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# SUS QUALITY ASSESSMENT

Marvin S. Weinstein, et al

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Richard J. Hecht

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The detonation pressure time curves recorded aboard the shooting ships, the USNS Silas Bent and the USNS Bartlett, were processed to acquire quality assurance statistics for the SUS used for acoustic sources. Bubble pulse periods were determined for each detonation from which an equivalent detonation depth was derived. For statistical purposes, the detonation depths are grouped in 2 foot classes centered on the even foot for the MK 61 (60 feet) and 10 foot classes centered on the decade, for the MK 82 (300 feet).

The fluctuation in source levels for each 1/3 octave band ot interest; 25, 50, 100, 160 and 250 Hz, was determined for each depth range class discussed above. The corrections range from +1.0 to -1.0 db, and are given in 0.5 increments in Table 3 of Chapter 3. The computations are based on the Gaspin & Shuler and the Weston formulations, since these are the only procedures which can be currently employed to obtain this information.

| 14. KEY WORDS | LINK A | | LINK B | | LINK C | |
|---|---|---|---|---|---|---|
| | ROLE | WT | ROLE | WT | ROLE | WT |
| CHURCH ANCHOR | | | | | | |
| Explosive Sources | | | | | | |
| Data Processing | | | | | | |
| Source Levels | | | | | | |
| SUS | | | | | | |

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M. S. Weinstein
R. J. Hecht

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UNDERWATER
SYSTEMS, Inc.
World Building • 8121 Georgia Ave. • Silver Spring, Md. 20910 • (301) 589-1188

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# SUMMARY

The detonation pressure time curves recorded aboard the shooting ships, the USNS Silas Bent and the USNS Bartlett, were processed to acquire quality assurance statististics for the SUS used for acoustic sources. Bubble pulse periods were determined for each detonation from which an equivalent detonation depth was derived. For statistical purposes, the detonations depths are grouped in 2 foot classes centered on the even foot for the MK 61 (60 feet) and 10 foot classes centered on the decade, for the MK 82 (300 feet). For the SUS deployed by the Bent, it is recommended that the 54, 56, 58, and 60 foot classes be processed for the MK 61s and the 280, 290, 300 and 310 foot classes be processed for the MK 82s. The data from the Bartlett is both of lower quality and inconsistent with that of the Bent; therefore, no recommendations can be made regarding the data derived from the SUS deployed by the Bartlett. ARL, University of Texas has been furnished listings and a digital tape from which the recommended shots can be determined.

The 1/3 octave band source levels for SUS have been extensively investigated in other programs.

Measured and predicted levels cover a range of as much as 8 db for the 25 Hz band. The spread is lower for other frequencies, but is still of the order of 5 db. Several sets of source levels are given in Tables 1 and 2 of Chapter 2. It is recommended that a single set of source levels be used for all propagation loss determinations so that comparisons can be made. The source levels used should be listed in all propagation loss reports.

The fluctuation in source levels for each 1/3 octave band of interest; 25, 50, 100, 160 and 250 Hz, was determined for each depth range class discussed above. The corrections range from +1.0 to -1.0 db, and are given in 0.5 increments in Table 3 of Chapter 3. The computations are based on the Gaspin & Shuler and the Weston formulations, since these are the only procedures which can be currently employed to obtain this information.

# CHAPTER 1
# SUS QUALITY ASSESSMENT

## Introduction

During the CHURCH ANCHOR Exercise, a series of SUS bombs were deployed by the vessels USNS Silas Bent and USNS Bartlett for the purpose of measuring acoustic propagation loss. Quality assurance procedures were instituted to ensure that the data obtained would not be affected by variations in source level or detonation depth. Magnetic tape recordings of the SUS pressure signals were obtained by each of the shooting ships. These tapes were processed to determine the bubble pulse period from each of the SUS bombs used for the propagation loss studies. From the bubble pulse period of the source, deviations in shot depth and band levels can be determined. The processing technique, results, and recommendations, are presented.

## Basic Data - USNS Silas Bent

The data obtained by the USNS Silas Bent was recorded in the FM mode on magnetic tape using two different sensors; (1) a towed seismic array, and (2) a hull mounted 3.5 kHz transducer. Time code IRIG B and voice annotations were also recorded in the direct mode. Approximately 3,222 SUS bomb shots were dropped from the Bent, distribution by type is shown in Table 1. The recorded data is considered to be of excellent quality, with two minor exceptions, tape 40 was blank, i.e., one 45 minute sequence was not recorded, and there was no time code on the last ten 45 minute sequences due to equipment failure - the result being "slightly lower confidence level" for that portion of the data.

## Basic Data - USNS Bartlett

The data obtained by the USNS Bartlett was recorded in the FM mode from a owed hydrophone using a high, medium, and low gain channel. Time code IRIG B and voice annotations of time were also recorded in the direct mode. Approximately 270 SUS's were dropped from the Bartlett, distribution by type are shown in Table 2. The data was recorded on 5 magnetic tapes. During the 2nd tape, the time code carrier shows slowing tape speed and extensive momentary decelerations and accelerations. Near the beginning of tape 4 the recorder was replaced and the data quality was good for tape 5.

## TABLE 1

### Tabulation of SUS Statistics for Those Dropped by the USNS Silas Bent

| SUS Type | MK 61 | MK 82 | MK 61 | MK 64 |
|---|---|---|---|---|
| Nominal Detonation Depth | 800 | 300 | 60 | 60 |
| Nominal Explosive Yield | 1.8 lb | 1.8 lb | 1.8 lb | 1.1 oz |
| Number Dropped | 697 | 695 | 696 | 829 |
| Number Processed | 0 | 655 | 654 | 0 |
| Number Not Recorded | - | 14 | 14 | - |
| Number Not Processable | - | 0 | 2 | - |
| Dud | - | 26 | 26 | - |
| Number Processed Outside of Depth Limits:* | | | | |
| Bubble Pulse High | - | 24 | 34 | - |
| Bubble Pulse Low | - | 43 | 18 | - |

*Discussed on page 16.

## TABLE 2

### Tabulation of SUS Statistics for Those Dropped by the USNS Bartlett

| SUS Type | MK 61 | MK 82 | MK 61 |
|---|---|---|---|
| Nominal Detonation Depth | 800 | 300 | 60 |
| Nominal Explosive Cut | 1.8 lb | 1.8 lb | 1.8 lb |
| Number Dropped | 90 | 89 | 89 |
| Number Processed | 0 | 58 | 60 |
| Number Not Recorded | - | 14 | 13 |
| Number Not Processable | - | 11 | 10 |
| Dud | - | 6 | 6 |

## Data Processing System

A block diagram of the data processing system is shown in Figure (1). The data from the tape recorder is preprocessed before being digitized for processing. The computer provides five functions:

1. Determination of bubble pulse period
2. Time code reader
3. Time code search
4. Display controller
5. System controller

The operator's chief function is to serve as an on-line quality assurance monitor. To assist him in this role the bomb shot is displayed together with the computer determined bubble pulse period on an oscilloscope for immediate observation; at the operator's option, a hard copy can be made for further study. System status and bubble pulse periods are presented on the TTY printer.

The data channel from the recorder is amplified to convert a nominal 1 volt rms signal from the recorder to a 10 volt peak signal for input to the 13 bit analog to digital converter. The data channel is sampled at a nominal 8 kHz derived from the time code carrier.

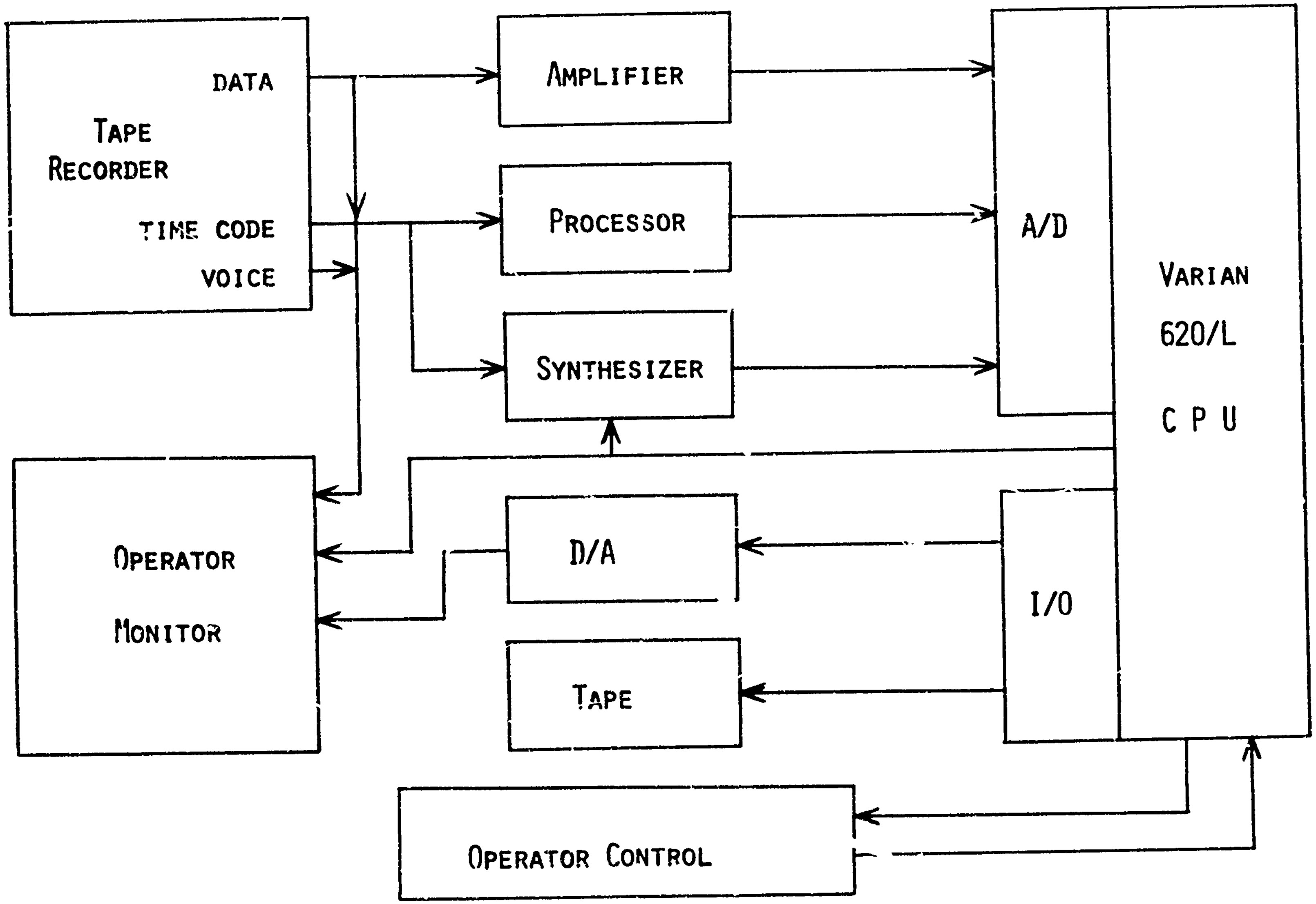

FIGURE (1). BLOCK DIAGRAM OF BUBBLE PULSE PROCESSING SYSTEM.

The time code channel from the recorder is utilized in two ways: (1) to determine the time; and, (2) to furnish a reference frequency to remove tape recorder speed errors. For determining time, the modulated time code is processed to obtain its envelope function which is then sampled by the A-D converter at a 4 kHz rate. As a reference frequency the time code carrier frequency is filtered, limited and multiplied by 4 in a phase locked loop. The synthesized frequency is then used as the sampling pulse for the A-D converter.

After a shot is detected and processed, the computer, through a D-A converter to an oscilloscope, repetitively outputs the digitized shot together with two pulses. One pulse showing the shock wave onset time and the other the bubble pulse maximum. This display is used by the operator to evaluate the quality of the determination. The option also exists to output the scope display on the chart recorder at a scale factor of 0.125 ms/1mm for further study. A typical display at 1/5 normal time scale is shown in Figure (2).

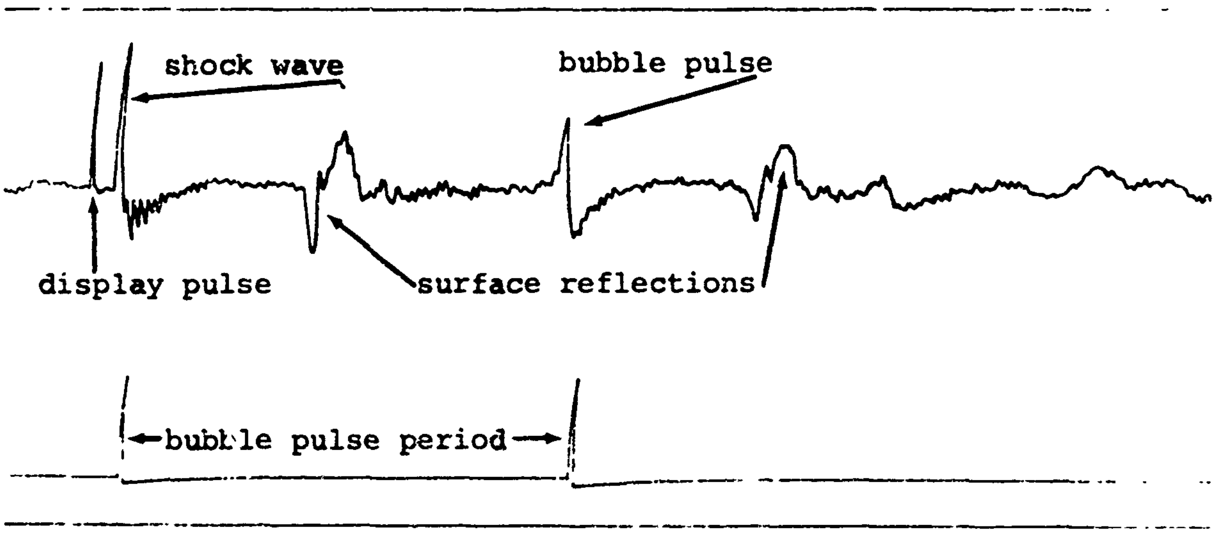

Figure (2). Typical SUS signal display at 1/5 normal time scale.

Using the measured bubble pulse period and assuming an explosive charge of 1.8 lbs of TNT; the detonation depth is derived from the following formula:

$$T = \frac{4.36\ W^{1/3}}{(Z + 33)^{5/6}}$$

where T = bubble pulse period

W = charge weight

Z = detonation depth

The curve for T as a function of Z was fitted with a polynominal, this was used to derive the detonation depth from the bubble pulse period.

## Computer Operation

The design of the system minimizes the recurrent menial tasks that the operator must perform so that he can concentrate on evaluating each bubble pulse determination. The initialization of the system requires the manual entry via the TTY of expected time of signal. A block diagram of the computer processing routines are shown in Figure (3). The system then monitors the time code until the decoded

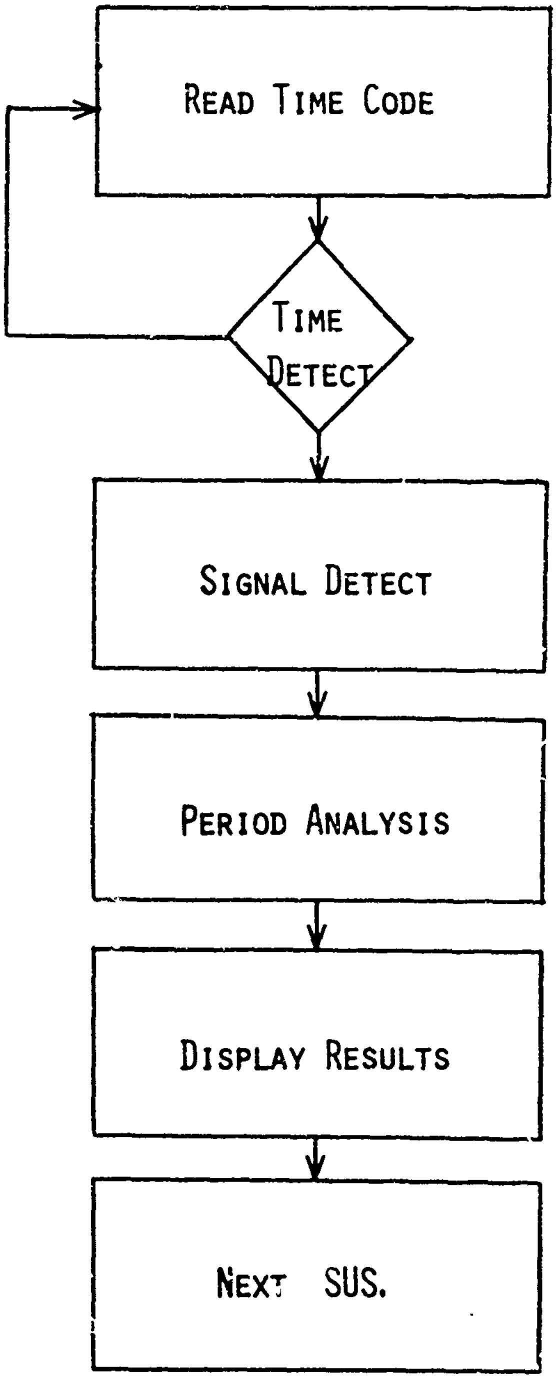

FIGURE (3). GENERALIZED BLOCK DIAGRAM OF COMPUTER PROCESSING FOR EACH SUS SIGNAL.

time is equal to the entered time minus 10 seconds at which time it begins monitoring the SUS signal. The shock wave is determined by level detection, when this happens the following block of digitized data is stored. The peak of the bubble pulse is determined by recurrent looks at the stored data with successively lower comparative levels. When the peak level has been found it is compared with the expected time frame of occurrence; if the detection is outside the time frame an alarm is sounded to alert the operator of a possible misdetermination. The determination is displayed following this.

## Processing Results - USNS Silas Bent

A total of 1309 detonation pressure time curves were processed. This represents 94% of the charges dropped. The remaining 6% includes 54 Duds, as well as unprocessable and unrecorded detonations. Table 1 summarizes this information.

Figures (4) and (5) show acumulative distributions as a function of bubble pulse period and shot depth. The most likely bubble pulse period is somewhat longer than the expected nominal

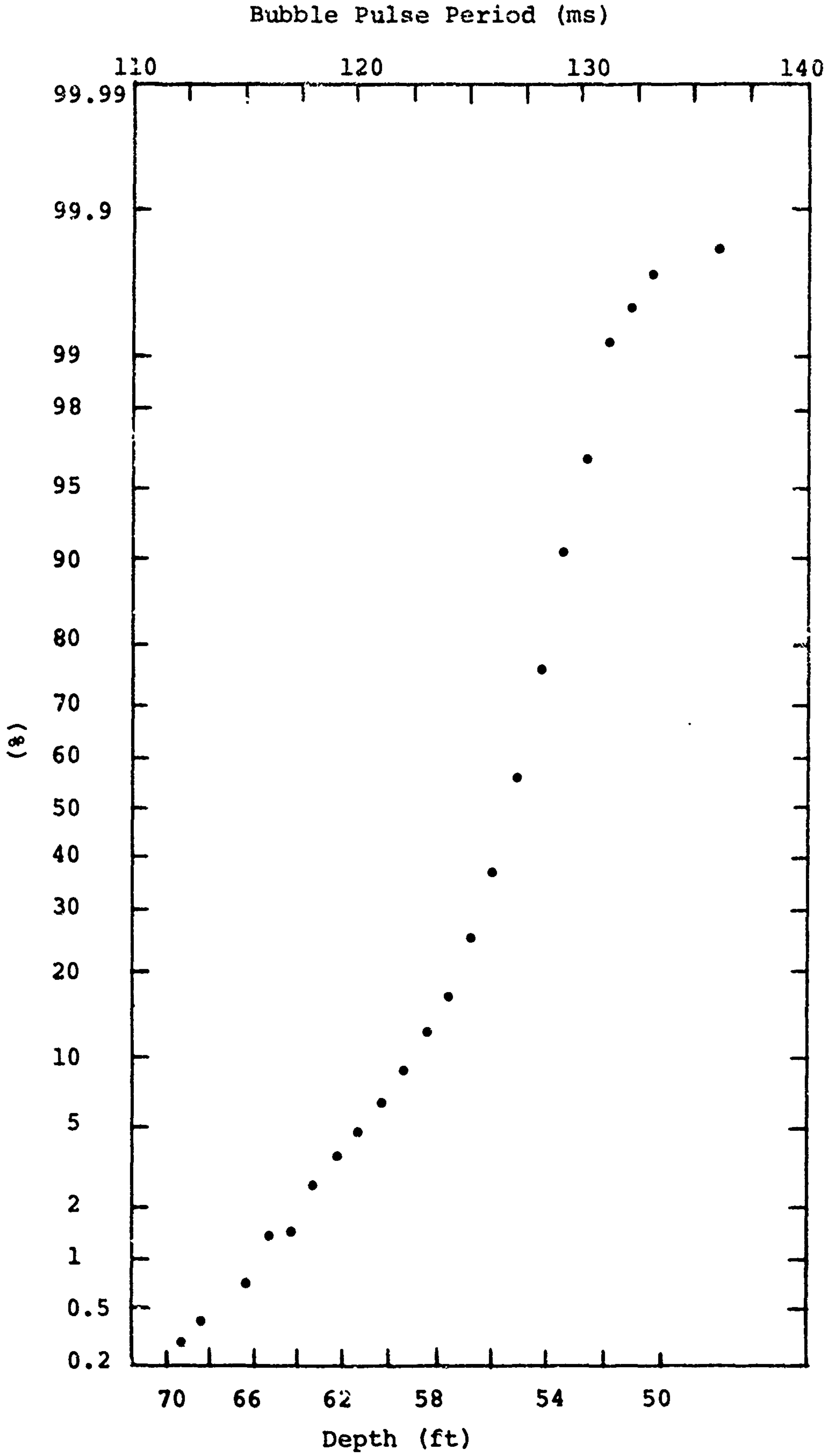

Figure (4). Cumulative distribution of bubble pulse period and derived shot depth from the MK 61 (60 feet) SUS charges dropped by the USNS Silas Bent.

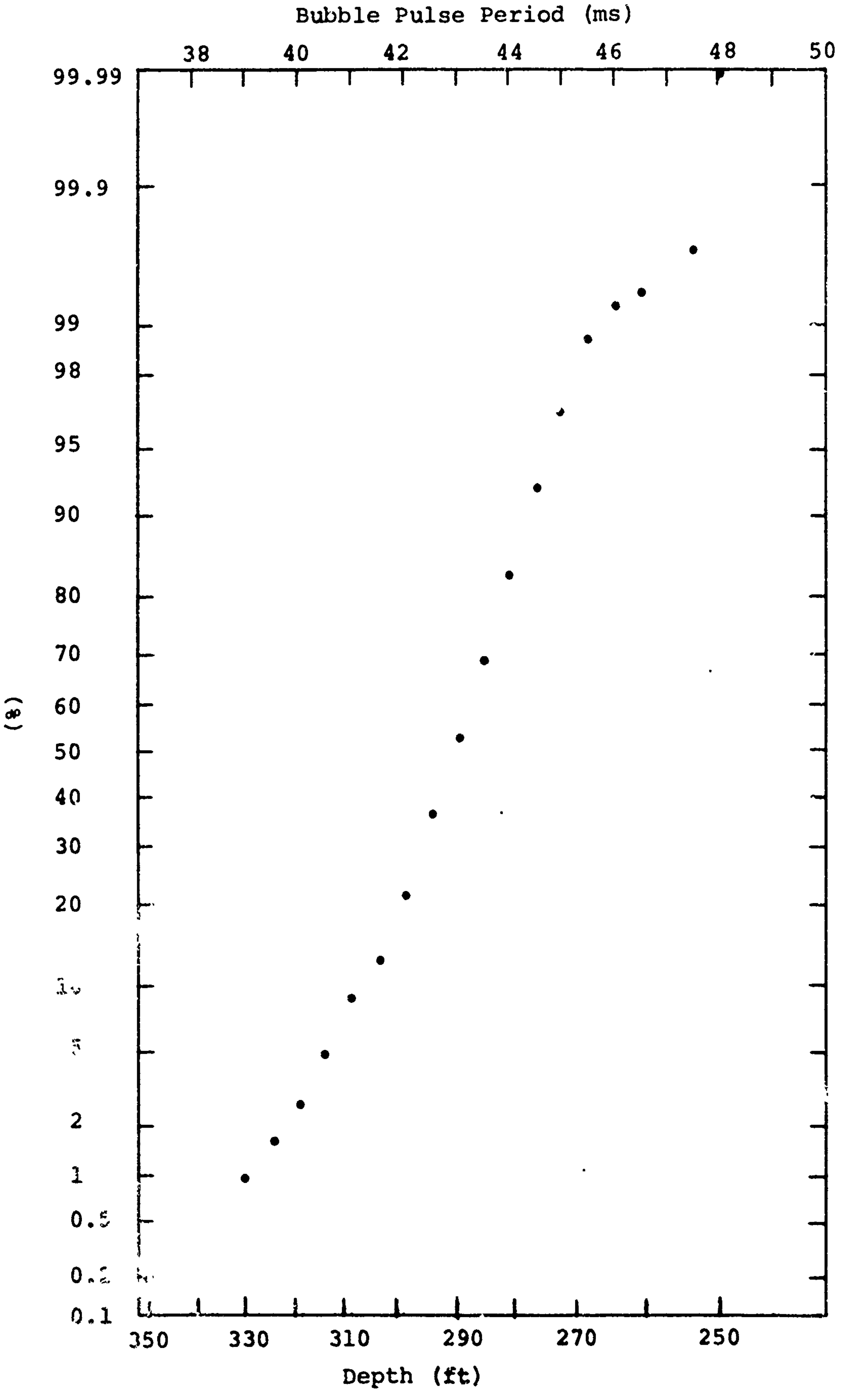

Figure (5). Cumulative distribution of bubble pulse period and derived shot depth from the MK 82 (300 feet) SUS charges dropped by the USNS Silas Bent.

value; 128 vs 121 ms for the MK 61 and 43.5 vs 42 for the MK 82.

This longer than nominal bubble pulse period in itself does not detract from the quality assurance concept, but may be the result of two things. The charges are detonating shallow, or the exploding charges vaporize some of the aluminum of the containers thus increasing the bubble pulse energy. In either event the shot to shot variation in source level is primarily controlled by the bubble pulse period regardless of its cause, assuming detonation of the whole charge. In evaluating the data, since the bubble pulse period is a function of both the effective charge and detonation depth, it seems desirable to improve the data quality by eliminating questionable shots. Since longer than average bubble pulse periods can generally be attributed to shallow detonations and short bubble pulse periods to partial detonation or deep detonation it seems desirable to recommend the deletion of the bottom and top 5% of the distribution shown in Figures (4) and (5). This limits the range of bubble pulse periods from 119 to 130 ms for the 60 foot MK 61s and from 41 to 45 ms for the 300 foot MK 82s. This corresponds to a little over one half the specified depth range tolerance for each of these SUS; such a tight distribution also indicates total detonation. Corrections in spectral level for the observed depth variations are shown in Table 3 of Chapter 3.

A shot list has been furnished to ARL which has become part of their computerized data bank. It is proposed that for each processed shot, that its shot number be compared with that in the data bank to determine if the bubble pulse period falls within the acceptable 90% range, if it does a suitable correction can be found from the computerized table of spectral corrections for the several shot depths and added to the source level. If the shot is outside the 90% range it is recommended that the shot not be processed.

Shot numbers 1933 to 1962 were not recorded and hence could not be evaluated. It is recommended that the processing of these shots be optional. The missing time code or the last ten reels of tape does not seem to materially affect the data quality, except that the quality cannot be proven. Subjective evaluation shows the data to have the same magnitude and the previous good tape speed control lends confidence to the reliability of the measurements obtained from these tapes.

## Processing Results - USNS Bartlett

A total of 118 detonation pressure time curves were processed. This represents about 61% of the data. The large amount of unprocessed data results from two causes besides duds; (1) tape speed errors in excess of 50%, and (2) shots not recorded while a malfunctioning tape recorder was replaced. Table 2 summarizes the above information.

Figures (6) and (7) show cumulative distributions as a function of bubble pulse period and shot depth.

If the top and bottom 5% of the distribution are rejected one finds that the longer bubble pulse periods are nearly identical to those observed from the Bent data but that the bounds of the shorter periods are about 15% less than for the Bent data. In another test only the data from the Visicorder and tape 5 were used; the bubble pulse periods for the MK 82's were offset from the Bent data by several milliseconds although they came from the same lot. Such discrepancies indicate that no positive quality assurance can be derived from the data at hand. It is recommended that array processing of the shots dropped from the Bartlett be optional since no reliable estimate of the quality of the SUS sources are available.

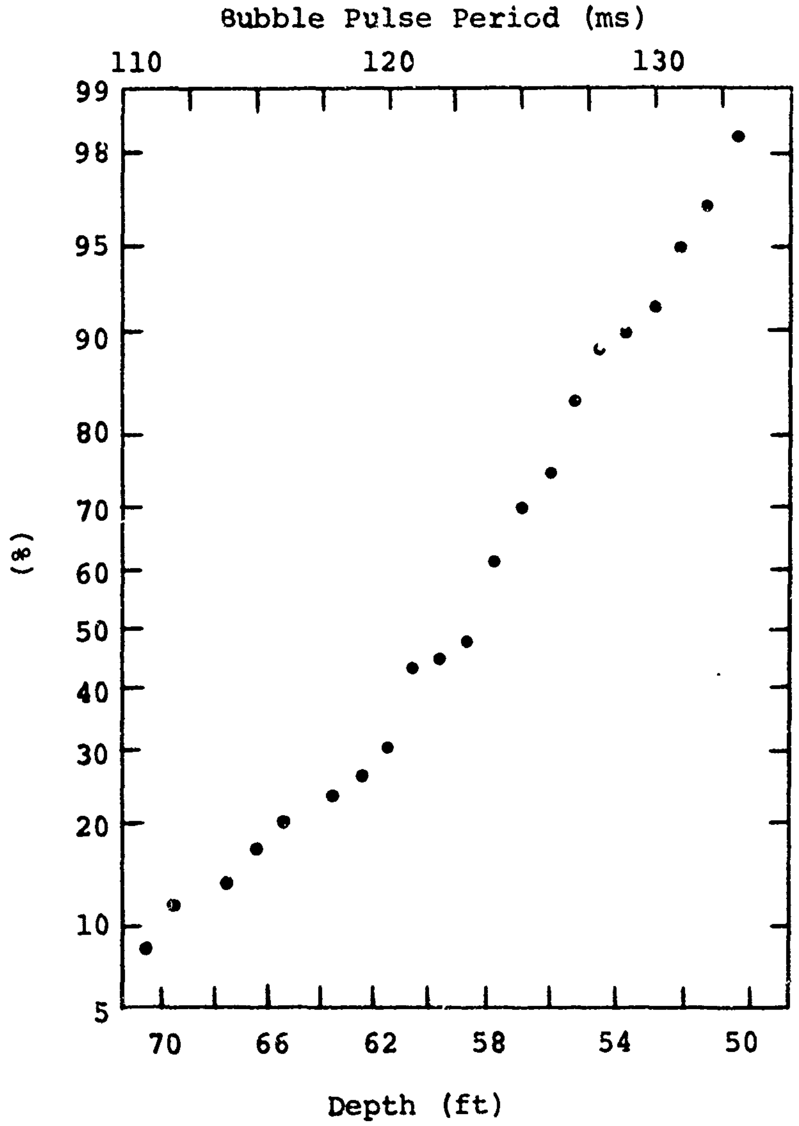

Figure (6). Cumulative distribution of bubble pulse period and derived shot depth from the MK 61 (60 feet) SUS charges dropped by the USNS Bartlett.

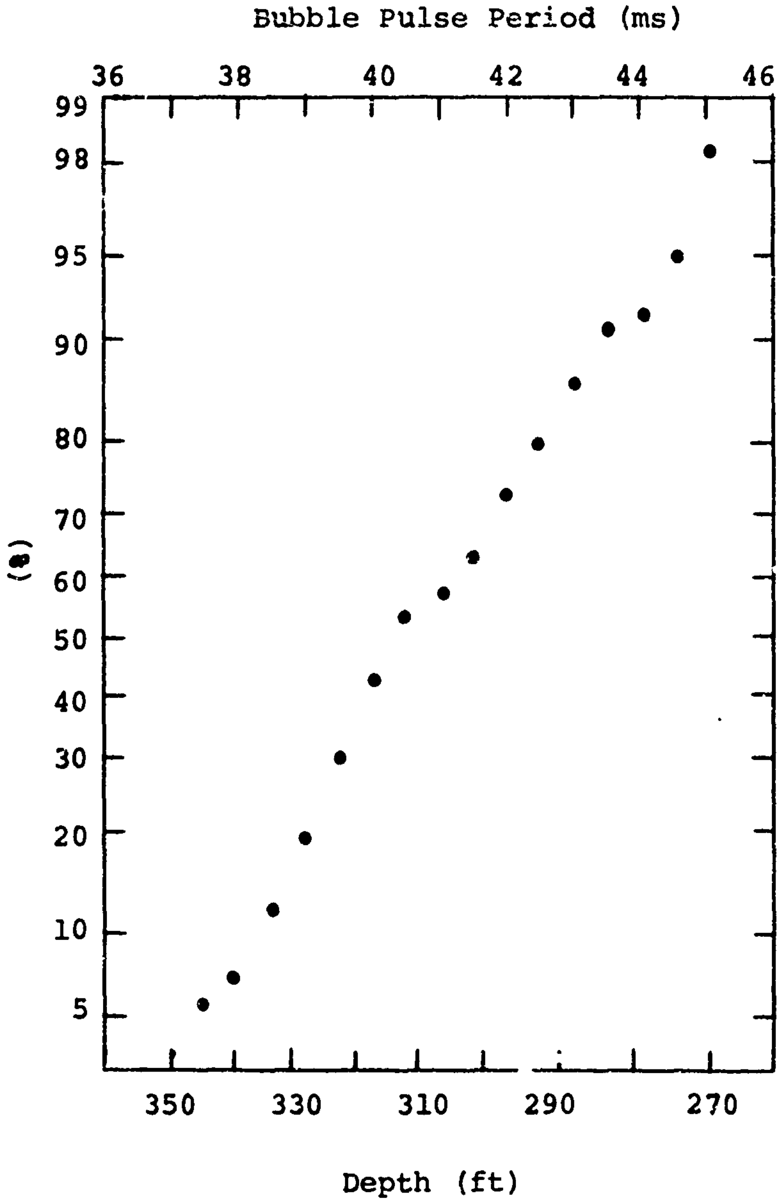

Figure (7).Cumulative distribution of bubble pulse period and derived shot depth for the MK 82 (300 feet) SUS charges dropped by the USNS Bartlett.

## Quality Control

Errors in the determination of the bubble pulse period have two origins, (1) the basic data, and (2) the measurement of the bubble pulse period. The bubble pulse period is defined as the time bounded by the onset of the shock wave from the explosion and the bubble pulse maximum. Tape speed variations on record and playback will affect the measured time. In the present processing scheme the time code carrier was used for controlling the sampling rate and hence the relative change in tape speed variations are removed. The only inaccuracy in this methodology is the deviation of the time code carrier from 1 kHz, which is small since it is derived from a crystal oscillator with a stability of 1 part in $10^{-5}$ per day.

The measurement of the bubble pulse period by automated processing will cause an error which is dependent on how closely each signal matches the anticipated signal for which the computer program was written. A check was made throughout the processing from sample shots, comparing the computer determination to a scientist's determination. The differences between the two different bubble pulse determinations are shown in Figure (8).

The operator monitored each shot for accuracy of bubble pulse period determination. Two rules were used to reject a computer determination.

1. The shock wave onset time was picked more than 3/8 ms ahead of the apparent onset time.

2. The bubble pulse maximum was not picked.

If one of the above conditions existed or the time frame alarm sounded the operator would make a paper record of the shot for post evaluation. If the computer determination was in error, corrections would be made to the bubble pulse period data manually. For the USNS Silas Bent data 15 corrections needed to be made for a total of 1309 processed shots. For the USNS Bartlett data 19 corrections were made for 98 automatically processed shots. This difference in error rate shows that better data quality can greatly improve the error rate in automatic data processing systems.

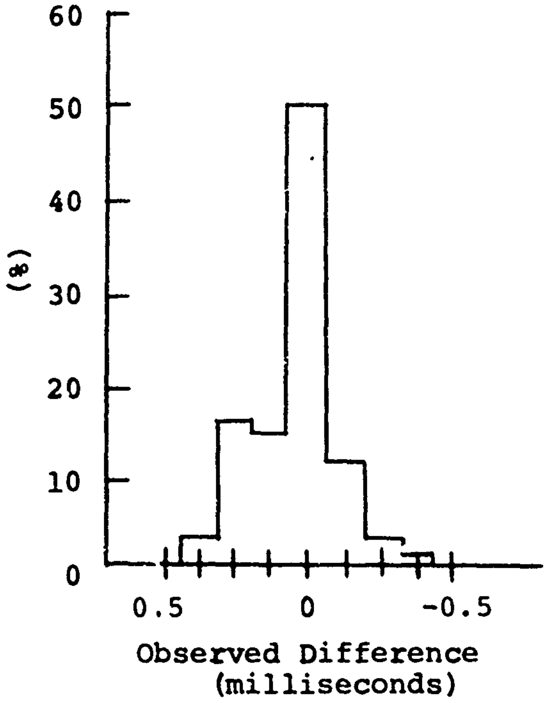

Figure (8). Distribution of differences between computer determined bubble pulse periods and manually determined periods from a sample of 150 determinations.

The Bartlett data shows that a considerable number of the detonations have unreasonably short bubble pulse periods. A probable cause for these short bubble pulse periods cannot be pinpointed, the MK 82s are from the same lot as those used by the Bent. It is doubtful that shipboard handling can make the difference, and the processing was the same as the Bent. Figure (9) shows the calibrated error voltage from the phase lock loop for the 1 kHz time code carrier at the end of tape 3. Although the speed stability is poor in this example, there is no evidence of losing lock as is demonstrated in Figure (10) for comparison.

Since the causes for the Bartlett data not agreeing with the Bent's, and because of the poor quality of the recordings, the quality of the bomb shot data from the Bartlett cannot be assured.

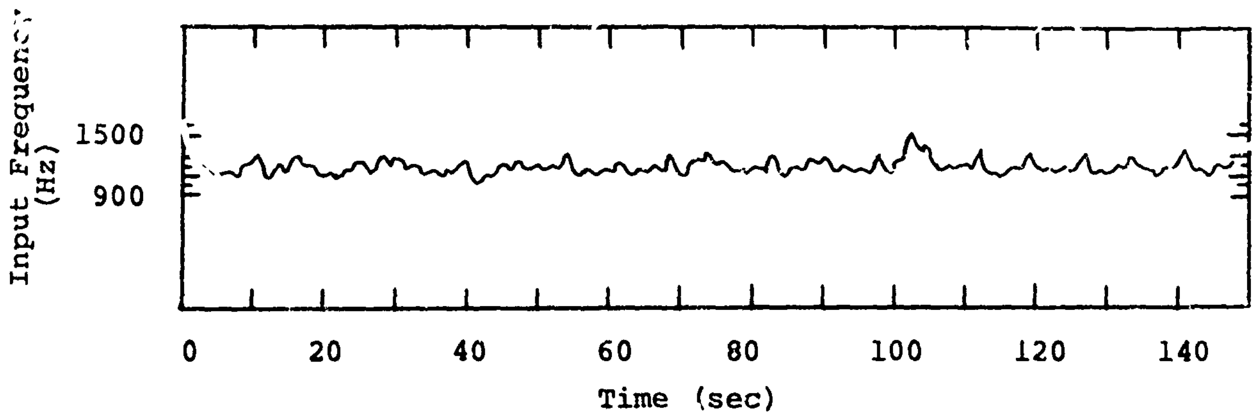

Figure (9). Phase lock loop error voltage as a function of frequency near the end of tape 3.

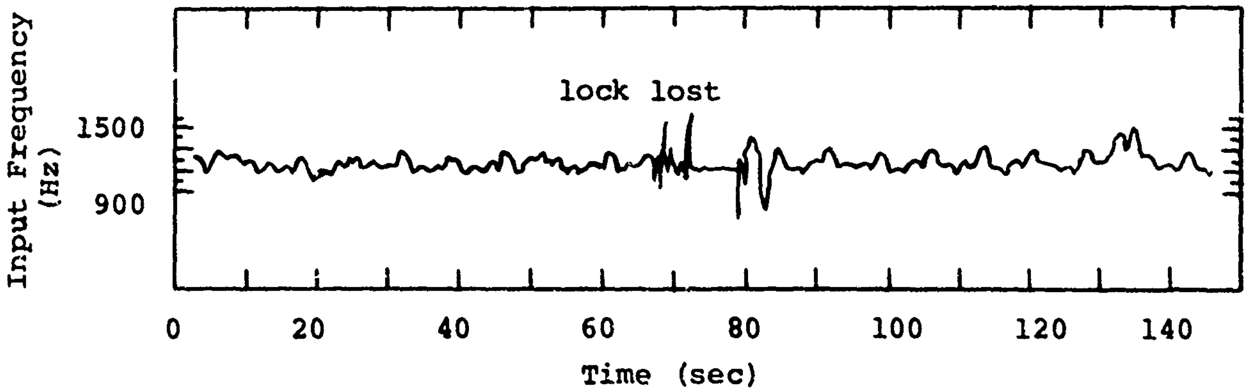

Figure (10). Example of a phase lock loop losing lock causing loss of synchronization.

# CHAPTER 2
# ABSOLUTE SOURCE LEVELS

Because of the extensive use of SUS bombs as explosive sources one would expect that their levels would be well known. Unfortunately this is not the case; equivalent source levels are known to only a few decibels, particularly at the lower frequencies and for the shallower detonation depths. This is due to a number of reasons, discussed below.

## Range Dependent Parameter

Simplified theory, Ref. (1), indicates that the early part of the shock wave can be represented by a decaying exponential, $p = Pe^{-t/\theta}$. The shock wave amplitude (P) decreases with range to the 1.13 power; the time constant ($\theta$) increases with range to the 0.22 power. Fourier analysis of this time function indicates that at very low frequency, $2\pi f << 1/\theta$, the energy contained in the shock wave decreases with range to the 1.82 power. At high frequency, $2\pi f >> 1/\theta$, the energy in the shock wave decreases with range to the 2.26 power.

The concept of an equivalent acoustic source level is based on the assumption that the signals can be treated by considering acoustic spreading loss and absorption. For an acoustic source in free space the energy decreases with range squared. Thus, at the shorter ranges the shock wave energy does not follow acoustic propagation laws. Since the shock wave amplitude decreases with range, it is assumed that a point is reached at which the amplitude is sufficiently low so that signal behaves as an acoustic signal for longer ranges. This introduces the concept of a transition range between shock wave and acoustic propagation laws. The equivalent acoustic source level of the SUS bomb should be determined at the transition range, and extrapolated back to one yard based on acoustic laws. The difficulty is that the transition occurs gradually, and is poorly understood. The concept of a specific transition range is a computational convenience. It has become fairly standard to compute the SUS bomb level at 100 yards, and to extrapolate back to one yard to obtain the equivalent source level. For a 1.8 lb SUS bomb, the shock wave amplitude at 100 yards is approximately 40 psi, hardly low enough for propagation to greater range to follow acoustic laws. As a result, equivalent levels will be too low at the lower frequencies, and too high at the high frequencies. There is a continuous transfer of energy from high to low frequencies as long as the signal follows shock wave laws. The differences resulting from the choice of computational range are by no means insignificant. For example, if the equivalent source levels were computed at 1,000 yards corresponding to a shock wave amplitude of about 4 psi, the low frequency level for the shock wave would be 1.8 db higher, and at the high frequencies it would be 2.6 db lower.

In addition to the shock wave, the bubble pulses contribute significant energy at the low frequencies, and little energy at the high frequencies. Since the bubble pulse propagation is believed to follow acoustic laws, the above cited difference of 1.8 db will be reduced considerably at the low frequencies, but the 2.6 db difference at the high frequencies would still be present.

In summary, if a rigorous procedure for computing the energy in the signal generated by SUS bombs were available, it is likely that the choice of 100 yards for the computation would result in equivalent source levels which tend to be too low at the low frequencies and too high at the high frequencies.

## Experimental Measurements

Approximate analytic functions which describe the major features of the signals generated by SUS bombs have been derived, Ref. (1). These analytic functions can be used to compute the spectra. Secondary effects which are not accounted for, or are poorly approximated by the formulae, result in equivalent acoustic source level errors of a few decibels. An attempt to take these into account using a graphical method based on experimental data is described in Ref. (2).

Mathematical computations are used rather than direct experimental measurement of spectral levels because of the special difficulties encountered in direct measurements, particularly for shallow detonations. The primary problem is that the surface reflection is received prior to decay of the bubble pulse train. For example, for a detonation depth of 60 feet, and a monitoring gage below the charge, the surface reflection arrives 24 milliseconds after the direct receipt of the signal. By contrast, the first bubble pulse arrives approximately 120 milliseconds after the shock wave. The reflected portion of the signal must be removed, or deconvolved, before the true source spectrum can be determined. This is difficult to achieve, because of two reasons. First, since the duration of the shock wave and bubble pulses is very short, milliseconds or less, deviations from a flat ocean surface must be accounted for. Secondly, because the pressures are quite high, and a 180° phase shift occurs at the surface, the reflected signal will produce cavitation. The result is a surface cut-off effect, truncating the shock wave and bubble pulses. As a result, the reflected signal cannot be precisely defined, and therefore, cannot be properly removed from the total signal. Nevertheless, attempts at such measurements have been made and are included in the tables presented later in this report.

It is apparent from the previous discussion of the range dependence of the shock wave, that comparisons between experimental and computed spectra must be undertaken for identical ranges. In past work, different investigations have used different ranges, but a tendancy to reduce levels to 100 yards has emerged in recent years. As noted, this may be too short since the shock wave amplitude for a 1.8 lb charge is still quite high at 100 yards. As a practical matter, increasing the range introduces additional difficulties. As the horizontal separation of charge and receiver is increased, the surface reflection arrives at an earlier time, and refraction effects may have to be considered. Placing the gage at a depth of 3,000 feet requires that the experiment be conducted in deep water with all the problems of control which that entails.

A major problem, frequently overlooked, is the nature of the charge itself. Theoretical analysis assumes a spherical charge, and does not take the charge casing into account. By contrast, SUS bombs are built with a rigid aluminum casing. It is known that the inclusion of aluminum dust in an explosive mixture alters the generated signal. Specifically, the bubble pulse period is increased, and probably its energy content is modified. The energy required to burst the casing may also modify the total radiated energy.

A second major problem with SUS bombs results from the manner in which the bombs are manufactured as determined from Ref. (3) and conversations with Mr. Greenlaw of NAVAIR. The nominal TNT yield is 1.8 lbs, but, additionally there is a nominal 1.1 oz of Tetryl in the booster, and 0.2 oz of Tetryl in the cup. The TNT is poured in three stages: (1) an initial pour to a specified volume, (2) a second pour to top off after the froth settles out from the first pour, (3) a third pour if after cooling the weight of the first two pours is less than 1.7 lbs. Because of this sequence in manufacture, and the weight tolerance, the TNT is layered, and the total yield, in our judgement, is between 1.7 and 1.9 lbs. The quality assurance procedure is based on measuring the first bubble pulse, so that whether variations are due to a variation in yield or detonation depth, the spectral correction will be properly accounted for. Errors in shot depth and absolute level will occur and are tabulated below.

Depth Error
 60 foot depth, ±2 feet
 300 foot depth, ±7 feet
Level Error
 low frequency level, ±.3 db
 high frequency level, ±.2 db

## Absolute Source Levels

Source levels from several different data sources are listed in Tables (3) and (4) for the 1/3 octave bands specified for processing CHURCH ANCHOR data. The differences between the various columns is discussed below.

1. Column (1) from Ref. (2), is a semi-empirical computation based on experimentally recorded pressure time histories for different depths and theoretical considerations. Any surface reflections occurring in the pressure time history of the detonation are removed by hand; the resultant hand drawn curve is digitized and an FFT was used to compute the spectral levels. It differs from the computations of columns (4) to (6) in two significant ways. The negative going portion of the signal is faithfully represented, whereas for columns (4) to (6) the negative going portion is approximated by a constant value rectangular impulse, extending from the shock wave to the last bubble pulse considered in the computation, balancing the positive going impulse. Secondly, the shock wave time constant ($\theta$) used in columns

(5) and (6) is given by Weston. It is known that ($\theta$) is correct only out to about $2\theta$ after which the shock wave decays more slowly. Weston, Ref. (1), notes that an alternative computation of the time constant from the measured impulse yields a value some 40% higher and may give a better representation of the low frequencies. Gaspin and Shuler, Ref. (2), go further, and indicate that the impulse for a 60 foot charge is 80% higher than Weston's value, based on the work of Slifko, Ref. (4). Unfortunately, this is based on an extrapolation, since Slifko worked with detonation depths of 500 feet or greater. The effect of these and other analytic differences is to increase the source level at low frequency and to decrease the level at high frequency for the Gaspin and Shuler computations.

2. Column (2) gives source levels provided by NAVOCEANO in connection with a prior USI program, Ref. (5). The data originated at NUSC from experimental measurements. The measurement range and the extent to which the surface reflection was removed is unknown to us. Column (3) gives a second set of source levels based on unpublished NUSC measurements.

3. Column (4) derived from Ref. (2) is stated to be a recalculation of levels based on the impulse

formula given by Weston, Ref. (1). The exact manner of computation, and whether the parametric values given by Weston were used, or those of Slifko, is not known to us.

4. Column (5) is computed using a modified form of Weston's analysis derived by Weinstein. It is based on a fourier analysis of the pressure time history using the analytic forms given by Weston, and including only the first bubble pulse.

5. Column (6) repeats the computation of column (5) but includes two bubble pulses. A comparison of columns (5) and (6) indicates that the inclusion of the second bubble introduces corrections of only a few tenths of a decibel, except for the 25 Hz band in Table (4).

6. Column (7) was provided to us by Earl Hayes of WHOI, and is based on experimental measurements performed by J. Busch of BTL. The measurements were made with MILS hydrophones at a range of about one n.m. The received signals were FFT processed. The effect of surface reflections was removed by analysis of the spectra.

An examination of these data sets indicates that, in general, the data provided by Busch (BTL) is a lower limit, while the computations by Gaspin & Shuler are an upper limit. Only a few data points lie outside these limits for the remaining data sets. Until the discrepancies between the data sets is resolved the selection of the best source level is reduced to a subjective judgement.

We recommend that whichever set of data is selected, it should be used for processing all LRAPP data, and that all propagation loss reports document the source levels used.

## TABLE 3

Source Level in 1/3 Octave Bands
1/8 lbs at 60 foot detonation depth
db re: 1 erg/cm$^2$/Hs at 100 yards

| Center Frequency (Hz) | Band Levels several data sources 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| 25 | 20.0 | - | 12.3 | 17.9 | 16.0 | 16.3 | 12.4 |
| 35 | - | 21.6 | - | - | - | - | - |
| 50 | 14.9 | - | 9.4 | 15.9 | 14.7 | 15.1 | 13.0 |
| 65 | - | 15.5 | - | - | - | - | - |
| 100 | 13.7 | 12.4 | 7.7 | 16.2 | 14.1 | 14.4 | 8.0 |
| 160 | 10.3 | - | 6.3 | 12.7 | 12.1 | 12.2 | 5.6 |
| 200 | - | 9.4 | - | - | - | - | - |
| 250 | 8.6 | - | 5.1 | 11.0 | 10.1 | 10.2 | 5.7 |
| 360 | - | 5.9 | - | - | - | - | - |

Data Sources

1. Gaspin & Shuler, Ref. (2)
2. NAVOCEANO & NUSC, reported in Ref. (5)
3. Unpublished NUSC Data
4. Weston, Ref. (1), as recomputed by Gaspin & Shuler, Ref. (2)
5. Weinstein, fourier transform of Weston parameters, one bubble pulse
6. Weinstein, fourier transform of Weston parameters, two bubble pulse
7. J. Busch, BTL

## TABLE 4

### Source Level in 1/3 Octave Bands
### 1.8 lbs at 300 foot detonation depth
### db re: 1 erg/cm$^2$/Hz at 100 yards

| Center Frequency (Hz) | Band Levels several data sources | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 25 | 20.7 | - | 18.7 | - | 16.1 | 18.1 | 15.8 |
| 50 | 15.7 | - | 13.2 | - | 15.1 | 15.3 | 11.8 |
| 100 | 13.3 | - | 10.2 | - | 13.3 | 13.8 | 8.7 |
| 160 | 11.5 | - | 8.5 | - | 12.1 | 12.1 | 6.7 |
| 250 | 9.1 | - | 6.9 | - | 10.1 | 10.2 | 5.0 |

Data Sources

1. Gaspin & Shuler, Ref. (2)
3. Unpublished NUSC Data
5. Weinstein, fourier transform of Weston parameters, one bubble pulse
6. Weinstein, fourier transform of Weston parameters, two bubble pulse
7. J. Busch, BTL

# CHAPTER 3

# FLUCTUATIONS IN SOURCE LEVELS

The preceding chapter was concerned with predicting the source levels for nominal yields of 1.8 lbs detonated at depths of 60 and 300 feet. In this chapter we will be concerned with the changes in source level which occur as a result of small deviations from these nominal values. Fluctuations in the received signal level can be ascribed to the following causes.

1. Changes in the bubble pulse periods due to either a variation of shot depth or yield will alter the shape of the source spectrum. The variation in source level in fixed bands is determined by the relationship of peaks and nulls in the spectrum relative to the measurement band. By measurement of the first bubble pulse period primary effects are identified.

2. A variation in yield will also change the total available energy. This was treated in the preceding chapter in which narrow error bands were established.

3. When the variation in bubble pulse period is due to a variation in yield, the computed detonation depth, based on the formula given below for a nominal yield of 1.8 lbs, will introduce a small error. This was also treated in the preceding chapter.

$$T = \frac{4.36(W^{1/3})}{(Z + 33)^{5/6}}$$

where: T = first bubble pulse period

W = yield (pounds of TNT)

Z = detonation depth (feet)

4. Variations in shot depth will also cause a variation in received signal level resulting from changes in the propagation loss, entirely apart from any changes which may occur in source levels. This effect will not be treated in this report.

The remainder of this chapter is devoted to an examination of the variation in source level due to item (1) above.

The goal of quality assurance for the SUS bomb data is to ensure that source level fluctuations do not exceed ±1 db. This is achieved in the following fashion.

1. Reject all SUS bomb shots which fall in the lower and upper 5% of the shot depth distribution so that the range of depths which need to be considered is small.

2. Apply spectral corrections in 1/2 db steps for the acceptable SUS bombs.

Although there are large differences between the spectral levels derived from the different computational procedures, the shape of the spectra are similar. Since the absolute levels are not rigorously correct, it follows that the detailed spectral shape will not be correctly given by any of the computational procedures. To establish corrected spectral levels we have compared the corrections derived from the computational models used for columns (1) and (6) of Tables (3) and (4). The corrections to be applied for the range of accepted shot depths is given in Table (5).

## Details of Comparison

Ref. (2) tabulates spectral corrections for a nominal shot depth of 60 feet, but not for 300 feet. To compute the correction at 300 feet the plotted spectrum was digitized and integrated after applying a spectral shift factor determined from the ratio of the bubble pulse period at 300 feet to that for other depths. To check the accuracy of this first order approximation the method was also applied for selected frequencies and detonation depths about a nominal depth of 60. A comparison of the corrections given in Ref. (2), the corrections computed from the curves published in Ref. (2), and the corrections computed with the analytic formula, are shown in Tables (6) and (7). The corrections listed in Table (5) agree with these results to within ±0.5 db.

## TABLE 5

Spectral Correction for square 1/3 octave bands. Corrections in db to be added to the nominal levels for 1.8 lbs detonated at 60 or 300 feet

| Detonation Depth | Center Frequency 25 | 50 | 100 | 160 | 250 |
|---|---|---|---|---|---|
| 54 | -0.5 | +1.0 | 0 | 0 | 0 |
| 56 | -0.5 | +1.0 | 0 | 0 | 0 |
| 58 | 0 | +0.5 | 0 | 0 | 0 |
| 60 | 0 | 0 | 0 | 0 | 0 |
| 280 | 0 | -1.0 | 0 | -1.0 | +1.0 |
| 290 | 0 | -0.5 | 0 | -0.5 | +0.5 |
| 300 | 0 | 0 | 0 | 0 | 0 |
| 310 | 0 | 0 | 0 | 0 | +0.5 |
| 320 | 0 | 0 | 0 | 0 | +1.0 |

TABLE 6

Comparison of Computed Spectral
Corrections, square 1/3 octave bands,
1.8 lbs, nominal depth 60 feet

| Depth | 25 Hz | | | 50 Hz | | | 100 Hz | | | 160 Hz | | | 250 Hz | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1a | 1b | 5 | 1a | 1b | 5 | 1a | 1b | 5 | 1a | 1b | 5 | 1a | 1b | 5 |
| 50 | -0.5 | -0.9 | -0.8 | +2.2 | +1.7 | +0.5 | -0.2 | - | +0.1 | +0.7 | - | +0.3 | +0.4 | - | 0 |
| 52 | - | - | -0.9 | - | - | +1.0 | - | - | -0.2 | - | - | +0.4 | - | - | -0.2 |
| 54 | - | - | -1.0 | - | - | +1.2 | - | - | -0.2 | - | - | 0 | - | - | 0 |
| 55 | 0 | -0.2 | - | +1.1 | +1.2 | - | -0.3 | - | - | +0.4 | - | - | +0.2 | - | - |
| 56 | - | - | -0.8 | - | - | +1.1 | - | - | -0.2 | - | - | - | +0.3 | - | 0 |
| 58 | - | - | -0.4 | - | - | +0.6 | - | - | -0.1 | - | - | +0.5 | - | - | -0.2 |
| 60 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Notes: (1a) From Tables in Ref. (2)

(1b) Computed from spectra published in Ref. (2)

(5) Analytic formulation derived from Ref. (1)

TABLE 7

Comparison of Computed Spectral
Corrections, square 1/3 octave
bands 1.8 lbs, nominal depth 300 feet

| Depth | 25 Hz | | 50 Hz | | 100 Hz | | 160 Hz | | 250 Hz | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1b | 5 | 1b | 5 | 1b | 5 | 1b | 5 | 1b | 5 |
| 270 | - | -0.3 | - | -1.2 | - | -0.3 | - | +0.2 | - | +0.2 |
| 280 | +0.5 | -0.1 | -1.2 | -0.8 | -0.1 | -0.1 | -1.3 | -.6 | +.6 | +1.0 |
| 290 | - | 0 | - | -0.3 | - | -0.1 | - | -.6 | - | +0.6 |
| 300 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | - | 0 |
| 310 | - | -0.1 | - | 0 | - | +0.2 | - | +0.6 | - | +0.6 |
| 320 | -0.4 | -0.2 | +0.3 | -0.1 | +0.1 | +0.2 | -0.1 | +0.7 | +0.9 | +1.1 |
| 330 | 0 | -0.4 | - | -0.4 | - | +0.2 | - | 0 | - | +0.6 |

Notes: (1b) Computed from spectra published in Ref. (2)

(5) Analytic formulation derived from Ref. (1)

## References

1. D. E. Weston, "Underwater Explosions as Acoustic Sources", Proceedings of the Physical Society, Vol. LXXVI, P. 233, 1960.

2. Joel B. Gaspin and Verna K. Shuler, "Source Levels of Shallow Underwater Explosions", NOLTR 71-160, 13 October 1971, Naval Ordnance Laboratory.

3. "Manual of Test Procedures for Signal Underwater Sound (SUS)", STF-TP-102, 12 October 1970, VAST, Inc.

4. J. P. Slifko, "Pressure Pulse Characteristics of Deep Explosions as Functions of Depth and Range", NOLTR 67-87, 21 September 1967, Naval Ordnance Laboratory.

5. "Reduction of Bomb Shot Data to Propagation Loss", May 11, 1970, Contract No. N62306-70-C-0142, Underwater Systems, Inc., CONFIDENTIAL.

DEPARTMENT OF DEFENSE
UNITED STATES OF AMERICA

**DEPARTMENT OF THE NAVY**
OFFICE OF NAVAL RESEARCH
875 NORTH RANDOLPH STREET
SUITE 1425
ARLINGTON VA 22203-1995

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|---|---|---|---|---|---|---|
| WHOI73-59 | Tollios, C. D. | THE ACODAC DATA PROCESSING SYSTEM | Woods Hole Oceanographic Institution | 730901 | AD0773114; ND | U |
| Unavailable | Russell, J. J. | DOCUMENTATION FOR COMPUTER PROGRAM SUMMARY: A COMPUTER PROGRAM TO SUMMARIZE SOUND SPEED PROFILE DATA | Naval Undersea Center | 731001 | AD0918907 | U |
| MC001Vol2 | Unavailable | CHURCH ANCHOR DATA ANALYSIS PLAN VOL 2 (U) | Maury Center for Ocean Science | 731001 | ND | U |
| 73-9M7-VERAY-R2 | Jones, C. H. | LRAPP VERTICAL ARRAY- PHASE III | Westinghouse Research Laboratories | 731105 | ADA001130; ND | U |
| 55 | Weinstein, M. S., et al. | SUS QUALITY ASSESSMENT | Underwater Systems, Inc. | 731201 | ND<br>AD785875 | U |
| ARL-TM-73-42 | Mitchell, S. K., et al. | QUALITY CONTROL ANALYSIS OF SUS PROCESSING FROM ACODAC DATA | University of Texas, Applied Research Laboratories | 731220 | ND<br>ADB000293 | U |
| Unavailable | Daubin, S. C. | CHURCH GABBRO TECHNICAL NOTE: CONTINUOUS CURRENT PROFILES | University of Miami, Rosenstiel School of Marine and Atmospheric Science | 740101 | AD0775333 | U |
| Unavailable | Bitterman, D. S. | ACODAC AMBIENT NOISE SYSTEM | Woods Hole Oceanographic Institution | 740101 | ADA009440 | U |
| ONR MC-002 VOL. 2; XONICS 885 | Unavailable | LONG RANGE ACOUSTIC PROPAGATION PROJECT (LRAPP). SQUARE DEAL DATA ANALYSIS PLAN (U) VOLUME 2 - ANNEXES | Maury Center for Ocean Science; Xonics, Inc. | 740101 | ND | U |
| ARL-TM-74-12 | Groman, R. O., et al. | SPECIAL HARDWARE FOR ARL ANALYSIS OF ACODAC DATA | University of Texas, Applied Research Laboratories | 740314 | ADA000295; ND | U |
| Unavailable | Unavailable | ASEPS NEAR FIELD TRANSMISSION LOSS MODIFICATION, P-2205 | Ocean Data Systems, Inc. | 740401 | ADA096583 | U |
| Report 001; MSAG-1 | Unavailable | MEASUREMENT SYSTEMS ADVISORY GROUP | Office of Naval Research | 740401 | ADA096586; ND | U |
| ACR-196 | Gregory, J. B. | PROJECT PACIFIC SEA SPIDER, TECHNOLOGY USED IN DEVELOPING A DEEP-OCEAN ULTRASTABLE PLATFORM | Office of Naval Research | 740412 | AD0529945; ND | U |
| Unavailable | Gottwald, J. T. | ANNUAL REPORT FOR 1 MAY 1973 - 30 APRIL 1974 | Tracor, Inc. | 740524 | AD0920210 | U |
| Unavailable | Unavailable | ACOUSTIC MODEL SUPPORT ACTIVITIES, P-2220 | Ocean Data Systems, Inc. | 740530 | ADA096584 | U |
| HCI-CMC-18540 | Daubin, S. C. | TRANSMISSION LOSS OF LOW FREQUENCY UNDERWATER SOUND IN THE CAYMAN TROUGH (CHURCH GABBRO TECHNICAL NOTE) | University of Miami, Rosenstiel School of Marine and Atmospheric Science | 740601 | ADC000424; ND | U |
| HCI-CMC-18343 | Daubin, S. C. | AMBIENT NOISE IN THE NORTHWEST CARIBBEAN SEA (CHURCH GABBRO TECHNICAL NOTE) (U) | University of Miami, Rosenstiel School of Marine and Atmospheric Science | 740601 | ND | U |
| Unavailable | Barnes, A., et al. | DISCRETE SHIPPING MODEL | Planning Systems, Inc. | 740604 | ND | U |