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SECTION III

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UNDERWATER PRESSURE TIME MEASUREMENTS

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(12) Iv.

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Report On

PRESSURE-TIME MEASUREMENTS

TESTS ABLE AND BAKER

This report was written by M. GREENFIELD, A. HIRSCH and B. STILLER of the David Taylor Model Basin staff. They designed the equipment described in the report and participated in Tests Able and Baker.

A. BORDEN, E. T. HABIB, D. EISENSTEIN and R. GAMOW, all of the David Taylor Model Basin, participated and assisted in the preparatory phases of the work at the Model Basin. Dr. A. BORDEN designed the diaphragm pressure gage used in Test Able.

The mine case units and ball bearing swivels used in both tests were designed and procured by K. WILCOXEN.

Information concerning hydrogen gas evolution from storage batteries and methods for eliminating explosion hazards were obtained from Dr. J. C. WHITE of the Naval Research Laboratory.

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DIGEST

Pressure-time measurements were made of the underwater pressure waves generated in Tests Able and Baker.

No records permitting analysis were obtained in Test Able because the explosion occurred some distance from the intended targets and pressures at the gage location were far below those for which the instrument had been set.

In Test Baker three pressure-time records were obtained. Because of poor response characteristics of the recording channels, the records obtained do not truly represent the pressure-time history of the shock wave. However, values for the real peak pressures and durations have been derived from the records and are discussed in the report.

A summary of the general features of the pressure records obtained are as follows:

The peak pressure at 2400 feet from the explosion center and at the bottom of the lagoon was approximately 1200 pounds per square inch. This is indicated by the piezoelectric gage record of 1320 ± 170 psi and the ball crusher measurement of 1080 psi. The duration pulse was approximately 4 milliseconds. A gage at a point 50 feet above the bottom and 2400 feet from the bomb indicated that it required about 8 milliseconds for the pressure to drop to zero.

At 3000 feet from the bomb and 50 feet from the bottom, the peak pressure was approximately 500 ± 80 psi. The duration was approximately 3 milliseconds. At this radial distance but at the bottom of the lagoon, the ball crusher gage gives a pressure of 375 psi.

The gage 2400 feet from the bomb and at the bottom also recorded a second pressure pulse approximately equal to the first in amplitude but with a much shorter duration. A third pressure pulse occurred 65 milliseconds after the first pulse. Its highest peak gave a pressure of approximately 590 psi.

All the records indicate that a slowly rising pressure was propagated in the water ahead of the shock wave, but a quantitative measure of it cannot be made from these records. This slowly rising pressure may be caused by the ground shock wave which is propagated faster than the water shock wave.

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A. General Description of Instrument Arrangement.

The function of this section of the Bureau of Ships Instrumentation Group was to obtain pressure-time measurements of underwater pressures resulting from Tests Able and Baker. It was desired to measure the variation of pressure with depth as close as possible to the explosion centers. To obtain the pressure variation with depth, it was decided to place gages near the bottom and to suspend others by floats 50 feet above the bottom of the lagoon. In order to place the gages and recording channels close to the explosions, four instrument containers, in the form of steel barrels, were designed to rest on the lagoon bottom 160 feet below the water surface. A general picture of the container and rigging is given in Figure 1. Due to practical limitations on the size of the instrument containers, it was decided that only two electronic channels and gage pickups could be used with each container. Although the actual pickups and recording channels for Test Able were quite different from those used for Test Baker, the space requirements were similar enough to allow the use of the same containers. Only slight alterations in the internal mounts were necessary to convert the barrels for use in Test Baker.

For Test Able the use of piezoelectric gages for pressure measurements was not feasible due to the long duration of the predicted shock wave - viz., in the order of tenths of a second. In order to obtain an adequate time constant for these gages, a very large capacitance would have been required, which would have made the normal size tourmaline-crystal gage extremely insensitive. Therefore a strain-wire gage was designed. This detector consists of a wire strain-gage element cemented to a diaphragm. The signal passed through an amplifier and was then recorded by a pen-and-ink recorder. Because of the long duration of the water pressures in Test Able, it was possible to supplement the diaphragm gages with mechanical gages. DeJuhasz pressure gages modified to fit limited space requirements were included. A detailed description of this apparatus will be found in Section C.

Naval Ordnance Laboratory ball crusher gages (14)* were mounted on the containers and used in both Tests Able and Baker. It was hoped that pressures thus obtained could be used as a check on the peak pressures obtained from the other instruments. This comparison will be found in Section D of this report.

* Numbers in parentheses indicated references on Pages 22 and 23.

It was estimated that in Test Baker, the duration of the pressure pulse at a distance of 1000 yards would be of the order of magnitude of a millisecond. This would ordinarily call for the use of a standard piezoelectric-gage pickup used with a standard electronic cathode-ray oscillograph and a recording camera. The weakest link in this channel was the cathode-ray oscillograph. No circuit was available that would insure that the beam would be properly centered at the right moment, nor was there time to design and build such a circuit. It was decided to retain the piezoelectric pickup and to select a recorder which would not have the above described difficulty. A magnetic wire recorder was chosen to substitute for the cathode-ray oscillograph and camera. This instrument is described in detail in Section C. Its chief weakness lay in its poor low frequency response characteristics. It was decided, however, to depend on analysis to interpret the record in terms of response characteristics of the magnetic-wire recorder. An analysis of this type, for the records obtained, is given in Section D of this report.

These recording channels with their power supplies were placed in the four instrument containers. Since each barrel was limited to two recording channels, it was possible to use only two external pressure pickups with each container; one attached to the container, and one suspended by means of a small float 60 feet off the bottom. In Test Able the mechanical DeJuhasz gage was attached to the outside of the container.

For purposes of remote control of the instruments, a radio receiver was mounted on a surface raft anchored to the instrument container. A wire was run from the radio receiver to the container instruments to provide electrical connection.

In order to recover the containers after each shot, a location buoy, designed to rise to the surface after a set time, was attached to the handling cables of each container. Figure 1 gives a general picture of the container and rigging. A detailed description is included in Section B.

B. Detailed Description of Instrument Container and Rigging.

The instrument housings (1) used in Tests Able and Baker were large steel cylinders rolled from 1" HTS plate. Rings cut from 2 1/4" M.S. plate were welded to each end of the cylinders to act as flanges for the mounting of the two removable covers which were also of 2 1/4" M.S. Six 2 1/4" steel stiffeners (see a, Photograph 208) were welded to each cover to provide strength. The covers were fastened to the flanges by means of 18 evenly spaced 1" steel bolts. Two I-beams, six feet long, were welded to the cylinder to provide a base (see Photograph 208 and Figure 1 for container details).

The total weight of the container was approximately 7400 lbs., the internal volume approximately 32 cubic feet. Using the data from tensile tests of the 1" HTS, and the fact that the cylinders were not more than 1/3" out of round. computations indicated the containers would withstand an external static pressure of approximately 2300 psi before yielding.

The instruments were mounted on individual plate-type Lord shock mounts on shelves in a removable frame. This cylindrical framework, shown in Photographs 209 and 210 and Figure 2, was placed in the container and attached to one end by means of heavy tube-type Lord mounts (see a and b, Photograph 211 and Figure 2). A tight packing of 3/4" sponge rubber served to shock mount the other end (see a, Photograph 212). A partition composed of a 1/4" and a 1/2" steel plate, separated by a 3/4" layer of felt, was placed between the motor generator and the electronic instruments, for electric shielding (see c, Photograph 209).

In order to allow passage of gage and control cables into the cylinder, four openings were drilled and tapped to accommodate washers and followers for a modified Bridgman-type packing gland (3), (4). Two additional holes were made to act as outlets for flushing the container with CO_2 gas. This will be discussed later in this section.

For Test Able two of the holes passed the cables leading to the diaphragm gages, one the power cable for the DeJuhasz gage mounted on the side of the cylinder and one the radio control cable. In Test Baker the DeJuhasz gage was not used and the lead hole was sealed off. For placement detail of holes see Photograph 213.

In order to provide a mount for gage attachment and an anchor for the floating gage, a 4-foot length of angle iron was placed along the top of the barrel and bolted to each flange (see a, Photograph 213). This angle iron also served as a mount for the terminal connecting box of the radio link wire described later in this section.

The gage suspended 50 feet above the bottom was securely tied to the anchor wire about 10 feet below a small wooden float. Electrical connection of the gage with the recording channel was accomplished by use of a copper conductor cable. This cable was fastened at intervals to the float anchor wire. On reaching the cylinder the copper cable was bent into a loop before entering the gland. This prevented strain at the seal (see d, Photograph 214) due to sideways motion of the float.

The gage at the lower level was mounted on the angle iron. For Test Able, brackets were welded to the angle iron and the diaphragm gages were securely bolted to them. For Test Baker the piezoelectric pickup was mounted on a piece of 3/4'' sponge rubber and lashed to the iron with sensitive element pointing upward (see e, Photograph 219). A short length of 1/8'' copper-conductor cable passing through a gland served as an electrical connection between the gage and the recording channel in the container.

The radio link rafts were anchored to the cylinders by means of a length of steel-wire cable shackled into a hole in the container-head stiffener (see a, Photograph 214 and a, Photograph 215). Rafts made up of six standard 5'x5'x7' Navy pontoons (Photograph 216) served as radio-link floats during Test Able. The rafts used in Test Baker were not alike, two being Navy telephone buoys (see Photograph 217), another a small wooden barge (Photograph 218), and the remaining one a pontoon raft that had been recovered after Test Able.

Electrical connection between the radio receiver on the raft and instruments of the underwater containers was accomplished by means of multi-conductor armored cable (see a, Photograph 219). This cable was fastened securely at 5' - 6' intervals along the entire length of the anchoring steel cable. Small loops were made in the conductor cable between each binding to allow the steel wire to absorb all the stresses due to raft motion. At the cylinder, the armored cable passed through a standard packing gland (see c, Photograph 219) into a standard Navy electrical terminal box. This box (see b, Photograph 219) was securely bolted to the angle iron. In the box the armor cable was spliced to a 3/8'' multi-conductor copper cable (see a, Photograph 220) which on leaving the terminal box entered the cylinder through a gland (see e and f, Photograph 214). The terminal box was sealed and filled with beeswax in order to protect the soldered joint from water and stresses.

The rigging for handling the heads and the whole container was standard. In order to handle the container heads, each weighin approximately one ton, it was necessary to drill holes in the stiffeners (see b, Photograph 214). These holes were located approximately in the vertical plane containing the center of mass of the head. By using these holes when lifting the head, the inner face remained perpendicular to the ground. The entire cylinder was lifted by means of a bridle (Photograph 215). The bridle shackled onto the container through two holes drilled in the stiffeners of each of the two heads (see c, Photograph 214). The ring of the bridle (see b, Photograph 215) was attached to a specially constructed swivel (5) (see c, Photograph 215). The purpose of the swivel was to allow the lowering cable to rotate freely without causing the container to rotate and entangle the gage wire. A length of 3/4" steel cable shackled to the swivel served to raise or lower the container.

In view of the high pressures expected, special attention was given to the methods of sealing the instrument container. All entering conductors were pressure tested. The wax-filled coaxial copper-tube conductors were subjected to a hydrostatic pressure of 1000 psi at one end. It was found that there was no appreciable water leakage through a 1-foot length.

To insure a good seal of the container, the opposing faces of the heads and flanges were carefully machined and matched. A strip of 3/8" diameter neoprene was cemented into a V-shaped groove (c, Photograph 211) machined into the face of the flange. This seal was found to hold against an internal pressure of 100 psi.

It was feared that the shock wave produced by the blast of both Able and Baker Tests, on striking the bare steel shell of the cylinders, would cause them to vibrate at a high frequency. This ringing would be in the range of the resonant frequencies of vacuum tube elements of electronic equipment inside the container. Distortion of the recording might have resulted. To prevent this, a thick pitch material (Pitch Mastik) was procured and when in a molten condition plastered over the entire cylinder surface to a thickness of at least one inch.

From tests it was found that the H_2 gas evolution of the batteries to be used inside the container was approximately 360 cc per hour, evolving a 3% explosive mixture in about 50 hours. It was feared that, since it would be necessary to keep the container sealed for many days before the test, an explosive mixture would be built up inside the container. Sparks generated by the electrical equipment on starting would ignite the H_2 and cause an explosion. Standard #2 CO_2 cylinders were procured and fittings made so that the containers could be thoroughly flushed after sealing, insuring an internal atmosphere of CO_2. Another flushing was given before reopening to minimize the possibility of explosion.

C. Recording Channels, Power Supplies, and Control Circuits.

Recording Channels - Test Able

The pressure sensitive element used in Test Able was a metal diaphragm gage with a wire strain-gage element cemented to the diaphragm as a detector, Figure 3. A gage element identical with the sensitive one was mounted on an insensitive part of the gage body. The two resistance gages in the body and two others mounted in an amplifier formed an a-c bridge circuit. The location of an insensitive arm of the bridge in the gage body increased the stability of zero voltage balance in the bridge circuit by compensating for temperature changes in both arms of the bridge. When the diaphragm was deformed by pressure, the bridge circuit became unbalanced and the unbalance in voltage was applied to an amplifier. The gage was connected to the recording channels by means of a soft copper cable having a coaxial conductor and a wax filling.

The amplifier (a, Photograph 210) changed input voltage into a current output which was fed into a Brush magnetic galvanometer (b, Photograph 210). The motion of the galvanometer coil was recorded on a moving strip of paper by a pen, using ink. The time scale was obtained by having the paper in the recorder driven by a synchronous motor.

In addition to the electronic method of measuring the pressure in the water from Test Able, a completely independent mechanical system was attached to each cylinder, Figure 1. This consisted of a commerical pressure gage made by DeJuhasz, which recorded the motion of a spring-backed piston as the pressure in the water acted on the piston. The motion was recorded on a strip of waxed paper, which rotated on a drum driven by a synchronous motor. The assembly is shown in Figure 4.

Recording Channels - Test Baker

The pressure sensitive element used in Test Baker was of the piezoelectric type. It consisted of four tourmaline crystals, each cut into a thin disk and plated on each face. They were then sweated together with solder (8). Their polarities were arranged so as to give an addition of their charges. This gave four times the sensitivity of a single crystal having the same area (9). The element was mounted on a soft copper cable which had a coaxial conductor and a wax filling. This cable was designed to eliminate spurious cable signals generated by pressure on ordinary cables. The assembly was dipped repeatedly into molten Zophar Mills wax (8) until a 1/8'' coating was built up all around the gage. Rubber tape was wrapped around the point where the wax ended on the copper cable. Several coats of Tygon were then applied over the wax coating. The leakage resistance of a completed gage (Figure 4 and d, Photograph 219) was of the order of 1000 megohms. This type of pickup was used because its natural frequency was over 10^6 cycles which enabled it to follow faithfully the transient nature of the expected shock wave.

To record the change in voltage generated by the piezoelectric gage during the explosion, its output was fed into a Brush magnetic-wire recorder, type 12016 (d and e, Photograph 209 and b, Photograph 212). The wire-recorder amplifier had an input impedance of 0.5 megohms at 1000 cycles. Multiplying this by the loading capacitance of 0.05 μ fds. on the gage, gave a time constant of 25 milliseconds. This enabled recording of shock waves having durations up to 5 milliseconds with a maximum of 10 per cent error due to leakage (11). After amplification, the signal passed into a wire recorder which consisted of a small induction coil, through which ran a fine stainless-steel wire at an average speed of 150 feet per minute. The variation in voltage from the gage was thus impressed upon the wire as a variation in intensity of magnetization.

Power Supply - Tests Able and Baker

In order to operate the recording equipment, a source of 110-volt 60-cycle alternating current, able to provide power of approximately 250 watts for Test Able and 100 watts for Test Baker, was required. For this purpose small motor-generator sets were procured (a, Photograph 221). These sets were rated at 110-volt 60-cycles, 450 watt output,32-volt DC input. Tests on several converters showed a variation of about ± 10% in output voltages and frequencies with constant input voltage. Frequency variations could not be adjusted due to lack of a speed governor.

The 32-volt direct current was supplied by storage batteries. In order to supply the 250 watts required for Test Able, it was necessary to install heavy-duty batteries. Two Navy R-17-B-6665 12-volt

Aerobatic spill-proof batteries with a cur draw rating of 68 amperes were used to supplement eight of the sm. l-type batteries described below.

It was feared that the underwater turbulence resulting from Test Baker might roll the cylinders over. Because of this, it was necessary to procure batteries that could vent and not spill acid in an inverted position. For this purpose a Navy Type 19029, 40-4 battery was chosen. This is a small, plastic, sealed battery with a standpipe-type vent, supplying 4 folts with a 5-hour draw rating of 40 amperes. Shelf life tests made on fully charged batteries showed no appreciable drop in power after standing at an average temperature of 86°F. and 65 - 70% relative humidity, for 10 days. Eight batteries were connected in series to the motor generator by means of banana-plug connectors. The batteries were set snugly into shelves bolted to the shock mounted frame (b, Photograph 221).

A test was run to determine the life of the 40-4 batteries under load, and the motor-generator output under test conditions. It was found that after six hours of continuous operation the motor-generator set was delivering 70% of its original valtage and the frequency had decreased 19% (see Figure 6).

Control Circuits

Owing to the inaccessibility of the barrels and their proximity to the explosions, it was necessary to use remote radio linkages for control. This led to the use of radio receivers placed on rafts floating on the surface of the water (a, Photograph 216). Each receiver was connected by a multi-conductor cable (a, Photograph 219) to a relay panel inside the cylinder containing the apparatus (c, Photograph 212 and f Photograph 209).

The transmission of a sequence of timing signals was to be provided by and be the responsibility of another technical group. All radio receivers were tuned to receive these signals. The operation was essentially the same for both tests and on Baker will be described. The first signal, which was received 30 minutes before the explosion time, was used to turn on the motor generators and amplifiers. This signal closed a non-locking relay in the receiver which in turn provided a short across terminal I in the relay panel (Figure 7). Relay A, a non-locking type, then closed sending 32 volts DC through terminal II to the motor generator which provided 110 volts AC to the magnetic wire-recorder amplifiers and to terminals III and IV.

The second signal received came 20 seconds prior to the explosion and started the recording instruments. The signal provided closure across terminal V in Figure 7. Locking-type relays B and C were then closed. Closure at B locked the 32-volt DC circuit shut and also sent 110 volts AC into the motors driving the wire magazines. Closure at C started a small motor turning in relay D. After a one minute run, this motor closed the switch in relay D which activated the unlocking coils in relay E. Opening of the switches in relay E cut the 32-volt DC circuit, stopping the motor generator, and also broke the 110-volt AC circuit to the magnetic-wire recorder motors. This cycle of operation made the apparatus sensitive to pressures occurring in the water during the period from 20 seconds before to 40 seconds after the explosion. A block wiring diagram of the equipment for Test Baker is given in Figure 8.

D. Analysis of Data.

Data and Results from Test Able

The instrumentation was located as follows:

Eight diaphragm gages were distributed by pairs on four containers placed on a circle of 150 yards radius about the NEVADA. One gage of each pair was five feet from the bottom of the lagoon, while the other gage was about 50 feet up from the bottom. The containers were located on four radii making angles of 45° with the fore and aft centerline of the NEVADA as shown in Figure 9.

Four DeJuhasz mechanical pressure gages were distributed, one on each barrel as shown in Figure 1; the gage was so located on the barrel that the pressure sensitive end was about 2 1/2 feet from the bottom of the lagoon.

Twenty ball crusher gages were distributed, five on each barrel, and so located that they were about five feet above the bottom of the lagoon.

No data were obtained from the eight strain wire gages because the explosion occurred some distance from the intended target. The instrument containers were approximately 425, 525, 800, and 825 yards from a point directly below the estimated position of the bomb burst. At these distances pressures ranging from about 100 psi to 20 psi might have been expected at the various gages. The sensitivity of the gages had been set so that a pressure of 1000 psi, as expected at 150 yards, would have produced a pen deflection of about 20 millimeters. The width of the ink on the recording paper was about one millimeter, corresponding to about 50 psi at the chosen sensitivity. The only two gages that might have produced a readable record were those on Barrel No. 1 at 425 yards. Unfortunately, the radio receiver did not function for that barrel.

A wax paper record was recovered from each of the DeJuhasz mechanical pressure gages. Again, the pressure was too small to allow interpretation of the peak reached or of the time history of the pressure pulse.

The deflections obtained on the ball crusher gages from Barrels

No. 2, 3, and 4 were too scattered and small to permit reliable estimates of the dynamic pressure from them. Practically the entire deflection for each gage was due to the static pressure head. The readings from gages on Barrel No. 1 are unreliable because this barrel was dropped about 100 feet to the bottom of the lagoon during the recovery operation.

Data and Results from Test Baker

Location of Gages

The four instrument containers were located at various radial distances from the bomb as indicated in Figure 9. Each container recorded pressures from two piezoelectric gages, one about five feet from the bottom of the lagoon and the other 50 feet up from the bottom.

Eight ball crusher gages were distributed, two on each container. The gages were located on the top of the container which put them about five feet above the bottom of the lagoon.

Analytical Procedure

Before analysis of the records was possible, it was necessary to transcribe the magnetic wire recordings into a visible record. The output from the wire recorder, in the playback position, was fed into the vertical axis amplifier of a cathode ray oscillograph. With no input to the horizontal axis amplifier, the spot moved in the vertical direction only. To obtain the time history of the record, a General Radio high speed camera was focused on the oscillograph screen and the film was run by parallel to the horizontal axis of the screen. Thus, while the spot on the screen moved up and down in accordance with the wire recorder output, the film moved by horizontally at a constant speed. The records obtained appear in Figure 10. The velocity of the film was obtained from a series of 60-cycle per second timing marks along the edge of the film.

Three pressure-time records were obtained. Two of these were recorded by gages that were 2400 feet from the center of the explosion. Of these, one was five feet, while the other was 50 feet from the bottom. The third record was obtained from a gage that was 3000 feet from the center of the explosion and 50 feet from the bottom. Each of these records will be discussed separately and in detail.

Peak Pressures

The peak pressures were calculated from the peak amplitudes of the pressure records and from the sine wave voltage calculations. In order to check the validity of this procedure, the response to a sine wave of a given voltage was compared with that to a DC step pulse of the same voltage. A small discrepancy was observed, and has been corrected for in the peak pressure calculations. To check the amplitude stability of the wire recorder, the output for a sine wave input of constant amplitude was observed. The amplitude was found to vary as much as 30%. In addition, when a given record was played back a number of times, the output amplitude would vary up to 10%. To obtain the value of the peak pressure as accurately as possible, the amplitude of the calibrating sine wave was averaged over several seconds and each pressure record was played back and recorded several times. The pressures obtained with Gages 3A and 4B are recorded in Table 1A. Unfortunately no sine wave voltage calibration was obtained for record 3B, so that its peak pressure could not be calculated. The error in peak pressure values is estimated to be ± 15%.

For the ball crusher gages the pressure was calculated by the formula:

$$P = (3.19 \times 10^4)\ X$$

where P is the peak pressure in pounds per square inch and X is the deformation of the copper balls in inches (14). Copper balls 5/32" in diameter were used. The values of the pressures obtained are listed in Table 1B. These values have also been corrected for an initial deformation due to the static head of water.

Peak pressure measurements by ball crusher gages were also made by the Bureau of Ordnance Group at various depths and distances from the explosion (13). The Bureau of Ordnance measurements for comparable locations are included in Table 1B.

Pressure Time History

The major source of error in the records is due to the poor low frequency response characteristics of the magnetic wire recorder, and in order to understand the nature of the distortion of the pressure pulses, it is necessary to consider the response characteristics of the amplifiers. Curves (a) and (b) of Figure 11 show the typical respone of a magnetic wire recorder when the input is, respectively, a positive or a negative DC step pulse. It is to be noted that the response A(t) of the amplifiers to these pulses is dependent on the sign of the input pulse. Also, this response is characteristic of a system possessing poor low frequency transmissibility. From Figure 11, it may be seen that the response curve is characterized by a slow initial rise followed by a fast rise. For simplicity in the analysis, it will be assumed that the response goes instantaneously to its peak value and the portion of the response curve before the peak is reached will be neglected. This method is not strictly correct and certain errors are introduced. In Figure 17, record 4B is compared with two computed curves based on identical inputs. Curve (b) was calculated on the basis of the above mentioned simplification and curve (c) was calculated without neglecting the slow initial rise. Since the rise begins approximately 1 1/2 milliseconds before the peak of the response curve, the peak for curve (c) will occur 1 1/2 milliseconds after the peak of curve (b). For purposes of comparison the time scale for curve (c) has been displaced so as to make the peaks coincide. The comparison of curves (b) and (c) shows that a slightly better fit to the actual record is obtained with the refined method. However, the lack of stability and consequent errors in the instrument are far greater than any errors introduced by the simplified analysis.

The procedure that will be used to determine the shape of the pressure-time pulse acting on the gage will be a process of assuming an input, calculating the response of the amplifier to this input based on its response to a step pulse, and fitting this calculated response to the actual pressure record. Of necessity this shape will be approximate and to facilitate the calculations it will be represented by rectangular steps of various magnitudes and durations. It may be assumed, for example, that the pressure-time pulse is a simple rectangular step of some definite duration. Then the response of the recorder to this input will be calculated graphically. This calculated response will be compared with the actual record. If the two curves are nearly the same, then it will be assumed that the input chosen is a good approximation to the actual pressure-time pulse. If the calculated response doesn't compare with the actual record, the assumed input will be altered until one is obtained that does lead to a proper response.

From the response of the amplifier to positive and negative step pulse, one may obtain the response of the system to a rectangular step.

A rectangular step may be considered as the superposition of two steps, opposite in sign but having the same amplitude, and infinite duration. If the second step of amplitude -1, starts at a time t_0 after the first step of amplitude +1, then the resultant is a rectangular step whose amplitude is 1 and whose duration is t_0. For the time interval $0 \leq t \leq t_0$, the response of the amplifier to the rectangular step is the same as the response to the positive step pulse of infinite duration, $A_+(t)$, curve (a), Figure 11. The general response for $t \leq t_0$ is

$$R(t) = A(t) - A_-(t-t_0)$$

Since a negative step was introduced at $t = t_0$, to complete the rectangular step, the response $A_-(t-t_0)$ should be read off the amplifier response curve corresponding to the negative step pulse, curve (b) Figure 11. Thus the response to a rectangular pulse is the difference in ordinates of the two response curves taken at the times indicated. It is evident that this method may be extended to find the response of the amplifier to a series of positive and negative pulses.

The shapes of the inputs which approximate the observed pressure records will be calculated by a series of approximations based on this method. Each input will have the appearance of a number of superimposed steps, each step beginning at a different time. The shape of the input is varied until an $R(t)$ is obtained which gives the best approximation of the record. Then the assumed input may be considered to approximate the actual pressure pulse which acted on the piezoelectric gage. It should be noted that this method only gives an indication of the shape and duration of the input.

In order to compare the actual record with the computed response to the assumed shape of input, it is necessary to plot the two curves on a common scale. All curves used in this analysis are plotted on the basis of a peak amplitude equal to unity.

The record shown in (a) of Figure 10 was recorded by gage and recorder 3A which were on the bottom of the lagoon, at a distance of 2400 feet from the explosion center. The gross characteristics are three pressure pulses. The second pulse has almost the same amplitude as the first and occurs some 22 milliseconds later. The third pulse has a much reduced amplitude and occurs about 65 milliseconds after the first.

Figure 12 shows the shape of the input for record 3A obtained by the method described above. This approximated the pressure pulse in the water. The calculated response of the amplifier to this input is compared with the actual pressure record in Figure 13.

The record obtained from Channel 3B is shown in curve (a) of Figure 14. The gage was 2400 feet from the bomb and 50 feet from the bottom. Figure 15 shows the response of amplifier 3B to positive and negative step pulses. The graphical technique described above was used again to determine the nature of the input that would produce the pressure record. Figure 16 shows the calculated input obtained in this manner. Curve (b) of Figure 14 shows the calculated response of the amplifier to this input. The inferred input indicated that the pressure drops rapidly in the first millisecond and then rises to approximately 1/3 the initial value for another five milliseconds.

Upon recovery, Barrel No. 4 was found to be flooded. Its amplifiers were ruined and only one wire magazine was salvaged. This produced record 4B from a gage 50 feet off the bottom of the lagoon and 3000 feet from the explosion center. The record from this magazine had to be played back on the amplifiers from Barrel No. 3. In order to check on possible distortionof the record when played back on a different amplifier from the one used in recording it, record 4B was played back on both amplifiers 3A and 3B.

The graphical technique described above was applied to a playback of record 4B on each of the two good amplifiers. Curve (a) of Figure 17 shows record 4B when played back on amplifier 3A. Application of the graphical technique gave the input shown in Figure 18. The calculated response of amplifier 3A to this input is compared with the pressure record in Figure 17.

Record 4B appears as Curve (a) in Figure 19 when played back on amplifier 3B. The graphical analysis produced the input shown in Figure 20. The calculated response of amplifier 3B to this input is compared with the pressure record in Figure 19.

A comparison of Figures 18 and 20 indicates that the playing back of record 4B on amplifiers other than the one used in recording does not introduce a significant distortion. The time history of each calculated input is very similar and the duration is approximately the same. The pressure decreases gradually to zero in approximately three milliseconds.

Examination of the records in Figure 10 indicates a slow rise in pressure preceding the shock wave front. A similar rise is found in the amplifier response curves to step pulses. However, the latter is of shorter duration and amplitude than the former. Therefore, it can be qualitatively said that a slowly rising, low pressure wave is propagated ahead of the shock wave in the water. This low pressure is probably due to the ground wave propagated in the bottom of the lagoon at a faster velocity than the shock wave in the water. Because of the overlapping of the amplifier defect on this part of the record, no quantitative measurements have been made on the ground wave effect.

Dr. Penney has derived a theoretical expression for the duration of the positive portion of the pressure pulse as a function of the gage depth and the peak pressure (12). This formula is:

$$T = 1.4 \times 10^{-3}\ GP^{1/2} \text{ milliseconds}$$

Where G is the gage depth in feet and P is the peak pressure in pounds per square inch, the gage at 2400 feet and at a depth of 180 feet recorded a peak pressure of 1320 psi. The formula gives eight milliseconds as the duration for this case. The indicated duration from this gage was about four milliseconds. The second gage at 2400 feet and at a depth of 130 feet indicated a duration of eight milliseconds. However, no value for the peak pressure was obtained at this location; and therefore, no comparable duration based on the formula can be calculated. The third gage at 3000 feet and at a depth of approximately 130 feet indicated a peak pressure of about 590 psi. The formula gives four milliseconds as the duration for this case. The indicated duration deduced from this record was about three milliseconds.

As was noted above, record 3A (shown in (a) Figure 10) has a second and third pressure pulse appearing at 22 and 65 milliseconds respectively after the first pulse. Dr. Penney has suggested that these later shocks may be due to the presence of the bottom and water surfaces at Bikini (11). These two surfaces acted as reflectors and set up an interference pattern. If two reflected waves should arrive in phase and reinforce each other, then secondary pulses might be produced. A graphical construction was made to determine whether such constructive interference would take place. It was assumed that the water was 180 feet deep, that the bomb was located 90 feet from the surface, that the gage was 2400 feet from the bomb and at the bottom. These are the circumstances for the gage that produced record 3A. The result of the graphical analysis was that a reinforcement of two reflected waves should take place approximately 17 milliseconds after the initial pulse. This was in fair agreement with the record which has a 22 millisecond interval between the first and second pulses.

APPENDIX

Methods and Operations in Planting and Recovery of Cylinders.

For recovery of the containers after the tests, two systems were devised; (a) the mine case (Photograph 222), and (b) the floating marker buoy (b, Photograph 216).

The principle involved in method (a) was to have a marker which would rest on the bottom during the test, filled with water so as not to be affected by the blast. After the explosion it would rise to the surface carrying with it recovery lines for the container. To accomplish this, four ordinary Mark IV mine cases were fitted with cover plates (c, Photograph 223), and watertight gaskets, valves and anchoring eyes. Gas units were built to fit into the mine cases. These units were cylinders containing a timing mechanism, mercury fulminate percussion cap and a quantity of lithium hydride (a, Photograph 223). At the time of lowering the equipment, the timing mechanism was set and sealed into the watertight cylinder. The cylinder was placed inside the mine case which was then filled with water, sealed and attached to a length of 1/4" steel cable. This cable was to act as a buoy anchor and recovery line for the 3/4" steel cable attached to the instrument container. The mine case was then lowered to the bottom where it remained for the set time interval. It was hoped that the case would rise after the blast when the timer would short an electrical circuit igniting the persussion cap. This would break the seal and release the lithium hydride into the water causing a large volume of gas to be generated. The two valves were placed one on each end of the case (a, Photograph 222), and so constructed as to open only in an inverted position, i.e., when it was hanging downward underneath the mine case. With this arrangement only water would be forced out by internal pressure.

As an alternate scheme, in case of failure of method (a), the floating marker buoy was used on Test Baker. These marker buoys were six feet lengths of 12" x 12" wood beams. A heavy ring bolt was securely fastened to the beam center and the whole log painted bright yellow. One end of a length of 1/4" steel cable was shackled into the ring bolt, the other end attached to the mine case. This cable served as a means for lowering the mine case and as a recovery line in the event of failure of the mine case to rise.

Prior to the planting of the cylinders, all cables were flaked in the standard Navy fashion (Photograph 224). Each container was equipped with a complete set of cables described in Section A. A coat of yellow chromate paint was placed on each container both for protection against rust and for underwater visibility in the event that diving would be required for recovery. After sealing the barrels a tank of CO_2 was emptied into each at atmospheric pressure, to remove as much O_2 as possible.

Two types of ships were used in the planting operations, a net tender (AN) and a salvage tug (ARS - Photograph 225). Of the two, the ARS proved to be the most successful due to the versatility of its boom as compared with the stationary bow horn of the AN. Therefore only operations with the ARS will be described.

The containers, complete with accessory cable and other gear, were placed on the fantail of the ARS (Photograph 208) below the stern boom. While the ARS was proceeding to station and obtaining a position fix, a mine case timer was set and sealed, and the gas unit set in position (Photograph 223). The case was then filled with water and the case cover securely fastened. The cables were then placed in position on the deck, lashings cut and the planting operation began. The boom hook was inserted in the bridle ring of the barrel which was lifted over the side (Photograph 215), and lowered into the water till the ring was just at the surface. The 50-foot gage pickup and a small wooden float were held well forward toward the ship's bow (d, Photograph 215). The radio-link armored cable and radio-raft anchor line were kept well to the stern. The 3/4" steel cable was given several turns around a steam winch directly below the boom and the end passed through an eye in the ship's rail directly above the ring. The swivel on the ring was then shackled to the 3/4" cable and the slack taken up by the winch. The boom hook was then removed, the strain being taken by the 3/4" steel lowering cable. The winch was then reversed and the container slowly lowered, all lines being carefully payed out as the operation progressed. When the 60 feet of airplane cable to which the small wooden float was attached had reached its end, a 200-foot length of bunk lashing was attached to the float and that was payed out. This was done to prevent the float from becoming entangled in any of the other cables. When the cylinder reached bottom, this line was cast off. Care was also taken in letting out the slack in the 3/4" line so as to drop it at the time when the drift was away from the cylinder so that it should not fall back on the body of the cylinder and foul the floating gage. On reaching the end of the 3/4" steel cable the length of 1/4" steel cable was attached and lowered. The mine case was lifted by the boom and held over the side in approximately the same relative position as the container. When the end of the line was reached, it was shackled to a ring in the mine case. The length of 1/4" cable was then attached to the other ring of the mine case and secured to a bit near the rail (Photograph 222). The mine case was then lowered by the boom until the strain was taken up by the 1/4" cable. The boom hook was then removed and the mine case lowered by hand until it reached the bottom. The remainder of the cable was quickly let out. Its end was attached to a marker buoy which was then thrown overboard. The radio float was then moored to the end of the radio-link cable and the electrical connection lashed to the receiver frame. The position was carefully recorded, Figure 9, and the ship proceeded to the next station.

Recovery after the tests was essentially the reverse of the process just described. On locating the marker buoy or mine case, the objects were lifted aboard and discarded, the attached cable secured to a line on the steam winch which pulled until the bridle ring again appeared on the surface. The boom hook was lowered to engage the bridle ring and the 3/4" cable was removed. The container was then brought aboard by means of the boom. The sealed holes were opened and a tank of CO_2 emptied into the container. The instrument container was returned to the laboratory ship for opening and removal of the records.

During the recovery operations, radiologists kept a constant check on the intensity of radioactive contamination of all recovered objects. Thus the group was kept informed as to the exposures received daily by each member due to his participation in the operations.

All of the containers were recovered after Test Able but only two of the four instruments containers were recovered after Test Baker. The remaining two could not be located because of the breaking of recovery lines during the blast. Diving operations were carried out for several days in the vicinity, but bottom conditions had changed violently so that it is assumed that the containers No. 1 and No. 2 were buried.

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2. Blueprints A-11634-7 (4 sheets) - Cylindrical Container Instrument Chassis, DTMB, 8 March 1946.

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12. Reasons for Expecting the Peak Pressure in Baker to Fall Off with Radius Faster than R^{-1} and Origin of Second Higher Peaks, by Dr. W. G. Penney.

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14. Report of Ball Crusher Gages Used in Tests Able and Baker, Bureau of Ships Instrumentation Group.

TABLE 1A

Playback of Record and Pressures Obtained

Record	Amplifier	Pressure psi
3A	3A	1360
3A	3A	1400
3A	3A	1210
		1320 (Average)
4B	3B	523
4B	3B	560
4B	3A	600
4B	3A	660
4B	3A	630
		590 (Average)

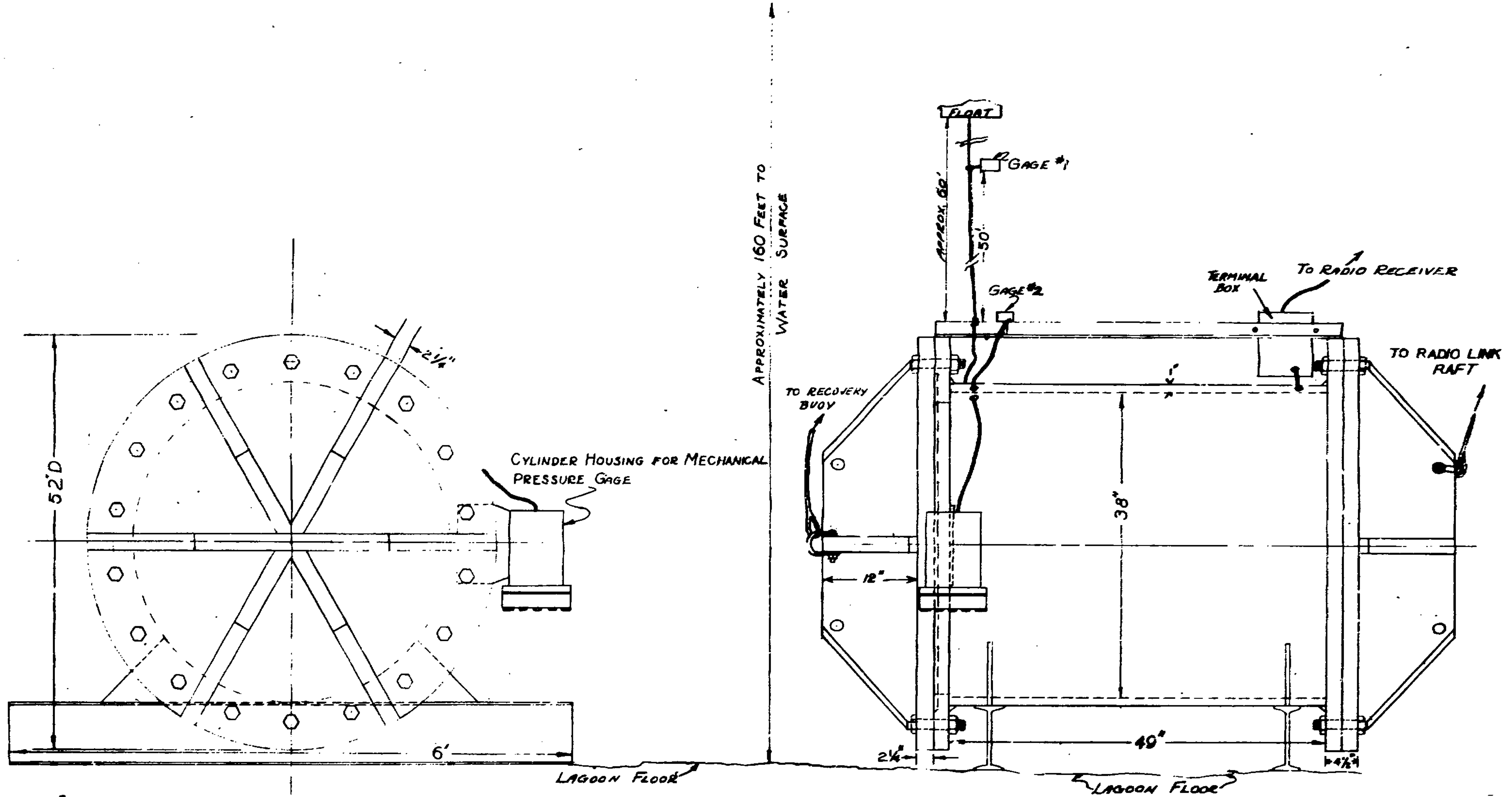
TOP SECRET

TABLE 1B

Peak Pressure Comparisons

Radial Distance from Explosion Center	Position	Peak Pressure Ball Crusher	Peak Pressure Piezoelectric
2060 ft.	Mid depth	1400 psi*	
2400 ft.	Bottom	1080 psi	1320 ± 170 psi
3000 ft.	Bottom	375 psi	
3000 ft.	50 ft. off Bottom		590 ± 80 psi
3040 ft.	Mid depth	800 psi*	

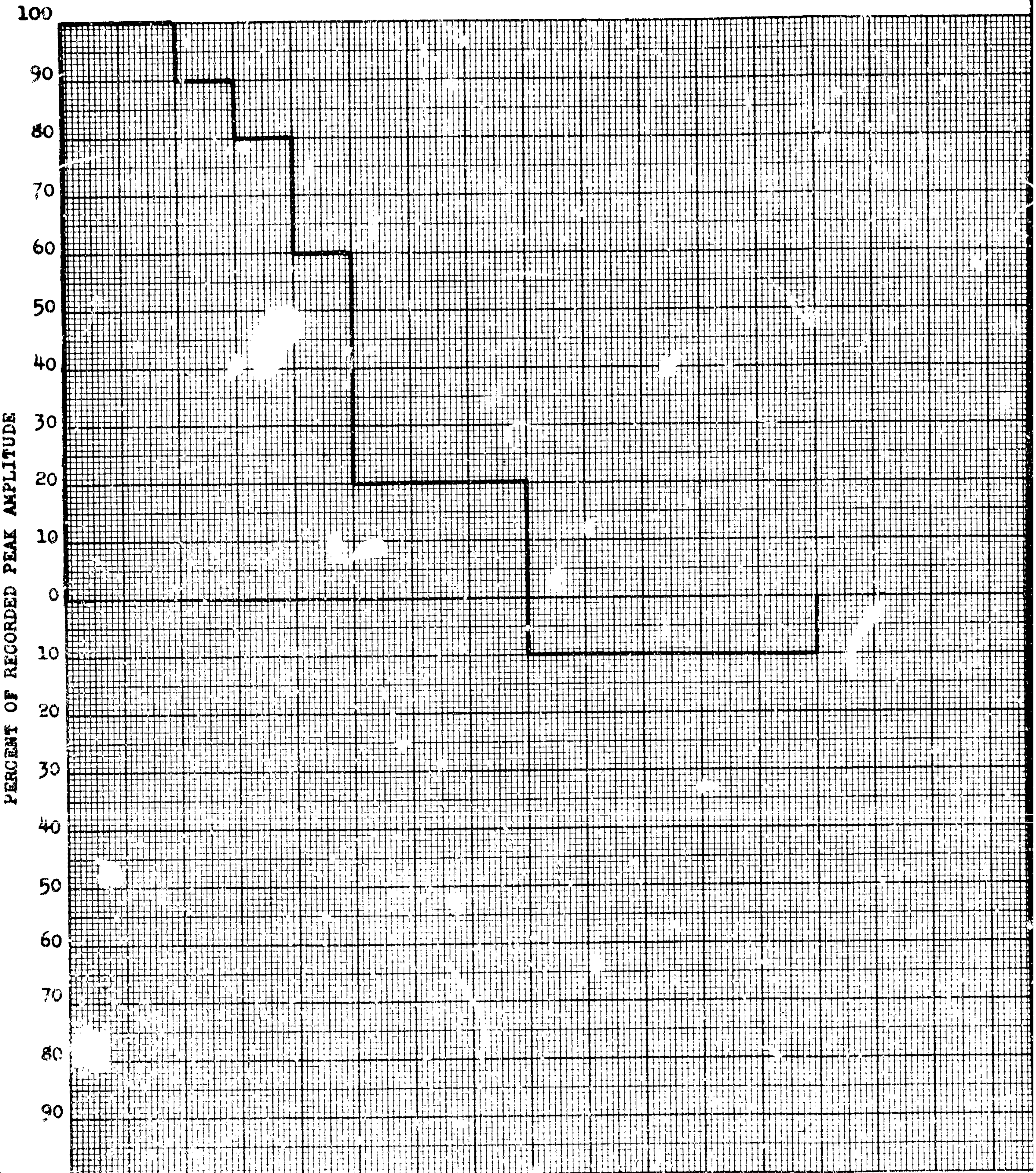
* Data obtained from NOL Report (13).



GENERAL ARRANGEMENT OF APPARATUS FOR UNDERWATER TIME-PRESSURE MEASUREMENTS

FIGURE 1

2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TIME IN MILLISECONDS

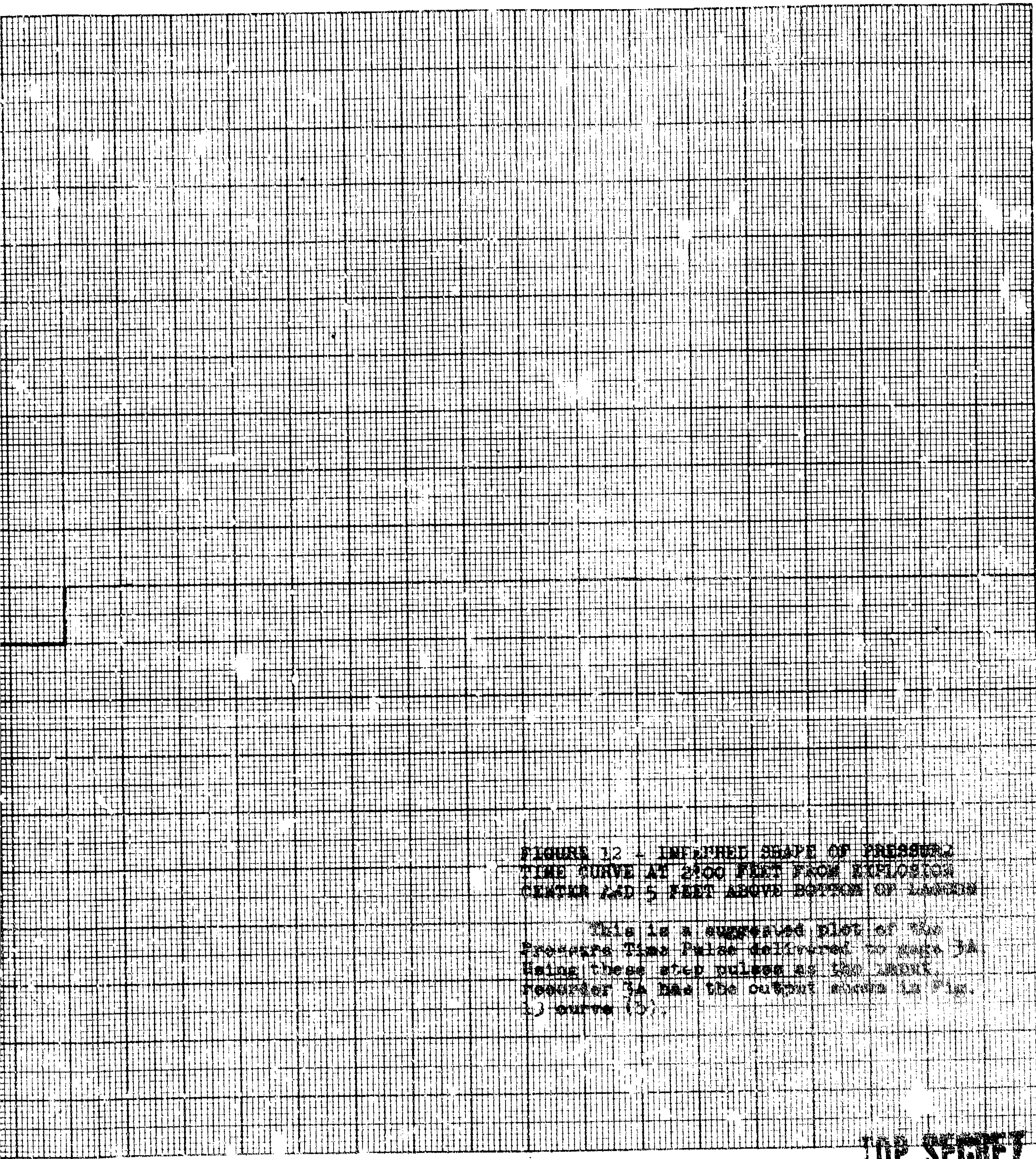
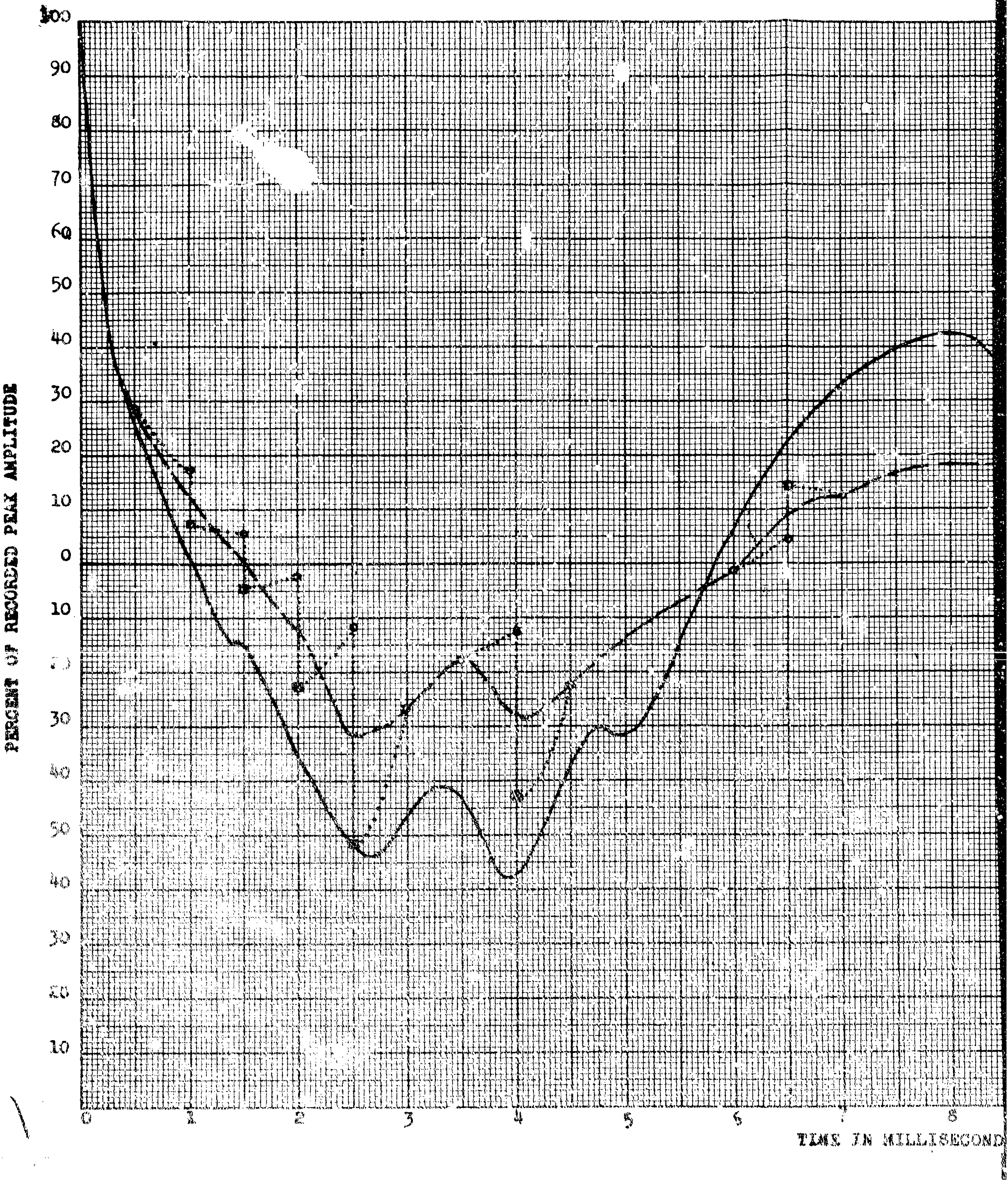


FIGURE 12 - INFERRED SHAPE OF PRESSURE TIME CURVE AT 2400 FEET FROM EXPLOSION CENTER AND 5 FEET ABOVE BOTTOM OF LAGOON

This is a suggested plot of the Pressure Time Pulse delivered to gage 3A. Using these step pulses as the input, recorder 3A has the output shown in Fig. 13 curve (3).



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PERCENT OF RECORDED PEAK AMPLITUDE
TIME IN MILLISECONDS

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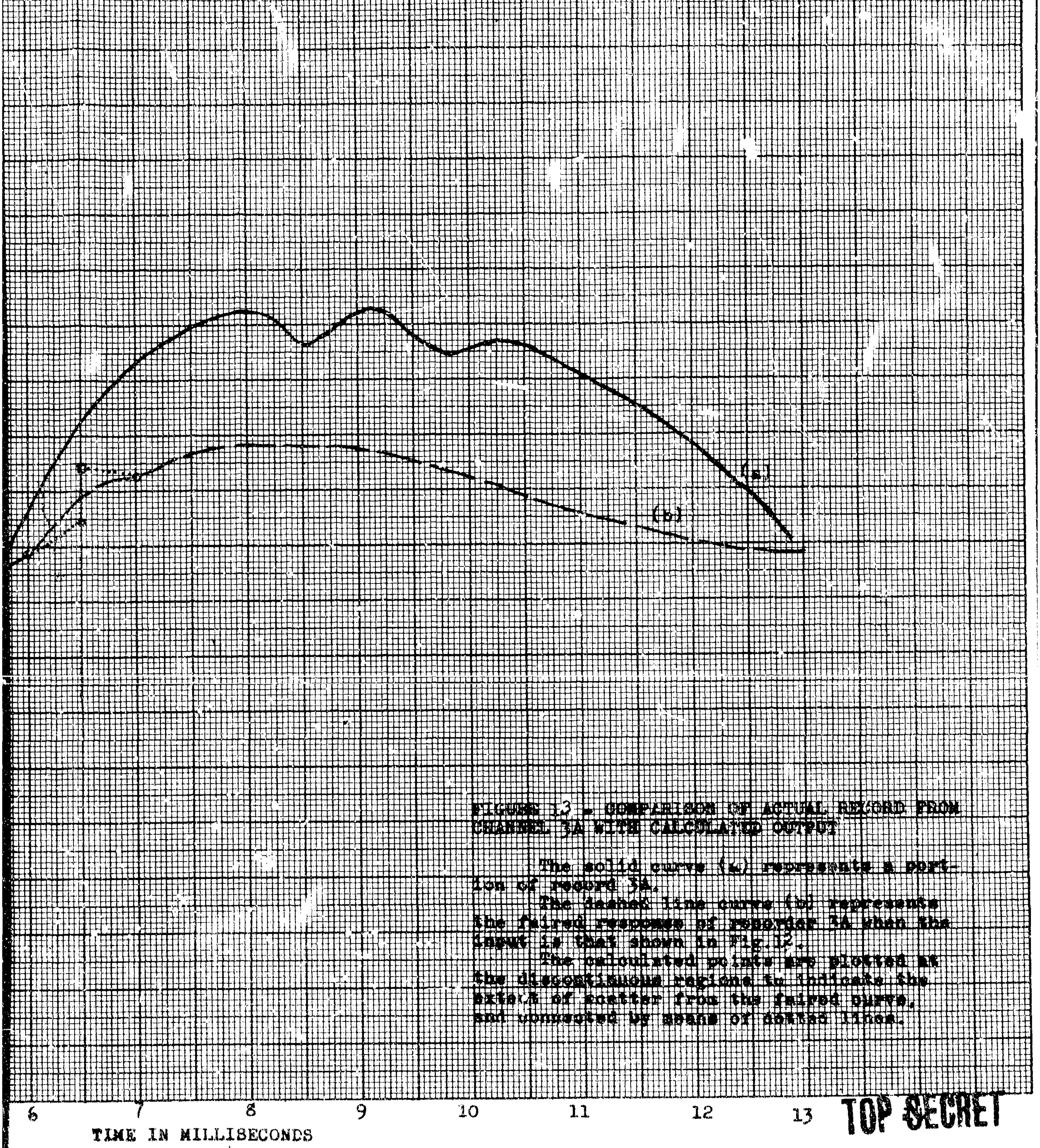

FIGURE 13 - COMPARISON OF ACTUAL RECORD FROM CHANNEL 3A WITH CALCULATED OUTPUT

The solid curve (a) represents a portion of record 3A.

The dashed line curve (b) represents the faired response of recorder 3A when the input is that shown in Fig.12.

The calculated points are plotted at the discontinuous regions to indicate the extent of scatter from the faired curve, and connected by means of dotted lines.

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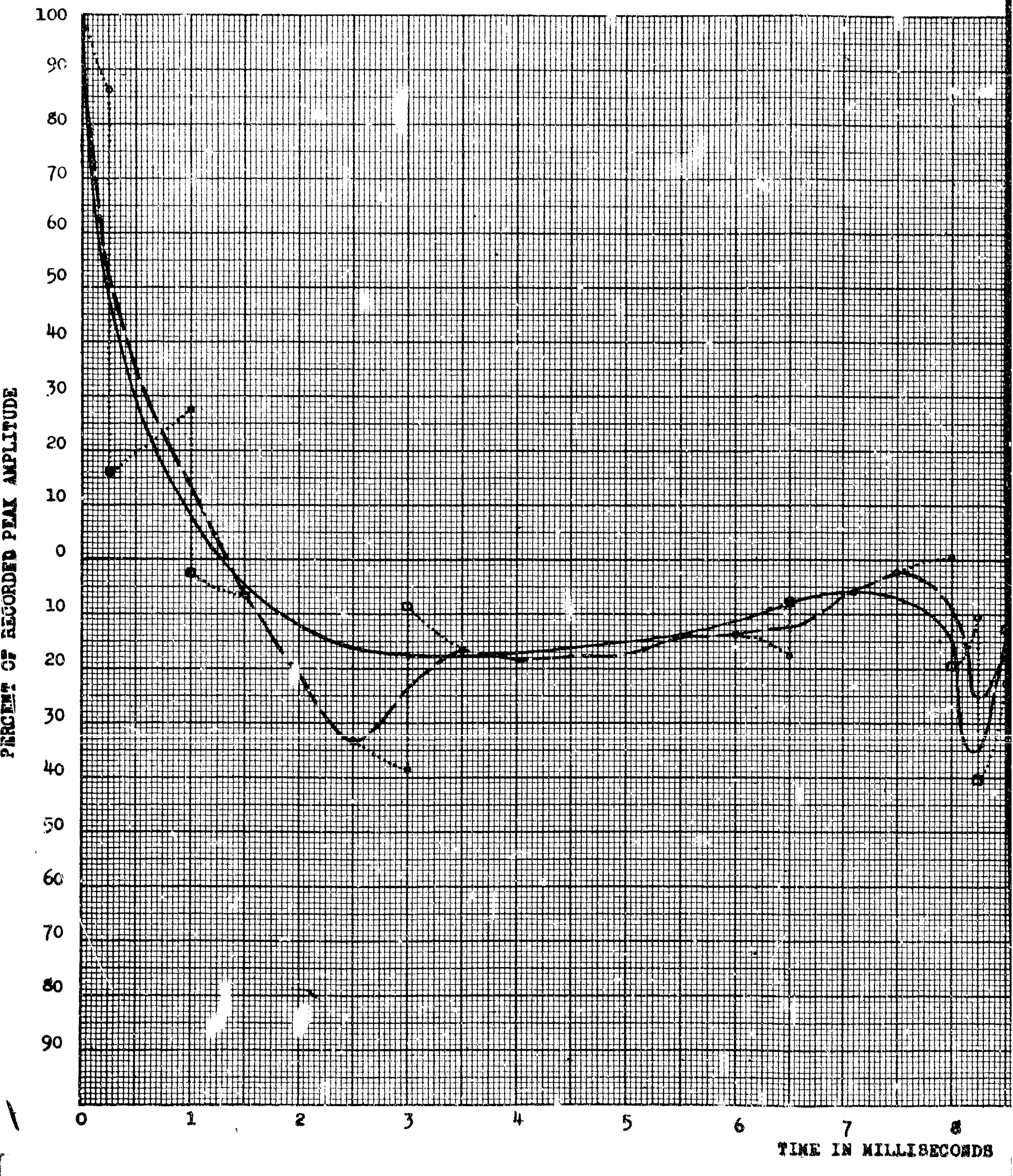

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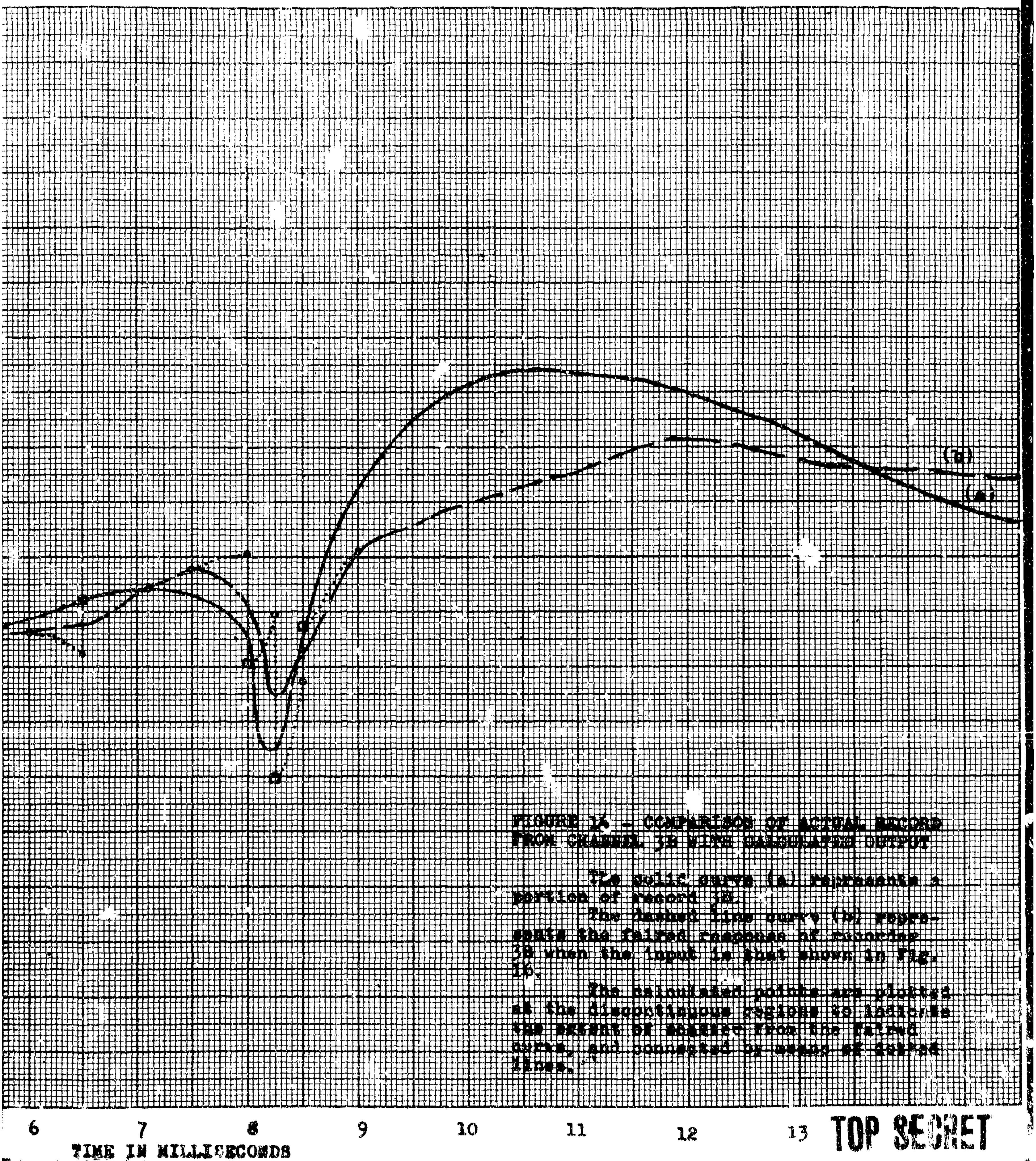

FIGURE 15 – COMPARISON OF ACTUAL RECORD FROM CHANNEL 3B WITH CALCULATED OUTPUT

The solid curve (a) represents a portion of record 3B.

The dashed line curve (b) represents the faired response of recorder 3B when the input is that shown in Fig. 16.

The calculated points are plotted at the discontinuous regions to indicate the extent of scatter from the faired curve, and connected by means of dotted lines.

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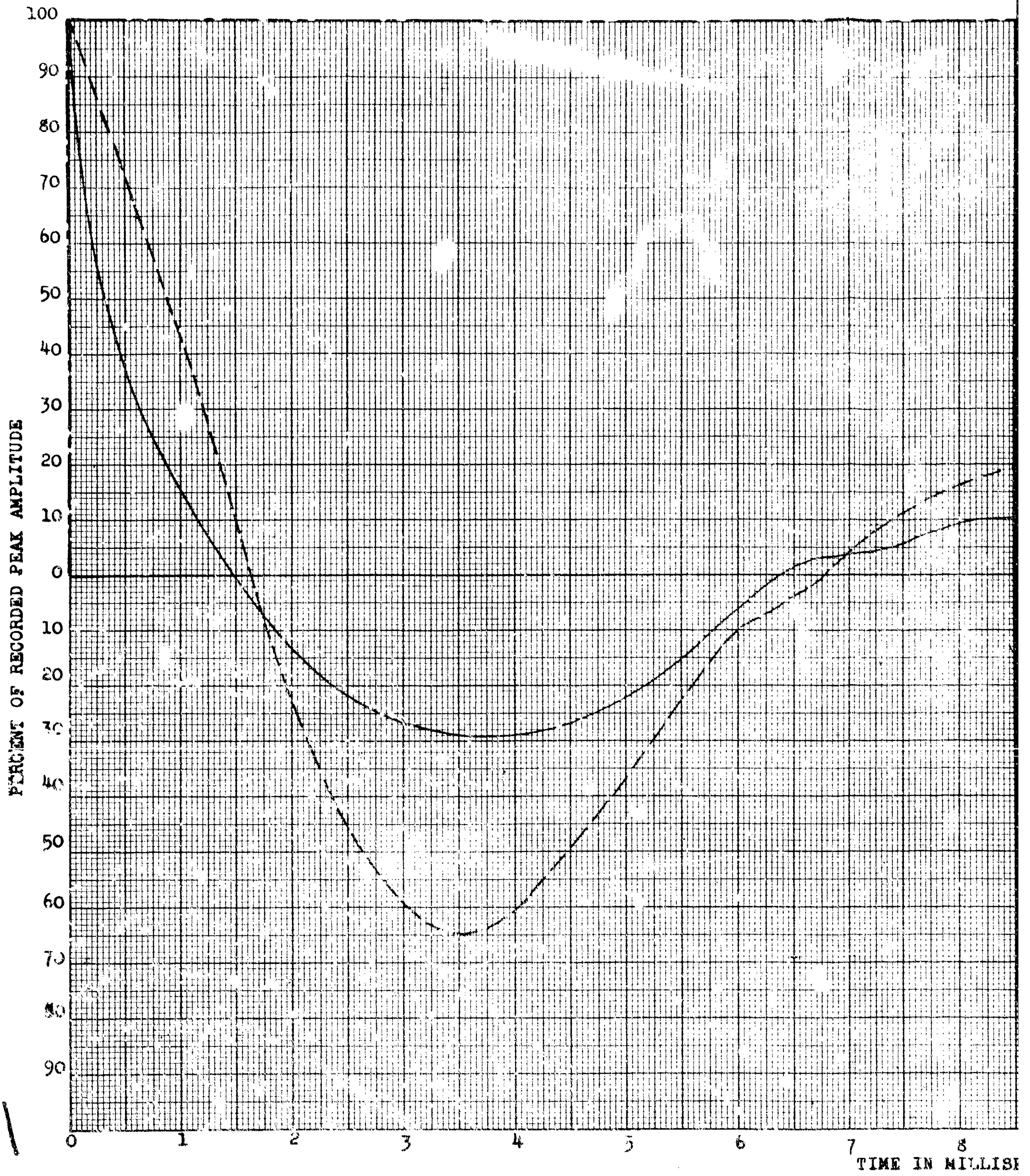
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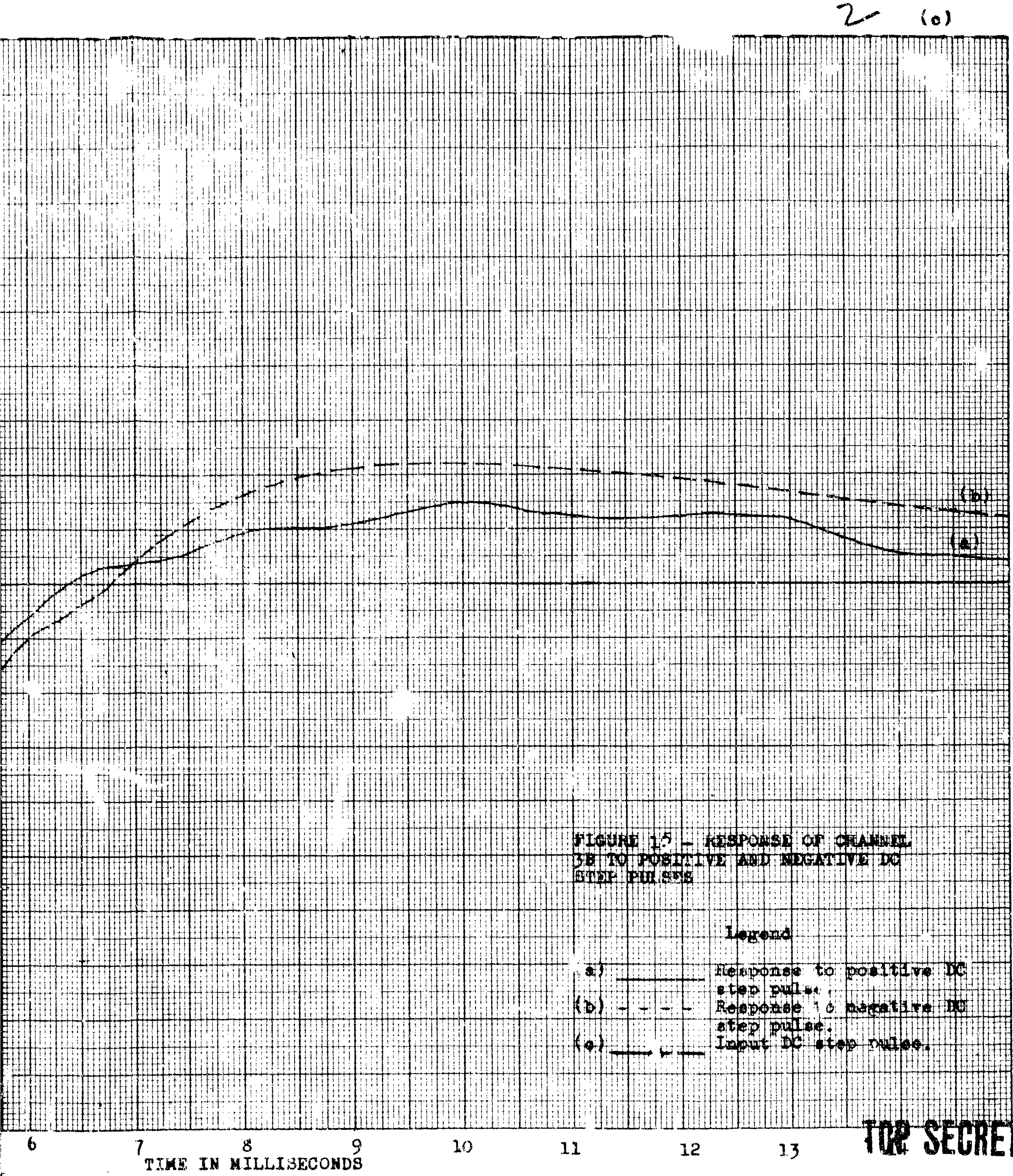

FIGURE 15 – RESPONSE OF CHANNEL 3B TO POSITIVE AND NEGATIVE DC STEP PULSES

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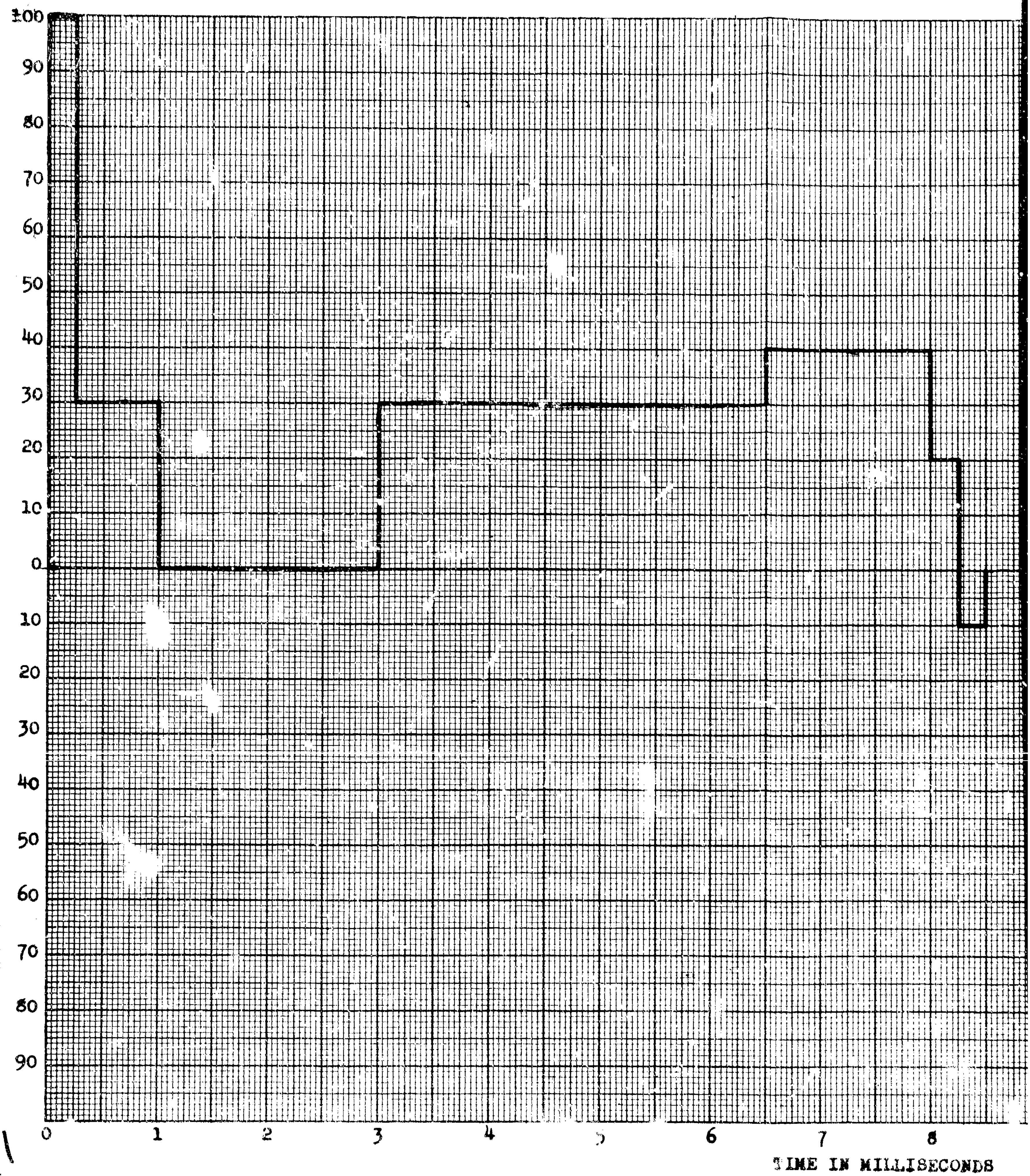

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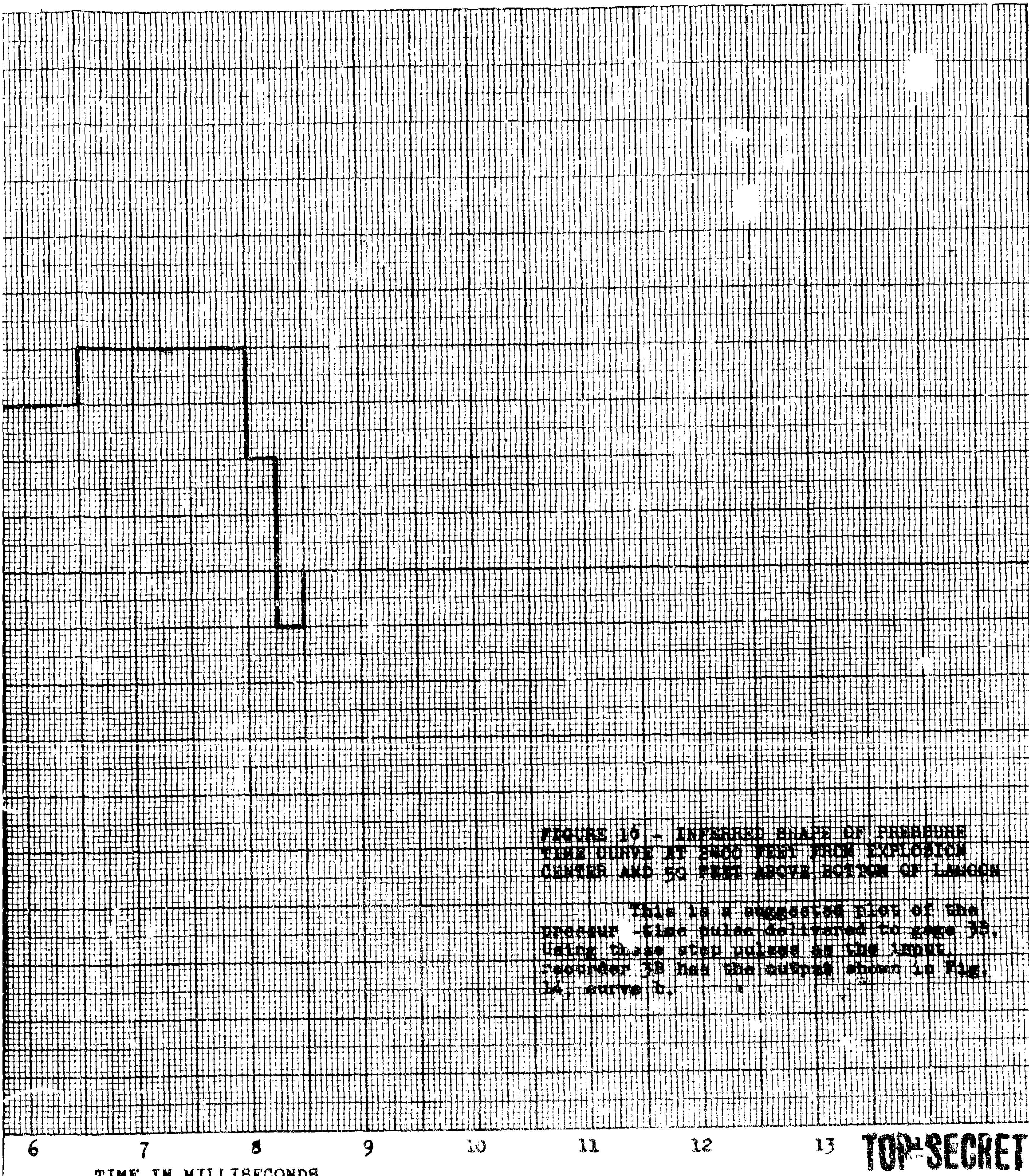
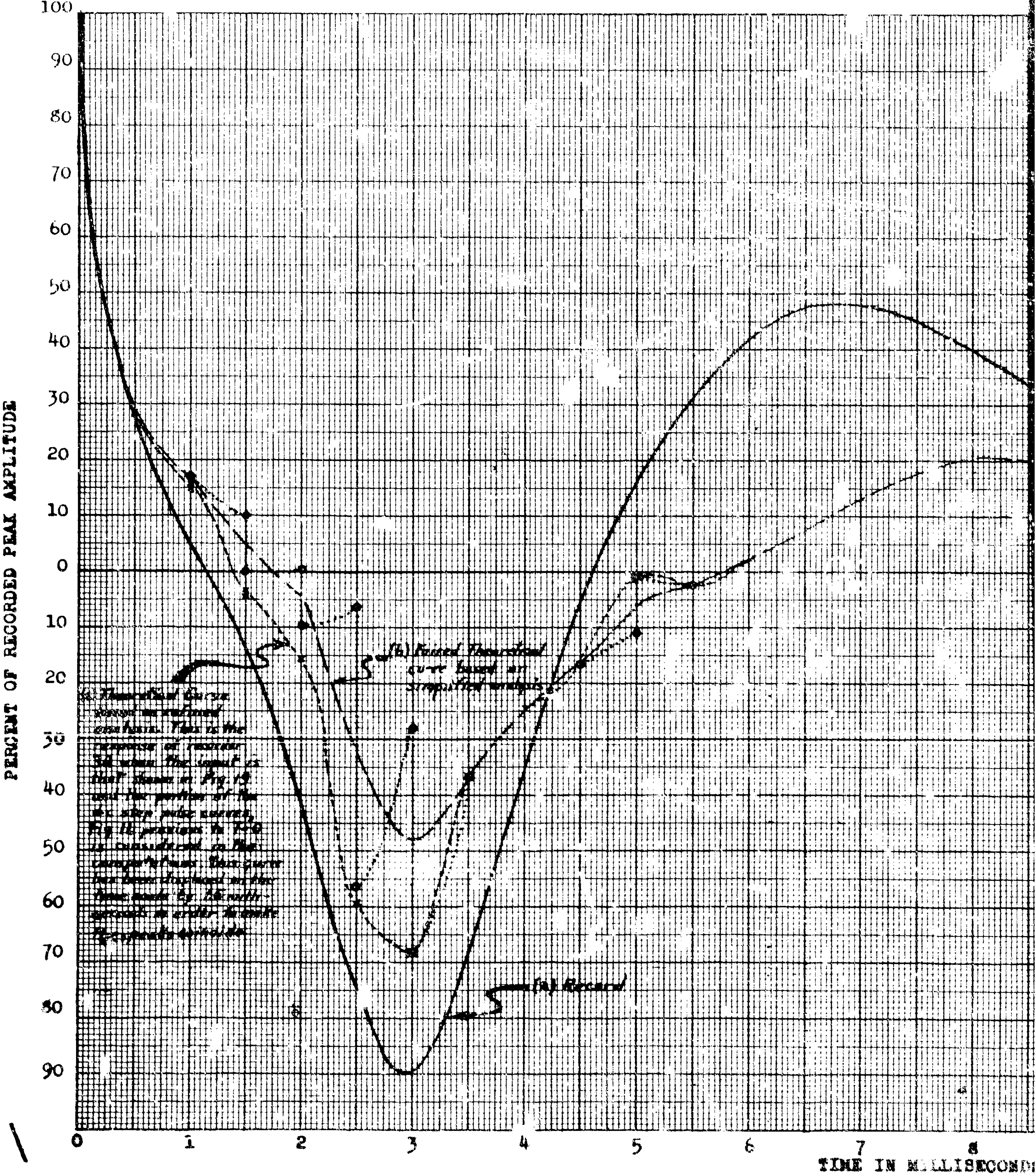


FIGURE 16 - INFERRED SHAPE OF PRESSURE TIME CURVE AT 2000 FEET FROM EXPLOSION CENTER AND 50 FEET ABOVE BOTTOM OF LAGOON

This is a suggested plot of the pressure-time pulse delivered to gage 3B. Using these step pulses as the input, recorder 3B has the output shown in Fig. 14, curve b.

TOP SECRET


PERCENT OF RECORDED PEAK AMPLITUDE
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TIME IN
(b) Faired Theoretical curve based on simplified analysis
(a) Record

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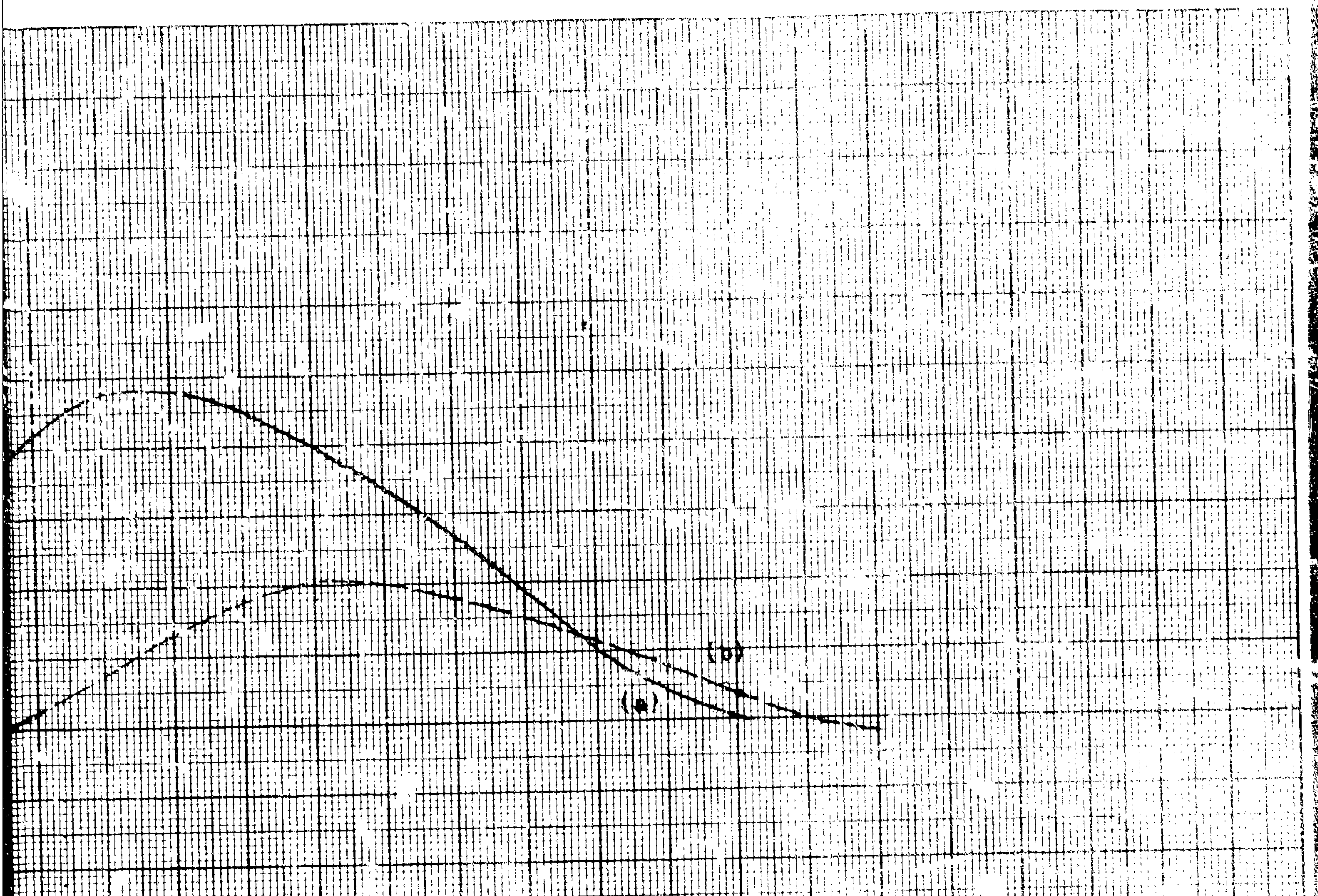

FIGURE 1[illegible] - COMPARISON OF ACTUAL RECORD 4B, AS PLAYED BACK ON 3A AMPLIFIER, WITH CALCULATED OUTPUT

The solid curve (a) represents a portion of record 4B.

The dashed line curve (b) represents the faired response of recorder 3A when the input is that shown in Fig.15.

The calculated points are plotted at the discontinuous portions to indicate the extent of scatter from the faired curve, and connected by means of dotted lines.

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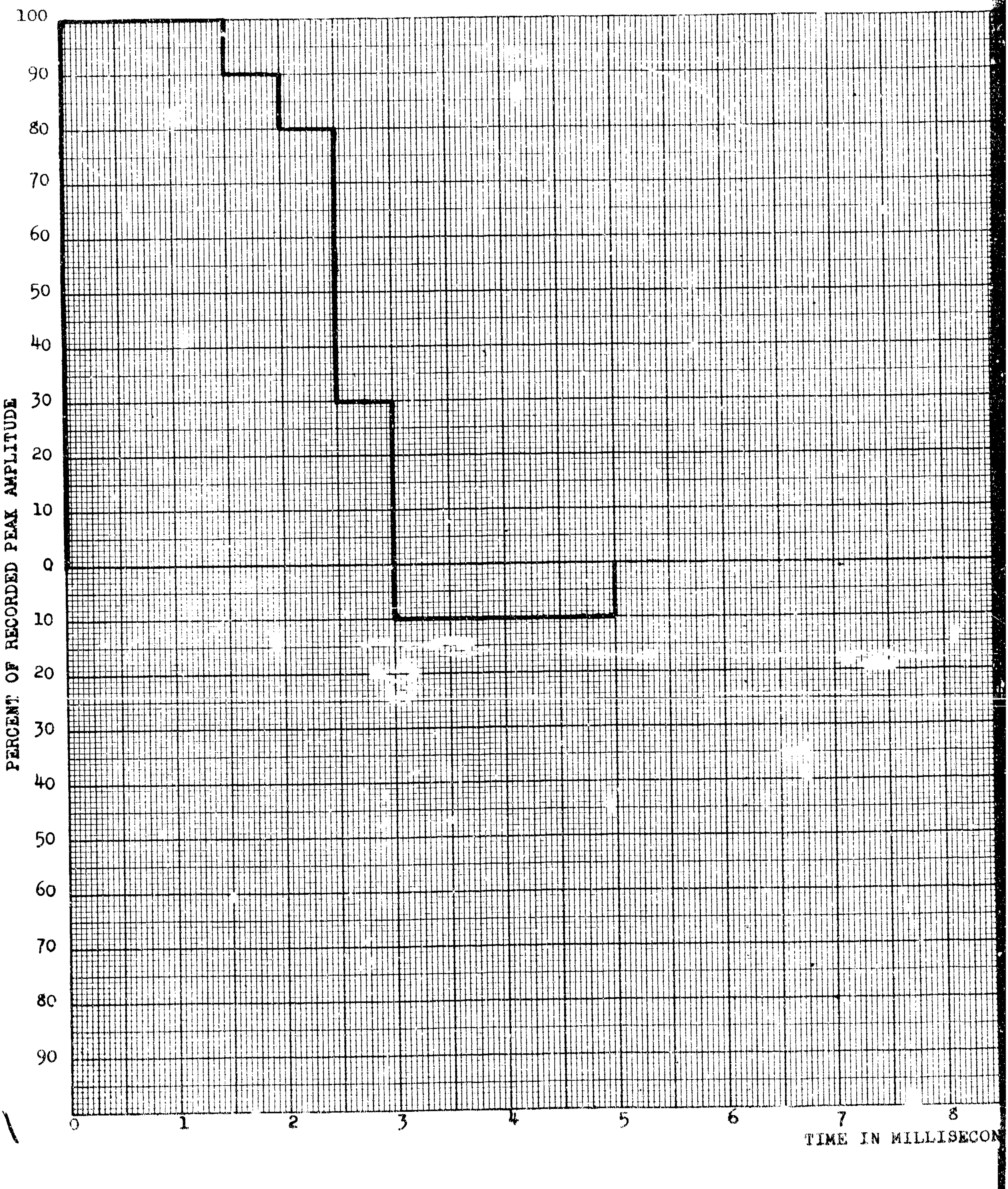
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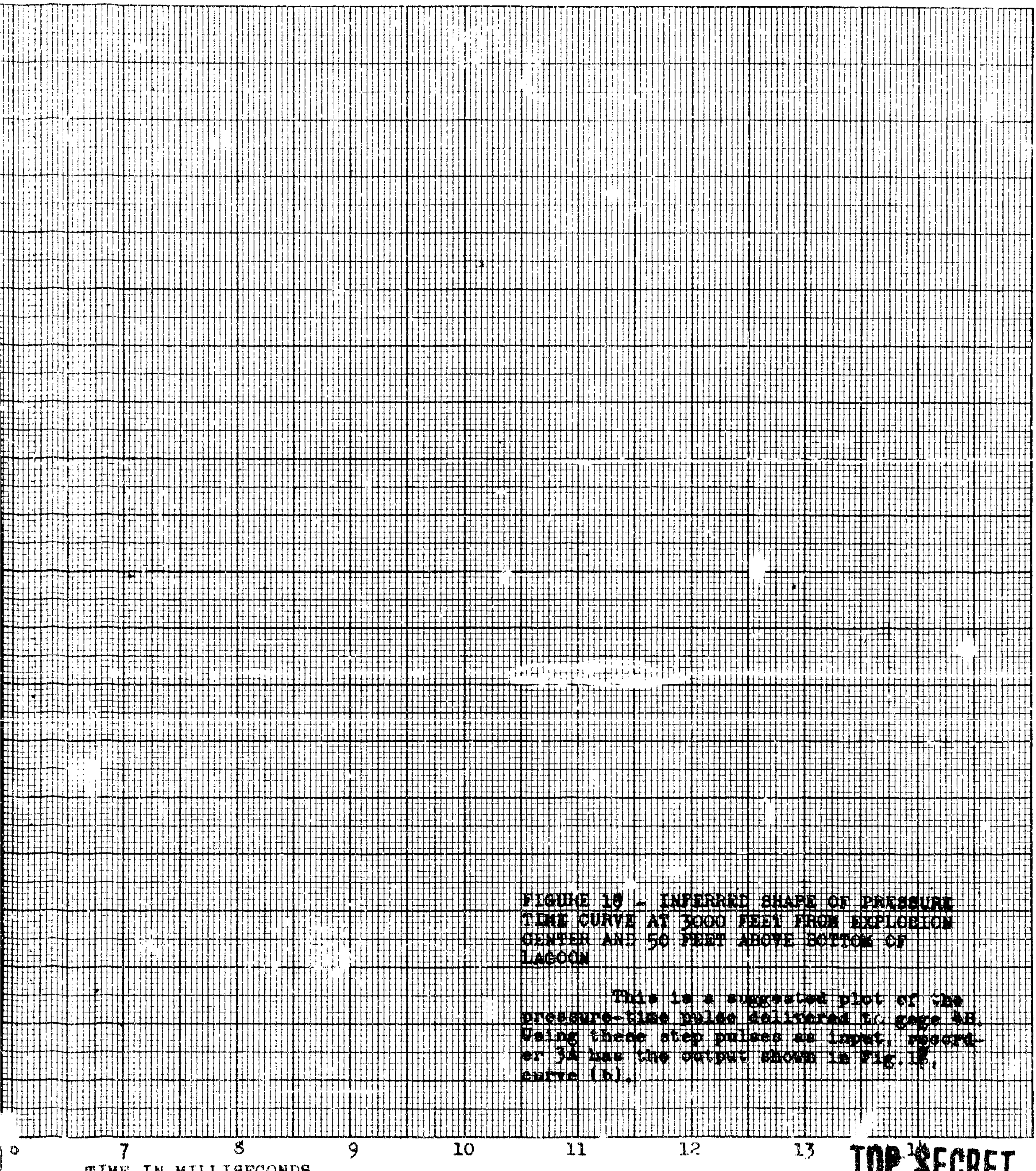

FIGURE 15 - INFERRED SHAPE OF PRESSURE TIME CURVE AT 3000 FEET FROM EXPLOSION CENTER AND 50 FEET ABOVE BOTTOM OF LAGOON

This is a suggested plot of the pressure-time pulse delivered to gage 4B. Using these step pulses as input, recorder 3A has the output shown in Fig.18, curve (b).

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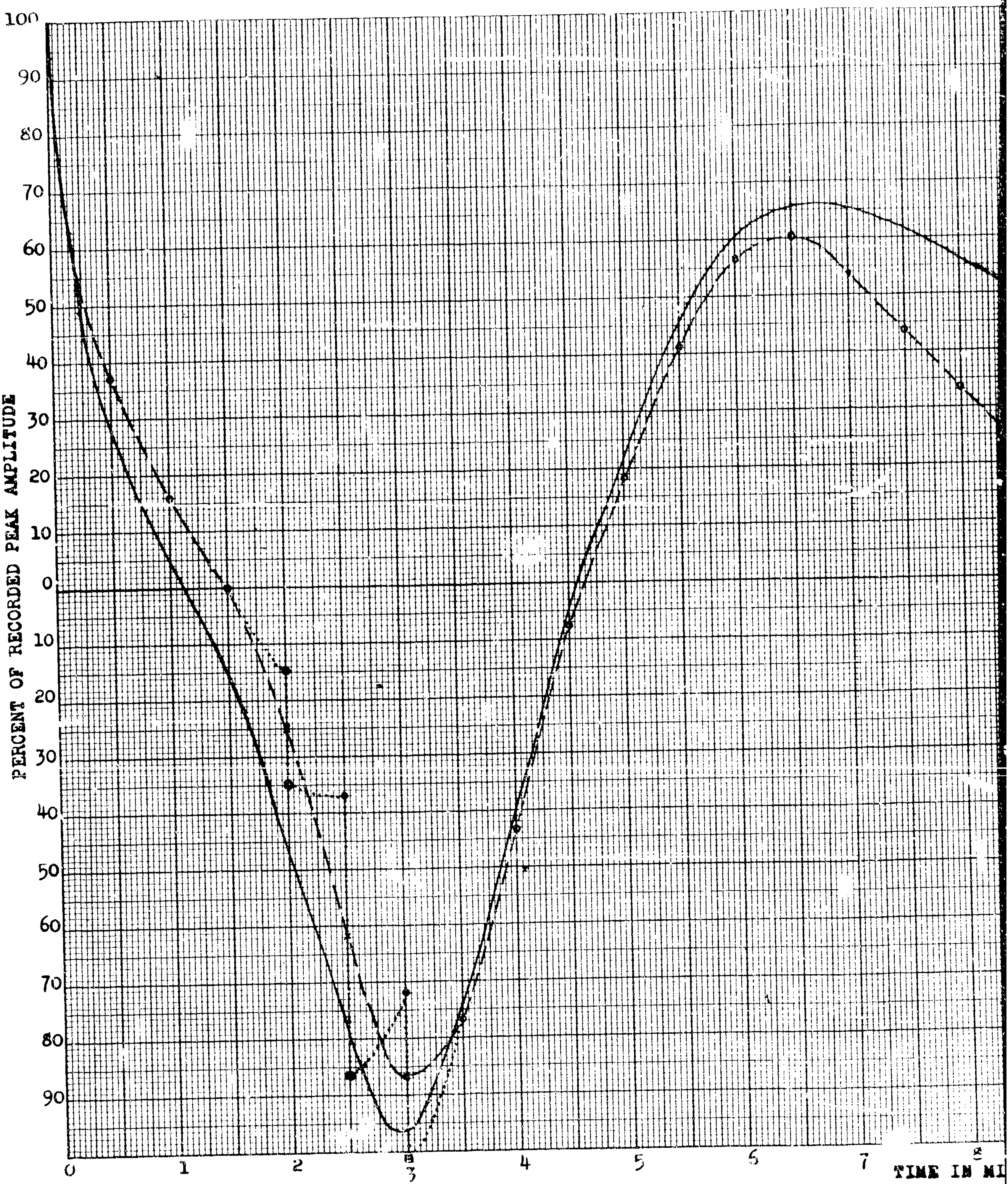

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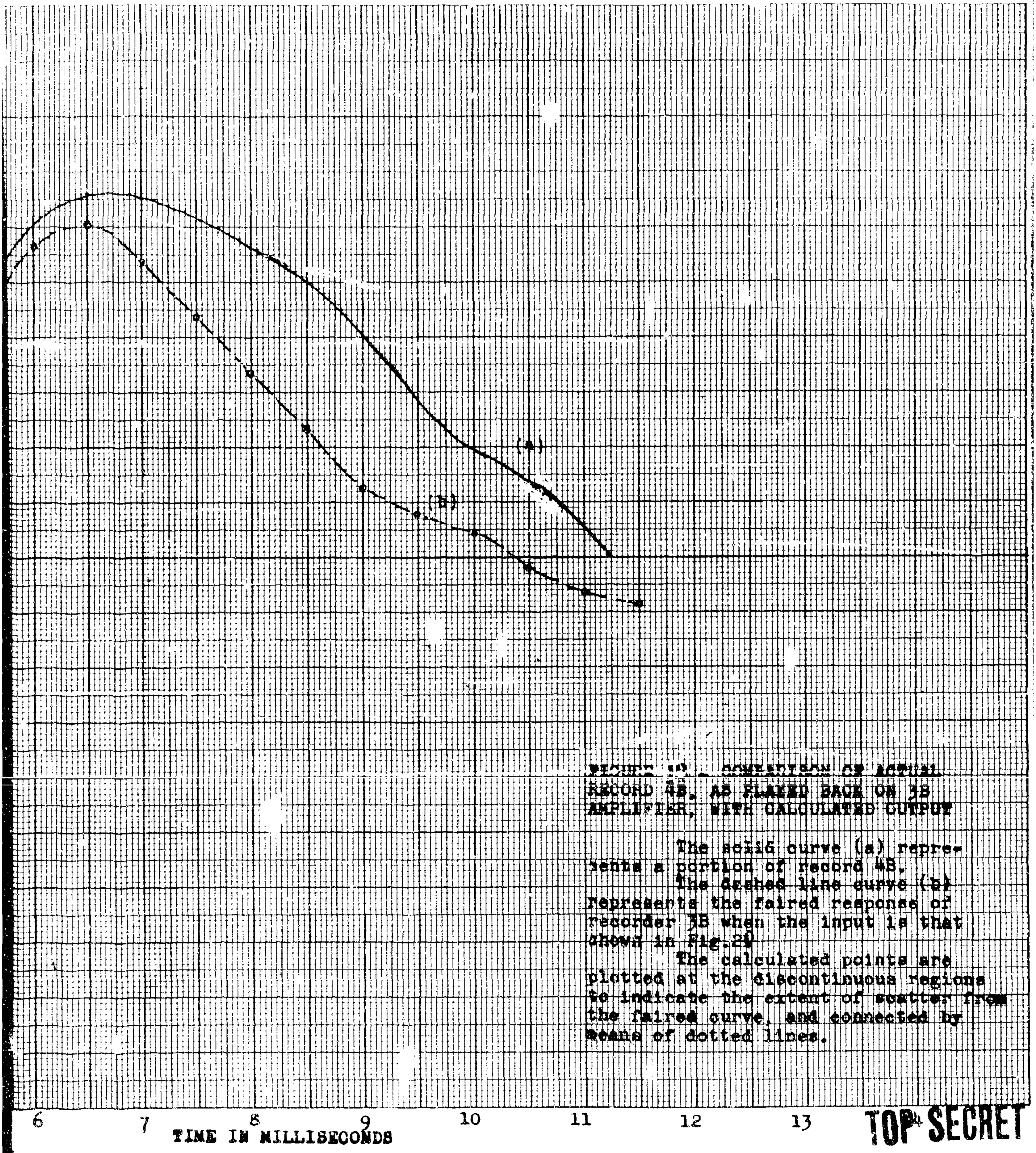
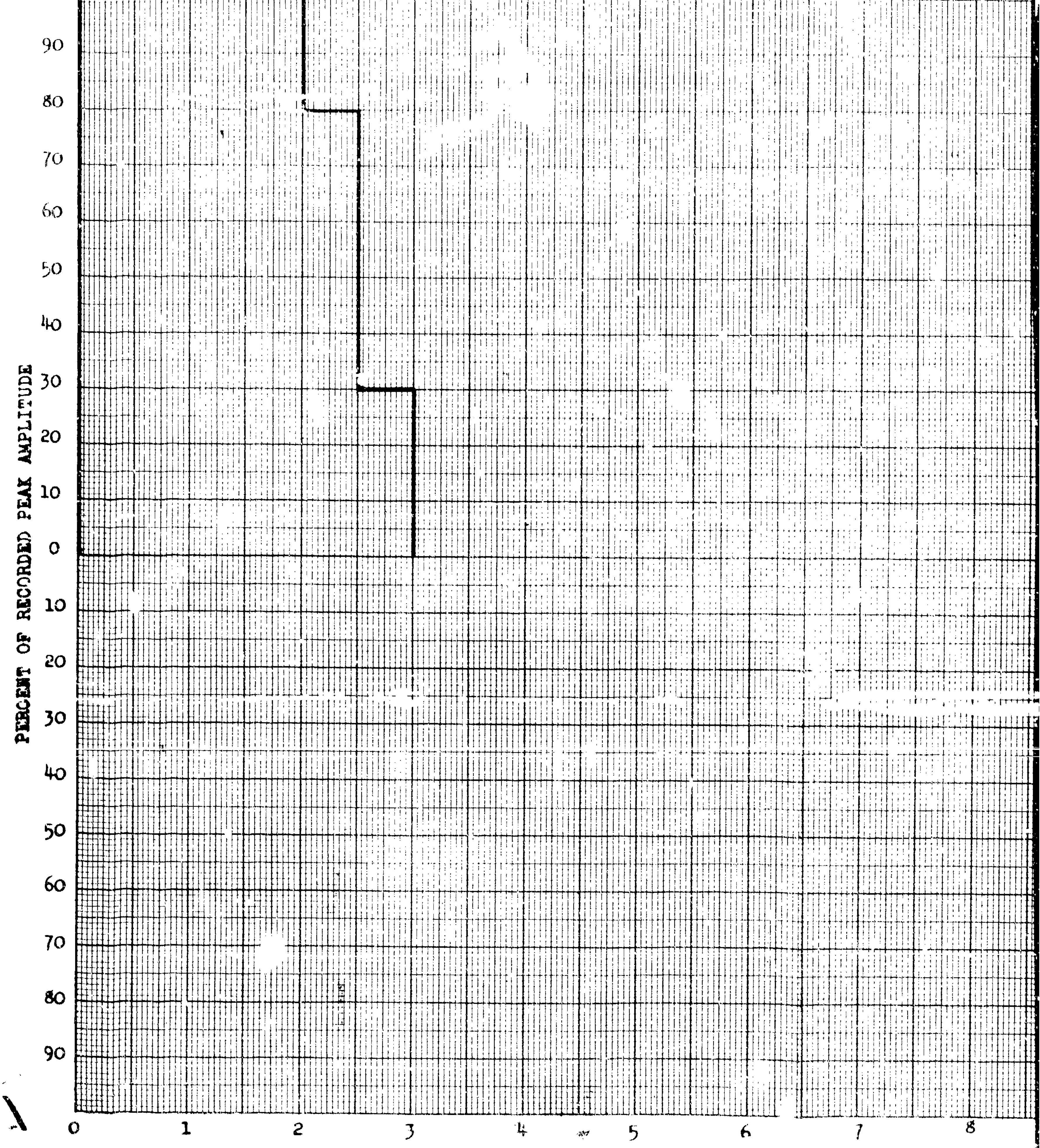


FIGURE [illegible] - COMPARISON OF ACTUAL RECORD 4B, AS PLAYED BACK ON 3B AMPLIFIER, WITH CALCULATED OUTPUT

The solid curve (a) represents a portion of record 4B.

The dashed line curve (b) represents the faired response of recorder 3B when the input is that shown in Fig. 29.

The calculated points are plotted at the discontinuous regions to indicate the extent of scatter from the faired curve, and connected by means of dotted lines.



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TIME IN MILLISECONDS

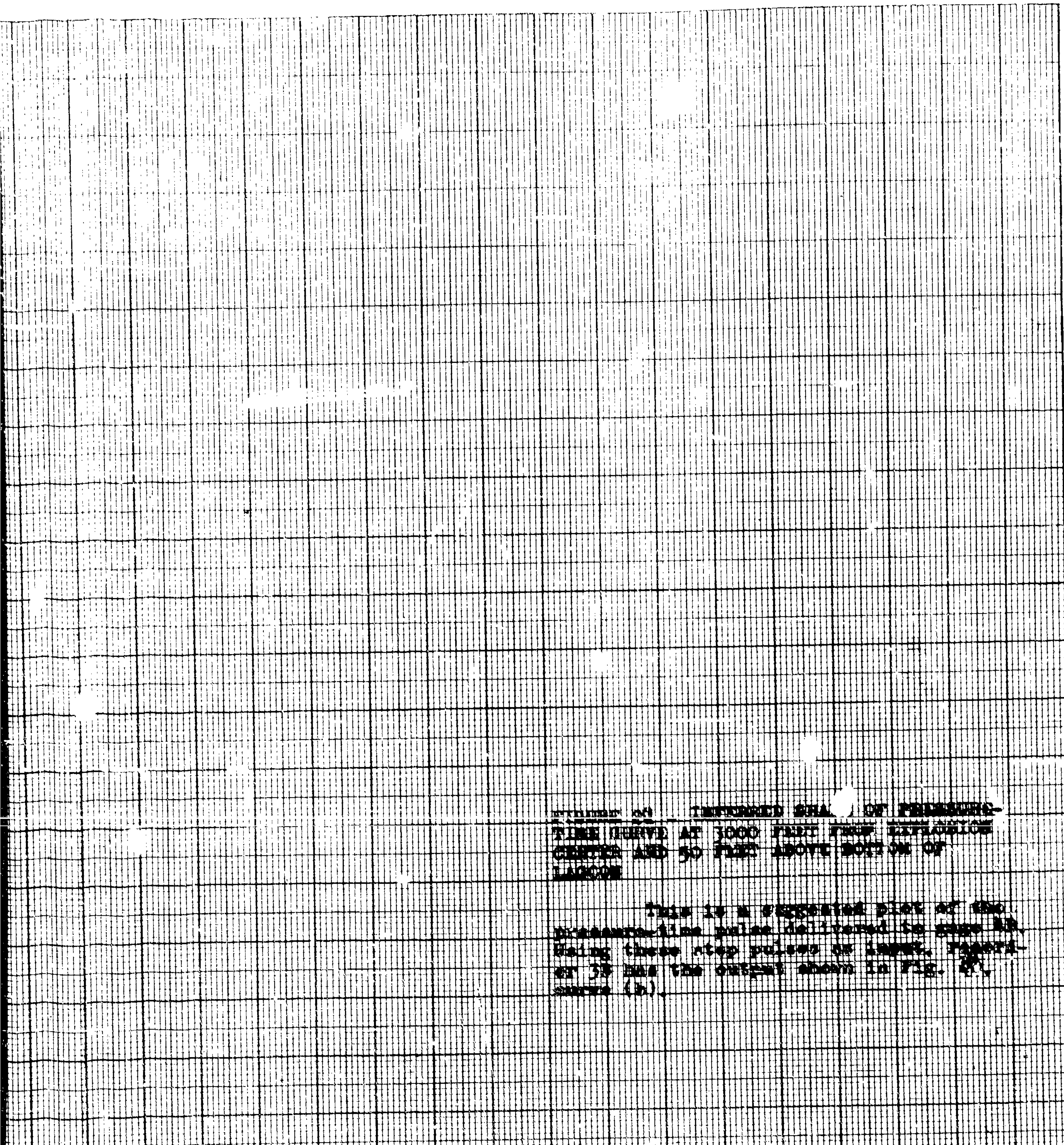

FIGURE [illegible] INFERRED SHA[illegible] OF PRESSURE-TIME CURVE AT 3000 FEET FROM EXPLOSION CENTER AND 50 FEET ABOVE BOTTOM OF LAGOON

This is a suggested plot of the pressure-time pulse delivered to gage [illegible]. Using these step pulses as input, recorder 3[illegible] has the output shown in Fig. [illegible], curve (b).

Defense Special Weapons Agency
6801 Telegraph Road
Alexandria, Virginia 22310-3398

TRC

18 April 1997

MEMORANDUM FOR DEFENSE TECHNICAL INFORMATION CENTER
ATTENTION: OMI/Mr. William Bush (Security)

SUBJECT: Distribution Statement Changes

The Defense Special Weapons Agency has reviewed and approved for **public release, all of the listed report; distribution statement "A"** now applies:

~~AD-473893L~~	XRD-173-Appendix 16	Cancelled
AD-473913	XRD-194-Section 3	
AD-B210866	WT-1321-Supp	✓ Completed 2-7-2000
AD-473915	XRD-196-Section 5.	

Ardith Jarrett
ARDITH JARRETT
Chief, Technical Resource Center