"ELECTROMAGNETIC PULSE RADIATION: A POTENTIAL BIOLOGICAL HAZARD?"

By

William C. Milroy, M.D., Ph.D.

Terence C. O'Grady, M.A.

Eric T. Prince, M.S.

Biomedical Research Laboratory
Naval Weapons Laboratory
Dahlgren, Virginia 22448 USA

Abstract:

Concern is arising as to the potential biological effects of Electromagnetic Pulse Radiation. Much of this concern is due to a lack of sufficient data rather than to any effects actually being observed. Available data are reviewed and ongoing research reported.

INTRODUCTION:

Electromagnetic pulse radiation, more commonly referred to as EMP, is the name used to denote electromagnetic radiation which is characterized by very high power extremely short duration pulses produced from electrical discharges. EM pulses occur naturally during lightning discharges. In a thunderstorm, field strengths of 20 KV/meter can exist under storm clouds with pulses occurring from lightning strokes producing fields up to 3 megavolts/meter.[1] EMP radiation can include a wide spectrum of frequencies (characteristic of nuclear EMP simulators) or be confined to certain discrete frequencies. This, of course, depends on the design and type of pulser system being considered. In general, EM pulses have extremely fast rise to peak times, on the order of a few nanoseconds, producing peak field strengths up to the megawatt per meter range, exponential decay times on the order of 500 nanoseconds, and slow repetition rates of about 1 pps. The average power output, however, is rather small. The question then is; Is there cause for concern for biological systems when the average power is so small (well below any established standards) but the peak power (for which no standard exists) is so high? There is presently insufficient data to answer this question.

The large amount of work done on continuous wave (CW) systems and pulsed wave (PW) systems has still not resolved the problems and controversies concerning the hazards of that type radiation. The introduction of EMP generators serves to further cloud the overall problem. Concern over the possible effects to biological systems of EMP generators arose due to considerations of the magnitude of peak field strengths associated with these types of generators, up to millions of volts/meter. Initial biological experiments with pulsers were prompted by the observation of a bird which inadvertantly flew into a pulser array just as a pulse was triggered. The bird immediately dropped to the ground and "flopped about in a rather disorganized way for a minute or so." After a short time the bird recovered and flew away. It was decided that the phenomenon deserved closer inspection.[2]

General Characteristics of Pulsers:

(SLIDE 1)

Nuclear EMP simulators consist basically of a high voltage generator, e.g. a Van de Graaf or Marx generator, which charges a capacitor bank. The capacitors are discharged into a load consisting of a wire antenna array creating a high potential difference between it and a ground plate. Break down of the air dielectric results, with an intense pulsed electromagnetic field created.

Representative of this type of generator are the Air Force Siege Array, the Navy EMPRESS facility and the AFRRI pulser. (SLIDE 2) Typical electromagnetic pulse properties are peak field strengths up to hundreds of KV/M, rise times in nanoseconds, exponential decays with durations up to microseconds, low average power densities, and rather slow pulse repetition rates. The frequency spectrum is very broad, running from D.C. to around 80 MHz.

Generators of this type are generally quite large. (SLIDE 3) The EMPRESS, for example, has a pulser weighing 3000 lbs. and an antenna 380 meters long. Even the AFFRI "laboratory size" EMP facility is rather large, occupying a 10' x 10' x 40' shielded room. It is powered by two 150 KV power supplies discharged through a spark gap switch into a 1.2 m x 10 m parallel plate transmission line.

High peak power pulse generators can also be built which can be "tuned" to produce a discreet narrow band of frequencies. Spark transmitters or Hertzian generators offer a means of producing extreme RF power levels over a wide frequency range. Devices of this type constituted the basis for spark telegraphy during the infant days of radio. For many years, this technology lay dormant because the vacuum tube presented a much better source of RF energy. Because of inherent limitations on cross field devices, spark transmitters are now being developed to produce extreme power levels for a variety of special tasks. (SLIDE 4)

Basically, these transmitters are simply capacitors which discharge through an inductor to produce a decaying sinusoid whose frequency is given by:

$$f = \frac{1}{2\pi\sqrt{LC}}.$$ [3]

To increase the magnitude of the RF oscillations one simply increases the voltage to which the capacitor is initially charged. Typical properties of pulses from these generators are much the same as those of the NEMP simulators with two significant exceptions; a narrow discreet frequency band characteristic of the pulser design and an oscillating sinusoidal decay rather than the broad frequency spectrum and essentially monophasic exponential decay of the NEMP pulse. The spark transmitters differ in circuit design from the NEMP simulators basically in that the capacitor discharges through an inductor to produce the oscillating RF field. The physical characteristics of the two types of generators differ considerably, however. (SLIDE 5) The spark transmitters, in general, are more compact and versatile for laboratory bench type work. They are fairly simple devices and fairly cheaply and easily constructed in a minimum of space. In this regard they lend themselves more readily to biological research.

For biological experimentation, the animal cages can be made as part of the capacitor or the circuit can be used to drive a parallel plate transmission line which encloses the animals.

Biological Effects:

Initial animal studies of EMP effects were done by Hirsch and his colleagues who trained a group of white laboratory mice to run a maze using hunger as motivation. After reaching a certain performance level the mice were placed under a pulser antenna array, in their maze, which was equipped with a solenoid operated starting gate. After the 600 KV/M pulse was triggered the mice were allowed to run the maze and were observed for any effects on their performance. It was found that there was a significant increase in the time it took the mice to run the maze and in some cases the animals returned to the starting box and refused to move. However, within an hour after the pulse the animals approached their preexposure performance rates and after several days were all seemingly unaffected in their performance. The authors concluded that the pulses had a temporary effect on the maze running but that the effect seemed reversible. In 1971 Hirsch and Bruner[4] expanded the above experiments to include primates and dogs in addition to mice. They exposed a naive monkey and an overly conditioned rhesus to the pulser at 300-600 KV/meter field densities. No behavioral effects were observed in either case. In addition, four untrained beagles were submitted to an extensive blood serum analysis (SMA-12 automatic analyzer) before and after exposure to the EMP field. Two of the animals were exposed in grounded cages while the two remaining animals were insulated from the ground plane. Again no significant changes were observed in the animals during or after the pulses. However the authors point out that the small number of test subjects and exposures prevent an adequate evaluation of EMP effects. They conclude that single or a few exposures to fields as high as 600 KV/meter can be endured without harmful effects.

Martin[5] has reported on observed and postulated effects of the pulse fields of the RPG, Seige 1.2 and Seige II generators. He divided the known effects of electromagnetic fields into two general catagories: heating of tissues and electrical shock. The heat effect has been well studied as has the conductance of currents through the body to produce shocks. He also considered RF burns, sensory effects such as the feeling of a "gentle breeze blowing on the skin" due to the effects of high field strengths, and electrical anesthesia produced by time varied magnetic or electrical fields. He then discussed the generators in question and the possibilities of their causing any of the above effects. The three generators discussed ranged in peak field strength from 17 KV/M (RPG) to 600 KV/M (Seige II) with all three producing a frequency spectrum of 0-80 MHz. The voltages and currents which would be induced in a person directly beneath the array are comparable to those produced by walking on a carpet or sliding across an auto seat, according to the author. However, only a fraction of the Siege array induction current flow through the torso while the discharge current in the case of walking on a carpet or sliding on a car seat completely flows through the torso. He points out that the wearing of shoes should provide enough resistance to induced current flow to negate perceiving such current. However, he goes on to recommend that in no case should personnel be allowed to be under the array when it is triggered since there is a hazard of becoming the discharge path for the entire generated energy. In terms of the dangers of heating occurring under the arrays, it was shown that the average power densities for all three of the arrays were well below the 10 mw/cm^2 ANSI standard or the 1 mw/cm^2 HEW microwave oven standard. The fear of inducing electrical anesthesia in personnel exposed to the EMP radiation produced by these arrays was stated to be ungrounded by the evidence current to the report. Martin therefore concluded that there appeared to be no serious biological effects associated with these particular arrays.

Two Russian workers[6] reported on the biochemical effects occurring in rats exposed to a low frequency pulsed field. The field strength involved in this study were 72 KA/M and 24 KA/M under exposure conditions of 15 daily exposures for 3 hours and 1.5-6 months of 1.5 hours daily exposures respectively. The frequency was very low, 7 KHz, and the pulse had a duration of 130 milliseconds with an interpulse length of 10 seconds. These pulses, of course, differ considerably from either the NEMP or tuned pulses. They investigated a variety of biochemical parameters and concluded that the pulsed fields, at both intensities, caused disturbances in carbohydrate-energy and nitrogen metabolism in the brain, liver, heart and skeletal muscles. They found a decrease in ATP and creatine phosphate to cause the observed shift in carbohydrate-energy metabolism. This was attributed to an intensification of glycolysis. The pulsed field also apparently interfered with the transformation of nitrogen compounds in the various organs - due to different mechanisms. These effects occur in a definite order in the organs: liver, skeletal muscles, heart and brain. The effects were reversible and gradually came back to normal levels in the organs according to the same order. Although the above effects were observed in a situation differing considerably from that of most EMP generators, the experiments should be considered at least as related to those with EMP fields since single discreet pulses (rather than pulse trains) of rather high peak power are used. There is certainly less comparability to the CW or PW units.

The most recent animal studies have been conducted by Baum,[7] et. al. at the Armed Forces Radiobiology Research Institute. These studies were undertaken to investigate the chronic effects on animals exposed to a pulsed field. A recent report on the groups' progress details the results to date. The animals are exposed to pulses having a peak field strength up to 500 KV/meter and an associated peak power density of 66.3 KW/M^2. The pulses have a repetition rate of 5/second with a 5 nanosecond rise time and 550 nanosecond exponential decay time. To date the animals have been exposed to 100 million pulses. A variety of clinical hematologies and chemistries have been done. Analyses of chromosome aberrations, induction of leukemia in leukemia-prone mice and hematopoetic function constitute the major biological parameters investigated. No changes over a control population were observed in the majority of these parameters. A slight elevation of reticulocytes and decrease in platelet count was observed but these were within acceptable levels. The studies are still in progress with the observation for later effects or malignancy being conducted on the aging rodents. The authors feel that the negative results so far appear to make such occurrances unlikely.

The USAF has conducted a study in which eight different pacemakers were implanted in dogs which were exposed to 5, 25 and 50 KV/M pulses -

no changes in performance of the devices were observed. Human exposure records have been compiled by the Air Force[8] over a period of years. (SLIDE 6) These may be summarized as follows: (1) 19 July 1968 - 15 November 1968 - 7 individuals, multiple exposures from 5-88 KV/M, (2) April 1969 - Nov 1969 - 10 individuals, 65 exposures from 5-80 KV/M, (3) Aug 1969 - 14 individuals, exposures to 30 pulse/sec repetitive pulses at 380 KV/M for periods of minutes to 3 hours. No acute effects were observed at the time of exposure or subsequently. Medical surveys of personnel working with EMP completed in 1971 by the Air Force proved inconclusive due to lack of a control population. In general no changes directly attributable to EMP exposures have been revealed by the Air Force studies. Bell laboratories has indicated that human exposures in their laboratories were as follows:

Peak Field (KV/M)	Estimated # of Exposures
1-2	10^5
2-5	10^4
5-10	10^4
10-20	10^3
20-50	10^2
50-100	10^0

No effects were observed in any of the personnel which were attributable to the fields.

Dr. F. G. Hirsch of Lovelace Foundation[9] has summarized his experience with EMP as "no evidence of any sort that EMP has a biological effect". No physiological changes have been detected in animals or humans exposed to large numbers of pulses up to 3 MV/M. His study of 150 exposed personnel has also been negative.

Biological Effects Research at NWL:

The Biomedical Research Laboratory at NWL has a very broad program of research on biological effects of nonionizing radiation. In addition to studies of effects of CW and PW radiation, a portion of the effort is devoted to a study of effects of high peak power electromagnetic pulses. Through a liaison with the Naval Ordnance Laboratory, we have access to the Navy's EMPRESS system. In addition, we are in the process of acquiring a pulser capability in our laboratory. (SLIDE 7) This solid dielectric spark-switched LC oscillator is a fairly simple and compact device. It is charged by a high-voltage power supply and discharged through the spark gap switch. Animal cages of a low dielectric material are placed between the plates which serve as capacitor as well as acting in place of the parallel plate transmission line. Field strengths of

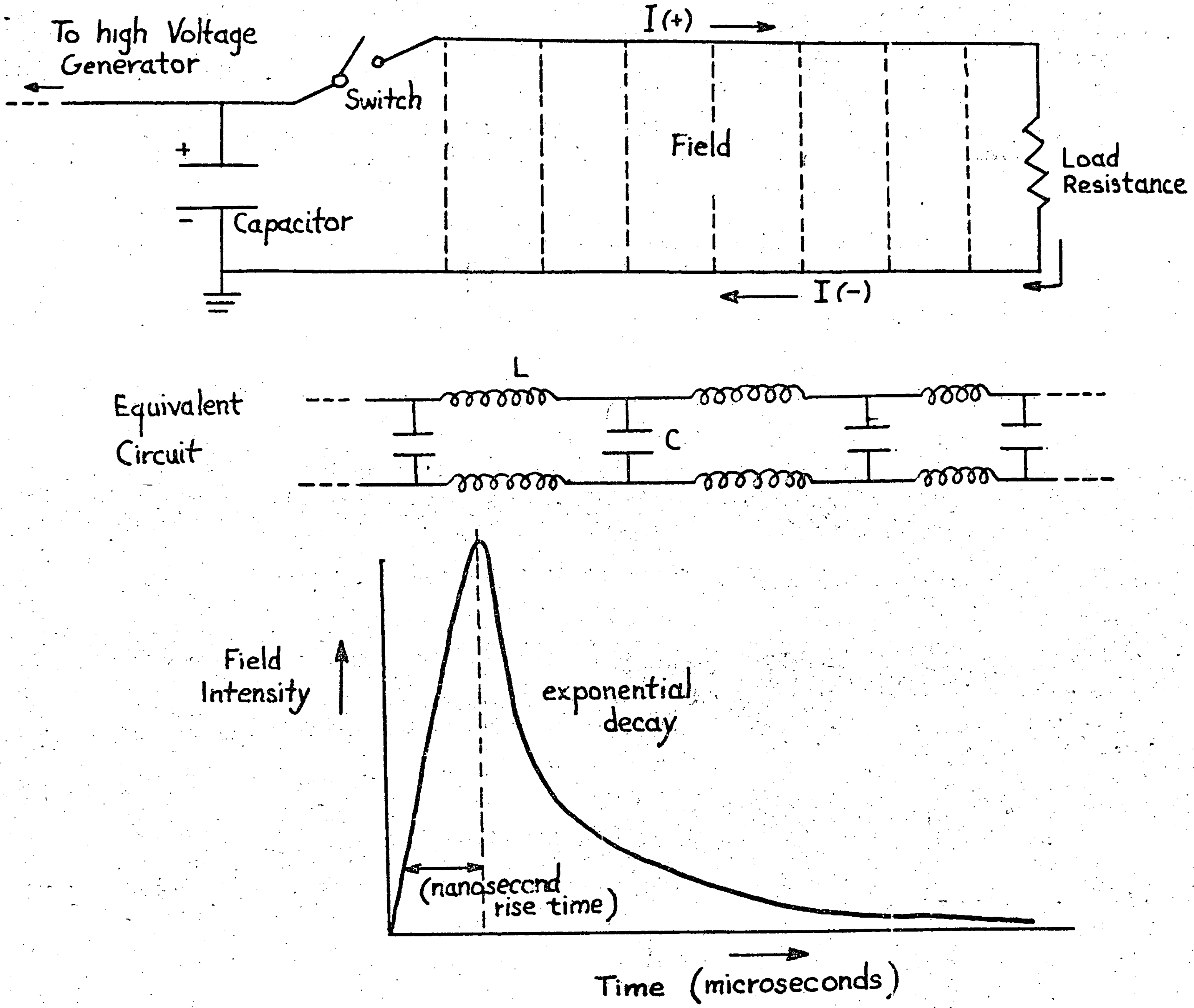
100 KV/M at a frequency of about 50 MHz are produced. It's pulse repetition rate may be varied up to several pulses per second.

Our investigations will include hematology and blood chemistry studies, electrocardiography and electroencephalography as well as investigations into more basic mechanisms of action such as enzyme kinetics and membrane function. We will also be carrying out behavioral investigations in an attempt to resolve some of the conflicting reports in this area. Additionally, we will be monitoring the medical surveillance program for personnel exposed to the EMPRESS facility and our own pulser system.

Conclusions:

It is generally agreed that there are presently no applicable safety standards for high energy electromagnetic pulses. The ANSI C95 committee has considered the problem and concluded that the 10 mw/cm^2 standard for microwave exposures is not applicable to high peak power, low average power pulses of this nature; nor is it applicable to the lower frequencies generally characteristic of EMP. They further concluded that there was no evidence available on which to base a good, reasonable, workable standard. A number of proposals for standards have been made, ranging from using the 10 mw/cm^2 microwave standard and averaging the power, to setting peak power standards. Suggestions for allowable peak powers have ranged from five to a hundred KV/M, all of which were based on experience without any firm experimental background. Suggestions for limitations on pulse repetition rates have also been made. It has been suggested, for example, that the general public be limited to exposures no greater than one pulse per minute based on the theoretical possibility of interference with cardiac electrical activity.

The fact of the matter is that there is no good standard presently available and no evidence available on which to base one. It would be totally unreasonable to set a standard based on sheer guess, using nothing but experience as a determining factor. Interim standards are generally not satisfactory because of the great resistance to changing any standard after it is established. It seems quite likely, however, that eventually, as sufficient data accumulates, standards will be set for electromagnetic pulse radiation. The standards may well consist of average power limits, peak power limits, pulse repetition rate limits; all three or some combination. As with electronic equipment development in the past it is most probable that development of EMP generators will proceed at a rapid rate and that the number, power outputs, and diversities of types of generators will continue to increase. Certainly we must have some sort of standards to protect both the general public and the occupationally exposed personnel. We must also, however, avoid unduly constraining this type of development by setting standards which are unduly restrictive.



To high Voltage Generator
Switch
I(+)
Field
Load Resistance
+
-
Capacitor
I(-)
L
Equivalent Circuit
C
Field Intensity
exponential decay
(nanosecond rise time)
Time (microseconds)

SEIGE ARRAY

	RPG	SIEGE 1.2	SIEGE II
PEAK FIELD STRENGTH {KV/M}	17	100	600
DURATION {μs}	1	1	50
PEAK POWER DENSITY {W/cm^2}	77	2.65×10^3	9.6×10^4
AVERAGE POWER DENSITY {MW/cm^2}	2.3	0.09	24
REPETITION RATE {S}$^{-1}$	60	0.07	0.01
FREQUENCY SPECTRUM {MHz}	0-80	0-80	0-80

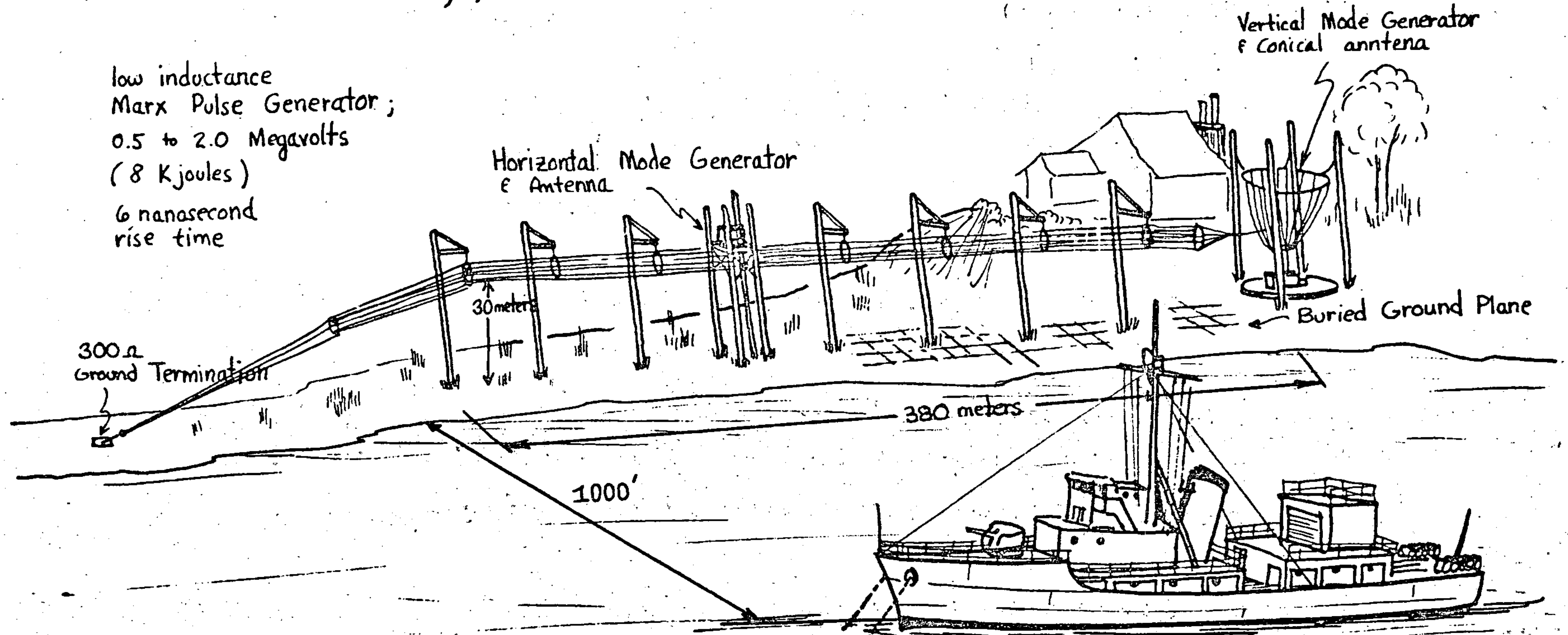
EMPRESS

FIELD STRENGTH	2 KV/M AT 300 METERS
ZERO CROSSING	300 NANOSECONDS
RISE TIME	6 NANOSECONDS
VOLTAGE OUTPUT	2 MV
ENERGY OUTPUT	8 KJ

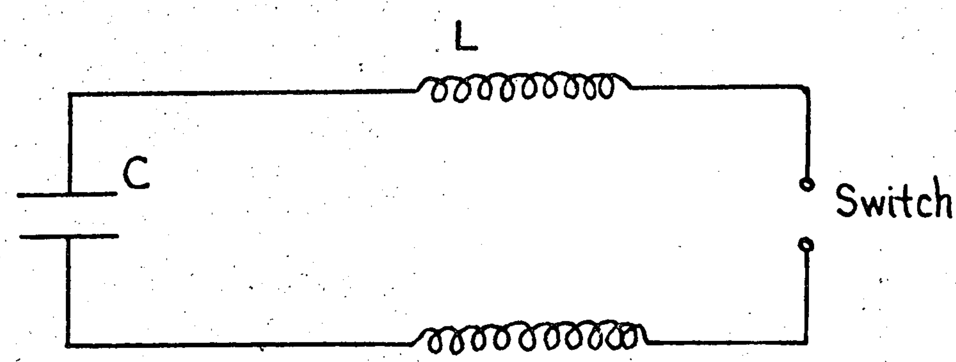
AFFRI

PEAK FIELD STRENGTH	500 KV/M
RISE TIME	5 NANOSECONDS
FALL TIME	550 NANOSECONDS
PRR	7 PPS
PEAK POWER DENSITY	66 KW/cm^2
AVERAGE POWER DENSITY	> 10 MW/cm^2
SPECTRUM	DOUBLE EXPONENTIAL

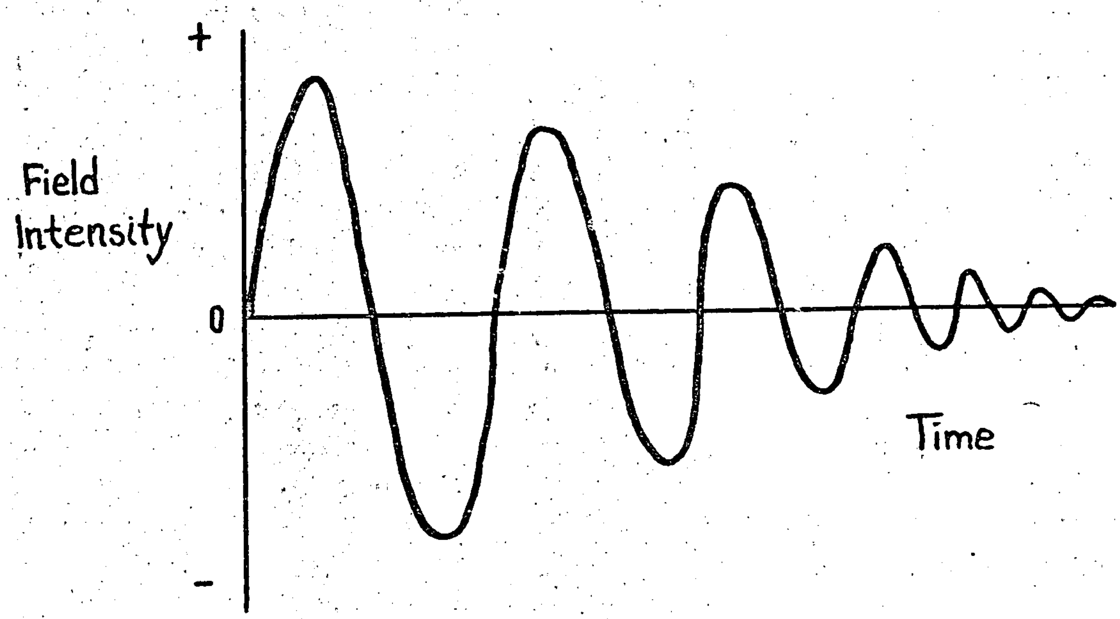
EMPRESS facility, Solomon's Island, Md.



Tuned EMP Generator



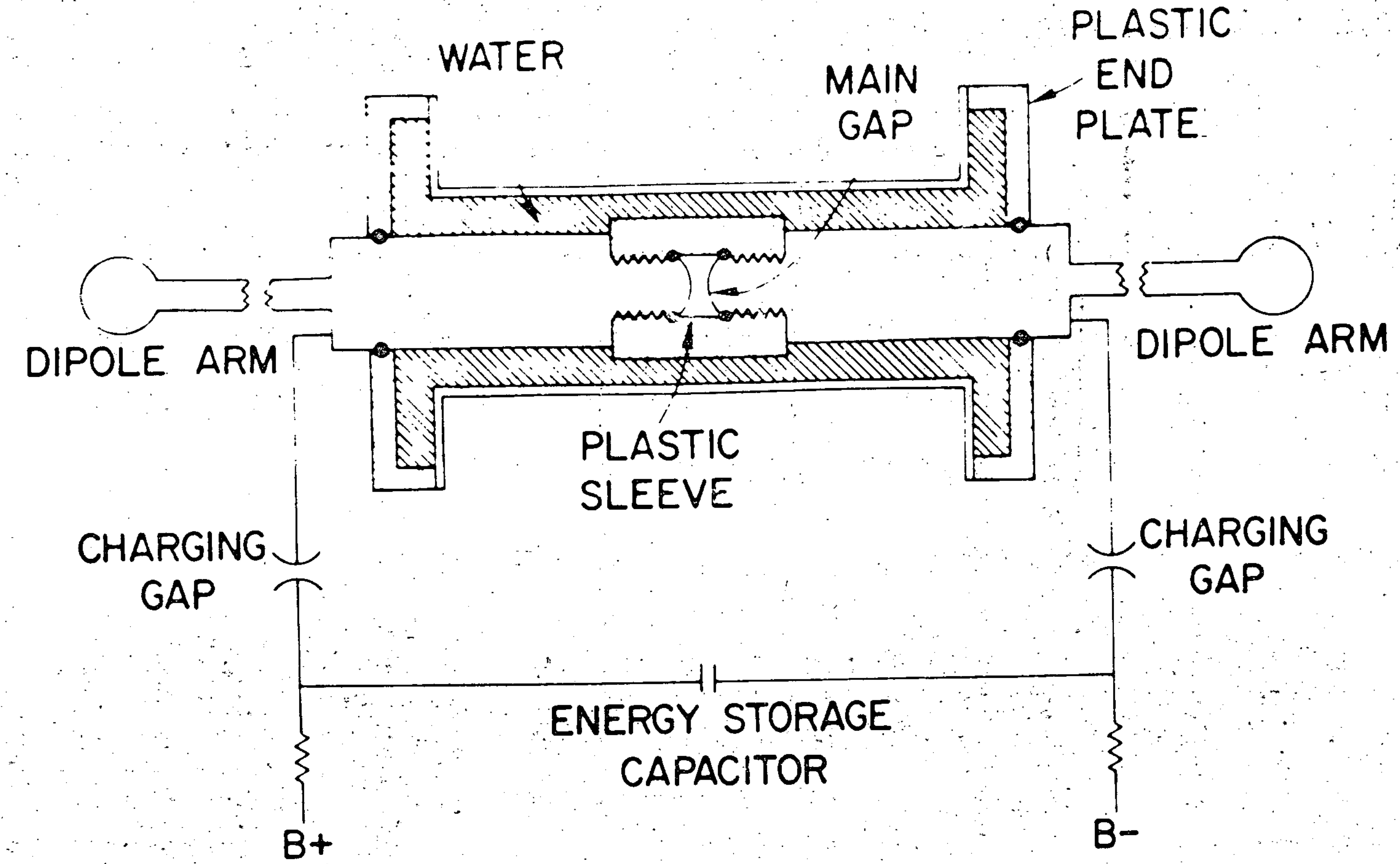
Schematic

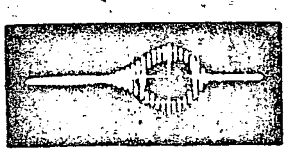


Pulse Shape

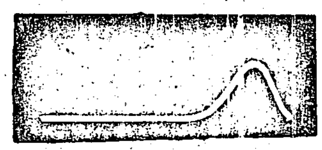
The Pulse Frequency is given by:

$$f = \frac{1}{2\pi\sqrt{LC}}$$





0.2 $\mu s/cm$
PULSE RECEIVED ON TEST DIPOLE CONNECTED TO CRO DEFLECTION PLATES



0.2 $\mu s/cm$
PULSE RECEIVED BY RECEIVER USING TEST DIPOLE AND 100 dB ATTENUATOR

USAF

FIELD	NO. OF INDIVIDUALS	NO. OF EXPOSURES.
5 - 88 KV/M	7	MULTIPLE
5 - 80 KV/M	10	65
380 V/M	14	30 PPS UP TO 3 HR.

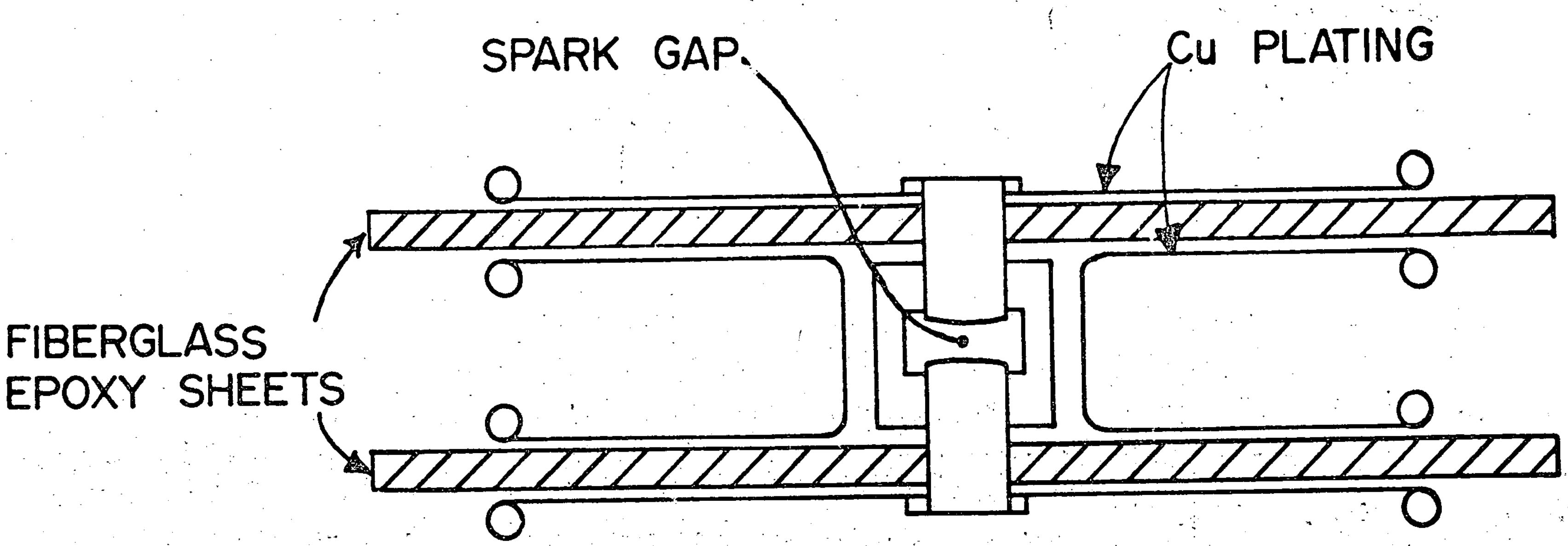
BELL LABS

FIELD (KV/M)	NO. OF EXPOSURES
1 - 2	10^5
2 - 5	10^4
5 - 10	10^4
10 - 20	10^3
20 - 50	10^2
50 - 100	10^0

HIRSCH

FIELD	NO. OF INDIVIDUALS	NO. OF EXPOSURES
UP TO MEGAVOLTS	150	MULTIPLE (SEVERAL YRS)

NO EFFECTS OBSERVED IN ANY PERSONNEL.



A SOLID DIELECTRIC SPARK-SWITCHED LC OSCILLATOR

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8. -------"Provisional Safety Criteria for Use in Electromagnetic Pulse (EMP)"; ANSI C-95 Sectional Committee on Radio Frequency Hazards letter C95 5-23 dated 25 July 1972 w/attachments

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