Absence of Electromagnetic Pulse Effects on Monkeys and Dogs

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The advent of increasingly small solid state electronic components such as integrated circuitry has been accompanied by an increased vulnerability of electronic devices to atmospheric electromagnetic fields, especially when they are subjected to such fields in the form of brief pulses. Electromagnetic pulses occur frequently in nature during lightning discharges and in outer space as the result of cosmic ray bombardment and other nuclear phenomena.

It has become necessary to study the effect of electromagnetic pulses on electronic systems to make them invulnerable, or at least substantially less liable to disruption, by employing shielding or other so-called "hardening" techniques. In order to conduct such studies electromagnetic pulse generators have been developed, and concern has been expressed by industrial hygienists and occupational medical people about possible biologic hazards associated with exposure of workers who operate in and about electromagnetic pulsed fields.

That there is concern can be easily understood when one realizes that the electromagnetic fields generated are measured in terms of hundreds of kilovolts per meter and total energies which are developed are expressed in megajoules. Just the size of the numbers involved is sufficient to occasion anxiety.

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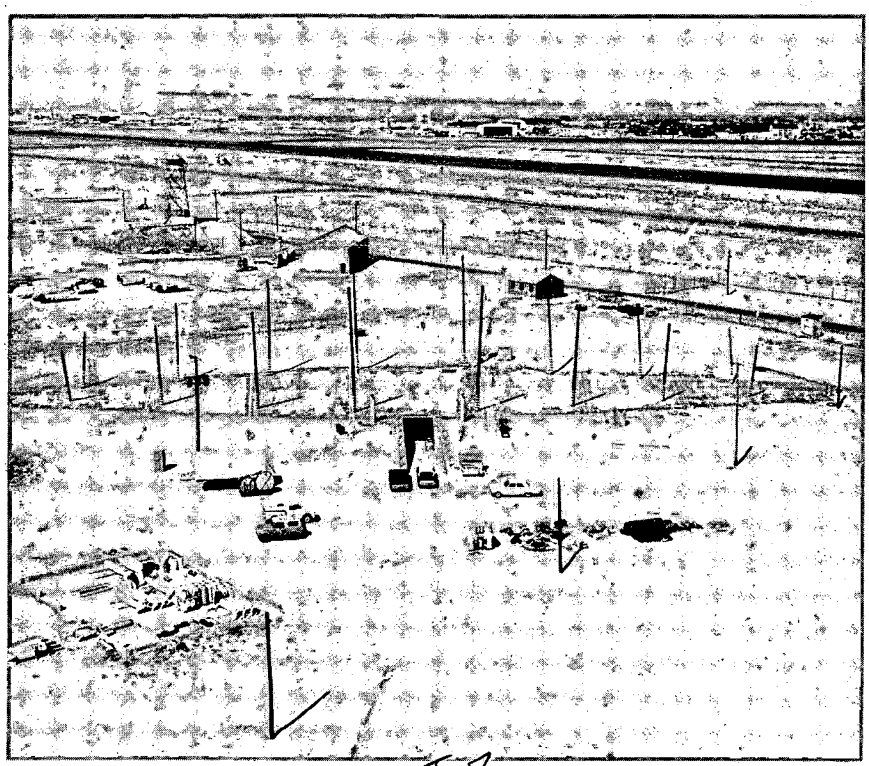
These pulse generators are impressive devices and are getting bigger all the time. Figures 1 and 2 show two Electro Magnetic Pulse installations which are currently in operation in the Albuquerque area. The second is large enough to accomodate a 12 story building between its antenna array and the ground plane. The first pulser has been frequently operated at 1.0 megavolt and the second at three.

The basic electrical circuit employed by these generators is show in Fig 3. A number of wires are suspended rather like guitar strings above a grounded metal grid. A Van de Graaff generator is used to charge up a bank of large capacity condensers. When these are discharged a pulse of electrical energy travels down the wires and sets up an electromagnetic field in the space between them and the ground. The field is distributed evenly in space so that its density at any particular point depends on where the field is located. Near the ends the density in the devices used is in the order of 500 to 600 kv/m and is less in the center.

The electromagnetic field is composed of two mutually orthogonal components, the electric field and the

Fig 1. – Aerial view of the "ALEC" EM pulsing facility.



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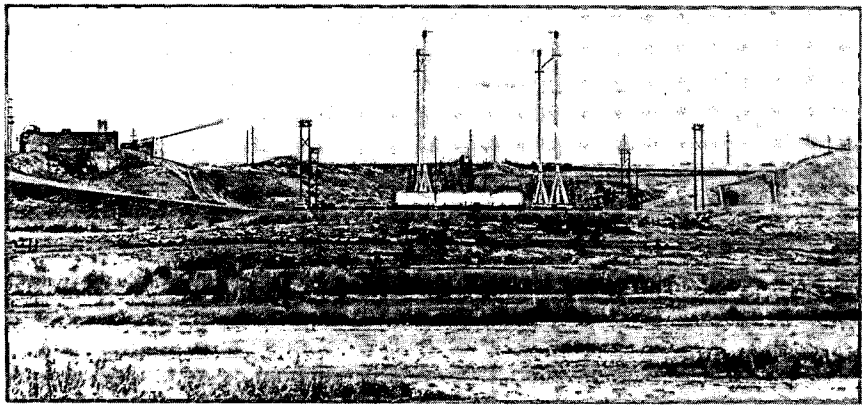


Fig 2. – The "ARES" EM pulsing facility.

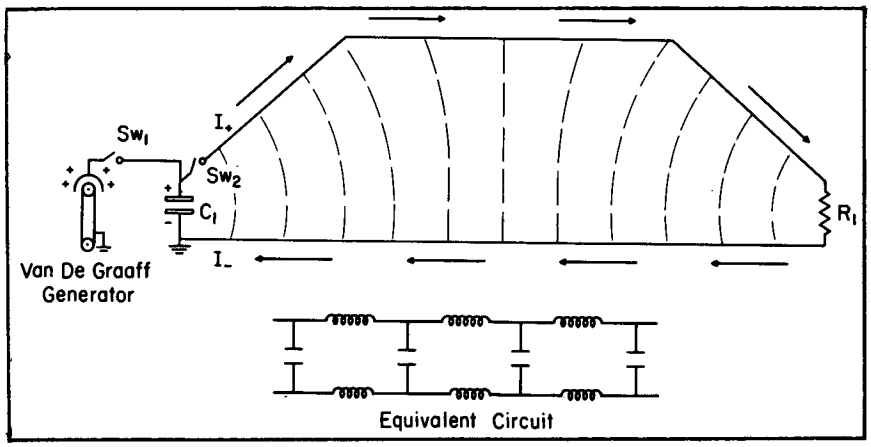


Fig 3. – Circuit diagram and equivalent circuit of a typical EMP generator.

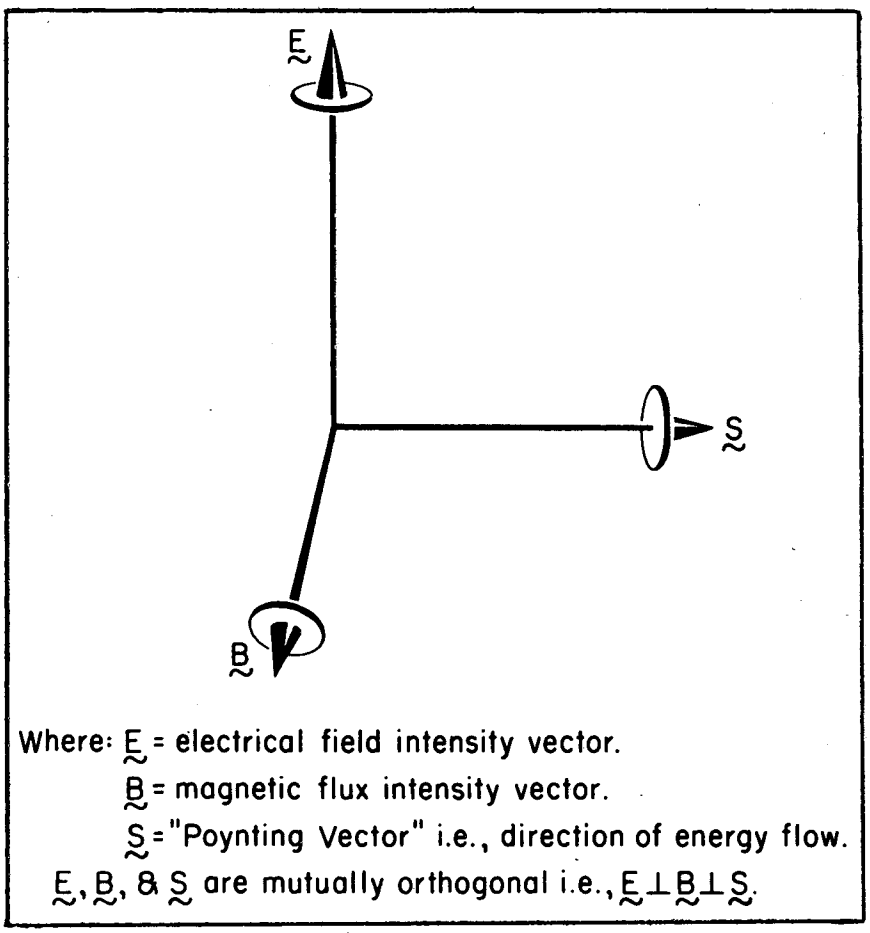


Fig 4. – Vector diagram of a typical field resulting from an EM pulse.

magnetic one. They move in a direction governed by the resultant vector as shown in Fig 4. The electric field is of primary interest in its impact on electronic systems.

The wave form is characterized by a rapid rise time to peak which occurs in about 3 nanoseconds. The decay is exponential, and results in a total time for the event in about 1 second. A somewhat idealized graph of the pulse is shown in Fig 5.

Ordinarily about 5 to 7 minutes are required to recycle the pulser. The time is a function of the recharging time of the condenser bank, and the desired peak voltage.

There is very little in the way of auditory or visual accompaniments to the pulse. In the daytime nothing is seen and one hears a crack similar to the sound of a small caliber firearm. At night there is a visible corona discharge with beautiful blue and lavenders which resembles St. Elmo's fire (Fig 6).

The field intensity is linearly related to the peak voltage generated by the condenser discharge (Fig 7). These curves are for the vertical distance between the antenna wires and the ground plate at which we worked on the two devices with which we have been involved.

In order to fully appreciate the difference between a field situation which we have, and another type of circuitry which is characterized by a current, it has been useful to me to regard the field in terms of atmospherics. There is a strong analogy between what happens in the case of electro magnetic pulsers, and the electric field which always exists and which changes quite dramatically during lightning discharges.

On a fair day we are in an electric field of probably 100 to 200 volts per meter. When a thunderstorm is building up this field increases in intensity by several orders of magnitude. When lightning discharge occurs there is a transfer of electric charges which creates a pulse rather like we have been discussing, and which is shown graphically in Fig 8. One can see that there is some disagreement between numbers among atmospheric physicists, but there is general agreement on the shape of the curve. The similarity to the shape of the EM pulse curve is readily apparent.

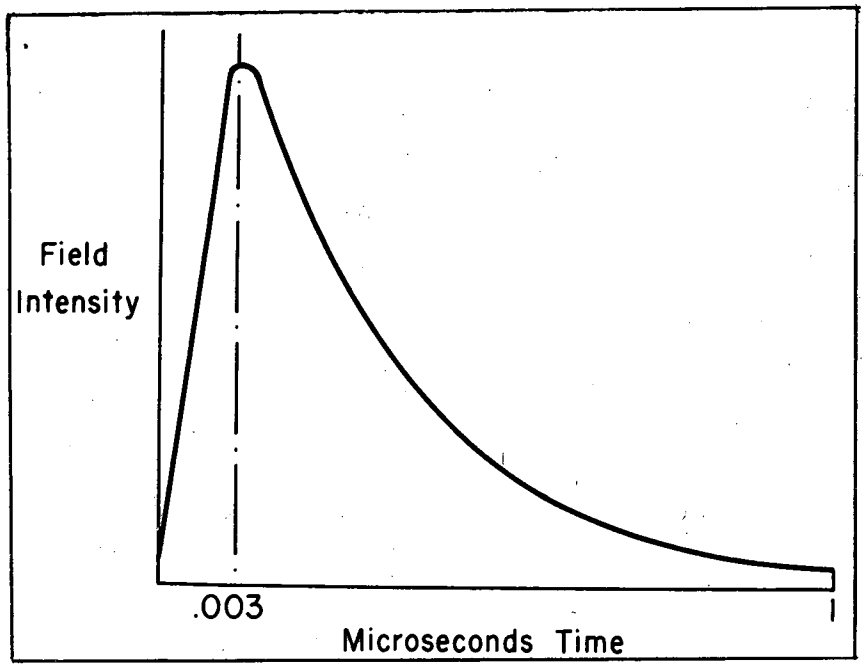


Fig 5. – Idealized EMP curve.

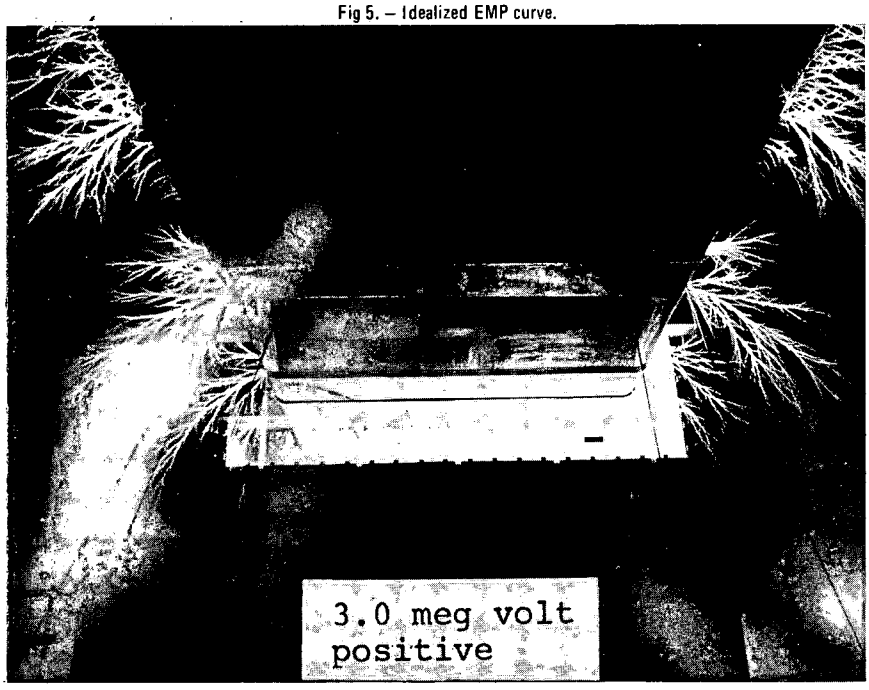


Fig 6. – View of an EMP at night.

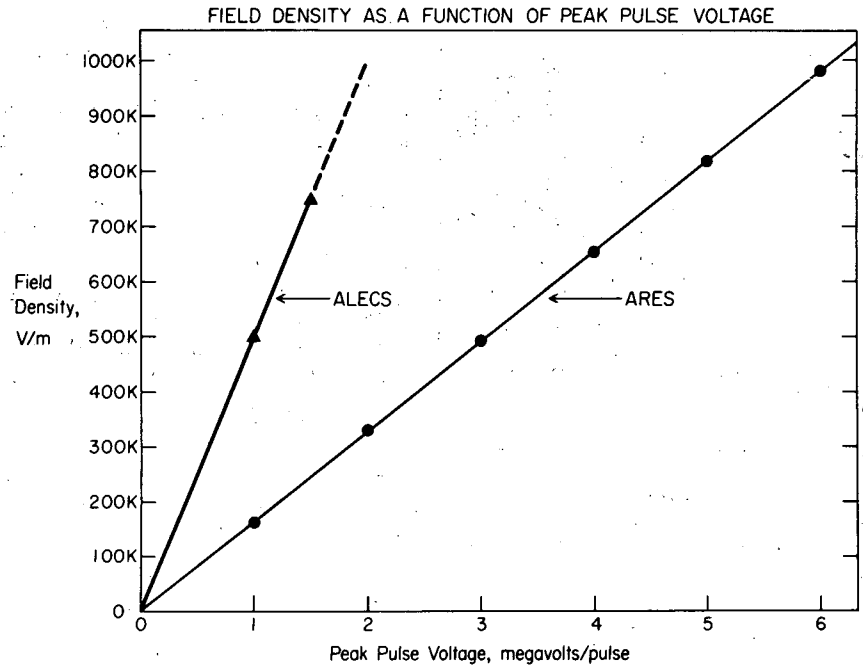


Fig 7. – Curves showing relationship between peak voltage and field density.

Depending on where one is in relation to the location of a lightning bolt one is exposed to a pulsed EM field of varying intensity. Fig 9 illustrates the situation and points out the various parameters which apply to control and intensity of the field accompanying the lightning stroke. These are the height of the thundercloud, the height of the thundercloud above the earth and the distance of the object of interest from the point on earth where the lightning strikes. Fig 10 depicts an equation derived by D. J. Malan.[4] When this equation is solved for ΔE the curve presented in Figs 11 and 12 results. The second curve is a plot of the close-in data. It can be seen that close by a lightning discharge results in field intensity measured in hundreds of kilovolts per meter and that these are somewhat comparable to the fields experienced when a person is in the field generated by a pulser.

The point of all this, is of course, that most, if not all of us has at one time or another been close to a lightning bolt. If we were not hit by it we suffered nothing more than a bad scare.

There have been a few reports in the literature of some temporary disruption of the ability to perform recently learned somewhat complex activities such as piloting an airplane or driving an automobile.[1] Thus to look into the possible effect on some such activity in an experimental animal seemed to be a promising place to look for an EMP effect.

Seven albino female rats were trained to run a conventional maze the design of which is shown in Fig 13. Fig 14 depicts the maze as it was employed in the field. After the animals had learned the maze-running to a point where they routinely turned in errorless performances, they were also conditioned to running in the field environment. They were subjected to three pulses of 600 kv/m and a decrement in performance was observed as illustrated in Fig 15. It can be seen that maze-running had become upset. The effect was temporary however, and within an hour the animals all performed at their preexposure level. No other evidence of physiological or psychological disturbances were apparent.[2]

Subsequent to the rat study additional efforts have been made to

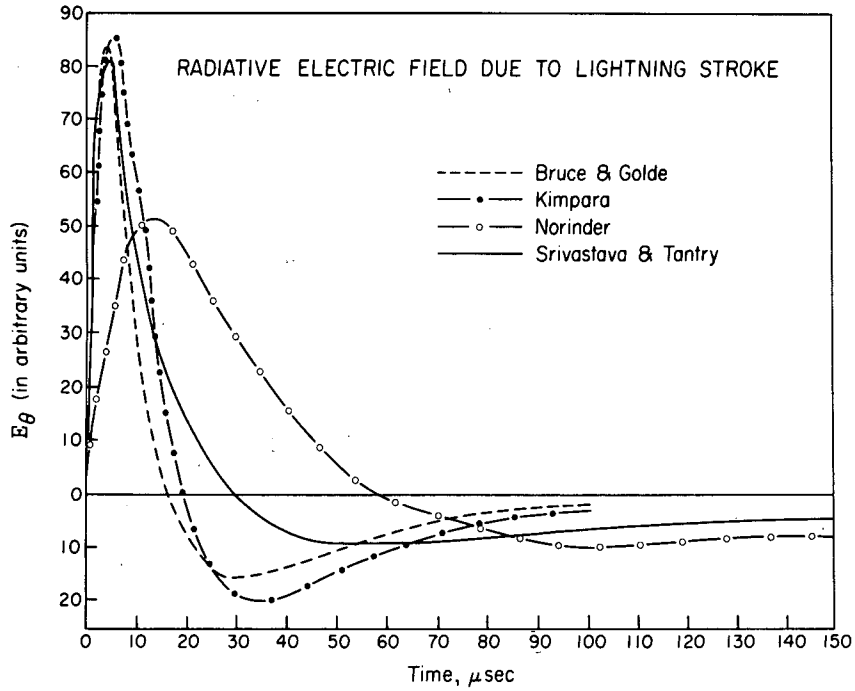


Fig 8. – Curves showing radiative electric field due to lightning stroke as calculated by several authors.

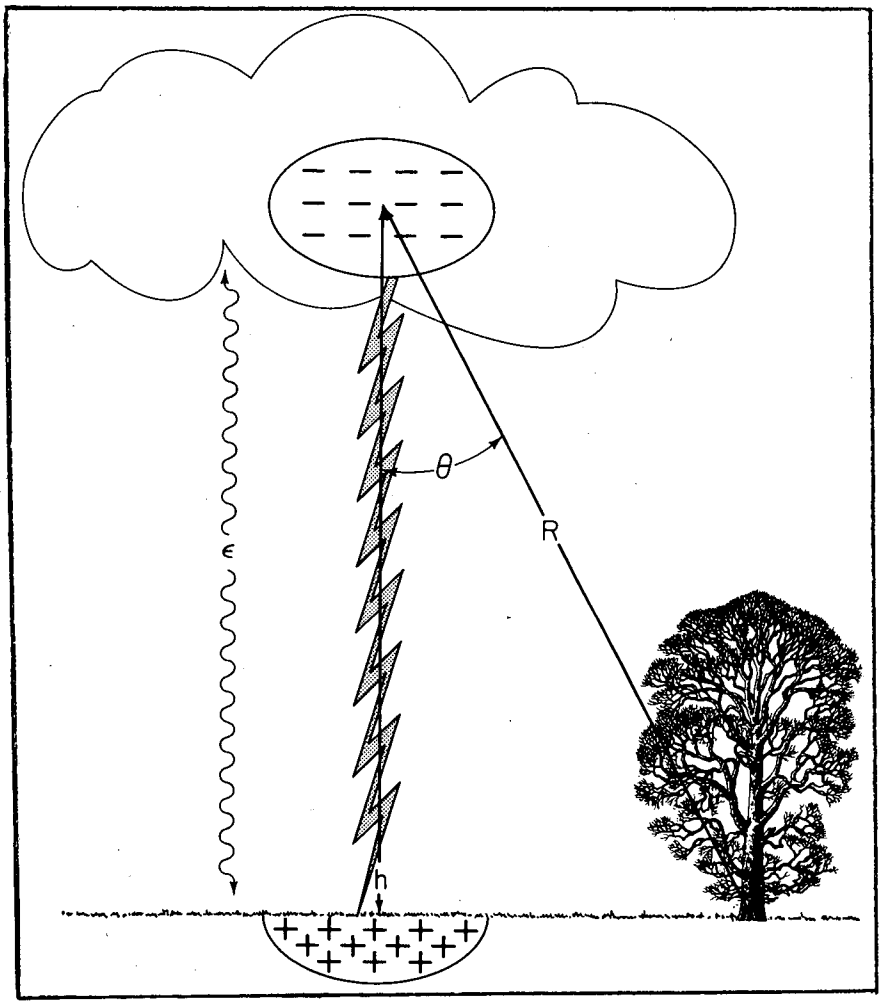


Fig 9. – A diagram showing the electrical situation prior to a lightning stroke. The symbol ϵ is the potential difference in the air between the thundercloud and the sky. The + and – symbols indicate the relative charge situation. The symbol h is the height of the cloud above the ground. The parameter R is the distance of an object of interest from the stroke and is a function of the angle Θ.

determine the existence and nature of EMP effects on other animals.

Monkeys

The first primate subject was an adult, male stumptailed macaque, *(Macaca sepciosa)* weighing about 14 kg. Although not trained for any specific task, the animal's customary behavior was well known to his handlers, as he had been in the animal colony a long time and had been subjected to a variety of previous experiments. The monkey was confined within a roomy wooden cage at the test site and exposed to eight pulses of from 300 to 600 kv/m spaced at 10 minute intervals. Following each pulse the animal was approached by his handlers who offered pieces of fruit and looked for unusual behavior of any sort.

The second primate tested was a male rhesus *(Macaca mulata)*, weighing about five kg. This animal had been previously trained on a shock-avoidance task whereby a pressing response was required on one of four plastic keys, whenever illuminated, or on a fifth key when a tone (200 to 20,000 Hz) was presented. Failure to respond within five seconds of stimulus presentation resulted in a brief, neck-collar-shock of 10 ma. This animal was thoroughly overtrained prior to EMP exposure and always responded immediately with virtually no errors or omissions. The monkey's wooden test cage and response panel were disconnected from all electrical circuits during each EMP. The performance task was run continuously except for brief interruptions prior to and following each pulse. Motion pictures were taken of the animal's behavior beginning 30 seconds before and for 150 seconds following each pulse. Ten pulses were administered successively, spaced approximately at 10 minute intervals. The first five pulses were about 300 kv/m, the next three were 450 kv/m, and the last two were 600 kv/m. This exposure series was repeated at a later date under similar circumstances, with the addition of a wire mesh floor on the monkey's case to connect him to the EMP ground plane.

Dogs

Four, untrained, adult dalmatian dogs were exposed to EMP's to determine whether hematologic or bio-

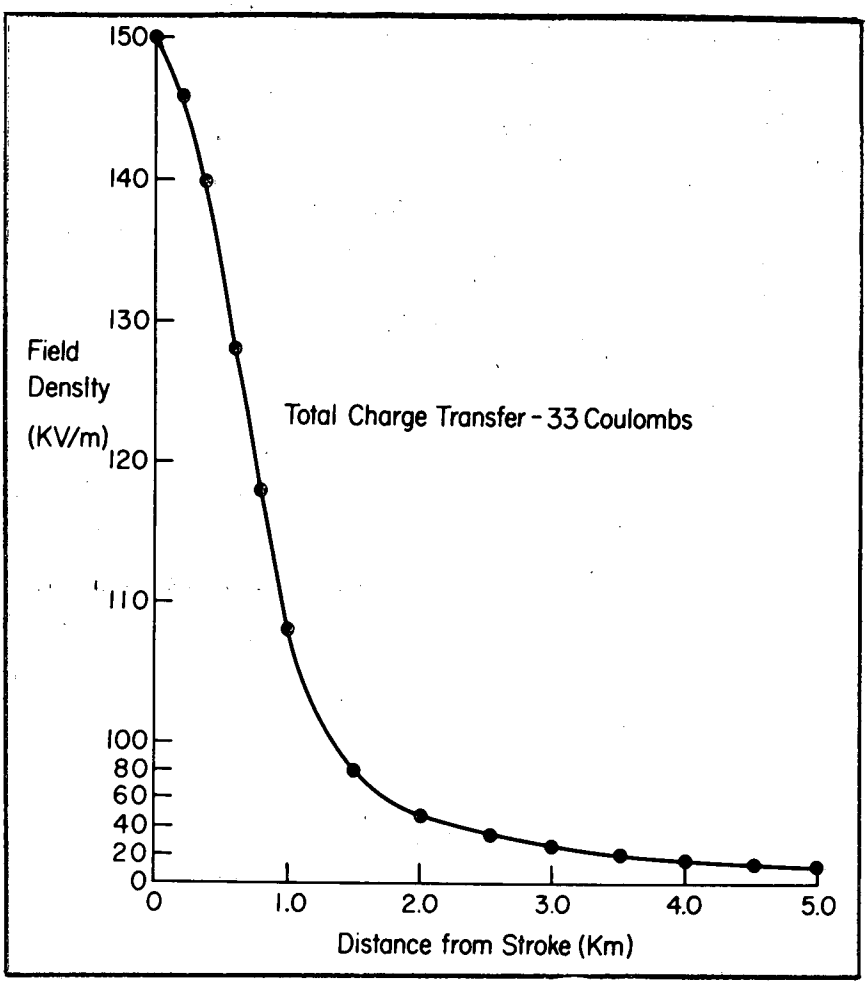


Fig 10. – The equation derived by D. J. Malan to calculate the charge transferral during a lightning stroke. The average stroke transfers 33 coulombs. Using the parameters depicted in Fig 10, the equation can be solved for ΔE.

CHARGE TRANSFERRED TO GROUND BY LIGHTNING

$$\Delta Q = 2\pi\epsilon_0 \left[\frac{h^2+R^2}{\text{sinarctan}\left(\frac{h}{R}\right)}\right] \Delta E = 5.55\times10^{-5}\times\frac{h^2+R^2}{\text{sinarctan}\left(\frac{h}{R}\right)}\times\Delta E$$

Where:

h = height of charge center above ground (Km)

R = distance from stroke to target (Km)

ΔE = vertical field charge (V/meter)

ΔQ = charge transferred (Coulombs)

from D. J. Malan

Fig 11. – Electrical field density (ΔE) vs. distance from a typical lightning stroke.

chemical changes occurred. Blood serum analyses were performed with an SMA-12 automatic analyzer on the four dogs prior to and following EMP administration. Two baseline SMA-12's were done, respectively, two weeks and one week prior to exposure. On each of three successive days pre-exposure, the dogs were adapted to the holding box in which they were to be pulsed. The box had four separate compartments, one per dog. Two of the compartments had wire mesh floors to provide contact between two of the animals and the pulser ground plane. The other two dogs were insulated from ground by a wooden floor.

The dogs received four EMP's of about 330 kv/m, spaced at 10 minute intervals. At 1-hour postexposure, blood was drawn and an SMA-12 and routine hematology were performed. The blood sample and tests were repeated 24-hours later.

Results

No behavioral alterations were observed in either the monkeys or the dogs following exposure to the EMP's. The stumptail monkey continued to accept bits of food readily and performed such manipulations as banana peeling with his customary dexterity when fed immediately after each pulse. He appeared alert and responsive and appeared completely normal to the veterinarian at later examinations.

The rhesus monkey continued to perform rapidly and without error on the avoidance-discrimination task following EMP exposure. The only visible changes for this animal were startle-like responses at the instant of pulsing, which were probably associated with the loud cracking noise of the discharge. The "startle" responses did not interfere with the animal's quick reaction times on the key pressing task or with the accuracy of his discriminations. Study of the motion pictures suggested that what appeared as startle may actually have been a quick, lunging movement toward the response panel triggered by the pulser noise and the flashbulb used as an event marker for the film. This is shown in Figs 16 and 17. This animal was so overtrained that any quick sound or visible movement would tend to initiate an approach to the panel. For example, the monkey would begin pressing the

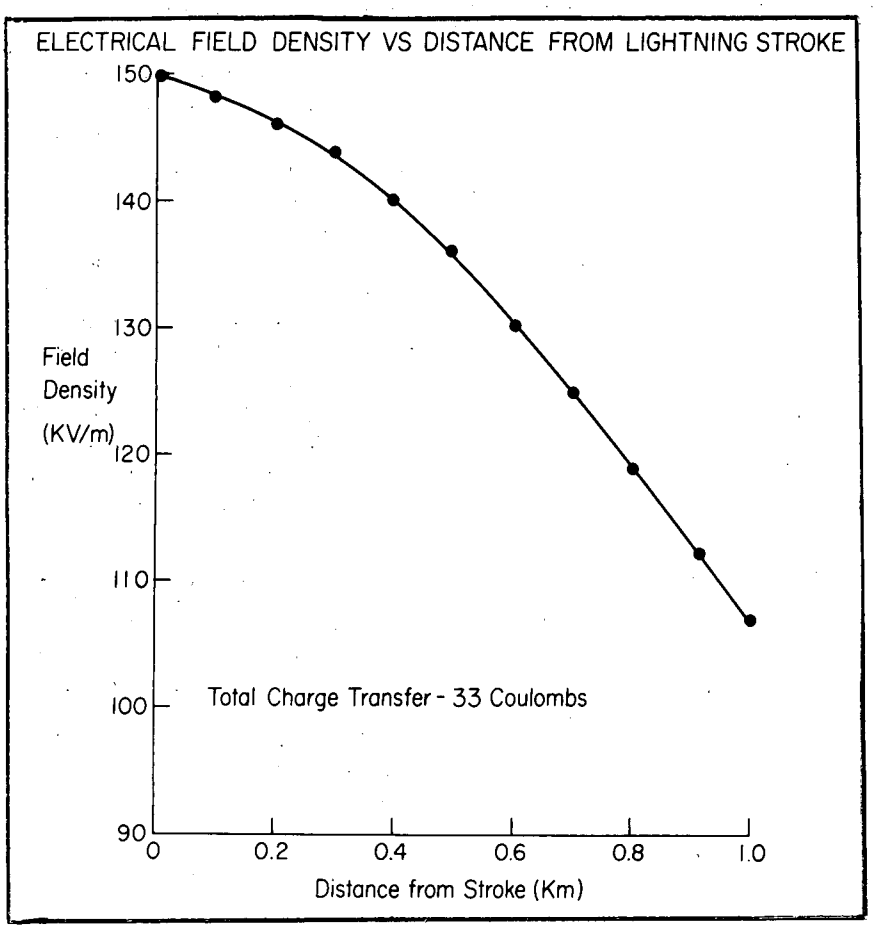


Fig 12. – Electrical field density (ΔE) vs. distance from a typical lightning stroke using data for only the first kilometer.

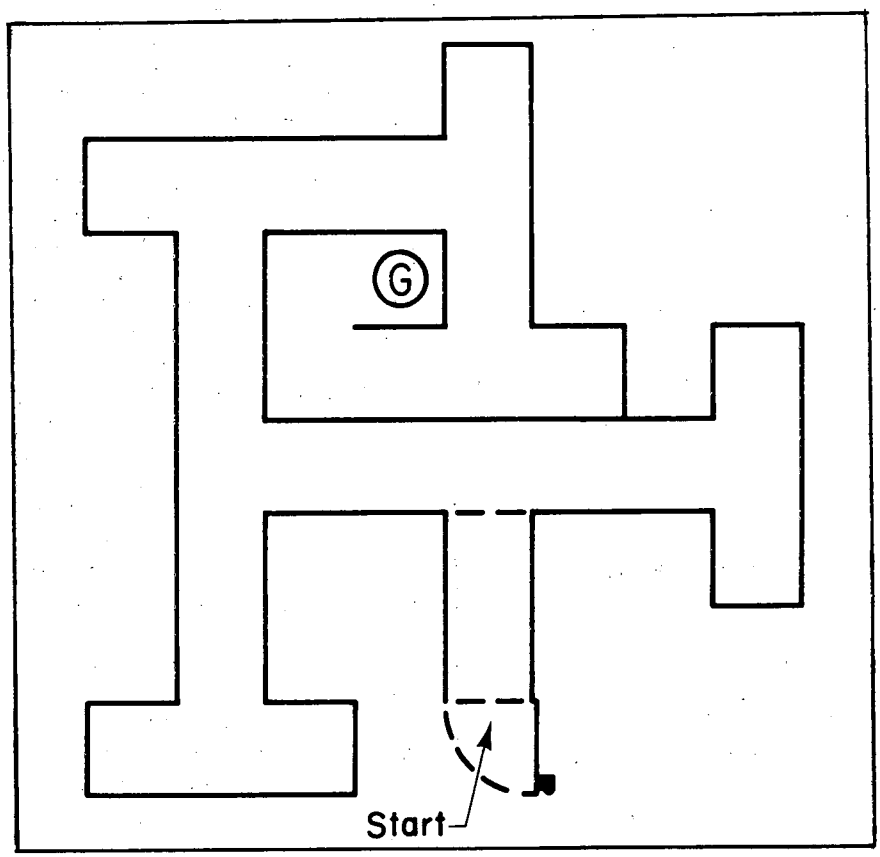


Fig 13. – A layout diagram of the maze used in the rat experiments.

audio key when the public address announcement was heard advising personnel to clear the area.

The second test occasion, where the moneky was connected to the ground plane through the mesh floor of the cage, likewise produced no detectable EMP effects on behavior. Observations by the veterinary staff revealed no untoward effects.

No noticeable changes were seen in the dogs' behavior at the time of, or following, any of the pulses. The SMA-12 andd hematological tests revealed no changes in blood chemistry. Veterinary examination of the dalmatians likewise showed no alterations.

In contrast to the earlier study using rats, the present investigation demonstrated no observable behavioral or other changes in two monkeys and four dogs. Aside from species differences between the two studies, numerous procedural differences exist which obfuscate any conclusions of whether EMP's affect animal behavior to a measurable degree. The absence of effects under the present test conditions implies that the EMP's are more innocuous than dangerous. It should be stressed, however, that the present miniature experiments investigated only single pulse exposures, with few repetitions, and over a short period of time.

Of more concern to health physicists are the possible effects of chronic exposure to high repetition rates received daily by such persons as the pulser maintenance staff. Some informal observations along these lines have been made at the Air Force Weapons Laboratory Dipole Facility by Capt. Kenneth Evans, USAF-MC and Capt. George Schwartz, USAF-MC (personal communications, 1970). In discussions presented at a symposium on EMP effects held recently at the Lovelace Foundation, Capt. Evans indicated that no adverse physical or psychological effects were found in personnel who had been variously exposed to EMP's (11 kv, 12/sec) over a long period of time.[3]

The present state of knowledge regarding EMP effects is inadequate. We feel with some confidence that single or a few exposures to field densities as high as 600 kv/m can be endured safely. We underscore the need, however, for experimental determination of the effects of long-term

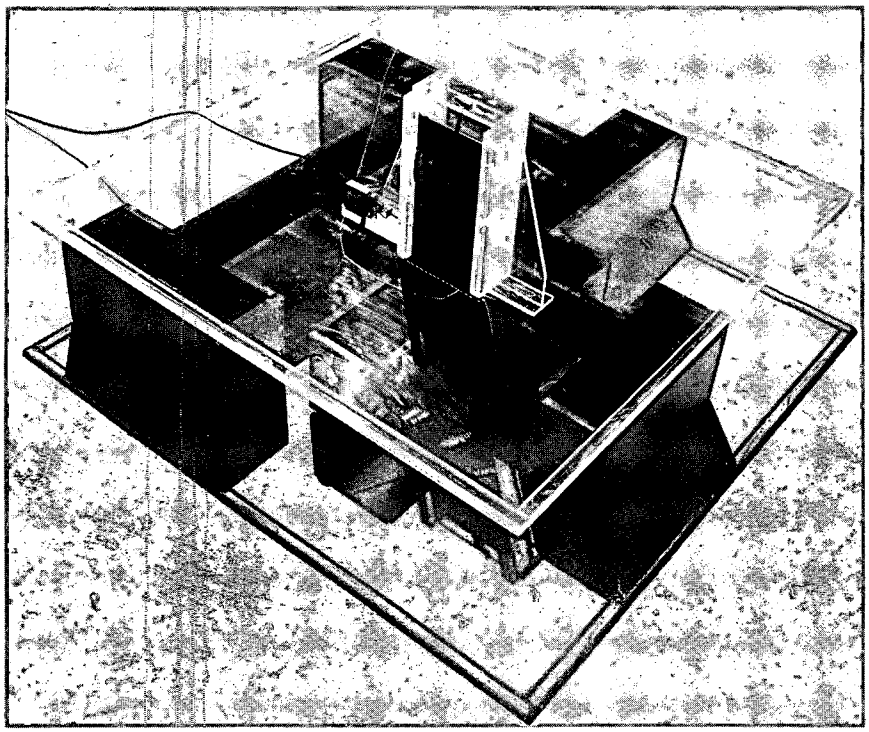


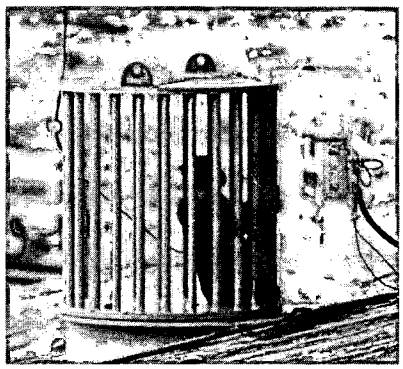
Fig 14. – A photograph of the maze used in the rat experiments.

SUMMARY OF MAZE RUNS

Date	Animal No.	Preexposure Runs		Pulse No.	Postexposure Runs			Remarks
		Time	Errors		Interval	Time	Errors	
11-16-67	14	3	0					
		3	0					
		3	0					
				1	immed.	16	0	"Startle"
				2	immed.	5	0	"Startle"
				3	immed.	NC	NC	"Froze" at starting gate.
					30 min	6	1	Frequent hesitation at decision points.
					1 day	4	0	
					2 days	4	0	
					3 days	5	0	
					4 days	4	0	
					5 days	3	0	
11-17-67	7	5	0					
		7	1					
		4	0					
				1	immed.	NC	NC	"Startle". Made wrong turn out of box. Returned to box.
				2	immed.	NC	NC	Did not leave box. Turned 180° and faced entry door.
				3	immed.	NC	NC	"Startle". Did not leave box.
					30 min	12	0	Hesitant at decision points and seemed "cautious".
					1 day	4		
					2 days	4		
					3 days	3		
					4 days	6		
					5 days	5		

Note: All times in seconds.

Fig 15. – A table showing the results of two representative rat experiments.



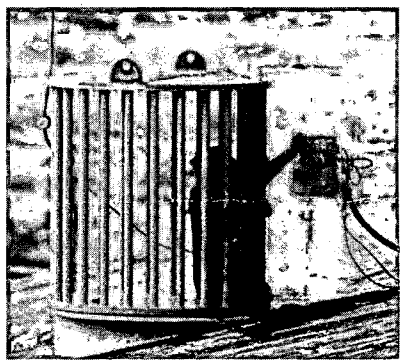


Fig 16. – Photographs of the operantly conditioned monkey performing in the pulsed field.

EMP exposure on animals lest the well-being of human personnel is jeopardized simply because no obvious deleterious, effects have been documented to date.

Planning is currently taking place to explore the matter of chronic exposures somewhat in depth using several species of animals. These studies will include both physiological and psychological observations. Hopefully at their conclusions we will have a better understanding of whether or not there is any biological hazard associated with exposure to electromagnetic pulses.

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References

1. Salvignac A, et al: Cecite temporaire par foudroiement en vol. *Rev Med Aeronaut Spat* 6:11-12, 1967.

2. Hirsch FG, McGiboney DR, Harnish TD: The psychologic consequences of exposure to high density pulsed electromagnetic energy. *Int J Biometeor* 12:263-270, 1968.

3. Hirsch FG, Bruner A, Rupprecht FC, eds. Proceedings of the Technical Coordination Conference on EMP Biological Effects, Lovelace Foundation for Medical Education and Research, Albuquerque, N.M., July 24, 1970.

4. Malan, DJ: The Physics of Lightning, English Universities Press Ltd, London 1963.