University of Nebraska Medical Center

42nd and Dewey Avenue
Omaha, NE 68105

# SAFETY TECHNICAL EVALUATION OF THE MODEL XR 5000 ELECTRONIC "STUN GUN"

## I. INTRODUCTION:

During the fall of 1984, the Douglas County Nebraska Sheriff's Office sought to gain an independent evaluation of a new electronic defensive weapon known as the Stun Gun. Although this device is being marketed widely without significant restrictions, those responsible for the decision whether or not to incorporate it into the Sheriff's inventory desired answers to certain safety questions about the device which had not been addressed heretofore in manufacturer's promotional materials or in other published reports about the device. In addition there are questions which would logically be raised by the public if such devices were to come into general use by law enforcement.

Accordingly, the evaluation team set about to find consultative resources with knowledge and experience both in the field of electrical safety and the medical aspects of the interaction of electrical stimuli with biological systems, - especially human subjects. This report constitutes the result of these evaluations.

**** Please Note: The Electronic cicuitry of the NOVA XR-5000 is identical to that of the TASER system, and is produced under patent license to John H. Cover. This safety study therefore applies directly to the TASER device as well as the NOVA XR-5000.**

## II. LITERATURE REVIEW:

A systematic review of the medical literature was undertaken utilizing the National Library of Medicine computer search service Medline. In addition various authors known to be active in the field of electrical safety and electrical injury were cross referenced through the UNMC library's Citation Index. Overall approximately 500 articles published between 1975 and the present were reviewed by title, author or by abstract. Approximately 20 of these were reviewed in depth.

The computer search criteria were adjusted to determine the effect on yield of pertinent articles. When strict criteria were employed, i.e., the combination of "electric injury", "electronic weapons", and various near modification of these descriptors not one pertinent article was recovered. This discovery suggested that there has not been significant reported work in the specific area covered by this report over the past 10 years. Significant confidence that the search was adequately sensitive was gained when such neighboring topics such as electric therapy, electronic torture and electric eroticism produced numerous reports. If this new control concept in law enforcement becomes as popular generally as it appears to be regionally, reports of this kind should be welcomed into the medical literature.

It should be noted that articles on electrical hazards and electrical safety do not always appear in medical journals. One likely location for such articles would be in professional engineering journals. Author cross referencing appears to have picked up most of these and it is doubtful that there are many of significance which were missed. The particular citations to the literature listed in the sections on Theory of Operation and Potential Medical Hazards are referenced in the appendix.

## III. THEORY OF OPERATION:

The stated mechanism for effectiveness of the Stun Gun is related to the interaction of the electrical impulses produced by the device with the nervous and muscular systems. The term "temporary incapacity" is used to describe the effect of the Stun Gun on persons in whom control of their aggressive actions is a primary police objective.

Nerve and muscle tissue, although differing rather substantially in certain specific characteristics of electrical stimulation, are in fact quite similar in the major category of "excitability." [1], which is of primary importance here.

Precise differentiation of which of these two types of tissue is stimulated preferentially by the electrical stimulus is made somewhat more difficult in gross laboratory evaluation by the fact that nerves normally activate muscles, therefore a particular muscle contraction in response to a Stun Gun stimulus, for example, might have been caused indirectly by activation of the motor nerve feeding that particular muscle and not directly by the muscle itself.

It is a well known principal of physiology dating back to the 1700's and the classical work of Galvani that nerve and muscle - including heart muscle - can be stimulated to react, each in its own characteristic way, by the application of electrical stimuli of the <u>proper</u> kind. From this knowledge one can postulate that some electrical stimuli may well be improper and hence ineffective in causing excitation of nerve and muscle. It is reasonable to assume that there is a spectrum of electrical stimuli which are in an intermediate zone between very effective and ineffective. Such stimuli may be called "marginally effective" and it is in this category that the output from the Stun Gun generator probably belongs.

Electrical energy in small amounts may stimulate tissue to respond normally. Higher energies may stimulate as well as damage tissue. This damage or injury effect is primarily, although not exclusively, related to the heating effect of electrical current passing through tissue. Specifically, heat production in watts is related to the current in amps squared. Each kind of excitable tissue; nerve, muscle, heart etc., is most efficiently excited by electrical stimuli of quite precise characteristics of intensity (voltage or current) and timing (pulse shape and duration). Deviation from the optimum characteristics in either direction means generally that more electrical energy must be injected to cause the same reaction thereby reducing the efficiency and tending toward thermal injury.

Nerves favor brief duration stimuli while heart muscle requires much longer duration impulses to become activated. This is due to the much higher electrical capacitance of heart tissue than of nerve tissue. Since the Stun Gun generates extremely short duration impulses measuring only a few millionths of a second, one might expect it to be totally ineffective in stimulating heart muscle no matter how intense the stimulus. This is indeed the case. These ultra short duration impulses are only slightly effective in stimulating nerves even though the intensity, as measured in terms of peak voltage, may be thousands of times greater than the minimum amount necessary if the stimulus were longer in duration.

The extreme brevity of the stimulus pulse as produced by the electronic timing circuit in the Stun Gun accounts for the fact that even though the pulses may be of such enormous voltage so as to cause ionization of the air the production of Ozone and the formation of discharge arcs, the duration of these pulses is so short that only a few nerves in the close vicinity of the pulse generator are actually stimulated. Cardiac tissue , normally far removed geographically from the Stun Gun in its customary mode of application, would not and could not be stimulated even if it were in direct contact with the Gun due to the unique characteristic of heart tissue requiring relatively prolonged stimulating pulses for effective stimulation.

The physiologic principal governing these observations is known as a "tissue chronaxie". The principal relates stimulus intensity to stimulus duration and, as noted above, is not constant but varies widely from one tissue type to another. It may vary from one moment to the next in the same tissue depending on physical and chemical surroundings.

The shorter duration an electrical impulse is, the higher its intrinsic frequency components. In the case of the Stun Gun the major energy component of the shock pulses are actually in the radio frequency spectrum rather than the audible sound spectrum where most functional nerve and muscle stimuli are located. This well known and predictable phenomenon results in the so-called skin effect[2] wherein high frequency electrical currents crowd to the surface of an electrical conductor such as the human body and does not penetrate to the nerves and muscles beneath. It is well known, for example, that one may touch a radio transmitter antenna possessing thousands of volts of electrical potential and experience no sensation or muscle contraction at all. The Stun Gun produces some sensation but not of the severity as would be expected if its pulses were of longer duration. The relationship between the frequency of stimulation and the gross effect on muscle contraction was determined by Dalziel.[3] Although his experiments relate the so called "let go" current to the frequency of stimulation, a somewhat different physiologic situation, the results have the advantage of having been obtained in human subjects.

As pointed out above, very short duration pulses are only marginally effective in stimulating excitable tissue. This is a desired circumstance in the design of the Stun Gun since the region of the body effected by the discharge of the pulses is quite limited and the effect on the body no matter how long the Gun is applied is brief. The device produces a brief period of incapacitation and no significant residual effect such as burning or damage to tissue appears to be possible. The heart is not directly stimulated at all and potentially hazardous subtle or gross rhythm abnormalities of the kind associated with accidental electrocution (from a faulty electrical appliance, for example,) is not possible. Furthermore, the energy requirement from the Stun Gun supply battery is low if the shock pulses are of short duration and produced at a low repetition rate. The Stun Gun produces pulses of such brief duration that the electrical energy contained in each pulse is only about 0.001 watt-second (Joules). At a pulse repetition rate of 20 pulses per second which is average for the Stun Gun, the amount of energy delivered in a one second discharge to a human subject (and the amount of energy drawn from the battery which should be roughly equal) would be about 2 watt-seconds (Joules). A fully charged 8.4 volt NICAD transistor radio battery such as is used in the Stun Gun will effectively deliver about 120 Joules. This would mean the gun can operate for about 2 minutes continuously or can produce about 30 shock bursts of four seconds each.

These performance specifications will vary from day to day and from unit to unit depending for the most part on the condition of the battery. The battery, in turn, is dependent on temperature as well as its usage history and its state of charge.

The physical and electrical design of the unit is quite straight forward with perhaps one exception, that being the purposeful placement of metal studs transversely across the output terminals. The configuration and spacing of these terminals promotes air breakdown and arc formation when the device is not under a dissipative load. The pulse is generated from a "fly back" type transformer similar to that used in television sets to generate the high electron accelerating voltage for the picture tube. The Stun Gun employs a much slower repetition rate ( 20 pulses per second) than a TV (15,000 pulses per second) and no high voltage rectifier is needed, thereby eliminating several critical and expensive components required of a TV. Furthermore TV set designers go to great lengths to prevent arcing and corona formation into surrounding air - processes which dissipate energy needlessly and create radio frequency interference in the vicinity. The Stun Gun on the other hand promotes arcing by the positioning of the sharp laterally positioned metal probes across the output in such a way that an audible and highly visible air discharge occurs for each pulse not dissipated into a subject through the forward facing probes. This "default discharge" is actually necessary for optimum operation of the device since it stabilizes the output between load and no load conditions.

A question frequently asked is "how is the Stun Gun different from a cattle prod". These devices are designed to repel animals through the means of electrical shocks. The cattle prod differs in several very important ways other than physical appearance. (See appendix). First the cattle prod is capable of causing tissue injury since its internal or source impedance is much lower than the Stun Gun (so is a fence charger as well as is an electronic automobile ignition) and it can cause greater amounts of electric current to flow through the body in a given time than can the Stun Gun even though the Stun Gun's voltage may actually be considerably higher. It is the deep penetration of electric current into tissue which not only stimulates but is potentially hazardous due to the thermal effects mentioned earlier. In addition the duration of the cattle prod's pulses are over 10 times longer than the Stun Gun's and the repetition rate is 10 times faster making it a very effective tissue stimulator as contrasted to the Stun Gun which, as noted above, is only marginally effective. Furthermore the longer duration of the cattle prod pulses bring them into the range of being able to stimulate the heart directly. Indeed the cattle prod pulse characteristics render it potentially hazardous to heart rhythm. However, because of the close electrode spacing (about 1 inch) and the great distance between the prod electrodes and the heart, the current flow pattern in the region of the heart is very limited in conventional usage.

The much larger battery packs required of cattle prods ( 2 ampere-hour as compared to the Stun Gun's .08 ampere-hour) attest to the major difference between these devices.

**Potential Medical Hazards:**

The Stun Gun is not a medical device. The manufacturer makes no claim of diagnostic or therapeutic efficacy about the device. Since no such claim is made the device does not fall under the jurisdiction of the Device Amendments to the Food and Drug Act - 1976 which laws prescribe detailed testing of new medical devices before manufacture. Also the FDA imposes strict regulations for quality assurance in the manufacturing process of medical devices.

No detailed performance specifications were provided with the instrument so there is no simple way short of returning the device to the factory to insure that its operating characteristics are being maintained. This presents a potential hazard from the standpoint of a possible performance failure. Although unlikely, a malfunction might cause a change in the electrical characteristics and result in the output becoming substantially more injurious even though the device appeared to function normally.

As pointed out in the preceding section, the Stun Gun's output when operating normally and when used in the prescribed manner is not a significant hazard to normal adults. Impulses delivered to the subject's face and especially near the eyes could affect vision and possibly cause eye damage. This possibility was not specifically tested in this protocol.

Electrically sensitive subjects, those whose heart rhythms are unstable because of being on certain drugs, or on pacemakers, or who have recently had chest surgery, or possibly a recent heart attack are a special class of individuals in whom lower than normal electrical currents or possibly even the fright of being shocked with the device could conceivably induce medical problems. Some of these possibilities were tested by creating an electrically unstable circumstance in an anesthetized animal and delivering the full output of the Stun Gun directly to the heart muscle by means of an intracardiac electrode catheter. Recordings of these trials are included in the appendix. The study showed no effect on cardiac rhythm or pumping and only a mild and transient effect on blood pressure with direct stimulation to the inside of the heart. Surprisingly the surface electro cardiogram only showed a minor shift in baseline during the application of the shocks and a prompt return to normal when the shocks were discontinued. Increased electrical susceptibility was created in the animals by injection of 1 mg of 1:1000 epinephrine intravenously. A characteristically rapid heart rate and blood pressure rise ensued but the Stun Gun was still ineffective in creating heart rhythm disturbances under these conditions of augmented sensitivity. Ordinary pacemaker pulses delivered under these circumstances caused immediate ventricular fibrilation.

Another type of enhanced electrical susceptibility that could concievably be encountered is in the subject with an implanted cardiac pacemaker. Pacemakers themselves have been reported to be susceptible to certain kinds of electromagnetic interference and even now patients with pacers are warned about the potential hazards of close proximity to microwave ovens, mobile radio transmitters and the like. Several reports have described interaction between ignition systems of automobiles and even power lawn mowers with cardiac pacers.

In order to test the possibility of interference of pacer function due to Stun Gun operation an anesthetized animal was paced with a programmable external pacer using body surface sensing electrodes (see appendix for details). In the "asynchronous" mode ( no sensing employed) the pacer was immune to Stun Gun shocks virtually anywhere on the animals body. Only when the shocks were delivered directly to the pacer itself did erratic pacing function occur. The erratic pacing caused extra randomly placed pacer pulses to be emitted. For the most part, these were only effective in causing extra heart beats limited to the duration of application of the shock. Following termination of the shocks the rhythm returned promptly to the preshock regularity. Neither the pacer nor the heart appeared to suffer any carry over effects at the conclusion of numerous repetitions of this test sequence. In the inhibited mode (sensing required) aberrent pacer function was noted with stimulation sites virtually anywhere on the animal's body. Although this mode of pacer operation is the most commonly employed in practice the degree of susceptibility noted is unlikely to cause serious clinical problems because the pacer is most likely to be temporarily inhibited and therefore produce few if any pulses of its own during this time.

The time of application of the Stun Gun is usually only a few seconds, the cardiac effect of which would probably be unnoticed by the patient and unimportant to the heart rhythm. Furthermore, the sensing electrodes for inhibited type pacers are positioned in the heart, (usually they are the pacer electrodes themselves) not on the body surface in close proximity to the Stun Gun as was the case in this test. Normally implanted pacers should be considerably less susceptible to this form of interference than was exhibited by this test. Finally the chance of encountering a person with a functioning demand pacer among the population of individuals likely to be recipients of Stun Gun discharges is probably less than 1 in 10,000 based on the prevalance of pacers in the population. The likelihood that a serious medical problem would arise in a subject even if he had a pacer and if the Stun Gun were employed in the prescribed way is probably less than 1 in 100, making the overall probability of serious consequences less than 1 in a million, hardly a practical concern when weighing the potential benefit of such effective devices in the hands of law enforcement.

One hazard of significance which was observed with the frequent use of the Stun Gun in testing was the phenomenon of operator shock. Under a variety of common circumstances some small fraction of the Stun Gun's output is fed back either through the device internally or across the plastic case externally to the operator's finger on the control switch. This problem was worse in high humidity or when the operator's hands were damp as with sweat. It is much worse if the plastic case becomes contaminated with partially conductive materials, such as salt solutions and the like.

The hazard is not one of operator incapacity as would be the case with the subject but a "startle" effect which could cause the operator to lose control of the device and possibly drop it at a critical time.

The problem was solved in the laboratory by simply wearing a surgeon's glove on the operating hand. A more practical solution would appear to relate to the basic construction of the device with a moisture barrier over the switch and other cracks and crevices to prevent their becoming an electrical pathway back to the operator's hand.

The sparks generated by the device are quite capable of igniting certain flammable materials, such as gasoline vapor. Caution should be exercised if such vapors are thought to be present.

The device appears to be relatively immune to direct physical abuse withstanding numerous edge drops on concrete from a height of 3 feet. The device operated at once on removal from a freezer chest where it had been stored for 24 hours. Battery depletion slows the rate of repetitive discharge. This suggests a handy way to determine quickly the residual battery charge. It should be emphasized that conventional transistor batteries are virtually worthless as a power source since their internal impedance is too high to provide the high current necessary to properly operate the device. Proper battery conditioning with the charger according to instructions is imperative.

Finally the device was discharged into the mucous membranes of the tongue of an anesthetized animal to ascertain the effects on mucous membranes. Muscle twitching did occur but no visible damage to the membranes was noted. Again, the effect directly on the eye was not tested. Until this is more thoroughly evaluated one should be cautious about the use of this device in the face area.

**ELECTRICAL CHARACTERISTICS:**

The following measurements were made using a Techtronic model 468 Digital oscilliscope in association with model P 6105 multiplies Probes. A specially constructed attenuator with a 1000 multiplier was employed to record open circuit potentials.

a) Pulse wave form

1. No load (arcing)
   moderately damped sinusoid -

   Peak to peak voltage approximately 100,000 V

   Period between pulses, 50 milliseconds

   Pulse decay constant. 0.6 Microseconds

2. Loaded (20,000 Ohms), no arcing

   Heavily damped sinusoid. Peak to Peak Voltage approximately 50,000 V

   Period - between pulses, 50 milliseconds

   Pulse decay constant 4 micro seconds.
   Instantaneous peak current, 20 amperes, each pulse

b) Repetition rate

1. 20 pulses per second both loaded and unloaded

c) Electro magnetic radiation

1. Broad spectrum centered about 2 Megahertz on Collins All Band Receiver

d) Power production in pulses

1. Average over 1 second 1.2 watts

e) Power consumption from battery

1. average over 1 second 3 watts

f) Failure modes

1. Discharged battery to terminal voltage of 6.5 volts or less results in cessation of pulse generation

2. Output shorted - no output, little effect on internal operation

3. Internal spark gap shorted - no measurable output

## SUMMARY

The SK 5000 Stun Gun was extensively evaluated from the standpoint of electrical safety by subjecting a stock model of the device to various physical and biological testing procedures. The output of the device has been characterized and found to belong to a class of pulse generators known as relaxation oscillators. The design is straight forward and familiar. It takes advantage of some miniaturization techniques for the size reduction needed for a hand held instrument. The output energy is very low even though the measured potential underload is in excess of 50,000 volts. Electrical "skin effect" and certain physiologic characteristics of excitable tissues make the device more effective in stimulating superficial nerves than muscles. Cardiac muscle appears to be completely insensitive to its effects. This finding greatly reduces the concern that the use of such a device in a wide variety of unknown subjects may result in untoward cardiac reactions of the kind seen in persons being shocked from faulty household or industrial appliances.

In addition to the lack of significant electrical hazards, the device appears also to be incapable of causing thermal effects such as burns to the skin or other tissues. The exceedingly sensitive tissue of the eyes were not tested however and remain as a continuing caution in the wide spread use of the device.

Certain potential hazards such as in igniting flammable substances and shock hazard to the operator were pointed out and discussed.

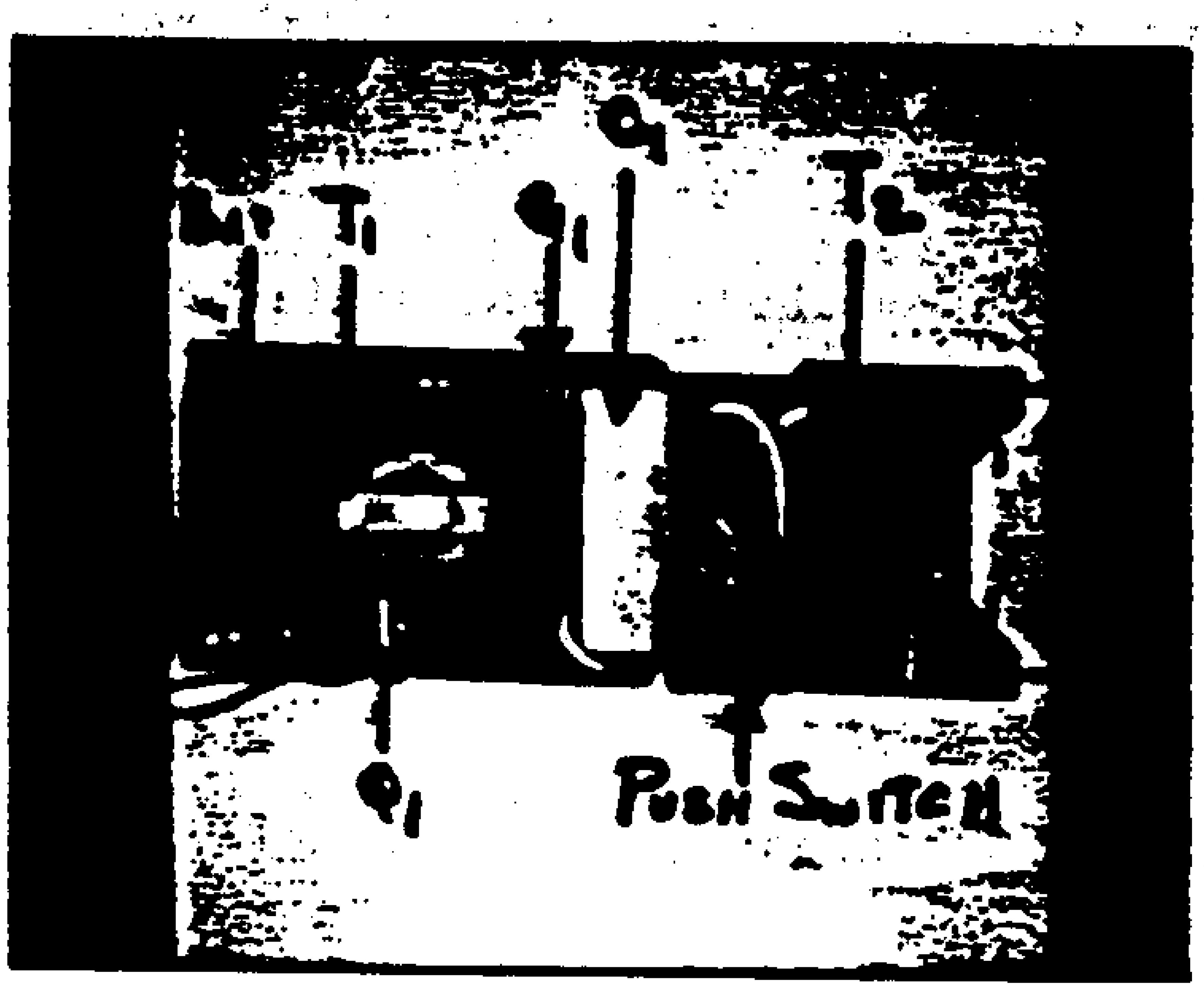
The entire subject of efficacy, the suitability of the device for its intended purpose, was not discussed. These and related subjects are for the most part, psychological and law enforcement matters and are not appropriate in this study.

I hope the information presented herein is useful in decisions relating to the acceptance of devices of this kind into law enforcement and in the educational process which will maximize effectiveness in the deployment of such devices if they are accepted.

Robert A. Stratbucker, M.D., Ph.D.

**APPENDIX**

**INTERNAL CONSTRUCTION OF STUN GUN**

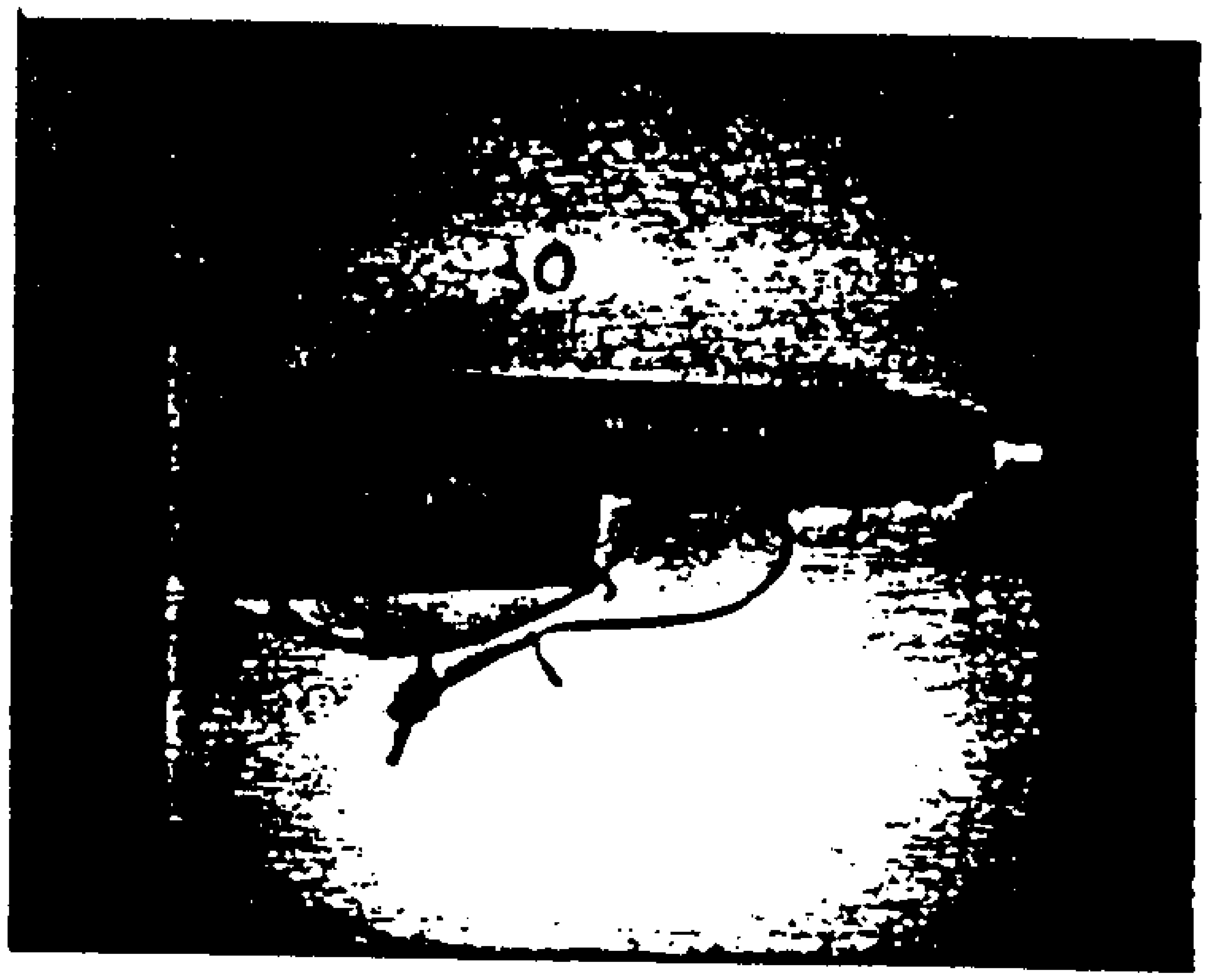


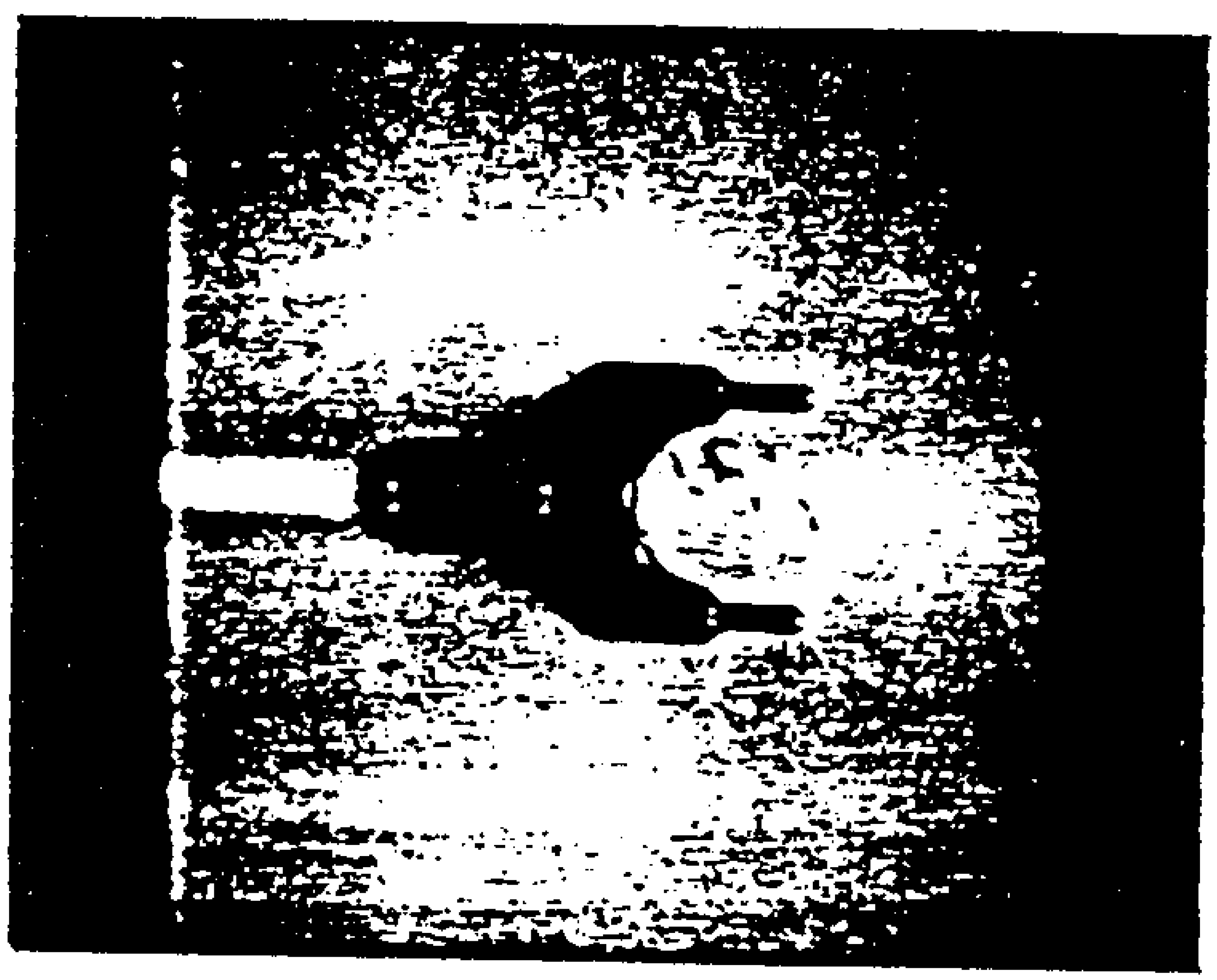

LABELS REFER TO SCHEMATIC DIAGRAM

The device is electronically a relaxation oscillator producing approximately 20 pulses per second. The pulses are delivered to a subject from the secondary winding of transformer $T_2$. An internal spark gap $G_1$ is an important part of the circuitry accomplishing much the same function as the ingition points of an automobile distributor. The output pulses are exceedingly narrow and contain much less energy than most familiar types of spark phenomena including automobile ignitions, fence chargers and the like.

# APPENDIX

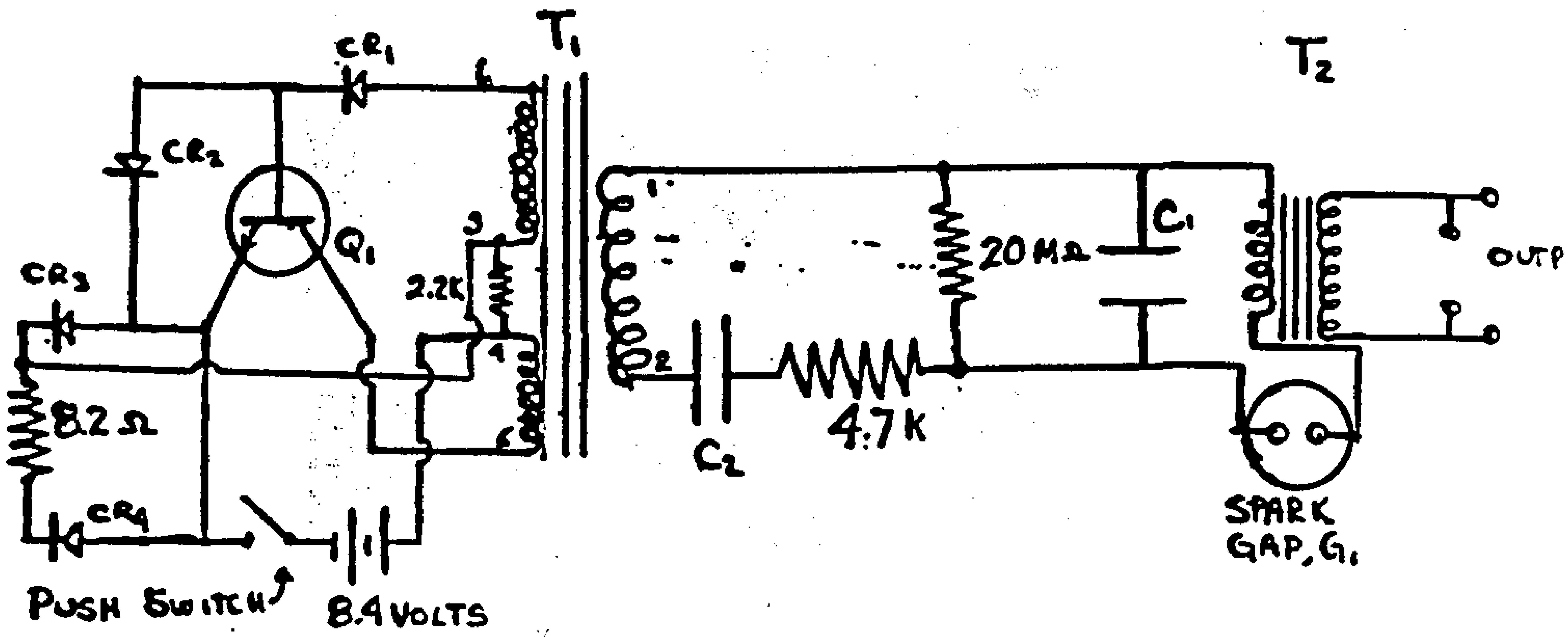
## TYPICAL CATTLE PROD



In this model the handle assembly is nearly all taken up with battery storage. The battery capacity is nearly 10 times that of the Stun Gun. Although the prod end has nearly the same dimensions as that of the Stun Gun the output voltage is much lower and no arc develops. The character of the pulses and the lower source impedance of the output result in a much greater and more penetrating current flow pattern than is available from the Stun Gun.

## SCHEMATIC CIRCUIT

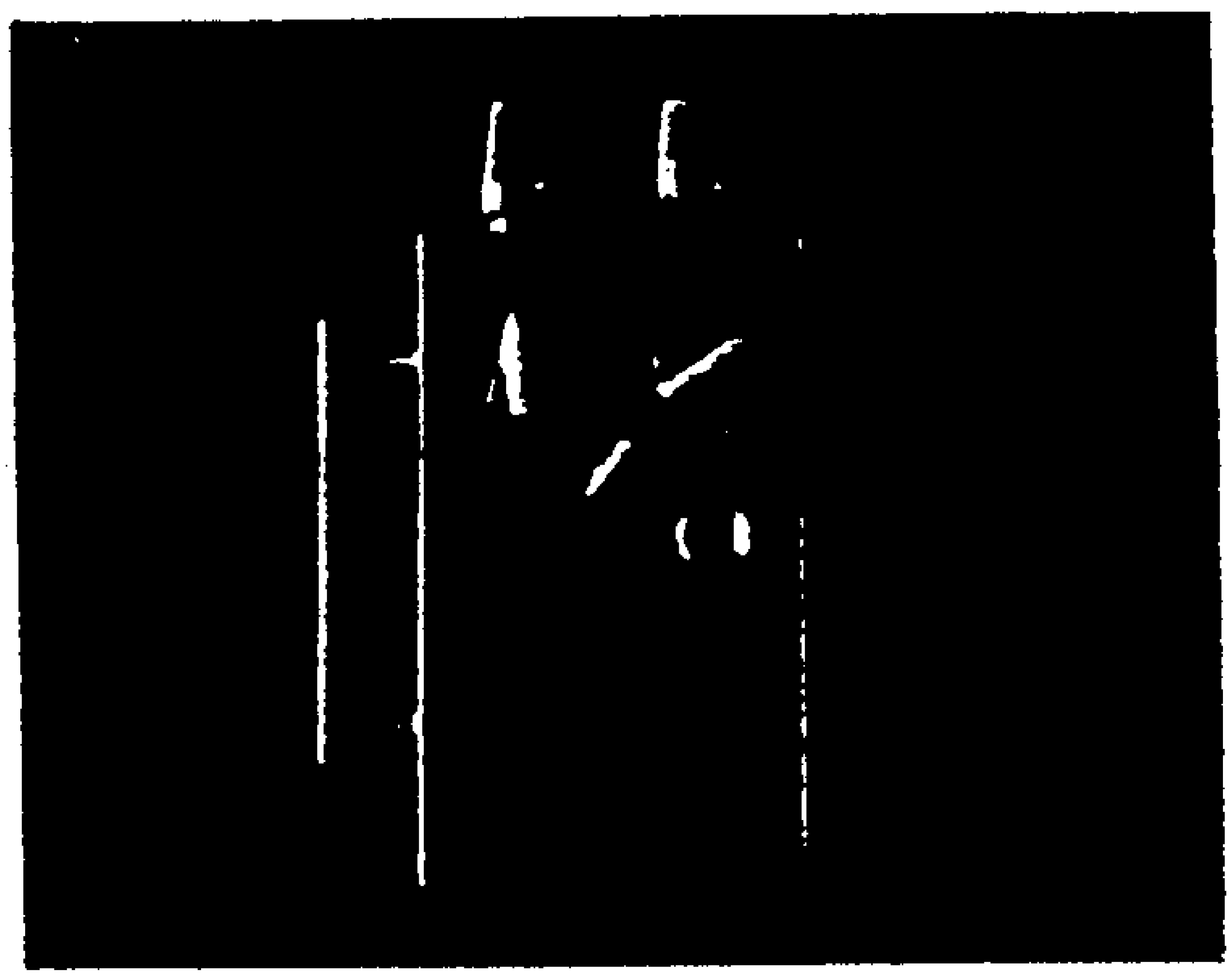



## DESCRIPTION

The basic circuit is that of a non-linear relaxation oscillator consisting of transitor $Q_1$, diodes $CR_1$,-4 and the dual primary windings of the oscillator transformer $T_1$. Pulses produced in the secondary of $T_1$ are applied across a small spark gap $G_1$ inside the unit (see photo.) When the charge across $C_1$ capacitor reaches the arc potential of the intenal spark gap, the developing magnetic field in $T_1$ collapses suddenly creating a brief high voltage pulse across the output terminals of $T_2$. Under unloaded conditions the high output voltage from the secondary of stepup transformer $T_2$ causes a spark discharge across the inner probes of the Stun Gun's output terminals. When in contact with a subject's body the output is sufficiently loaded that the arc potential is not reached although the internal spark gap $G_1$, continues to spark and an effective output voltage continues to be delivered. This latter pulsatile voltage is the effective "incapacitating output" of the device.

The circuit appears optimized for maximum voltage output. It is difficult to imagine any component failures which would result in output parameter changes which would cause the unit to suddenly become electrically dangerous. Most failure modes which were simulated resulted in the unit failing to function at all. The inherent battery capacity being as low as it is effectively limits dangerous emissions from the Stun Gun under most component failure scenarios.

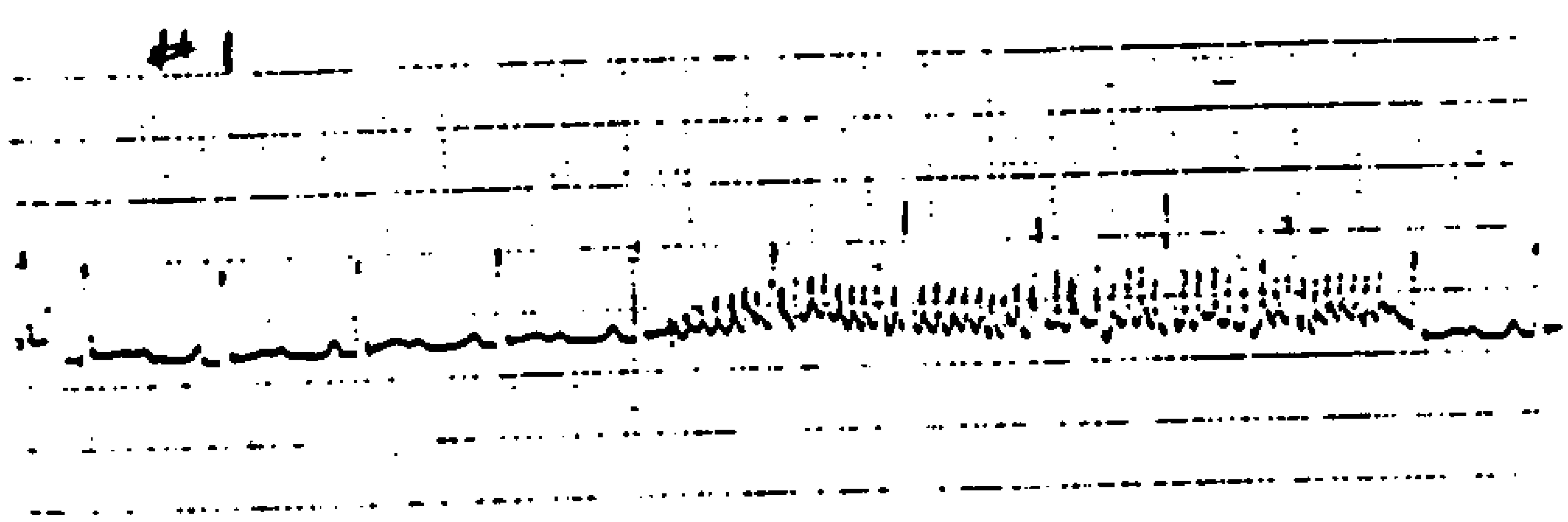
# EXTERNAL PACERMAKER



Typical external pacemaker used in these experiments. In this series 1 mg of epinephrine solution 1:1000 was injected intravenously and the tracings were done within a minute or so afterward. The purpose of the study was to investigate the possibility of increased susceptibility of the heart to Stun Gun impulses in a situation of heightened rhythm instability and lowered VF threshold.

## PHYSIOLOGIC EXPERIMENTS

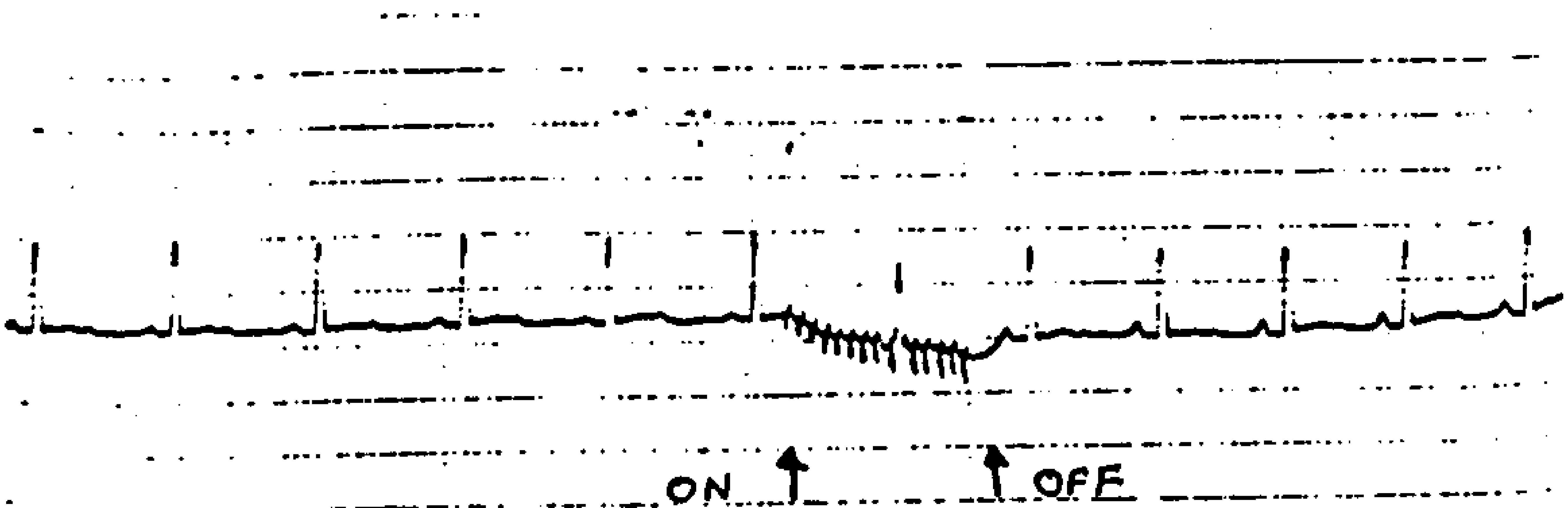
The first series of experiments were designed to determine the effect if any of cutaneous stimulation of an animal in the chest region using the Stun Gun.




SWINE
STUN GUN APPLIED TO LEFT THORAX

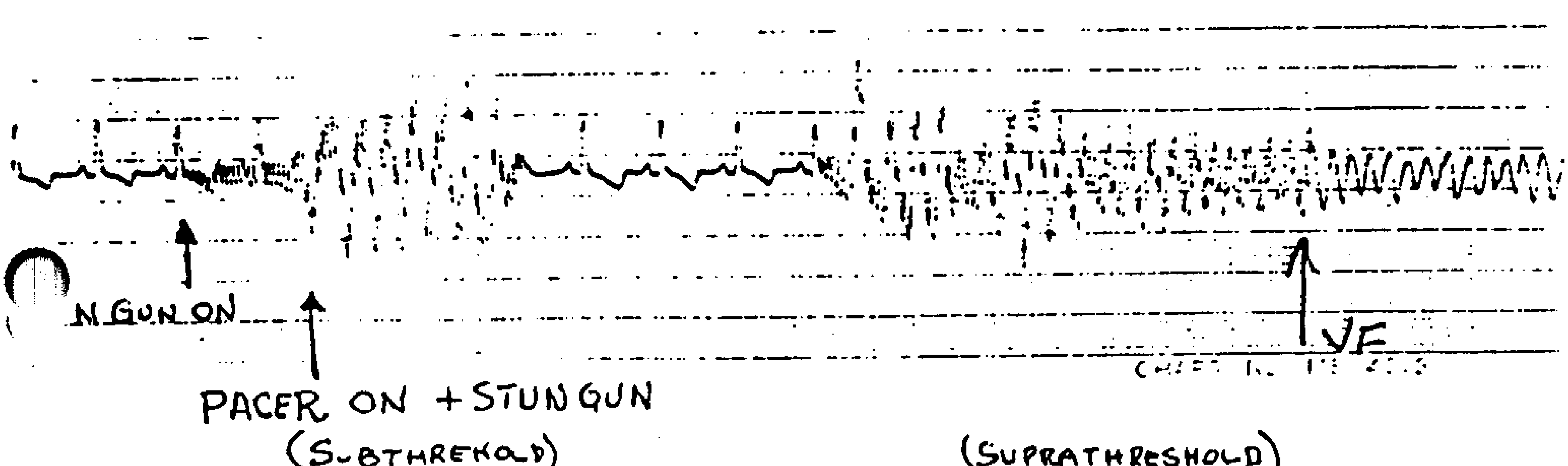
one notes a regular sinus rhythm which is encumbered by a small baseline artifact when the Stun Gun is applied to the left chest using electrode paste. Note that the QRS rhythm remains unaltered.

The second series of experiments involved the use of a pacemaker pulse generator delivering pulses to the right ventricle by means of a bipolar catheter in the right ventricle.

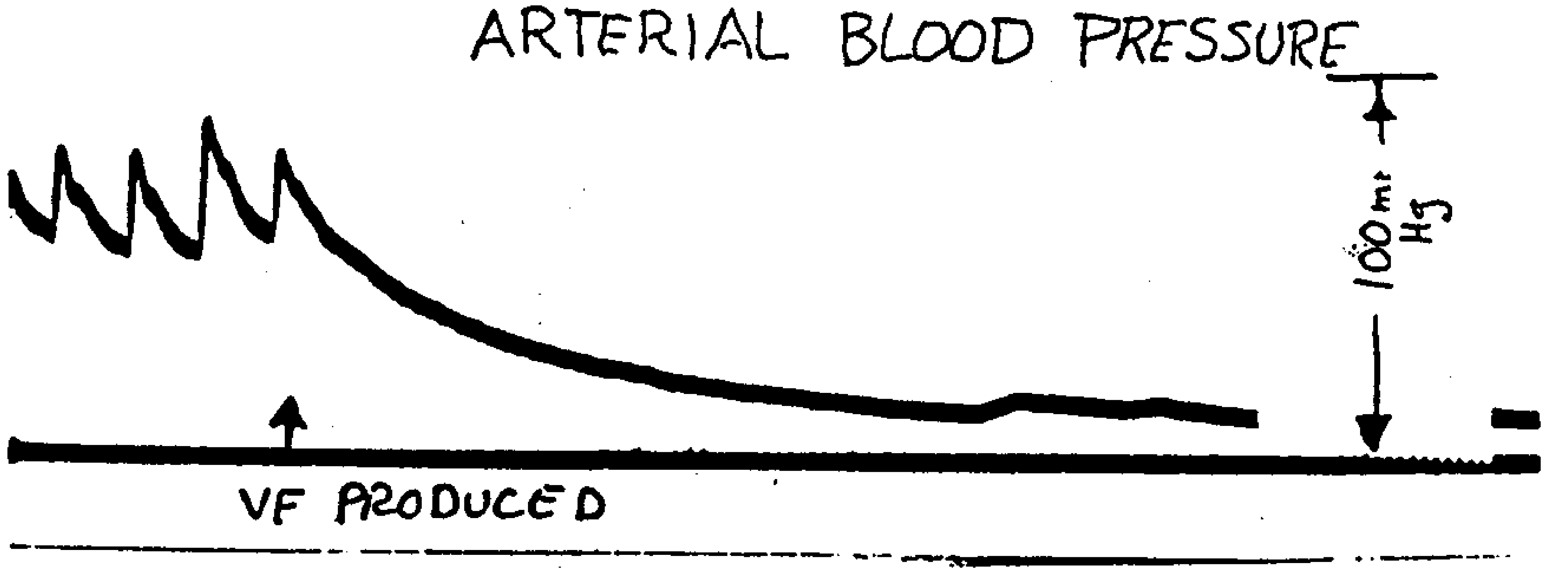



STUN-GUN-FIRED THROUGH CATHETER IN RIGHT VENTRICLE

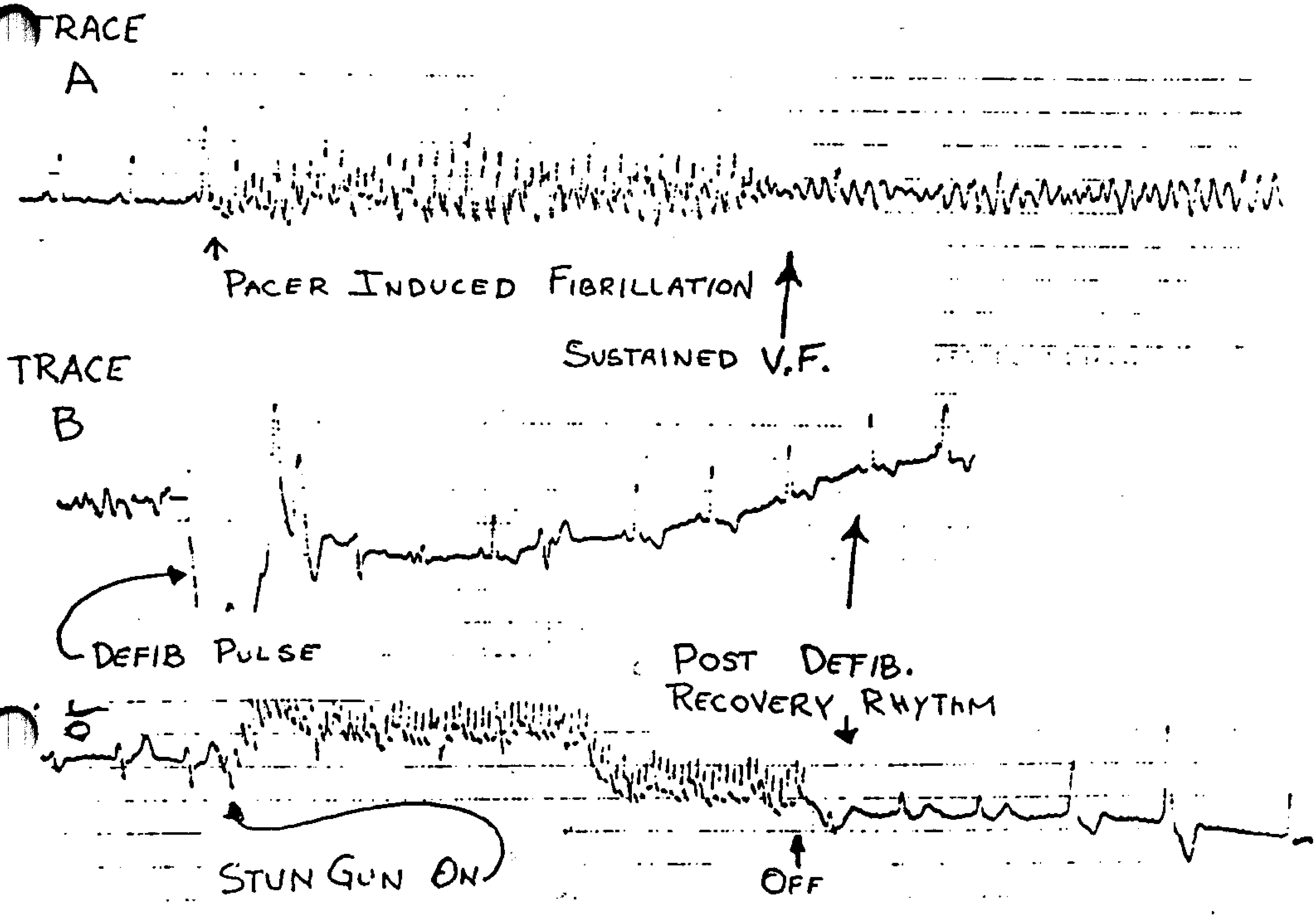
This trace shows the pulse generator artifact on the baseline at the left. The intensity was adjusted to determine VF threshold and at the arrow VF was produced. Pulse generator was set at approximately 50 pulses per second.



The trace below shows the blood pressure response to the onset of ventricular fibrillation as produced by the pacer.

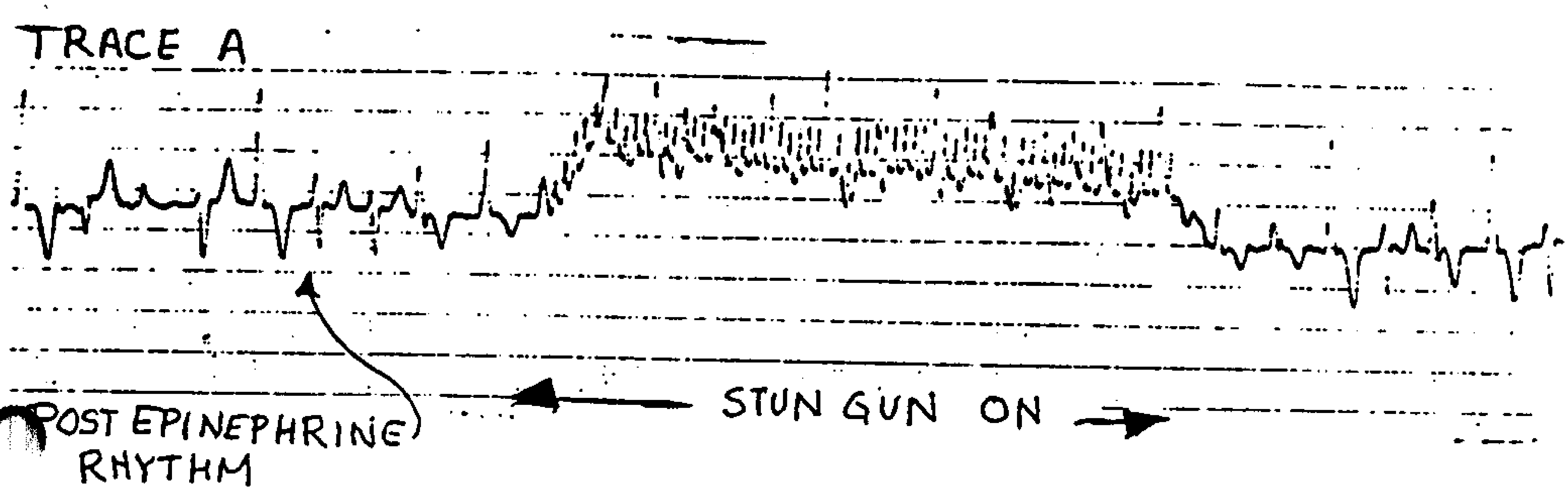



In this sequence the stimulator is increased in amplitude until VF is produced at the arrow in Trace A. Defibrillation is accomplished with external paddles and 100 Joules at the point indicaetd in Trace B. In Trace C the post recovery unstable rhythm is superimposed with Stun Gun activity delivered to the left chest without significant change in rhythm.

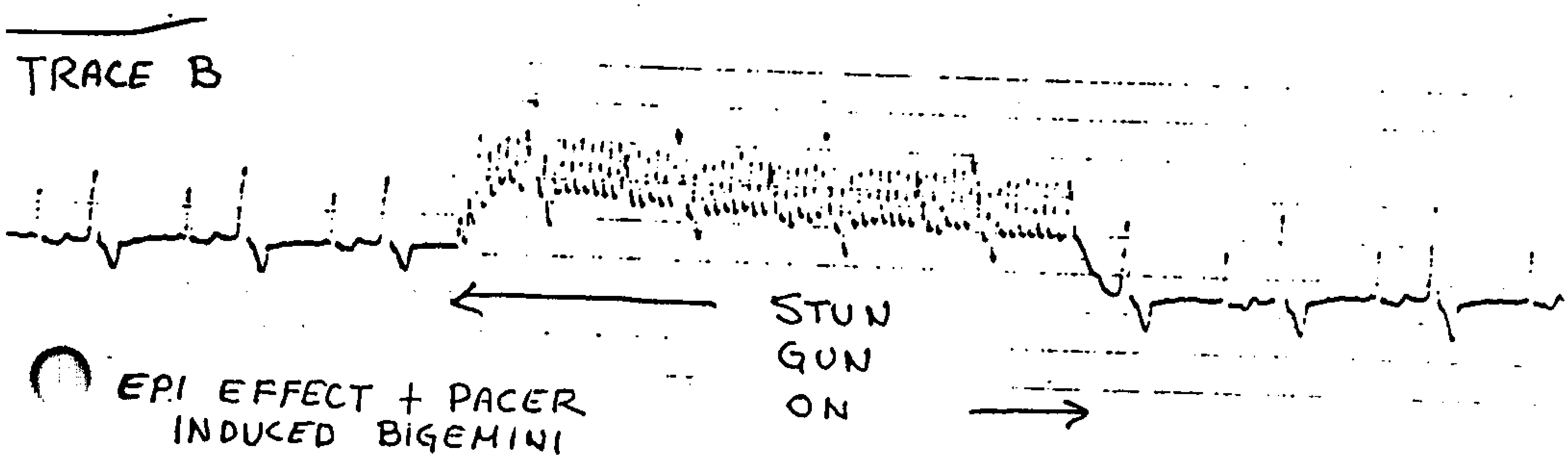


This experiment attempts to demonstrate the lack of effect of Stun Gun stimulation superimposed on an unstable rhythm immediately following defibrillation. The sequence is uninterrupted in time.

In trace A a complex rhythm is noted which resulted directly from the epinephrine injection. A profound tachycardia and hypertensive response ensued. The Stun Gun delivered pulses to the left thorax at the time indicated and no additional rhythm abnormalities developed.




In Trace B the pacer was adjusted to produce bigemini with the epinephrine effect still well in place. This added degree of instability was not affected by the Stun Gun applied as in Trace A.



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