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California Institute of Technology
Seismological Laboratory
December 31, 1964

Final Report - Grant NsG-535

This project became active on October 1, 1963 and terminated on December 31, 1964.

This report is a summary of experimentation conducted in studying the deployment of instrumentation into large arrays by a method applicable to use on the lunar surface. Particular emphasis was placed on its use for extension of an array of geophones or explosive charges to perform a seismic refraction study of lunar layering to depths of approximately 500 feet. In order to make such a determination, a signal introduced into the ground, usually by an explosion, and transmitted through surface layers and layers at depth, is observed by an array of geophones. Arrivals by various paths are received by the array which is at a distance several times the depth of penetration to be studied. Alternately, several explosions in array, fired singly, and detected by a single geophone, or a combination, may be used. In order to determine depths of layers and wave propagation velocities within them it is necessary to know accurately the distance between source and detector, and the time lapse between introduction of the signal into the surface and its reception by the geophone. The development program was directed toward testing the feasibility of methods of determining these values, as well as methods of deployment of geophones or explosives. The technique of determining layer depths, velocities in them, etc. from the recorded data, is well covered in detail in many texts. Velocity in a single layered rock media determined by use of a single geophone and several explosions at various ranges is shown in Fig. 1.

Originally it was expected that the usefulness of devices described herein would be on Surveyor or Surveyor-type follow-on missions in which space and weight limitations would be severe, and in which emplacement would be mechanized. With this in mind, an effort was made to select the lightest, most compact and least complicated technique. Manual distribution and distribution by roving vehicles having previously been ruled out, the choice remained between extending devices, rockets, or throwing devices.

An experimental pneumatic-extendor was constructed for evaluation. This consisted of a plastic film 'air-mattress' device in which two sheets of plastic film were joined longitudinally to form a number of parallel tubes, this was then tightly rolled. When inflated from the free end the rolled portion was forced forward. Such a device could carry the necessary circuitry and light weight instrumentation for a variety of experiments. The original unit was 200 feet long and was successfully extended though it was not without problems.

A second unit 2000 feet long was tried. This consisted of a simple plastic film tube of 8" diameter and .005" wall thickness. In this case the deflated and rolled tube was axled and arranged to tow a ruddering sled for directional stability. It was extended to 1500 feet on a relatively smooth dry-lake bed.

In both units difficulty was encountered with a tendency to inflate around the roll if the forward progress was obstructed. In the later unit there was a tendency to change direction with minor surface irregularities. It is felt that this type of extendor with further development has usefulness for short distances and could be materially improved over the early test devices.

A brief study was made of the technique of rocket-towing a cable strung with geophones or explosives. Several conferences were held with Jet Propulsion Laboratory experts in the rocket field who felt that the technique was valid. However, in the final analysis the weight and volume considerations seemed to be well in favor of mortar and projectile distribution of packages if the problem of ranging and time-break or data transmission could be solved.

For reasons of energy coupling and safety, it is conventional practice to bury the charges used in explosion seismology work. However, on a mission such as Surveyor this would be an extremely difficult matter. Therefore, before launching on design of projectiles and the system it was necessary to determine the effectiveness of small surface explosions in generating seismic signals in various materials. It was also necessary to know whether or not the presence or absence of an atmosphere influenced the energy introduced into the ground.

The latter effect was studied by Dr. E. E. Minor, Chief of the Terminal Ballistics Laboratory of the Aberdeen Proving ground. It is shown by his work that the effect of atmospheric backing is negligible if the explosion is close to the surface. (See Fig. 2).

To determine ground amplitudes, frequencies, and amplitude fall-off with distance, a series of tests were made in the vicinity of N.A.S.A.'s Goldstone Deep Space Instrumentation Facility. In these, many detonations of several explosive materials of selected sizes and shapes were fired on a variety of rock and soil bases. The signals were detected and recorded at distances ranging from a few hundred feet to ten thousand feet by a set of explosion seismology field equipment belonging to the Seismological Laboratory and another provided by the Jet Propulsion Laboratory. The instruments had previously been calibrated for magnification -vs- frequency by placing geophones on a shake-table oscillating sinusoidally at known frequency and amplitude. Comparison of trace amplitude with table amplitude gave a magnification value for each test frequency. A magnification curve, photographs of some of the equipment used, and an explosive charge in place are shown in Figure 3 a, b, c.

Three types of explosives were used. These were PETN sheet approximately 3/32" thick, 1 lb. cans of primer composed of a TNT-ammonium nitrate mixture, and 'broomstick' charges made of primer cord wrapped in a groove about a wooden dowel. The largest sheet charge covered a 4' x 8' area; no significant difference in amplitude was read for large area charges of PETN or concentrated charges of the same weight. Dimensions were kept to values which might conceivably be used on a moon experiment; these were still essentially point sources considering the ranges studied. The broomstick charges were oriented both normal and radial to the shot-geophone axis, and detonated from ends and center. Detonation velocity along the 'stick' was more or less matched to the material on which the test was made. These charges gave the poorest results of the three materials tested. For weight reasons and problems of orientation on the moon, backed charges and orientated shaped-charges were not tried.

Amplitude fall-off-vs-charge-size, amplitude fall off with distance, and representative amplitudes for equal charge at constant distance on different base materials are shown in Fig. 4 a, b, c.

With the present state of the art, solid state geophysical amplifiers having input noise figures of well below 1 μv peak-to-peak over a band width of 2 - 100 cps are readily available. A typical commercially available 4.5 cps geophone weighing $\frac{1}{2}$ lb., with a 1000 ohm coil will develop approximately 0.2 v/cm/sec velocity of the mass relative to the frame, across a 1000 ohm load.

It is necessary to use sufficient explosive to cause the generated geophone signal to be large compared to amplifier noise, perhaps by a factor of 10. Fig. 5a shows the ground amplitude-vs-frequency required to give approximately 10 µv output from a typical geophone. The range of predominate first-arrival frequencies is indicated, later phases contain lower frequencies and larger amplitudes. Amplitude distribution vs-frequency is shown in Fig. 5b.

From the curve of Fig. 4a, a typical ground amplitude at 2000 feet distance from a 16 lb explosion is read to be 3.5×10^{-4} mm. If it is assumed that no greater distance will be used in the lunar experiment and since curve Fig. 4c shows the amplitude-vs-charge relationship to be linear, the charge required at 2000 feet for 10µv output at 11 cps will be

$$\frac{7 \times 10^{-6}}{3.5 \times 10^{-4}} \times 16 \text{ or about } 1/3 \text{ lb.}$$

From this it is seen that geophones and amplifiers of ordinary capability but adapted to the space environment will be satisfactory.

For weight reasons, as mentioned earlier, the mortar-projectile method of deployment was chosen for test. In early experiments it was found that a 1 lb, 2" x 3" dummy projectile could be thrown approximately 1000 feet by a mortar having a barrel about 6" long, elevated 45°, and with a propelling squib containing 1 gram of explosive. This range is equivalent to about 6000 feet on the moon and represents a muzzle velocity of about 180 fps and a launch acceleration of approximately 1000 G.

From our experiences in design and testing of electronic and mechanical components for the Ranger 3, 4 and 5 instrument capsules, which were tested to 5000 G survival, it appeared there would be no difficulty in achieving survival of telemetry or time break devices, explosives, fuses, and mechanical parts which might be included in a projectile. There was no reason to believe that geophones using packaging principles developed for the Ranger seismometer could not also survive such treatment. (See Wayne Miller, "Electronic packaging for 5000g survival", CIT Report No. 1041, August 1961.)

Use of elevation angle and muzzle velocity for range determination seemed unreliable because of unknown base stability, and would require additional sensors and telemetry. This method would demand impact detonation to avoid range error from tumbling after impact.

Other methods such as optical ranging, radar, etc., appeared too complicated for the experiment specifications and were considered only briefly.

What was seemingly the most direct and simplest ranging method, (which was developed to prototype status) was one in which a metering line is pulled from a reservoir at the mortar and measurement of the line extended by an encoder registers the range. In this device, even if the projectile ricochets after landing the tumbling distance is registered.

To try this concept the early test mortar was fitted with a 'spinning-reel' type of spool containing several thousand feet of nylon mono-filament line .010" in diameter the free end of which was attached to the projectile. The line was carried satisfactorily by the projectile with moderate shortening of range.

With this method of ranging, it appeared best to delay detonation until after the projectile had come to rest on the surface for two reasons; first, tumbling would tend to remove any slack that existed in the line, and, second; at short ranges the possible lightness of impact at lunar G would require rather sensitive impact triggers, which could concievably be actuated by minor accelerations applied to the projectile in flight by the line.

Detonation by either an electric or pyrotechnic time delay device initiated at launch therefore seemed worthy of study.

Further development of techniques and components were oriented toward the system illustrated in Fig. 6 which embodies the philosophies discussed above.

Functioning of the system shown is as follows:

(1) The geophone, and a lunar surface package containing a number of mortars, each of which is loaded with a projectile and propelling charge is emplaced.

This package is connected by cable to a control and data routing package aboard the spacecraft. Contained in each projectile is a pyrotechnic time delay fuse, and explosive charge, a time-break radio transmitter, battery pack and pressure switch. A means of igniting the fuse and closing the switch by the launch gas pressure is provided. Each mortar tube is fitted with a range metering line spool and an encoder for reading the line length extended.

Contained within the control package is a programmer, a range signal generator, a 'time-break' radio receiver, the geophone amplifier, a relative-time clock and the data recorder. (If data is telemetered directly in real time the latter two items can be omitted and relative time superimposed at reception). Power supply would presumably be part of the space craft facilities.

(2) A 10 second command pulse starts the programmer and activates the receiver, geophone amplifier, range signal generator and clock. ("A" Power).

(3) After a period for stabilization, the programmer applies "B" power which launches the projectile and, if on-site recording is used, starts the recorder.

The time-break transmitter and the time delay detonator aboard the projectile are activated at launch. Increments of length of metering line pulled from the reservoir by the projectile is indicated by modification of a signal applied to the range encoder.

(4) Several seconds after impact the time-delay detonator explodes the charge. Cessation of the carrier from the time-break transmitter is sensed by the receiver and indicates the instant of explosion. Waves generated by the explosion are detected by the geophone, amplified and recorded. Timing signals accurate to 1 ms must be superimposed or recorded in parallel with the other data to establish travel times. This may be an A.C. signal of constant frequency (500 cps) which may also be the range signal if time is applied on-site.

(5) Programmer turns off all power.

(6) Each shot may be made on-command, or, a continuous command signal will cause re-cycling until all units are fired and the data recorded or telemetered.

(Note that in the prototype package the first cycle of the programmer fires explosive pin-pullers within the package allowing the covers to extend and lock.)

The initial phase of work in development of devices for the system of Fig. 6 consisted of trials of various models of mortars, using aluminum dummy projectiles propelled with electric squibs loaded with various powder charges. The purpose of this was to develop a 'feel' for range repeatability, charge requirements, etc. It was soon evident that laboratory work was necessary to determine whether muzzle velocity could be controlled accurately enough to give a reasonable distribution of projectile ranges.

A test set-up was made in an underground tunnel at the Seismological Laboratory for measurement of velocities. Squib charges were weighed and loaded at the laboratory not so much as to establish the method in which the explosives should be packed as to determine if good repeatability was possible in such devices.

It was found that results with commercial squib ignitors followed by a powder charge were rather variable, probably due to the fact that the ignitor provided a substantial portion of the propelling force. Since it was felt that in assembly of flight hardware, loading would be the task of ordnance experts, it was decided to approach the problem from a direction intended only to verify the validity of distribution by mortar. Therefore, because of the high cost of electric squibs used initially, and the number of tests it was apparent would be required, propelling charges were packaged in standard .45 caliber cartridge cases and detonated with standard percussion caps struck by a solenoid-operated firing pin. With much experimentation excellent repeatability of muzzle velocity was achieved. Fig. 7 a, b shows a muzzle velocity record and a plot of several four-shot samples.

After establishing loads of readily available powders for various ranges, a number of field tests were made. In these, groups of shots intended to have the same range were fired and the scattering observed; Fig. 8 is typical. While it is expected that ordnance specialists might better the uniformity of distribution, these tests demonstrated that such a system is adequate for performance of the seismic experiment. (It should be noted that absolute uniformity of spacing and precisely specified range is not required; it is required to have only a reasonably well spaced array, and knowledge of the actual dimensions to within a few percent.)

A number of range encoders based on determination of the length of metering line extended were proposed. Among these were measurement of the capacity between insulated wires in the coiled state and partially extended, frequency sensitive devices, follower fingers to drive a counter as the line stripped from the spool, intermittent coating of the line with a conductor to make contact as it passed over the spool lip, spring contacts operated by the line at various increments of line length, and several others. Most of these were constructed and tried; the one showing greatest promise and having the highest reliability was a variation of the latter contact device in which fine short-circuiting wires across resistors in series were snapped at increments of line length equal to the tolerance permissable for each range.

The final mortar with the range encoder in place is illustrated in Fig. 9. Fig. 10 shows the metering line spool and encoder, and illustrates the looping of the range line through the shorting wires, and Fig. 11 is a typical test range record (in which the signal is D.C.).

For the system shown in Fig. 6 it is required that the projectile carry an explosive charge weighing approximately 1/3 lb or less, a time delay fuse and detonator, a radio transmitter with battery pack for time break indications and a means of switching on the transmitter and initiating the time delay fuse.

Both electronic or electric, mechanical, and pyrotechnic time delay devices were considered. From the standpoint of directness, simplicity and reliability, considering the launch and impact accelerations to be experienced, there was little question of the choice of a pyrotechnic device provided one with sufficient delay could be obtained in the dimensions necessary. Since flight time for a 2000 feet range at lunar gravity with muzzle elevation of 45° is about 27 seconds, it was felt that a delay time of 35 seconds would be adequate.

At the suggestion of Dr. E. E. Minor and Mr. Beauregard Perkins of the Aberdeen Proving Grounds, the pyrotechnic section of the Piccatinny Arsenal was contacted for advice.

Mr. Samual Sage, Mr. Gary Weingarten, Mr. Stanley Resnick, and Mr. Seymour Lopatin of the Arsenal were particularly helpful in advising on the subject of fuses.

While design and construction of a prototype by the Arsenal appeared to be too costly for the project budget, much general knowledge of the subject and confidence in the choice of pyrotechnic devices was gained.

An experimental fuse, adequate for test purposes was fabricated at this laboratory. This consisted of an aluminum spiral about which was wound a section of lead "spitter-fuse". A thin, close fitting metal case enclosed this assembly in such a way that the exposed end of the "spitter-fuse" was in contact with a percussion cap; ignition was accomplished by striking the cap with a sharp object.

Dimensions of the fuse are $\frac{1}{2}$ x 3" and burning time about 20 seconds. This time is more than adequate for testing at earth G. flight time.

In early exploration of pyrotechnic fuse capability, discussions were held with the Bermite Powder Company, (Guy J. Bishop, Customer Relations and Technical Liason). This company showed a marked interest in developing such a device, again the cost quoted was prohibitive. Recently, however, Bermite has listed in its catalog a pyrotechnic device which appears to have been designed with our application in mind. The dimensions and delay are nearly identical to our original specifications (Bermite designation is No. B 16000, dimensions are .308" x 2.990", and delay is 30 seconds). If development is extended on this experiment this source should be noted.

Frequency of the time break transmitter was chosen to give a substantial radiation from the projectile with minimal or no antenna, and yet not so high as to be seriously affected by line-of-sight transmission characteristics. Tests were made with 27 mc, 60 mw input, transceivers under conditions when the transmitter and receiver were almost in contact with a conducting ground plane (water table essentially at the surface of a dry-lake-bed) and in a situation when the transmitter and receiver were on the surface of granite thinly covered with sandy alluvium.

In both cases the transmitter antenna was a 6" long rod extending from the case; the receiver antenna was a 3 ft rod. In the latter situation a low hill was between transmitter and receiver. Keying of the carrier was easily read to distances in excess of 2500 feet.

The transmitter designed for the projectile consists of a crystal controlled emitter-coupled R. F. oscillator and a 1 kHz square-wave oscillator. The R. F. oscillator, operating at 27.255 mHz is amplitude modulated at 1 kHz so that it may be detected on a standard AM receiver, (Johnson No. 242-163).

The design of the transmitter was dictated by three requirements. First; the unit must be ruggedized to withstand the high launch acceleration and possibly an even greater deceleration upon landing.

Second; the transmitter must start reliably during or shortly after the high g launch and continue to operate during and after impact. Since batteries are often adversely affected by high g accelerations the transmitter must also operate reliably over a wide voltage range.

Finally, the R. F. circuitry should be designed to radiate as much power as possible without an antena. To satisfy this requirement, the tank coil was wound with as large a diameter as would fit within the constraints of the mortar package.

A large number of circuit configurations were investigated, constructed and tested. It became clear that meeting the first requirement, reliable starting, was a primary basic problem. Since ruggedization of the package requires encapsulation of the components, no R. F. tuning to optimize the operation could be performed after assembly. The components used for tuning (variable chokes and capacitors) are relatively fragile due to their moving elements, and also their characteristics usually are affected by the encapsulant. Therefore it is desirable that the circuit be designed to work properly without trimming elements.

Crystals for operation in the range of 27 mHz are usually cut for fifth harmonic resonance. For circuits where the Q of the tank circuit is high and when one may trim the circuit there is no difficulty in operating at the fifth harmonic of the crystal. Our experience with breadboard R. F. oscillators however indicated that without critical adjustment adjustment, the circuit might oscillate at the third harmonic of the crystal rather than the fifth harmonic. When crystals cut to the third harmonic mode were obtained we found it much easier to construct the circuit for reliable starting.

All of the circuit components were selected for the rugged characteristics. The semiconductors are silicon, mesa or planar devices which our experience with the Ranger program has shown to be capable of withstanding very high g levels.

The most fragile component is the crystal. A number of commercial units were tested and found to be incapable of standing the severe acceleration. Some of our own crystal mounting techniques were tried without much success. Either the crystal was not supported sufficiently or if it was, the mount seriously affected the operation of the crystal. Finally, a ruggedized unit supplied by Bliley (part No. BH6WB) was found to be more than adquate. Our testing of this unit has resulted in no failures.

A schematic of the transmitter is shown in Fig. 12 a. Q_1 and Q_2 make up the square wave oscillator and Q_3 and Q_4 the R. F. oscillator. Turn on time of the unit is less than 5 m sec. Reliable operation is obtained between 5 and 20 volts. The power required at 12 volts is approximately 700 mw.

The construction of the unit is a cordwood package with all the circuit elements within the tank coil, (Fig. 12 b). The pyrotechnic time-delay fuse passes through the center of the transmitter package. The battery pack is located on the top of the cordwood package so that the circuit, batteries and tank coil may be encapsulated into one unit.

One of the power leads from the batteries to the transmitter is wrapped around the explosive charge to assure turn-off upon detonation in the event that the unit is blown clear in one piece.

Satisfactory reception range with no transmitting antenna was about 1800 ft.

It is felt that a state-of-the-art receiver equipped with a beat-frequency-oscillator for continuous-wave carrier reception would give highly satisfactory results.

Initiation of the transmitter and the pyrotechnic fuse is accomplished by driving a firing pin with the launch gas pressure causing the pin to force a switch ring forward locking it into a contact recess, and at the same time piercing the fuse ignitor cap. The firing pin and switch ring are normally retained by a shear diaphragm. Fig. 13 shows the projectile in section, and Fig. 14 pictures a projectile.

Initially it was intended to design a solid state programmer in which, after command, cycles of the timing 'clock' frequency would be counted to initiate the various functions outlined earlier at proper intervals. However, it appeared that such a device would be far more complicated than justified the ends when compared to a motor-cam-relay type of device. Also, isolation of circuitry with the switches and relay could be a safety factor. The programmer is shown in Fig. 15.

Five mortars and projectiles were assembled into the package shown in Fig. 16 a, b.

The covers when released extend by spring power to become part of the supporting platform. Spikes on the cover edges perform both the functions of damping of the opening impulse from striking of the surface and "hob-nailing" to prevent skidding. If the surface material is very soft, the cover web provides a snow-shoe support surface. This unit was test fired in conjunction with the programmer. Observations of range encoders and time break transmitter signal were made using one of the Laboratory's multi-trace seismic recording cameras; Fig. 17 shows a test in progress. Results of tests of the development prototype described above were as follows:

(1) The package was tested at lunar G for operation of the door opening function; this was satisfactory. See Fig. 18.

(2) The mortars aboard the package were fired to ranges equivalent to from 1000 to 3400 feet at lunar gravity. On firm lake bed material, embedding of the spikes restricted motion of the package to 5/8" longitudinally. On loose dust base (Portland cement) the package was shifted 13" to the rear but without directional change.

(3) Transmitter switches on all projectiles functioned and all fuses ignited.

(4) The programmer functioned properly.

The development model transmitter was fired several times to muzzle velocities of 150 fps or more without failure. These launches were made from a separate test mortar; no transmitters were included in the package shots.

It should be noted that preliminary to testing of the complete package many individual tests of mortars, encoders, fuses etc., were made. No explosives were carried in any of the projectiles. It was not considered necessary to verify the behavior of seismic amplifiers, geophone or the refraction determination technique with the model since these are already well defined by common usage. Effort was concentrated on the less conventional components and techniques.

Following are notes on the behavior of some items studied in the system development, paralleling experiments, alternate devices and suggestions of subjects for further study.

Projectile and Line Behavior

No attempt was made to control the attitude of the projectile and it was observed to tumble somewhat in flight. Being in the presence of atmosphere this may have been aerodynamic, or due to unsymmetrical forces at launch, or from the metering line; in any case it was regarded as unimportant.

In most tests a nylon line of .010" diameter was used. This material weighs only 2 grams per 100 ft. and is very strong. Friction at the reservoir with line removal of 100 fps was measured at 4 grams. Projectiles are decelerated by line friction and forces due to acceleration of the line mass. If the total of the forces are taken to be constant over the entire flight time, in vacuum and at lunar gravity, the range of a projectile weighing 500 grams launched with a velocity of 100 fps will be shortened from approximately 1900 ft. to about 1600 ft. With allowance for air resistance, these figures compare well with those observed in field tests in which range was shortened from about 1000 ft. to 750 ft.

In atmosphere and with the only friction loading being that due to removal from the spool, the metering line floated and closely followed the trajectory of the projectile. Slack line measured to be almost the difference between the straight line and the trajectory length. Addition of slight friction at the spool by encoder contacts or break-wires reduced the slack to negligible amounts.

Range shortening was small in tests of an encoder in which a loop of line was pulled from between contact leaves; it was somewhat greater in one using break-wires. Fig. 11 was recorded using the latter encoder but with break-wires somewhat heavier than necessary. Note that near the end of the flight the velocity of line removal from the spool is also reducing due to change in direction of the projectile, particularly with high trajectories. The effect of friction and mass acceleration can be offset by increases in propelling charge. Since propelling charge required is small, this is not difficult.

In vacuum and at lunar gravity, the light line will follow approximately a straight line from the reservoir to the projectile, the straightness depending on mass of the line to be accelerated by changing direction of the projectile along the trajectory, on tension in the line and sag under gravity. A tolerance of range measurement of $2\frac{1}{2}$ per cent has been accepted as being adequately precise. Each encoder is arranged to sample as many as 20 increments of line length each equal to $2\frac{1}{2}$ per cent of the planned range, after an initial fixed minimum is extended.

Tests made with fine parallel copper wire 'cable' (Spectra-Strip 2-42) were successful. Range was shorter than with nylon line due to increased mass to be accelerated and additional friction at the spool. Use of a conducting cable opens an avenue to wire transmission of data, time break, detonating signal, etc. No failures resulted in tests of the wire line.

Shrouding of the metering line spool reduces whipping of the line, protects the encoder and provides a means of sealing the mortar unit if desired.

Geophone distribution

An experimental self-orienting geophone (Fig. 19) capable of withstanding distribution by mortar was constructed and fired with a muzzle velocity of 150 fps. A 2 wire cable as above was connected to the unit; continuity was maintained and the geophone suffered only minor damage, (cracking of ceramic insulators). This device was of proportions in which its length was large compared to its diameter so that in almost any situation it would lie so that its response axis would be near vertical, the active element is trunioned about the axis on elastic mounted bearings; in the test it oriented properly.

Alternate mortar bases

Several alternate mortar bases were tested. Among these were two in which the mortar was freely mounted in an encasing tube allowing the mortar to drop until the breech rested directly on the ground, thus applying recoil to the ground instead of to the base. One of these units was an inflatable device shown in Fig. 20. Properly folded, it will orient right side up regardless of emplacement attitude (see Fig. 21). In test, all five tubes were charged alike and 1 lb. projectiles were thrown into a 40 ft. group at 500 ft. range. The second unit embodied mechanical casing and support members similar in principle to that shown in Fig. 16, except that the mortars were aligned normal to the launch axis and on opening the case cover became the elevation support.

Items for further study

(1) Completely sealed containers for all components for use in event that long term storage on the lunar surface is required before or after deployment. This must include a study of materials survival to lunar environment.

(2) Alternate detonation systems, including remote triggering by wire line, etc.

(3) Acceleration and time-delay arming of the projectile to eliminate hazard of explosion in the vicinity of the base

station.

(4) Containment of gases from the launch explosion and projectile explosion, and anti-recoil methods for application to the mortar.

(5) Gas front propagation and its behavior relative to acceleration of surface debris as well as its reception by the geophone.

(6) Study of best mortar and charge techniques.

(7) Methods of projectile shrapnel suppression.

(8) Study the coupling of energy into the ground from very small explosions to ascertain if the relationship of energy versus charge remains linear as the charge is reduced to very small amounts of explosive.

It is possible that the gas front propagation may be of a velocity such that it will arrive at the geophone simultaneously with the desired seismic signals. If of sufficient energy, it could seriously interfere with the data signal.

Even on launch to maximum range the pressure within the mortar tube does not exceed a value easily contained in thin walled vessels. It appears to be a relatively simple matter to eliminate muzzle blast by placing a perforated closure disc behind the projectile; on launch, the disc is retained at the muzzle, containing the gas, which leaks slowly. Some experimentation was done on this with very promising results, including some reduction in recoil.

It was found in our experiments that within reasonable dimensions, mortar length had little effect on projectile velocity. Barrel lengths from a fraction of the projectile length to 1½ times its dimension were tried. Loading was such as to give a velocity of approximately 100 fps; velocity dropped slightly with the longer barrel and substantially with a very short length. We chose a barrel slightly in excess of the projectile length for convenience in packaging.

Accompanying this report is a reel of 16 mm mortar pictures including both normal and high speed (200 fr/sec) photos of several mortar firings, showing behavior of bases, line extension, etc. Note that the high speed camera has a lens coverage angle near 180°; this gives the projectiles in flight the appearance of curving as they approach the edge of the field.

It is felt that the goal of this grant has been achieved in that distribution by mortar has been demonstrated to be a valid method. A number of devices have been constructed to serve as a starting place in the design of flight hardware when the particular requirements for a designated flight are known and specified.

F. E. Lehner
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12/31/64

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Draftsman	½
Secretary	½

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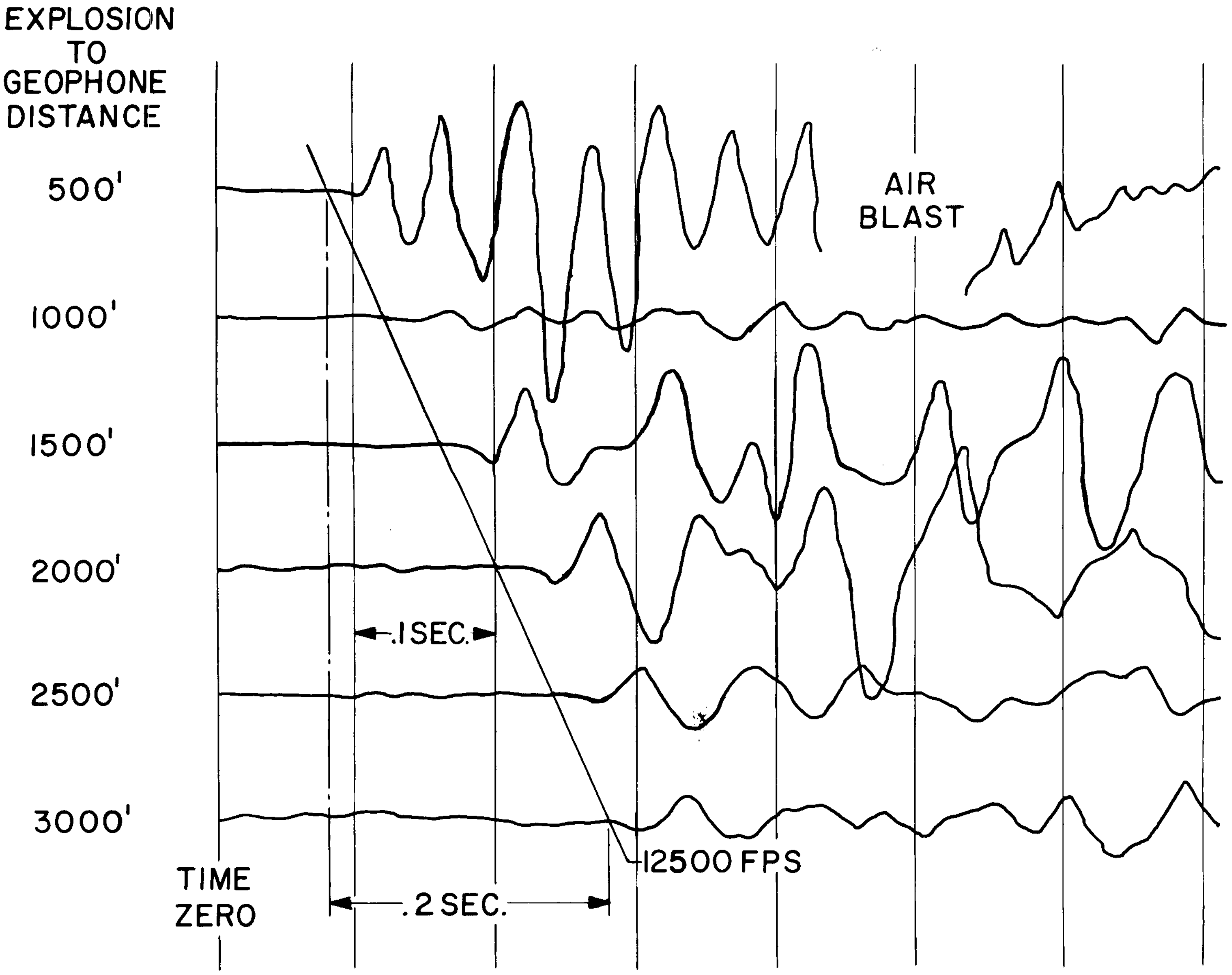
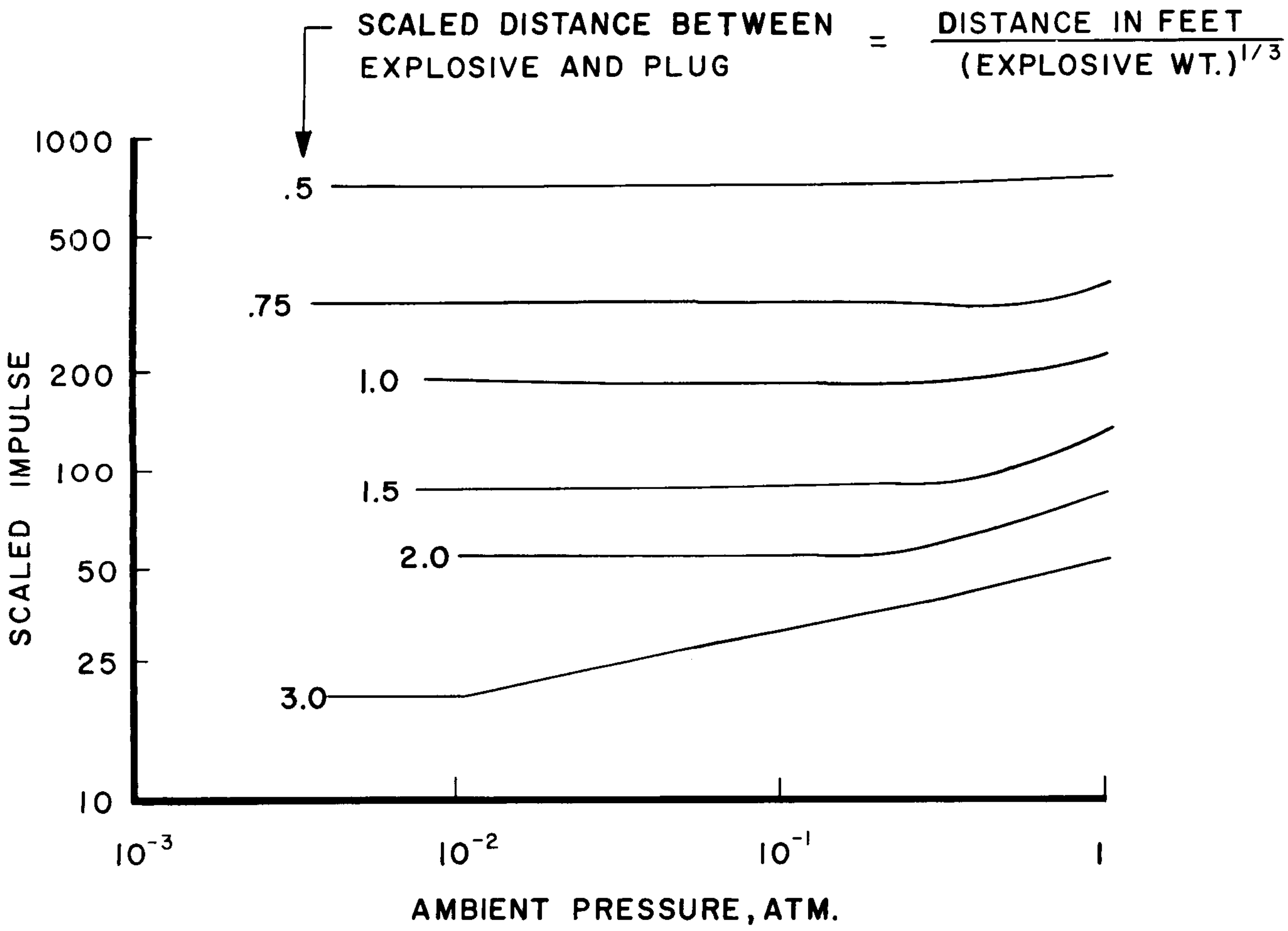
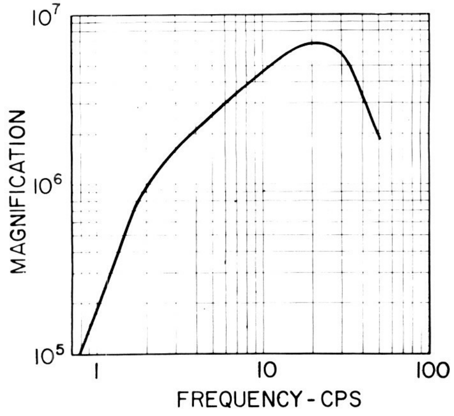

EXPLOSION
TO
GEOPHONE
DISTANCE
500'
1000'
1500'
2000'
2500'
3000'
TIME
ZERO
.1 SEC.
.2 SEC.
12500 FPS
AIR
BLAST

Figure 1

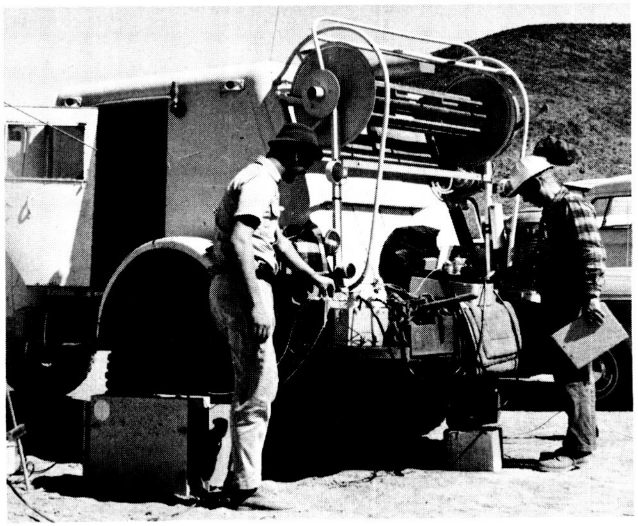


IMPULSE AS A FUNCTION OF SCALED DISTANCE AND AMBIENT PRESSURE

Figure 2



(a)



(b)

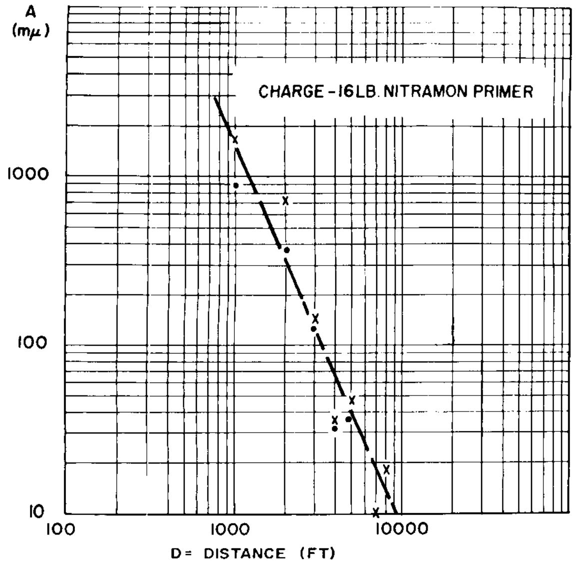
(c)

(a) MAGNIFICATION VS FREQUENCY RESPONSE OF TEST EQUIPMENT.

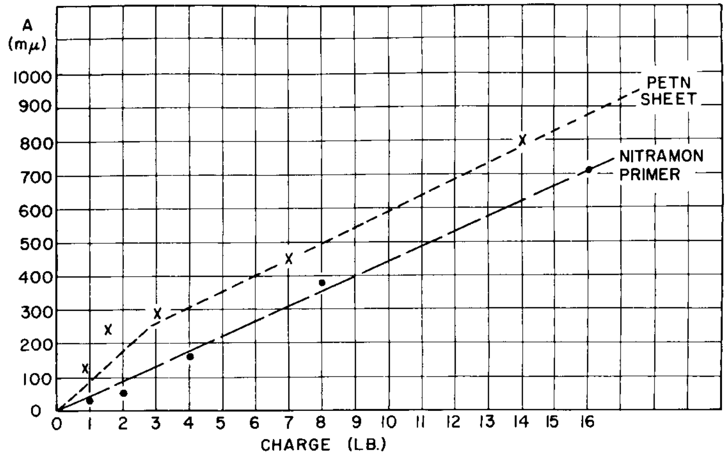
(b) PART OF INSTRUMENTATION USED IN TEST.

(c) PETN CHARGE EMPLACEMENT.

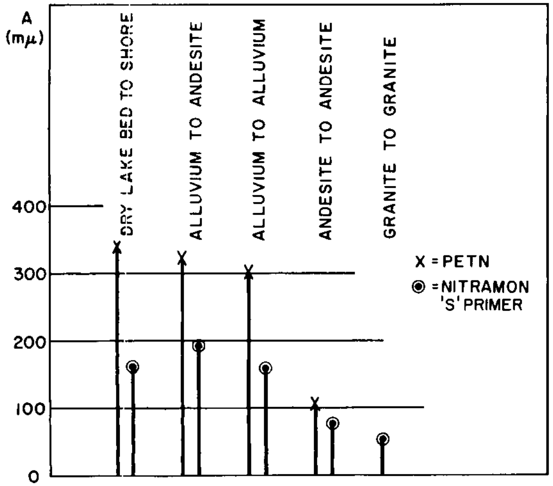
Figure 3



(a)



(b)



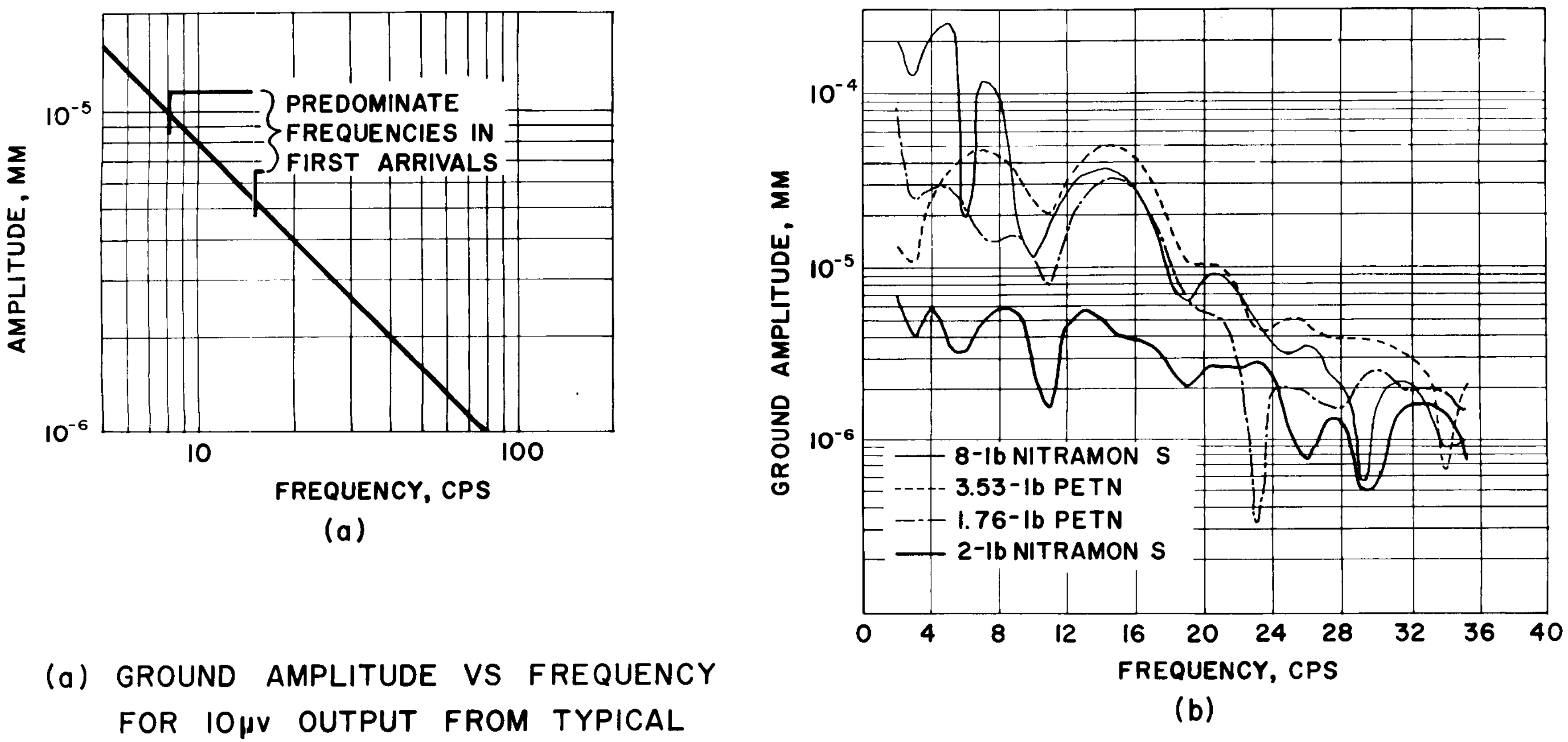
(c)

(a) - GROUND AMPLITUDE FALL-OFF WITH DISTANCE.

(b) - GROUND AMPLITUDE VS CHARGE SIZE AT 1000 FT DISTANCE.

(c) - COMPARISON OF GROUND AMPLITUDES WITH EXPLOSIONS AND GEOPHONE ON VARIOUS MATERIALS.

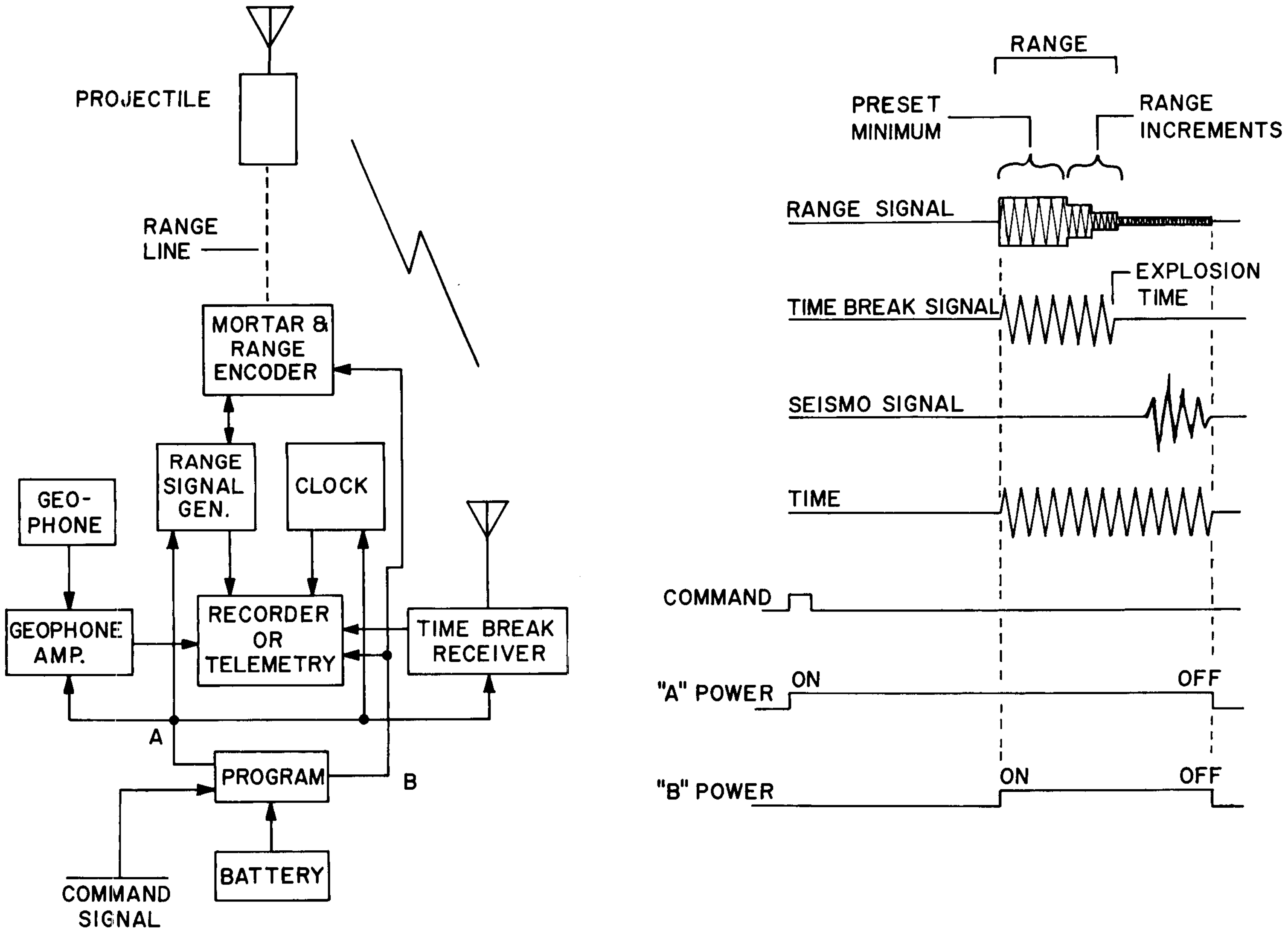
Figure 4



(a) GROUND AMPLITUDE VS FREQUENCY FOR 10μv OUTPUT FROM TYPICAL GEOPHONE.

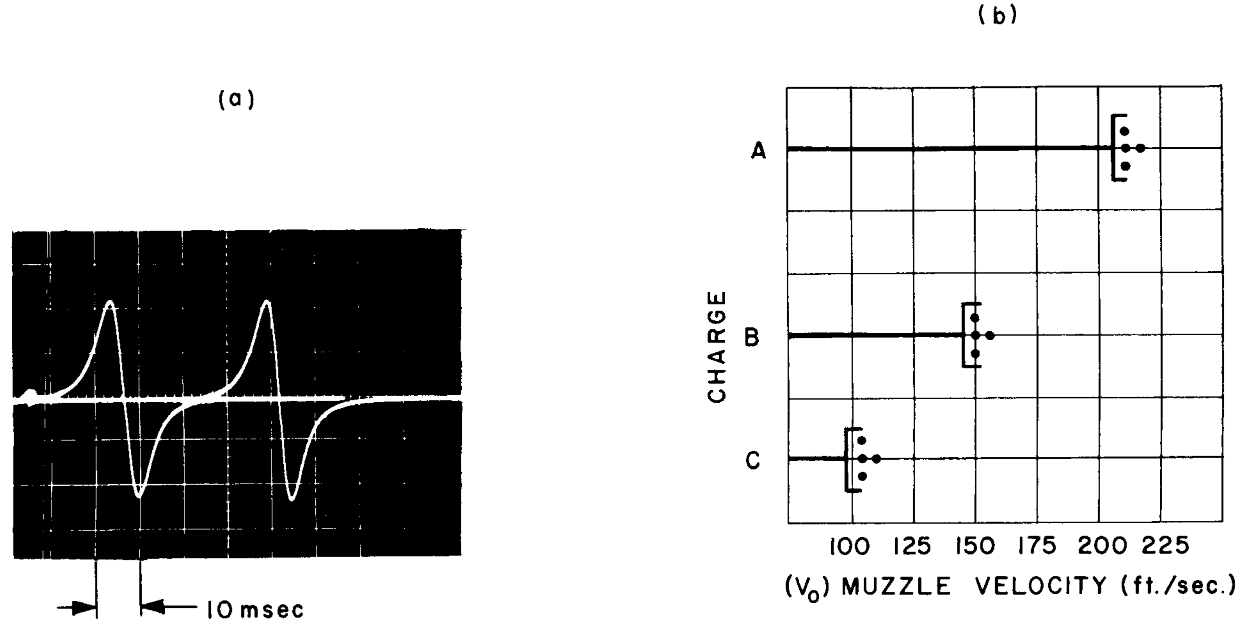
(b) GROUND AMPLITUDE VS FREQUENCY DISTRIBUTION FROM EXPLOSIONS AT 1000 FEET DISTANCE.

Figure 5



SCHEMATIC OF LUNAR SEISMIC
REFRACTION SYSTEM

Figure 6



TYPICAL MUZZLE VELOCITY
MEASUREMENT (V_0)

CHARGE:
A = 1000mg "BULLS EYE"
B = 350mg HERCULES H-4
C = 200mg HERCULES H-4

V_0 VS PROPELLING CHARGE
(1LB. PROJECTILE)

Figure 7

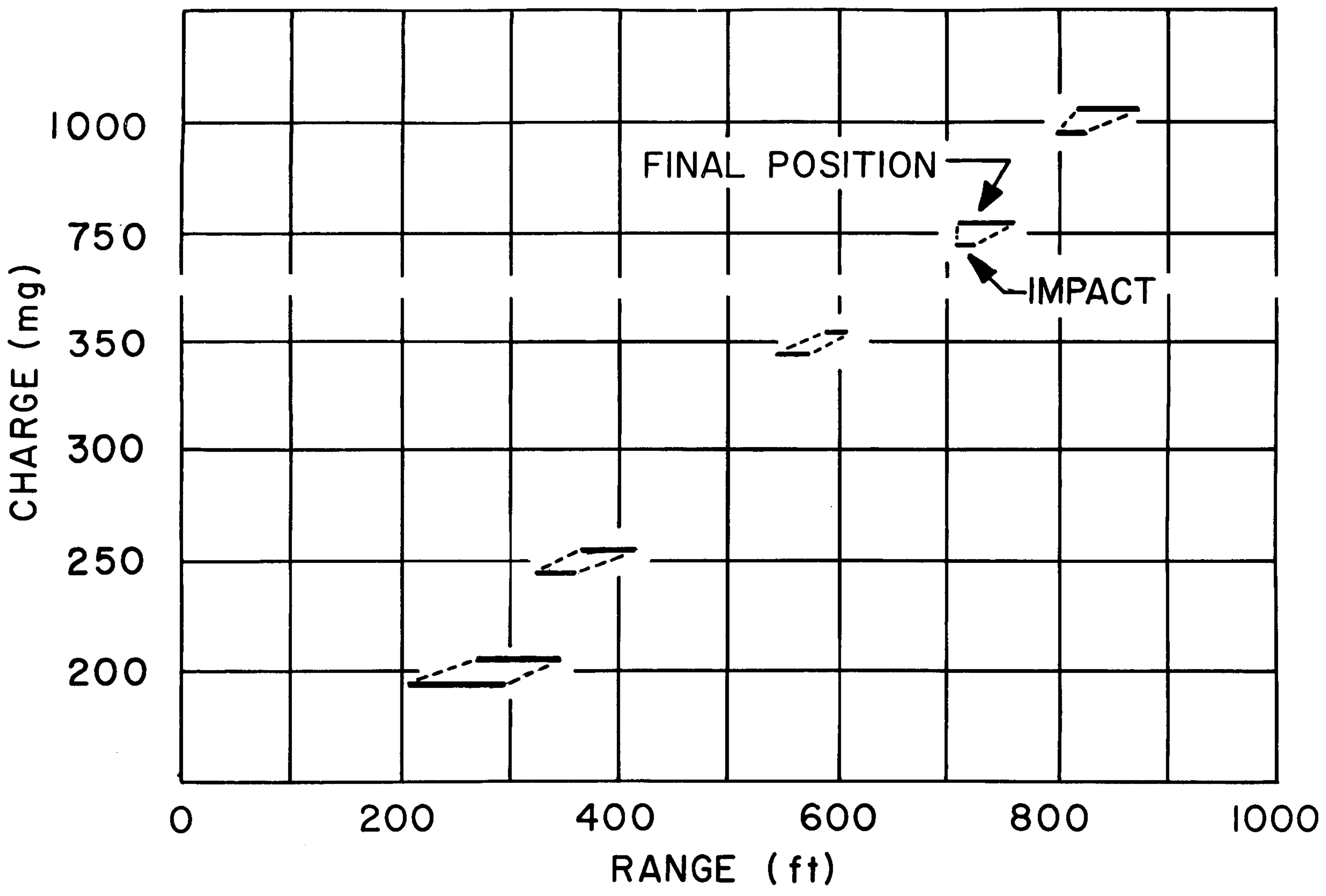

FINAL POSITION
IMPACT
CHARGE (mg)
1000
750
350
300
250
200
0
200
400
600
800
1000
RANGE (ft)

Figure 8

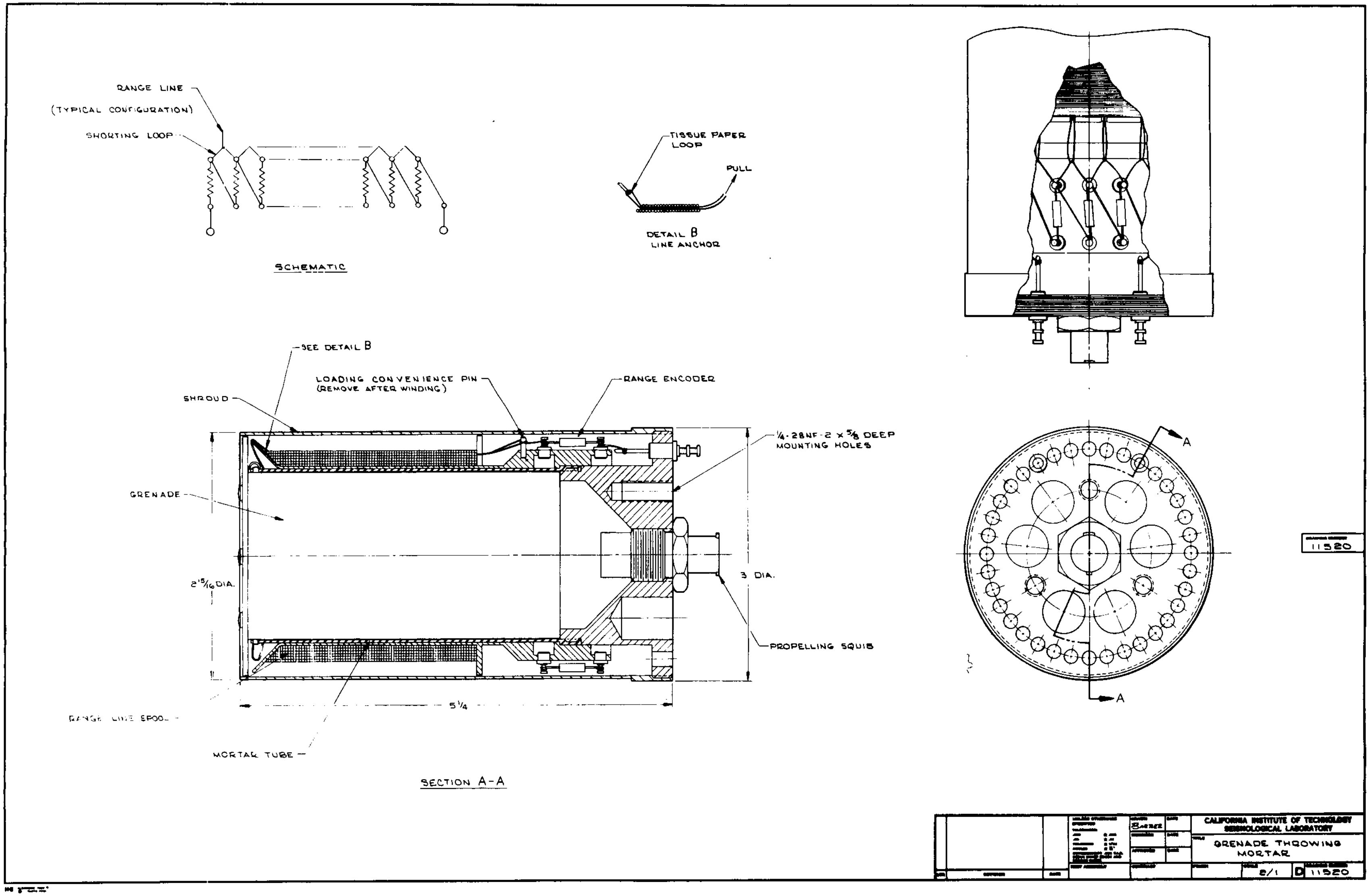

RANGE LINE
(TYPICAL CONFIGURATION)
SHORTING LOOP
SCHEMATIC
TISSUE PAPER LOOP
PULL
DETAIL B
LINE ANCHOR
SEE DETAIL B
LOADING CONVENIENCE PIN (REMOVE AFTER WINDING)
RANGE ENCODER
SHROUD
GRENADE
¼-28NF-2 x ⅝ DEEP MOUNTING HOLES
2 15/16 DIA.
3 DIA.
PROPELLING SQUIB
5¼
RANGE LINE SPOOL
MORTAR TUBE
SECTION A-A
A
A
11520
CALIFORNIA INSTITUTE OF TECHNOLOGY
SEISMOLOGICAL LABORATORY
GRENADE THROWING MORTAR
Barber
2/1
D
11520

Figure 9

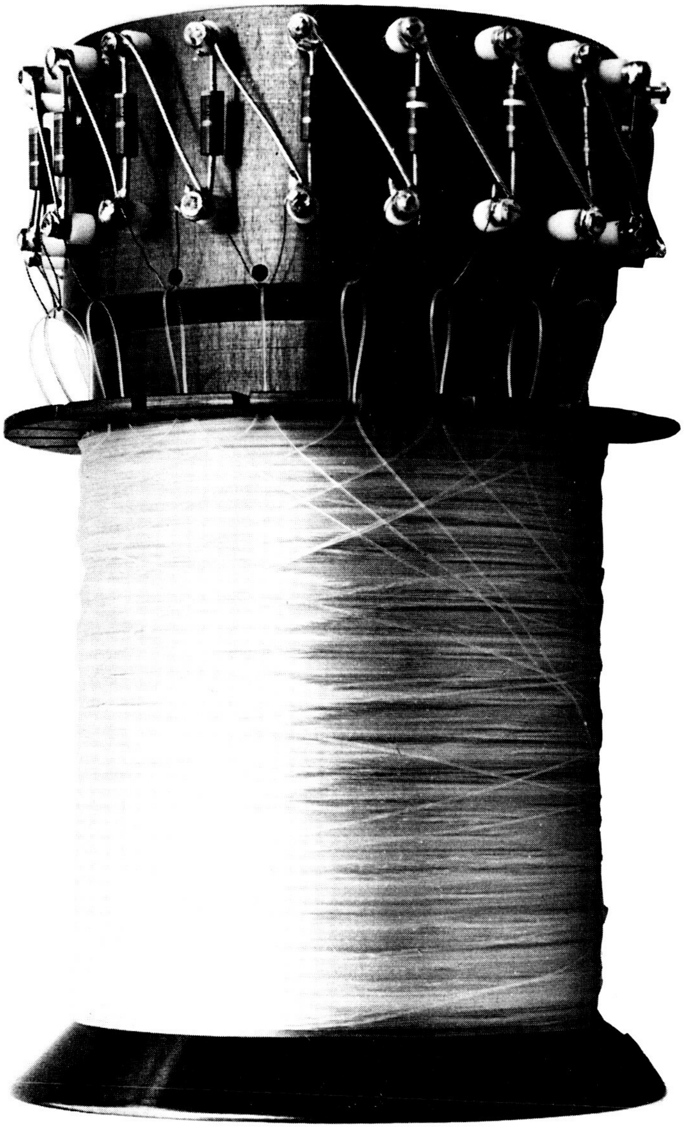


Figure 10

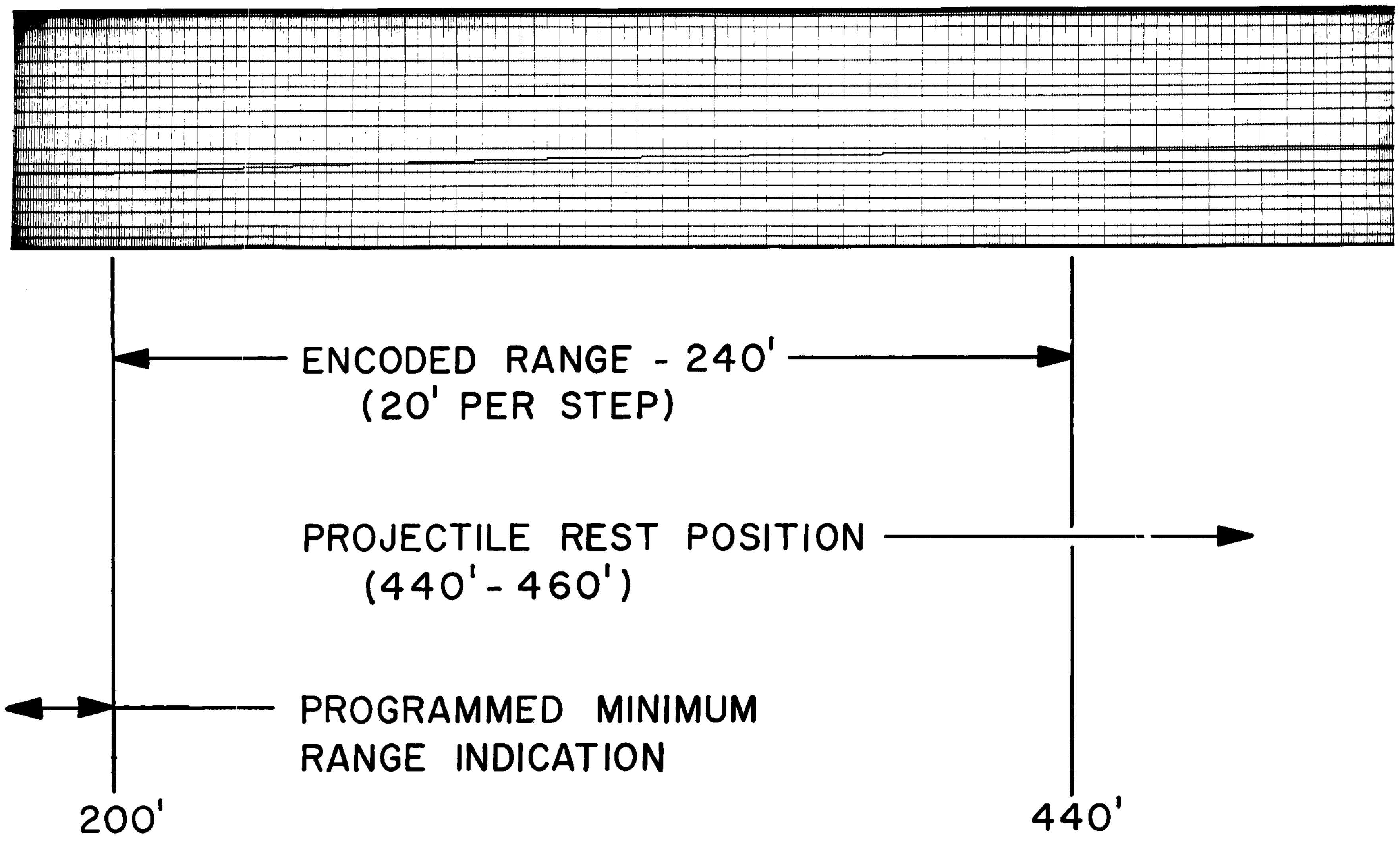
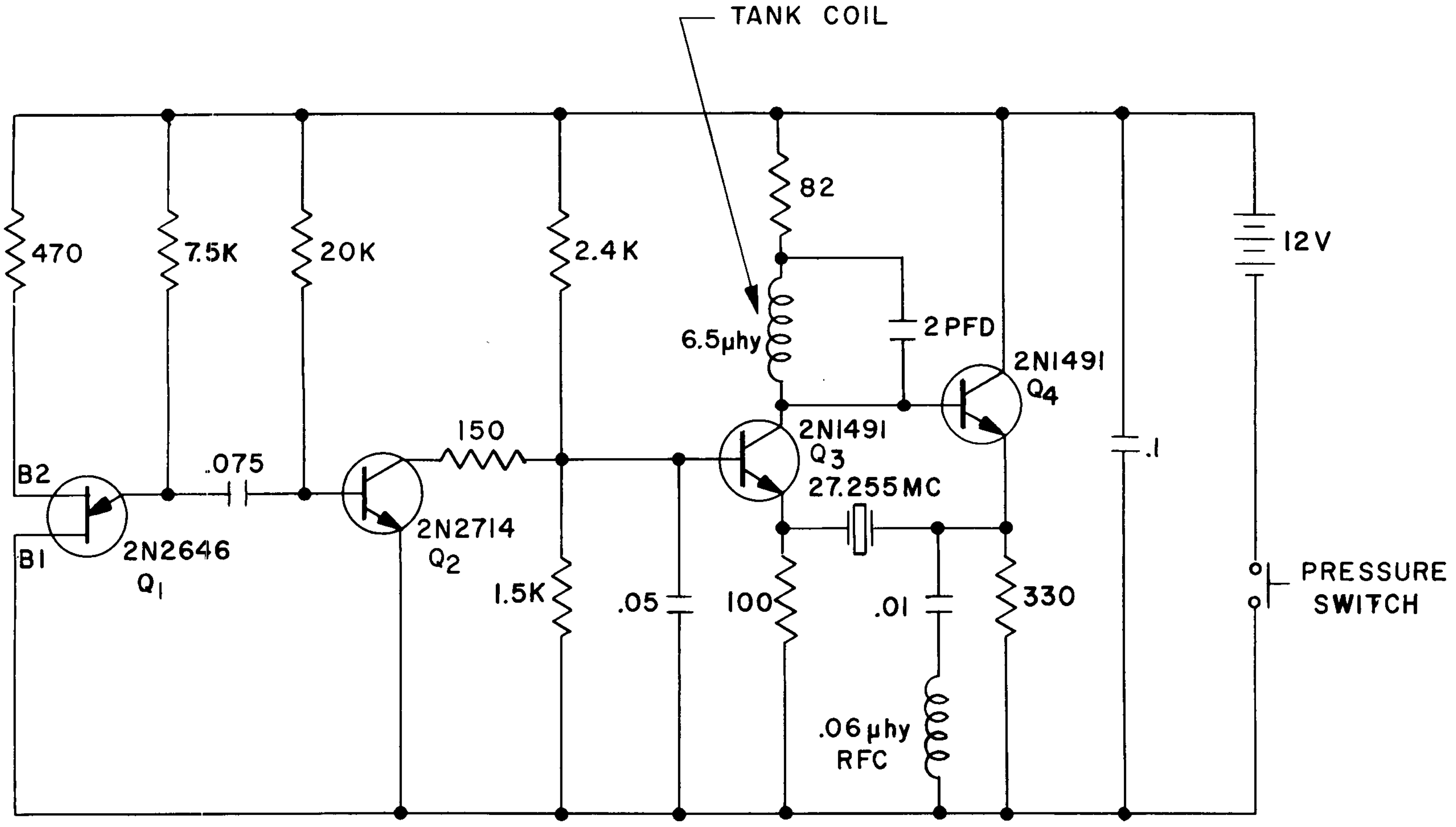

ENCODED RANGE - 240'
(20' PER STEP)
PROJECTILE REST POSITION
(440'-460')
PROGRAMMED MINIMUM
RANGE INDICATION
200'
440'

Figure 11



SCHEMATIC

Figure 12a

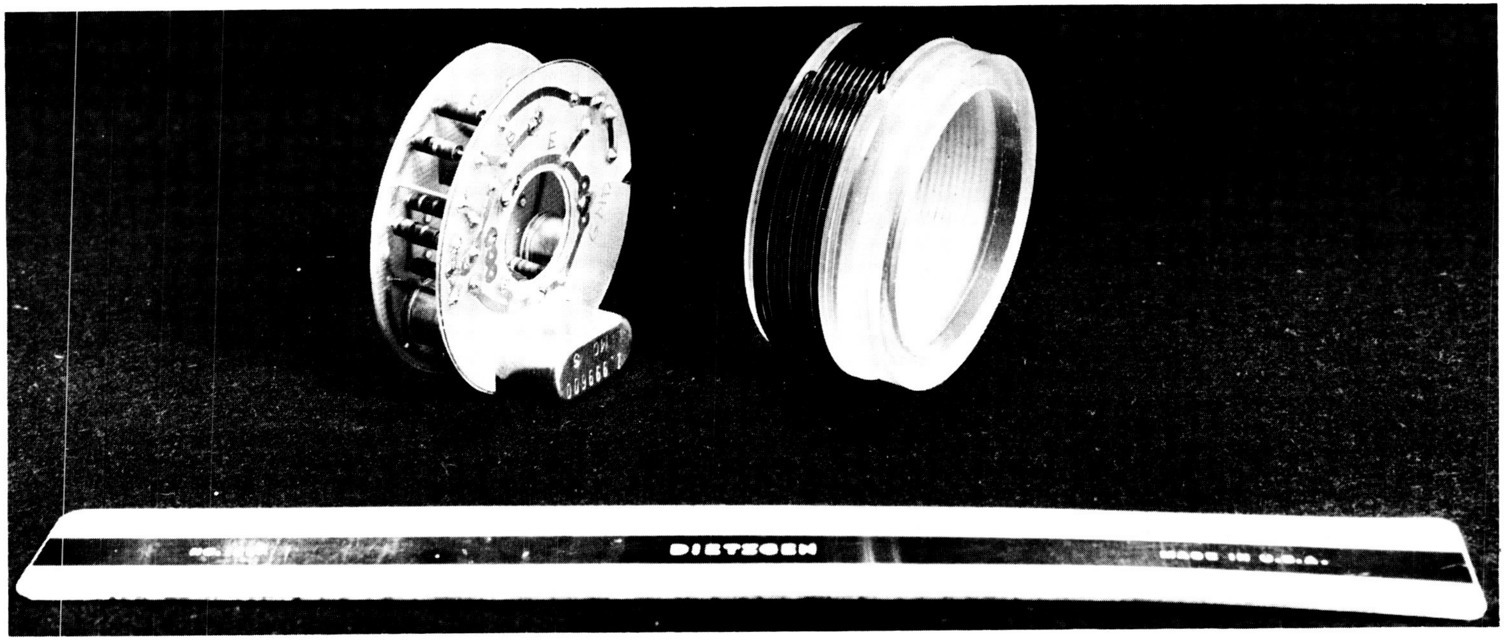


Figure 12b

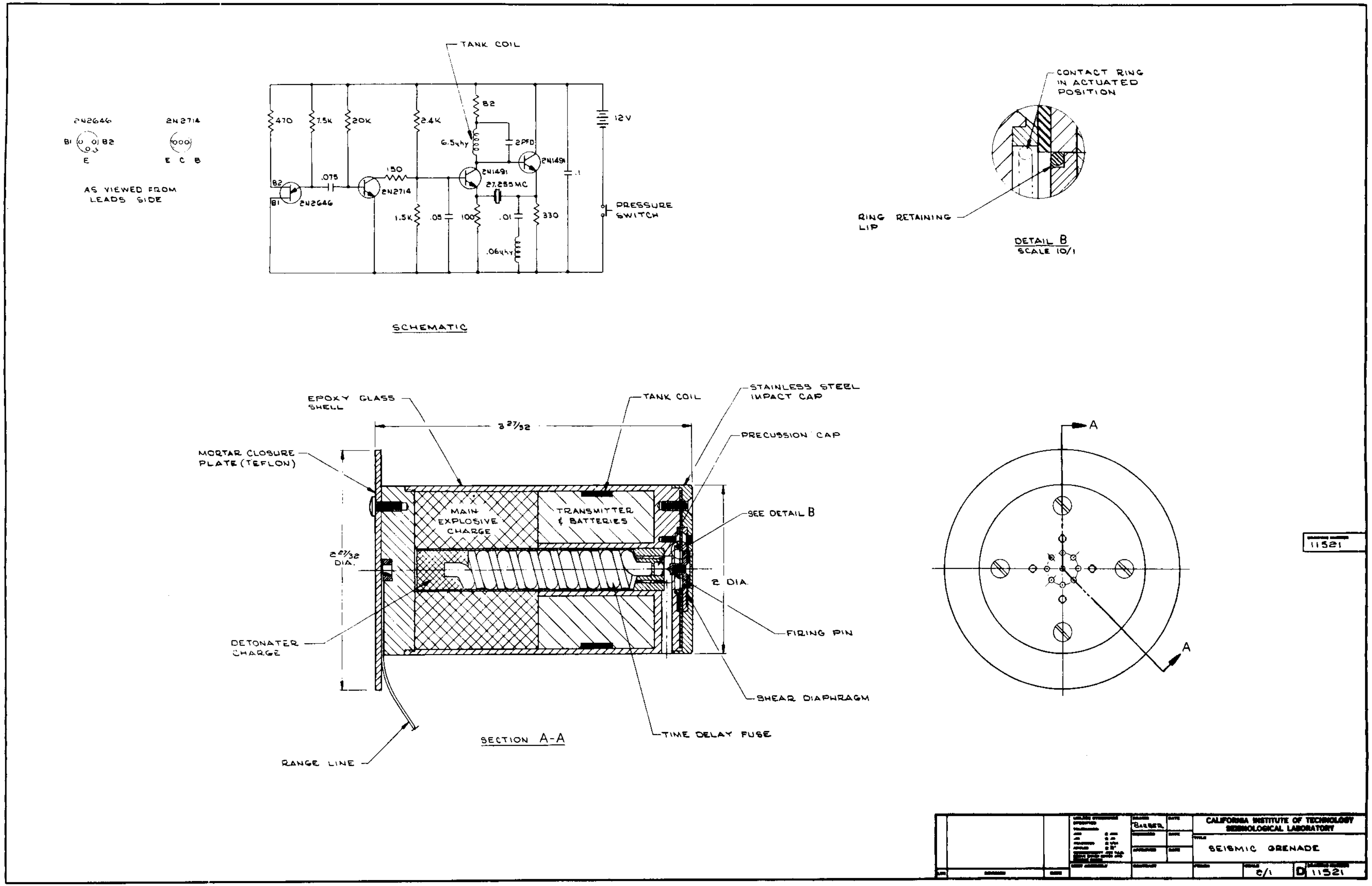

TANK COIL
2N2646
B1 E B2
2N2714
E C B
AS VIEWED FROM LEADS SIDE
470
7.5K
20K
2.4K
82
6.5μhy
2PFD
2N1491
2N1491
.1
12V
B2
B1
2N2646
.075
150
2N2714
27.255MC
1.5K
.05
100
.01
330
.06μhy
PRESSURE SWITCH
SCHEMATIC
CONTACT RING IN ACTUATED POSITION
RING RETAINING LIP
DETAIL B
SCALE 10/1
EPOXY GLASS SHELL
TANK COIL
STAINLESS STEEL IMPACT CAP
PRECUSSION CAP
3 27/32
MORTAR CLOSURE PLATE (TEFLON)
MAIN EXPLOSIVE CHARGE
TRANSMITTER & BATTERIES
SEE DETAIL B
2 27/32 DIA.
2 DIA.
DETONATER CHARGE
FIRING PIN
SHEAR DIAPHRAGM
TIME DELAY FUSE
SECTION A-A
RANGE LINE
A
A
11521
BARBER
CALIFORNIA INSTITUTE OF TECHNOLOGY
SEISMOLOGICAL LABORATORY
SEISMIC GRENADE
2/1
D
11521

Figure 13

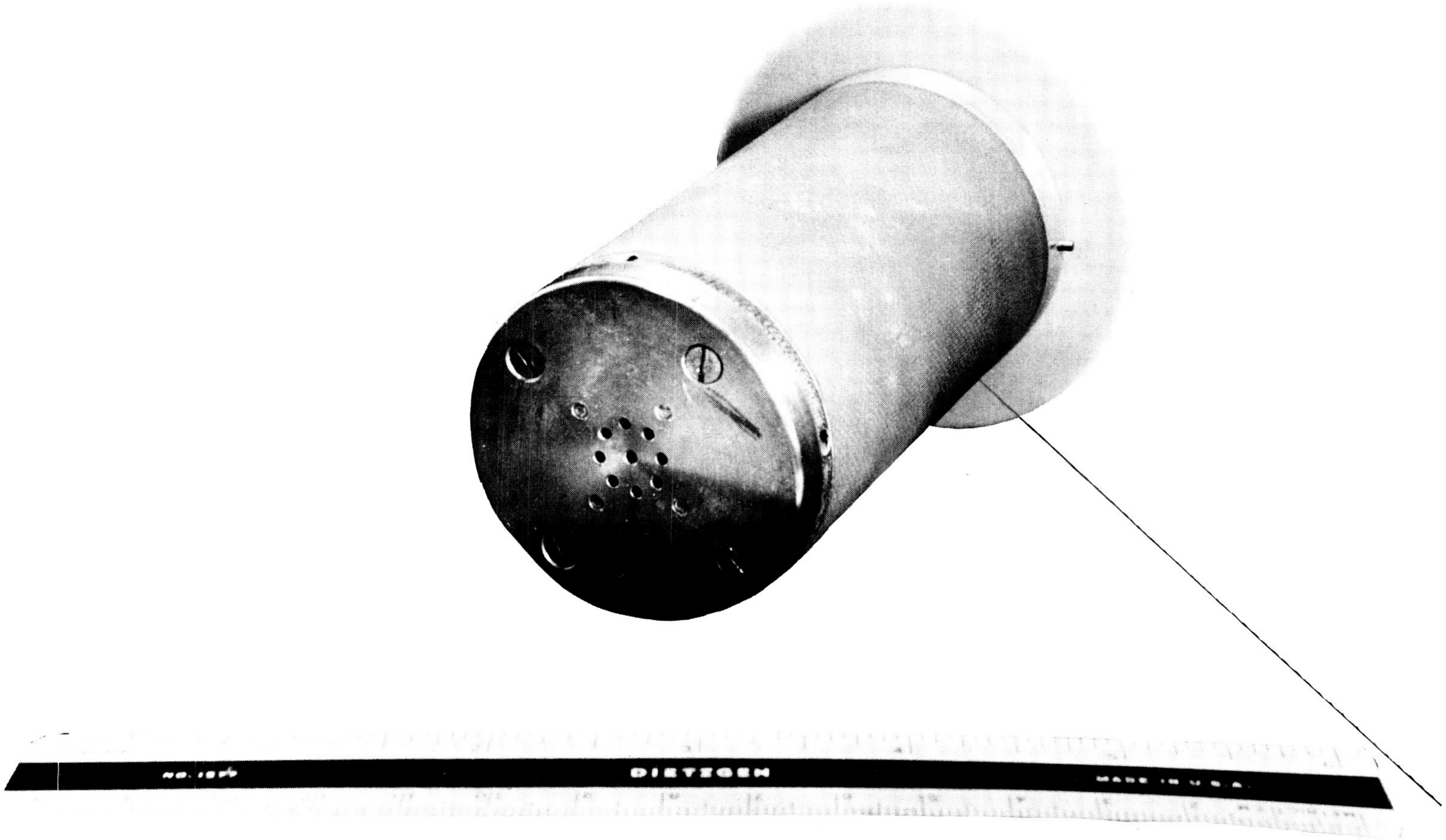


Figure 14

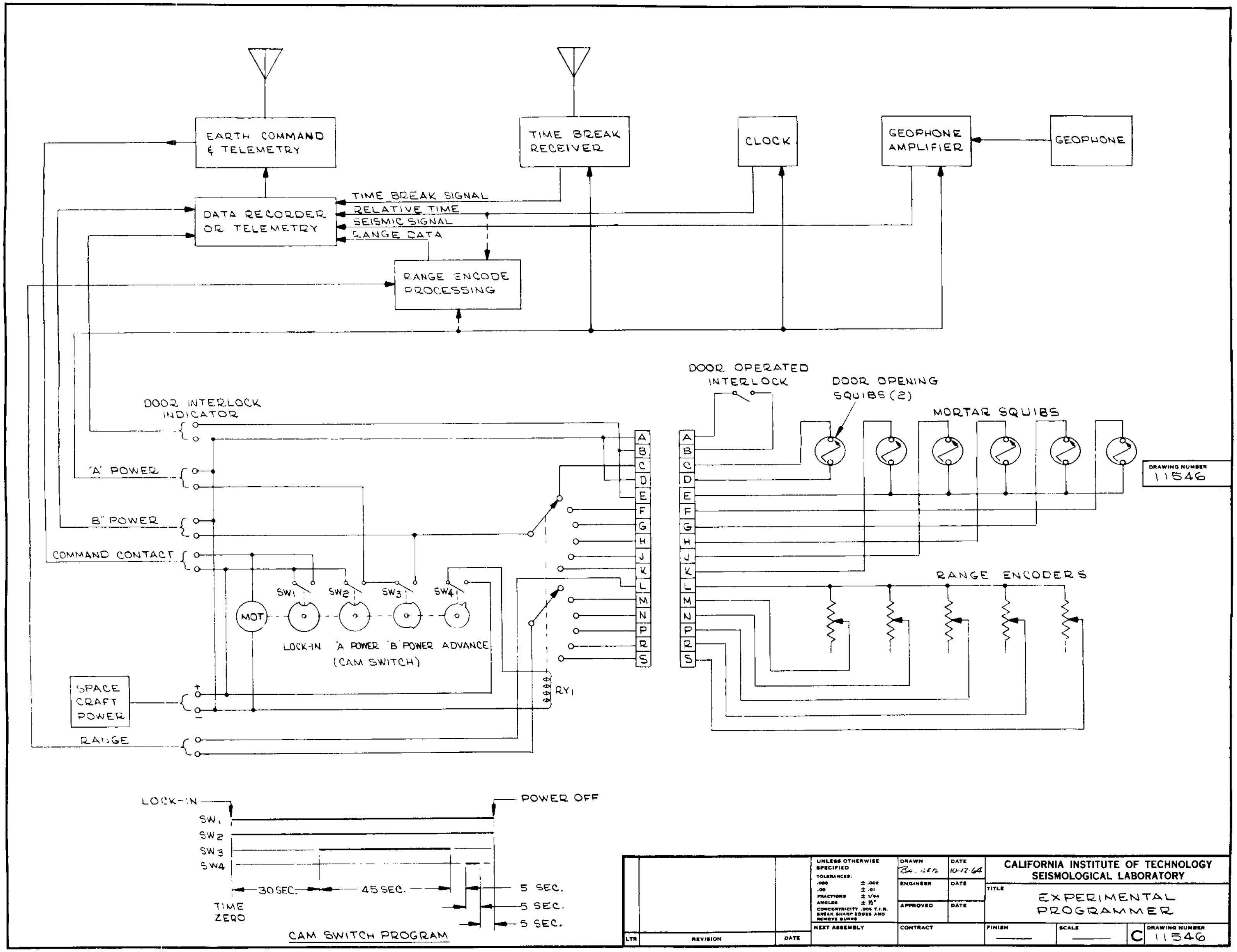

EARTH COMMAND & TELEMETRY
TIME BREAK RECEIVER
CLOCK
GEOPHONE AMPLIFIER
GEOPHONE
DATA RECORDER OR TELEMETRY
TIME BREAK SIGNAL
RELATIVE TIME
SEISMIC SIGNAL
RANGE DATA
RANGE ENCODE PROCESSING
DOOR OPERATED INTERLOCK
DOOR OPENING SQUIBS (2)
MORTAR SQUIBS
DRAWING NUMBER 11546
DOOR INTERLOCK INDICATOR
"A" POWER
"B" POWER
COMMAND CONTACT
A B C D E F G H J K L M N P R S
SW1 SW2 SW3 SW4
MOT
LOCK-IN "A" POWER "B" POWER ADVANCE
(CAM SWITCH)
RANGE ENCODERS
SPACE CRAFT POWER
+
−
RY1
RANGE
LOCK-IN
POWER OFF
SW1
SW2
SW3
SW4
30 SEC.
45 SEC.
5 SEC.
5 SEC.
5 SEC.
TIME ZERO
CAM SWITCH PROGRAM
UNLESS OTHERWISE SPECIFIED
TOLERANCES: .000 ± .002 .00 ± .01 FRACTIONS ± 1/64 ANGLES ± ½° CONCENTRICITY .005 T.I.R. BREAK SHARP EDGES AND REMOVE BURRS
NEXT ASSEMBLY
DRAWN
DATE 10-17-64
ENGINEER
DATE
APPROVED
DATE
CONTRACT
CALIFORNIA INSTITUTE OF TECHNOLOGY SEISMOLOGICAL LABORATORY
TITLE
EXPERIMENTAL PROGRAMMER
FINISH
SCALE
C
DRAWING NUMBER 11546
LTR
REVISION
DATE

Figure 15

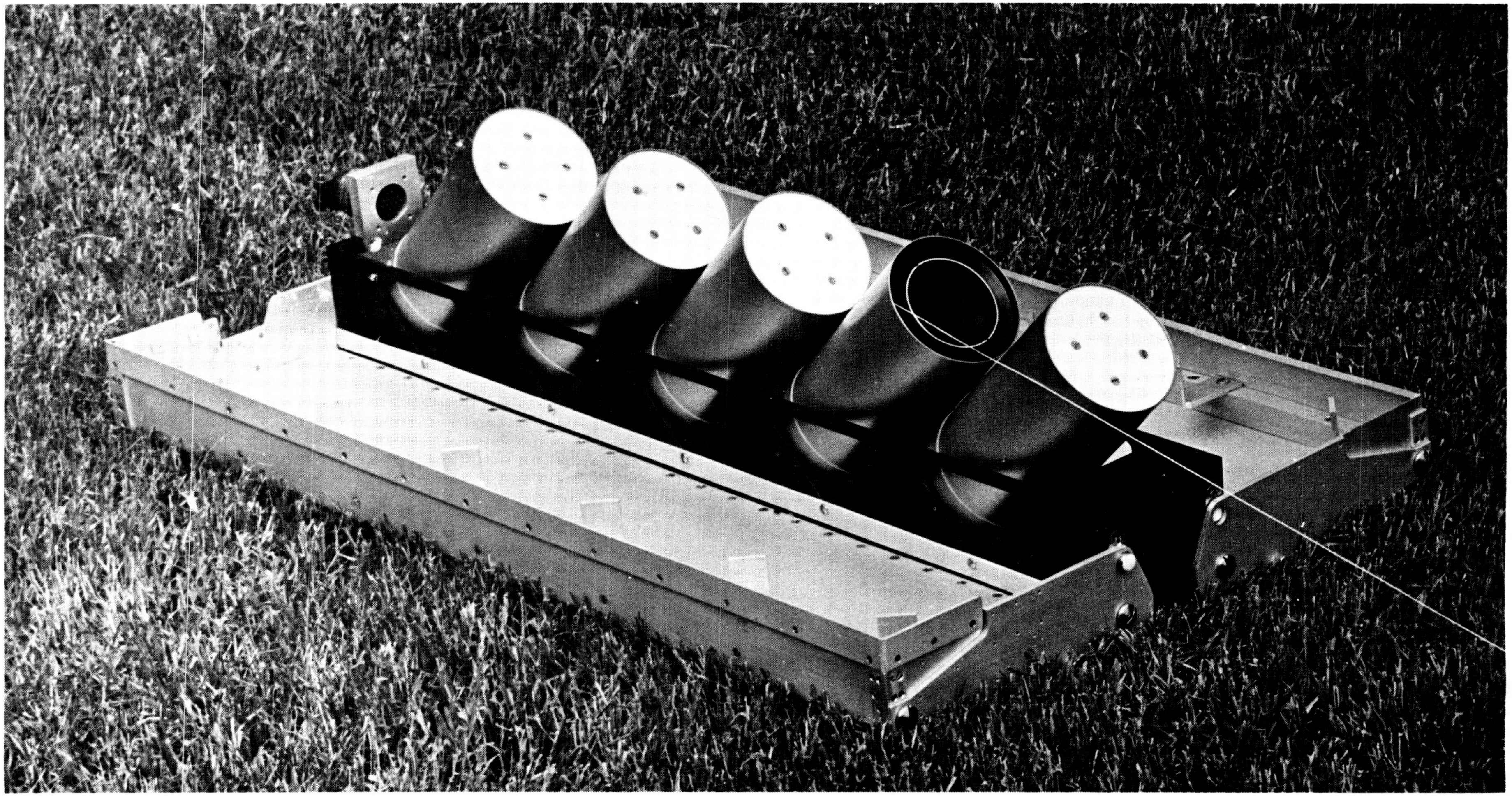


Figure 16a

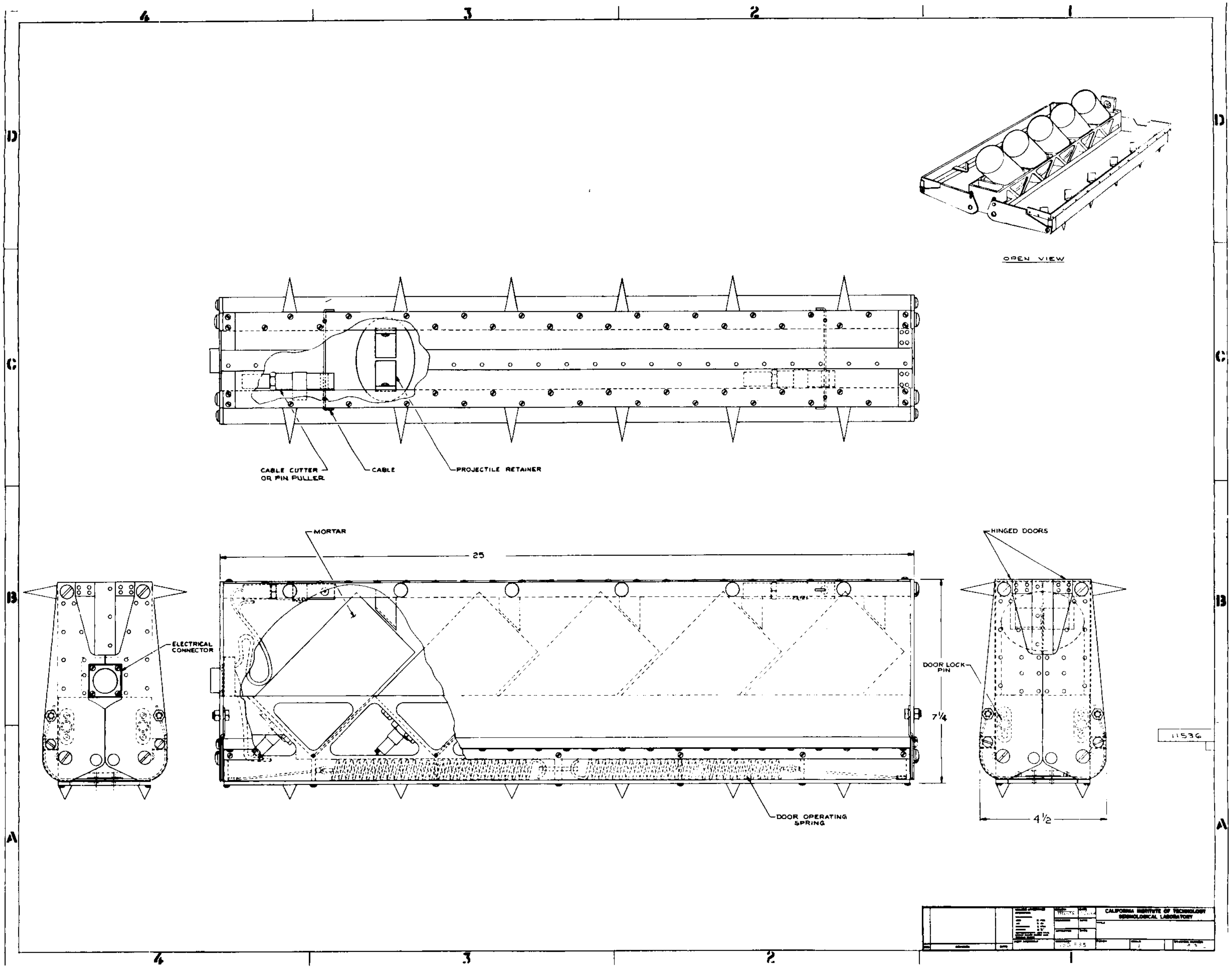

OPEN VIEW
CABLE CUTTER OR PIN PULLER
CABLE
PROJECTILE RETAINER
MORTAR
25
HINGED DOORS
ELECTRICAL CONNECTOR
DOOR LOCK PIN
7¼
4½
DOOR OPERATING SPRING
11536
CALIFORNIA INSTITUTE OF TECHNOLOGY
SEISMOLOGICAL LABORATORY

Figure 16b

Figure 17

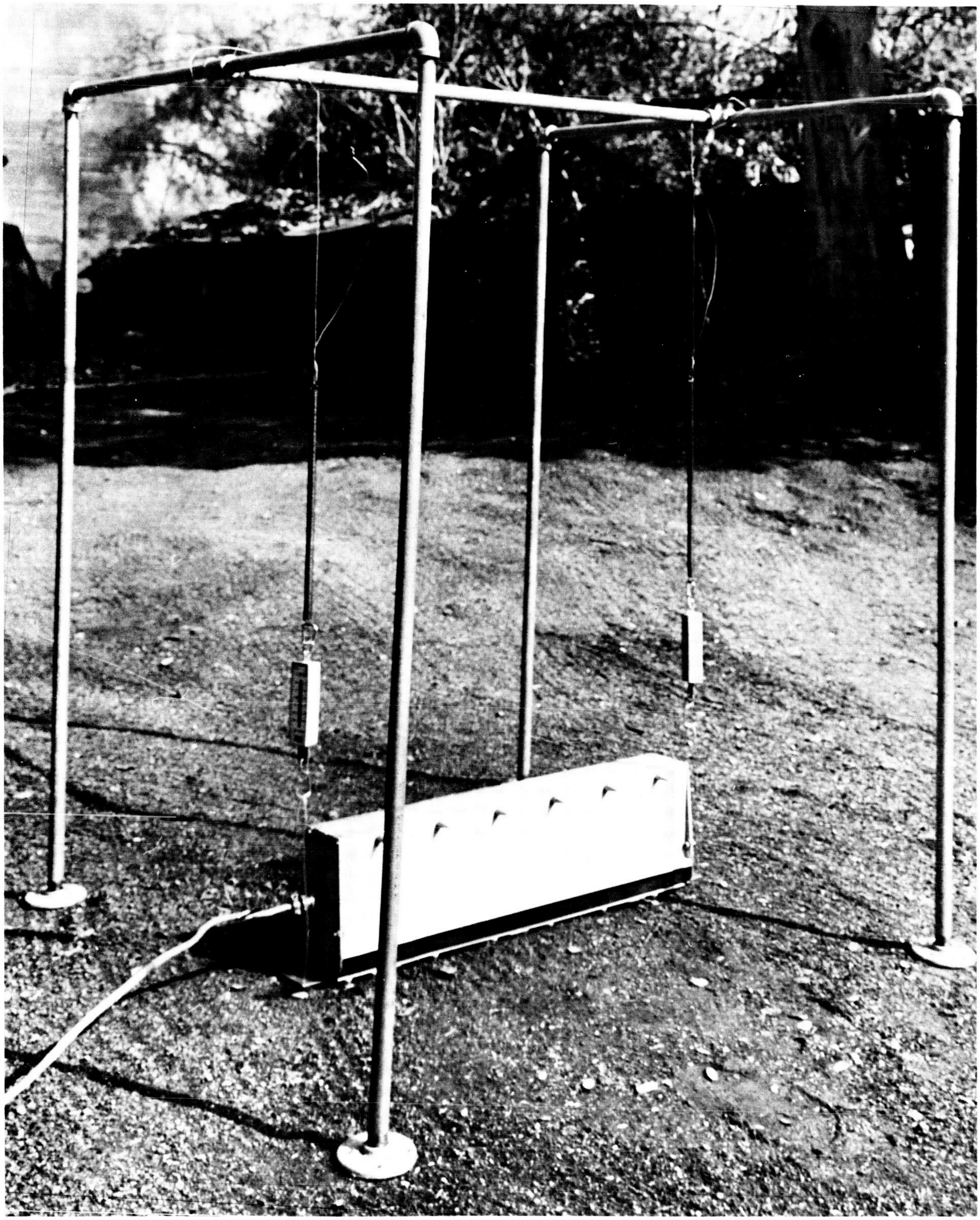
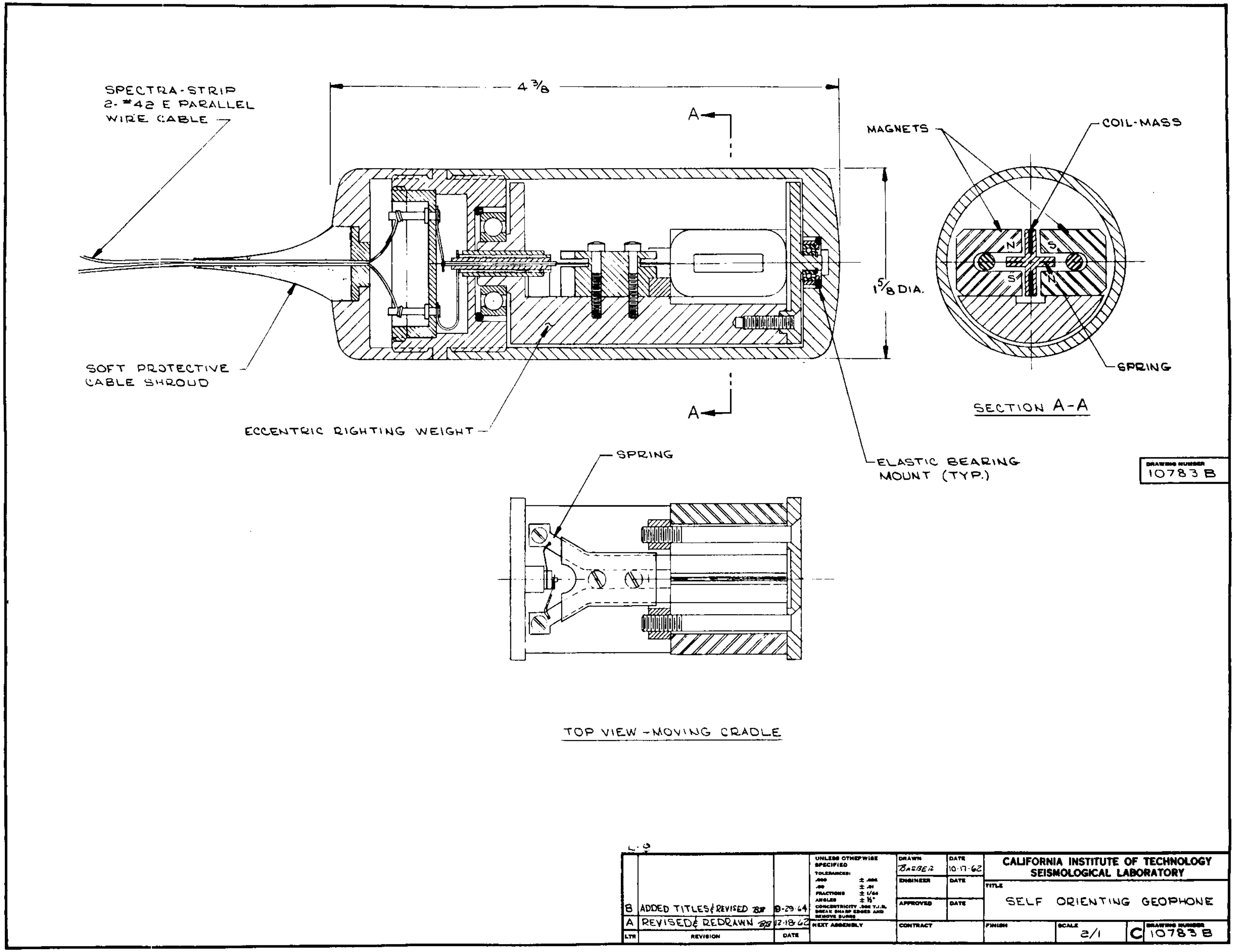


Figure 18



LTR	REVISION	DATE
B	ADDED TITLES & REVISED BB	8-29-64
A	REVISED & REDRAWN BB	12-18-62

UNLESS OTHERWISE SPECIFIED
TOLERANCES:
.000 ± .005
.00 ± .01
FRACTIONS ± 1/64
ANGLES ± ½°
CONCENTRICITY .005 T.I.R.
BREAK SHARP EDGES AND REMOVE BURRS
NEXT ASSEMBLY

DRAWN: Barber DATE: 10-17-62
ENGINEER: DATE:
APPROVED: DATE:
CONTRACT:

CALIFORNIA INSTITUTE OF TECHNOLOGY
SEISMOLOGICAL LABORATORY

TITLE: SELF ORIENTING GEOPHONE

FINISH:
SCALE: 2/1
C
DRAWING NUMBER: 10783 B

Figure 19

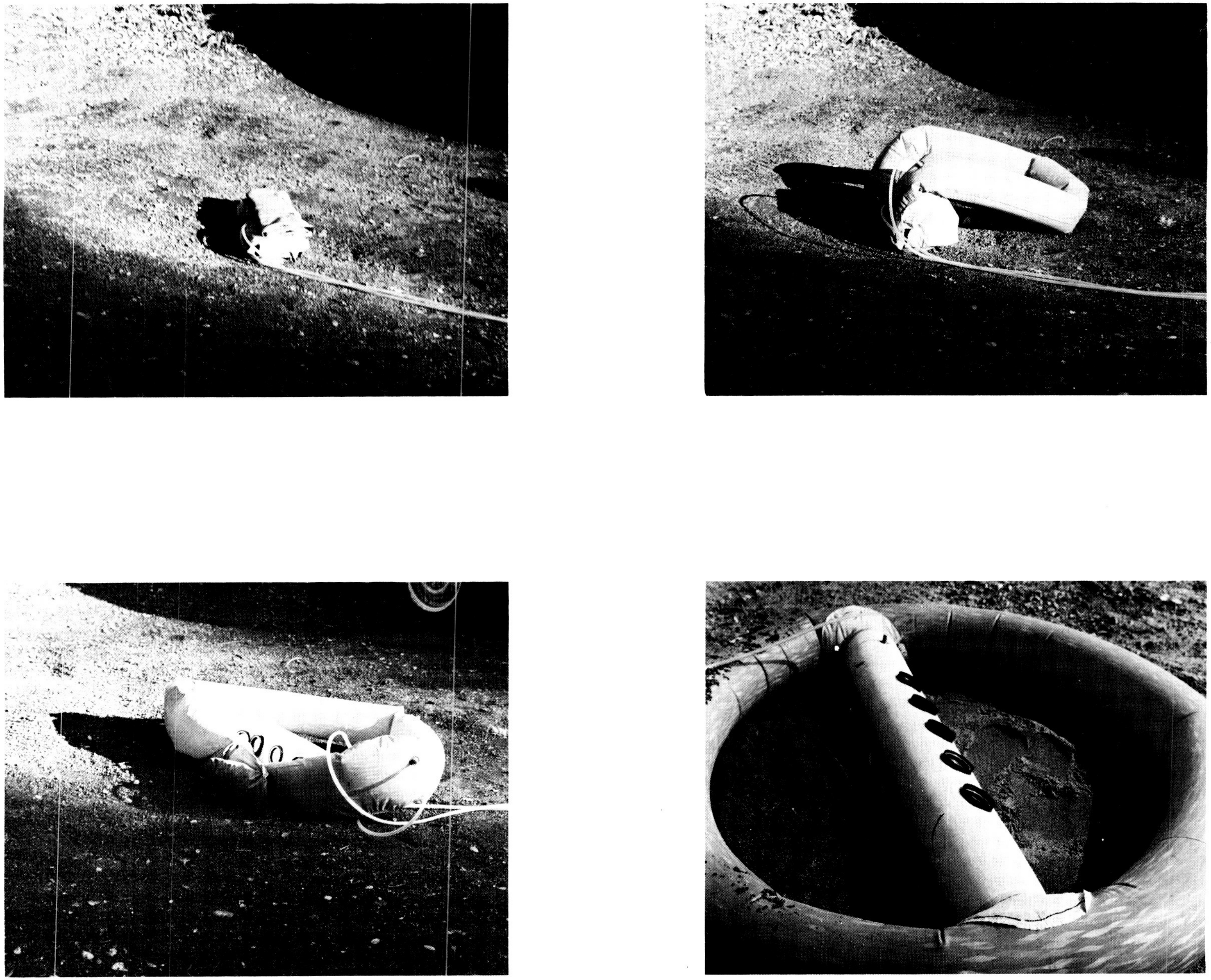


Figure 20

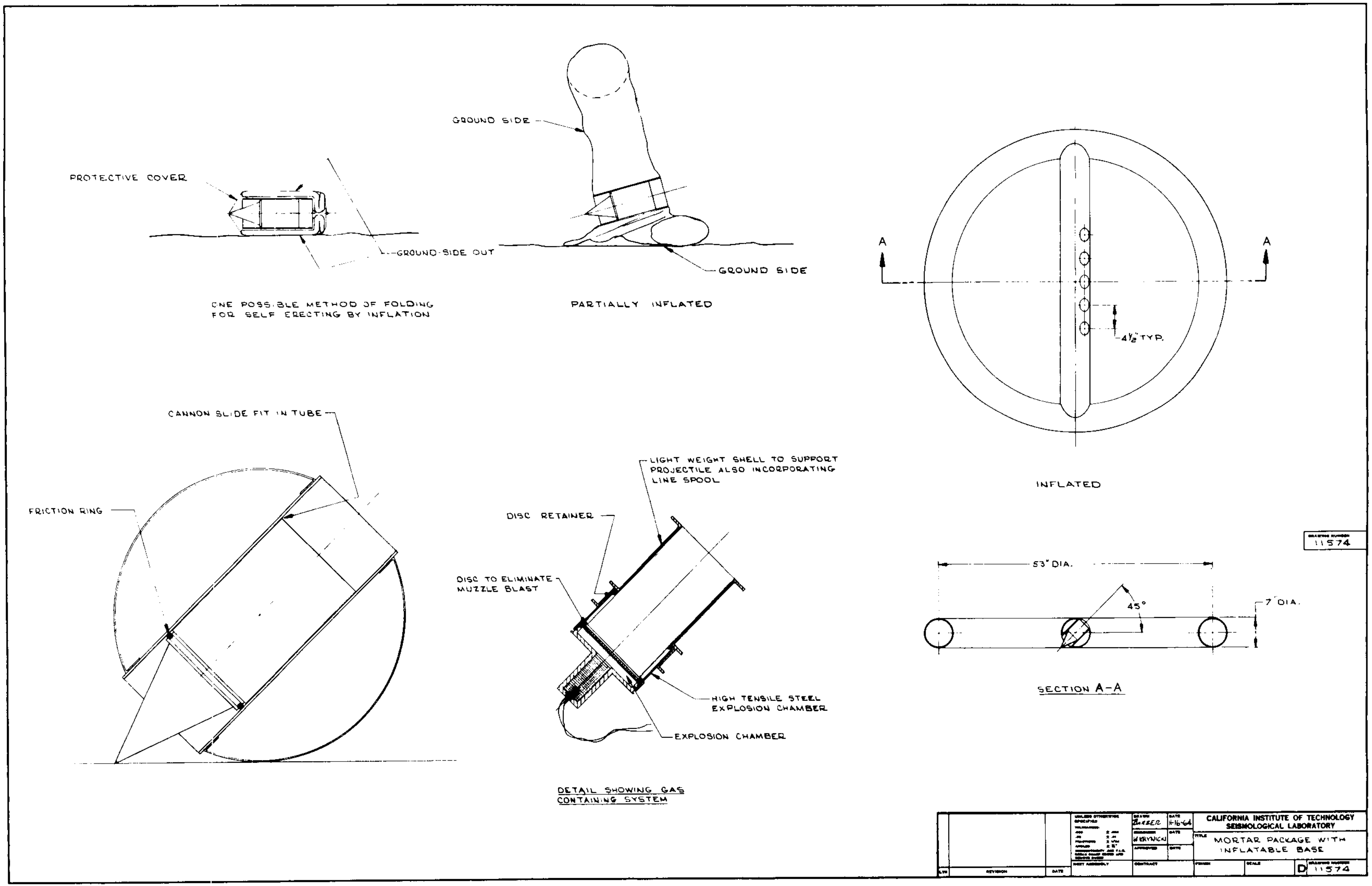

PROTECTIVE COVER
GROUND SIDE OUT
ONE POSSIBLE METHOD OF FOLDING FOR SELF ERECTING BY INFLATION
GROUND SIDE
GROUND SIDE
PARTIALLY INFLATED
A
A
4½" TYP.
INFLATED
CANNON SLIDE FIT IN TUBE
FRICTION RING
LIGHT WEIGHT SHELL TO SUPPORT PROJECTILE ALSO INCORPORATING LINE SPOOL
DISC RETAINER
DISC TO ELIMINATE MUZZLE BLAST
HIGH TENSILE STEEL EXPLOSION CHAMBER
EXPLOSION CHAMBER
DETAIL SHOWING GAS CONTAINING SYSTEM
11574
53" DIA.
45°
7" DIA.
SECTION A-A
DRAWN BARKER
DATE 1-16-64
W KRYNICKI
CALIFORNIA INSTITUTE OF TECHNOLOGY SEISMOLOGICAL LABORATORY
TITLE MORTAR PACKAGE WITH INFLATABLE BASE
D 11574
REVISION
DATE

Figure 21