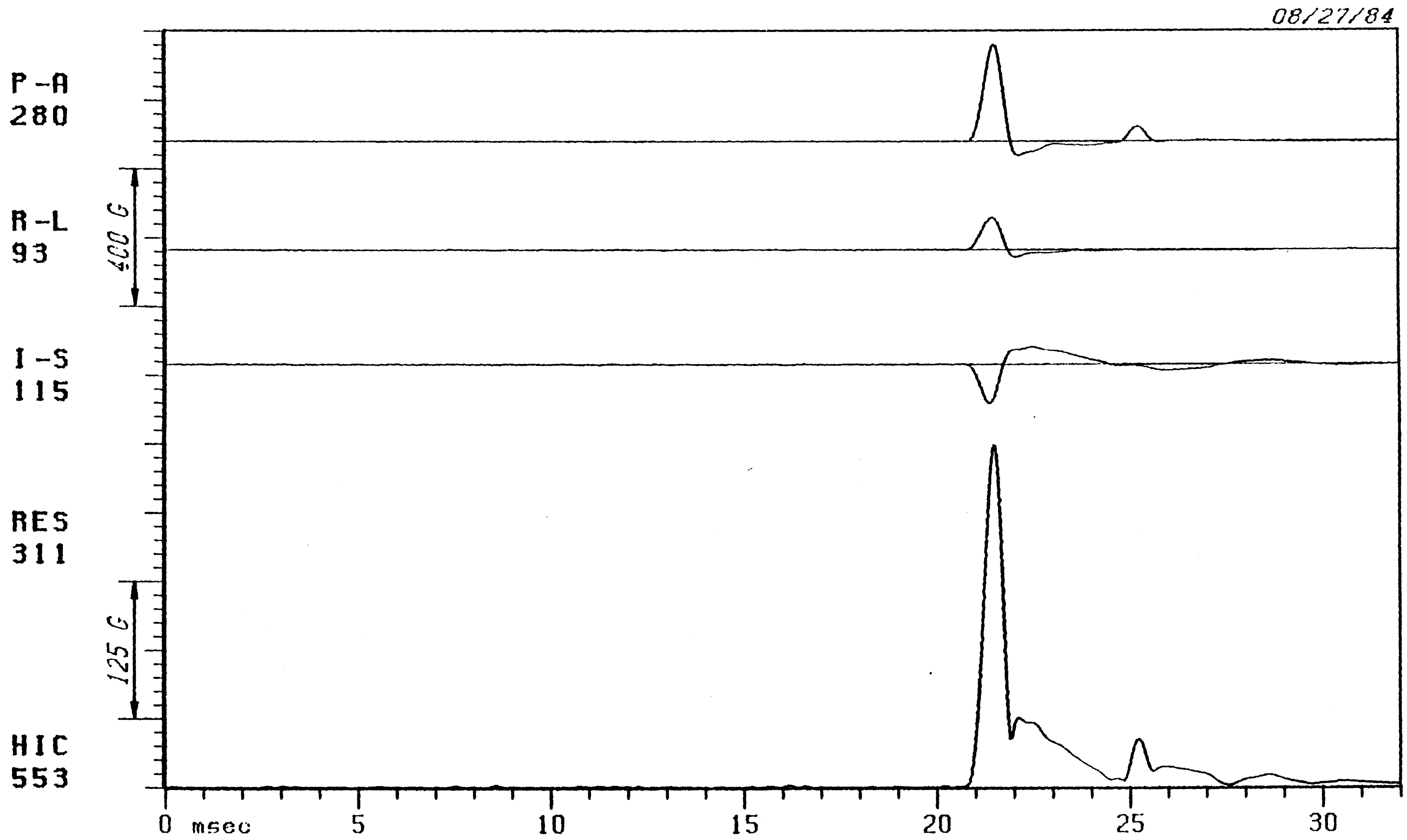

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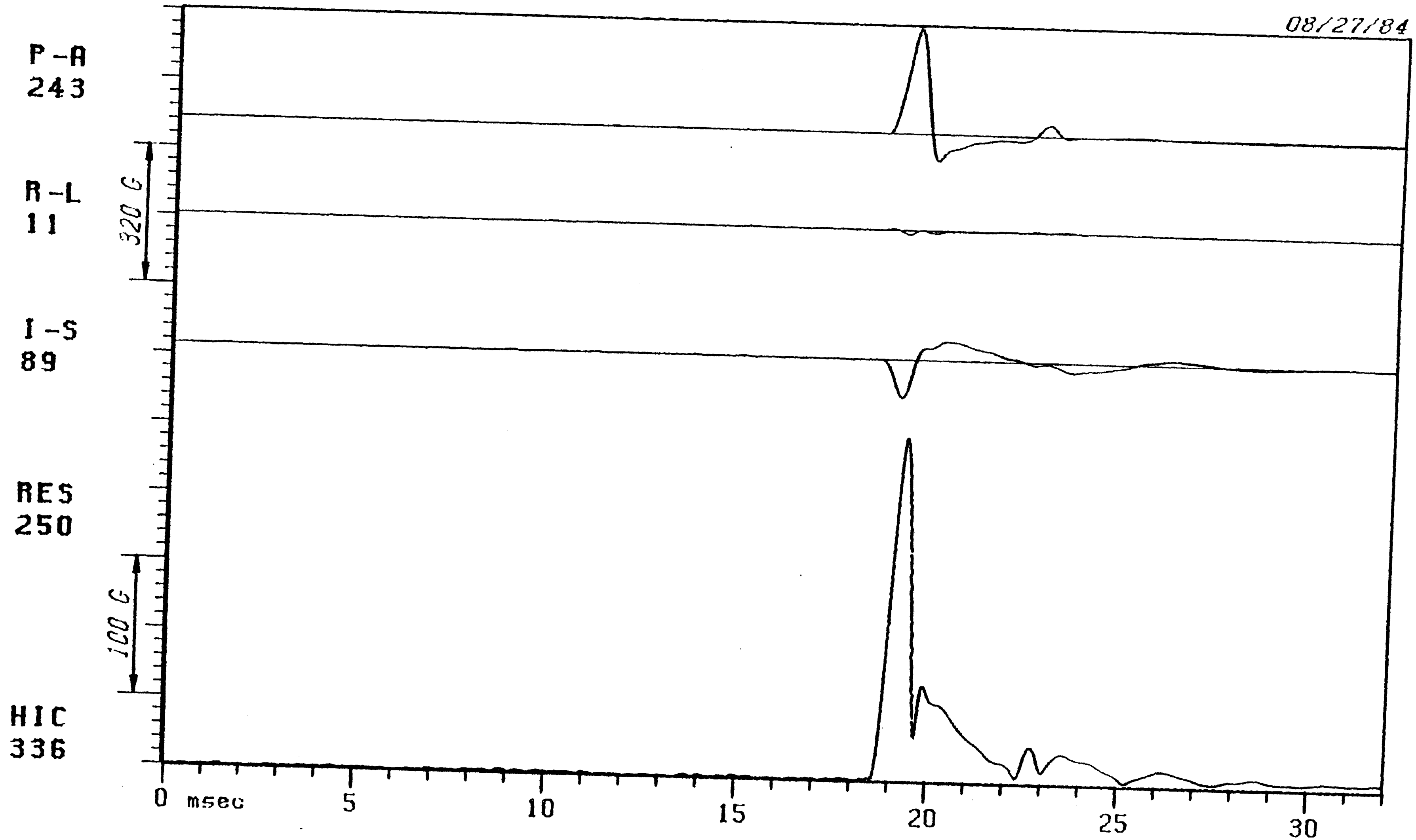

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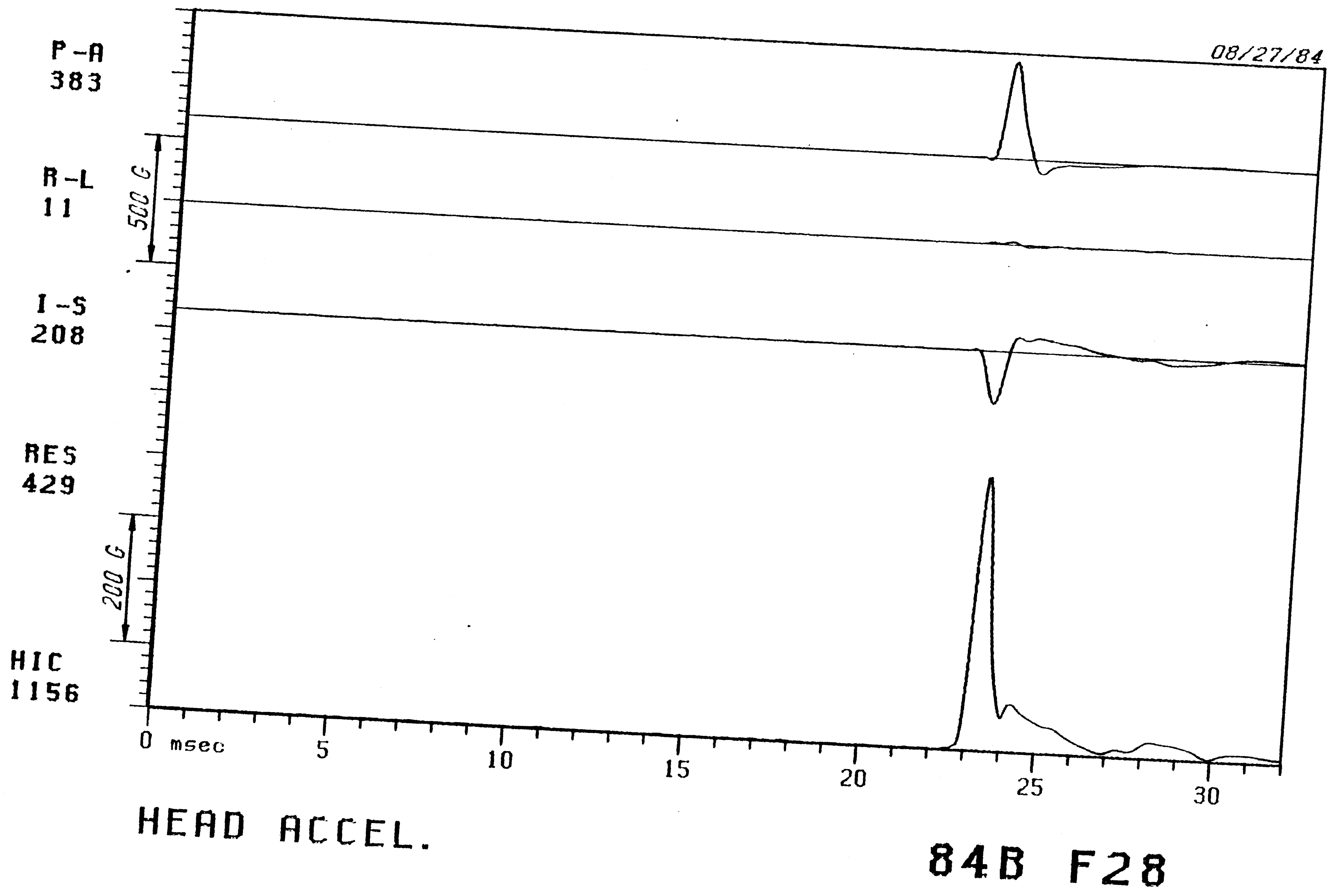
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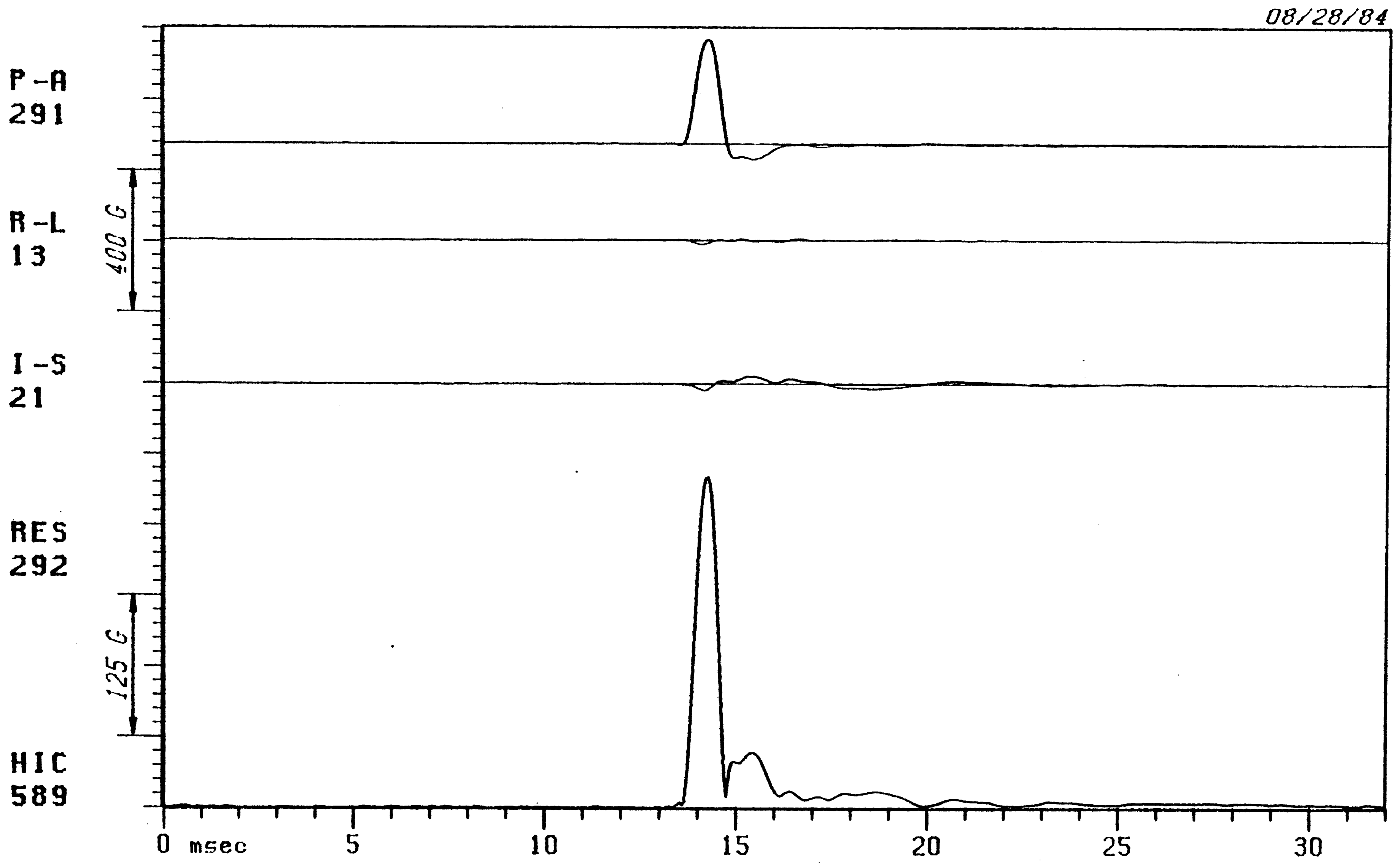
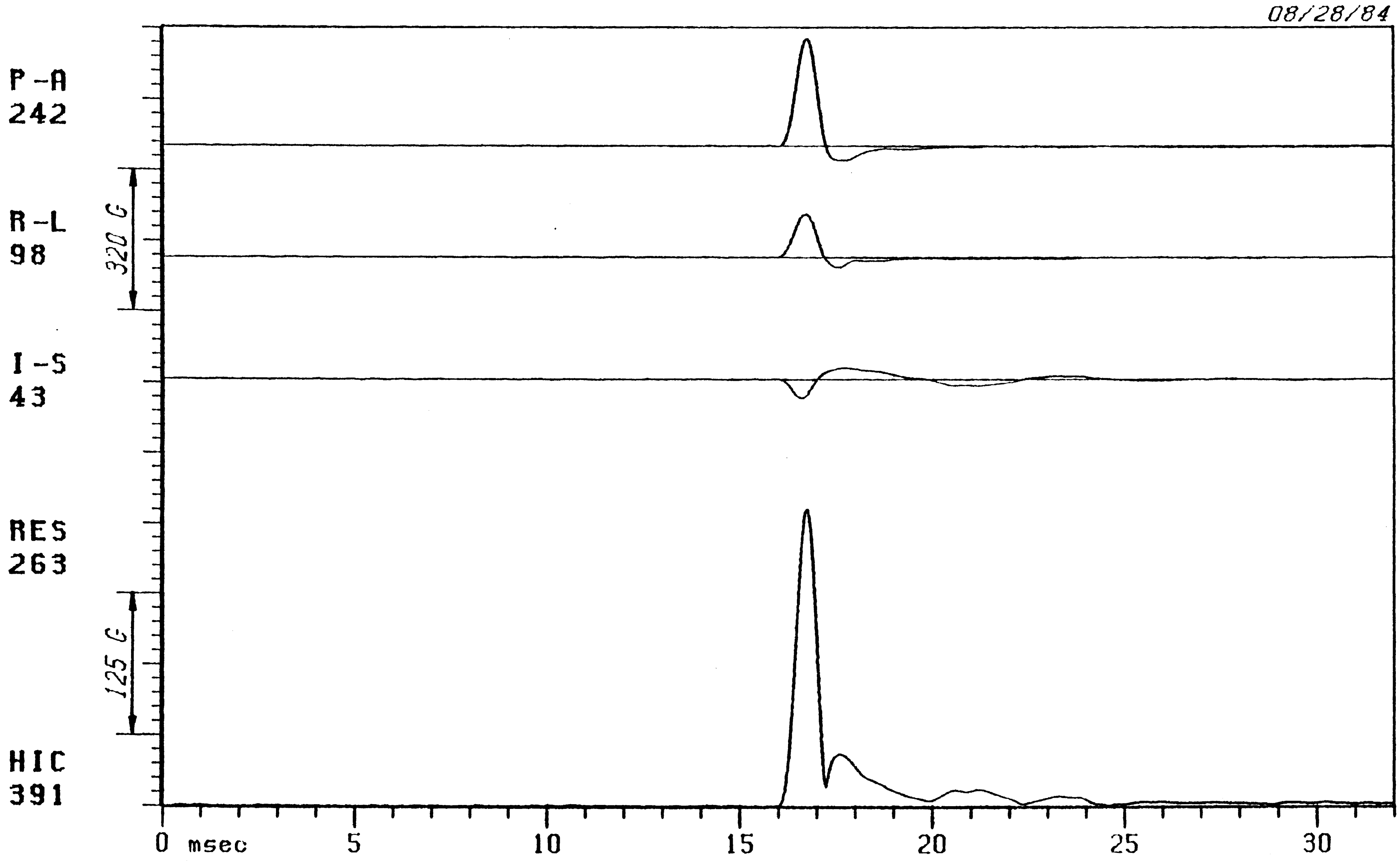
HEAD ACCEL.
84B F28



HEAD ACCEL.

84B F29



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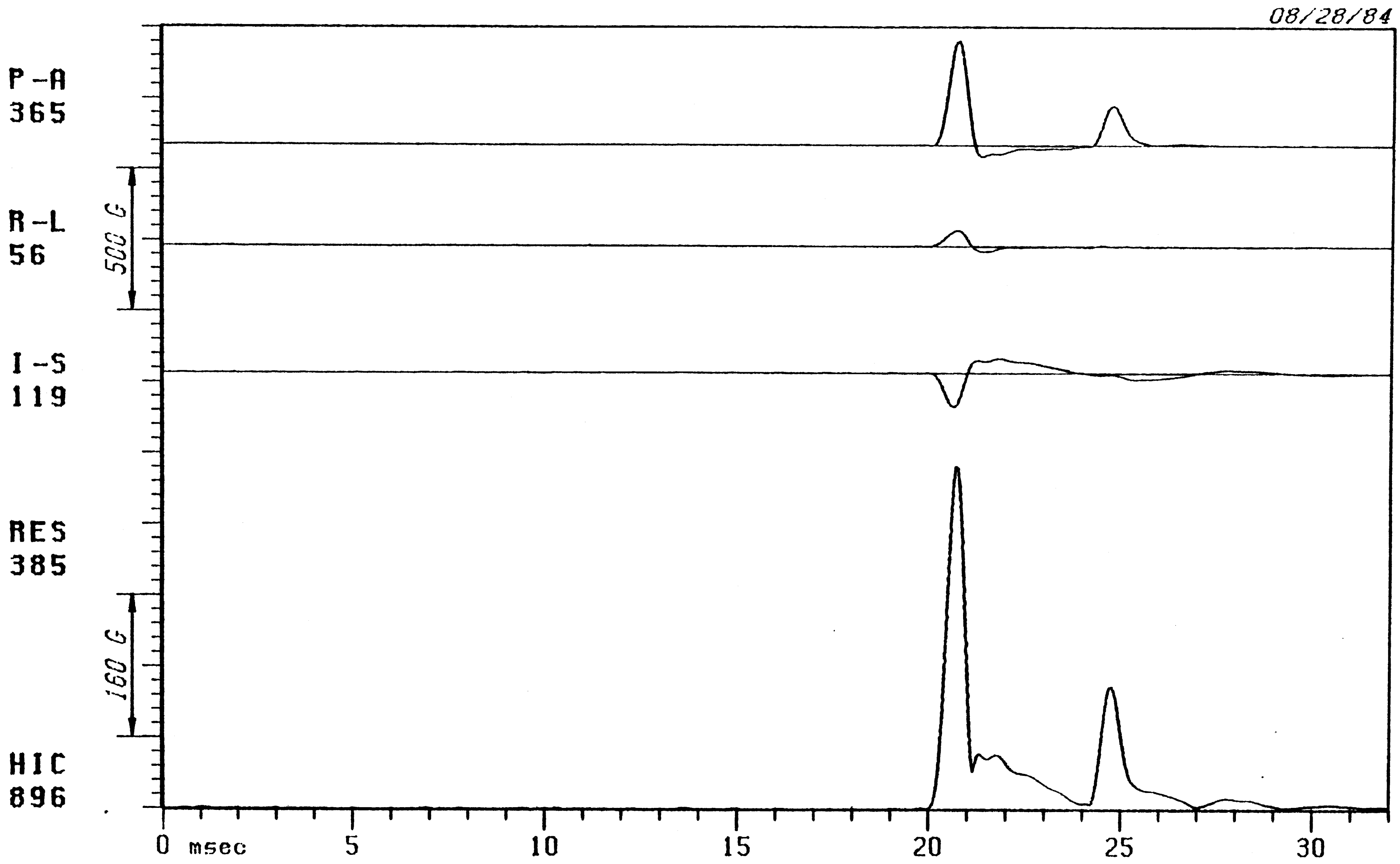
84B F30



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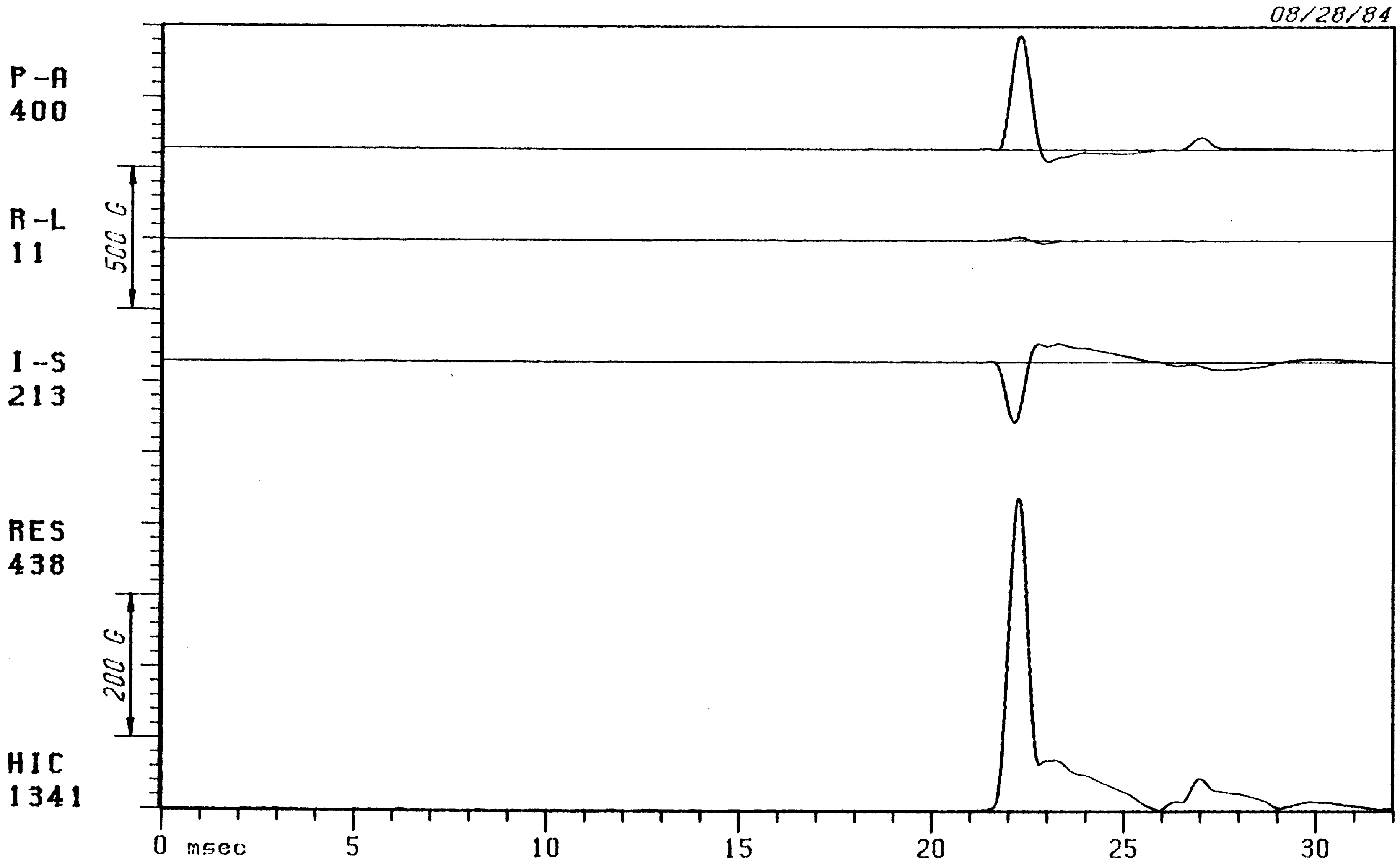
84B F31



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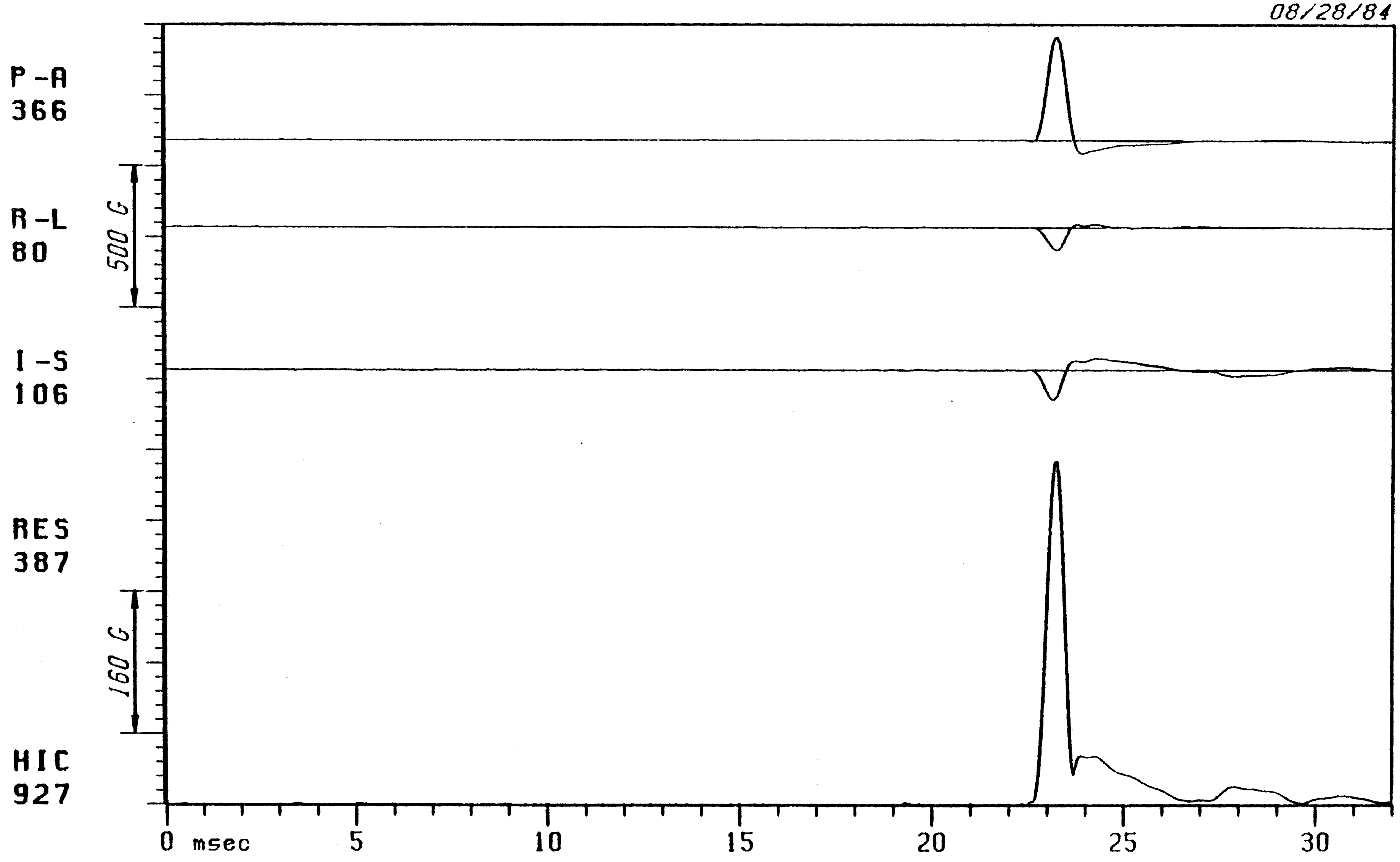
84B F32



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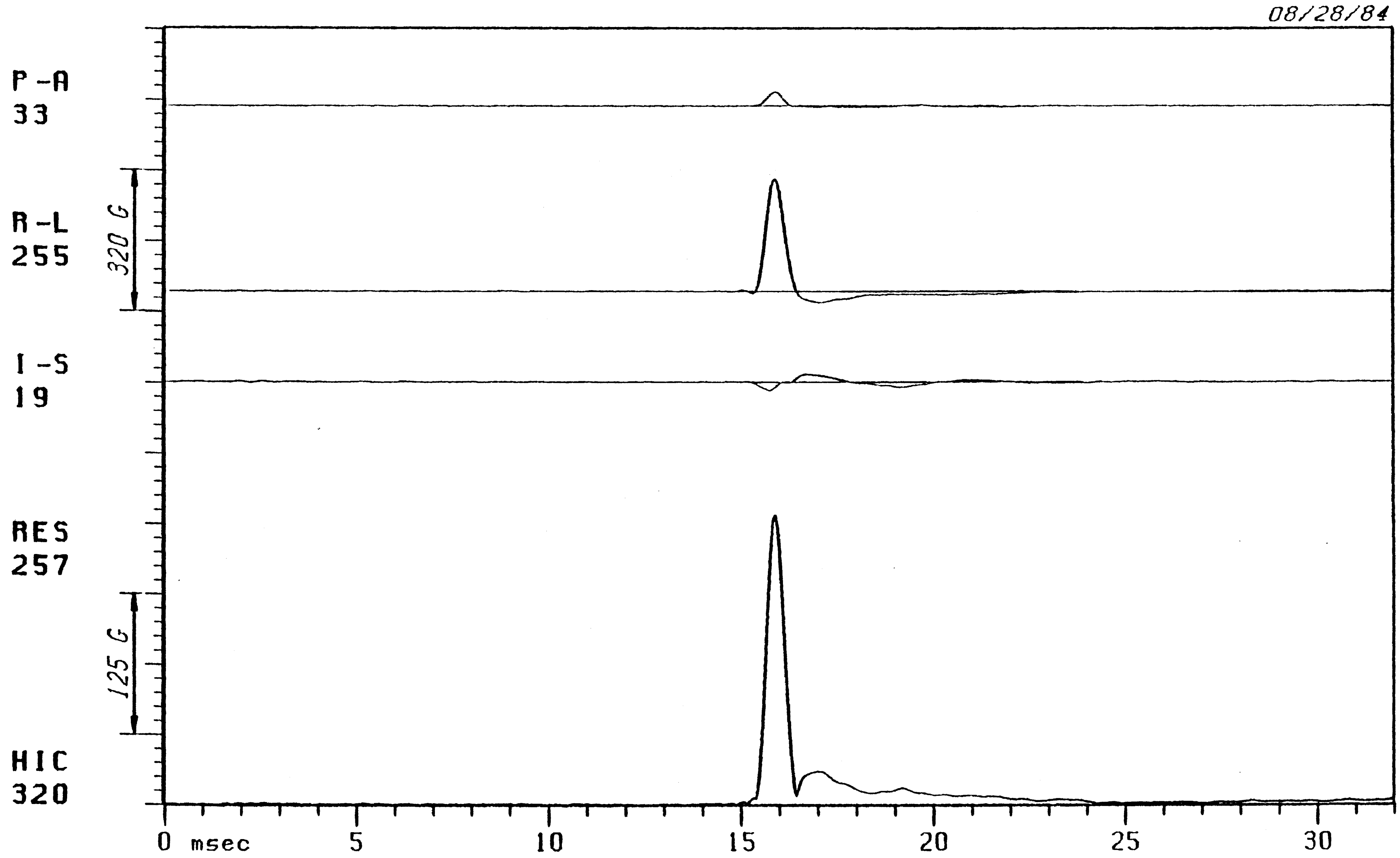
84B F33



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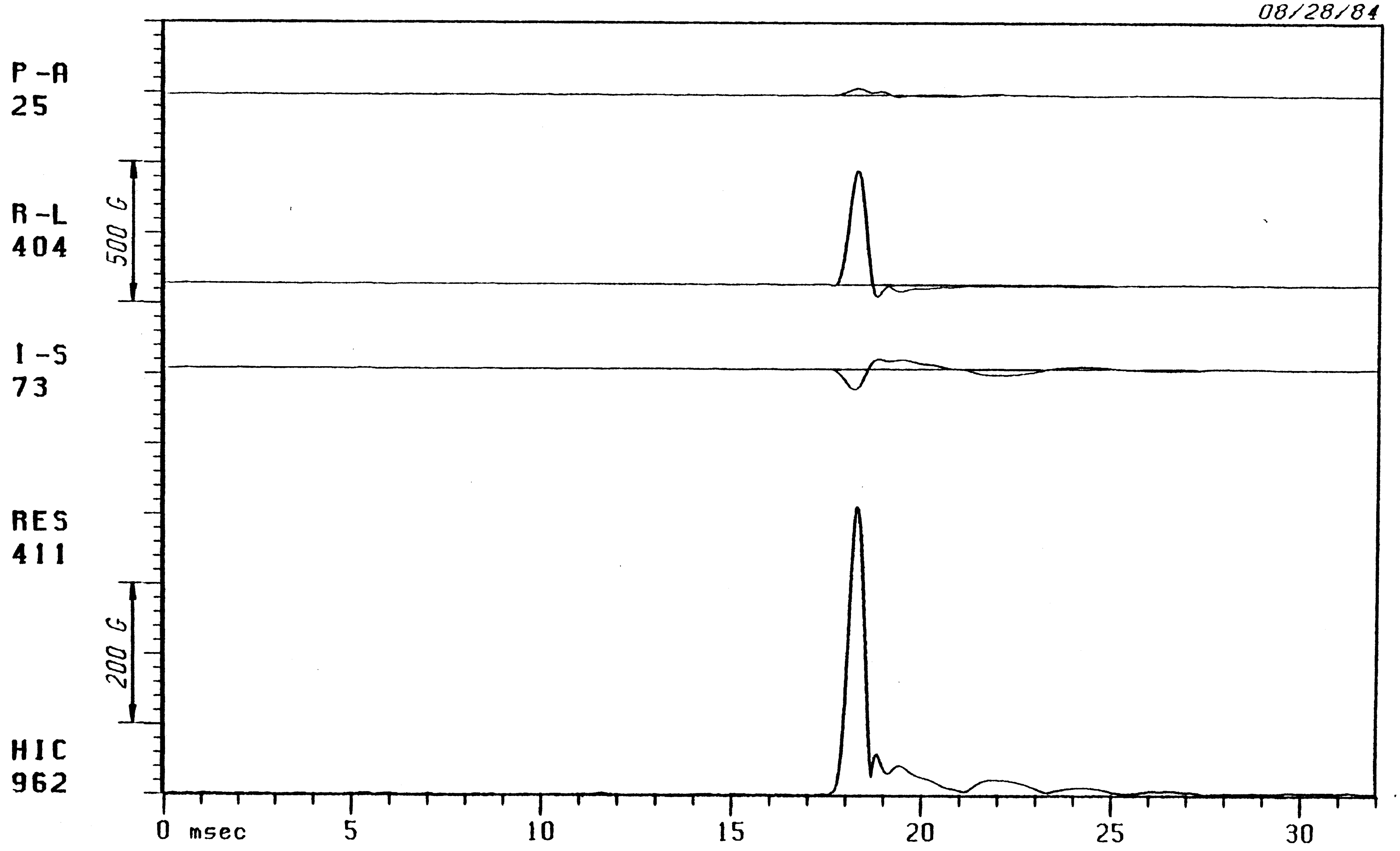
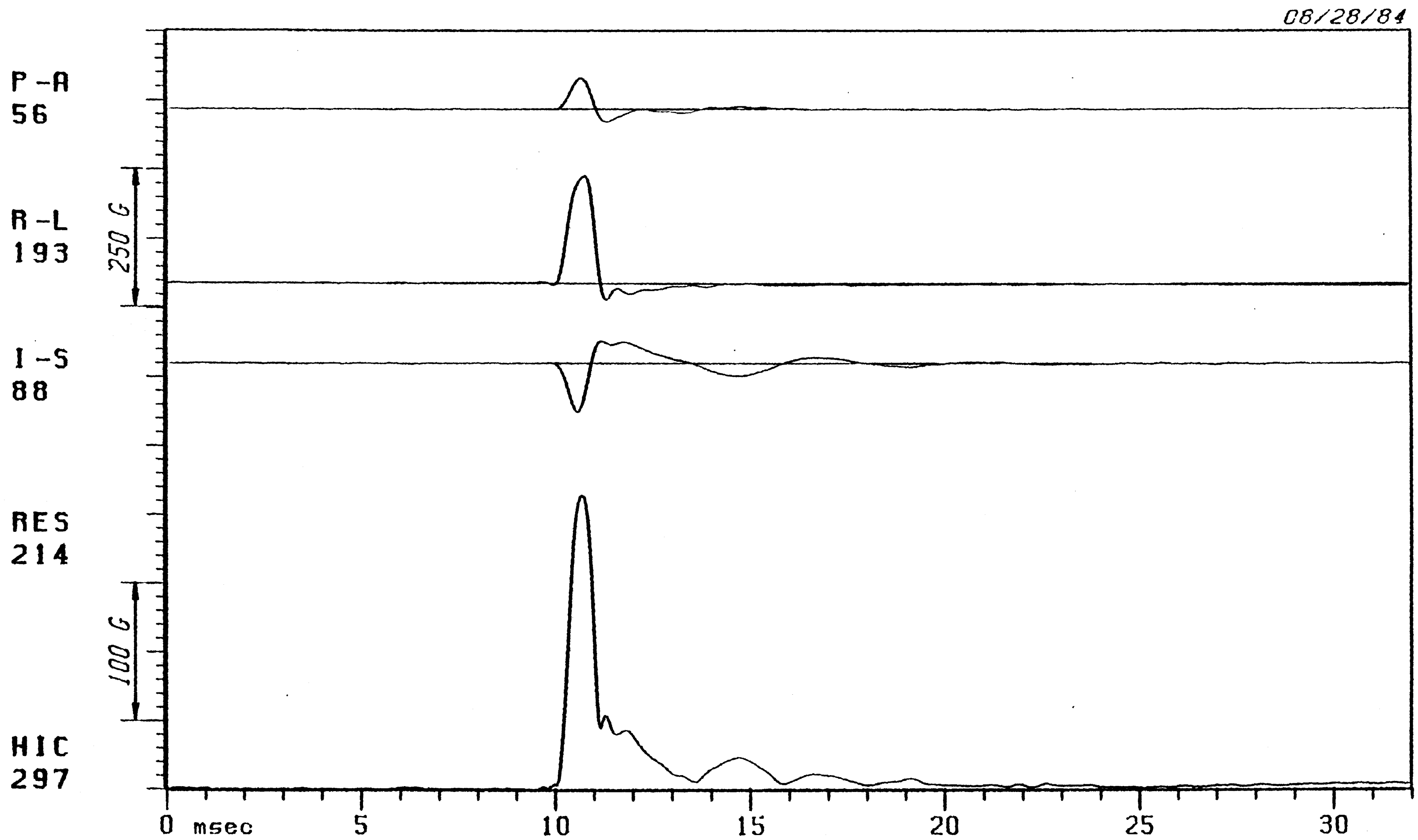
84B 534



HEAD ACCEL. 84B S35



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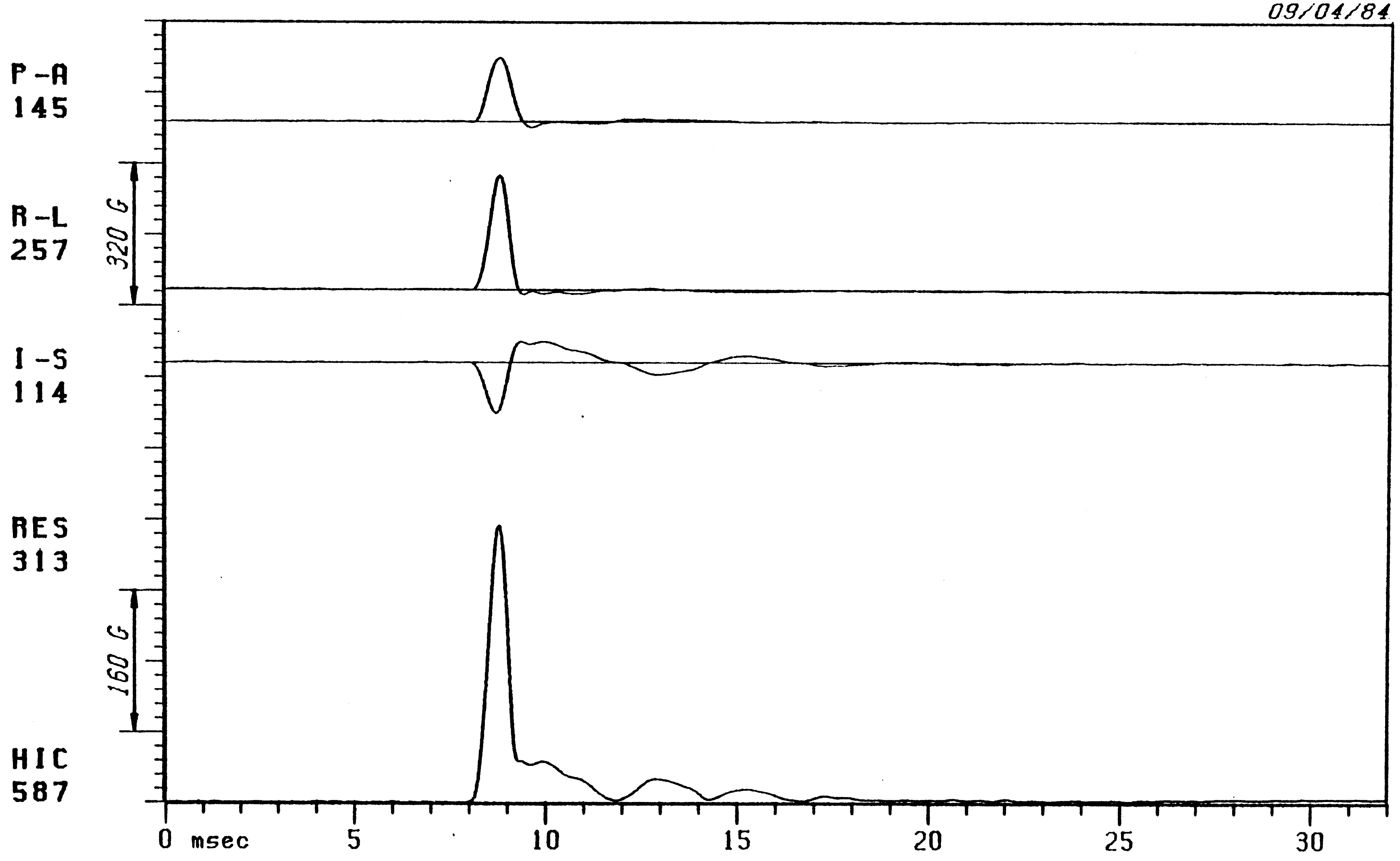
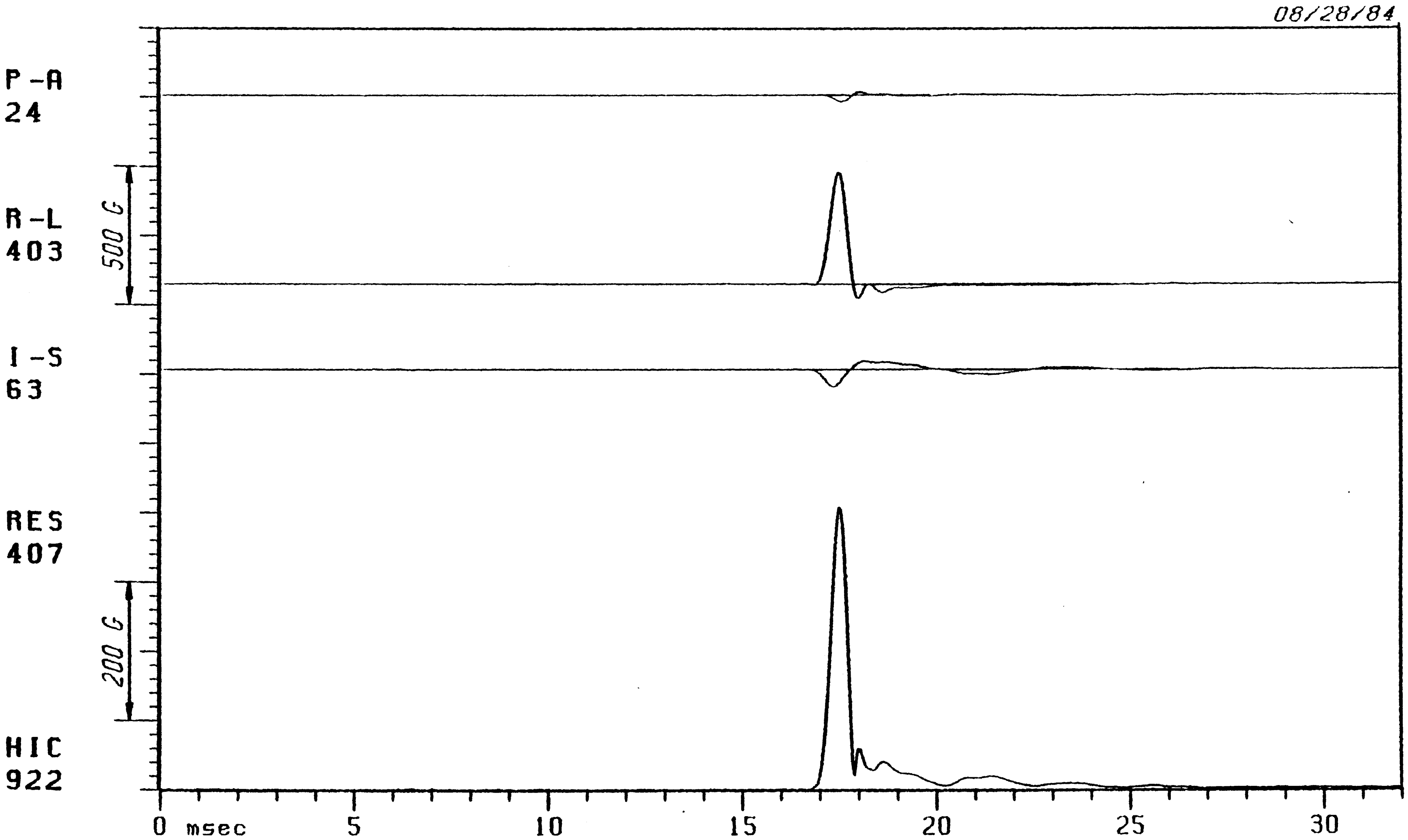


HEAD ACCEL.

84B S37



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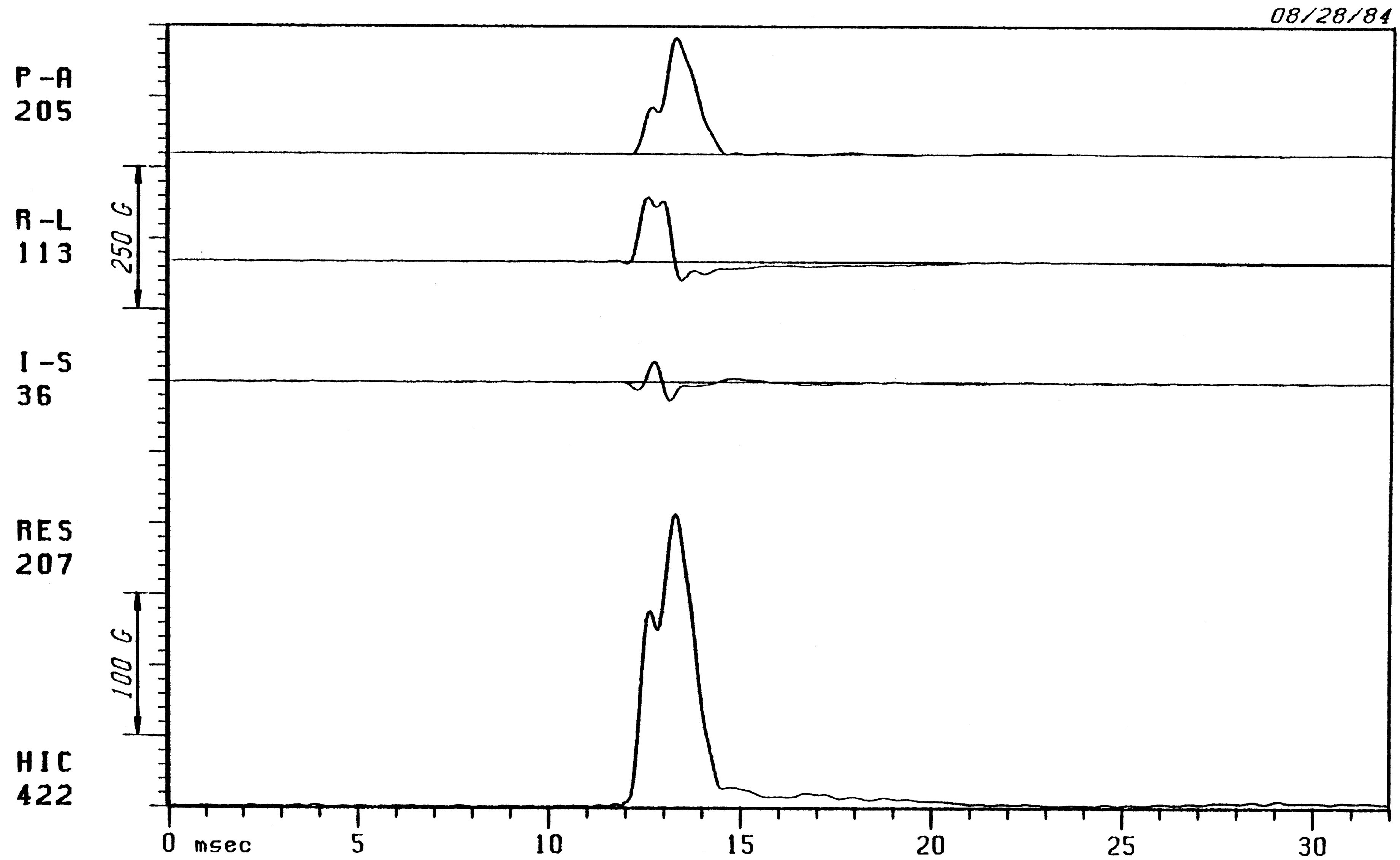
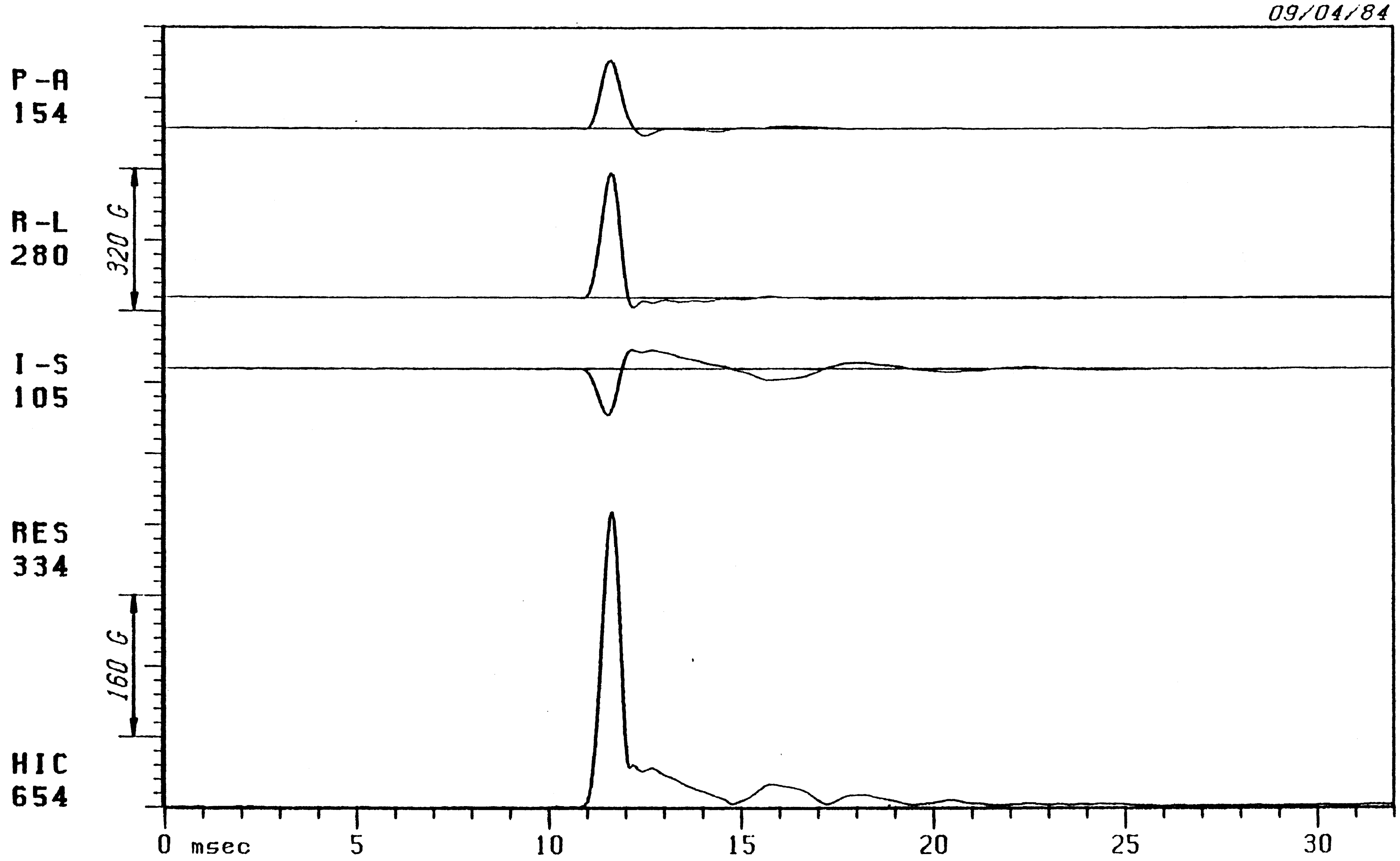
84B 540



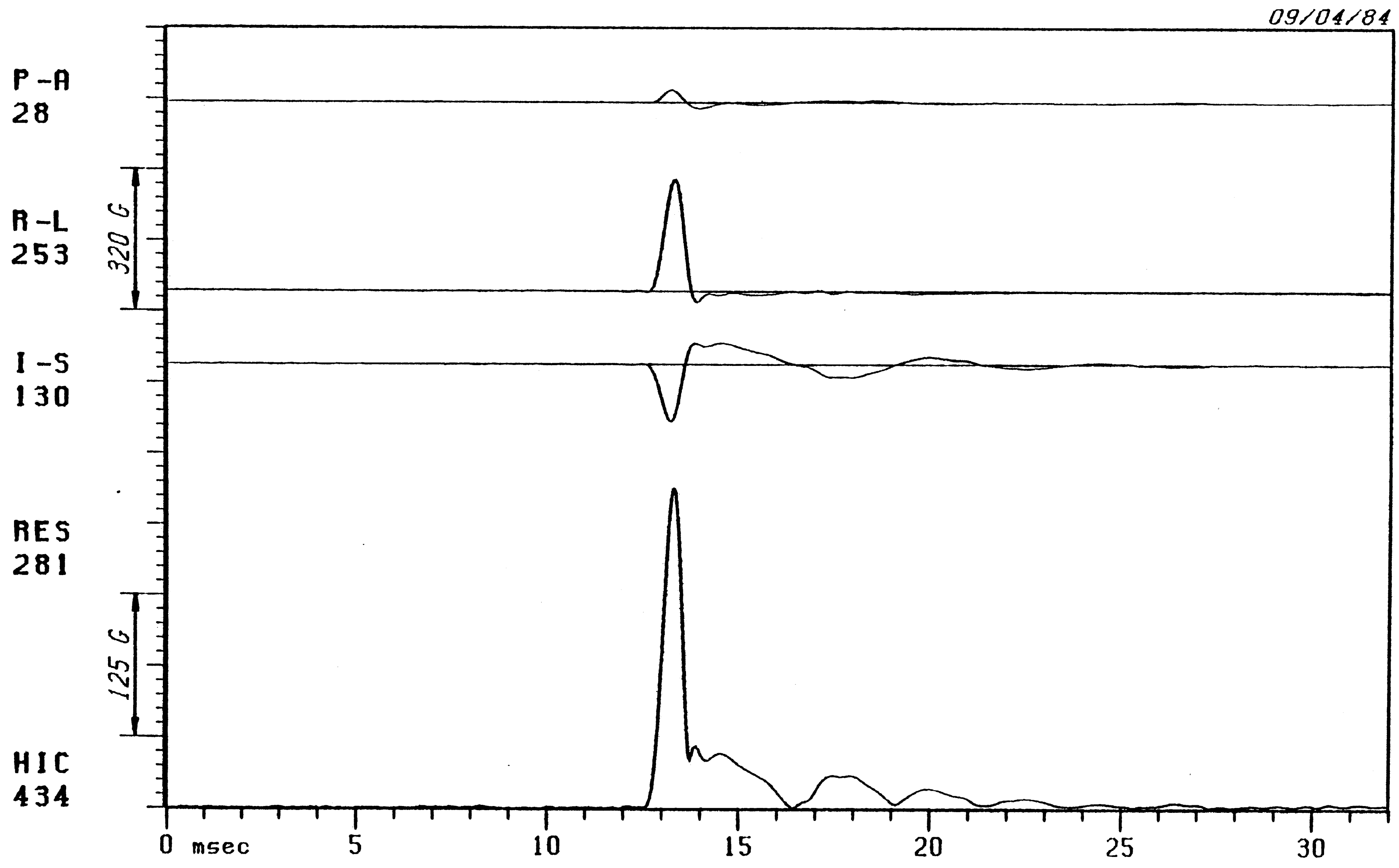
HEAD ACCEL.

84B S41



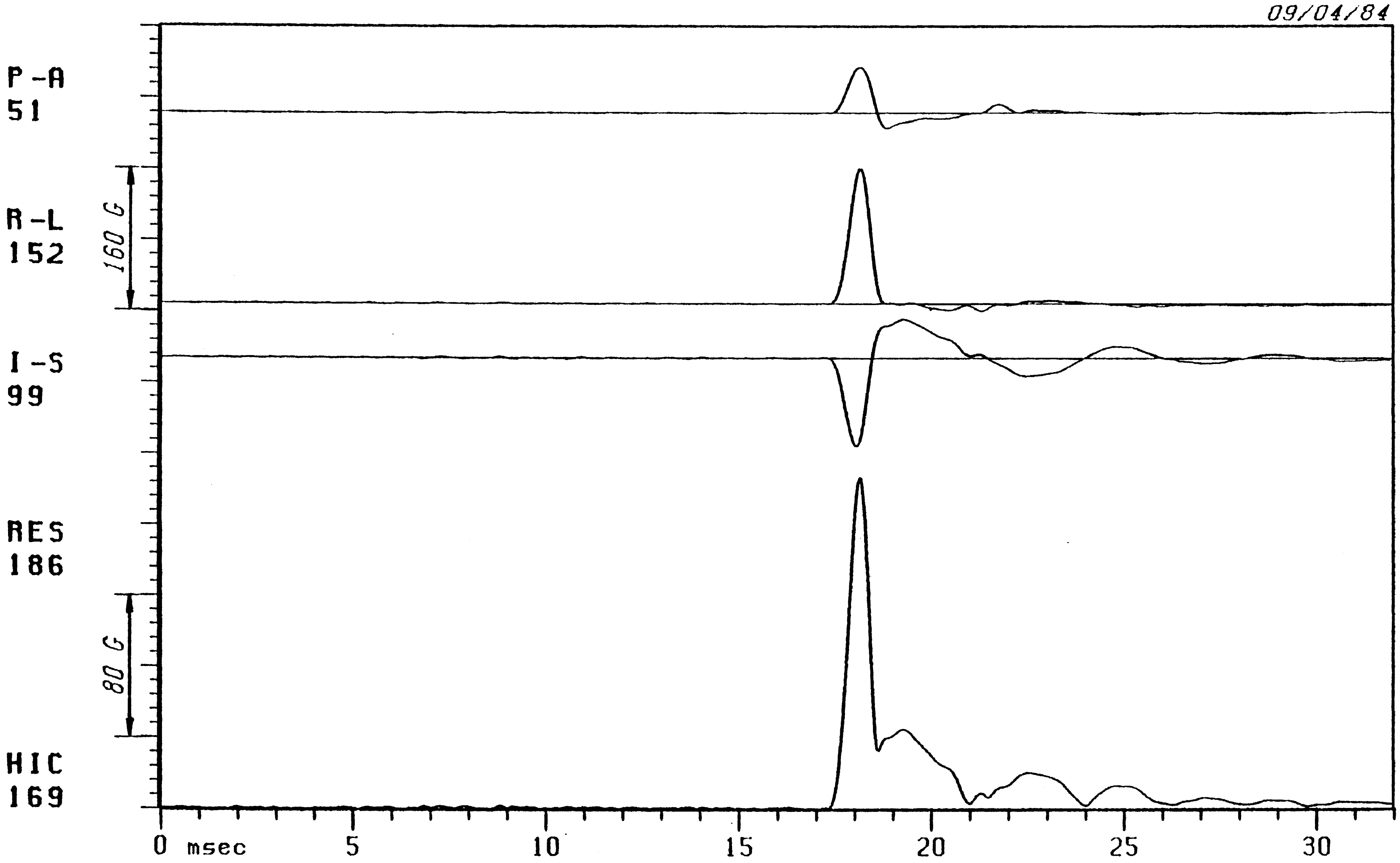
HEAD ACCEL.

84B 542



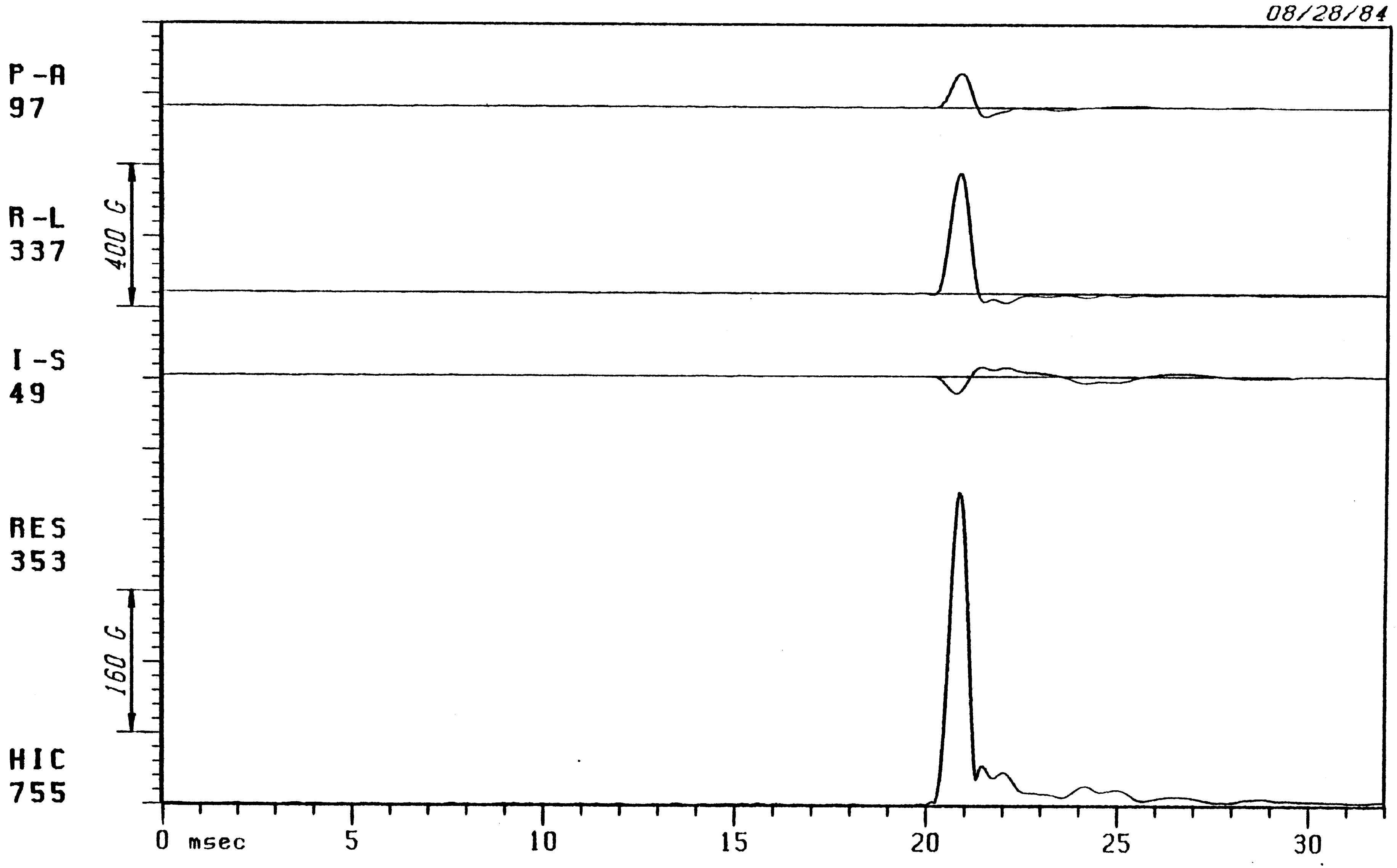
HEAD ACCEL.

84B S43



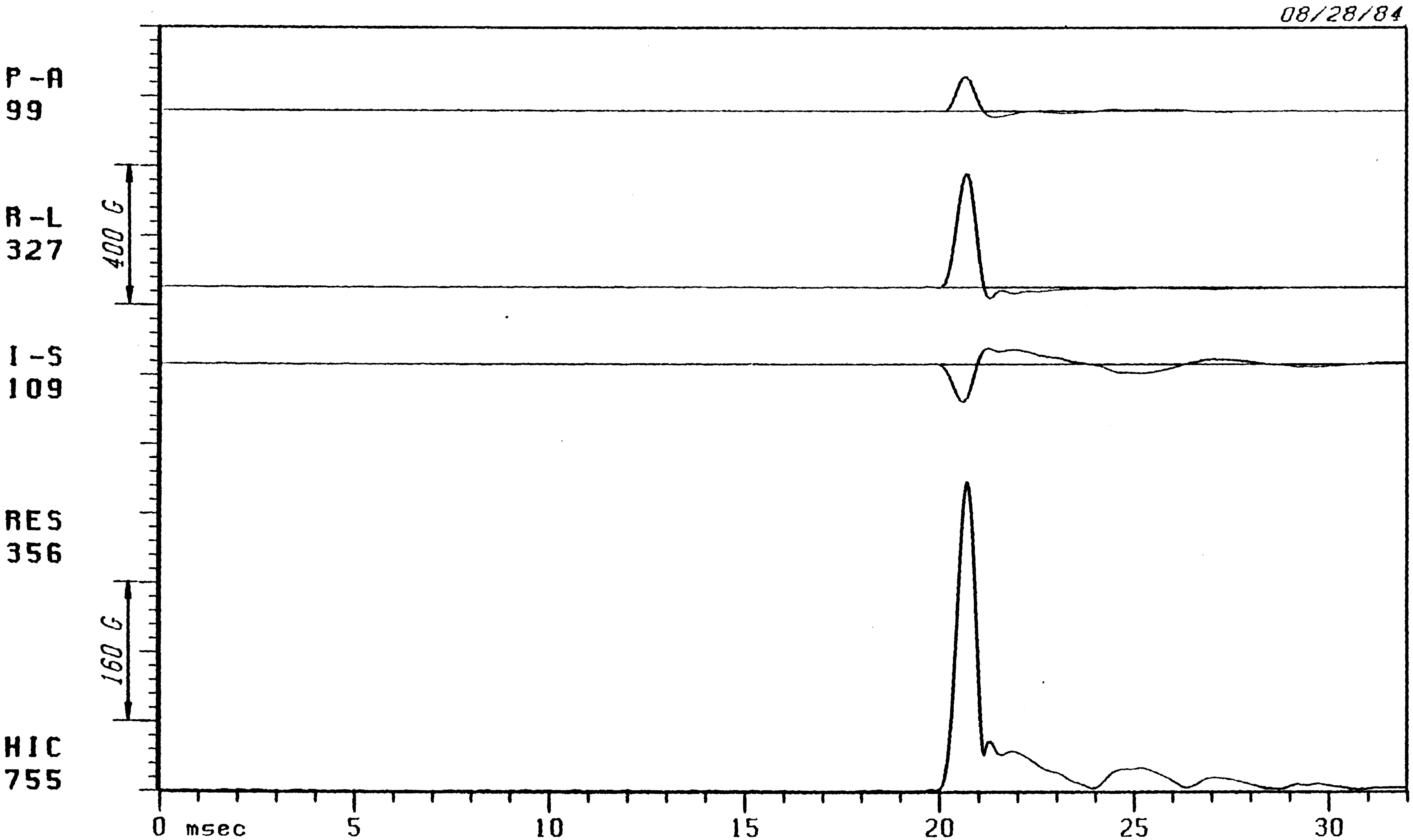
HEAD ACCEL.

84B S44



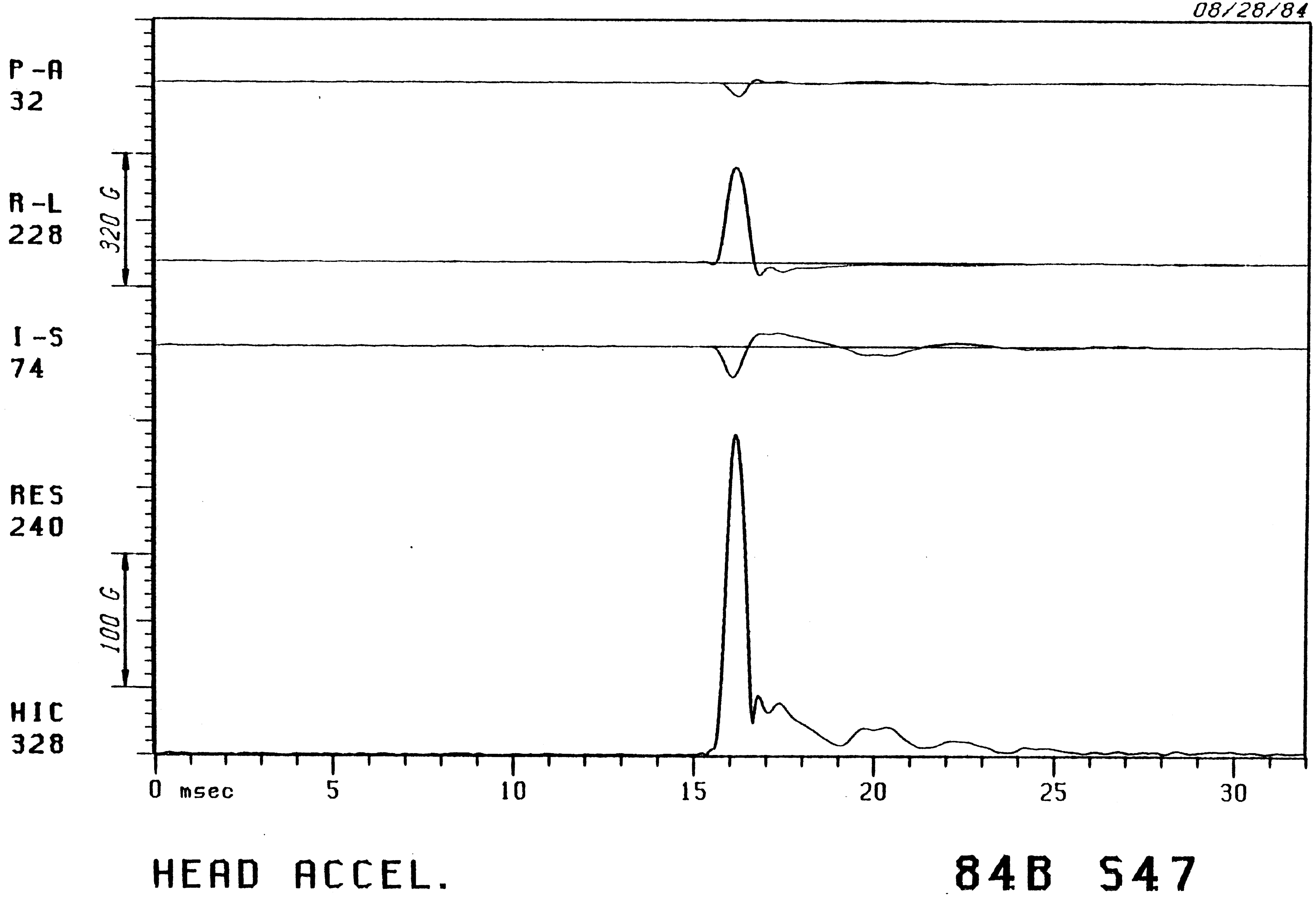
HEAD ACCEL.

84B S45

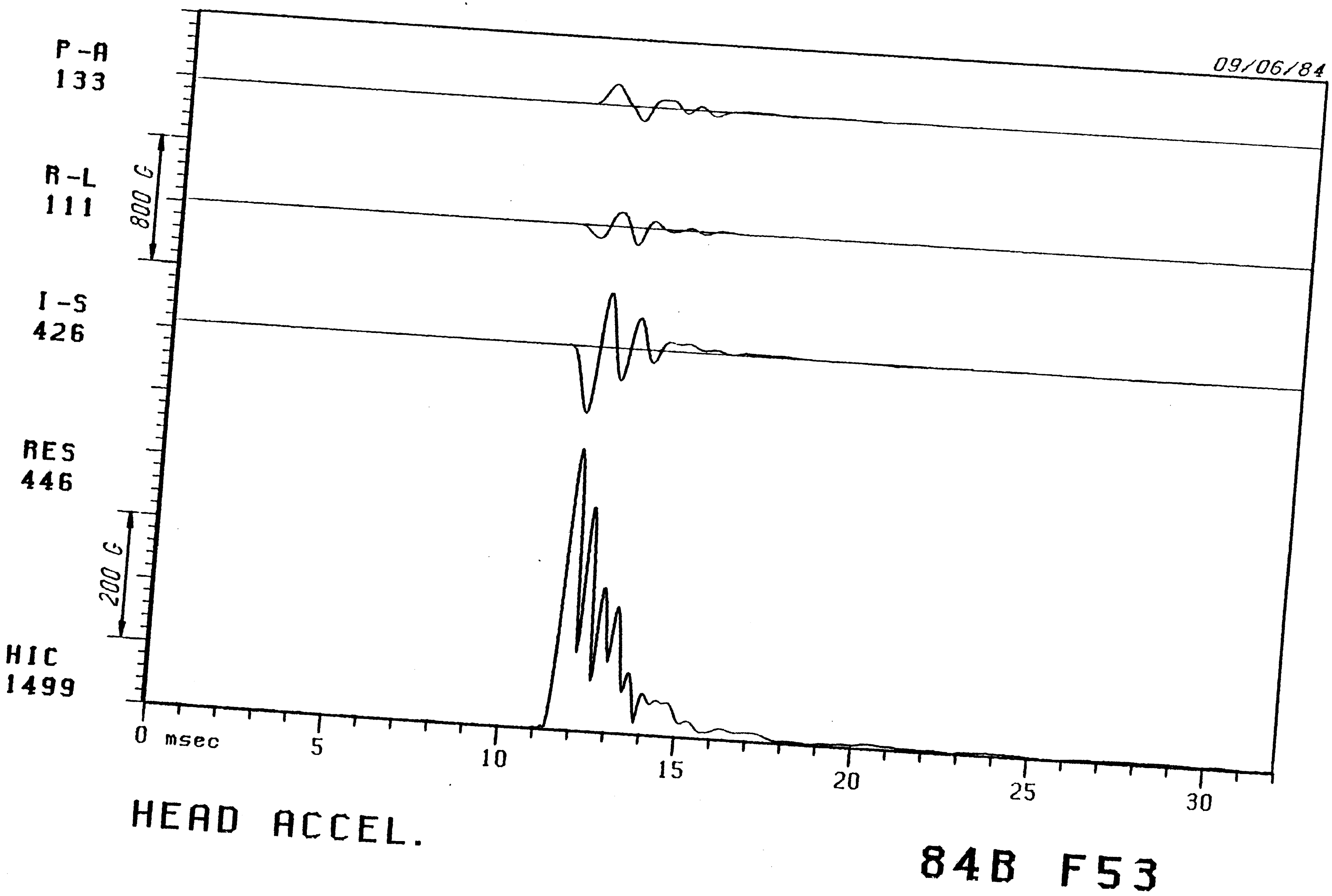


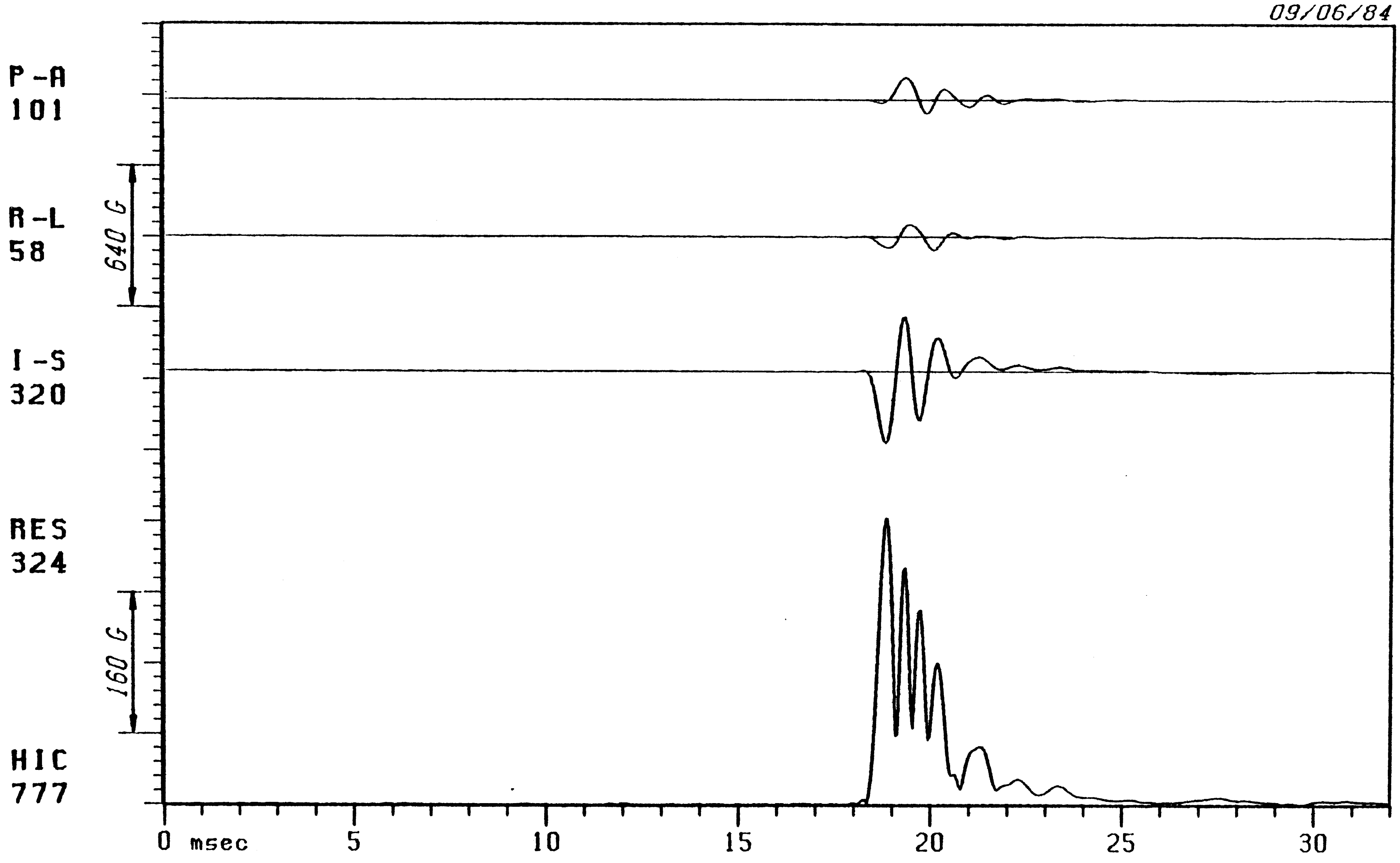
HEAD ACCEL.

84B S46


08/28/84
P-A
32
R-L
228
I-S
74
RES
240
HIC
328
320 G
100 G
0 msec
5
10
15
20
25
30
HEAD ACCEL.
84B S47

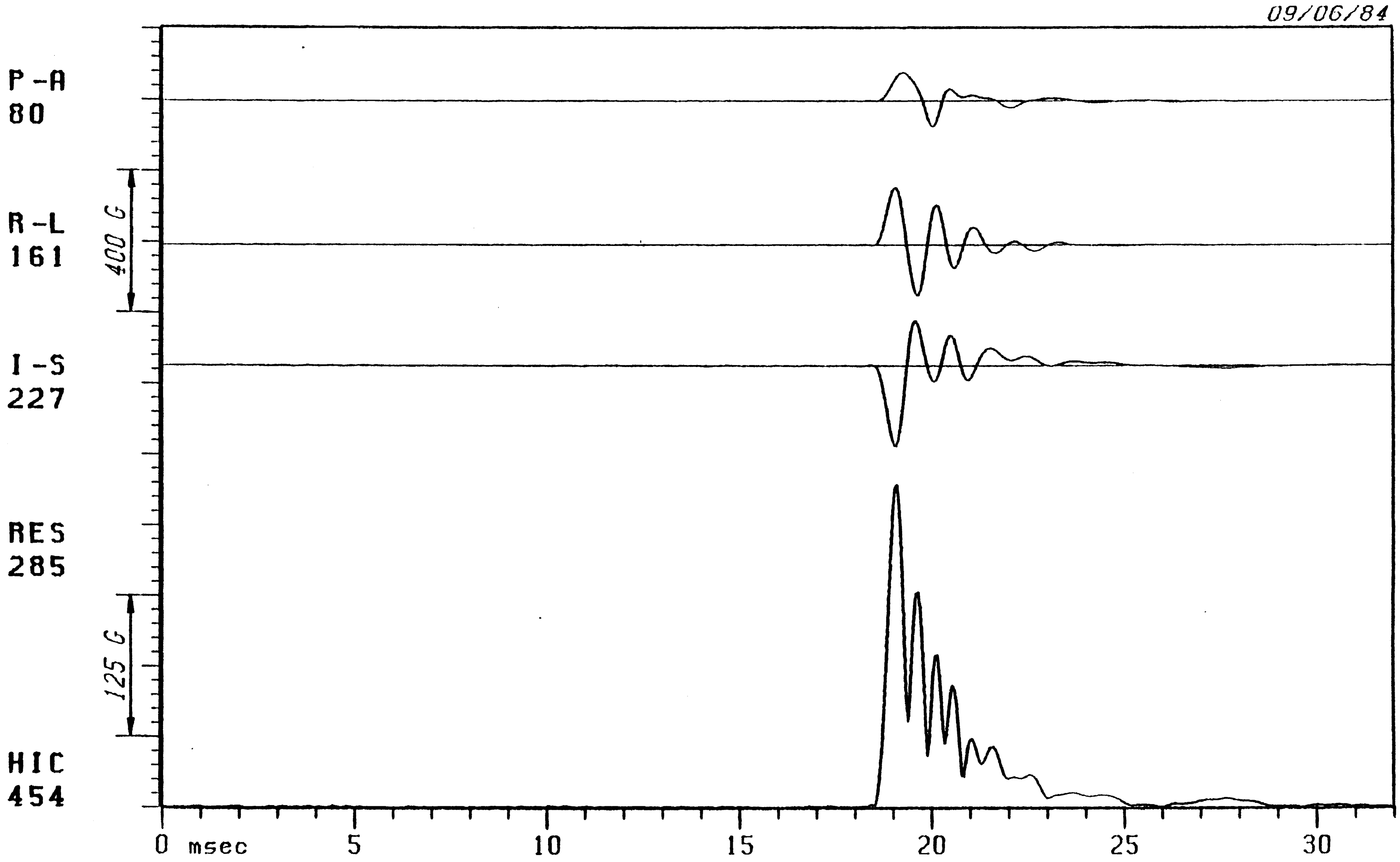
HSRI Dummy Results


P-A
133
R-L
111
I-S
426
RES
446
HIC
1499
800 G
200 G
09/06/84
0 msec
5
10
15
20
25
30
HEAD ACCEL.
84B F53



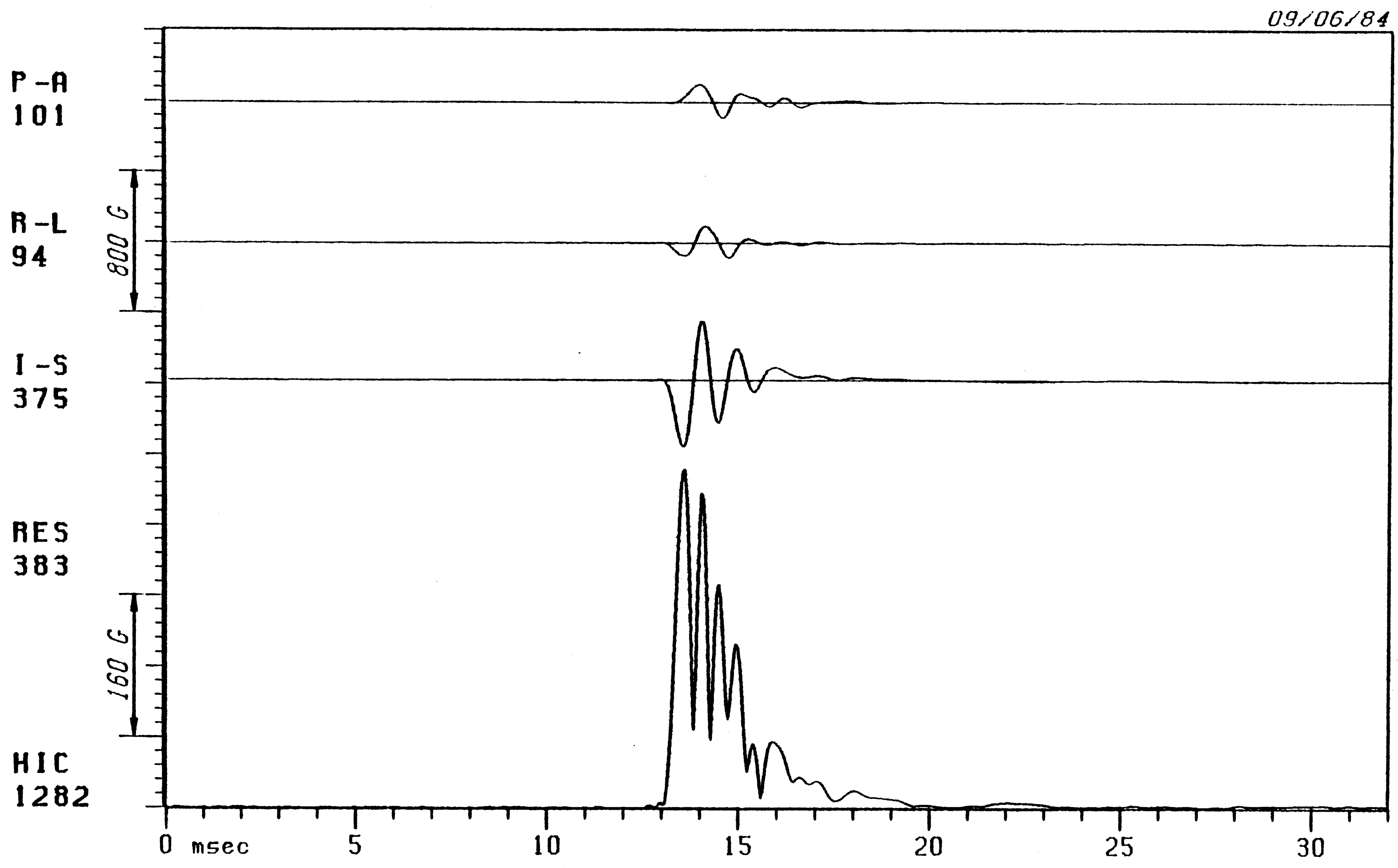
HEAD ACCEL.

84B F54



HEAD ACCEL.

84B F56



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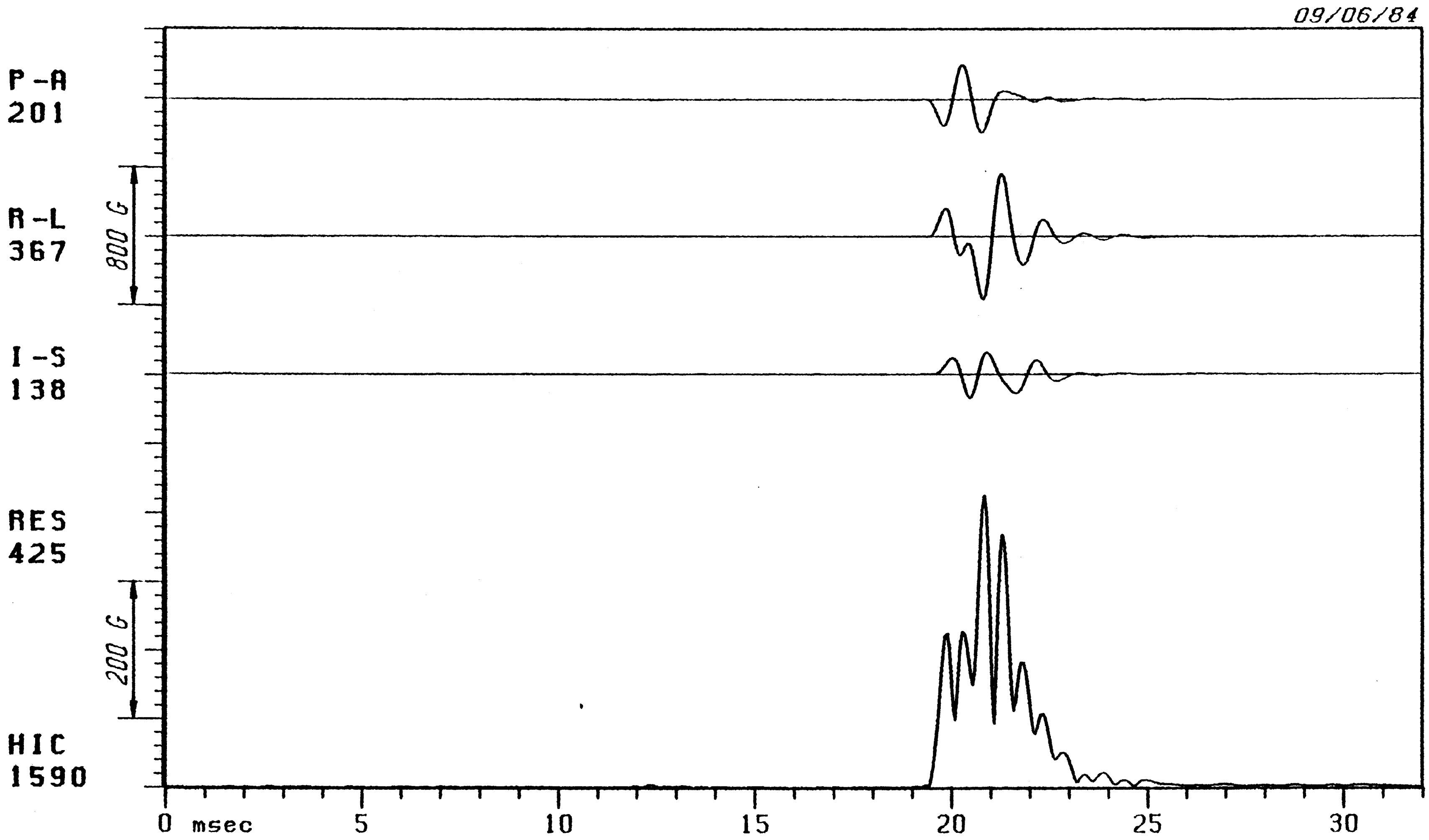
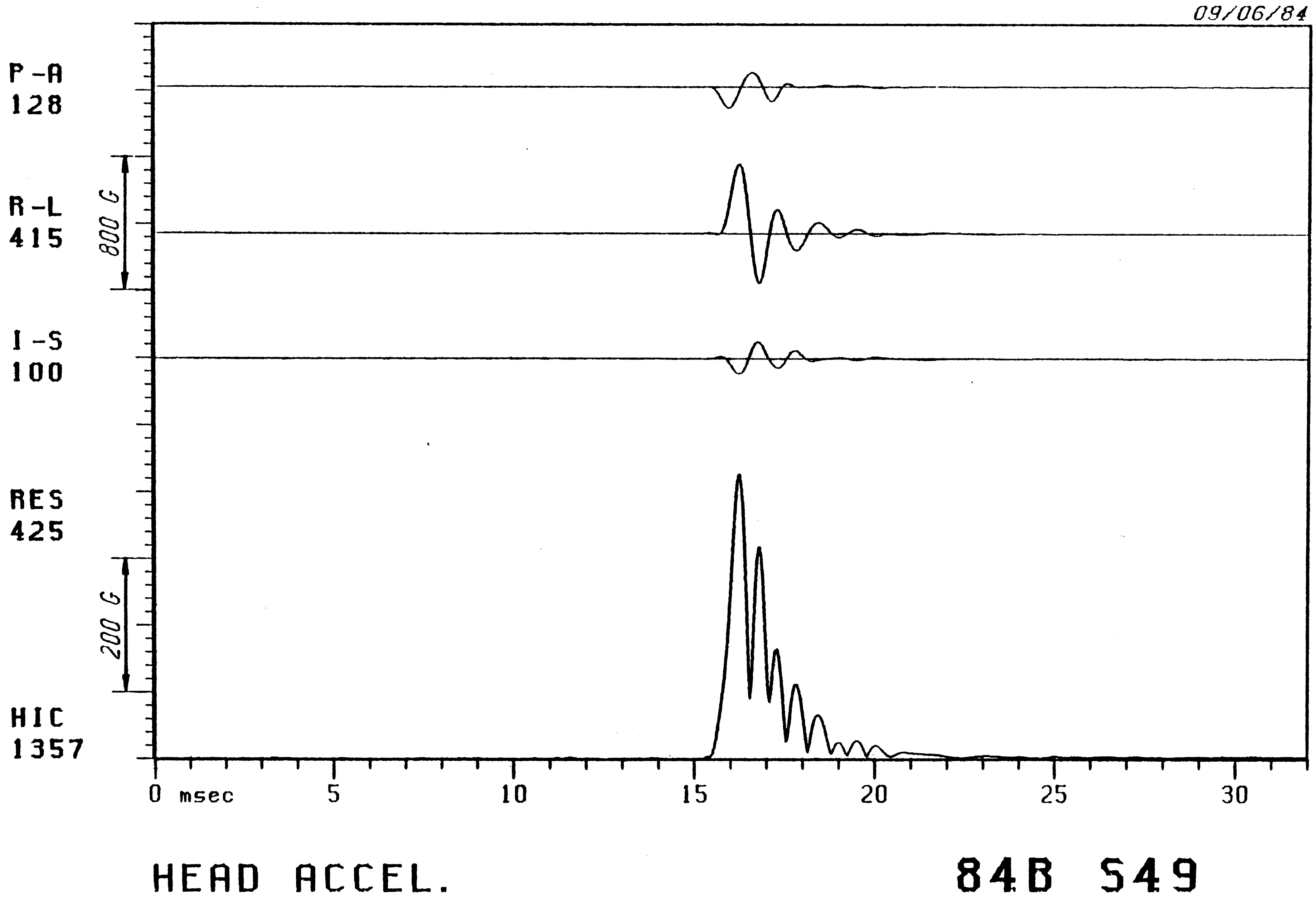
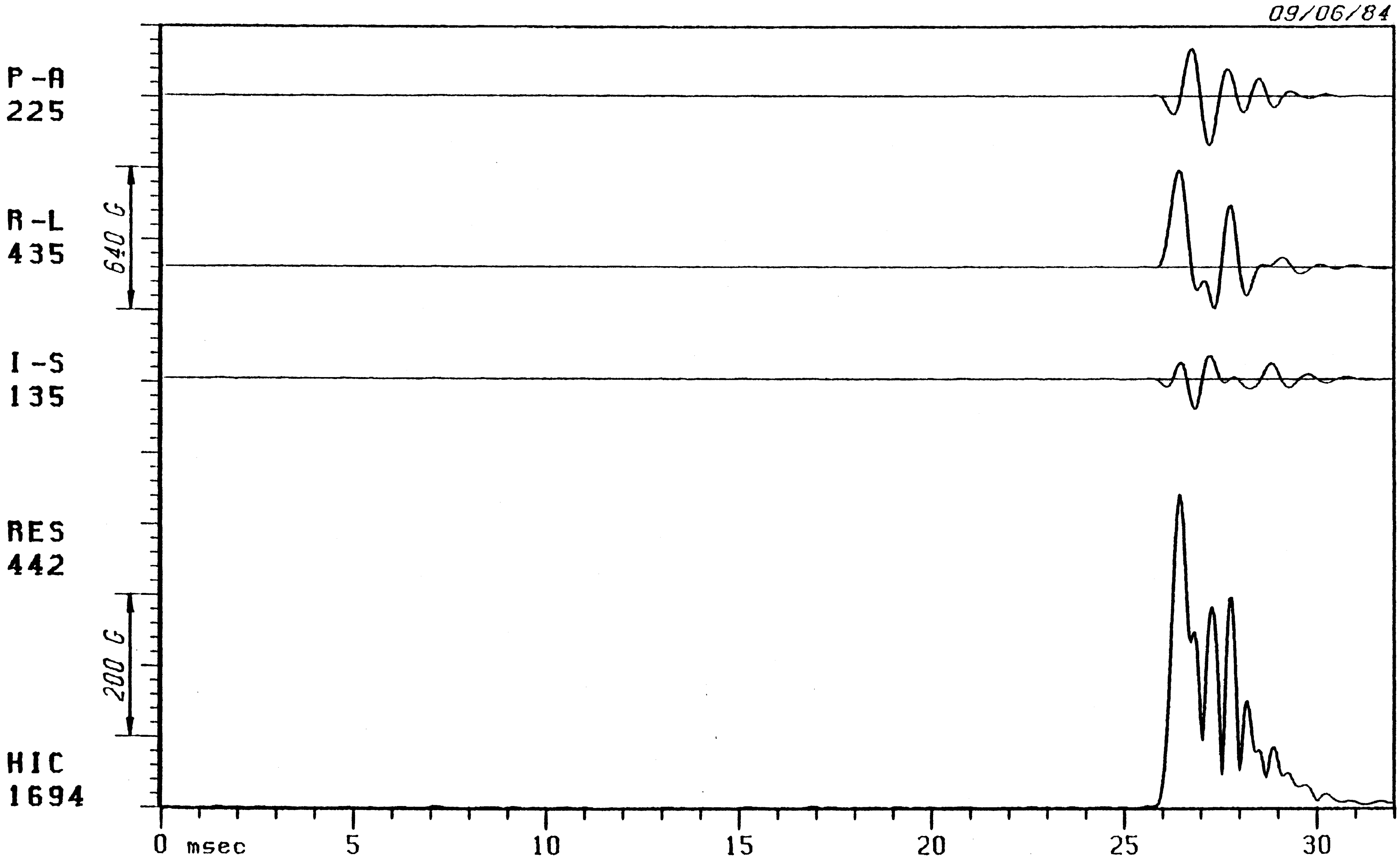
84B F57



HEAD ACCEL.

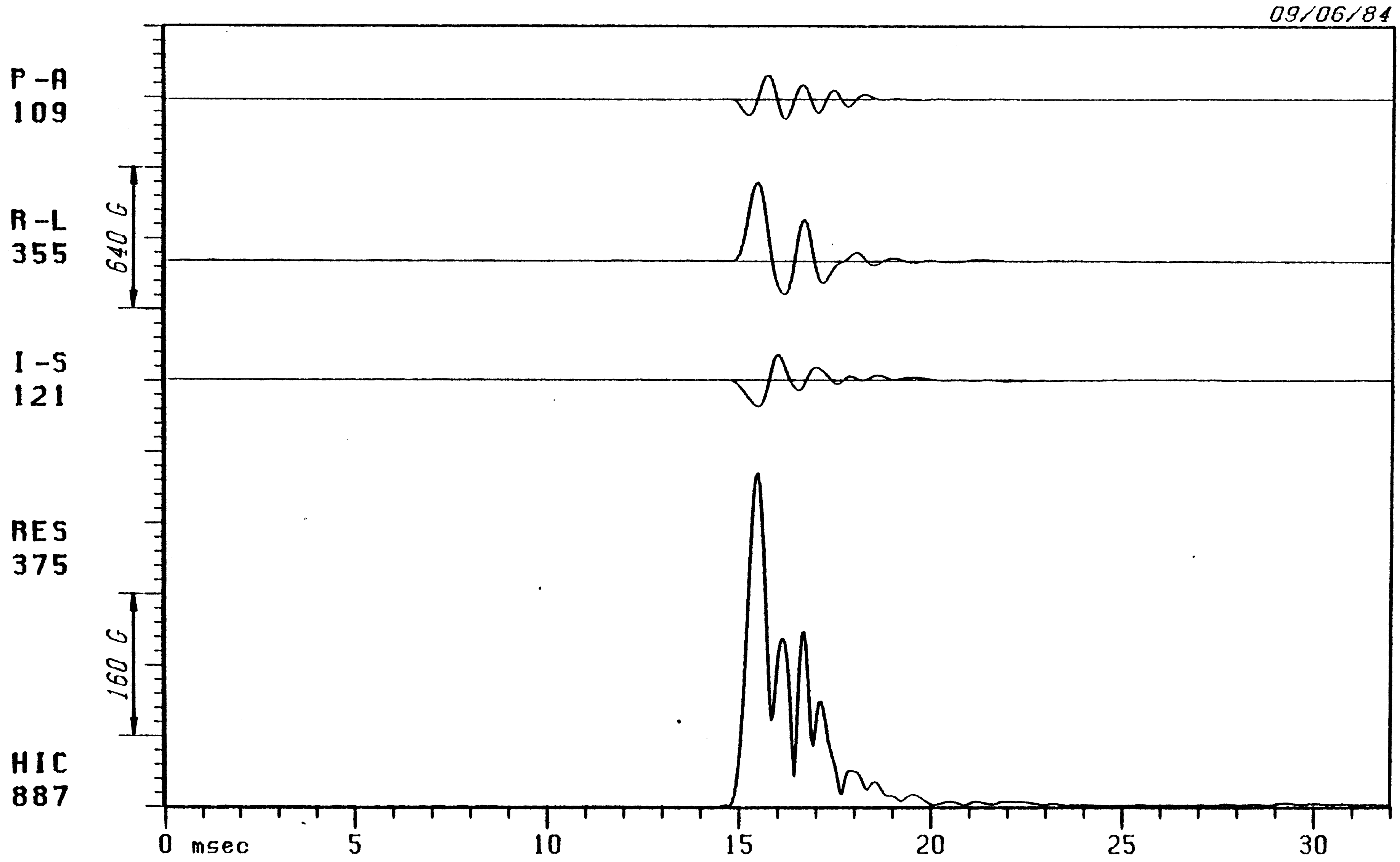
84B 548


09/06/84
P -A
128
R -L
415
800 G
I -S
100
RES
425
200 G
HIC
1357
0 msec
5
10
15
20
25
30
HEAD ACCEL.
84B S49



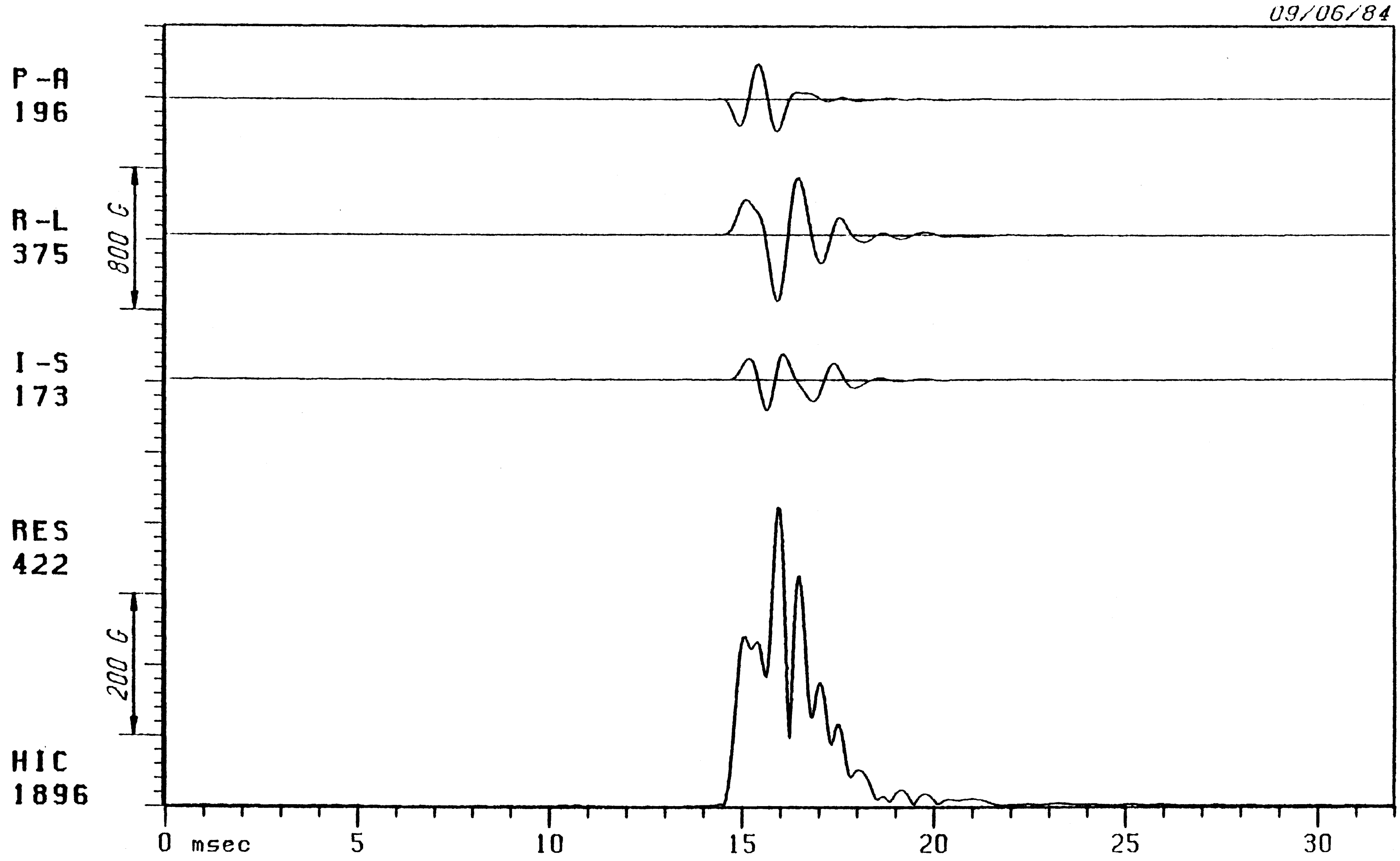
HEAD ACCEL.

84B S50



HEAD ACCEL.

84B S51



HEAD ACCEL.

84B S52