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SPECTRUM AND OCTAVE BAND ANALYSIS OF  
PRESSURE PULSES FROM DEEP UNDERWATER  
EXPLOSIONS

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SPECTRUM AND OCTAVE BAND ANALYSIS OF  
PRESSURE PULSES FROM DEEP UNDERWATER EXPLOSIONS

by

Mary Alice Genau

ABSTRACT: Fourier spectra were computed on the IBM 7090 for analog tape recorded pressure pulses of underwater explosions fired at sea in February 1965. Depth: ranged from 500 to 14,000 feet; charges weighed 1 to 88 pounds; the compositions fired were TNT, pentolite, HBX-3, and Nitramex. Reduced spectra of charges weighing up to 57 pounds agreed with previous results from 1 and 10 pound charges at the same depths. Only slight differences due to composition were found.

UNDERWATER EXPLOSIONS DIVISION  
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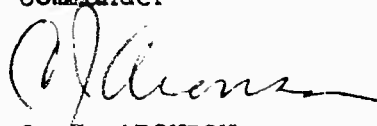
5 October 1966

SPECTRUM AND OCTAVE BAND ANALYSIS OF PRESSURE PULSES FROM DEEP UNDERWATER  
EXPLOSIONS

The work reported here is an extension and continuation of studies on the frequency spectra of explosions in the ocean. It was carried out under Task NOL-785 for the Advanced Research Projects Agency.

Mention of commercially available instruments or materials does not constitute an endorsement by the Laboratory.

E. F. SCHREITER  
Captain, USN  
Commander



C. J. ARONSON  
By Direction

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SPECTRUM AND OCTAVE BAND ANALYSIS OF  
PRESSURE PULSES FROM DEEP UNDERWATER EXPLOSIONS

## 1. INTRODUCTION

Weston (reference a)\* derived an analytical approximation of a frequency spectrum analysis which is applicable to the pressure pulse near a relatively shallow underwater explosion. In order to determine the effect of depth upon the spectrum, Christian and Blaik (reference b) performed a spectrum analysis in 1964 on data obtained earlier by several different investigators. The data they used, which was all recorded near the surface, was from 1- to 10-lb charges fired at depths between 7000 feet and 22,000 feet.

To extend the range of depths to shallower conditions, and to include larger charges, a series of shots was fired at sea in 1965. The experimental conditions for these shots are given in Table 1; for comparison, the conditions for the earlier experiments are also shown. This paper reports the results of the frequency spectral analyses performed on the 1965 shots.

## 2. EXPERIMENTAL CONDITIONS

The experiments were carried out in February 1965 about 200 miles east of Eleuthera, in water about 18,000 feet deep. The gage for recording the pressure pulses was suspended from the USNS GILLIS at a depth of about 200 feet. The charges were fired at depths ranging from approximately 500 to 14,000 feet directly beneath the ship.

One Atlantic Research Corp. Type LC-32 hydrophone was used to pick up the pressure pulses. The same gage output was recorded on two oscilloscope channels, using different gains and sweep speeds. Almost immediate observation of pressure-time data was obtained from Polaroid prints. FM magnetic tape recordings were also obtained from the same gage at 60 inches per second on the FR-600 tape recorder. The frequency response of the FM recorder was essentially flat from 0-20 kcs; the hydrophone, however, gave some low frequency distortion (reference c).

Most of the charges fired were TNT and HBX-3; 1-lb, 8-lb, and 55-lb charges were used. In addition, some 1-lb pentolite and 88-lb Nitramex\*\* charges were used. Attempts to fire 1000-lb TNT charges failed (reference d). All charges were boosted with pentolite which in turn was initiated with hydrostatic firing devices which were set for nominal depths of 500, 800, 1200, 3000, 4500, 7000, 10,000, and 14,000 feet.

\* References are listed on page 8.

\*\* Manufactured by E. I. Dupont de Nemours & Co. The composition is 16% TNT/4% DNT/30%  $\text{NaNO}_3$ /35%  $\text{NH}_4\text{NO}_3$  plus iron and phosphorus.

The shot data are given in Table 2.

### 3. DATA ANALYSIS

**3.1 Method of Data Reduction.** The analog tape data was digitized by the Mathematics Department of the David Taylor Model Basin on their Computer Data Format Translator (CDFT), which has a capability of sampling 2000 times per second. The analog tapes were played back on the DTMB Ampex FR-600 at 3-3/4 inches per second and sampled and digitized 1875 times per second on the CDFT. Since the data was recorded at 60 inches per second, this is equivalent to sampling at 33 microsecond intervals in real time. The sampling should have been performed at 25 microsecond intervals in order to observe the Nyquist criterion of sampling 20 kc data. However, sampling at the next lower playback speed of 1-7/8 inches per second resulted in too much noise and so was not done.

A fiducial marker one millisecond ahead of the pressure pulse on the analog tape initiated digitizing by the Computer Data Format Translator. The 1-millisecond baseline was digitized so that the average value of the baseline could be obtained. The sampling rate was sufficient to average out the dominant high frequency noise; however, the baseline was too short to average out the inherent 60 cycle noise.

The number of times a pulse was sampled ranged from about 500 samples for the deep shots to 5000 samples for the shallow shots. The digitized tapes were the input to the IBM 7090 computer program, NEWGRL, described in reference (e).

**3.2 Types of Analysis Performed.** Three types of computation were carried out on the IBM 7090 computer. These were:

(1) The energy spectral density  $E(f)^*$  of the positive phase of the shock wave only was computed as described in reference (e). The energy spectral density was computed in increments of 50 cps from 50 cps to 16 kcs, and the points were connected by straight lines by the CAL COMP 565 plotter.

(2) The spectrum was similarly computed for the pressure pulse through several pressure oscillations until the pressure returned to the noise level. The frequency interval at which the spectrum was computed was smaller than 50 cps to better define the spectrum for shallow shots which have long bubble periods. In all cases, the integration was carried out to the end of the positive phase of the last bubble pulse observed on the tape records. The number of bubbles integrated is given for each shot in Table 2.

---

\*  $E(f) = \frac{2}{\rho c} |A(f)|^2$  where  $A(f)$  is the amplitude spectrum described in reference (e) and  $\rho c = 1.506 \times 10^5$ .

(3) The energy in octave bands from low frequencies up through the 8-16 kcs band was also computed on the IBM 7090 for both cases--the shock wave alone and with several pulses. The lower octave band energies were included since it was of interest to determine the rate at which the energy decreased with decreasing frequency for frequencies less than the bubble period frequency.

3.3 Accuracy of DTMB Computer Data Format Translator. Since the CDFT had not been used previously for analyses of explosion pulses, several checks were run. In one instance, the same record was digitized twice on different days.

The agreement between pairs of frequency spectra was found to be quite good at low and mid-frequencies, except that even slight shifts in the baseline affected the lowest frequencies noticeably. At the highest frequencies, differences were found in the slopes of the spectral density curves; these were attributed to the sampling rate which was not fast enough in this region.

This matter is discussed in more detail in Appendix A.

In addition, an analysis of the oscilloscope data for a few shots was made in order to obtain an overall check of the spectrum results digitized by the CDFT. Data reduction of the oscilloscope records was done as outlined in section 4 of reference (e). The two methods gave good agreement.

#### 4. ENERGY SPECTRUM OF THE TOTAL PULSE

4.1 Effect of Number of Bubbles Integrated. Figure 1 shows two spectra computed from the same digital tape. In one case the computation was stopped at the end of the positive phase of the first bubble pulse, and in the other the computation was stopped after the third bubble pulse.

There appear to be two effects attributable to the difference in integration time. First, the maximum energy shifts to higher frequencies for the integration through the larger number of bubble pulses. Second, the spectrum computed through one bubble pulse is smoother than that through three, where the second and third oscillations are somewhat distorted. Both effects are due to the fact that the bubble pulse amplitudes and periods decrease with successive pulses.

4.2 Effect of Charge Weight. To examine the effect of charge weight on the spectrum, a comparison is made in Figure 2 among the spectra of three TNT charges fired at nearly 4400 feet and weighing 1, 8, and 57 pounds. The 1- and 57-pound shots were integrated through three bubbles and the 8-lb shot was integrated through two bubbles.

In Figure 2 the energy level has been reduced by the factor (weight<sup>4/3</sup>) after Weston (reference a), and the frequency has been reduced by multiplying

by (weight<sup>1/3</sup>). It is observed that these reduction factors result in good agreement among spectra of varying charge weight ranging from 1 to 57 pounds where the charge composition and burst depth are the same.

4.3 Effect of Range-Depth. Since the shots were recorded near the surface, the effects of burst depth and propagation distance upon the spectra are difficult to separate (reference b). The effect of depth-range upon the spectrum is illustrated in Figure 3 in which a plot of the spectra of three 1-lb HBX-3 charges where the vertical charge-to-gage range,  $R_v$ , is equal to 1154 feet, 4335 feet, and 9637 feet respectively.

In Figure 3 the energy level has been reduced by  $R^{-2}$ , a spherical spreading factor. The spectra are affected by depth, as expected. The low frequency differences are caused by the effect of depth on the bubble period; the maximum energy is at a frequency proportional to  $z_0^{-5/6}$ , where  $z_0$  is the hydrostatic depth. The apparent attenuation of higher frequencies with range may or may not be real; resolution of this question requires further analysis of these data.

4.4 Effect of Charge Composition. In Figure 4, three one-lb charges of different compositions fired at a vertical range of about 1150 feet are compared. The relatively flat slope of -4.5 dB for HBX-3 in the 7-16 kcs band is probably an artifact caused by the sampling rate discussed previously (Section 3.3 and Appendix A). The slopes of the other two spectra are -9 dB and -10 dB per octave for TNT and pentolite, respectively. The TNT and pentolite spectra appear to agree rather well. In contrast the HBX-3 spectrum has two differences:

(1) The maximum peak and corresponding peaks have shifted to lower frequencies because of the longer first bubble period.

(2) The amplitude of oscillation of the spectrum for HBX-3 is not so great as for TNT or pentolite. This is attributed to bubble pulse pressures damping out at a faster rate than those of TNT and pentolite.

The slopes of the three spectra are similar at frequencies below the bubble period frequency.

Figure 5 shows the maximum energy spectral density reduced by  $w^{4/3}$  plotted versus vertical range for all the 1965 data. The scatter in the data is such that no statistically significant conclusions can be drawn. However, the HBX-3 points would average perhaps 2 dB higher than the TNT points. The TNT points average about 2 dB lower than those reported by Christian and Blaik (reference b) for TNT and pentolite combined. Finally, the Vitramex data appear to be the lowest.

## 5. OCTAVE BAND ANALYSIS

Using Simpson's Rule, the energy in ten octave bands starting with the 15-30 cps band and including the 8-16 kcs band was computed on the

IBM 7090 computer for all the 1965 shots. This analysis was performed for the positive phase of the shock wave (except for the lowest bands) and also for the pulse including several bubbles, and is presented in Tables 3 and 4, respectively.

5.1 Octave Band Energy for the Shock Wave. Figure 6 is a plot of octave band energy of the positive phase of the shock wave for four HBX-3 charges, weighing from 1 to 50 pounds and fired at a vertical range of about 4200 feet. The experimental energy level was reduced by multiplying by the weight factor,  $w^{4/3}$ , and multiplied by the spherical spreading term relative to 100 yards,  $[R(\text{yds})/100]^2$ . Also, the frequency was multiplied by the factor (weight $^{1/3}$ ). This results in the energy spectrum level for a 1-lb charge at 100 yards range.

The next four plots (Figures 7-10) present the shock wave octave band energy of all the 1965 data, for TNT, HBX-3, pentolite, and Nitramex, respectively. The octave band energies and the frequency were reduced by the same factors as in Figure 6, and each curve was obtained by drawing by eye an average line through the data for each of the nominal ranges. In general, the scatter about each of the curves drawn is about the same as that shown in Figure 6. However, for certain depths\* the relatively few data points and the scatter of the data in the 8-16 kcs band resulted in curves which are not reliable in the high frequency region.

At the very low frequency end of the spectrum, the energy level approaches the shock wave impulse. In this region, the energy decreases with increasing depth and this is characteristic of all data. This is expected since the shock wave impulse decreases faster than  $\text{range}^{-1}$  (reference f) for all compositions. The spread in the reduced spectra decreases with increasing frequency until a minimum is obtained at about 2000 cps x lbs $^{1/3}$ . As the frequency increases further, the spread in energies increases again; the energy in general decreases with increasing depth as occurred at the low frequencies.

The change in the shock wave spectra at the low frequency end as the depth is varied is a consequence of the change in the waveform with depth. As the depth increases, the shock wave duration decreases, resulting in a shorter pulse which will produce less energy in the lower frequencies.

The HBX-3 spectra show 1 to 3 dB higher energy than TNT at the lowest frequencies for all ranges. Since the spectrum approaches the impulse at zero frequency, this higher energy level for HBX-3 is caused by higher shock wave impulse (reference f). In general, the TNT and HBX-3 data are in good agreement at all but the lowest frequencies. Pentolite is 1 dB to 3 dB higher than TNT for all frequencies at the three ranges for which data exist. Nitramex is 2 dB or 3 dB lower than TNT at most frequencies for corresponding depths. Nitramex has a slope of -6 dB per octave in the high frequencies; this is a relatively high slope.

\* TNT data at nominal depths of 1200 ft and 4500 ft; HBX-3 data at nominal depths of 1200, 2000, 4500, and 10,000 ft; Nitramex data at the nominal depth of 3000 ft.

There are two slight anomalies in the HBX-3 data: the 2000 ft data are consistently 1 or 2 dB higher than the 1200 ft data, and the energies for the one 3000 ft depth shot fired are higher than the 1200 ft depth energies. Again these comparisons are based on statistically inadequate data.

5.2 Octave Band Energy for the Total Pulse. The next four plots (Figures 11-14) show the octave band energy for the total pulse (shock wave plus one or more bubble pulses as indicated in Table 2) for the four compositions. Again the energy level is reduced by weight<sup>4/3</sup> and multiplied by the spherical spreading factor; the frequency is reduced by weight<sup>1/3</sup> as in Figures 7-10. The octave band energy density points were connected by straight lines and the maximum value is an extrapolation of these curves at the bubble period frequency.

It is observed in the four sets of data that there is no systematic change in the slope of the line for frequencies less than the bubble period frequency. An accurate determination of the slopes for these frequencies could not be made since in general there were only two octave bands below the bubble period frequency. Furthermore, the difficulty in determining the value of the baseline (discussed in Section 3.1) may have resulted in large variations of energy for the lowest bands. However, the curve in this region usually has a steeper slope (8 dB or 9 dB per octave) than the slope of 3 dB or 4 dB per octave reported by Christian and Blaik (reference b), and is believed to be more realistic, since it is based on considerably more data and a more closely spaced frequency analysis.

In comparing the data for different charge compositions at the same ranges, it was observed that TNT and HBX-3 have comparable energy levels for reduced frequencies greater than  $1 \text{ kc} \cdot \text{W}^{1/3}$ . However in the low frequency region, the maximum energy for HBX-3 is greater than that for TNT and occurs at lower frequencies. Pentolite has a 2 dB to 4 dB higher energy level than TNT for most frequencies. It must be noted that there is only one pentolite shot and only one weight--1 pound--at each of the three ranges. Nitramex was observed to have a 2 dB to 4 dB lower energy level than TNT for all frequencies; this, too is based on scanty data.

## 6. CONCLUSIONS

- (1) The good agreement previously found between the reduced total pulse energy spectra of 1- and 10-pound charges has been shown to hold up to 57-pound charges.
- (2) The total pulse energy spectra of charges fired at various vertical ranges between 500 and 14,000 feet vary with depth as expected from previous work.
- (3) The total pulse energy spectra of TNT and pentolite are almost identical; the HBX-3 spectrum shows a maximum (and succeeding peaks) at a

lower frequency, less oscillation, and smaller attenuation at the highest frequencies. The energy of the maximum was not statistically different for the four compositions fired; however, HBX-3 gave the highest values and Nitramex the lowest.

(4) The octave-band energy for the shock wave alone and for the total pulse show the effect of depth in sharpening the shock waveform and decreasing the bubble period. The low frequency drop off of 8-9 dB per octave for the total pulse energy is believed to be a better value than the previous one.

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- (f) M. Blaik and E. A. Christian, "Near-Surface Measurements of Deep Explosions I. Pressure Pulses from Small Charges", J. Acoust. Soc. Am. 38, 50-56 (1965).
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TABLE 1

COMPARISON OF PREVIOUS AND CURRENT EXPERIMENTAL CONDITIONS

|                                | Christian and Blaik<br>(reference b)                                              | February 1965<br>Sea. Trials                                                                                           |
|--------------------------------|-----------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------|
| Charge Weight                  | 0.4 to 10 lbs                                                                     | 1 to 88 lbs                                                                                                            |
| Charge Depth                   | 7000-22,000 ft                                                                    | 500-14,000 ft                                                                                                          |
| Charge Composition             | TNT, Pentolite                                                                    | TNT, Pentolite, HBX-3,<br>Nitramex                                                                                     |
| Position of Recording<br>Gages | Vertically above<br>charge near surface                                           | Vertically above<br>charge near surface                                                                                |
| Pulse Sampling Method          | Pressures sampled at<br>discrete time intervals<br>from paper and film<br>records | Pressures from analog<br>tape data electronically<br>sampled and digitized<br>using Computer Data<br>Format Translator |
| Length of Pulse<br>Analyzed    | To minimum pressure<br>or end of negative<br>phase after second<br>bubble pulse   | To end of positive<br>phase of last<br>observable bubble<br>pulse                                                      |
| Lowest Octave Band             | 250-500 cps                                                                       | 15-30 cps                                                                                                              |

TABLE 2

## SHOT STATISTICS

| Charge Weight<br>(lb) | Charge Composition | Nominal Depth<br>(ft) | Burst Depth<br>(ft) | Shot Number | Number of Bubble Pulses Included In Spectrum Computation |
|-----------------------|--------------------|-----------------------|---------------------|-------------|----------------------------------------------------------|
| 1                     | TNT                | 500                   | 517                 | 22          | 1                                                        |
|                       |                    | 500                   | 575                 | 48          | 2                                                        |
|                       |                    | 500                   | 607                 | 33          | 1                                                        |
|                       |                    | 800                   | 873                 | 49          | 2                                                        |
|                       |                    | 800                   | 893                 | 67          | 2                                                        |
|                       |                    | 1,200                 | 1,158               | 42          | 3                                                        |
|                       |                    | 1,200                 | 1,241               | 70          | 2                                                        |
|                       |                    | 2,000                 | 1,983               | 27          | 3                                                        |
|                       |                    | 3,000                 | 2,963               | 45          | 3                                                        |
|                       |                    | 3,000                 | 3,032*              | 10          | 3                                                        |
|                       |                    | 4,500                 | 4,411               | 24          | 3                                                        |
|                       |                    | 4,500                 | 4,502*              | 52          | 3                                                        |
|                       |                    | 7,000                 | 7,402*              | 77          | 3                                                        |
| 1                     | PENTOLITE          | 500                   | 552                 | 64          | 3                                                        |
|                       |                    | 1,200                 | 1,377               | 68          | 2                                                        |
|                       |                    | 7,000                 | 6,621*              | 5           | 3                                                        |
| 1                     | HBX-3              | 1,200                 | 1,331               | 46          | 3                                                        |
|                       |                    | 2,000                 | 1,891               | 65          | 4                                                        |
|                       |                    | 4,500                 | 4,228*              | 51          | 3                                                        |
|                       |                    | 4,500                 | 4,517               | 56          | 3                                                        |
|                       |                    | 10,000                | 9,824               | 73          | 4                                                        |
| 8                     | TNT                | 500                   | 430                 | 26          | 1                                                        |
|                       |                    | 500                   | 571                 | 31          | 1                                                        |
|                       |                    | 800                   | 892                 | 12          | 1                                                        |
|                       |                    | 1,200                 | 1,139               | 72          | 3                                                        |
|                       |                    | 1,200                 | 1,237               | 43          | 2                                                        |
|                       |                    | 1,200                 | 1,250               | 69          | 2                                                        |
|                       |                    | 2,000                 | 1,871               | 21          | 3                                                        |
|                       |                    | 2,000                 | 2,031               | 35          | 3                                                        |
|                       |                    | 2,000                 | 2,051*              | 4           | 2                                                        |
|                       |                    | 3,000                 | 2,924               | 47          | 3                                                        |
|                       |                    | 4,500                 | 4,305               | 32          | 3                                                        |
|                       |                    | 4,500                 | 4,372               | 25          | 2                                                        |
|                       |                    | 4,500                 | 4,542               | 55          | 3                                                        |
|                       |                    | 14,000                | 13,300*             | 18          | 3                                                        |
|                       |                    | 14,000                | 13,400              | 36          | 3                                                        |
| 8                     | HBX-3              | 1,200                 | 1,182               | 44          | 3                                                        |
|                       |                    | 1,200                 | 1,358               | 11          | 2                                                        |
|                       |                    | 4,500                 | 4,202               | 50          | 2                                                        |
|                       |                    | 10,000                | 9,849               | 71          | 3                                                        |
|                       |                    | 14,000                | 13,540*             | 75          | 3                                                        |

\* Depth determined from bubble period.

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TABLE 2

SHOT STATISTICS (cont'd)

| Charge Weight (lb) | Charge Composition | Nominal Depth (ft) | Burst Depth (ft) | Shot Number | Number of Bubble Pulses Included In Spectrum Computation |
|--------------------|--------------------|--------------------|------------------|-------------|----------------------------------------------------------|
| 57                 | TNT                | 2,000              | 1,844            | 8           | 2                                                        |
|                    |                    | 2,000              | 1,923            | 29          | 2                                                        |
|                    |                    | 4,500              | 4,282            | 37          | 2                                                        |
|                    |                    | 4,500              | 4,413            | 20          | 3                                                        |
|                    |                    | 7,000              | 6,608*           | 3           | 3                                                        |
|                    |                    | 7,000              | 7,147*           | 79          | 3                                                        |
|                    |                    | 14,000             | 14,340           | 62          | 3                                                        |
| 50                 | HBX-3              | 2,000              | 1,813            | 63          | 2                                                        |
|                    |                    | 3,000              | 2,891            | 78          | 3                                                        |
|                    |                    | 4,500              | 4,443            | 53          | 2                                                        |
|                    |                    | 7,000              | 7,498            | 57          | 3                                                        |
|                    |                    | 10,000             | 9,547            | 59          | 2                                                        |
| 88                 | NITRAMEX           | 3,000              | 2,793            | 38          | 2                                                        |
|                    |                    | 3,000              | 2,900            | 19          | 1                                                        |
|                    |                    | 7,000              | 7,051            | 39          | 3                                                        |
|                    |                    | 10,000             | 10,308           | 40          | 3                                                        |

TABLE 3

SHOCK WAVE SPECTRUM  
Octave Band Energies (ergs/cm<sup>2</sup>)1-lb TNT

| Shot<br>No. | Range<br>(ft) | Octave Bands |         |         |          |        |        |        |         |
|-------------|---------------|--------------|---------|---------|----------|--------|--------|--------|---------|
|             |               | 60-125       | 125-250 | 250-500 | 500-1000 | 1-2kc  | 2-4    | 4-8    | 8-16kcs |
| 22          | 337           | 254.3        | 268.3   | 292.3   | 312.1    | 320.1  | 262.0  | 110.6  | 42.73   |
| 48          | 397           | 113.9        | 145.5   | 169.5   | 237.2    | 214.9  | 180.7  | 101.6  | 41.50   |
| 33          | 426           | 127.2        | 155.7   | 203.8   | 274.4    | 226.7  | 210.7  | 108.1  | 64.42   |
| 49          | 694           | 29.01        | 46.74   | 58.60   | 71.23    | 67.28  | 56.67  | 32.52  | 20.05   |
| 67          | 705           | 32.16        | 54.16   | 74.68   | 75.60    | 91.14  | 75.63  | 46.74  | 30.37   |
| 42          | 978           | 12.81        | 21.91   | 31.03   | 38.15    | 35.72  | 28.19  | 15.82  | 8.149   |
| 70          | 1,059         | 11.42        | 20.15   | 30.17   | 35.10    | 35.63  | 19.99  | 11.84  | 2.423   |
| 27          | 1,806         | 2.986        | 5.526   | 9.571   | 12.03    | 11.62  | 9.525  | 5.137  | 2.733   |
| 45          | 2,782         | 0.7330       | 1.377   | 2.519   | 3.702    | 3.891  | 2.729  | 1.157  | 0.2811  |
| 10          | 2,850         | 0.7659       | 1.437   | 2.611   | 3.674    | 3.191  | 2.364  | 1.194  | 0.5183  |
| 24          | 4,244         | 0.5972       | 2.185   | 2.244   | 2.051    | 1.862  | 1.350  | 0.6679 | 0.3866  |
| 52          | 4,322         | 0.2604       | 0.4961  | 0.9567  | 1.661    | 2.041  | 1.605  | 1.003  | 0.7627  |
| 77          | 7,222         | 0.07285      | 0.1390  | 0.2699  | 0.4795   | 0.6162 | 0.3864 | 0.1846 | 0.07060 |

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TABLE 3  
SHOCK WAVE SPECTRUM (continued)

1-lb Pentolite

| Shot<br>No. | Range<br>(ft) | Octave Bands |         |         |          |       |        |        |         |
|-------------|---------------|--------------|---------|---------|----------|-------|--------|--------|---------|
|             |               | 60-125       | 125-250 | 250-500 | 500-1000 | 1-2kc | 2-4    | 4-8    | 8-16kcs |
| 64          | 367           | 320.8        | 331.0   | 429.5   | 528.4    | 493.2 | 382.8  | 225.0  | 140.2   |
| 68          | 1,191         | 11.19        | 20.17   | 32.33   | 32.22    | 34.04 | 24.75  | 11.16  | 2.039   |
| 5           | 6,441         | 0.1426       | 0.2716  | 0.5234  | 0.9055   | 1.072 | 0.6494 | 0.3142 | 0.1039  |

1-lb HBX-3

|    |       |         |        |        |        |        |        |         |         |
|----|-------|---------|--------|--------|--------|--------|--------|---------|---------|
| 46 | 1,154 | 11.12   | 19.36  | 28.38  | 28.21  | 25.55  | 17.72  | 9.596   | 3.267   |
| 65 | 1,705 | 5.789   | 10.31  | 15.73  | 16.45  | 14.31  | 9.484  | 4.188   | 0.7816  |
| 51 | 4,048 | 0.4218  | 0.7966 | 1.485  | 2.276  | 2.135  | 1.529  | 1.020   | 0.7547  |
| 56 | 4,336 | 0.3632  | 0.6860 | 1.280  | 1.968  | 1.905  | 1.057  | 0.4586  | 0.09841 |
| 73 | 9,637 | 0.05319 | 0.1015 | 0.1966 | 0.3463 | 0.4251 | 0.2193 | 0.09335 | 0.01492 |

8-lb TNT

|    |     |       |       |       |       |       |       |       |       |
|----|-----|-------|-------|-------|-------|-------|-------|-------|-------|
| 26 | 249 | 2252. | 2781. | 2833. | 3031. | 2133. | 1366. | 712.4 | 394.8 |
| 31 | 384 | 2288. | 2327. | 2712. | 3433. | 2259. | 1464. | 578.6 | 153.6 |
| 12 | 715 | 472.3 | 576.7 | 602.7 | 629.9 | 436.7 | 274.6 | 163.7 | 111.5 |
| 72 | 951 | 273.8 | 377.8 | 417.7 | 390.1 | 322.6 | 184.5 | 83.74 | 32.35 |

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TABLE 3  
SHOCK WAVE SPECTRUM (continued)

8-1b TNT

| Shot No. | Range (ft.) | Octave Bands |         |         |          |        |        |        |
|----------|-------------|--------------|---------|---------|----------|--------|--------|--------|
|          |             | 60-125       | 125-250 | 250-500 | 500-1000 | 1-2kc  | 2-4    | 4-8    |
| 43       | 1,059       | 201.2        | 270.1   | 296.7   | 324.9    | 275.9  | 150.0  | 90.39  |
| 69       | 1,067       | 198.7        | 292.9   | 306.7   | 299.1    | 254.7  | 142.6  | 83.61  |
| 21       | 1,701       | 56.84        | 92.39   | 112.8   | 107.7    | 90.66  | 43.23  | 18.04  |
| 35       | 1,854       | 37.16        | 62.51   | 80.35   | 86.04    | 76.15  | 38.16  | 18.77  |
| 4        | 1,871       | 48.77        | 79.68   | 97.00   | 101.3    | 69.12  | 36.75  | 18.06  |
| 47       | 2,743       | 13.18        | 23.49   | 35.76   | 36.85    | 30.81  | 14.03  | 6.036  |
| 32       | 4,130       | 4.598        | 8.445   | 14.19   | 15.77    | 10.96  | 5.241  | 2.098  |
| 25       | 4,200       | 5.266        | 9.616   | 15.79   | 16.32    | 10.78  | 5.086  | 1.985  |
| 55       | 4,362       | 5.359        | 9.788   | 16.08   | 16.50    | 9.930  | 5.034  | 2.450  |
| 18       | 13,119      | 0.2072       | 0.3900  | 0.7184  | 1.044    | 0.7329 | 0.2505 | 0.1154 |
| 36       | 13,222      | 0.2455       | 0.4652  | 0.8786  | 1.401    | 1.208  | 0.4037 | 0.1716 |

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8-1b HBX-3

|    |        |        |        |       |       |        |        |        |
|----|--------|--------|--------|-------|-------|--------|--------|--------|
| 44 | 1,000  | 309.0  | 328.6  | 359.0 | 343.3 | 264.4  | 153.6  | 92.49  |
| 11 | 1,178  | 172.0  | 207.0  | 220.9 | 201.6 | 176.3  | 88.13  | 41.93  |
| 50 | 4,022  | 7.294  | 12.79  | 18.32 | 15.88 | 12.14  | 5.552  | 2.615  |
| 71 | 9,665  | 0.8808 | 1.636  | 2.857 | 3.465 | 2.118  | 1.049  | 0.5494 |
| 75 | 13,360 | 0.3539 | 0.6618 | 1.187 | 1.556 | 0.8795 | 0.4448 | 0.1815 |

TABLE 3

## SHOCK WAVE SPECTRUM (continued)

57-lb TNT

| Shot<br>No. | Range<br>(ft.) | Octave Band |         |         |          |       |       |        |         |
|-------------|----------------|-------------|---------|---------|----------|-------|-------|--------|---------|
|             |                | 60-125      | 125-250 | 250-500 | 500-1000 | 1-2kc | 2-4   | 4-8    | 8-16kcs |
| 8           | 1,660          | 751.0       | 831.9   | 847.8   | 736.4    | 360.4 | 183.9 | 82.84  | 30.27   |
| 29          | 1,744          | 609.2       | 680.8   | 704.8   | 553.2    | 405.7 | 189.0 | 88.03  | 37.28   |
| 37          | 4,102          | 72.27       | 111.7   | 113.7   | 77.97    | 43.34 | 20.67 | 7.918  | 1.336   |
| 20          | 4,251          | 65.02       | 106.0   | 120.9   | 81.86    | 48.61 | 22.62 | 10.40  | 4.765   |
| 3           | 6,428          | 17.14       | 30.23   | 43.42   | 29.02    | 13.80 | 7.376 | 3.553  | 1.296   |
| 79          | 5,967          | 20.13       | 34.86   | 47.29   | 32.00    | 15.55 | 7.207 | 4.182  | 2.532   |
| 52          | 14,162         | 2.778       | 5.020   | 7.895   | 6.765    | 3.173 | 1.333 | 0.7216 | 0.4124  |

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50-lb HBX-3

|    |       |       |       |       |       |       |       |        |        |
|----|-------|-------|-------|-------|-------|-------|-------|--------|--------|
| 63 | 1,626 | 1246. | 1066. | 1038. | 703.4 | 479.6 | 200.0 | 103.2  | 30.46  |
| 78 | 2,760 | 302.2 | 373.1 | 323.8 | 251.1 | 147.2 | 73.81 | 48.23  | 36.76  |
| 53 | 4,259 | 96.83 | 133.3 | 121.8 | 93.32 | 46.58 | 22.07 | 13.55  | 8.560  |
| 57 | 7,326 | 17.76 | 29.56 | 34.49 | 17.82 | 10.75 | 5.039 | 2.607  | 1.283  |
| 59 | 9,419 | 4.428 | 7.694 | 10.46 | 6.415 | 3.562 | 1.606 | 0.7515 | 0.3440 |

TABLE 3  
SHOCK WAVE SPECTRUM (continued)

88-lb Nitramex

| Shot<br>No. | Range<br>(ft) | Octave Bands |         |         |          |       |       |       |         |
|-------------|---------------|--------------|---------|---------|----------|-------|-------|-------|---------|
|             |               | 60-125       | 125-250 | 250-500 | 500-1000 | 1-2kc | 2-4   | 4-8   | 8-16kcs |
| 38          | 2,610         | 314.0        | 357.9   | 314.4   | 231.3    | 138.1 | 68.41 | 41.72 | 22.05   |
| 19          | 2,751         | 220.1        | 275.0   | 230.9   | 164.3    | 83.97 | 44.03 | 22.29 | 11.53   |
| 39          | 6,864         | 15.37        | 25.65   | 31.34   | 21.82    | 10.54 | 5.340 | 3.036 | 1.829   |
| 40          | 10,122        | 5.577        | 9.850   | 14.21   | 9.577    | 4.607 | 2.609 | 1.503 | 1.077   |

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TABLE 4

SPECTRA OF PULSE INCLUDING SEVERAL BUBBLES  
Octave Band Energies (ergs/cm<sup>2</sup>)1-lb TNT

| Shot<br>No. | Range<br>(ft) | Octave Bands |         |         |         |         |          |        |        |        |         |
|-------------|---------------|--------------|---------|---------|---------|---------|----------|--------|--------|--------|---------|
|             |               | 15-30cps     | 30-60   | 60-125  | 125-250 | 250-500 | 500-1000 | 1-2kcs | 2-4    | 4-8    | 8-16    |
| 22          | 337           | 70.73        | 597.9   | 444.8   | 492.7   | 471.7   | 618.7    | 377.8  | 240.8  | 127.1  | 50.46   |
| 48          | 397           | 29.47        | 313.1   | 335.6   | 298.8   | 290.9   | 311.8    | 192.6  | 176.9  | 103.4  | 80.59   |
| 33          | 426           | 14.88        | 362.7   | 319.8   | 262.8   | 317.8   | 400.1    | 255.4  | 203.9  | 113.0  | 68.05   |
| 49          | 694           | 3.534        | 36.54   | 155.0   | 108.3   | 110.7   | 101.9    | 70.28  | 48.74  | 22.47  | 6.783   |
| 67          | 705           | 4.238        | 46.54   | 209.3   | 149.3   | 141.4   | 120.6    | 103.3  | 79.84  | 18.98  | 31.13   |
| 42          | 978           | 1.531        | 10.69   | 88.72   | 53.18   | 58.54   | 54.48    | 38.71  | 28.15  | 16.35  | 9.208   |
| 70          | 1,059         | 0.8263       | 9.404   | 94.46   | 49.97   | 65.27   | 50.74    | 39.25  | 21.81  | 12.42  | 2.490   |
| 27          | 1,806         | --           | 0.3819  | 12.72   | 33.78   | 20.37   | 19.45    | 13.15  | 9.696  | 5.229  | 2.791   |
| 45          | 2,782         | --           | 0.1640  | 1.502   | 11.67   | 7.031   | 6.538    | 4.666  | 2.838  | 1.188  | 0.3023  |
| 10          | 2,850         | --           | 0.04314 | 1.005   | 11.84   | 6.928   | 7.138    | 3.474  | 2.518  | 1.221  | 0.5411  |
| 24          | 4,244         | --           | --      | 0.2017  | 3.016   | 6.096   | 3.312    | 2.446  | 1.457  | 0.6876 | 0.3957  |
| 52          | 4,322         | --           | --      | 0.2080  | 2.709   | 6.028   | 3.369    | 2.862  | 1.712  | 1.009  | 0.7766  |
| 77          | 7,222         | --           | --      | 0.01588 | 0.1795  | 2.410   | 1.279    | 0.7812 | 0.4141 | 0.1953 | 0.07955 |

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TABLE 4  
SPECTRA OF PULSE INCLUDING SEVERAL RUBBLES (continued)

1-lb Pentolite

| Shot<br>No. | Range<br>(ft) | Octave Bands |       |         |         |         |          |        |        |        |        |
|-------------|---------------|--------------|-------|---------|---------|---------|----------|--------|--------|--------|--------|
|             |               | 15-30cps     | 30-60 | 60-125  | 125-250 | 250-500 | 500-1000 | 1-2kcs | 2-4    | 4-8    | 8-16   |
| 64          | 367           | 35.35        | 862.1 | 621.1   | 818.6   | 651.6   | 772.0    | 579.9  | 385.1  | 236.2  | 154.4  |
| 68          | 1,191         | 0.4993       | 7.270 | 92.01   | 56.69   | 67.58   | 50.84    | 43.38  | 26.66  | 11.66  | 2.750  |
| 5           | 6,441         | --           | --    | 0.04316 | 0.5254  | 4.574   | 2.614    | 1.722  | 0.7499 | 0.3236 | 0.1114 |

1-lb HBX-3

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|    |       |       |       |          |        |       |        |        |        |         |         |
|----|-------|-------|-------|----------|--------|-------|--------|--------|--------|---------|---------|
| 46 | 1,154 | 1.332 | 13.65 | 84.59    | 62.59  | 41.87 | 40.15  | 27.86  | 20.49  | 14.09   | 9.571   |
| 65 | 1,705 | --    | 2.213 | 44.04    | 40.41  | 24.34 | 19.69  | 14.17  | 9.679  | 4.394   | 0.8385  |
| 51 | 4,048 | --    | --    | 0.4638   | 6.5    | 5.082 | 2.487  | 2.273  | 1.505  | 1.034   | 0.7620  |
| 56 | 4,336 | --    | --    | 0.3124   | 5.860  | 4.831 | 2.262  | 1.806  | 1.071  | 0.4591  | 0.09497 |
| 73 | 9,637 | --    | --    | 0.009145 | 0.1022 | 1.643 | 0.7860 | 0.3927 | 0.2255 | 0.09197 | 0.01570 |

8-lb TNT

|    |     |       |       |       |       |       |       |       |       |       |       |
|----|-----|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| 26 | 249 | 4749. | 6262. | 4216. | 3798. | 3761. | 3603. | 2026. | 1400. | 800.  | 407.9 |
| 31 | 384 | 5450. | 5252. | 4407. | 3443. | 3443. | 4413. | 2345. | 1321. | 631.2 | 195.0 |
| 12 | 715 | 343.1 | 1079. | 1151. | 841.4 | 804.3 | 1002. | 473.4 | 302.4 | 166.9 | 102.0 |
| 72 | 951 | 106.1 | 994.4 | 771.1 | 653.5 | 587.2 | 451.3 | 324.4 | 184.9 | 83.48 | 35.59 |

TABLE 4  
SPECTRA OF PULSE INCLUDING SEVERAL BUBBLES (continued)

8-1b TNT

| Shot No. | Range (ft) | Octave Bands |       |         |         |         |          |        |        |        |         |
|----------|------------|--------------|-------|---------|---------|---------|----------|--------|--------|--------|---------|
|          |            | 15-30cps     | 30-60 | 60-125  | 125-250 | 250-500 | 500-1000 | 1-2kcs | 2-4    | 4-8    | 8-16    |
| 43       | 1,059      | 43.65        | 685.2 | 418.8   | 508.1   | 423.3   | 384.4    | 274.6  | 149.8  | 96.50  | 78.93   |
| 69       | 1,067      | 33.89        | 816.0 | 465.3   | 576.2   | 419.4   | 374.6    | 264.8  | 141.8  | 90.74  | 50.08   |
| 21       | 1,701      | 6.587        | 130.1 | 319.3   | 209.8   | 165.2   | 131.1    | 93.40  | 43.59  | 19.77  | 7.089   |
| 35       | 1,854      | 2.890        | 74.70 | 279.0   | 142.7   | 124.6   | 108.5    | 76.36  | 40.76  | 20.01  | 9.820   |
| 4        | 1,871      | 8.143        | 97.86 | 282.7   | 170.6   | 150.1   | 130.8    | 69.57  | 40.16  | 19.77  | 8.790   |
| 47       | 2,743      | 1.207        | 12.19 | 123.0   | 61.61   | 61.83   | 42.36    | 27.48  | 14.48  | 6.293  | 2.282   |
| 32       | 4,130      | --           | 1.283 | 25.93   | 45.57   | 28.49   | 20.09    | 11.88  | 5.468  | 2.182  | 0.6974  |
| 25       | 4,200      | --           | 1.739 | 28.52   | 50.63   | 30.21   | 20.27    | 11.52  | 5.200  | 2.053  | 0.4179  |
| 55       | 4,362      | --           | 1.588 | 26.92   | 49.07   | 30.22   | 19.89    | 10.09  | 5.238  | 2.544  | 1.179   |
| 18       | 13,119     | --           | --    | 0.07169 | 1.039   | 5.158   | 1.872    | 0.7354 | 0.3014 | 0.1182 | 0.03905 |
| 36       | 13,222     | --           | --    | 0.09460 | 1.071   | 6.455   | 2.397    | 1.352  | 0.1627 | 0.1879 | 0.05728 |

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8-1b HBX-3

|    |        |       |       |        |       |       |       |        |        |        |         |
|----|--------|-------|-------|--------|-------|-------|-------|--------|--------|--------|---------|
| 44 | 1,000  | 271.4 | 1047. | 704.4  | 457.2 | 399.6 | 350.5 | 274.3  | 156.0  | 99.11  | 86.89   |
| 11 | 1,178  | 77.91 | 634.0 | 423.5  | 302.4 | 245.4 | 245.6 | 174.3  | 92.73  | 54.20  | 30.73   |
| 50 | 4,022  | --    | 3.934 | 64.98  | 23.37 | 19.19 | 15.65 | 12.12  | 5.694  | 2.672  | 1.146   |
| 71 | 9,665  | --    | --    | 0.8871 | 15.52 | 5.108 | 3.152 | 2.214  | 1.053  | 0.5600 | 0.2715  |
| 75 | 13,360 | --    | --    | 0.1385 | 3.228 | 5.966 | 2.135 | 0.8574 | 0.4420 | 0.1832 | 0.05301 |

TABLE 4  
SPECTRA OF PULSE INCLUDING SEVERAL BUBBLES (continued)

57-lb TNT

| Shot No. | Range (ft) | Octave Bands |        |        |         |         |          |        |       |        |        |
|----------|------------|--------------|--------|--------|---------|---------|----------|--------|-------|--------|--------|
|          |            | 15-30cps     | 30-60  | 60-125 | 125-250 | 250-500 | 500-1000 | 1-2kcs | 2-4   | 4-8    | 8-16   |
| 8        | 1,660      | 541.3        | 2043.  | 1491.  | 1341.   | 1012.   | 906.0    | 377.6  | 176.5 | 92.90  | 33.82  |
| 29       | 1,744      | 523.2        | 2042.  | 1567.  | 1010.   | 850.6   | 514.2    | 415.5  | 191.7 | 94.11  | 43.31  |
| 37       | 4,102      | 10.04        | 123.5  | 410.4  | 198.6   | 157.0   | 85.79    | 43.69  | 21.39 | 7.780  | 1.816  |
| 20       | 4,251      | 5.954        | 116.6  | 380.0  | 208.3   | 158.8   | 91.98    | 49.97  | 24.33 | 10.78  | 5.735  |
| 3        | 6,428      | 1.092        | 10.41  | 141.5  | 94.73   | 58.53   | 36.00    | 14.91  | 7.433 | 3.770  | 1.500  |
| 79       | 6,967      | 1.085        | 12.59  | 163.6  | 103.6   | 62.93   | 40.21    | 16.27  | 7.394 | 4.549  | 2.619  |
| 62       | 14,162     | --           | 0.3849 | 5.309  | 37.64   | 14.47   | 8.615    | 3.447  | 1.441 | 0.8080 | 0.4317 |

50-lb HBX-3

|    |       |       |       |       |       |       |       |       |       |        |        |
|----|-------|-------|-------|-------|-------|-------|-------|-------|-------|--------|--------|
| 63 | 1,626 | 2411. | 2406. | 1558. | 1158. | 1045. | 786.2 | 494.5 | 209.4 | 107.1  | 37.19  |
| 78 | 2,760 | 200.3 | 1153. | 577.8 | 365.5 | 325.0 | 267.1 | 145.5 | 73.13 | 50.18  | 37.76  |
| 53 | 4,259 | 16.34 | 328.3 | 328.3 | 142.8 | 121.7 | 101.0 | 45.91 | 23.64 | 14.43  | 8.836  |
| 57 | 7,326 | 1.303 | 14.72 | 153.2 | 44.05 | 35.30 | 18.90 | 10.98 | 5.207 | 2.733  | 1.369  |
| 59 | 9,419 | --    | 1.529 | 38.98 | 19.29 | 9.856 | 6.634 | 3.693 | 1.680 | 0.7933 | 0.4035 |

TABLE 4  
SPECTRA OF PULSE INCLUDING SEVERAL BUBBLES (continued)

35-lb Nitramex

| Shot<br>No. | Range<br>(ft) | Octave Bands |       |        |         |         |          |        |       |       |       |
|-------------|---------------|--------------|-------|--------|---------|---------|----------|--------|-------|-------|-------|
|             |               | 15-30cps     | 30-60 | 60-125 | 125-250 | 250-500 | 500-1000 | 1-2kcs | 2-4   | 4-8   | 8-16  |
| 38          | 2,610         | 177.0        | 1153. | 662.2  | 448.8   | 329.1   | 226.5    | 127.1  | 75.57 | 65.22 | 30.71 |
| 39          | 2,751         | 139.2        | 698.5 | 395.5  | 337.2   | 239.5   | 193.5    | 77.08  | 39.68 | 20.10 | 6.189 |
| 39          | 6,864         | 0.4785       | 8.782 | 114.7  | 53.34   | 32.55   | 24.04    | 10.41  | 5.646 | 3.843 | 2.032 |
| 40          | 10,122        | --           | 1.696 | 34.58  | 44.88   | 18.44   | 10.14    | 4.861  | 2.698 | 1.591 | 1.118 |

SHOT 5 1-LB PENTOLITE BURST DEPTH=6620 FT.  
(DATA OF SAME DIGITAL TAPE FILE)

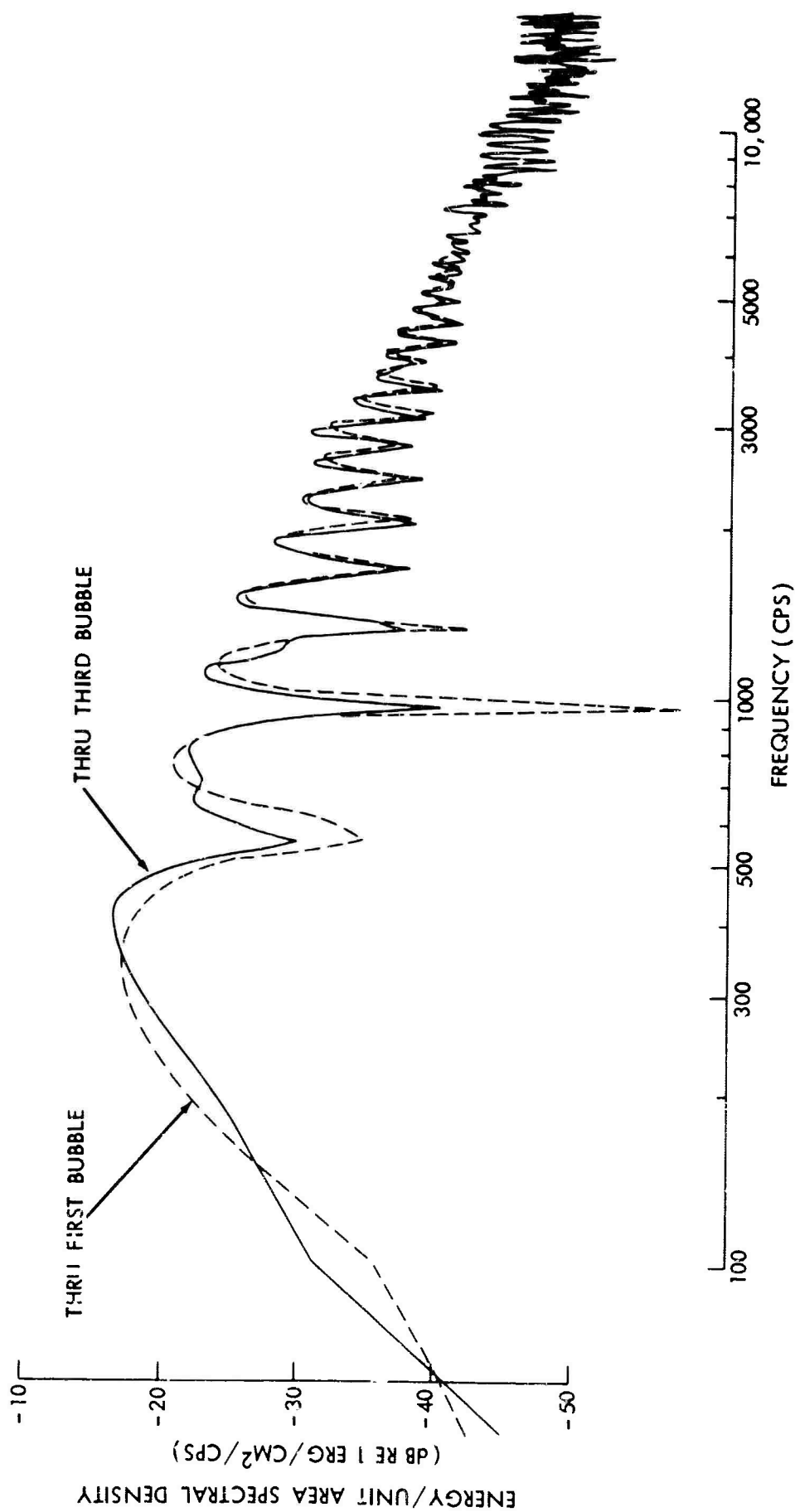


FIG. 1 EFFECT OF NUMBER OF BUBBLES INTEGRATED UPON ENERGY SPECTRUM

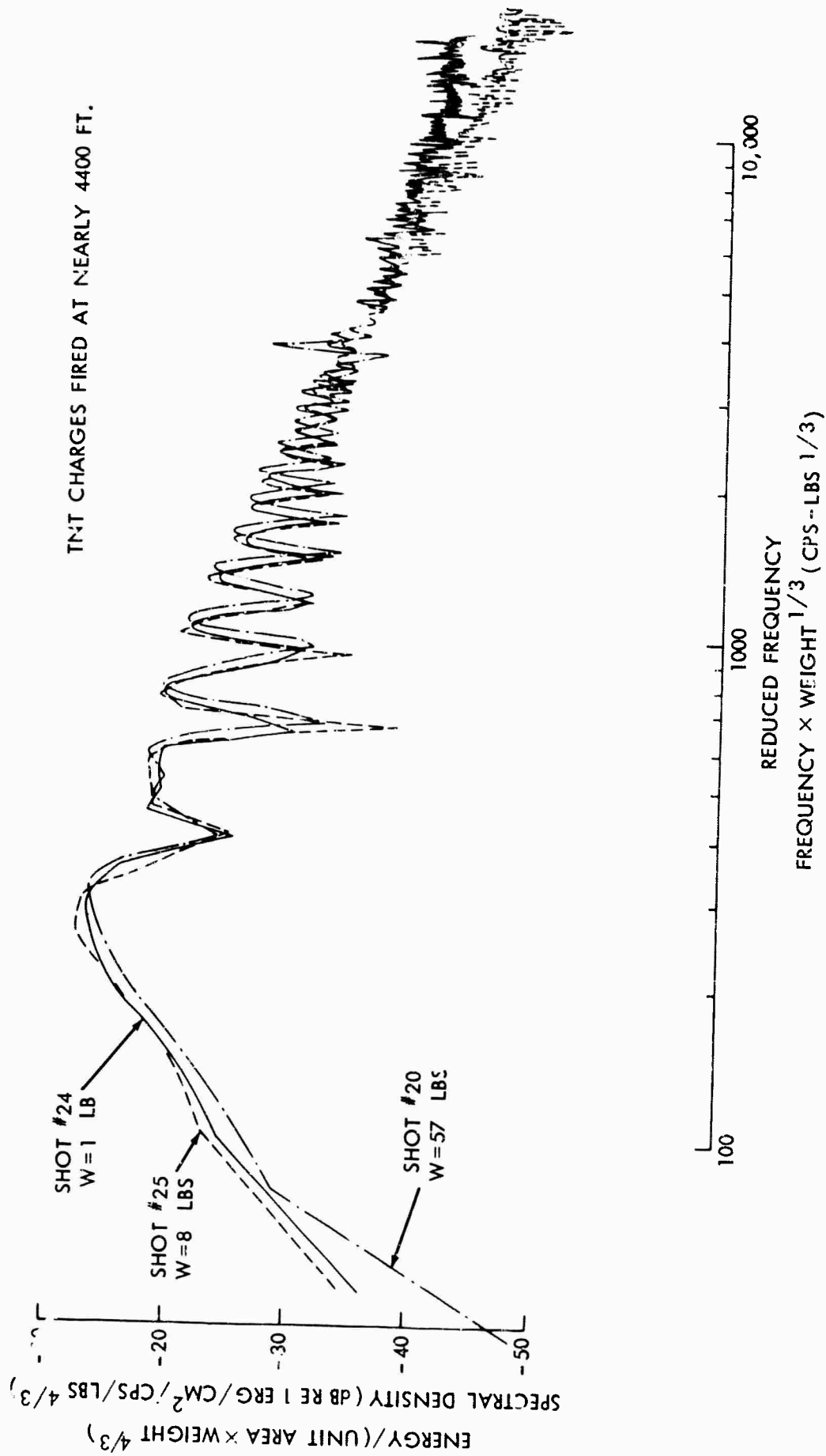


FIG. 2 EFFECT OF CHARGE WEIGHT ON ENERGY SPECTRUM

1-LB HBX-3 CHARGES

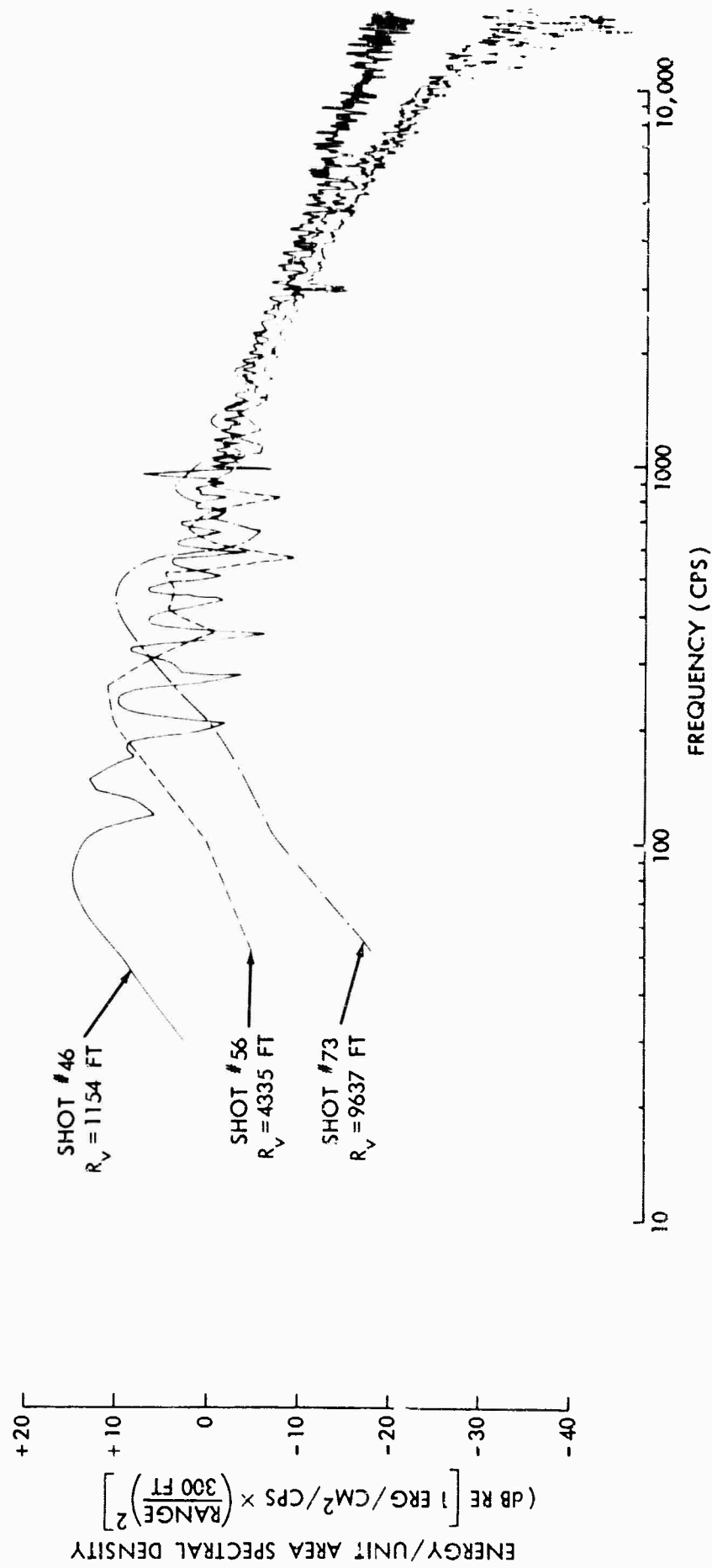


FIG. 3 EFFECT OF RANGE-DEPTH UPON ENERGY SPECTRUM

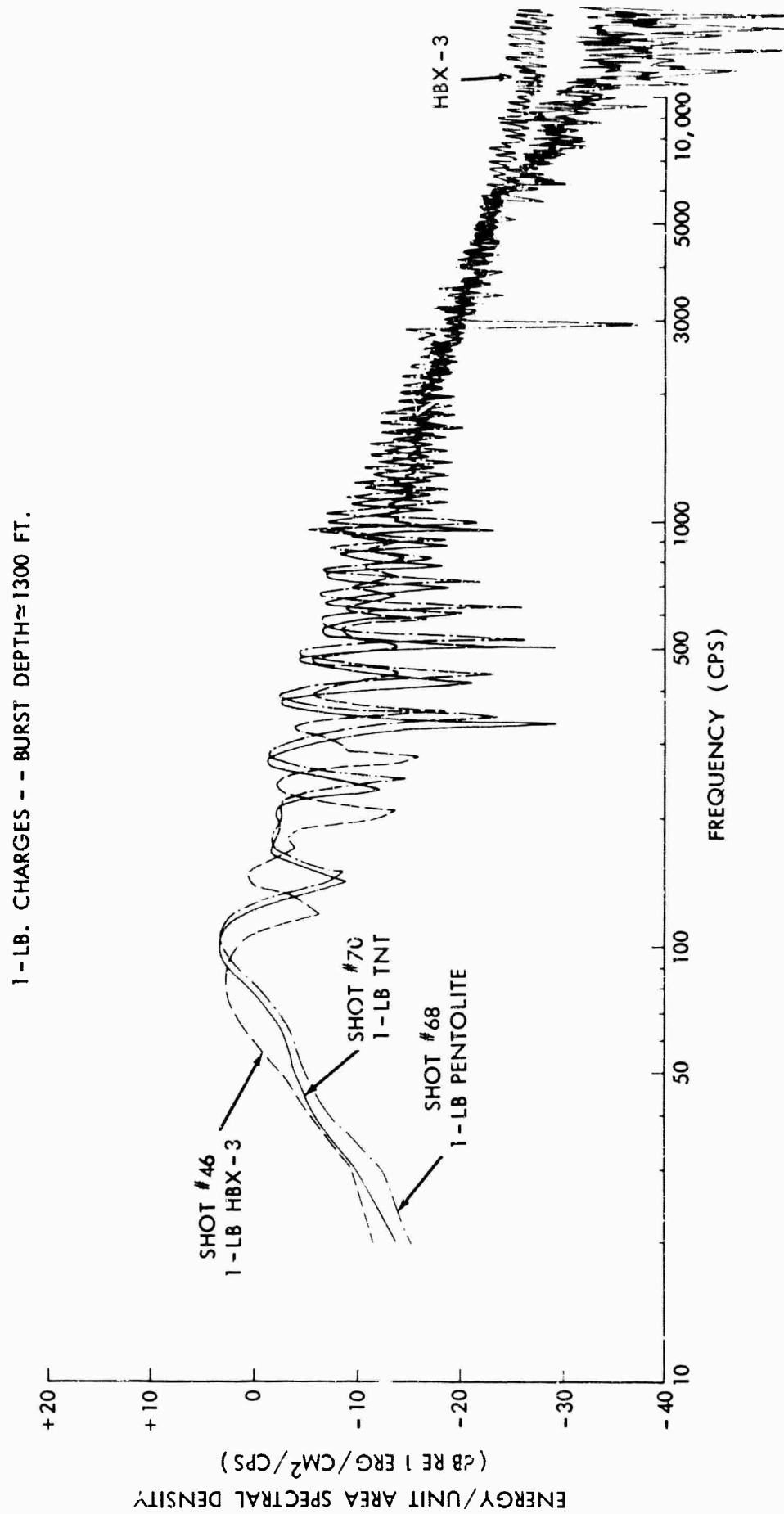
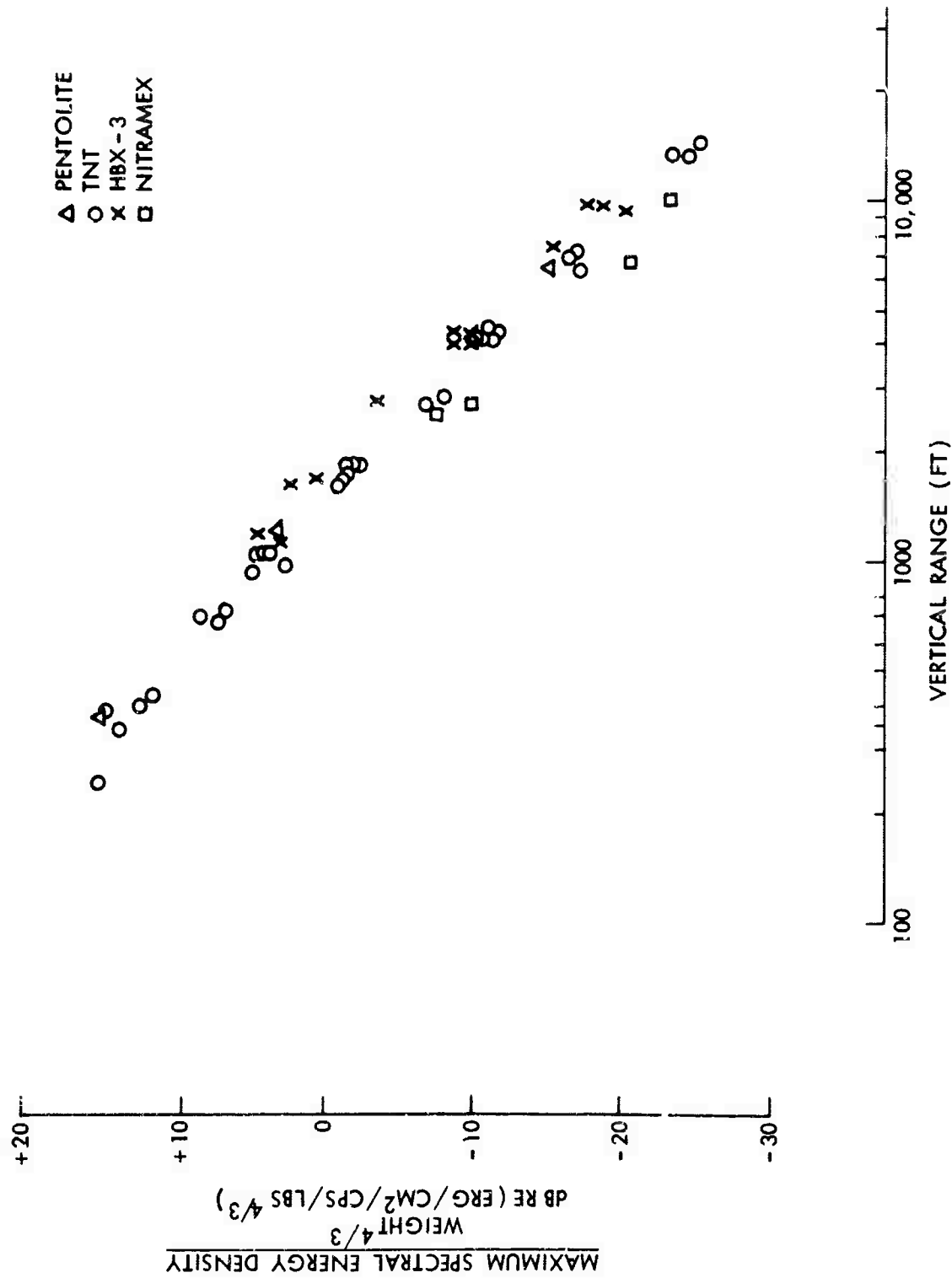


FIG. 4 EFFECT OF CHARGE COMPOSITION UPON ENERGY SPECTRUM



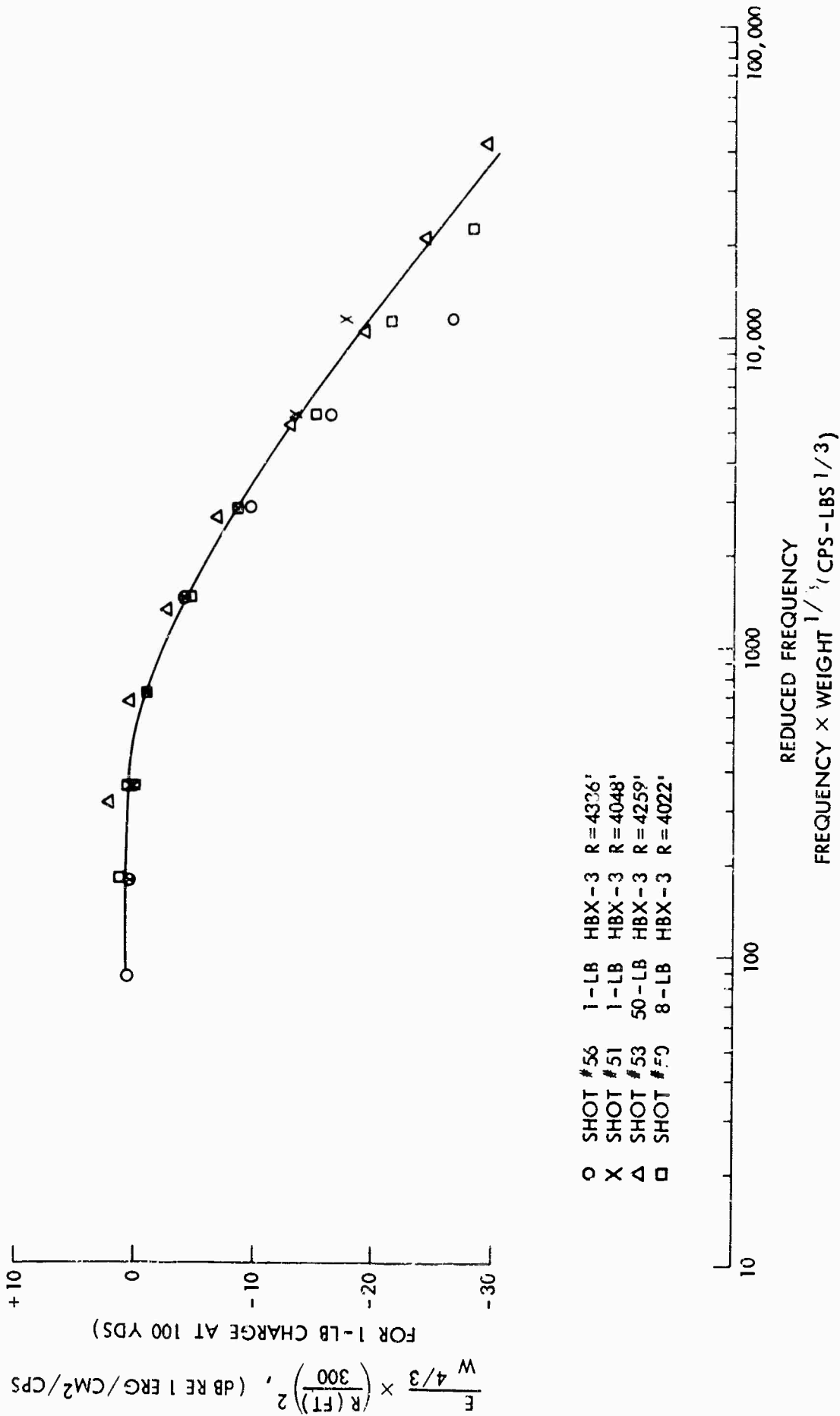


FIG. 6 SHOCK WAVE OCTAVE BAND ENERGY FOR HBX-3 CHARGE

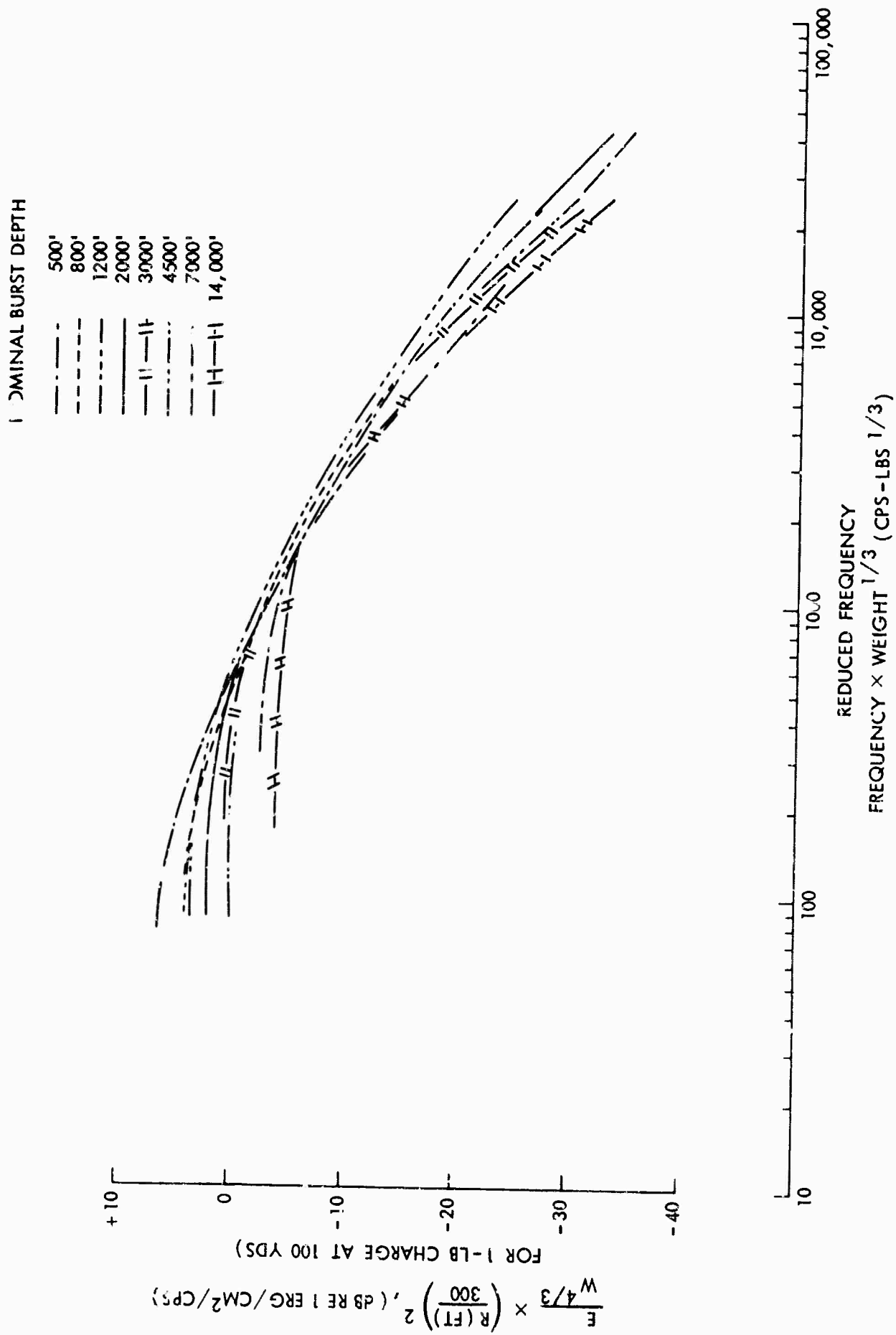


FIG. 7 SHOCK WAVE OCTAVE BAND ENERGY FOR TNT CHARGES

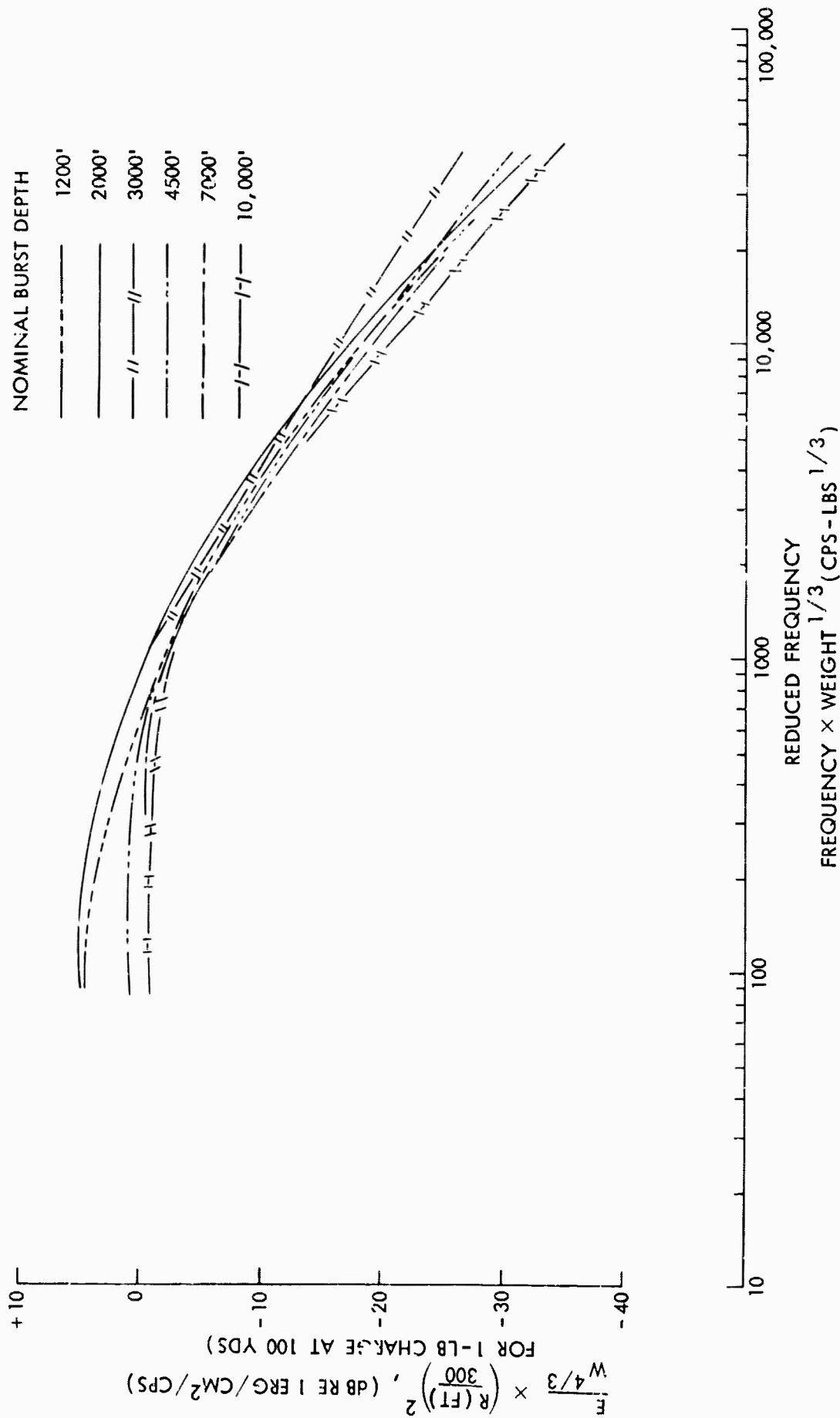


FIG. 8 SHOCK WAVE OCTAVE BAND ENERGY FOR HBX-3 CHARGES

NOMINAL BURST DEPTH  
 --- 500'  
 --- 1200'  
 --- 7000'

FOR 1-LB CHANGE AT 100 YDS)  

$$\frac{E}{W} \times \left( \frac{R(FT)}{300} \right)^2, (dB RE 1 ERG/CM^2/CPS)$$

30

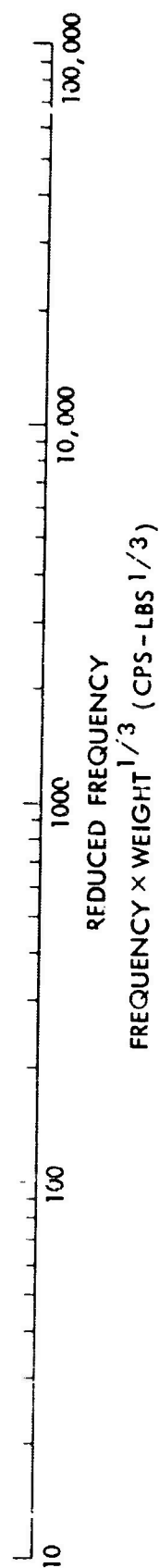


FIG. 9 SHOCK WAVE OCTAVE BAND ENERGY FOR PENTOLITE CHARGES

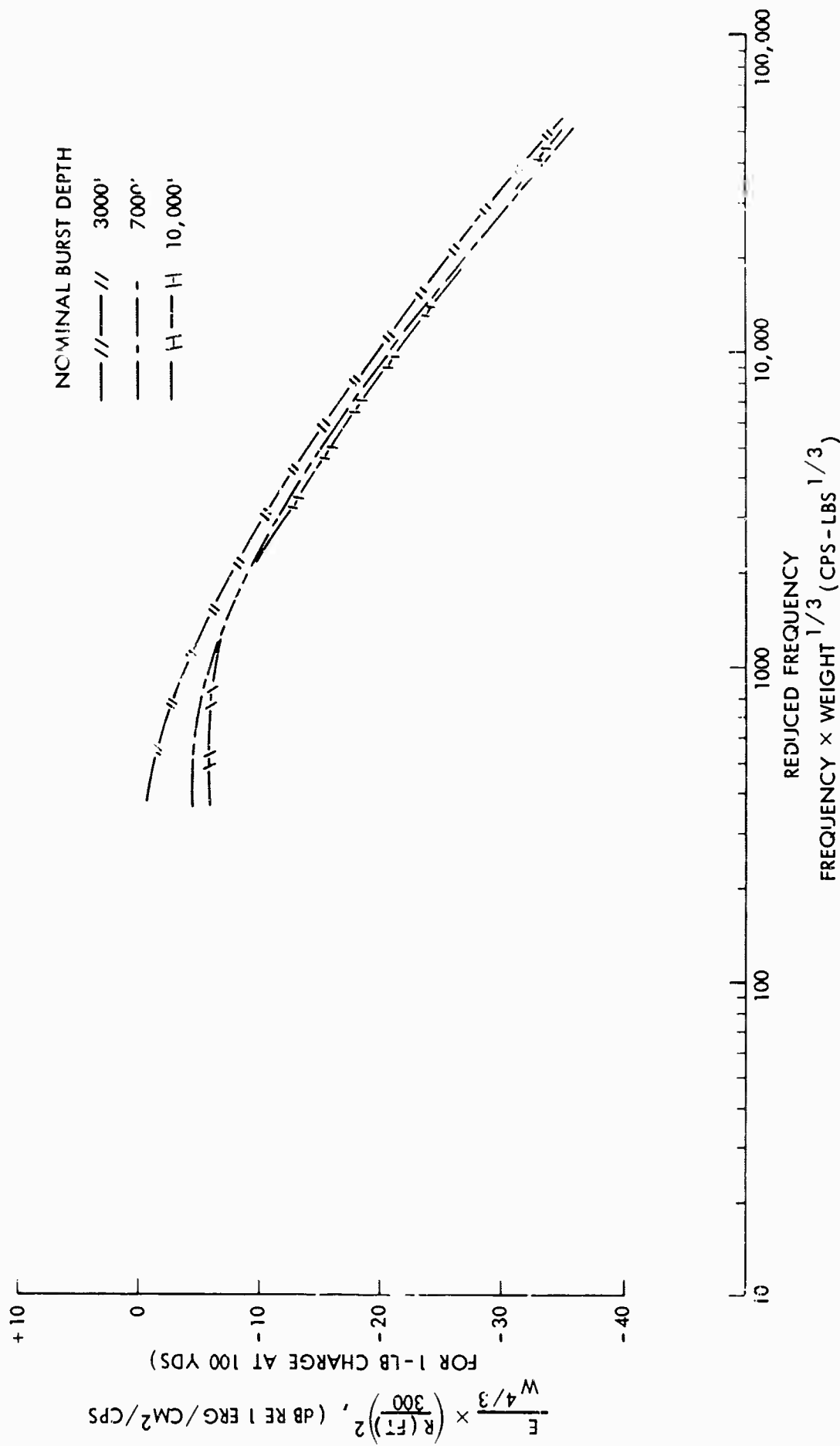


FIG. 10 SHOCK WAVE OCTAVE BAND ENERGY FOR NITRAMEX CHARGES

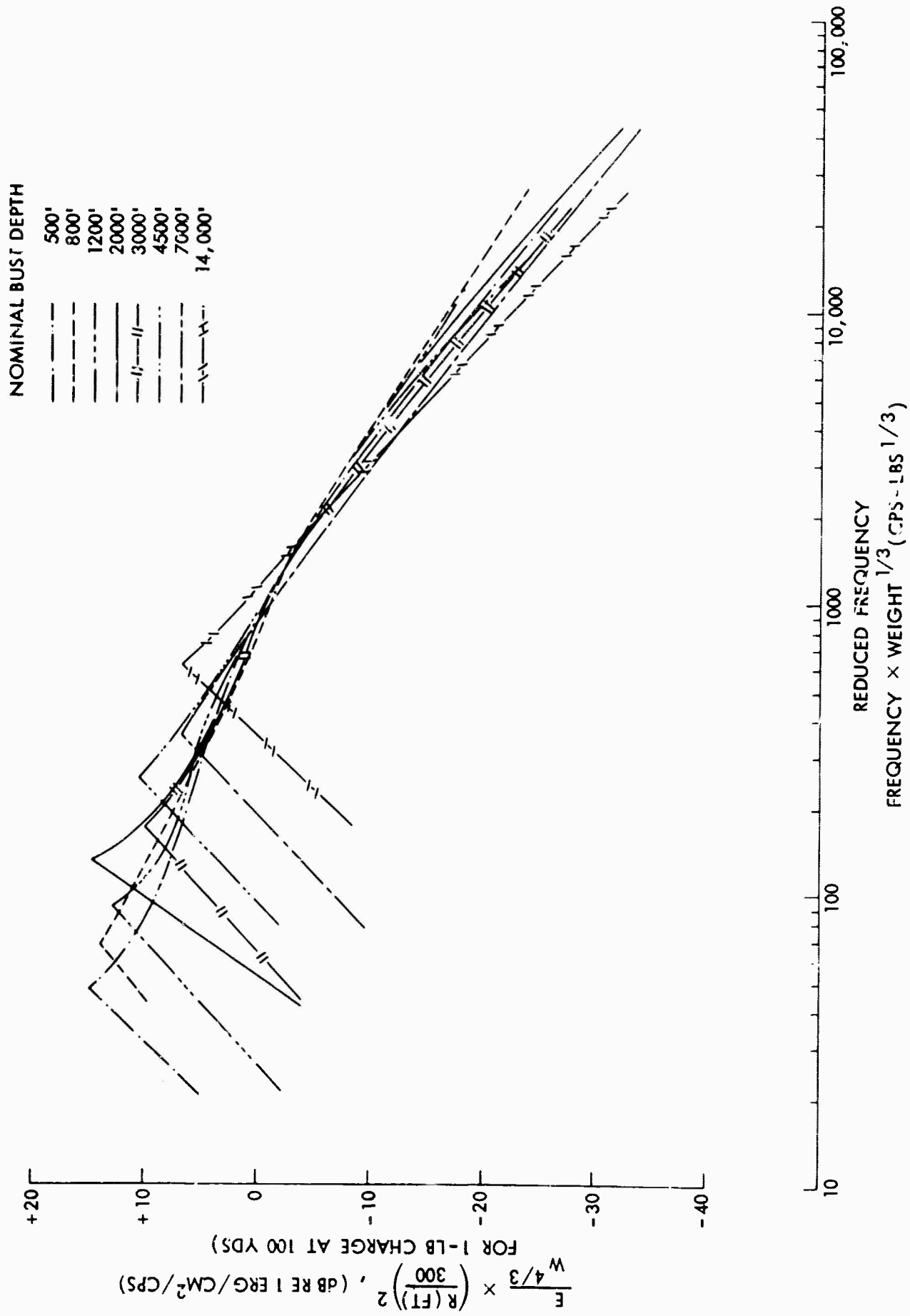


FIG. 11 TOTAL PULSE OCTAVE BAND ENERGY FOR TNT CHARGES

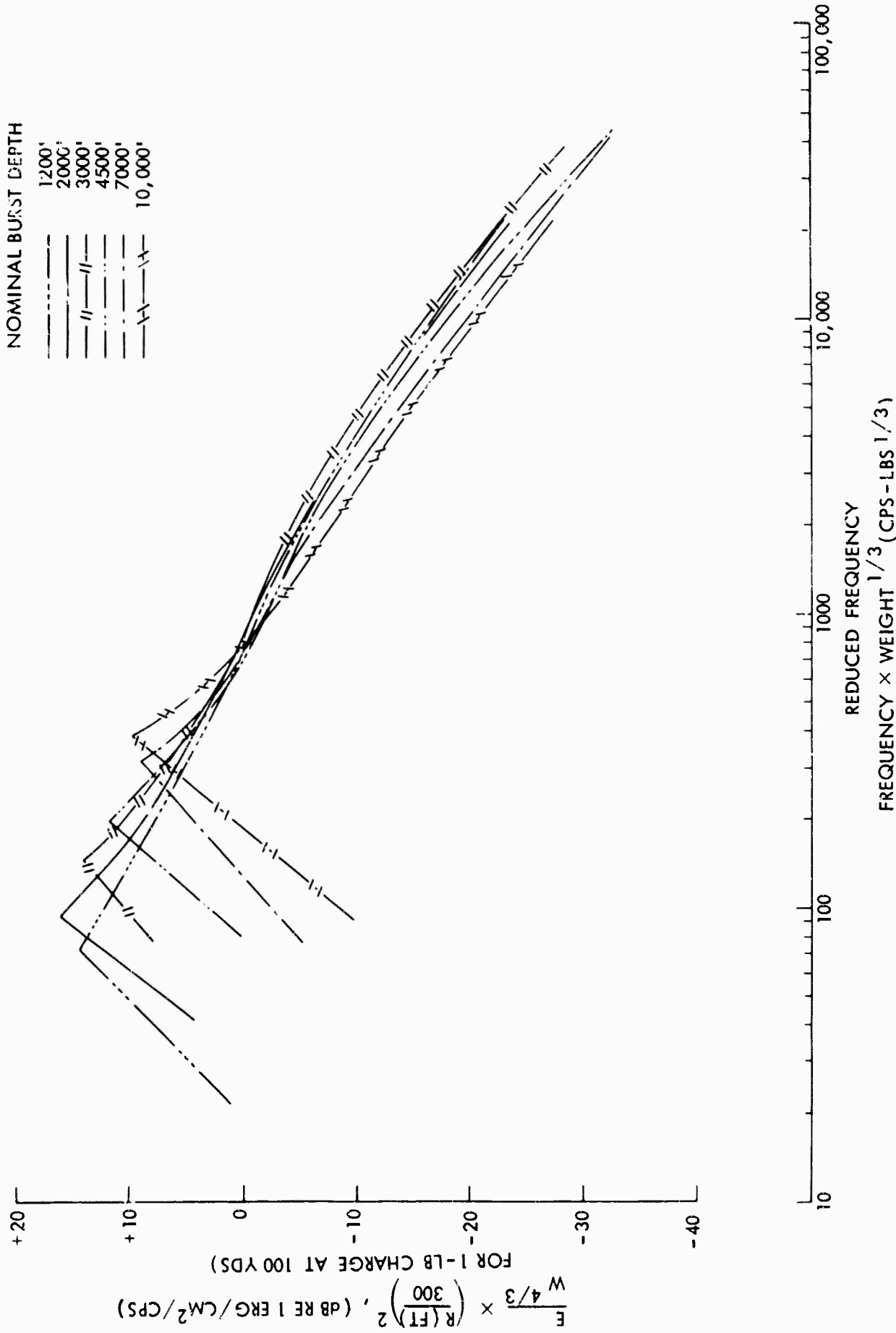


FIG. 12 TOTAL PULSE OCTAVE BAND ENERGY FOR HBX-3 CHARGES

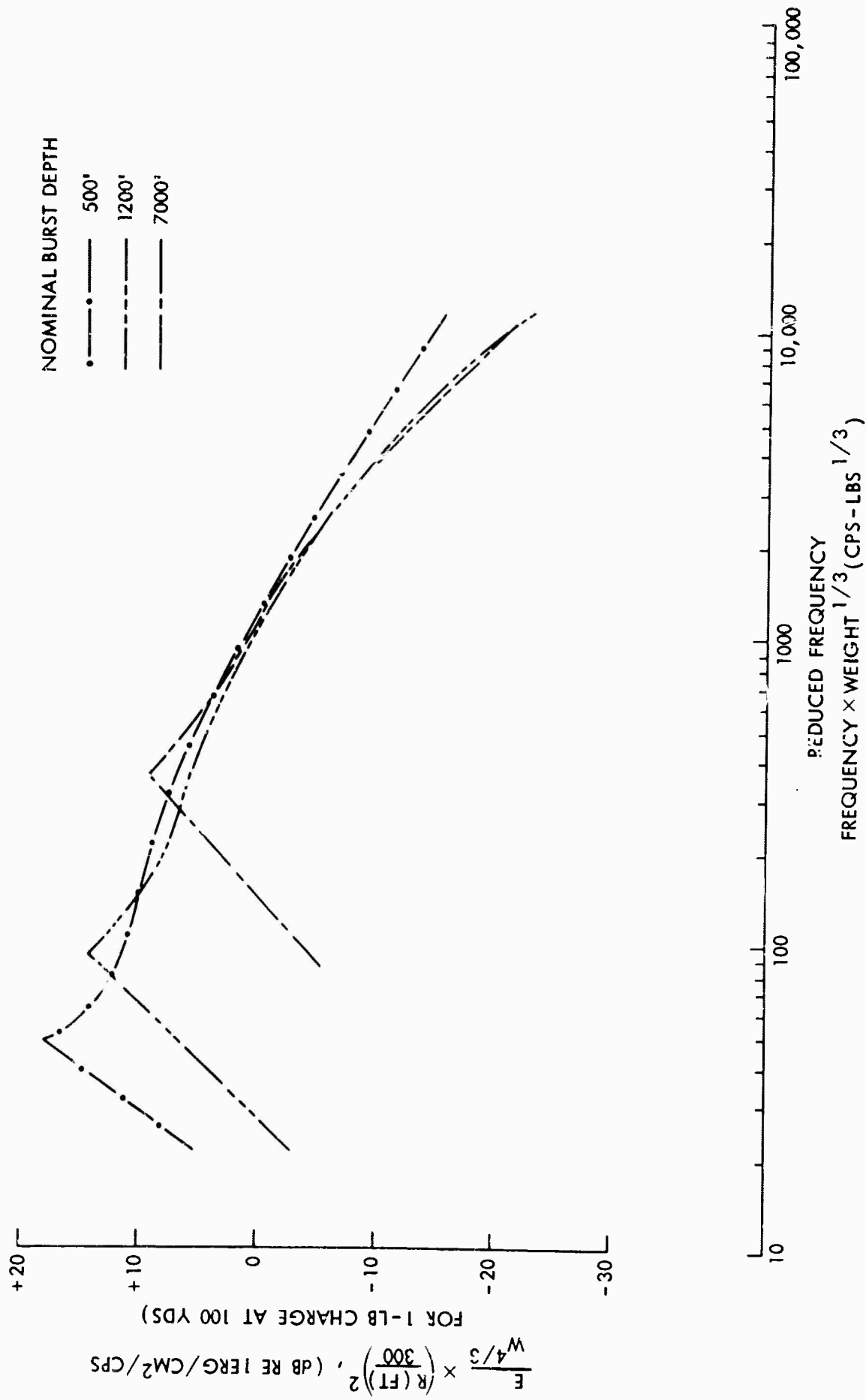


FIG. 13 TOTAL PULSE OCTAVE BAND ENERGY FOR PENTOLITE CHARGES

NOMINAL BURST DEPTH

3000'  
7000'  
10,000'

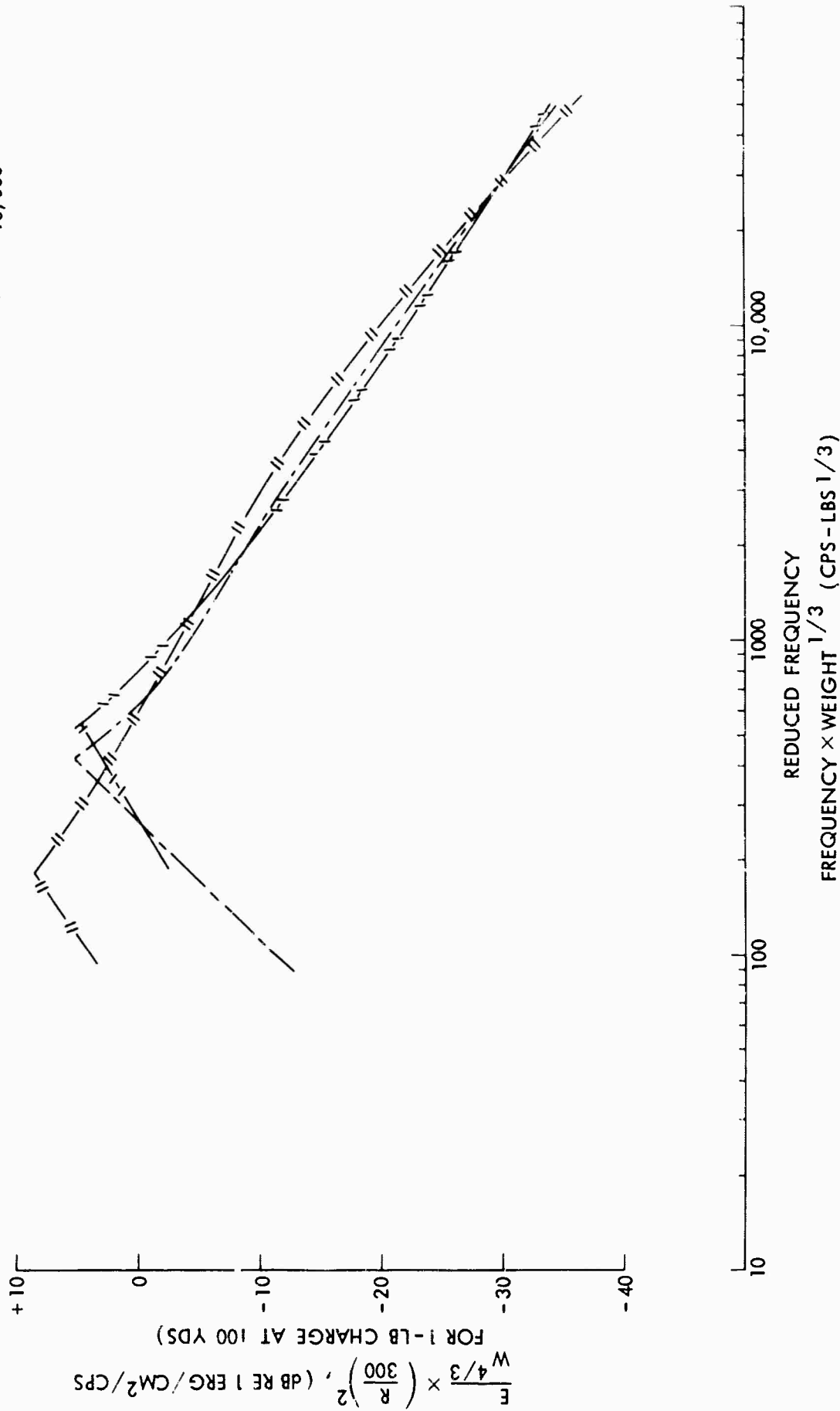


FIG. 14 TOTAL PULSE OCTAVE BAND ENERGY FOR NITRAMEX CHARGES

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## APPENDIX A

## REPRODUCIBILITY OF SPECTRA FROM DIGITIZED DATA

In order to test the DTMB Computer Data Format Translator with our analog tapes, repeat runs of digitization were made and the results compared. This was done for a record which was analyzed only for the positive shock wave pulse, and for another record analyzed through the first bubble pulse.

Figure A-1 illustrates typical energy spectra of the positive phase of the shock wave. The two plots shown are of the same shot, No. 46, a 1-lb HBX-3 charge fired at 1330 feet, the difference being that the analog data was digitized on different days. This was done to check the reproducibility of the DTMB equipment. The spectrum becomes level at the lower frequencies and approaches the impulse\* at zero frequency. The reproducibility of the shock wave spectra at low and mid frequencies is observed to be quite good.

The spectrum of an exponential pulse should ideally have a -6 dB per octave slope in the high frequencies (reference g). However, in Figure A-1 the slopes of the spectra are -5 dB per octave and -11 dB per octave, respectively. Although the sampling was at 33 usec intervals in both cases, the sampling was probably initiated at different times, resulting in digitizing different portions of the pressure-time data. In this particular case, where the  $\theta$  values are the order of 50 usec, A\*\* about 150 usec, and the sampling interval 33.3 usec, reading different pressures on the rise and near the peak could result in different slopes in the spectrum at the highest frequencies. This was verified by reading the same pressure-time Visicorder record on the Telereadex in such a way that the sampling was controlled by starting the sampling at different times relative to the discontinuous rise of the shock wave. It becomes apparent that the sampling should have been at closer intervals; however, the available 16.6 usec sampling rate was not used because it introduced too much noise, as mentioned before.

Figure A-2 shows examples of energy spectra of a pulse integrated to the end of the positive phase of the first bubble pulse. Here again the same analog data was digitized twice. As expected for oscillating functions, the maximum energy occurs at the oscillating frequency; i.e., at the bubble period frequency (35 cps) and then continues to oscillate at integral multiples of this frequency. At 500 cps, the interval in which the spectrum was computed was changed from 5 to 50 cps; therefore,

\* Impulse is defined as  $\int_0^T p(t)dt$ , where T is the duration of the pressure pulse,  $p(t)$ , being integrated.

\*\*  $\theta$ , the time constant of the pressure pulse, is defined as the time where the pressure falls to  $1/e$  of its maximum value,  $p_m$ .

the 35 cps oscillations are not well defined for frequencies greater than 500 cps. It is apparent that the spectra are in good agreement from the bubble fundamental frequency to about 6-8 kcs. In the high frequencies, the slight differences in slope are again attributed to the relatively coarse sampling rate and the uncontrolled starting point of the sampling.

Although the characteristics of the two curves from about 20 cycles to about 5 cycles are similar, the discrepancies are 3 to 5 dB. This large discrepancy is probably due to the different baselines calculated, since a slight shift in the baseline could produce relatively large differences in the impulse.

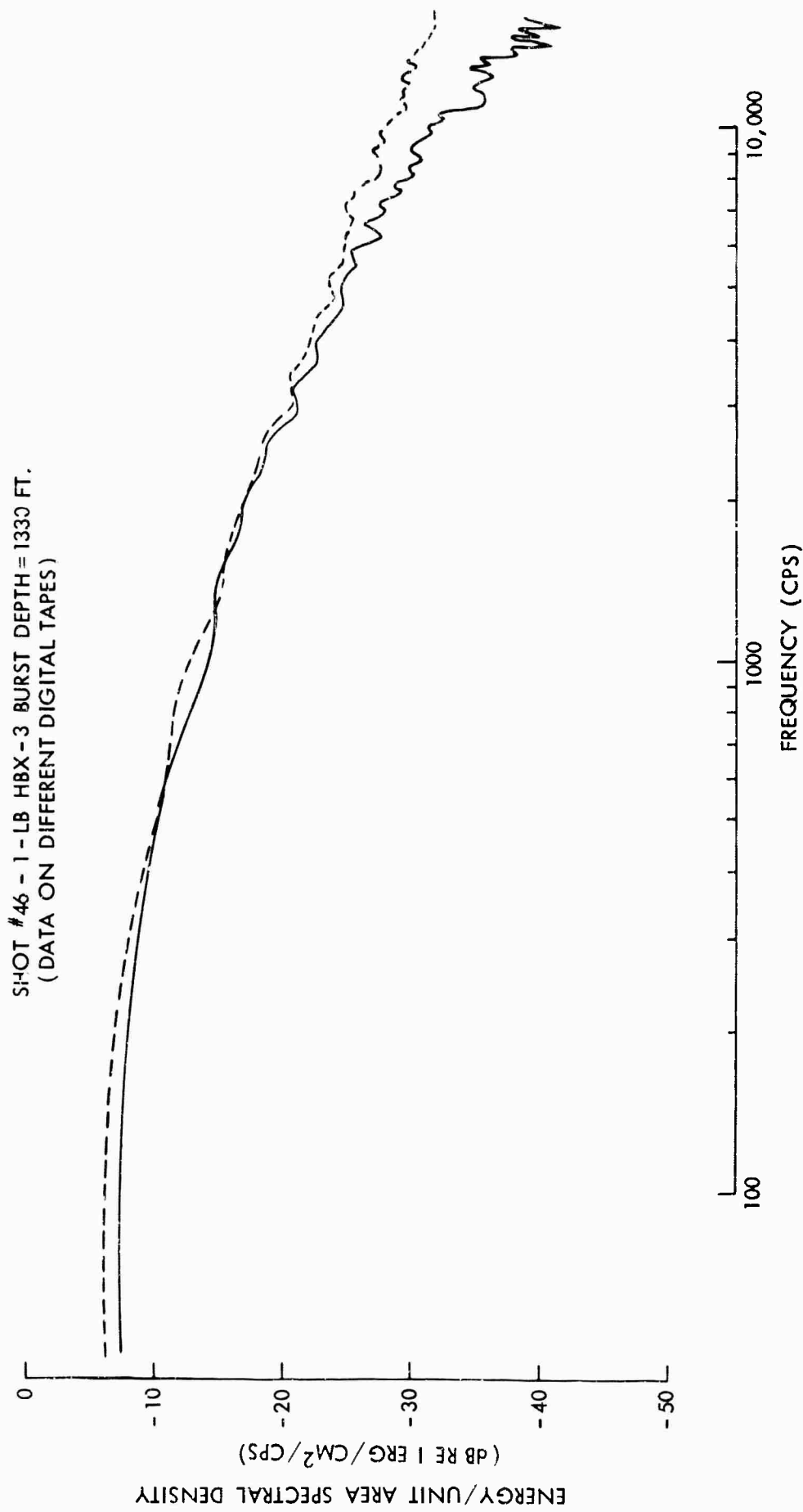


FIG. A-1 REPRODUCIBILITY OF SHOCK WAVE SPECTRUM

SHOT 12 - 8-LBS TNT BURST DEPTH=890 FT.  
(DATA ON DIFFERENT DIGITAL TAPES)

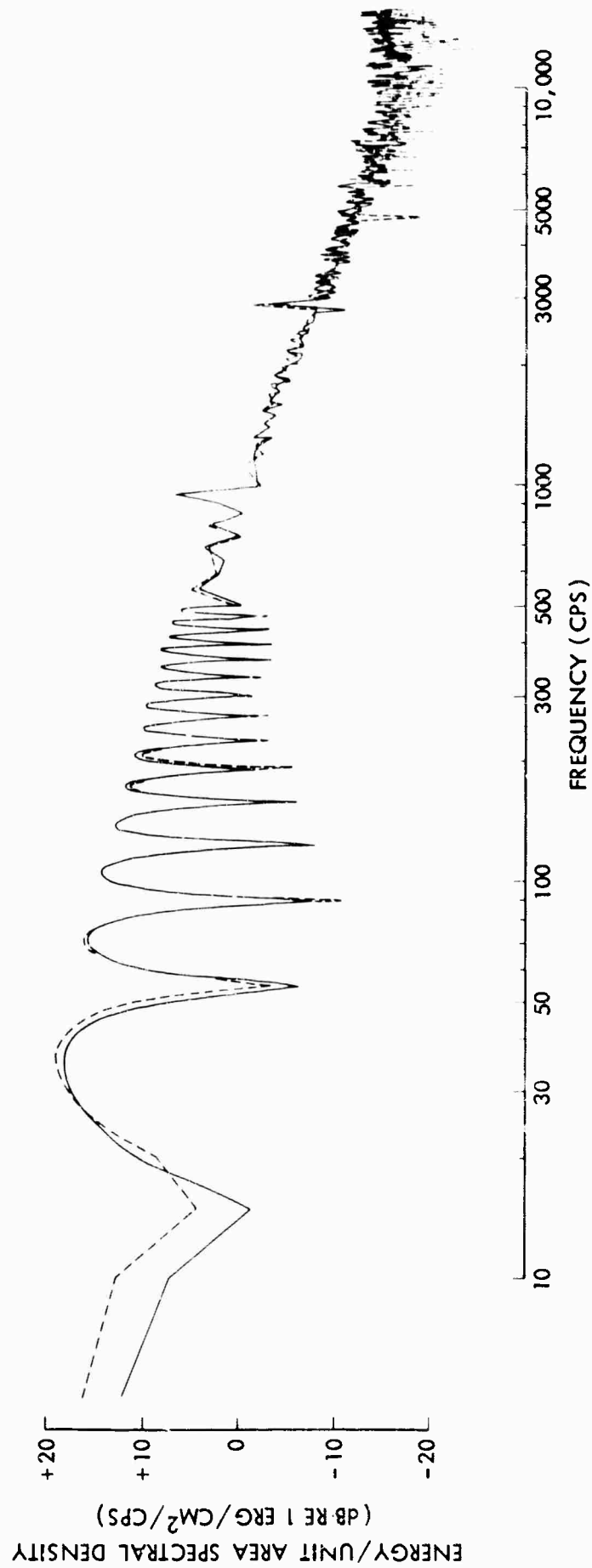


FIG. A-2 REPRODUCIBILITY OF TOTAL PULSE SPECTRUM

Unclassified

Security Classification

DOCUMENT CONTROL DATA - R & D

Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified

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|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--|-----------------------------------------------------------------------------|-------------------------|
| 1. ORIGINATING ACTIVITY (Corporate or other)<br><br>U. S. Naval Ordnance Laboratory<br>White Oak, Silver Spring, Maryland                                                                                                                                                                                                                                                                                                                                                                          |  | 2a. REPORT SECURITY CLASSIFICATION<br><br>Unclassified                      |                         |
| 3. REPORT TITLE<br><br>Spectrum and Octave Band Analysis of Pressure Pulses From Deep Underwater Explosions                                                                                                                                                                                                                                                                                                                                                                                        |  | 2b. GROUP                                                                   |                         |
| 4. DESCRIPTIVE NOTES (Type of report and inclusive dates)                                                                                                                                                                                                                                                                                                                                                                                                                                          |  |                                                                             |                         |
| 5. AUTHOR(S) (First name, middle initial, last name)<br><br>Mary Alice Genau                                                                                                                                                                                                                                                                                                                                                                                                                       |  |                                                                             |                         |
| 6. REPORT DATE<br><br>5 October 1966                                                                                                                                                                                                                                                                                                                                                                                                                                                               |  | 7a. TOTAL NO OF PAGES<br><br>50                                             | 7b. NO OF FCFS<br><br>7 |
| 8a. CONTRACT OR GRANT NO                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |  | 9a. ORIGINATOR'S REPORT NUMBER(S)<br><br>NOLTR 66-128                       |                         |
| b. PROJECT NO Task NOL-785/ARPA                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |  | 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) |                         |
| c.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |  |                                                                             |                         |
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| 13. ABSTRACT<br><br>Fourier spectra were computed on the IBM 7090 for analog tape recorded pressure pulses of underwater explosions fired at sea in February 1965. Depths ranged from 500 to 14,000 feet; charges weighed 1 to 88 pounds; the compositions fired were TNT, pentolite, HBX-3, and Nitramex. Reduced spectra of charges weighing up to 57 pounds agreed with previous results from 1 and 10 pound charges at the same depths. Only slight differences due to composition were found. |  |                                                                             |                         |

| 14<br>KEY WORDS                                                                                                                        | LINK A |    | LINK B |    | LINK C |    |
|----------------------------------------------------------------------------------------------------------------------------------------|--------|----|--------|----|--------|----|
|                                                                                                                                        | ROLE   | WT | ROLE   | WT | ROLE   | WT |
| Un' rwater Explosion<br>Sho' Waves<br>Frequency Spectrum<br>Underwater Sound<br>Bubble Pulses<br>TNT<br>HSX-3<br>Pentolite<br>Nitramex |        |    |        |    |        |    |