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FIELD MEASUREMENTS OF ELECTROMAGNETIC ENERGY RADIATED BY RF STABILIZED ARC WELDERS

Herman Garlan, L. Glen Whipple and Irving L. Weston

Washington, D. C. 20554

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ABSTRACT

This report presents the results of field strength measurements made on 152 RF welders in commercial installations in the United States. The data emphasizes the importance of a good low-impedance ground and good shielding in reducing radiation. Am empirical formula for attenuation of field with distance is obtained which may be used to extrapolate the radiated field from an RF welder measured with quasi-peak detection at distances between 100 and 2,000 feet. On the basis of this formula, three-fifths of the measured installations radiated less than 15 microvolts per meter at 1,000 feet.

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I. INTRODUCTION:

In 1962, field engineers of the Federal Communications Commission measured the radiation from a number of radio frequency stabilized arc welders (hereafter referred to as RF welders) located in various parts of the United States, to determine the magnitude of the electromagnetic field radiated by such RF welders. This report presents an analysis of these measurements.

RF welders use radio frequency (RF) energy to initiate and to stabilize the arc when welding nonferrous metals such as aluminum. The RF energy is generated by means of a spark gap and radiation occurs over a broad band of frequencies centered at approximately three megacycles per second (3 Mc/s). This report is not concerned with radiation from conventional arc welders, which are considered to be incidental radiation devices 1/ and as such are regulated by Part 15 of the FCC Rules.

II. HISTORY OF WELDER REGULATION:

In 1948, the Commission adopted rules regulating the conditions under which miscellaneous ISM 2/ equipment can be operated without a license in accordance with Part 18 of the FCC Rules. RF welders are classed as miscellaneous equipment since the RF energy is used for the ionization of gas 3/ at the welding electrodes in order to permit initiation of the arc without contamination of the weld by contact with the electrode. As miscellaneous equipment, RF welders would be

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1/ An incidental radiation device is defined in §15.4(c) of the FCC Rules as "a device that radiates radio frequency energy during the course of its operation although the device is not intentionally designed to generate radio frequency energy".

2/ ISM stands for Industrial, Scientific and Medical.

3/ Miscellaneous equipment is defined in §18.3(d) of the FCC Rules as any apparatus other than medical diathermy or industrial heating equipment "in which radio frequency energy is applied to materials to produce physical, biological, or chemical effects such as heating, ionization of gases, mechanical vibrations, hair removal, and acceleration of charged particles, which do not involve communications or the use of radio receiving equipment."

subject to a radiation limit of 15 microvolts per meter (uv/m) at 1,000 feet on frequencies outside the ISM bands. On the basis of a welding industry report that no equipment had been designed which could comply with this limit and still weld satisfactorily, a delay was granted in the effective date of Part 18 as it applied to RF welders. In 1952, these welders were placed under temporary regulations which imposed a radiation limit of 10 uv/m at one mile for a period of two years. This time limit was extended three times and, in 1955, the temporary regulations were continued indefinitely pending final action in Docket Proceeding No. 11467.4/

III. THE REGULATORY PROBLEM:

The Commission's regulation of RF welders is designed to minimize interference to all licensed services. Consequently, the rules contain limits on the radiated field strength at a specified distance as noted in the preceding paragraph. Since it is frequently impossible to measure radiation at the specified distance along the radial of maximum radiation, the rate of field attenuation with distance must be known to determine whether a given RF welder installation complies with the rules.

In practice, the field at a given distance is made up of an induction field component, which is inversely proportional to the distance squared ($E = \frac{K_1}{d^2}$), and a radiation field component, which is inversely proportional to the distance ($E = \frac{K_2}{d}$). At a distance of $\lambda/2\pi$ (about 1/6 wave length) the induction and radiation fields are equal. The induction field will predominate at closer distances and will continue to be a factor out to about 16λ. The field may also be affected by reradiation of energy induced in any metallic conductor in the vicinity of the welder and conducted to a point near the measuring site. The prediction of a value for n (the exponent of d in the equation $E = \frac{K}{d^n}$) thus is possible only in very general terms.

The measurements reported here resulted in an average value for n in the above empirical formula of 1.45 with a standard deviation of ± 0.57. These figures apply to quasi-peak measurements of radiation from RF welders over a distance range of 100 to 2,000 feet. With these limitations in mind, the use of 1.5 as a value for n appears reasonable for regulatory purposes, although the rate of field decay with distance for any particular RF welder installation may vary considerably from this value.

4/ See FCC Rules, Part 18, Subpart F.

IV. ANALYSIS OF MEASUREMENTS:

Measurements are reported for 152 welders located in California, Louisiana, Maryland, Missouri, Oregon, and Washington. These measurements were made by FCC field engineers using field strength meters calibrated at the FCC Laboratory. Correction factors were provided by the Laboratory for those meters not incorporating a quasi-peak detection circuit by comparison with measurements of RF welder fields made on a Stoddart NM20B.

Seventy-two RF welder installations are described in detail in this report. The radiation from each welder is presented in graphical form in Figures 1-27, with field strength in microvolts per meter plotted against distance in feet. Note the change in ordinate values of Figures 12, 19, 21, 22, and 23. Table 1 lists the installation features and operating environment of each welder. Information is included on the method of grounding, type of building construction, proximity to power lines, etc., which may be useful in evaluating the field strength vs. distance data. A tabulation of field strengths at 1,000 feet as read from the graphs is also included for each welder.

Table 2 presents the range of slope (the exponent of d in the previously discussed expression $E = \frac{K}{d^n}$) for 71 of the welders in Table 1. No slope is indicated for welder 16 (Figure 6). A straight line through the plotted points would represent virtually no decay of field with distance. As noted in Table 1, this is apparently a case of re-radiation since the radial of maximum radiation follows the power line and there is considerable unshielded wiring in the vicinity of the welder. Welder 16 is replotted in Figure 25 as a broken line graph. Welders No. 61 and 67 (Figures 21 and 23) are likewise replotted in Figures 26 and 27. The radiation measurements reported for these two welders indicate the possibility of a cyclic decay in field. Such a phenomenon might be explained by reflected and re-radiated energy combining in and out of phase at various distances.

Field strength measurements on 80 RF welders were reported at only one or two distances. Although detailed data on these installations are not included in this report, the measurements are given in Tables 3 and 4. The field strength at 1,000 feet for these welders is calculated on the assumption that the field decays at the rate of $\frac{1}{d^{1.3}}$. On this basis, two-thirds of these 80 welders radiated less than 15 uv/m at 1,000 feet. Welders 120 - 137 in Table 4 are worthy of special note since the first measurement was taken inside the building and the second measurement outside. All these welders were installed in metal buildings with the exception of Nos. 126, 127, 131 - 134 which were operated in wooden structures. Welders 135-137 were in a metal building with a perforated metal reinforced concrete floor well bonded to the walls. This structure shows an extremely high degree of signal attenuation. The other welders in this group show varying degrees of attenuation.

V. ANALYSIS OF ENVIRONMENTAL EFFECTS:

Fifty-four different RF welder models were measured in the 72 installations reported in detail. Seven of these models accounted for 25 of the installations, since some models were used at as many as six locations. A comparison of installation and environmental factors and the field strength at 1,000 feet was made for each of these seven models to determine the relative importance of welder design and quality of installation. Welders Nos. 5, 12, 21, and 24 are arbitrarily designated as model A. In like manner, welders Nos. 61 and 68 are designated model B, welders Nos. 7, 36, 41,46, 51, and 52 are model C, welders Nos. 11 and 39 are model D, welders Nos. 25, 38, 45, and 58 are model E, welders Nos. 33, 43, 50, and 53 are model F, and welders Nos. 19, 60, and 72 are model G.

All four installations of model A welders were grounded by connection to the power line neutral rather than to an earth ground adjacent to the welder. Nevertheless, two of these welders radiated less than 7.5 uv/m at 1,000 feet. Much higher levels of radiation were reported for the two other model A welders. One unit, installed in a metal building clost to a 13,000 volt power line, radiated 37 uv/m at 1,000 feet. The other welder was measured along a radial passing through a 10 x 12 foot opening in the wall of the metal building and produced a field strength of 22 uv/m at 1,000 feet.

Four model F and two model C welders were all installed in a corrugated metal structure having about one-fourth of the wall area devoted to windows. All 6 welders were grounded by rods driven four and one-half feet into the earth. The field from each of these welders was higher than would be expected from a well-grounded unit operated in a metal building. The average field strength was 44 uv/m at 1,000 feet with one welder measuring 100 uv/m. The large amount of glass in the walls of the building would appear to reduce the effectiveness of the shielding afforded by the metal walls. The other four model C welders, with one exception, all had good grounds and radiated less than 15 uv/m at 1,000 feet. The exception was a portable welder mounted on a rubber tired dolly and grounded through the power line neutral. This unit measured 40 uv/m at 1,000 feet.

One of the model E welder installations radiated a field less than 0.5 uv/m at 1,000 feet. This extremely low level of radiation was probably due to the excellent ground used at the welder. A twelve-foot rod had been driven into the earth and the upper portion of this rod was surrounded by a four-inch pipe filled with water. Other installations of the same model welder measured up to 20 uv/m at 1,000 feet even with an earth ground and operating in a metal building.

The three model G welders are perhaps the most noteworthy examples of the importance of a good installation in reducing the radiated field. Radiation from two of these welders exceeded 450 uv/m at 1,000 feet. Both installations used the power line neutral as ground and one of these was connected to the AC supply by an unshielded cable. In marked contrast, the third model G welder radiated less than five uv/m at 1,000 feet. The equipment had an earth ground at the welder and all welding operations were confined within a fifteen-foot radius of the welder.

Although the 100 to 1 range in radiated field strength of the model G welders is larger than would normally be encountered, the measurements reported here indicate that a good installation is a far more important factor than the choice of welder model in determining the level of radiation.

VI. CONCLUSIONS:

The field measurements made in this study show that all installations with low radiation had a good low-impedance ground, good shielding of the welder installation (by stored materials or a well-bonded metal building), a compact operation (short leads between welder, ground and work), or a combination of these factors. On the other hand, installations with high levels of radiation were found to have a poor ground, poor shielding, unshielded wiring in the welder area, or high voltage power lines in the vicinity which picked up and re-radiated the welder field. All the RF stabilized welders measured in this study appeared well designed. A careful installation in accordance with the manufacturer's instructions should limit radiation to well under the temporary limit of 10 uv/m at one mile.

Using the empirical formula developed in this report, three-fifths of the measured welders radiated less than 15 uv/m at a distance of 1,000 feet. Lack of a good, low-impedance, earth ground at the welder and reradiation of RF energy picked up by unshielded wiring near the welder appear to be prime sources of excessive radiation. Careful attention to low-impedance grounding of the welder and shielding of all wiring in the vicinity should reduce radiation to the point that all RF stabilized arc welders could comply with the 15 uv/m limit at 1,000 feet as required for miscellaneous equipment under Part 18 of the FCC Rules.

VII. ACKNOWLEDGMENTS:

The authors gratefully acknowledge the assistance of the engineers in the Commission's Field Engineering Bureau whose conscientious efforts made this report possible. Particular thanks is given for the assistance of those field engineers in the Los Angeles, California; San Diego, California; New Orleans, Louisiana; Baltimore, Maryland; Kansas City, Missouri; Portland, Oregon; and Seattle, Washington field offices who made the measurements reported herein. The authors also appreciate the helpful suggestions made by Braxton Peele concerning the preparation of the graphical presentations.

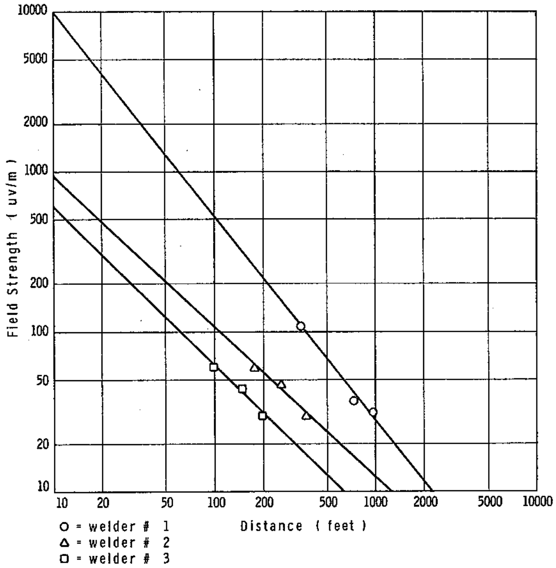
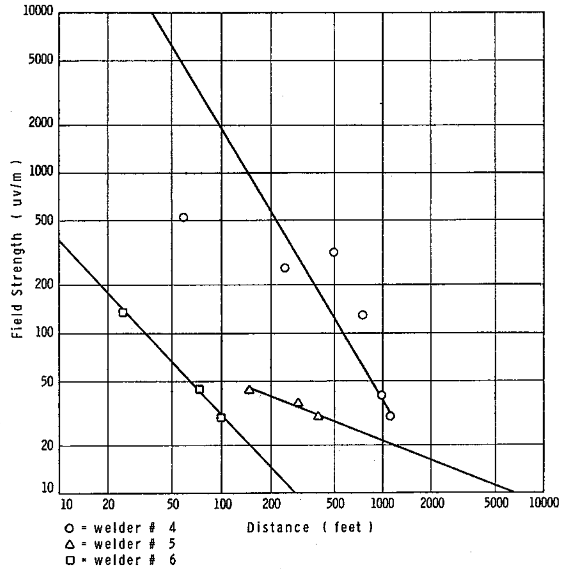


Figure 1



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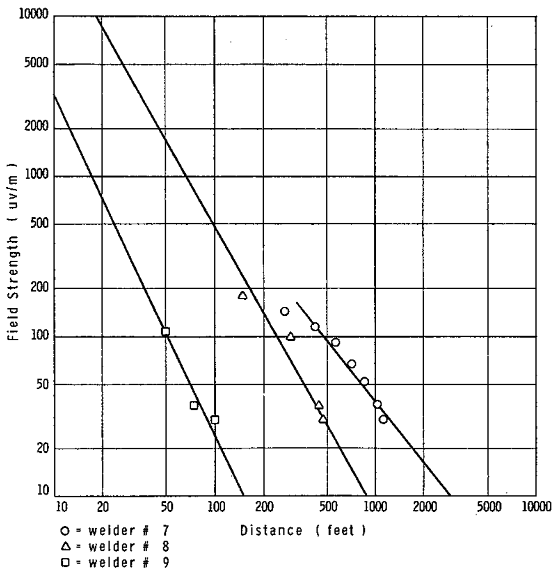

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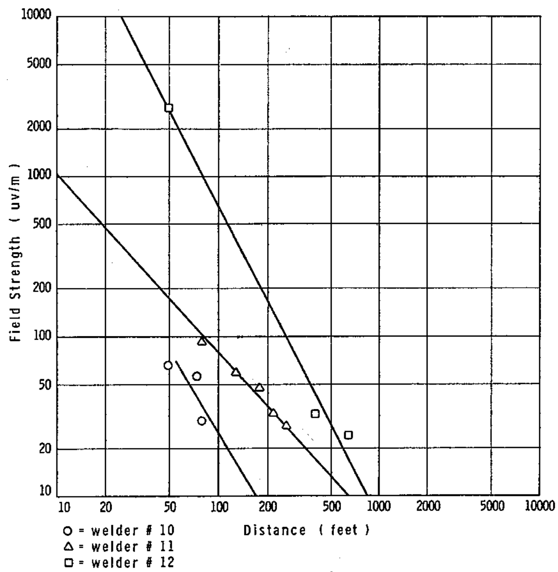

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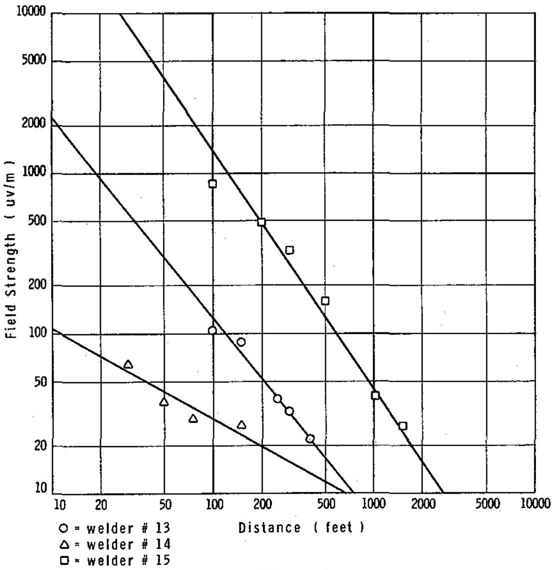

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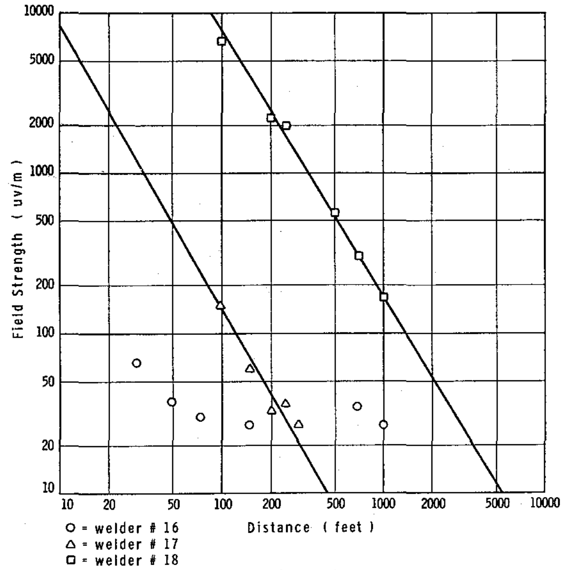

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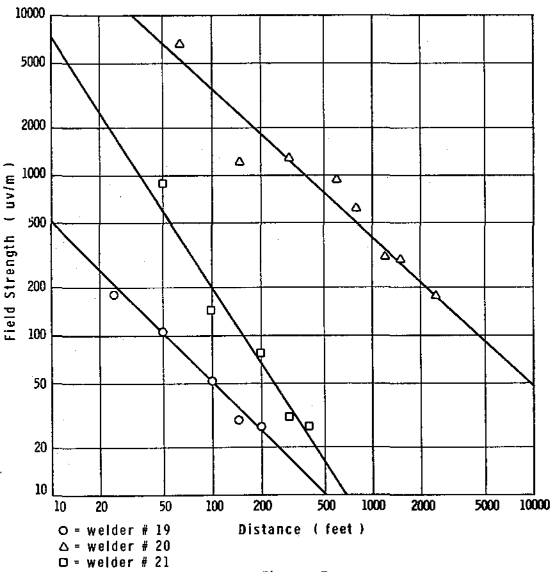

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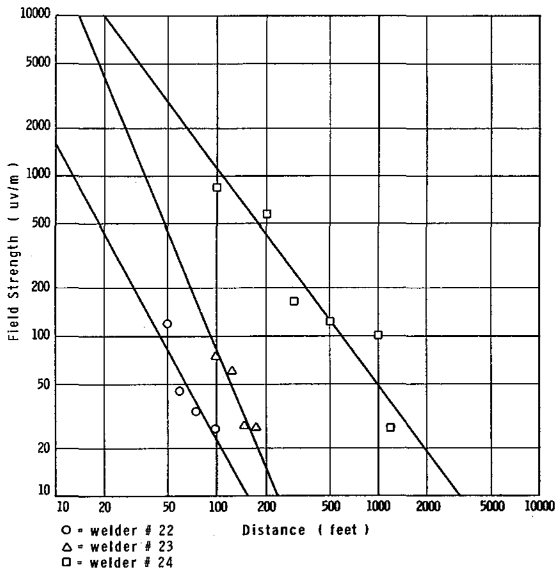

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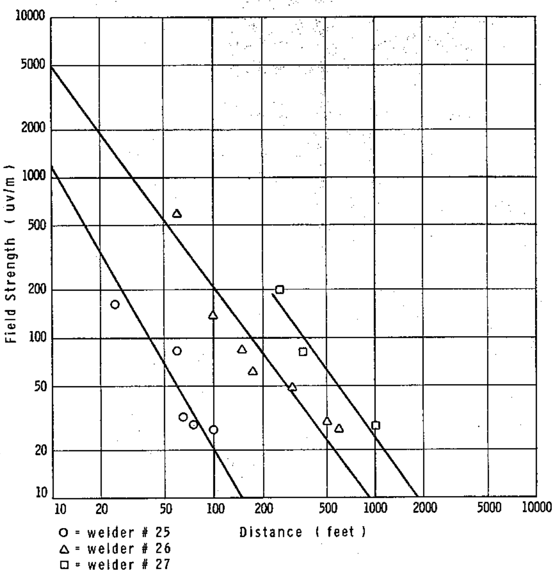

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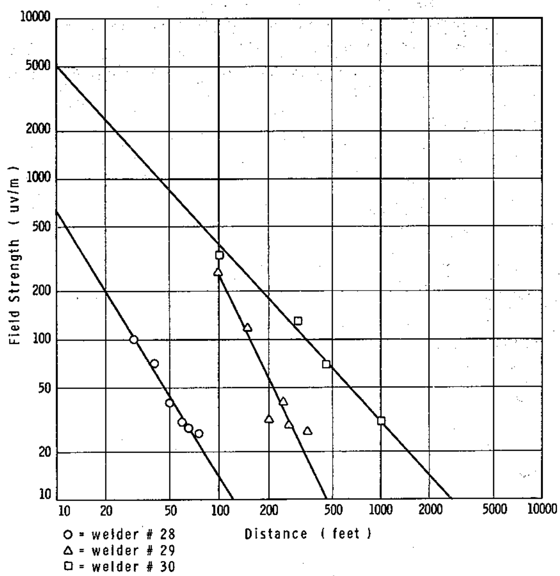

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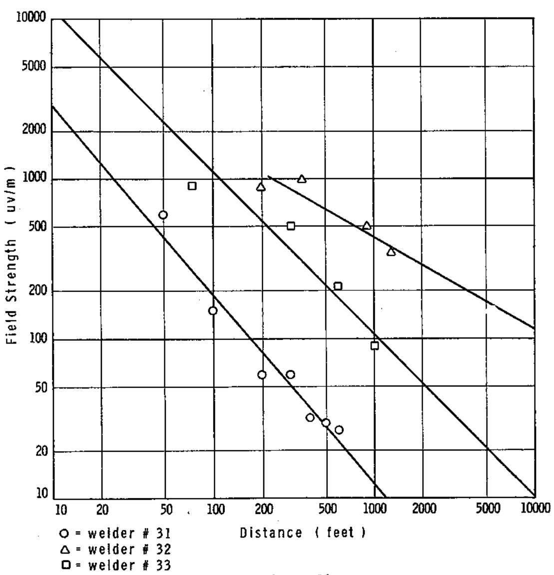

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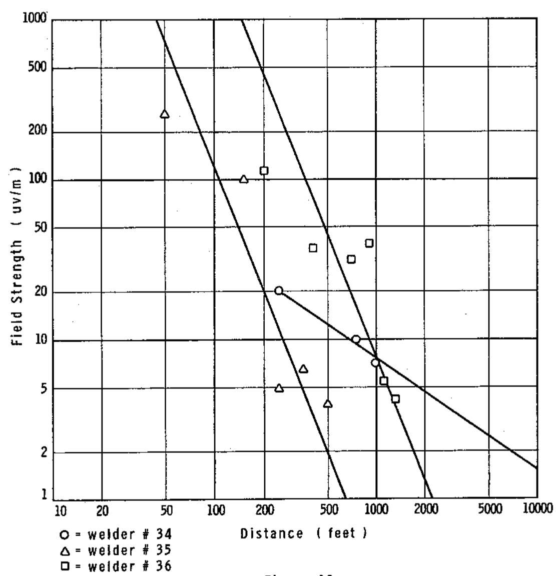

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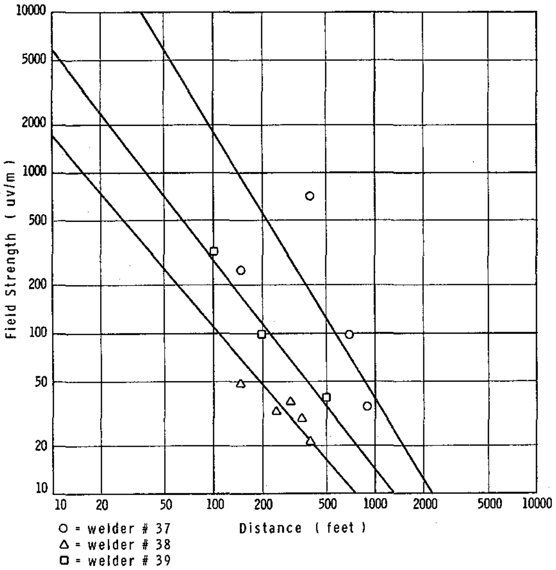

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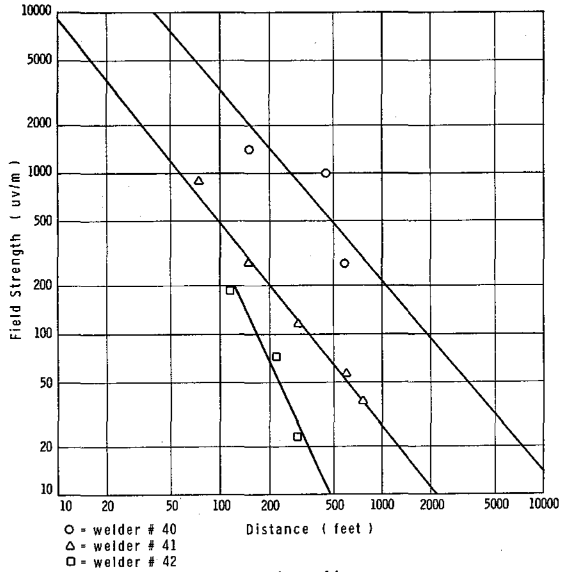

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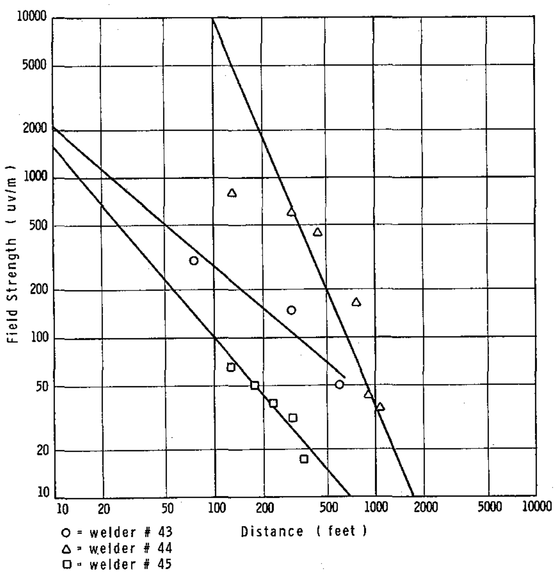

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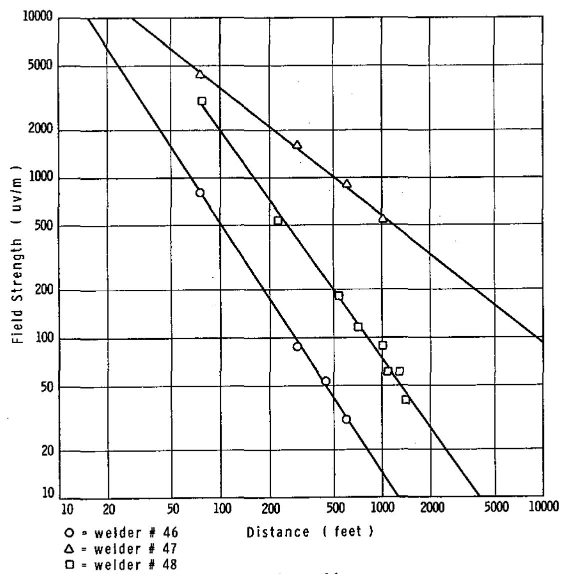

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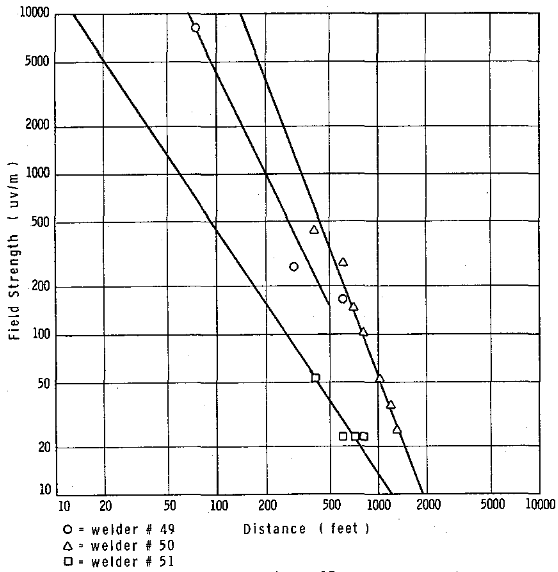

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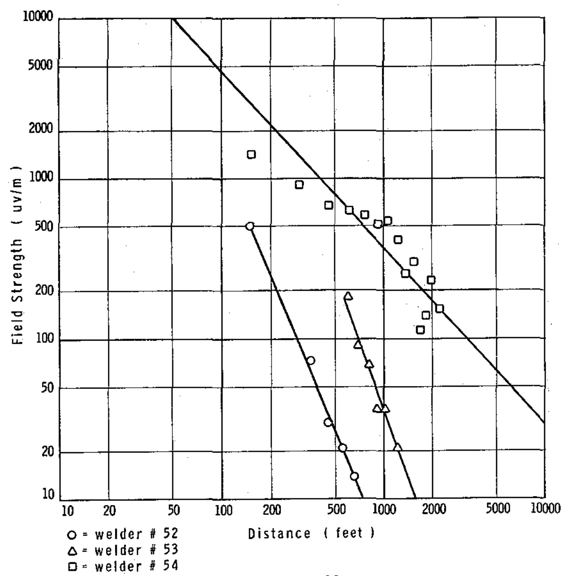

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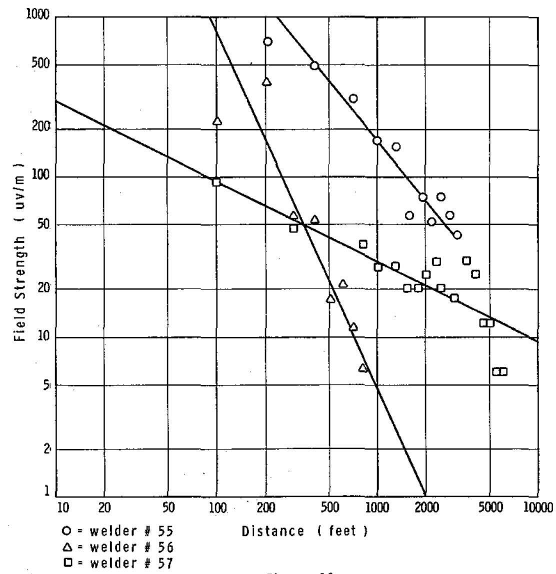

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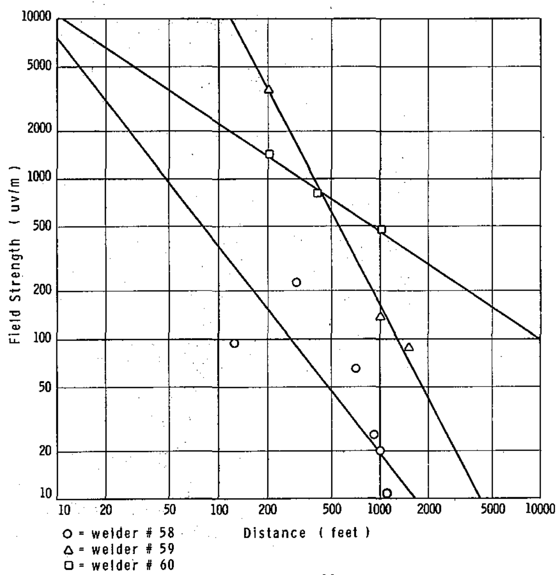

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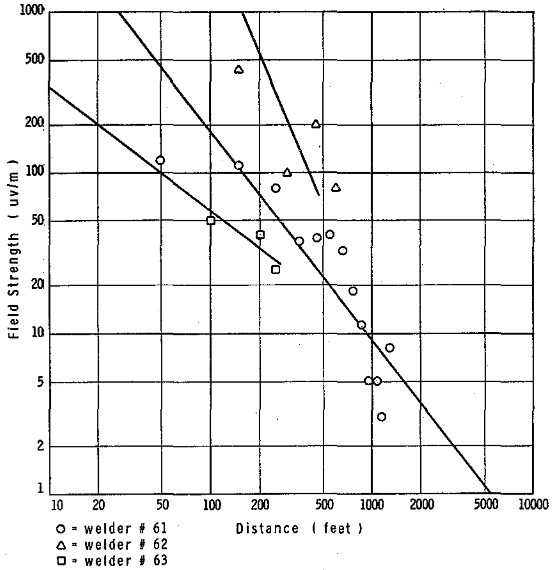

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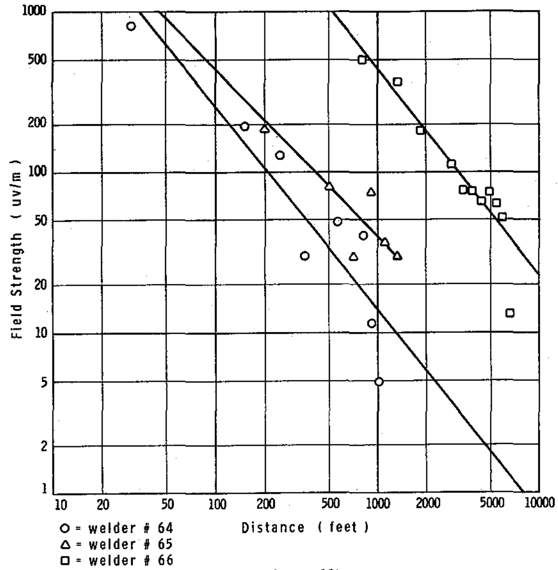

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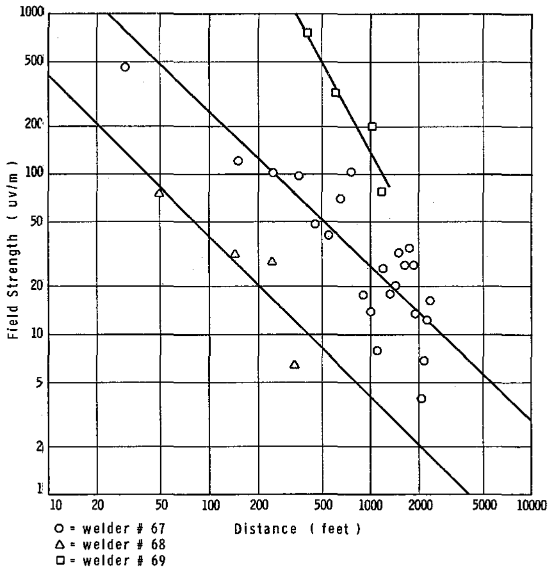

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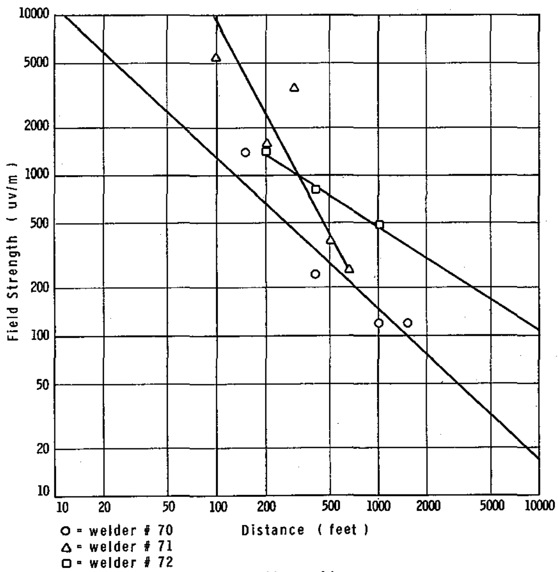

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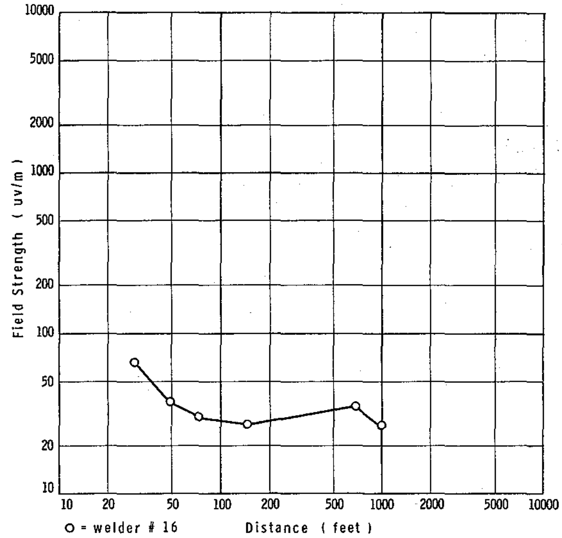

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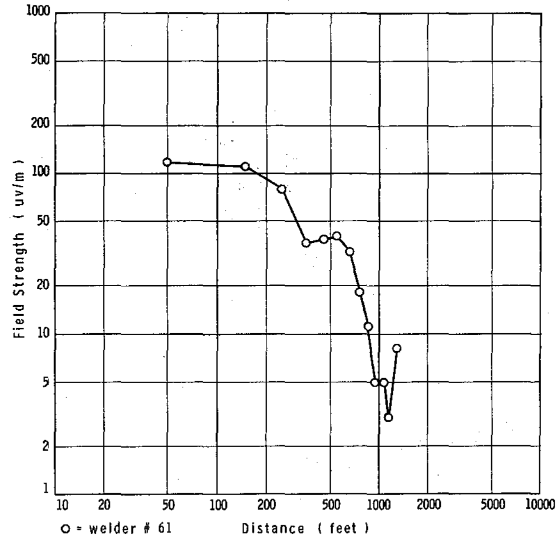

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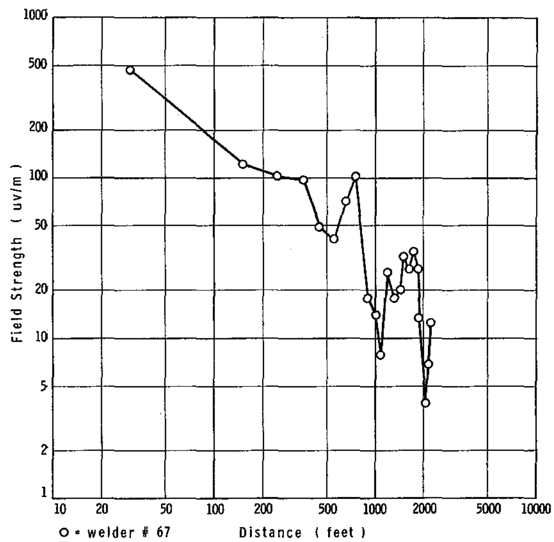

Figure 27

Table 1

Welder Number	Frequency of Maximum Radiation (Mc/s)	Field Strength at 1000 feet (uv/m)	Grounding	Welding Lead Length (ft.)	Building	Area	Certification	FS Meter	Remarks
1	3.7	28	PL	15		LI&R	Yes	Ra	
2	3.4	13	W	15	B&C	HI	Yes	Ra	Good installation
3	4.1	6.4	W	10		HI	Yes	Ra	Good installation
4	4.5	38	PL	15		I	Yes	Ra	Mounted on rubber tired dolly
5	4.2	22	PL	10	M	I	R	Ra	Major lobe through 10 x 12 open door
6	2.1	2.5	W		W	HI	Yes	Ra	Good installation
7	2.8	40	PL	8		HI	R	Ra	Mounted on rubber tired dolly
8	4.2	8	W	10		I	Yes	Ra	Good installation
9	0.85	0.3	PL			HI	Yes	Ra	Good installation
10	0.65	0.4	PL	15	M	HI	Yes	Ra	Grounded metal building
11	3.8	6.2	PL	15	W	LI	Yes	Rb	
12	18	7.3	PL	15	M	I	No	S	
13	2.1	7.0	PL	20	RC	I	No	Rb	Mounted on dolly
14	3.6	7.5	PL	40	RC	I	No	Rb	Mounted on dolly
15	3.5	53	PL	15	CB	S	Yes	Rb	High voltage power line nearby
16	3.1	27	PL		CB	I	No	Rb	Open wiring in vicinity, radial follows power lines
17	4.0	3.7	PL	25	M	I&R	No	Rb	Mounted on dolly
18	1.9	165	PL	25-15	C	R	No	Rb	Mounted on dolly
19	2.6	4.9	W	25-15	C	LI	No	Rb	Very compact operation
20	1.7	390	PL	15		I	No	Rb	Mounted on dolly in screen room, high voltage power line nearby

Table 1 (cont'd)

Welder Number	Frequency of Maximum Radiation (Mc/s)	Field Strength at 1000 feet (uv/m)	Grounding	Welding Lead Length (ft.)	Building	Area	Certification	FS Meter	Remarks
21	3.2	5.7	PL	25-10	C	I&R	No	Rb	Mounted on dolly
22	2.5	0.3	PL	25-10	C	LI	No	Rb	Very compact operation
23	2.2	0.3	PL	25-15	M	R	No	Rb	Mounted on dolly
24	2.9	37	PL	25	M	B&R	No	Rb	High voltage power line nearby
25	3.4	0.5	W	25	RC	LI	Yes	Rb	Excellent ground
26	2.7	17	W	25-15	CB	I&R	No	Rb	
27	0.78	24	PL	20	M	LI	No	S	
28	3.9	0.6	PL	25-15	M	LI	Yes	Rb	
29	2.2	2.4	PL	12	M	LI	Yes	Rb	
30	18	30	PL	15	M	I	No	S	Many power lines nearby
31	1.9	12	PL	12	M	S	No	Rb	Mounted on dolly
32	2.4	430	PL	15	M	LI	No	S	Major lobe through open side of building
33	24	100	W	12	M	HI	No	S	1/4 wall area is windows
34	0.78	7.4	PL	20	M	LI	No	S	
35	3.6	0.6	W	12		B&R	Yes	Ra	
36	4.9	7.4	W	12		B&R	No	Ra	
37	0.9	24	W	25	CB	LI	No	S	
38	3.7	9	W	15		I&B	No	Ra	
39	2.6	15	PL	16		I&R	No	S	
40	4.3	220	PL	25	M&CB	LI	No	S	

Table 1 (cont'd)

Welder Number	Frequency of Maximum Radiation (Mc/s)	Field Strength at 1000 feet (uv/m)	Grounding	Welding Lead Length (ft.)	Building	Area	Certification	FS Meter	Remarks
41	25	27	W	12	M	HI	No	S	1/4 wall area is windows
42	25	2.3	W	12	M	I	No	S	Excellent ground and shielding by building
43	21	36	W	12	M	HI	No	S	1/4 wall area is windows
44	25	35	PL	12	M	I	No	S	
45	3.7	12	W	12	M	I	R	Ra	
46	24	15	W	12	M	HI	No	S	
47	4.8	580	W	12	M	HI	No	S	
48	7.6	70	PL	12	M	I	No	S	
49	15	37	W	12	M	HI	No	S	
50	21	55	W	12	M	HI	No	S	1/4 wall area is windows
51	25	14	W	12	M	HI	No	S	1/4 wall area is windows
52	2.6	4.5	W	12	M	I	No	S	
53	24	34	W	12	M	HI	No	S	1/4 wall area is windows
54	4.5	360	PL	15	CB	I	No	S	
55	2.5	160	PL	25	M		No	S	Rural area near airport
56	5.3	4	PL	15		LI	R	Ra	
57	3.5	32	W	30			R	Ra	
58	3.8	20	W	12	M		R	Ra	
59	2.8	160	PL	25		HI	No	S	
60	2.6	460	PL			R	No	S	

Table 1 (cont'd)

Welder Number	Frequency of Maximum Radiation(Mc/s)	Field Strength at 1000 feet (uv/m)	Grounding	Welding Lead Length (ft.)	Building	Area	Certification	FS Meter	Remarks
61	3.7	5.7	W	12		I	R	Ra	
62	2.6	19		60		I&R	No	S	Good installation on truck body, no earth ground
63	2.6	7.7	W	12		I&R	R	S	
64	4.1	8	PL	15		B&R	No	Ra	
65	3.3	39	W	12		B&R	No	Ra	
66	3.3	380	W	15		LI	Yes	Ra	Many power and telephone lines in area
67	3.4	26	PL	15		B&R	R	Ra	
68	4.3	3.2	W	12		B&R	Yes	Ra	
69	2.7	110	W	15		R	No	S	Poor wiring in shop
70	2.2	137	W	25		S	No	S	
71	2.6	120		15		I	No	S	Temporary water pipe ground
72	2.6	455	PL	18		R	No	S	Unshielded AC supply cable

Table 1 (cont'd)

Explanation of Symbols

Grounding	PL	Through power line neutral
	W	Ground rod at welder location
Welding lead length	25 - 15	25 foot leads coiled to 15 feet
Building (construction of building in which welder is operated)		
	B	Brick
	C	Concrete
	CB	Concrete Block
	RC	Reinforced Concrete
	M	Metal
	W	Wood
Area (type of area where welder is located)		
	LI	Light Industrial
	I	Industrial
	HI	Heavy Industrial
	R	Residential
	B	Business
	S	Shipyard
Certification (unit has been certified as complying with FCC Rules)		
	R	Reportedly certified but no certificate available
FS Meter	Ra	RCA 308A (corrected to read quasi-peak)
	Rb	RCA 308B (corrected to read quasi-peak)
	S	Stoddart NM20B (using quasi-peak detection)

Table 2
Distribution of Exponent n in the Formula

$$E = k \frac{1}{d^n}$$

n	Number of Welders
0 - .34	0
.35 - .45	1
.46 - .54	1
.55 - .65	3
.66 - .74	2
.75 - .85	2
.86 - .94	2
.95 - 1.05	8
1.06 - 1.14	4
1.15 - 1.25	8
1.26 - 1.34	6
1.35 - 1.45	4
1.46 - 1.54	4
1.55 - 1.65	3
1.66 - 1.74	4
1.75 - 1.85	3
1.86 - 1.94	2
1.95 - 2.05	3
2.06 - 2.14	1
2.15 - 2.25	1
2.26 - 2.34	1
2.35 - 2.45	4
2.46 - 2.54	0
2.55 - 2.65	2
2.66 - 2.74	0
2.75 - 2.85	2
2.86 - 3.00	0

Table 3
One Point Measurements

	Measured Field				Measured Field		
Welder Number	Distance (feet)	Field Strength (uv/m)	Extrapolated Field at 1000 ft. (uv/m)	Welder Number	Distance (feet)	Field Strength (uv/m)	Extrapolated Field at 1000 ft. (uv/m)
73	100	30	1.0	93	100	4	0.1
74	100	30	1.0	94	100	5	0.2
75	100	30	1.0	95	100	4	0.1
76	100	30	1.0	96	600	20	9.3
77	100	30	1.0	97	150	57	3.3
78	100	30	1.0	98	30	501	2.6
79	100	30	1.0	99	800	147	105
80	100	30	1.0	100	800	15	11
81	100	30	1.0	101	800	49	36
82	100	30	1.0	102	800	39	28
83	100	30	1.0	103	528	315	130
84	1,000	36	36	104	100	400	12
85	200	15	1.4	105	100	320	10
86	35	15	0.1	106	150	88	5.2
87	200	600	53	107	150	100	5.8
88	1,600	26	53	108	150	56	3.2
89	300	15	24	109	150	36	2.1
90	1,500	600	1,100	110	150	2,000	115
91	1,600	26	53	111	175	18	1.3
92	100	5	0.2	112	150	39	2.3

Table 4
Two Point Measurements

Welder Number	Measured Field: Distance (feet)	Measured Field: Field Strength (uv/m)	Extrapolated Field at 1000 ft. (uv/m)	Measured Field: Distance (feet)	Measured Field: Field Strength (uv/m)	Extrapolated Field at 1000 ft. (uv/m)
113	100	67.5	2.3	150	30	1.8
114	100	52.5	1.7	120	30	1.2
115	100	60	1.9	150	30	1.8
116	100	67.5	2.3	150	30	1.8
117	50	67.5	0.8	100	30	1.0
118	50	55.5	0.6	100	30	1.0
119	100	60	1.9	150	30	1.8
120*	66	16,000	275	339	112	22
121*	66	18,000	305	363	700	150
122*	65	750	12	66	147	2.6
123*	65	7,000	118	300	157	26
124*	65	1,000	16	300	176	29
125*	65	852	14	180	77	5.8
126*	65	100,000	1,680	495	300	105
127*	65	100,000	1,680	360	5,000	1,100
128*	65	3,500	58	162	63	4.3
129*	65	1,700	28	80	57	1.3
130*	65	50,000	840	372	188	43
131*	100	10,900	340	200	275	25
132*	300	579	96	1,000	97	97

* Measurement 1 inside bldg, measurement 2 outside bldg.

Table 4 (cont'd)
Two Point Measurements

Welder Number	Measured Field: Distance (feet)	Measured Field: Field Strength (uv/m)	Extrapolated Field at 1000 ft. (uv/m)	Measured Field: Distance (feet)	Measured Field: Field Strength (uv/m)	Extrapolated Field at 1000 ft. (uv/m)
133*	150	3,500	205	300	155	26
134*	100	4,400	140	275	92	13
135*	50	12,000	130	130	4	0.2
136*	50	4,900	53	130	3	0.1
137*	50	14,000	155	130	3	0.1
138	1,000	500	500	2,000	60	175
139	1,000	640	640	2,000	100	290
140	70	100	1.5	160	20	1.2
141	70	200	3.0	160	200	12
142	70	640	12	160	200	12
143	70	200	3.0	160	20	1.2
144	125	80	3.6	150	24	1.4
145	100	400	13	200	20	1.8
146	100	200	6.2	200	40	3.6
147	50	3,200	36	500	36	13
148	150	100	5.8	500	64	23
149	600	36	16	1,000	24	24
150	150	48	2.8	350	24	5.0
151	500	120	44	1,000	18	18
152	175	23	1.6	300	23	3.8

* Measurement 1 inside bldg; measurement 2 outside bldg.