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ELECTRIC SHOCK AS IT PERTAINS TO THE ELECTRIC FENCE

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OFFICES AND TESTING STATIONS
207 East Ohio Street, Chicago 11, Ill.
161 Sixth Ave., New York 13, N. Y.
2550 Dundee Road, Box 247, Northbrook, Ill.
1655 Scott Lane, Santa Clara, Calif.

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ABSTRACT

This bulletin describes an investigation, occupying about three years, of electric shock as it pertains to the electric fence. The plan of the investigation included studies of the nature of electric shock and its physical effect on animals and humans, including body electrical resistance, and factors such as voltage, frequency, amount and nature of current passing through the body, duration of current, duration of "off" period and element of anticipation.

Data on each of these factors were compiled (a) from studies made by independent investigators, including accident records; (b) from tests on human beings performed by the staff of Underwriters' Laboratories, Inc.; (c) from a report of a fatal electric fence accident; (d) from a field survey of reported experience with fences in use.

Safety for a two-year-old child when exposed to contact with an electric fence is determined by the investigation, and is used as a criterion for Laboratories' recommendations as to safe characteristics and operation of electric fence controllers of both the alternating-current and battery-operated types.

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ELECTRIC SHOCK AS IT PERTAINS TO THE ELECTRIC FENCE

By H. B. Whitaker*

INTRODUCTION

This bulletin constitutes the third edition of a report (September 1939) on an investigation of electric shock as it pertains to the electric fence, conducted by Underwriters Laboratories, Inc. for the Prime Manufacturing Company, Milwaukee, Wis., and National Carbon Company, New York, N. Y. The cooperation and support of these manufacturers is fully acknowledged.

One of the most recent and novel applications of electricity in the rural areas today is the electric fence. Physically, the electric fence differs from the conventional type of barbed-wire or woven-wire fence in that it is of simpler construction (usually having one wire) and does not require the mechanical strength or stability of the older types. Functionally, it is different in that it controls animals by means of fear rather than by strength or by causing pain. The electric fence is composed of two distinct parts, namely, the fence wire, and the electric controller which supplies the electrical energy to the fence wire.

Electric fence manufacturers claim that this type is more economical, portable, and in some cases, more effective than the ordinary fence.

While the idea of applying electric shock as a restraining medium to humans and animals is not new, it is only within the past few years that manufacturers have developed this principle on a commercial basis. While the actual number of manufacturers is not definitely known, it is estimated that there are at least 100 in the United States. The popularity of the electric fence is indicated somewhat by a statement of Professor H. W. Riley of the New York State College of Agriculture, who estimated that there were probably between 50,000 and 100,000 units in operation at that time (1938).[1]

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[1]For all numbered references see list, page 55.

*Assistant Electrical Engineer; under supervision of R. B. Shepard (deceased), Electrical Engineer, both of Underwriters' Laboratories, Inc.

In October 1936, Underwriters' Laboratories received an application for investigation of an electric fence controller. The sample of the device submitted consisted essentially of a transformer and a current interrupter which permitted the transformer to be energized at regular intervals. One side of the transformer secondary winding was intended for direct connection to ground, and the other, through a high series-resistance, to a one-strand barbed-wire fence.

The operating principle of the electric fence is that the animal, in attempting to go through the fence, establishes an electrical circuit through its body to the ground. In this position, the animal receives the electrical shock supplied by the electric fence controller. After receiving a number of these shocks the psychology of the animal is such that it is inclined to avoid further contact with the fence wire, having learned that the fence is the source of an unpleasant sensation.

In September 1937, Underwriters' Laboratories, Inc. received an application for the investigation of a battery-operated electric fence controller. The sample of the device submitted consisted essentially of a transformer with a "quick-make and break" mechanism connected in the primary circuit. This unit derived its energy from a 6-volt dry-cell battery, a voltage being induced in the transformer secondary winding during the "making" and "breaking" of the current in the primary winding. One side of the transformer secondary winding was intended for direct connection to ground, and the other, to a one-strand barbed-wire fence.

There are units of other types upon the market at the present time which do not necessarily embody either of the above constructions. The principle of applying shock as a restraining medium however, is the same, regardless of the type of unit supplying the electrical energy.

This report covers an investigation of the electric shock hazard connected with the use of the electric fence, preparatory to the investigation of the electric fence controllers themselves. This report is not intended to establish the acceptability of any electric fence controller, but merely to present data and draw conclusions on the subject of electric shock, since this presents the major hazard in the operation of the device.

Since it is not possible to conduct tests upon human beings to determine what constitutes a safe value of current, safe time of contact, etc., it is necessary to present data some of which have no direct bearing upon the case, but which must be borne in mind in formulating conclusions.

PLAN OF INVESTIGATION

The purpose of this investigation has been to determine the maximum value, and the nature of that current, which, within certain limits of frequency and time of contact, can be considered as not being hazardous to human life. It is proposed to establish that value as one which will be safe when experienced by a two-year-old child under the conditions most favorable to the reception of an electric shock. Information which will be presented later indicates that the child is more liable than the adult to injury from a given electrical shock. The worst conditions under which the child might contact an electrified fence wire would include the following: The child barefooted, standing in a pool of water, or mud, and falling across or grasping the wire with two wet or sweaty hands, the wire, so far as the child is aware, being an ordinary non-electrified fence wire.

The data pertaining to this subject are available chiefly from review of the records of electrical accidents and test records of laboratory investigations. These two sources are considered jointly in the establishment of safe operating characteristics of electric fence controllers.

A preliminary study of the electric fence controller and the nature of electric shock disclosed that the following characteristics need to be reckoned with in insuring the safe operation of these devices: (1) voltage, (2) frequency, (3) current and "on" period, and (4) "off" period.

Also pertinent to the establishment of safe operating characteristics of electric fence controllers is the consideration of a report of the only known fatality which has occurred with a commercially-produced electric fence controller.

A field survey was also necessary to investigate certain features of the electric fence not indicated by the review of accident records or laboratory tests.

NATURE OF ELECTRIC SHOCK

The following general statements regarding the nature of electric shock are considered to be pertinent in connection with the study of these data.

Death from electric shock may result from any one or combination of the following causes[2]:

(1) Paralysis of the respiratory muscles, producing death from asphyxia.
(2) Hemorrhage, produced by increasing blood pressure during the passage of electric current.
(3) Heart failure, resulting from ventricular fibrillation.
(4) Respiratory failure, due to nervous inhibitions or actual damage to the nervous system.
(5) Skin and flesh burns, with resultant complications.

(1) **Paralysis of Respiratory Muscles:** The first of these causes, while it may in itself be responsible for death, is, in most cases, associated with one of the other causes. It is a condition that results from continuous contraction of the muscles. In this condition, the lungs fail to function normally, and the victim suffocates.

(2) **Hemorrhage:** As the current passes through the blood stream, the effect is to raise the temperature of the blood and increase the pressure, with the result that the walls of the blood vessels break. This condition accounts in part for the usually severe hemorrhage following electrical accidents.

(3) **Heart Failure:** This is of chief concern since it is the primary cause of death in the larger mammals from contact with circuits which allow only a relatively low value of current to pass through the victim. Ventricular fibrillation is a condition in which the heart muscle fibers, instead of contracting in a coordinate manner, contract separately and at different times. When this condition is present, the heart ceases to function as the circulator of the blood. The heart is thrown into ventricular fibrillation by the passage of relatively low values of current through the ventricles. Some animals recover spontaneously from ventricular fibrillation, once the current is interrupted. Some, on the other hand, do not recover spontaneously. Man is in the latter group.

(4) **Respiratory Failure due to Nervous Inhibitions or Damage to the Nervous System:** These results of the passage of larger amounts of current through the body are usually associated with higher potentials. When the body contacts a circuit and receives a high-intensity electric shock, the nervous system involved in the current path is temporarily paralyzed. The most common result of this paralysis is respiratory failure. Breathing may be initiated by the use of artificial respiration or the application of a bodily jolt or jar. The paralysis of other parts of the body is sometimes involved and may persist for considerable periods after the current has been interrupted. The passage of a high current for even a short period of time often causes the nerves to lose their irritability and conductivity.

(5) **Skin and Flesh Burns:** Aside from the fact that electrical burns are apt to be deeper and, therefore, more serious than they outwardly appear, they are not different from other burns. They usually occur at the point of contact of the victim with the electrical circuit, and are the result of passages of current through an extremely high-resistance contact.

RECORD OF INVESTIGATION

GENERAL

Generally speaking, the factors which determine the seriousness of electrical shock are:—

(1) Body electrical resistance.
(2) Voltage and frequency of the circuit.
(3) Amount and nature of current passing through the body.
(4) Part of the body through which the current passes.
(5) Length of time current flows through the body.
(6) Element of anticipation.

Each of these factors will be considered separately in the review of accident records and laboratory tests necessary to the establishment of safe operating characteristics of electric fence controllers.

REVIEW OF ACCIDENT RECORDS AND LABORATORY TESTS

BODY ELECTRICAL RESISTANCE

General

Necessary to the establishment of the safe operating characteristics of electric fence controllers is a consideration of the human body as a conductor of electricity

As a conductor, the human body is made up of two parallel paths. One of these, the outer skin, is of relatively high resistance, whereas the other, composed of the blood stream and the body tissues, is of relatively low resistance.

Laboratory tests[3] have shown that human tissue, as an electrical conducting medium, is somewhat analogous to a circuit consisting of a high resistance in parallel with a high capacitance. The chief resistance of the body in an electrical circuit is at the point of contact with the circuit. Repeated tests have shown that thoroughly dry skin on the hands has a resistance of approximately 40,000 to 50,000 ohms per square centimeter. This resistance drops to as low as 1000 ohms per square centimeter when the hands are wet.

Several measurements[4, 5] of body resistance taken during criminal electrocutions have shown that with the use of large electrodes and with approximately 2,000 volts potential applied, 8 to 10 amperes of current flow through the body. This would indicate that under these conditions the human body has a resistance of approximately 200 ohms.

This value of body resistance hardly seems justifiable in connection with the electric fence application because it is not possible to obtain as large an area of contact with a single wire electric fence as can be obtained by means of wrist, head, and leg electrodes such as are employed in criminal electrocutions. Since the area of contact determines, to a large extent, the value of resistance recorded, the conditions of criminal electrocution are not sufficiently comparable to those under which contact with an electric fence may be made to warrant accepting the 200-ohm value.

The large amount of current used in criminal electrocutions also is another factor which would tend to cause a lower value of resistance, due to increased temperature of the body. An average body temperature of approximately 138 degrees Fahrenheit has been recorded[6] during criminal electrocutions.

Laboratory Tests

Because the conditions of criminal electrocutions are not sufficiently comparable to those of contact with an electric fence to be used in the determination of body resistance, suitable tests were conducted at the Laboratories for the determination of this value.

The outer skin of an individual offers the greatest resistance to the flow of electrical current. Therefore it was necessary to reduce to as great a degree as possible the effect of the high skin resistance.

In the electric fence application, this is usually accomplished by means of a high voltage which has the effect of breaking down the skin resistance. The current output of the device is limited by inherent impedance.

Since it was not possible to apply a high voltage with unlimited current as a means of determining the body resistance, the skin resistance was reduced by having the subject immerse his hands and feet in a 20 per cent solution of sodium chloride prior to grasping the hand electrodes and prior to standing upon the foot electrode. Preliminary tests, using this solution, indicated that the electrolysis current from hand to hand of an adult did not exceed approximately 3.5 micro-amperes, if measured in series with a 3000-ohm resistance. Since the measuring current for children was in no case less than 1 milliampere, and for adults 5 milliamperes, the error due to electrolysis current could be considered negligible.

Preliminary tests indicated the body resistance to be independent of the value of current employed between 1 and 15 milliamperes, provided a constant area and pressure of contact were maintained, and provided the individual wet his hands in the solution each time prior to being measured.

The measuring current was derived from 12 volts of dry cell batteries which were connected directly across two 3000-ohm series resistances. The potential applied to the subject was gradually built up from zero by means of the potentiometer method until the necessary current value was obtained. The body resistance was then calculated from readings of the applied voltage and the resultant current.

The hand electrodes consisted of two No. 10 Awg bare copper wires twisted together and supported approximately 6 inches apart on porcelain insulators. The foot electrode was a copper plate, No. 30 gauge, approximately 14 inches square. In measuring the body resistance from hand to hand, the individual firmly grasped the electrodes with his hands, which he had previously immersed in the brine solution. In measuring the body resistance from hands to feet, the individual stood upon the copper plate, having previously immersed his feet in the brine solution, and grasped the electrodes with his hands, which he had also previously immersed in the solution.

Preliminary tests indicated that the lowest value of contact resistance was recorded when the individual grasped the wire electrode rather than when a pressure was applied only to one side of the wire as would be the case should a person merely lean against the fence. For this reason each individual was instructed to grip the wire firmly rather than apply a constant pressure to it.

The current employed was 5 milliamperes except in those cases where the resistance was so high as to make it impossible to obtain a flow of 5 milliamperes with the 12-volt potential.

The results of these tests upon adult individuals, employees of the Laboratories, are given in Table 1.

An examination of Table 1 indicates that for the limited number tested, there are no trends or relationships established between the body resistance of the individuals and their sex, age, height, or weight. For this reason, it was felt necessary to conduct these same tests upon children, as the foregoing data did not indicate whether the resistance of children under the given conditions would be greater or less than that recorded for adult individuals.

Similar tests were conducted upon a number of children having an age range of 3 to 15 years. The results are given in Table 2.

To prevent imparting any sensation to the subjects, the measuring current in this series of tests did not exceed 1 milliampere. This value of current was used in all cases except those where the body resistance was so high as not to permit this flow of current from the 12-volt potential.

Conclusions

A study of the following tabulated data shows that the body resistance of children, under the conditions of measurement employed, is higher than that of adults measured under the same conditions. It appears safe to assume, therefore, that the lowest body resistance which might be reckoned with in connection with the electric fence application would not be less than 500 ohms. In determining the output of an electric fence controller which might be received by an individual accidentally contacting the fence, it appears that a total resistance load of not less than 500 ohms on the output side of the controller should be used in series with the measuring galvanometer.

TABLE 1
BODY RESISTANCE OF ADULTS

SUBJECT					OHMS RESISTANCE FOR PATHS				
Subject No.	Sex	Age Years	Height Ft. In.	Weight Lbs.	Hand to Hand Dry	Hands to Feet Dry	Hand to Hand Wet	Hands to Feet Wet	Right Hand to Feet Wet
16	F	40	5— 0	125	13,400	6,400	1,820	830	1,220
11	F	45	5— 0	140	12,100	13,500	1,900	730	930
20	F	20	5— ½	107	11,800	5,400	2,200	910	1,220
19	F	19	5— 1	100	6,600	2,800	1,820	860	1,200
31	F	20	5— 2	119	13,000	6,520	2,440	980	1,400
12	F	25	5— 2	120	7,000	......	2,260	1,030	1,450
22	M	32	5— 3	120	8,500	3,120	1,700	860	1,160
18	F	34	5— 3	125	12,100	6,000	2,010	820	1,200
15	F	31	5— 3	178	9,200	......	1,760	730	1,050
32	F	27	5— 3½	110	17,000	5,900	2,600	1,180	1,950
17	F	26	5— 4	128	8,800	3,900	2,300	1,000	1,460
14	F	24	5— 4	136	7,100	2,800	1,950	780	1,110
39	M	58	5— 4	180	15,200	4,700	2,340	870	1,230
28	F	21	5— 4½	140	12,000	4,800	2,720	1,200	1,740
3	F	20	5— 5	119	10,300	5,100	1,830	780	1,080
4	M	33	5— 5	130	......	5,200	......	720	960
27	F	32	5— 5	130	11,300	5,100	2,540	1,160	1,670
24	M	36	5— 5	137	13,300	1,550	930	790	1,080
35	M	32	5— 5	142	10,400	4,300	1,880	880	1,210
40	M	23	5— 5	145	15,550	3,700	1,700	860	1,260
38	M	37	5— 5	163	11,850	4,700	1,620	800	1,100
30	F	18	5— 6	120	13,200	6,600	2,100	860	1,300
29	F	18	5— 6	128	12,400	5,500	2,100	910	1,260
33	F	25	5— 6	160	13,600	5,600	2,220	1,020	1,380
13	F	37	5— 7	115	7,400	5,000	2,200	1,020	1,430
25	F	30	5— 7	134	13,600	5,800	2,000	970	1,200
34	M	47	5— 8½	175	9,500	3,600	1,860	850	1,100
9	M	32	5— 9	151	9,400	4,700	1,700	750	1,100
26	F	33	5—10	116	10,300	5,000	2,080	910	1,360
8	M	28	5—10	145	10,600	......	1,620	760	1,140
6	M	25	5—10	145	18,000	5,000	1,540	630	930
1	M	30	5—10	150	8,240	3,600	1,760	810	1,160
7	M	24	5—11	160	11,600	4,200	1,640	760	1,110
5	M	19	5—11	161	......	5,800	......	830	1,100
10	M	26	5—11	170	8,700	3,000	1,520	660	980
23	M	37	6— 0	135	13,600	6,010	1,920	840	1,150
2	M	23	6— 0	165	9,600	3,900	1,750	950	1,110
37	M	38	6— 0	182	9,860	3,600	1,700	820	1,220
36	M	24	6— ¾	165	7,200	3,000	1,340	610	820
21	M	44	6— 1	208	14,600	3,600	1,840	820	1,320
Maximum		58	6— 1	208	18,000	13,500	2,720	1,260	1,950
Minimum		18	5— 0	100	6,600	1,550	930	610	820

VOLTAGE

General

In the consideration of voltage characteristics of electric fence controllers, two distinct facts need to be established. The first is whether or not the open-circuit voltage of the controller need be limited, provided the current output of the controller is limited by internal impedance. The second is the maximum value of open-circuit voltage which can be permitted, assuming the current is in no way limited, except possibly by 15-ampere branch-circuit fuses in the supply circuit.

TABLE 2

BODY RESISTANCE OF CHILDREN

SUBJECT					OHMS RESISTANCE FOR PATHS					
Subject No.	Sex	Age Years	Height In.	Wght. Lb.	Hand to Hand Dry	Hands to Feet Dry	Right Hand to Feet Dry	Hand to Hand Wet	Hands to Feet Wet	Right Hand to Feet Wet
98	F	3	35	31	11,860	5,700	7,400	3,350	1,780	2,680
81	F	4	38	31	21,800	6,600	2,600	2,410	2,100	3,300
94	M	4	39	41	8,000	4,100	5,700	2,940	1,640	2,210
90	F	5	40	34	11,900	3,800	5,600	2,800	1,900	2,100
51c	F	5	41	38	7,700	3,700	....	2,630	1,010	....
66	F	5	43	38	....	1,960	2,700	1,680	1,100	1,630
77	F	5	48	51	31,000	6,400	7,600	2,810	1,500	1,940
82	M	6	47	49	8,100	3,100	1,900	1,940	1,150	1,400
100c	M	7	49	52	23,300	5,200	9,900	4,100	1,820	2,750
70	F	7	49	60	20,600	3,450	5,300	2,550	1,410	1,810
79	F	7	50	55	15,500	4,200	5,200	2,060	1,100	1,470
103	F	8	49	49	7,600	5,400	8,730	3,350	2,420	3,100
88c	M	8	50	48	240,800	55,000	....	5,200	4,200	5,700
53	M	8	50	55	12,000	5,850	6,500	11,860	1,360	1,850
102	F	8	51	61	43,600	12,950	35,450	4,500	1,670	2,210
71	M	8	52	67	23,900	5,000	7,950	2,570	1,230	1,810
99	M	9	50	54	19,280	5,600	9,000	2,840	1,380	1,980
67c	F	9	50	60	....	10,000	19,000	...	1,760	2,820
75	F	9	52	56	27,000	6,300	7,700	2,430	1,210	1,780
91	M	9	53	67	6,100	2,420	3,400	2,570	1,400	1,940
61	F	10	50	54	10,700	3,450	4,700	2,200	1,500	1,620
97	M	10	52	71	20,400	5,000	8,300	2,140	1,060	1,520
84	F	10	53	57	21,000	5,000	....	2,600	1,260	1,780
86c	F	10	55	74	52,500	8,500	11,000	3,500	1,810	2,700
62c	M	10	59	128	33,000	5,100	9,750	2,880	1,380	1,990
74	M	11	56	80	21,200	5,600	8,200	1,740	1,080	1,500
95	M	11	56	93	13,150	3,800	6,300	2,100	1,230	1,710
55	M	11	57	70	3,900	2,200	3,380	1,700	1,170	1,670
92	F	11	57	71	12,130	3,800	5,300	3,300	1,730	1,600
76	M	11	58	113	9,900	3,000	5,000	2,100	1,000	1,460
104c	F	11	59	77	196,000	13,000	28,000	4,400	1,910	2,610
65	F	11	60	109	4,500	2,120	3,000	2,080	1,140	1,640
68	M	12	57	78	10,000	3,000	5,250	2,350	1,100	1,650
69	M	12	57	78	16,400	4,300	5,300	2,200	1,030	1,620
85	F	12	59	80	11,280	5,100	4,400	2,450	1,360	1,880
83	M	13	54	67	7,700	2,800	4,000	2,400	1,300	1,830
96	F	13	57	78	9,700	2,910	5,000	2,680	1,200	1,790
89	M	13	57	98	31,950	8,100	10,500	2,800	1,600	1,840
87c	F	13	59	97	33,700	7,700	9,300	3,400	1,960	2,770
80	F	13	61	81	6,600	2,750	3,700	2,010	1,010	1,480
93	M	13	61	90	22,000	4,600	9,100	2,310	1,200	1,640
73	M	14	56	87	3,800	1,810	2,840	2,040	1,020	1,580
60	M	14	58	87	12,100	4,000	4,700	2,100	1,040	1,500
72	M	14	59	91	9,400	3,100	5,200	2,250	1,220	1,800
64	M	14	63	114	50,400	11,000	17,400	2,460	1,400	1,900
101	M	15	62	109	23,400	3,700	7,600	2,810	1,210	1,890
78	M	15	63	111	5,100	2,000	4,300	1,920	860	1,270
Maximum	....	15	63	128	240,800	55,000	35,450	11,860	4,200	5,700
Minimum	....	3	35	31	3,800	1,810	1,900	1,680	860	1,270

Note: c— Denotes subject colored.

While there are no definite data available on the effect of electric shocks received from a source of constant current with different open-circuit voltages, it is generally conceded that, where the current is not limited, the only effect of the voltage is to force more current through the circuit. Numerous tests[20,25] have conclusively demonstrated that the severity of electric shock is proportional to the current flow through the victim rather than to the voltage at which the shock occurs.

As previously stated, the effect of the higher voltage, when the current is definitely limited by inherent impedance of the device, is to cause a breakdown of the high skin resistance, with the result that the individual will not further reduce the output of the device to a point which would make it ineffective.

Due to the nature of the installation of electric fences, there is automatically established a maximum open-circuit voltage beyond which the unit ceases to function effectively. The result of too high a voltage, with limited current flow, is that the entire output of the controller escapes as current leakage along the fence wire, there being no output available at the further extremities of the fence to restrain the animals.

In view of the above facts, it is not considered necessary to establish a maximum open-circuit voltage on those controllers where the current output is definitely limited by inherent impedance of the device.

The maximum safe voltage supplied by a device which does not incorporate current-limiting features, is one of such value that, in addition to not causing personal injury, it will also permit the individual to free himself from contact with the circuit. In this connection a review of the electrical accident records and laboratory tests was deemed advisable.

Accident Record

In considering electrical accident records, it should be borne in mind that these data, in addition to being very scarce, cannot usually be relied upon for accuracy. Because of the many variables involved, it is practically impossible to determine accurately all conditions present at the time of the accident. The time of contact with the electrical circuit, and the amount of current received by the victim are seldom, if ever, accurately known.

While there are records of numerous instances in which individuals have received fatal shocks at 110 volts or above, with the current limited by 15-ampere fuses, this study deals with the minimum voltages present in fatal accidents, and the following cases[2] are presented:

(1) In England, one fatality has resulted from contact with a circuit of 65 volts at 50 cycles.

(2) In Vienna, one fatality has resulted from contact with a circuit of 60 volts at 50 cycles.

(3) In Italy, one fatality has resulted from contact with a circuit of 45 volts at 50 cycles.

Laboratory Tests

In 1930, a series of tests was conducted at Underwriters' Laboratories[7] in an effort to determine the maximum current that an individual could withstand for a short time and still have voluntary control of his muscles. In these tests, members of the Laboratories' staff were used as subjects. The electrodes consisted of pliers held in each hand. While the tests were recorded on alternating current, tests with direct current indicated slightly higher values could be withstood for a short time until a hot spot occurred at the point of contact.

In these tests the voltage, as well as the current, was recorded. The results of these tests are given in Table 3.

TABLE 3

Subject	AC Voltage	Milliamperes	Calculated Impedance-Ohms
A	40.0	6.0	6,670
B	32.0	7.5	4,260
C	25.0	6.0	4,110
D	20.0	8.0	2,500
E	20.0	8.0	2,500
F	33.0	9.5	3,470
G	21.0	6.0	3,500
H	30.0	10.0	3,000
I	29.0	8.0	3,620
J	31.0	6.0	5,160
K	30.0	10.0	3,000
L	21.0	9.0	2,330
M	30.0	8.0	3,750
Maximum	40.0	10.0	6,670
Minimum	20.0	6.0	2,330
Average	27.8	7.8	3,560

An examination of the above results indicates that the minimum voltage recorded on the 13 subjects tested was 20 volts.

The International Harvester Co.[8] once conducted tests to determine what voltage could be safely handled by their men while working in wet boilers. In these tests, one side of the circuit from a variable transformer was connected to a galvanized bucket which was filled with water. The other side of the circuit was connected to a hand electrode, which the subject held. With the free hand, the subject then tried to pick up an object immersed in the bucket of water. Twenty-two men were subjected to these tests. It was found that under these conditions the maximum voltage an individual could withstand was between 12 and 20 volts. The results of these tests led Dr. S. W. Johnson, who conducted the tests, to state that regardless of the general health of the man, anything over 12 volts was extremely dangerous.

In 1900, Prevost and Batteli[9] found that alternating-current potentials as low as 15 to 25 volts, at a frequency of 150 cycles, caused death of dogs.

In experiments with direct current, it was noted that voltages up to 50 were not fatal to dogs although the time of contact was as much as 5 seconds. Above 50 volts, up to 550, the direct current was uniformly fatal.

T. C. Gilbert[10] pointed out that European technicians have established the fact that circuits of potentials of 20 to 24 volts are definitely dangerous to animals. According to this writer, there are cases where animals have been killed at potentials that could not have exceeded 24 volts when all factors were taken into consideration. In one particular case, it was stated that a potential gradient upon the earth's surface of 10 volts was the cause of death of an animal.

Opinions

Jellinek,[11] an early writer on the subject of electric shock, believed that currents resulting from voltages greater than 25 volts should be considered dangerous.

Dr. A. Zimmern,[12] an early experimenter with electric shock, stated that a potential of 65 volts to ground may cause death.

Tousey,[13] an author on medical electricity, stated that 10 volts applied for a period of 1 second would produce fibrillation provided the heart lay in the direct path between the electrodes.

Conclusions

Taking all the above facts into consideration, it seems that for electric fence controllers, the open-circuit voltage need not be limited provided the device incorporates inherent current-limiting features.

Where no inherent current-limiting features are incorporated in the device, the maximum safe voltage to which an individual may be subjected should not exceed 12. This is based upon the theory that a potential of 12 volts or less will rarely, if ever, cause a breakdown of skin resistance sufficient to permit a current flow through the body of such intensity as to cause lack of muscular control or physical injury to the person.

FREQUENCY

General

Data, which will be presented later, seem to indicate that for continuous (uninterrupted) current a somewhat higher value of direct than alternating current can be withstood by the body without suffering ill effect.

The chief difference in the physical effect of direct, as opposed to alternating current, is that the direct current does not cause contraction of the muscles to the extent associated with alternating current. Laboratory tests indicate that an individual can withstand a decidedly higher value of direct than alternating current and still maintain control of his muscles. At higher voltages, the contraction of the muscles at the time of contact with a direct-current circuit is so violent as to have the effect of a repelling blow. The contraction associated with direct current differs from that associated with alternating current in that the direct-current contraction occurs chiefly at the time of making and breaking of the circuit and, therefore, is not as steady a contraction as results from alternating current.

Where the current is interrupted, few data are available as to the differences between direct and alternating current in its effect upon the body. It has been generally supposed[25] that, as the contact time is shortened, and the frequency of interruption is increased, the values of direct and alternating current necessary to set up ventricular fibrillation tend to approach each other.

Laboratory Tests

Two items of interest in regard to ability to withstand high-frequency currents were noted in reviewing the data.

Kouwenhoven, Hooker, and Lotz,[14] as a result of their experiments upon dogs, found the average value of current necessary to produce fibrillation at a frequency of 1260 cycles per second was more than twelve times the value at 60 cycles.

d'Arsonval,[9] in 1892, found that he could withstand as much as 3 amperes without ill effects, at a frequency which ranged from 4,000 to 1,000,000 cycles per second.

Conclusions

In view of the scarcity of data pertaining to short duration shocks on direct current, and to the lack of data involving frequencies higher than the commercial 60 cycles per second, there is no present warrant for permitting greater values of current than indicated herein regardless of the frequency employed. Due to the difference in the physical effect of direct and alternating current, a slight difference in the "off" period of the two types of controllers appears to be warranted.

CURRENT

General

In the establishment of safe current values for electric fence controllers, it is necessary to bear in mind that current alone can not be considered independent of the time of contact.

A safe value of current that may be taken indefinitely is one that, in addition to not causing bodily injury, would also permit the individual to free himself from contact with the circuit.

The allowable value established for the output current of the intermittent type of electric fence controller should be one that will not permit bodily injury. This statement assumes, of course, that an ample "off" period is provided which will permit the individual to free himself from contact with the circuit before receiving a second shock impulse.

Accident Record

In the consideration of electrical accidents, it should again be pointed out that the accuracy of these data cannot usually be relied upon due to the many variables involved at the time of the accident.

The difficulty of determining what minimum currents may have been fatal is realized by considering the three cases pointed out previously where people have been killed on extremely low-voltage circuits. (See page 14.) Using 500 ohms as the body impedance of the subjects considered in these three cases, the resultant current would be (1) 130 milliamperes, (2) 120 milliamperes, and (3) 90 milliamperes, respectively. Using 2,000 ohms, the resultant currents would be (1) 32.5 milliamperes, (2) 30 milliamperes, and (3) 22.5 milliamperes, respectively. It is obvious, therefore, that no definite conclusions can be drawn from these data as to what minimum current may be fatal.

In the *Proceedings of Public Hearing on Electric Fence Controllers*, published as the result of a meeting of interested parties in Salem, Oregon, in November 1936, are recorded the following field experiences:

(1) A three-year old girl came in contact with an electric fence which was limited in output to 25 milliamperes, but which was not provided with a current interrupter. She was unable to release herself from the wire until the circuit was broken.

(2) The same thing was experienced by a young man of 21 years of age under similar conditions.

(3) A young man was unable to free himself from a continuous-current circuit in which the current was limited to 18 milliamperes.

(4) A dog was killed by current from a 110-volt fence which was in series with a 7.5-watt lamp. Theoretical maximum current is 68 milliamperes.

(5) A three-year old boy was killed by contact with a 110-volt fence in series with a 30-watt lamp. Theoretical maximum current is 270 milliamperes.

The following accidents were reported to the Laboratories in a field survey conducted as a part of this investigation:

(1) A 15-year old boy was unable to release himself from an electric fence in which the current was limited by a 25-watt, 110-volt lamp. Theoretical maximum current is approximately 230 milliamperes.

(2) A cow was killed by contact with an electric fence in which the current was limited by a 75-watt, 110-volt lamp. The device employed no current interrupter, and the shock was experienced following a heavy rain. The theoretical maximum current is 680 milliamperes.

(3) One cow was unable to release herself from an electric fence in which the current was limited by a 25-watt, 110-volt lamp. There was no current interrupter provided. The maximum theoretical current output is approximately 230 milliamperes.

Laboratory Tests

Continuous Current—The data given in Table 3, page 15, indicate that the maximum continuous current, which any of the individuals tested could withstand and yet retain voluntary control of their muscles, was 10 milliamperes. The minimum value recorded was 6 milliamperes and the average for the 13 subjects tested was 7.8 milliamperes.

Thompson,[15] of the Electrical Testing Laboratories, conducted an extensive series of tests upon a number of individuals and found that for women the average maximum tolerable value of current was 5.15 milliamperes. The corresponding value for men was found to be 8.35 milliamperes. The average for all was 7.1, and the maximum value recorded in this series of tests was 20.0 milliamperes.

Grayson[16] reported that similar tests performed upon 42 men indicated that the average man could detect 1.2 milliamperes, and that none could withstand a current of more than 8 milliamperes without serious discomfort.

R. R. Corrie[17] conducted a similar experiment, performing a test upon himself. He found that a current of 14 milliamperes caused paralysis of certain parts of his body.

Gilbert,[18] as a result of tests to determine the specific contact resistance of the hands, found that the average individual could not easily free himself from a circuit greater than 15 milliamperes. He also found that the sensations, experienced by most people with the same current flowing, were in general agreement, although the resistance varied within wide limits, not only with different people but with the same person.

Quite recently, tests have been conducted at the University of California[19] to determine the maximum value of current from a 60-cycle circuit that could be released by the average individual. The tests indicated that for a pathway hand-to-hand, the maximum average tolerable current for 56 men subjected to 81 tests was 13.9 milliamperes.

For the pathway of the current through the body from one hand to one foot, the hand gripping a No. 10 Awg wire, and the foot placed upon a flat metal disc, it was found that the average maximum "release value" for 42 men subjected to 55 tests was 12.6 milliamperes. It was also found that right-handed people could release approximately ½ milliamperes more with the right hand than with the left.

The age range of the subjects was 20 to 40 years. There was no marked difference between wet and dry hands, but wire size did have an effect.

While the following test results have no bearing in the establishment of a continuous value of current which may be considered as not hazardous, they are included at this point as a matter of interest. These test results were recorded in the *British Medical Journal*[9] of 1913.

(1) In 1855, Mann applied electrodes directly to the human heart and found that an alternating current of 15 to 30 milliamperes did not adversely affect the heart's action.

(2) Dixon's and Mann's experiments disclosed that a current through the chest of from 15 to 30 milliamperes did not upset the heart's action.

(3) Trotter found that a direct current of 35 milliamperes from hand to foot was not fatal.

Interrupted Current—Prevost and Batteli,[9] in 1900, found that at a frequency of 50 to 60 cycles, death resulted from a current of 70 milliamperes when the victim (dog) was in contact with the circuit for a period of 4 to 5 seconds. It was also noted that higher currents would not necessarily set up fibrillation, but would invariably result in inhibition of the respiratory system.

Weiss and Zacon,[9] in 1911, secured similar results in their tests on dogs. A current of 70 to 100 milliamperes was fatal when applied for only a few seconds. The application of 35 to 40 milliamperes did not set up fibrillation, but produced inhibition of respiration.

More recent study has been given to the subject of electric shock by Kouwenhoven, Langworthy, and Hooker[20] at Johns Hopkins University. In most of their tests, rats were used for subjects. The rat is an animal which recovers spontaneously from ventricular fibrillation. The object of these tests was not to determine the minimum current that would set up ventricular fibrillation, but to provide evidence in support of general theories of electric shock which have been prevalent since the subject was first studied.

Roughly, the tests consisted of subjecting the rats to potentials of 110, 240, 500 and 1000 volts for periods ranging from 1 second to 1 minute. In these tests, the rats were anaesthetized. The electrodes were placed upon the head and tail of the subject.

Because of the fact that none of these data would be applicable in arriving at the maximum value of current that can be considered as not hazardous to human life, they are not tabulated here. The following general conclusions were drawn, however, and seem to be relevant to this phase of the investigation:

(1) The 110-220 volt, alternating-current circuits are more dangerous to rats than the direct-current circuits of the same voltage.

(2) The 1000-volt, direct-current circuit is more dangerous than the corresponding alternating-current circuit.

(3) A large rat can withstand a greater shock than a smaller rat and still survive.

(4) There is no difference in sexes as to ability to withstand shock.

(5) The longer the contact with the circuit, the greater the chances of death become.

(6) The danger increases as the voltage is raised. (Current not limited.)

(7) The contraction of the body musculature is greater with alternating current than with direct current.

(8) Paralysis depends more upon the voltage of the initial shock than upon the duration of it. (Current not limited.)

TABLE 4

No. of Subjects	Voltage	Milli-amperes	Contact Time (Sec)	Maximum Contact Time—Yet Recovered (Sec)	Results*
11	110 ac	10-48	10-30	10 sec—severe as 30 sec	7 recovered 3 died 1 paralyzed
33	110 dc	28-47	5-60	20	28 recovered 4 died 1 paralyzed
29	220 ac	80-210	5-35	14	8 recovered 11 died 10 paralyzed
[illegible]	220 dc	110-250	5-30	5-10	10 recovered 8 died 1 paralyzed
26	500 ac	240-490	1-4	4	10 recovered 3 died 13 paralyzed
37	500 dc	280-640	1-4	4	18 recovered 17 died 2 paralyzed
34	1000 dc	500-1000	0.5-4	none survived 1 sec	7 recovered 20 died 7 paralyzed

*Recovery, in every case, was brought about by artificial respiration.

(9) The death of the rats in every case resulted from respiratory failure.

(10) The injuries are not directly proportional to the amount of current that passes through the body. Not only must initial voltage be taken into account, but also the duration of the contact and the size of the animal.

In a later series of tests conducted at Johns Hopkins,[21] using rats as subjects, more attention was given to the influence of time of contact. This information is given in Table 4.

Continuing the investigation of electric shock, Kouwenhoven and Langworthy[22] conducted another series of tests upon rats to determine the importance of the paths of the current through the body. In these tests, 1000 volts, both alternating and direct currents were used, and the time of contact was 2 seconds. The results of these tests are given in Table 5.

TABLE 5

Position of Electrodes	No. of Subjects	Voltage	Amperes	Results
Head and tail	6	ac	0.7-0.84	2 recovered 3 died 1 paralyzed
Head and tail	3	dc	0.7-0.84	all died
Right foreleg and tail	12	ac	0.6-0.84	4 recovered 5 died 3 paralyzed
Right foreleg and tail	12	dc	0.5-1.00	5 recovered 3 died 4 paralyzed
Left foreleg and tail	12	ac	0.6-0.84	4 recovered 5 died 3 paralyzed
Left foreleg and tail	12	dc	0.5-1.00	5 recovered 3 died 4 paralyzed
Right and left foreleg	..	ac	......	all animals died on both ac and dc
Right and left hind leg	7	ac	0.6-1.2	6 recovered 1 died
Right and left hind leg	7	dc	0.8-1.2	5 recovered 2 died

The above results indicate that death was more certain where the current passed through the brain or heart or both. These results also sustain a previous contention that a potential of 1000 volts, direct current, is more deadly to the rat than alternating current at the same voltage.

Further studies carried out with rats at Johns Hopkins[23] conclusively demonstrated that repeated shocks at intervals of three days had no cumulative effect. It is not felt necessary to include these data, however, as a similar conclusion has been drawn from more recent studies.

Recent experiments were conducted by Kouwenhoven, Hooker, and Lotz[14] to study the effect of frequency as it pertains to electric shock. In this particular series of tests, fully anaesthetized dogs were used. Their chests were opened and electrodes were placed upon the heart. It was found, as a result of these tests, that with direct current the dog's heart is most responsive to currents at a frequency of 40 to 100 interruptions per second. As the frequency of interruption is increased beyond this range, the heart is less responsive and requires greater values of current to establish ventricular fibrillation. With alternating current, there is little, if any, significant difference in the reaction of the heart to shocks from 25 to 60-cycle circuits. In each test the current was allowed to flow for a total time of 2 seconds. The results of this investigation are given in Table 6.

TABLE 6

Frequency (Cycles per Sec.)	Values of Fibrillating Current in Milliamperes			
	Interrupted D.C.		Alternating Current	
	Mean	Maximum	Effective	Maximum
25	0.52	1.04	0.81	1.14
40	0.35	0.70	0.71	1.00
60	0.31	0.62	0.75	1.06

Continuing their research into the nature of electric shock, Kouwenhoven, Hooker, and Langworthy[24] recently performed a series of experiments to determine what per cent of the total current received during an electric shock actually passed through the heart. To accomplish this, tests were conducted upon dogs as subjects. The current-measuring devices were small ring current transformers ranging in internal diameters from 5/8 to 3½ inches. The subjects were anaesthetized, their chests opened, and the current transformers were placed around the heart in such a manner as to completely encircle it, yet cause as little disturbance as possible.

Preliminary study revealed that the current distribution through the body remained constant for a period of 30 minutes following the death of the animal. This fact was utilized in collecting the following data. It was also found that in seven cases the average current necessary to induce fibrillation was 8.6 milliamperes. The minimum value recorded was 6 milliamperes, the maximum 15. The time of contact was 5 seconds.

The results of this investigation are given in Table 7.

TABLE 7

No.	Lbs.	Io	Per Cent of Io Passing Through Heart for Following Pathways												
			H / T	H / RHL	H / LHL	H / RFL	H / LFL	RFL / LHL	RFL / RHL	RFL / T	RFL / LFL	LFL / LHL	LFL / RHL	LFL / T	RHL / LHL
1	8.0	160	9.0	....	....	....	....	....	....	....	....	....	....	....	....
2	8.0	55	9.0	....	....	....	....	....	....	....	....	....	....	....	....
3	9.5	170	....	....	....	....	....	....	....	....	0.8	....	....	....	....
4	9.0	150	7.7	8.4	8.8	5.5	3.9	....	....	....	....	6.6	6.4	6.9	0
5	10.7	150	8.5	10.1	10.0	3.1	1.0	6.8	7.1	7.0	1.3	8.8	8.5	8.8	0
6	9.3	150	8.8	8.7	8.3	6.6	0.0	7.5	7.7	7.5	6.7	6.3	6.5	....	0
7	7.5	150	7.5	....	....	3.9	1.1	6.2	6.2	7.0	4.7	....	....	....	0
8	11.0	150	9.7	10.8	9.8	0.5	0.5	8.3	8.3	7.7	0.0	8.0	8.6	7.6	0
9	11.3	170	10.5	10.4	10.3	0.0	4.3	9.5	10.3	9.1	3.9	5.5	5.3	4.7	0
Average	9.4	....	8.8	9.7	9.4	3.3	1.8	7.7	7.9	7.7	2.9	7.0	7.1	7.0	0

The following legend should be used in interpretation of the data given above:

No. —Identification number of subject.
Lb. —Weight of subject in pounds.
Io —Total current passing through body in milliamperes.
H —Head.
T —Tail.
RHL—Right hind leg.
LHL—Left hind leg.
RFL—Right foreleg.
LFL—Left foreleg.

Probably the most recent experiments relating to electric shock were conducted by Ferris, King, Spence and Williams.[25] In these experiments the fibrillation of the heart was detected by means of the electrocardiograph.

The first one of these experiments was conducted with a view to determining the order of susceptibility of different animals to fibrillation. In these tests the electrodes were attached to the right foreleg and to the left hind leg of the animal. The duration of the shock was 3 seconds, and the voltage employed was 60 cycles, alternating current. The data collected in these tests are summarized in Table 8, while the relationship between the minimum fibrillating values and the body and heart weights are shown graphically in Graphs Nos. 1 and 2 respectively.

TABLE 8

Species	No.	Average Weight: Body Lb.	Average Weight: Heart Grams	Current in Milliamperes: Minimum Fibrillating Aver.	Minimum Fibrillating Range	Maximum Nonfibrillating Average
Guinea pig	10	1.21	1.8	28	18-45	20
Rabbit	10	4.85	6.0	30	19-44	25
Cat	10	6.38	15.0	29	19-39	23
Dog	10	48.50	170.0	110	70-220	92
Pig	9	174.00	300.0	240	170-270	200
Sheep	25	123.00	270.0	250	160-390	240
Calf	10	154.00	420.0	310	210-470	270

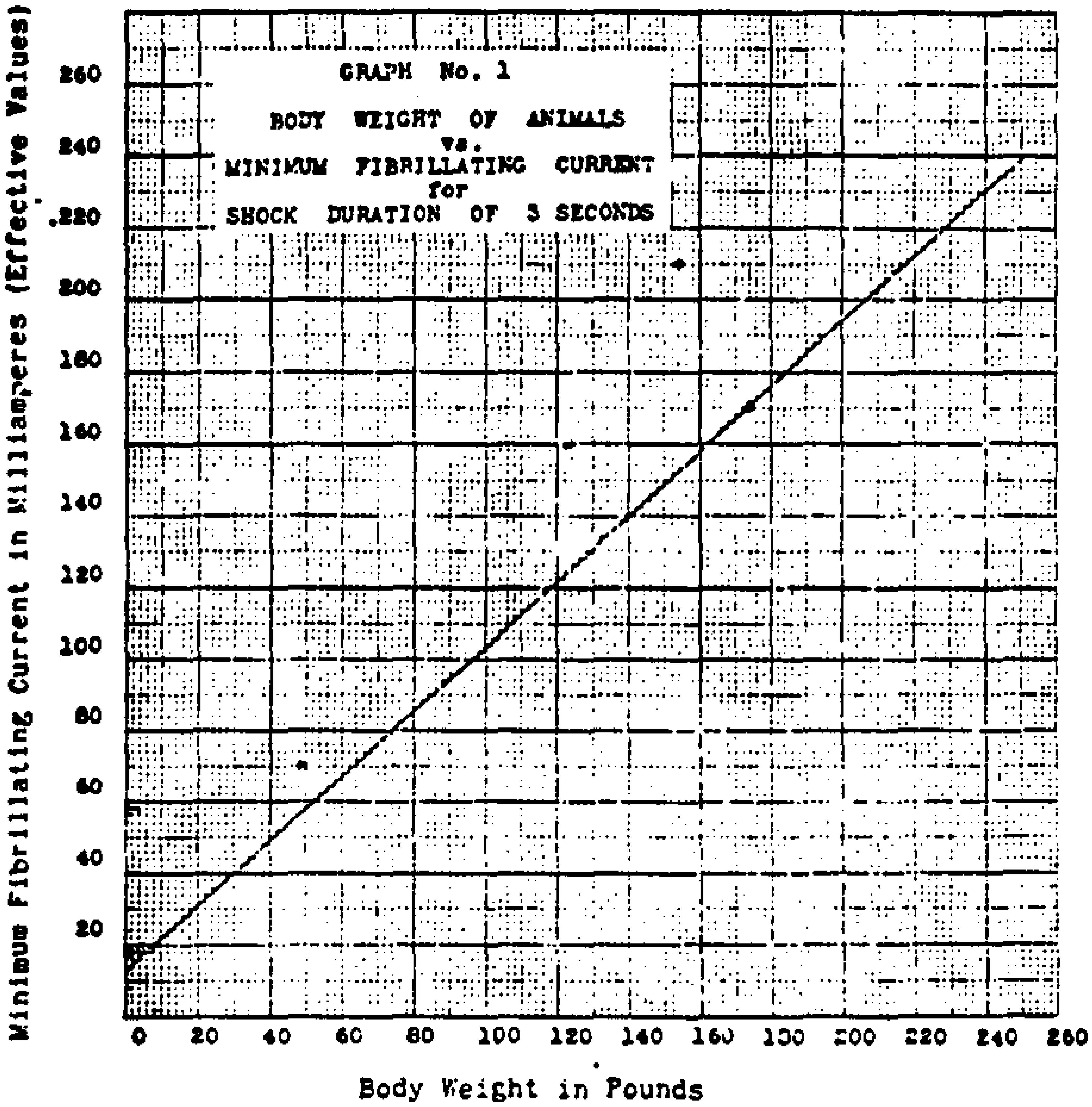


FIG. 1—BODY WEIGHT OF ANIMALS VS MINIMUM FIBRILLATING CURRENT FOR SHOCK DURATION OF 3 SECONDS.

It will be noted from Graphs Nos. 1 and 2, which express the relationship between minimum fibrillating current and body weight, and between minimum fibrillating current and heart weight, respectively, that the current required to produce fibrillation varied approximately in direct proportion to the body weight and heart weight of the animal. For this reason, it was concluded that the tests upon sheep, having approximately the same body weight and heart weight as an adult human, could be interpreted as what might be expected when man receives a similar electric shock.

Physiologists have, through years of laboratory experimentation, substantiated the fact that the response of the heart of the dog and sheep to a given stimulus is the same as that of a human to the same nature and intensity of stimulus.

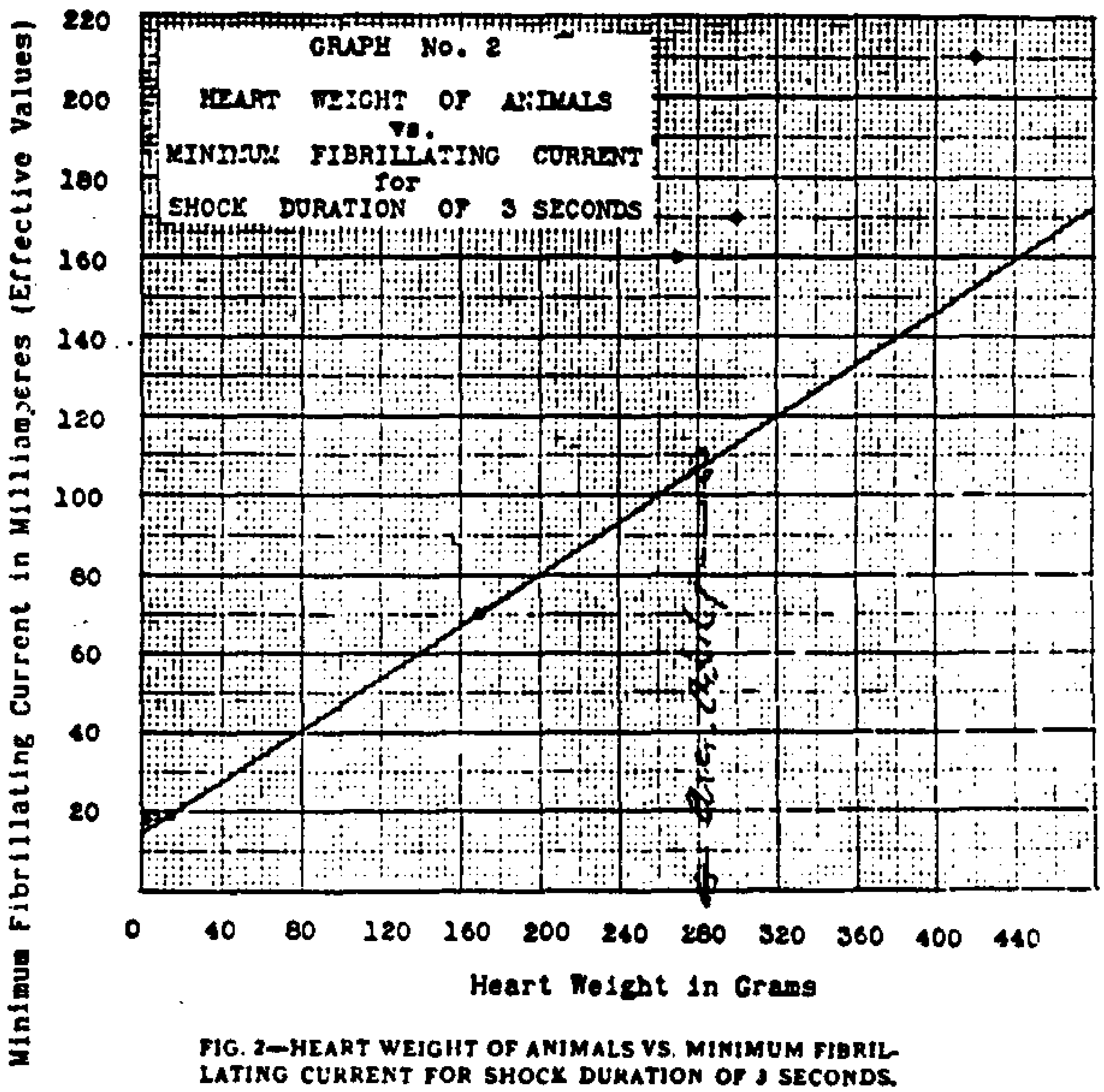


FIG. 2—HEART WEIGHT OF ANIMALS VS. MINIMUM FIBRILLATING CURRENT FOR SHOCK DURATION OF 3 SECONDS.

Basing their work upon this fact, the experimenters next conducted a group of tests upon sheep to determine the effect of different current paths. In these tests, 60-cycle, alternating current, was used and the period of shock was 3 seconds. The results of these tests are tabulated in Table 9.

TABLE 9 ✓

Electrode Position	No. of Animals	Current in Milliamperes: Minimum Fibrillating, Aver.	Current in Milliamperes: Minimum Fibrillating, Range	Current in Milliamperes: Maximum Nonfibrillating, Average
Right front leg and left hind leg	20	250	160-390	240
Right front leg and left front leg	10	390	300-730	360
Head and left hind leg	10	300	120-430	260
Left front leg and right chest	10	240	140-390	200
Right and left chest	11	260	170-410	240
Right and left hind leg	5	No fibrillation up to 12.4 amperes		

On the basis of these results, the authors concluded that a current in excess of 100 milliamperes at 60 cycles, alternating current, when passing from hand to foot of an individual, would cause a dangerous shock if the duration of contact was one second or more.

The next feature of electric shock investigated was the effect of the frequency. The pathway of the current was from one foreleg to an opposite hind leg. The information secured from a series of tests upon sheep using a duration of contact of 3 seconds is summarized in Table 10.

TABLE 10

Type of Current and Frequency (Cycles/Sec.)	No. of Animals	Current in Milliamperes		
		Min. Fibrillating		Max. Nonfibrillating
		Average	Range	Average
dc	11	1300	700- 2100	1100
ac 25	10	320	190- 490	290
ac 60	25	250	160- 390	240

It may be concluded from the above data that a greater value of direct current than of alternating current is necessary to induce ventricular fibrillation. It is also noted that there is slight difference between the effect of 25 and of 60-cycle circuits as regards electric shock.

The most significant fact disclosed by this series of experiments was the effect of the phase of the cardiac cycle of the heart at the time the shock is encountered, and the duration of the shock, in the setting-up of ventricular fibrillation. Of 370 shocks applied to 38 different sheep for periods of 0.12 seconds, only one shock definitely outside the partial refractory phase (interval during which the heart is changing from contraction to expansion) resulted in ventricular fibrillation. This partial refractory phase for sheep constitutes about 20 per cent of a complete heart cycle. For humans, this partial refractory phase constitutes a somewhat larger per cent of the heart cycle. With sheep it was found that a current of 15 amperes was necessary to induce fibrillation outside the partial refractory phase.

It was definitely established that the most critical time at which shock could be encountered was at the beginning of the partial refractory phase. To study the effect of shocks encountered for various durations of time

TABLE 11

No. of Animals	Average Body Weight Lbs.	Duration of Contact (Sec.)	Per Cent of Time of Complete Heart Beat	Minimum Fibrillating Current (Amps.)
11	125	0.03	6.6	1.70
10	139	0.03	6.6	1.90
7	161	0.10	22.0	1.40
13	143	0.12	26.4	1.20
12	132	0.12	26.4	1.60
10	134	*0.47	103.3	0.18
25	12[illegible]	*3.00	660.0	0.16

*Did not necessarily [illegible] at beginning of partial refractory phase.

beginning at this phase of the cardiac cycle, tests were conducted and data were recorded as indicated in Table 11.

Per cent of time of complete heart beat was calculated upon an average pulsation for sheep of 132 beats per minute. Interval between shocks on the same sheep was not less than 5 minutes.

It was concluded from these results that about ten times the current is required to cause fibrillation if the duration of shock is reduced from 3 to 0.10 seconds.

It was further shown through another series of tests that successive shocks at 5 minute intervals had little, if any, cumulative effect. The electro-cardiograph, in every case, showed the heart to be normal within 5 minutes after the application of the current, provided fibrillation had not been set up.

In attempting to interpret the data presented above as they apply to a two-year old child, the following information[26,27] will be useful:

TABLE 12

Age	Average Heart Weight, Grams	Average Body Weight, Lbs.	Average Pulse Rate—Pulsations Per Min.
At birth	20.6	.....	130-140
1 year	23.6	.....	115-130
2 years	44.5	20.0	110-115
3 years	60.2	30.7	90-100
5 years	72.8	39.7	86-96
10 years	122.6	.....	84-94
Adult	283.0	154.0	60-80

As we have no direct data from which the relationship between time of contact and minimum fibrillating current for a two-year old child can be determined readily, it is necessary to make certain assumptions in deducing values from available data relative to animals.

Table 8 gives minimum fibrillating current for animals of different body and heart weights, when the duration of contact is 3 seconds. These values entered as points on the graphs, Figs. 1 and 2, indicate that the minimum fibrillating current for different species of full-grown animals is approximately in direct proportion to their body and heart weights.

Graphs Nos. 1 and 2 are straight lines drawn through the lower current values recorded rather than through mean current values.

Although the available data on the variation of minimum fibrillating current with body weight for a single species do not cover the range of weights represented by humans, it seems safe to assume that this variation in man will be well above that represented by Graph No. 1. This assumption is supported by the fact that the minimum current necessary to cause fibrillation in all the animals tested, having body weights both greater than and less than man, was larger than that represented by Graph No. 1. We must further assume that the relationship between the minimum fibrillating current for the different body and heart weights will be a constant ratio so long as the shock period is the same percentage of the heart cycle of each animal, and the shock is initiated at the same point in the heart cycle. Using these assumptions as a basis, the relationship between time of contact and minimum fibrillating current for a two-year old child can be determined. This is accomplished in the following manner.

Using the first body weight given in Table 11, namely, 125 pounds, it is noted from Graph No. 1 that the minimum fibrillating current, when the duration of shock is 3 seconds, is 126 milliamperes. This value is recorded opposite 1 (a) of Table 13. (See page 30.)

Also, from Graph No. 1, it is noted that for a body weight of 20 pounds, weight of an average two-year-old child, the minimum fibrillating current, when the duration of shock is 3 seconds, is 31 milliamperes. This value is recorded opposite 1 (b) of Table 13.

By dividing 31 by 126, a ratio is established between the minimum fibrillating current for body weights of 20 pounds and 125 pounds, when the duration of shock is 3 seconds. This value is given in the third column of Table 13 opposite 1 (b).

Referring again to Table 11, it is noted that the minimum fibrillating current for a body weight of 125 pounds and shock duration of 0.03 seconds is 1700 milliamperes. This value is recorded opposite 1 (a) in the fourth column of Table 13.

Assuming the ratio of minimum fibrillating current for two different body and heart weights to be constant so long as the shock period occupies the same percentage of the heart cycle, the minimum fibrillating current for a two-year old child, when the shock duration covered 6.6 per cent of the heart beat, is found by multiplying 1700 milliamperes by the established ratio, 0.246. Using the average heart rate for a two-year old child of 115 pulsations per minute, it is calculated that the time corresponding to 6.6 per cent of the complete heart beat is 0.034 seconds. These derived values of minimum fibrillating current and time for a two-year old child are recorded opposite 1 (b) in the fourth and fifth columns of Table 13.

From Graph 2, it is noted that the minimum fibrillating current based on the heart weight of a two-year old child is 29 milliamperes. This value is somewhat less than the minimum fibrillating current of 31 milliamperes, based on the body weight of the two-year old child. It is logical to assume, therefore, that if the values of minimum fibrillating current for short durations of shock had been recorded on the basis of heart weights, they might have been somewhat lower, and the derived values for the two-year old child would have been correspondingly lower. For this reason, the derived value of minimum fibrillating current for the two-year old child, namely, 418 milliamperes, is now multiplied by the ratio of 31 to 29, 0.935. The result is 391 and this value is recorded opposite 1 (c) in Column 4 of Table 13.

TABLE 13

Body Weight Lb.	Min. Fibrillating Current at 3 Sec. Contact MA	Ratio (b)/(a)	Min. Fibrillating Current for Corresponding Time of Contact		Per Cent of Time of Complete Heart Beat
			MA	Sec.	
1. (a) 125	126	....	1700	0.03	6.6
(b) 20	31	0.246	418	0.034	6.6
(c)			391	0.034	
2. (a) 139	139	....	1900	0.03	6.6
(b) 20	31	0.223	424	0.034	6.6
(c)			396	0.034	
3. (a) 161	159	....	1400	0.10	22.0
(b) 20	31	0.195	273	0.115	22.0
(c)			255	0.115	
4. (a) 143	143	....	1200	0.12	26.4
(b) 20	31	0.217	260	0.137	26.4
(c)			243	0.137	
5. (a) 132	132	....	1600	0.12	26.4
(b) 20	31	0.235	376	0.137	26.4
(c)			352	0.137	
6. (a) 134	135	....	180	0.47	103.3
(b) 20	31	0.229	41.2	0.530	103.3
(c)			38.6	0.530	
7. (a) 123	124	....	160	3.00	660.0
(b) 20	31	0.250	40.0	3.44	660.0
(c)			37.4	3.44	

Using a heart rate for sheep of 132 pulsations per minute, 0.03 seconds is calculated to constitute 6.6 per cent of a complete heart beat. This value is recorded in the last column of Table 13.

The other values of minimum fibrillating current and time of contact for a two-year old child (20 lb.), shown in Columns 4 and 5 of Table 13, are derived in a similar manner.

If the lower values of derived minimum fibrillating current for a two-year old child, and the corresponding time of contact as indicated on lines (c) in columns 4 and 5 respectively of Table 13 are recorded on rectangular coordinate paper, and a curve is drawn through the mean values of these points, it will be noted that the relationship between these values of minimum fibrillating current and contact time follows roughly the curve of a rectangular hyperbola.

Shocks causing minimum fibrillating currents for time of contacts corresponding to heart beats of 103.3 and 660 per cent, as shown in Table 11, did not necessarily start at the beginning of the partial refractory phase

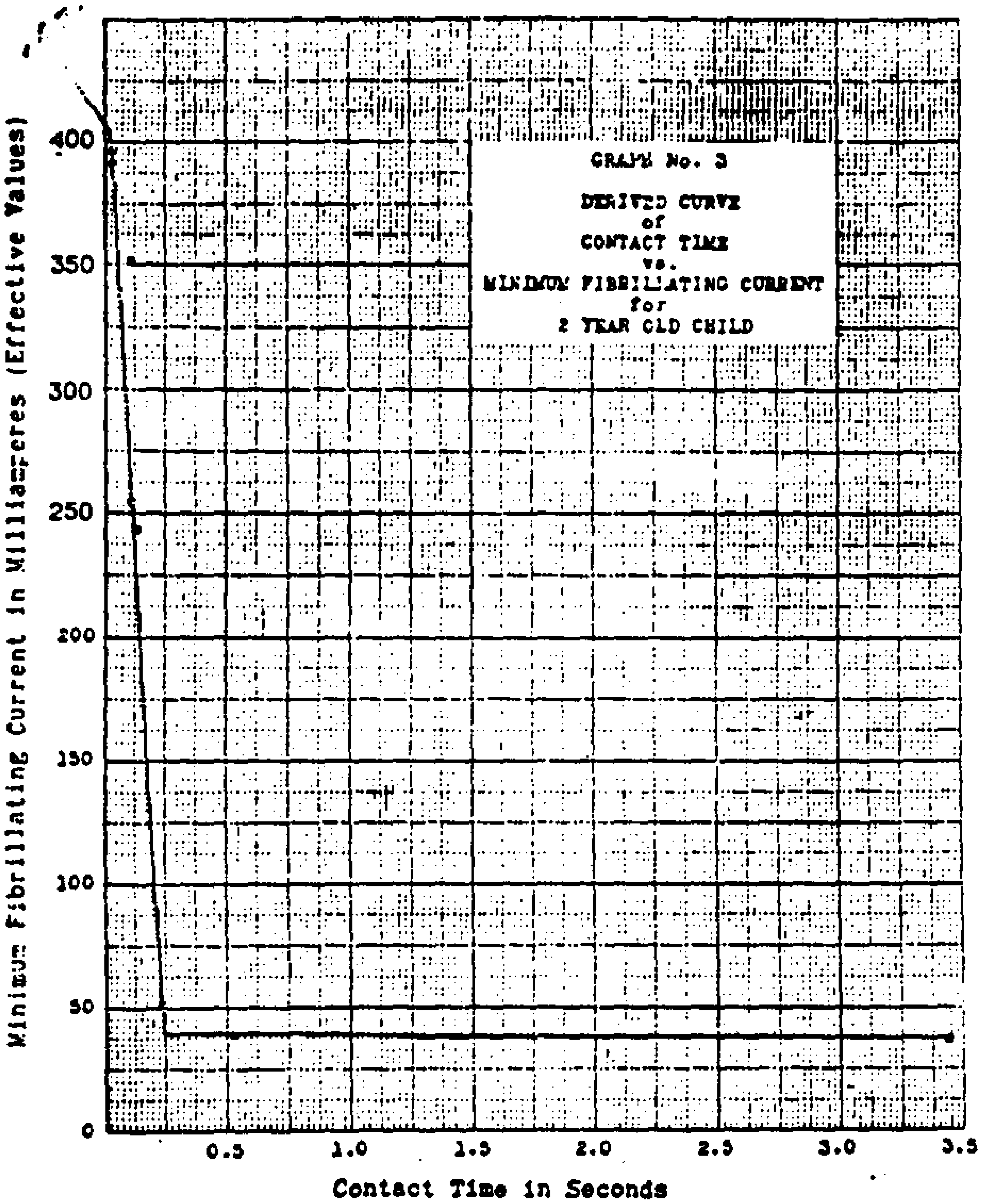


FIG. 3—DERIVED CURVE OF CONTACT TIME VS. MINIMUM FIBRILLATING CURRENT FOR 2-YEAR OLD CHILD.

of the cardiac cycle of the heart. It may be questionable, therefore, whether the values recorded would have been lower if the shocks had started at the beginning of the partial refractory phase. On the other hand, these values of minimum fibrillating current are so nearly alike that it would seem to indicate that the difference is explained by the difference in body weights

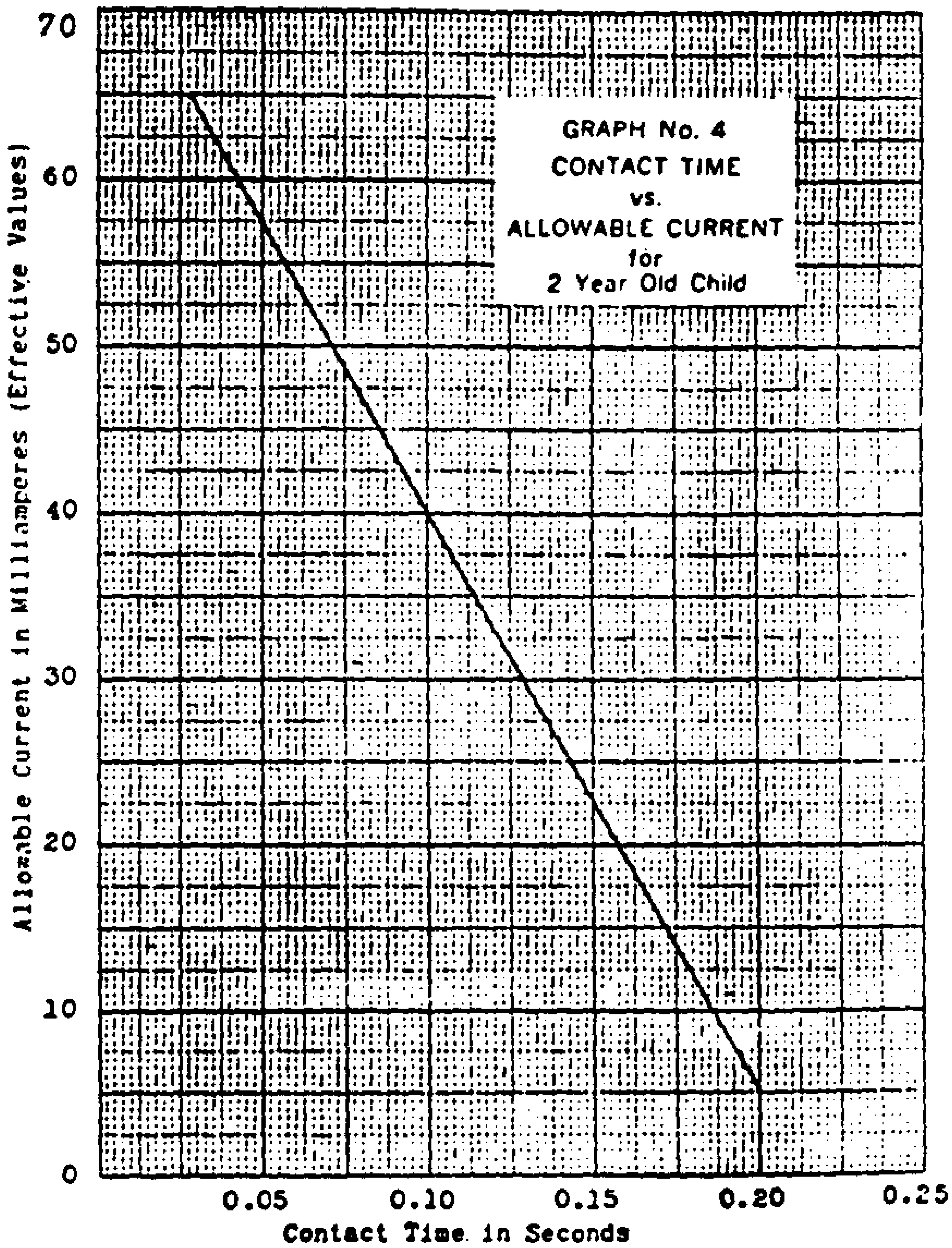


FIG. 4—CONTACT TIME VS. "ALLOWABLE CURRENT" FOR 2-YEAR OLD CHILD

and that the phase of the heart at which the shock is initiated can be neglected whenever the duration of contact covers the complete cardiac cycle. If the ratio between the values recorded for 103.3 (180 milliamperes) and 60 (160 milliamperes) per cent of a complete heart cycle is compared with the ratio for minimum fibrillating currents of corresponding body weights, as shown by Graph 1, the ratio will be 1.125 against 1.09. This indicates that the above statement is approximately correct.

After consideration of the facts pointed out in the preceding paragraphs, it was apparent that the expression of the relationship between minimum fibrillating current and time of contact for a 2-year old child, which would produce the maximum of safety for those periods of time upon which data were lacking would be to form the curve by the intersection of two straight lines. The direction of one line would be determined by the lowest values of derived fibrillating current for those shocks incurred at the beginning of the partial refractory phase of the cardiac cycle, and the direction of the other by the two derived values of fibrillating currents which covered the complete cardiac cycle. This method of construction would result in the establishment of the lowest possible values of minimum fibrillating currents covering the time range upon which the data were lacking. This relationship between minimum fibrillating current and time of contact for a 2-year child, as indicated opposite (c) in columns 4 and 5 of Table 13, is thus expressed in Graph No. 3. (Fig. 3).

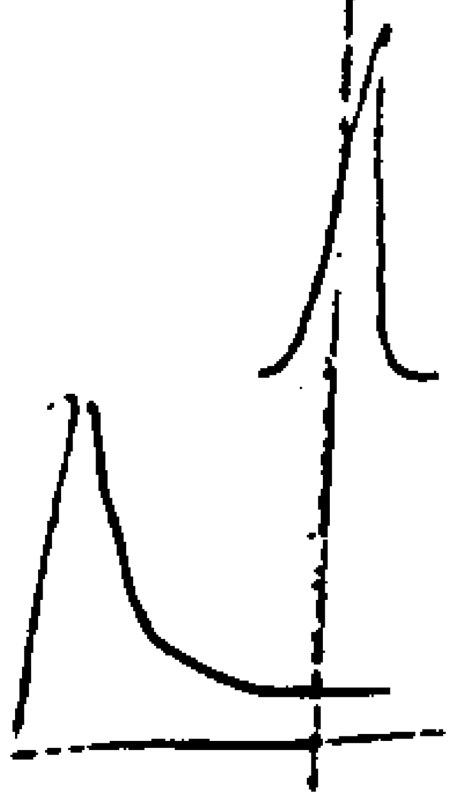
Having established the minimum current that might be expected to cause fibrillation in the heart of a 2-year old child for the time of contact, as indicated on Graph No. 3 (Fig. 3), an "allowable current" curve may be produced simply by dividing the minimum fibrillating current values by some factor of safety and plotting these against the corresponding values of time of contact.

In construction of an "allowable current" curve, it was arbitrarily decided to terminate the curve at 65 ma as the maximum allowable current value, and the maximum allowable output as 4 ma-sec. It was also decided that the "on" period of an intermittent type controller should not exceed 0.20 sec. This resulted in terminating the lower point of the curve at 5 ma. The curve determined by these points maintains a safety factor of approximately 6 between the minimum fibrillating and allowable current values. Such a curve is shown in Graph No. 4 (Fig. 4).

The adoption of a factor of 6 between the curves of "Minimum Fibrillating Current" and "Allowable Current" is based on the fact that there are no available data on repeated shocks at less than 5 min. intervals, whereas the majority of electric fences supply electric shock impulses at the rate of approximately 60 per min. Also, it has been shown that no arbitrary "off" period could be established which would, in all cases, guarantee that the individual could free himself from the electric fence before receiving a second and possibly an indefinite number of shock impulses. The factor of six also represents and takes into consideration certain pathological cases which could not be adequately covered in available data pertaining to normal individuals.

Before an attempt is made to interpret Graph No. 4 as it applies to battery-operated units, further consideration should be given to Graph No. 3. If the milliampere-second values for those shocks which were initiated at the beginning of the partial refractory phase of the heart cycle and represented by the vertical line of Graph No. 3 are tabulated, it will be found that the maximum values occur at approximately 0.1 sec. For shorter and longer shocks, a smaller milliampere-second shock would result in producing ventricular fibrillation. If, however an average curve is produced, indicating all the shocks which covered approximately one complete heart cycle or less, the curve thus formed will represent, for time of contact of 0.1 sec and greater, approximately a constant product of current and time.

Unlike a-c type controllers, most battery-operated controllers do not maintain a constant current output during the "on" period. During much of the "on" period, the decaying current is of such a small value as to seem to have no physiological effect. In view of this fact and the relationship noted in the preceding paragraph, it was decided that the maximum allowable output for battery-operated controllers should not exceed 4 ma-sec. for controllers which had an "on" period between 0.10 and 0.20 sec. For controllers having on "on" period less than 0.10 sec, the allowable output would be determined by multiplying the current indicated in Graph No. 4 by the "on" period (time of contact) to determine the milliampere-seconds permitted.



Peak Currents—There are no data to establish the variation of minimum fibrillating current with time of contact when the time is so short that the current wave appears to be only a peak.

While it is generally conceded that the current-time relationship previously discussed follows the curve of the rectangular hyperbola, there are no data to definitely prove this point.

Auto Ignition

In review of these data, it was noted that peak currents as high as 50 to 80 amperes, at a frequency of 6 to 10 megacycles had been measured by the National Bureau of Standards[28] in their study of the electric character of the spark discharge of automotive ignition systems. Because of the high-frequency involved, these data are not altogether applicable to the establishment of an allowable current peak in an electric fence controller. They do, however, indicate that high currents of extremely short duration have been experienced by persons innumerable times without ill effects.

To determine the effects of high surge currents and voltages, tests on rats were conducted at Johns Hopkins,[29] using a surge generator with a capacity of 200,000 volts, 400 amperes, at 4 micro-seconds. The results of these tests are given in Table 14.

$Q = I \times t = 400 \times 4 \times 10^{-6} = 1600 \times 10^{-6} = 1.6 \times 10^{-3}$

$E = \frac{1}{2} Q V^2 = \frac{1}{2} \cdot 1.6 \times 10^{-3} (2 \times 10^{5})^2 = 1.6 \times 10^{-3} = 160 J$

[illegible]

TABLE 14

Group	Path of Current	No. of Subjects	No. Recovered	Breathing	Heart Action	Resuscitation
1	Head to reclined body	3	3	Good	Good	Not needed
	Shoulder to reclined body	3	3	Good	Good	Not needed
	Hip to reclined body	1	1	Good	Good	Not needed
2	Tail to head	4	0	None	None	Failed
3	Back of head to tail	1	0	Feeble	Feeble	Failed
4	Back of neck to tail	4	0	None	Feeble	Failed
5	Shoulder to tail	4	3	Weak	Good	1 Failed
	Middle of back to tail	4	3	Good	Good	1 Failed
	Total	24	13			

400 amps
20 KV
4 ms

On the basis of these tests, it was concluded that high surges affect the nervous system. When the current passed through the entire body from head to tail, none of the rats survived.

While these data do not represent what might be expected in the case of animals which do not recover spontaneously from ventricular fibrillations, they do indicate that as far as the respiratory system is concerned, an extremely large amount of current can be passed through the body without injury if the time of contact is infinitesimal.

Prevost and Batteli[9] found, in experiments on dogs, using induction coils and condensers supplying voltages ranging from 1500 to 33,000, that the effects of the discharges were in proportion to neither the voltage nor the quantity of electricity but to the electric energy measured in joules. As the duration of the shocks was approximately one one-thousandth of a second with energy of approximately 1000 joules per shock, it would seem to indicate that very high currents can be withstood provided the duration of contact is extremely short.

Preliminary investigations in the recording of peak currents indicated that the peak recorded was dependent upon the frequency of the galvanometer, the amount and quality of light employed, the type of film used, and the care exercised in developing, other factors being equal. Because of these many variables, it was proposed that the minimum frequency associated with the peak current be limited rather than the amplitude of that peak current. As previously pointed out, the hazard connected with electric shock seems to decrease as the frequency is increased beyond the conventional 60-cycle current.

Taking the above factors into consideration, it was decided that the peak current of any transient associated with the output of an electric fence controller when tested with a load on the secondary output circuit comparable to the body resistance of an adult, using as a measuring device a galvanometer having a natural frequency of approximately 3,000 cycles per sec., should be of such a nature that the elapsed time between the increasing and decaying current waves measured at 300 ma should not exceed 0.0003 sec. Assuming that the current wave at the 300-ma point represents ½ cycle, the minimum frequency for peak currents as high as 300 ma is thereby limited to approximately 1700 cycles per sec.

Opinions

The following opinions of several persons as regards the maximum value of current that can be considered as not being hazardous to life is of interest. It must be borne in mind that these values are uninterrupted current, in no way limited as to time of contact. Also, it should be considered that while some of these values are arrived at by review of actual test records, others are, no doubt, merely arbitrary quantities selected by the specified individuals.

Prof. F. A. Kartak,[30] Department of Electrical Engineering, Marquette University, stated that 10 milliamperes will ordinarily not be fatal, but will cause an extremely uncomfortable sensation. Thirty milliamperes is extremely painful, and when increased to 100 milliamperes, a most dangerous condition exists. He further stated that 500 milliamperes would be fatal in most cases.

Prof. Kouwenhoven[2] of Johns Hopkins University, stated that 100 milliamperes at 60 cycles may cause death, and that for normal persons the current ought not to exceed 30 milliamperes.

Doctor Jaffee,[5] Department of Pathology, College of Medicine, University of Illinois, in reviewing the early data upon electric shock, stated that 70 to 80 milliamperes, alternating current, or 200 to 250 milliamperes, direct current, are dangerous to a normal human being.

Doctor M. G. Lloyd, of the National Bureau of Standards, stated that 10 to 20 milliamperes cannot be endured with comfort, that currents over 25 milliamperes may be fatal, and currents maintained at more than 100 milliamperes are almost sure to be fatal.

Weis,[9] a early experimenter with electric shock, stated that a current of from 70 to 90 milliamperes is necessary to throw the heart into fibrillation.

d'Arsonval,[9] also an early experimenter, believed that 100 milliamperes was necessary to set up fibrillation.

Ferris, Spence, Williams, and King stated, in their report, "Effect of Electric Shock on the Heart,"[25] that the maximum current to which man may be safely subjected for shocks of 1 second or more in duration is about 100 milliamperes.

Conclusions

On the basis of the foregoing, it may be concluded,

(1) That the maximum continuous (uninterrupted) current to which an individual may be safely subjected is 5 milliamperes (effective values).

(2) That the maximum interrupted alternating current, assuming the interruption is sufficiently long to permit the individual to release contact with the circuit before receiving a second shock, should not exceed the values indicated on Graph No. 4 (Fig. 4), for the corresponding periods of contact, and that no single shock impulse should have a duration greater than 0.20 seconds.

(3) That the maximum output permitted for battery-operated controllers should not exceed 4 milliampere-seconds for "on" periods between 0.10 and 0.20 seconds, and that the output permitted for "on" periods less than 0.10 seconds should not exceed the current-time product determined from Graph No. 4, assuming that the time between "on" periods is sufficiently long to permit the individual to release contact with the circuit before receiving a second shock.

(4) That the time associated with peak currents as high as 300 milliamperes should not exceed 0.0003 seconds.

$3\times10^{-4} \times 3\times10^{-2} = 9\times10^{-2} = .09$ ma-s
4 ma-s ≈ .1 ma-s

"OFF" PERIOD

General

Before the data available on the general subject of electric shock, the majority of which are based on single impulse shocks, can be adapted to the electric fence controller, which supplies successive shocks at approximately 1-second intervals, it is necessary to establish an "off" period which will insure that under ordinary conditions the average individual will be able to release himself from the electrical circuit before receiving more than one shock impulse.

Some electrical fence manufacturers claim that a current of sufficient intensity to cause contraction of the muscles is needed to provide an effective fence. If such is the case, it is necessary that the "off" period be one which will allow the individual to free himself from the circuit, assuming that he has received an electrical shock which would not permit him to release the fence at the time of receiving the impulse. Some electric fence manufacturers also state that it is desirable and necessary, to insure an effective fence, that the "off" period be as short as possible.

Laboratory Tests

To determine what should constitute the minimum "off" period for an electric fence controller, tests were conducted at Underwriters' Laboratories, Inc. to determine the time required for an adult individual to release a tight grip upon a wire, which had been set up to simulate the electrified fence conductor.

While it was not practical to pass enough current through the individual's body to cause such contraction of the arm muscles, as might result should a current in excess of 10 milliamperes, alternating current, be passed continuously through that part of the body, this condition was simulated by having the individual tightly grip wire electrodes.

The hand electrodes were built to simulate barbed wire, and each consisted of two No. 10 Awg bare copper wires twisted together and held in a horizontal position by two porcelain insulators approximately 14 inches apart. The foot electrode was a galvanized sheet-metal plate, approximately 14 inches square.

In the tests where the current path was from hand to feet, the individual removed his shoes before stepping upon the foot electrode.

Each individual was subjected to three tests. In the first test, the path of the current through the body was from hand to hand. In the second test, the current path was from right hand to both feet, and in the third test the current path was from left hand to both feet.

While the individual was tightly gripping the wire electrodes with dry hands, an electrical stimulus was applied to the individual through the electrodes, and the time necessary for the individual to release his grip upon the wire was recorded by means of an oscillograph.

The stimulus was supplied from a group of "B" batteries connected in series directly across a variable resistance. The voltage across the person being tested was varied by the potentiometer method, so as to cause a current flow of from 6 to 10 milliamperes, depending upon the sensitivity of the subject under test. The set-up was so arranged that it was impossible for the individual to receive a shock of greater duration than 0.45 seconds. Regardless of the lack of response of the individual to the stimulus, no current in excess of 10 milliamperes was employed.

For each particular individual, the stimulus was gradually increased in voltage from zero to that required to cause the individual to withdraw his hand involuntarily when the circuit was made or broken. When a stimulus of 10 milliamperes was not sufficient to cause the involuntary withdrawing of the hand, it was withdrawn only after the individual had deemed it necessary through the regular thought process. The voltage necessary to cause the involuntary withdrawing of the hand of the individual, or which would cause 10 milliamperes to flow through the subject, was determined. The oscillograph was then connected in series with the person, and this voltage was suddenly impressed upon the individual as he tightly gripped the electrodes, the resulting circuit being broken by the person's release of the electrodes. The time required to release was determined by comparing the direct-current wave with a 60-cycle timing wave, both of which were photographed at the time the circuit was closed through the individual.

Twenty-nine persons, employees of Underwriters' Laboratories, Inc. were subjected to this test. The age range of the individuals tested was 19 to 42 years.

The results of these tests are given in Tables 15, 16 and 17.

TABLE 15

Path—Hand to Hand

Subject				Stimulus Current in MA	Body Resistance in Ohms	Release Time in Sec.
No.	Sex	Weight in Pounds	Age in Years			
29	F	105	19	6	8,000	0.155
4	F	136	21	6	13,050	0.242
6	F	134	23	6	7,170	0.261
1	M	157	24	6	12,600	0.176
13	M	135	24	10	8,400	0.210
26	F	128	24	8	9,125	0.178
15	F	120	25	10	8,300	0.229
9	F	125	26	6	9,330	0.212
10	M	135	26	8	6,870	0.219
8	F	129	28	6	11,000	0.279
12	M	165	28	6	13,350	0.194
20	M	132	29	10	4,200	0.184
21	M	135	29	8	10,250	0.180
14	F	122	30	6	10,000	0.356
16	M	155	30	8	7,250	0.296
7	F	114	34	6	10,000	0.261
17	M	145	34	8	7,250	0.395
18	M	180	39	8	11,250	0.213
2	M	140	40	6	12,680	0.269
3	F	110	40	8	8,330	0.229
11	M	135	40	10	8,000	0.274
24	M	150	40	6	12,800	0.255
Maximum		180	40	10	13,350	0.395
Minimum		105	19	6	4,200	0.155
Average for Age Group 16-24						0.203
Average for Age Group 21-30						0.229
Average for Age Group 25-29						0.214

As the age range covered by the tests recorded in Tables 15, 16 and 17 was not sufficient to represent human beings at large, it was necessary to derive a correlation between the times actually recorded and what might be expected for small children and for older individuals.

For this purpose, data pertaining to the variation of human reaction time with age were reviewed, and the following information was disclosed.

A series of tests was once conducted at the University of Minnesota[31] for the purpose of determining the relationship that existed between the reaction time of an individual and his age. The age range of the individuals tested varied from 4 to 60 years. The number of subjects was twenty in each group except Group F, which contained ten. There were two different sets of tests conducted. One set of tests was the determination of the reaction time of the individual to a light stimulus, the other was the determination of the reaction time to a sound stimulus. The number of males in each group was 50 per cent. The results of these tests are given in Table 18.

TABLE 16

Path—Right Hand to Feet

Subject				Stimulus Current in MA	Body Resistance in Ohms	Release Time in Sec.
No.	Sex	Weight Pounds	Age in Years			
29	F	105	19	6	5,670	0.155
4	F	136	21	6	13,050	0.240
1	M	157	24	6	8,660	0.228
13	M	135	24	10	5,450	0.238
26	F	128	24	8	6,370	0.306
15	F	120	25	10	5,700	0.370
25	F	138	25	10	4,600	0.175
9	F	125	26	6	5,670	0.226
10	M	135	26	8	7,060	0.152
8	F	129	28	6	10,320	0.264
12	M	165	28	6	7,170	0.217
20	M	132	29	10	2,700	0.181
21	M	135	29	8	6,430	0.205
14	F	122	30	8	10,500	0.237
16	M	155	30	10	3,400	0.306
19	F	116	31	8	6,250	0.198
7	F	114	34	6	26,900	0.307
17	M	145	34	8	4,870	0.297
22	M	170	38	10	4,000	0.223
18	M	180	39	8	7,000	0.195
3	F	110	40	8	8,000	0.228
11	M	135	40	10	6,300	0.267
24	M	150	40	8	6,870	0.226
Maximum		180	40	10	26,900	0.370
Minimum		105	19	6	2,700	0.152
Average for Age Group 16-24						0.233
Average for Age Group 21-30						0.239
Average for Age Group 25-29						0.224

TABLE 17

Path—Left Hand to Feet

Subject				Stimulus Current in MA	Body Resistance in Ohms	Release Time in Sec.
No.	Sex	Weight Pounds	Age in Years			
29	F	105	19	6	5,670	0.173
4	F	136	21	6	6,500	0.202
6	F	134	23	6	5,330	0.202
27	F	112	23	10	5,800	0.221
13	M	135	24	10	4,900	0.289
26	F	128	24	8	6,370	0.223
15	F	120	25	10	6,100	0.207
25	F	138	25	10	6,100	0.322
9	F	125	26	6	5,500	0.247
10	M	135	26	8	7,125	0.197
8	F	129	28	6	8,000	0.294
12	M	165	28	6	6,830	0.247
20	M	132	29	10	3,100	0.216
21	M	135	29	8	6,630	0.193
14	F	122	30	8	10,500	0.240
16	M	155	30	10	3,600	0.212
19	F	116	31	8	5,500	0.247
17	M	145	34	8	4,620	0.313
18	M	180	39	8	6,750	0.264
3	F	110	40	8	12,320	0.263
11	M	135	40	10	6,600	0.329
24	M	150	40	8	7,380	0.244
23	M	121	42	10	6,000	0.280
Maximum		180	42	10	12,320	0.329
Minimum		105	19	6	3,100	0.173
Average for Age Group 16-24						0.218
Average for Age Group 21-30						0.234
Average for Age Group 25-29						0.240

TABLE 18

Age in Years	Group	Reaction Time in Seconds			
		Male Average		Female Average	
		Light Stimulus	Sound Stimulus	Light Stimulus	Sound Stimulus
4-10	A	0.34	0.34	0.62	0.59
11-20	B	0.24	0.23	0.23	0.31
21-30	C	0.22	0.19	0.26	0.20
31-40	D	0.26	0.24	0.34	0.30
41-50	E	0.27	0.25	0.36	0.31
51-60	F	0.38	0.37	0.44	0.42

The results shown in Table 18 indicate that the fastest group as a whole was that having an age range of 21-30 years. If the males and females are considered together, the average for Group C, which might be taken as a base in computing the relative slowness of the other groups would be: reaction to light, 0.24 seconds, reaction to sound, 0.20 seconds.

The relative speeds of reaction times of the youngest and oldest groups compared with the fastest group are given in Table 19.

TABLE 19

Age in Years	Group	Stimulus	Reaction Time in Seconds	Factor of Slowness Based on Group C
21-30	C	Light	0.24	1.00
21-30	C	Sound	0.20	1.00
4-10	A	Light	0.48	2.00
4-10	A	Sound	0.47	2.35
51-60	F	Light	0.41	1.70
51-60	F	Sound	0.40	2.00

In another series of tests, conducted at Stanford University,[32] more attention was given to the grouping by age limit. These tests were conducted for the purpose of determining how the reaction time varied with the age of adults. The age range here was from 25 to 89. The stimulus employed was both auditory and visual.

Test No. 1 consisted of lifting the finger at any desired moment which the subject wished and returning it as quickly as possible to its original position. Test No. 2 consisted in applying pressure with the forefinger at the moment the stimulus was perceived. Test No. 3 consisted of lifting the finger upon perception of the stimulus. The results of these tests are given in Table 20.

TABLE 20

Age in Years	No. of Subjects	Reaction Time in Seconds		
		Test No. 1	Test No. 2	Test No. 3
25-29	9	0.14	0.23	0.21
30-34	11	0.13	0.24	0.22
35-39	13	0.15	0.23	0.21
40-44	15	0.15	0.21	0.21
45-49	17	0.17	0.23	0.23
50-59	9	0.13	0.20	0.22
60-69	11	0.18	0.28	0.23
70-79	11	0.20	0.30	0.26
80-89	4	0.20	0.28	0.28

Using the reaction time of the group having an age range from 25 to 29 years as a base, the relative reaction time of the slowest group, age range 70-79 years, is indicated in Table 21.

TABLE 21

Age in Years	Reaction Time in Seconds		
	Test No. 1	Test No. 2	Test No. 3
25-29	0.14	0.23	0.21
70-79	0.20	0.30	0.26
Factor of Slowness based upon Age Group 25-29	1.43	1.30	1.24

Further work[33] has been done to determine the variation of the reaction time for an age range of 3½ years to maturity. In this series of tests, the stimulus was both visual and auditory, and the individual's time response was recorded by his pressure upon a key which interrupted the recording means.

The results of these tests are given in Table 22.

TABLE 22

Age in Years	Sex	Reaction Time in Sec.	No. of Cases
3½ 3½	Male Female	0.580 0.622	27 27
4½ 4½	Male Female	0.406 0.458	28 29
5½ 5½	Male Female	0.364 0.414	54 57
6½ 6½	Male Female	0.282 0.309	29 34
7½ 7½	Male Female	0.279 0.260	34 29
8½ 8½	Male Female	0.230 0.262	18 12
9½ 9½	Male Female	0.244 0.205	13 9
10½ 11½	Both Both	0.229 0.198	12 7
College Students	Both	0.175	56

It will be noted from the above tabulation that the group having the fastest reaction time as a whole is the one composed of college students. Using the reaction time of this group as a base, the relative speed of reaction time for the youngest age group, 3½ years, is found to be 3.43 times as slow as the college group, age 16-20.

This information is shown in tabular form in Table 23.

TABLE 23

Age Group	Reaction Time in Seconds (Both Sexes)	Factor of Slowness Based on College Students
16-24 3½	0.175 0.601	1.00 3.43

If the average "release time" for each particular age group, as shown in Tables 15, 16, and 17 is calculated, it will be found that for the age group 16-24 it is 0.218 seconds. For the age group 21-30, it is 0.234 seconds, and for the age group 25-29, it is 0.226 seconds.

If it is now assumed that the variation of release time with age is in the same ratio as the variation of reaction time to visual and auditory stimulus with age, the release time of any age group can be calculated by multiplying the time of the basic group by the factor of slowness of the group under consideration.

These data are shown in Table 24.

TABLE 24

Basic Age Group in Years	Subject Age Group in Years	Factor of Slowness of Subject Based on Basic Group	Average Release Time in Seconds of Basic Group From Tables 15, 16, 17	Derived Release Time in Seconds for Age Group Shown in Col. 2
16-24	3½	3.43	0.218	0.748
21-30	4-10	2.35	0.234	0.550
21-30	51-60	2.00	0.234	0.468
25-29	70-79	1.43	0.226	0.373

In the interpretation of these data, it should be borne in mind that the reaction time in releasing the fence wire will be an involuntary reaction not requiring a thought process, while the data pertaining to the variation of reaction time with age are based upon reactions which require a thought process. Also, it should be borne in mind that tests have shown that, in general, the reaction to a touch stimulus of adequate intensity will be faster than the reaction to an auditory or visual stimulus.

As previously pointed out, the contraction of the muscles associated with direct, as opposed to alternating current, is not nearly so pronounced, and it seems justifiable, therefore, that some difference in the time required for an individual to free himself from the electric fence circuit be allowed. The nature of the stimulus supplied by the battery-operated electric fence controllers is actually a peak current having an amplitude several times that of the 5 or 10-milliampere stimulus used in the preceding tests for recording the reaction time of adults. Since the time required to perceive the sensation is somewhat inversely proportional to the intensity of the stimulus, it is reasonable to assume that the time to release the fence wire will be lessened when the stimulus is supplied by the fence controller. The difference in the contraction associated with direct, as opposed to alternating current, was shown in tests by Kouwenhoven and Langworthy[2] who found, that with rats, the contraction on high-voltage, direct-current circuits was so severe that the victims were often thrown away from the conductors, while on the low-voltage circuit it was often impossible to let go. While the current associated with the higher voltage on the battery-operated controllers is not of the order used in these tests, it is reasonable to suppose that the higher voltage has a repelling effect not found with the low-voltage circuit.

Conclusions

On the basis of the above facts, it seems reasonable to conclude that an "off" period of 0.90 seconds for alternating-current controllers and 0.75 seconds for battery-operated controllers will permit normal individuals likely to come in contact with electric fences sufficient time to free themselves from the electrical circuit before receiving a second impulse shock.

TOPPENISH ACCIDENT

DESCRIPTION

The following accident is believed to be pertinent to the consideration of setting up requirements for safe electric fence controllers since supposedly it is the only accident which has occurred with a controller constructed and distributed by a commercial manufacturer. The following report of the accident was made by Mr. W. R. Volheye, Chief Electrical Inspector of the State of Oregon, to Mr. C. H. Gram, Commissioner, Bureau of Labor, Salem, Oregon.

"On November 22, [1937] the writer made a trip to Toppenish and Yakima, Washington, to make an investigation of the circumstances surrounding the death of Maurice Harman. [16 years of age.]

"This death was caused through accidental contact with an electrically-charged fence wire. The boy's companions, John Jump and Steve McCumber, state that they had been hunting on the property of Ernest Rowe, 3 miles west of Toppenish. While walking along a very muddy roadway bordering a field surrounded by a single electrically-charged fence wire, the Harman boy slipped and fell over the wire. He grasped the wire with his hands and attempted to regain his footing. Due to the very slippery condition of the ground, he failed to do so and called to his companions to assist him. Knowing that the fence was charged, they feared to touch him and attempted to sever the wire by firing their shotguns. Five shots were fired at close range without cutting the wire. Steve McCumber then started to the Rowe house for help. John Jump then attempted to lift the Harman boy from the fence by his coat. He found this difficult to do and some time elapsed before he succeeded. By this time Harman had ceased to struggle. He was gasping for breath, and when Jump examined his pulse beat, he found it to be very faint and irregular. He then attempted to restore breathing or pulse beat. A car had been brought from the house and Harman was placed in it and started for Toppenish. He was dead when they arrived.

"Mr. W. M. Drake, Deputy Coroner at Toppenish, who is also the undertaker who embalmed the body, stated that he found no burns that he could recognize as such. He said that there were slight scratches on both hands and some small blisters. Not being an M.D., he did not feel qualified to pass judgment. When Dr. W. H. Carver, the County Coroner, arrived from Yakima, he identified the blisters as electrical burns.

"Dr. Carver also stated that he felt that the conditions had been nearly perfect for an electrocution due to the saturated condition of the earth, the broken skin on the hands, and the fact that the boy's clothing and skin were very wet. He said that the boy's skin was still wet when he arrived and examined the body. He stated further that in his opinion a lower current value would have had very little bearing on the results in the case. He said further that he knew of several hunters who had touched this wire without injury".

Mr. Volheye also stated that an investigation of the installation revealed that there were no evident factors which would tend to cause an increased life hazard. The electric fence controller was installed on the back porch of the Rowe residence.

"The porch was completely screened, including the steps leading to ground level. Entrance to the kitchen was also from this end of the porch and the service cabinet was between the kitchen door and the end of porch. Service conduit extended to nearest wall and service drop was attached at this point. Wiring is concealed. Opposite end of porch used for a bed. A porcelain receptacle with duplex current tap was mounted on the wall near the bed. The controller was hanging on the same wall between the receptacle and the end of the porch. Although the cord had been disconnected [at time of investigation], it had evidently been plugged into the current tap. Two insulated wires were pushed through the porch screen and attached to the controller. One of these was connected to a ground rod driven into the earth near the house wall, the other was connected to bare wire running in opposite direction.

"The wire running in the direction of the point of contact was supported on the back wall of the garage and barn and on several 10 or 12-foot posts until it reached the field which the fence surrounded. From this point on it was supported on stakes approximately 34 inches high. The distance from the house to the field was approximately 1000 feet. The distance around the field was approximately 800 feet and the accident occurred approximately 300 feet from this extremity of the fence. The fence extended from the house approximately 1700 feet in the opposite direction. No line wires were touching or near the fence wire."

Professor F. E. Price, of the Oregon State College of Agriculture, gained possession of the unit and forwarded it to Underwriters' Laboratories, Inc. for test and examination.

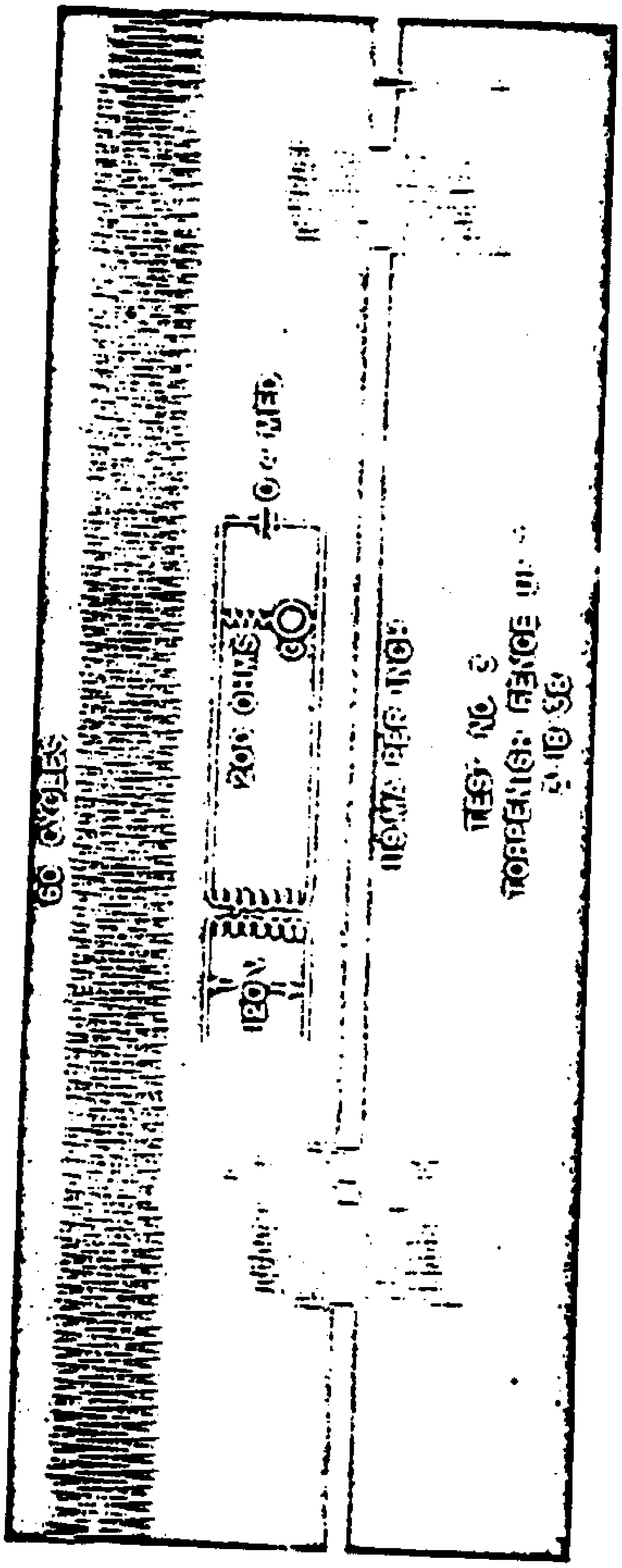


FIG. 5, TEST NO. 3, TOPPENISH FENCE UNIT

LABORATORY INVESTIGATION

An examination of the unit disclosed that it was of the alternating-current transformer type, the current interruption being provided by means of a mercury tube switch mounted on the end of a revolving shaft which in turn was propelled through a gear train by means of a small shaded-pole induction motor. The current-interrupting means was provided in the secondary circuit of the transformer.

The primary and secondary of the transformer were wound on separate legs of the core. The electrical connection of the unit was such that the transformer and motor were connected in parallel to the 110-volt source of supply.

A 6-foot length of Type POSJ supply cord was attached to the unit, and the construction employed was such as to prevent the possibility of the primary becoming grounded to case.

The unit was examined carefully, and there was no evidence that the current interrupting means had been shunted out of the circuit, although this could be accomplished by going inside the unit and transposing two wires.

The case itself was made of sheet steel, approximately ⅛ inch in thickness, and provided with an overlapping door which would, when closed, tend to exclude rain.

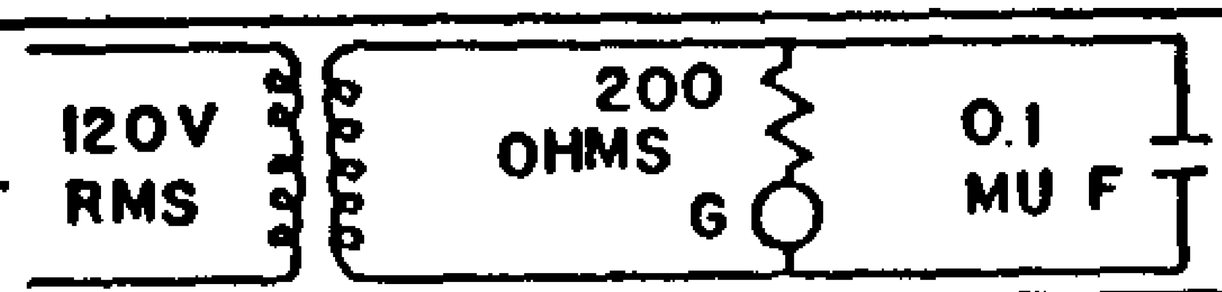
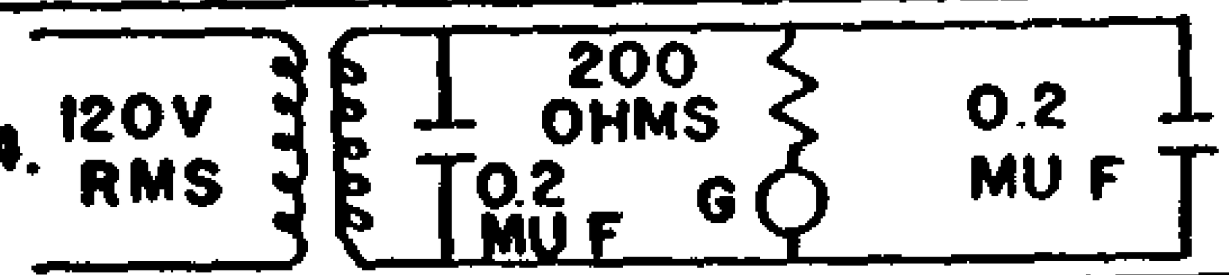
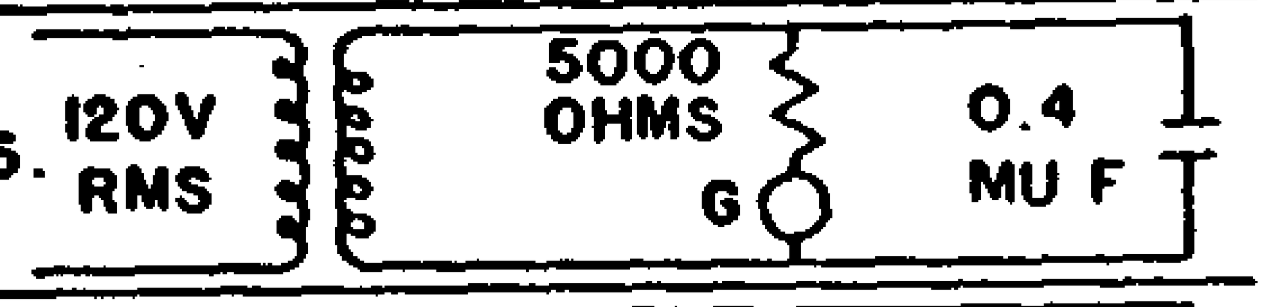
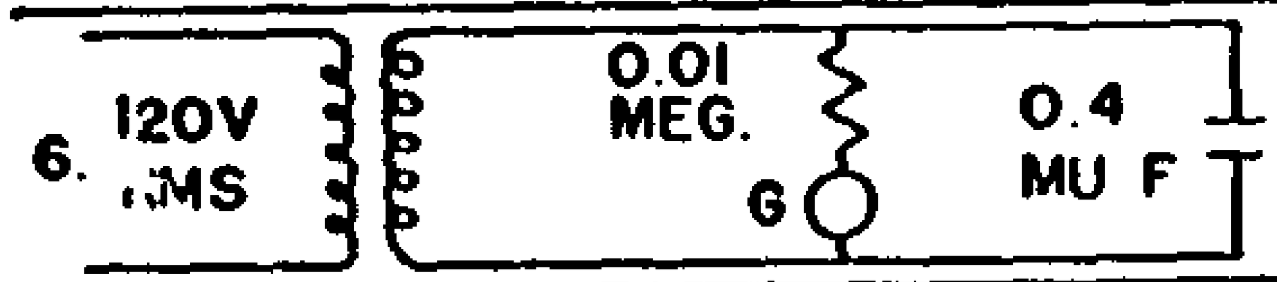
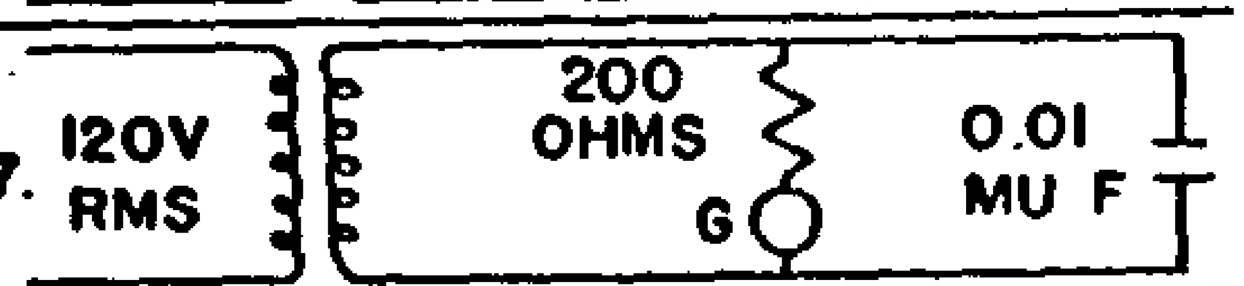
To determine the output characteristics of this device, oscillograms were taken under various load conditions on the secondary of the transformer. In each case the device was connected to the Laboratories' 120-volt, alternating-current source of supply, and a series resistance of at least 200 ohms was placed in the galvanometer circuit to record the delivered output current. By means of a vacuum tube thermocouple and milliameter, preliminary output readings taken with the current interrupting mechanism shunted out of the circuit indicated that the output of the device was the same with a load of either 500 or 200 ohms non-reactive resistance in the secondaries of the transformer. Various values of capacitance were also connected in parallel with this resistance to simulate fence capacitance, which is approximately 0.015 microfarad per mile of fence, when the installation is approximately 3 feet above the ground.

Oscillograms were taken under various test conditions, and the accompanying reproduction (page 47), is representative of the results obtained.

The complete results of these tests are shown in Table 25.

After the unit had been in operation for approximately two hours, an alternating-current potential of 900 volts was impressed between the primary and secondary. One side of the transformer was connected to the enclosure. No breakdown occurred during the 30-second period during which the potential was applied.

TABLE 25-OSCILLOGRAMS ON TOPPENISH FENCE UNIT

Measuring Circuit Diagrams	Description of Recording: Impulse No.	Wave Trains Per Impulse	Time Between Impulses (Sec.)	Description of Train: No.	Peak Current (MA)	RMS (MA)	Time (Sec.)	Time Between Trains (Sec.)	Total "On" Time (Sec.)
1. 	2*	2	0.965	1	71.4	49.2	0.125		....
				2	71.4	49.2	0.008	0.075	0.208
3. 	1	2	0.965	1	95.0	49.2	0.116	0.016	....
				2	95.0	49.2	0.058		0.190
	2	2	....	1	101.0	49.2	0.125	0.066	....
				2	101.0	49.2	0.008		0.19
4. 	1	2	....	1	101.0	49.2	0.108	0.016	....
				2	71.4	49.2	0.042		0.166
5. 	1	2	0.965	1	65.5	45.2	0.116	0.033	....
				2	65.5	45.2	0.033		0.182
	2	1	....	1	65.5	45.2	0.116	....	0.116
6. 	1	2	0.965	1	50.0	34.5	0.125	0.066	....
				2	30.0	21.2	0.008		0.199
	2	2	....	1	50.0	34.5	0.108	0.016	....
				2	50.0	34.5	0.042		0.166
7. 	1	2	....	1	71.4	49.2	0.108	0.016	....
				2	95.0	49.2	0.033		0.157

*First impluse recording destroyed by tear in film.

The voltage was then gradually increased until at 1880 volts the insulation between the motor coil winding and the lamination broke down. The transformer was uninjured.

Four samples of the motors used upon this unit were then secured, and subjected to current leakage and dielectric strength tests.

One of the motors was installed in the original unit, a second was placed inside the enclosure of the unit, and the remaining two were placed outside the enclosure. The unit with the two extra motors was then sealed in a glass container, in which a constant temperature of 90 degrees Fahrenheit and a relative humidity of 90 per cent were maintained for a period of 72 hours.

Before being subjected to the moisture test, the insulation resistance measured between the motor windings and the laminations, on each of the four samples, was in excess of 450,000 ohms. The resistance measured between the primary circuit of the completely assembled controller unit and the case was also in excess of 450,000 ohms.

Following the exposure to moisture, these same values of insulation resistance were recorded.

The motor samples were next subjected to a dielectric strength test. The sample that had been placed inside the enclosure indicated a breakdown voltage of 1380 volts, while the sample that was outside the enclosure had a breakdown voltage of 1420 volts.

One of the motors, which had been outside the case during the exposure, was allowed to run uninterrupted for a 12-hour period to drive out the absorbed moisture. A breakdown voltage was then applied and was found to be 1400 volts.

Before applying the breakdown voltage, the three samples acceptably withstood a potential of 1220 volts (twice rated primary voltage plus 1000) applied for one-minute periods.

CONCLUSIONS

In view of the information obtained regarding the accident, and in view of the tests upon the unit involved, it is concluded that a 16-year old boy had been killed as a result of contact with an electric fence in which the current was limited to 49.2 milliamperes with the time of each shock impulse ranging from 0.116 to 0.20 seconds. The total time of contact with the fence circuit is not definitely established, but it could hardly have been less than five minutes if the foregoing description of the accident is accepted.

It is also concluded that no arbitrary "off" period can be established which will guarantee that under all circumstances the individual will be able to free himself from the fence circuit prior to receiving a second shock impulse.

This accident also demonstrates that a safety factor between the curve of minimum fibrillating current for a two-year old child, and the curve of "allowable current" for a two-year old child is warranted.

FIELD SURVEY

GENERAL

Aside from the electrical shock which is received when an individual contacts an electric fence, there is also a certain physical shock due to the suddenness of stimulation, and this associated result of contact with the electric fence, should also be taken into consideration in deciding whether or not these devices can be considered as not being hazardous to human life. While it is realized that this is a factor over which it is not possible to exert influence, it is recognized that such a phenomenon does exist.

Physiologists[34] have long recognized the fact that the resistance of the skin varies with the emotional state of the individual. The element of anticipation is quite a factor in man's ability to withstand the passage of current through his body. Jellinck[5] tells of a case where a man, accustomed to demonstrating his ability to withstand the passage of current from a 500-volt, direct-current potential, was killed when he took hold of the live wire, thinking it dead.

FIELD EXPERIENCE

In an attempt to determine how much of a factor surprise is, as it relates to the ability of the individual to withstand a sudden and unexpected electric shock, 50 users of electric fences were interviewed, and their experiences touching upon this point were recorded.

This field investigation was conducted in the locality in which electric fencing originated, and in which all types of units have been employed. Many of these units were made by farmers themselves and were capable of delivering currents up to 1 ampere at 110 volts.

In each case, the farmer was encouraged to tell of specific instances where individuals had, unknowingly, touched the fence and received an electric shock which came to them altogether as a surprise. The farmer was then questioned as to the condition of the ground at the time, the type of electric fence unit, the age of the individual, and the person's reaction upon receiving the shock.

The total electric fencing in use in each year by this group of farmers was approximately 70 miles.

In the limited number of cases shown below, very young and very old individuals have accidentally received an unexpected shock due to contact with an electric fence under conditions most favorable to receiving a high-intensity shock. These cases are summarized in Table 26.

TABLE 26

User	*Description of Fence Unit	Years of Use	Miles of Electric Fencing	Shock Experience
A	7.5 W, 110 V Intermittent	5	1	5-year old child accidentally contacted electric fence. Ground was wet but child's feet dry. Reaction—noise and quick release, no ill effects.
B	7.5 W, 110 V Continuous	4	1½	5-year old child accidentally touched fence. Ground was moist, feet dry. Child wore shoes. Response—child cried, but no difficulty in releasing, no fainting, no ill effects.
C	7.5 W, 110 V Intermittent	1	1½	3-year old child accidentally touched the fence. Child wore shoes, ground dry. Response—child became slightly scared but no undue panicky condition, no difficulty in releasing himself, no ill effects.
D	6 W, 110 V Intermittent	2	2	4-year old child accidentally touched fence. Ground dry, child wore shoes. Response—Child jumped back, no ill effects.
E	20 ma, 350 V 40 ma, 130 V Intermittent	½	¾	Two boys between ages of 8 and 10 years received shocks in an attempt to hang wet swimming suits on electrified fence wire. Boys were barefooted, suits were wet, but ground dry. Response—boys jumped back in surprise upon receiving shock, but then laughed about it. No ill effects.
F	7.5 W, 110 V	5	2	7-year old child holding to hand of 60-year old woman grasped fence causing adult to receive surprise shock. Adult felt current but child apparently did not. No ill effects to either.
G	25 W, 110 V	5	2½	Two 2-year old children received shocks accidentally. Children wore shoes, ground was wet. Response—no difficulty in releasing, no crying, no panicky condition, no ill effects.
H	7.5 W, 110 V Continuous	5	2	Intoxicated adult individual received surprise shock in trying to climb over electrified fence. Response—sudden release, noise, but no ill effects.
I	10 W, 110 V Continuous	6	1	4-year old child accidentally ran into electrified fence. Ground was fairly dry. Response—child did not become frightened or experience any difficulty in getting off wire. No ill effects.
J	25 W, 110 V Intermittent	4	1	6-year old child received accidental shock while playing around straw stack where ground was very moist. Response—child jumped back in surprise but no difficulty experienced in releasing wire and no ill effects.

TABLE 26 (Cont'd)

User	*Description of Fence Unit	Years of Use	Miles of Electric Fencing	Shock Experience
K	7.5 W, 110 V Intermittent	4	1	4-year old child accidentally touched electric fence while playing in water tank. Response—child cried and became slightly scared, but no ill after-effects.
K	7.5 W, 110 V Intermittent	4	1	Adult accidentally received strong electric shock by rising up into barbed-wire fence, barb piercing the flesh, while one hand was in water trough. Response—no trouble in releasing, no ill effects.
L	6 W, 110 V Intermittent	10	2	2-year old child, barefoot, followed parent out into yard and contacted electric fence accidentally. Grass was wet with dew. Response—child let out cry but experienced no difficulty in releasing wire. No ill effects.

*Theoretical output of current—7½ watt, 68 milliamperes; 10 watt, 91 milliamperes; 25 watt, 230 milliamperes; 6 watt, 20-40 milliamperes.
Intermittent—"On" and "off" periods of controller approximately 1½ seconds each.

A total of 19 experiences was recorded where children under 12 years of age had received unexpected electric shocks. Reports stated that in no case was any difficulty experienced in releasing the fence wire, any fainting on the part of the victim, or any great amount of fear experienced, or any ill effects whatever noted later on.

The experiences of 30 adult individuals, who had also received unexpected shocks as the result of contact with electric fences, were also recorded. Reports indicated that in no case was any difficulty experienced in releasing the fence wire, any fainting upon the part of the victim, or any fear with accompanying nervousness experienced, or any ill effects whatever noted later on.

OPINIONS

Medical authorities at Northwestern University, Universities of Illinois, Wisconsin, Minnesota, and Kansas, were consulted and their opinions obtained regarding fright as a factor in the results of electric shock. It was the opinion of all of these authorities that fright, regardless of the nature of the stimulus, might cause an ill effect on the individual. All but one of these men felt unable to predict whether fright, sufficient to adversely affect the heart of a normal individual, could be caused by an electric shock so weak as not to set up fibrillation in the heart of a two-year old child. One authority expressed the opinion that such a weak shock was not capable of causing fright or surprise that might in itself be injurious to a normal individual

CONCLUSION

From the above statements and reports of field experiences, it is concluded that fright and surprise, which might be experienced by reason of receiving an unexpected shock from an electrified fence having output characteristics which are not of sufficient intensity to set up ventricular fibrillation in the heart of a two-year old child, will not be sufficient to adversely affect the individual who receives the shock.

RECOMMENDATIONS

Taking into consideration all the data presented and discussed herein, and bearing in mind the device and subject to which an attempt has been made to adapt these data, we recommend the following as constituting safe electrical operating characteristics of electric fence controllers:

1. VOLTAGE

That where the current output is limited by inherent impedance of the device, the open-circuit voltage need not be limited.

2. FREQUENCY

That regardless of the frequency employed, the output current shall not exceed the values indicated in 3 (a) and 3 (b) below.

3. CURRENT

(a) **Alternating-Current Type Controllers**—That for intermittent type controllers the output current shall be interrupted in such a manner as not to exceed the current-time relationship expressed in Graph No. 4, Fig. 4.

(b) **Battery-Operated Type Controllers**—That for intermittent type controllers the output current shall be interrupted in such a manner as not to exceed the current-time relationship of 4.0 milliampere-seconds for "on" periods between 0.10 and 0.20 seconds. The output of controllers having "on" periods less than 0.10 seconds, shall not exceed that permitted by graph No. 4 for the time involved.

(c) **Peaks**—That the time associated with peak currents as high as 300 milliamperes should not exceed 0.0003 seconds.

4. "OFF PERIOD"

(a) **Alternating-Current Type Controllers**—That the "off" period between successive shock impulses shall not be less than 0.90 seconds.

(b) **Battery-Operated Type Controllers**—That the "off" period between successive shock impulses shall not be less than 0.75 seconds.

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No. 8. Generation of Static Electricity in Blower Systems.
No. 9. Electrical and Physical Characteristics of Naturally-Aged Rubber-Covered Wire.
No. 10. Electrolytic Oxygen and Hydrogen Plants and their Operation.
No. 11. Study of Phase Displacement in Electrical Circuits from Linearly Expanded Lissajous Figures.
No. 12. Hydraulic Friction Losses in 1½-in. and 2½-in. Cotton Rubber-Lined Fire Hose.
No. 13. Fire Exposure Tests of Loaded Timber Columns.

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