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TRANSIENTS INDUCED IN ELECTRICAL CABLES BY NUCLEAR RADIATION PULSES

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UNITED STATES ARMY

ELECTRONICS RESEARCH AND DEVELOPMENT LABORATORY

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ABSTRACT

Current transients generated in various types of electrical communication cables under irradiation from a mixed neutron and gamma pulse were measured as a function of applied voltage, repeated exposure, distance from source, and interposed shielding. Results are reported for coaxial radio-frequency cables RG-59 B/U, RG-62 A/U and RG-81/U, electrical telephone cable WD-1/TT, and parallel wire TV antenna cable. The radiation source was the bare critical assembly of the Sandia Pulse Reactor Facility. By individually measuring the transients in both cable conductors, the response of the coaxial cables was found to differ characteristically from that of the equivalent pair cables. Applied voltage exerts a strong influence on the magnitude and polarity of the response signal. Repeated exposures under unchanged conditions lead to marked or even drastic reductions of the transient signal level. For reasons yet to be determined, the anticipated signal attenuation by increasing the distance from the source and by interposing radiation shields could not be verified under the conditions selected in this experiment.

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CONTENTS

FIGURES

CONTENTS (Contd)

TABLES

TRANSIENTS INDUCED IN ELECTRICAL CABLES BY NUCLEAR RADIATION PULSES

INTRODUCTION

The response of transmission cables to incident nuclear radiation pulses has been studied with increasing intensity during recent years.[1] This interest is based upon the indispensable role of cables in military electronic systems and perhaps even more on their extensive use as an accessory in the measurement of radiation effects in parts, devices, and circuits. In this case, the cables are frequently exposed to the same radiation field as the test objects, and under unfavorable conditions, the noise transient generated in the cables can seriously distort or completely obliterate their output signal. It is, therefore, impossible to make meaningful measurements on circuit components as long as the nature and magnitude of the cable transients remain unknown or unpredictable.

This report describes a series of measurements made on various types of transmission cables during exposure to the mixed neutron-gamma radiation pulse of the Sandia Pulse Reactor Facility (SPRF), Albuquerque, N. M.[2] The experiment was performed in April 1962.

Experimental Plan

Based upon the information from previous experiments[3,4] and particularly on the results of the preceding experiment at SPRF,[5] the present investigation was planned to clarify the influence of the following parameters on the response of various cables:

1. Applied dc voltage (0 to ±536v)
2. Cable polarity with respect to ground
3. Exposure history (up to 10 pulses with varying "annealing" intervals)
4. Distance of exposed cable from reactor (0 to 96 in.)
5. Neutron and gamma shielding

Unfortunately, not all of the above parameters were covered with sufficient emphasis, and in some cases definite conclusions cannot yet be derived from the results available. This is particularly true for items 4 and 5 above. The data obtained are nevertheless reported here for the record.

The above measurements were mostly planned from the viewpoint of studying the cable response in terms of the "conversion" of the absorbed radiation energy into an electrical noise signal. An additional experiment was performed to determine the effect of the radiation pulse upon an rf carrier signal traveling along the cable through the radiation field. The results of this experiment are being reported separately.[6]

A significant difference of the experimental plan as compared to earlier studies consisted in the use of previously unexposed specimens for each measurement, except where the effect of repeated pulses was being studied.

The following cable types were included in this investigation:

1. Coaxial Radio-Frequency Cable RG-59 B/U, according to MIL-C-17/29 A.
2. Coaxial Radio-Frequency Cable RG-62 A/U, according to MIL-C-17/30.
3. Coaxial Radio-Frequency Cable RG-81/U, according to MIL-C-17/37.

4. Electrical Telephone Cable (Infantry Field Wire, Twisted Pair) WD-1/TT, according to MIL-C-13294.
5. Television Antenna Cable, 300 ohm – Commercial Grade.

The experimental plan emphasized the study of cable types 1 and 2, with only a relatively small number of measurements provided for the other cables. In view of the wide scatter of the data encountered in this experiment in general, the results on cable types 3, 4, and 5 must be considered, however, the data are included in the report as a matter of record.

Measuring Methods

The configuration of the cable directed toward the radiation source was essentially that of a hairpin loop (Fig. 1). The total length of the test cable was 30 ft; the center part at about 14 ft was formed into a U-shaped bend with a distance of about 5 inches between legs. One end was connected to the patch panel at the reactor room wall and from there to the mobile laboratory outside; the other end was also brought back close to the patch panel in order to avoid high intensity exposure. This end was not terminated electrically; the shield was cut off about ½ in. back from the insulated center conductor, and the whole end was cast into epoxy resin to prevent air ionization.

The shield of the RG-81/U cable consists of solid copper tubing and its dielectric is magnesium oxide powder. It was, therefore, very difficult to bend the samples into the loop configuration shown in Fig. 1, and it is believed that the insulation may have developed cracks in the process. These may have influenced the cable response.

The response of the cables was generally measured as a current-vs-time pulse through a 1,000-ohm resistor outside the radiation field connecting the two conductors of the cable, one of which was grounded (Fig. 2a). The coaxial cables RG-59 B/U and RG-62 A/U were measured in the "normal" and in the "reverse" cable connection polarity. In the "normal" polarity the shield is grounded and the center is above ground, while in the "reverse" polarity the center is grounded and the shield is above ground. The battery, if any, was always inserted in the off-ground leg. In some measurements the response of each of the two conductors was observed individually by inserting 1,000-ohm resistors in each leg (Fig. 2). This method showed significant differences in the response of the two conductors and thereby demonstrated its value as an analytical tool.

The polarity of the current pulses (Fig. 3) has been defined as follows: The current flow is positive when positive charges move along the off-ground conductor (usually the center conductor, but not always) from the unexposed end toward the radiation source. This is the same direction in which a positive current flows if a battery is inserted in the off-ground conductor at the unexposed end so that its positive terminal points toward the radiation source. A return path from the exposed end toground is always assumed to be available at least momentarily during the burst. By this definition, electrons are flowing along the center conductor away from the radiation source to ground via the measuring resistor R, when the current pulse is positive.

Negative current flow is the opposite of the above, i.e., positive charges move from the off-ground conductor to ground away from the radiation source via the measuring resistor, in the same way as when a battery is inserted in the off-ground conductor with the positive terminal pointing toward R rather than toward the radiation source. Electrons will then flow from ground through R and the off-ground conductor toward the radiation source.

This definition is explained here in detail because it is at variance with the practice of several other workers in the field and even with that used in other USAELRDL reports.[1,3,4] It has been adopted here, however, because it not only assures that a quiescent, battery-generated current through the cable will have the same sign as a radiation-induced current pulse if the flow is in the same direction, but it also represents the current flow direction in the exposed end of the cable rather than that in the measuring resistor. The latter point is quite important in attempts to analyze the pulse generating mechanisms, where one wishes to know the direction of electrons flowing in either conductor.

The polarity of the cable connection (normal or reverse) must be considered in comparing the response pulses. Assuming that we observe a negative current pulse in a normally connected cable with no applied voltage, one should expect a positive current pulse for the case of reversed cable polarity, provided that the direction of the current generated in the cable is independent of the connection mode.

Similarly, the current values observed individually in two conductors by means of separate measuring resistors should be equal in magnitude and opposite in sign, if the radiation pulse generates a current flowing towards the radiation source in one conductor and returning in the other.

Experimental results at variance with these predictions are frequently encountered, particularly where a voltage is applied to the cable. They point to a more complex system of current sources and sinks than that envisaged by the simple current model in a continous circuit. Since such deviations may hold the key for the understanding of the basic behavior of the cable in the radiation field, it is highly important to know the magnitude, direction, and time dependence of the current flow in every part of the exposed cable.

The cable response pulse coincides usually in time with the instantaneous dose pulse as observed by SEMIRAD[7] and MgORAD[8] dosimeters,* and it also resembles its typical bell shape. In some cases, however, the response pulse is more complex and consists of a symmetrical or unsymmetrical oscillation about the current axis. With almost no exceptions the oscillation is limited to two peaks and its total duration is equal to that of the single peak pulse and that of the primary radiation burst itself. Oscillatory pulse responses in cables have been theoretically analyzed by K. Ikrath.[9]

The data tabulated in this report are the single or double peak values of the observed current response pulses in microamperes. Since the measuring resistor was 1,000 ohm in all cases, the data represent also the peak voltage across this resistor in millivolt. Double peak values are reported as a pair of numbers with the appropriate sign: In tables they are listed as $\begin{matrix}-70)\\+10)\end{matrix}$, in the text as −70/+10, and the top or the first number is the peak occurring first in time.

While it would be desirable to normalize the measured current values with respect to the unit length of the exposed cable and the unit rate of gamma radiation, we believe that the basis for such normalization is not yet sufficiently developed. Even if the rate of incident radiation were accurately known for each point along the exposed cable, the rate of radiation energy deposition could not be ascertained because the absorption characteristics of the cables are unknown.

Furthermore, if the exposed cable is arranged roughly along a radius of the reactor room, the radiation dose and dose rate should decline with a $1/R^2$ relationship with increasing distance

*SEMIRAD (Secondary-Electron-Mixed Radiation Detector)
MgORAD (Magnesium-Oxide Radiation Detector)

R from the reactor. It is, therefore, impossible to define an "effective" or "equivalent" exposed length of the cable as long as the relation between the dose rate of the incident radiation and the signal generated in the cable is unknown.

We have, therefore, refrained from normalizing the data reported here. Instead we are using the peak-pulse current values taken directly from the oscilloscope records. The arrangement of the cable specimen for the determination of the effect of shielding and of distance is schematically shown in Fig. 4. The shielding consisted of one polyethylene block 8 x 8 x 2 cu in. for neutrons and two lead bricks forming an 8 x 4 x 4 cu in. shield for gamma radiation. These blocks were placed in front of the exposed cable loops.

The closest distance between reactor screen and cable loop referred to as "0" was approximately one inch for the unshielded specimens and about 6 inches for the shielded ones. Other distances used were 24 in., 34 in., 60 in. and 96 in. Since the total length of the specimens was the same in all cases, it was inevitable that a considerable portion of the cable was "curled up" behind the test stand in the 60-in. and 96-in. experiments. It was believed that the contribution from this part of the cable would be negligible because of the greatly reduced dose and dose rate in the vicinity of the reactor well.

EXPERIMENTAL RESULTS

Effect of Voltage and Cable Polarity upon First-Exposure Response

a. Normal Cable Polarity

All cables exhibit sizeable pulse current signals in their first exposure even if the circuit does not contain a battery. The range of these currents is given in Table 1. The data are seen to scatter very widely; in RG-59 B/U and RG-62 A/U, even the current polarity differs for the extreme samples.

Nevertheless, there are significant features discernible for the various cable types. Without applied voltage the majority of the cable signals is negative in sign, i.e., the electrons are flowing through R into the off-ground conductor. In the case of WD/1-TT, only a single measurement was made. In RG-59 B/U and RG-62 A/U, the positive current occurred only in one out of nine and in one out of six samples, respectively (Table 3 and 5). The signals for RG-59 B/U, WD-1/TT, and the TV cable are comparable in size, but the signals of RG-62 A/U are generally more than ten times as large.

With a voltage of +268v applied, the response signals become more positive as would be expected, but the majority of the RG-62 A/U samples remains still strongly negative.

The peak response signals of the various cables are plotted vs the applied voltage in Fig. 5-7. Here, too, the scatter of data and the ambiguity in sign are evident over much of the voltage range from −536v to +536v, which was covered in this experiment. The straight lines drawn through these points are therefore rather arbitrary. They do show, however, that the slope of the peak current-vs-voltage curve is definitely different for the different cable types. Assuming that this slope represents the minimum value to which the insulation resistance of the cable loop drops during the radiation pulse, one obtains the results listed in Table 2.

Because of the finite current at zero applied voltage, these resistance values are obviously fictitious. For the WD-1/TT field wire and the TV cable, the distinction between "normal" and "reverse" cable polarity is meaningless because both conductors are equivalent. The results are, therefore, listed in between the two columns of Table 2.

b. Reverse Cable Polarity

In coaxial cables connected in the reverse polarity (shield off-ground, center conductor grounded), the current flow direction without applied voltage appears to be mostly positive, i.e., the opposite of the direction in the normal cable polarity (Table 3 and 5). Where both currents are of the same magnitude, this finding would be consistent with the existence of a temporary conductive path across the exposed cable portion, because in both cable polarity modes the current would flow from shield to center conductor. Where the currents are different, other mechanisms must be operative by which additional sources or sinks for electrical charges are provided.

With the application of voltage to the reverse polarity cable, the peak current increases much more than in the case of the normal connection. This is borne out by Fig. 5 and 6, and by the "insulation resistance" values listed in Table 2. The reverse polarity "resistance" values of RG-59 B/U and RG-62 A/U are much lower but also much more alike than their normal polarity values.

c. Individual Leg Measurements

The difference in response observed in coaxial cables when the cable polarity is changed was at first highly surprising. It means that the pulse current generated by the radiation is not the same in both conductors, but that the signal from the shield is much larger than that from the center conductor. This would seem to indicate that the conductors act as independent "antennas" for the conversion of radiation energy rather than as a closed continuous circuit.

Further consideration of this fact led to the conclusion that in the normal polarity case, we measure mostly the contribution from the center conductor, while the larger pulse from the shield escapes observation by flowing directly to the ground. In order to measure the individual contributions from both conductors during the same radiation pulse, 1,000-ohm measuring resistors were inserted in both legs, thus placing both conductors above ground in a symmetrical manner (Fig. 2b).

The results obtained by this method are included in Table 3, 5 and 9. Since the measurements so far have not yet been made with various applied voltages, their discussion is included in the section dealing with the effects of repeated exposure.

d. Summary of Results in First-Exposure Experiments

1. Sizeable pulse currents are generated during the radiation pulse in all cables when no voltage is applied to the conductors. Negative polarity of these pulse currents is predominant in the center conductor of coaxial cables, while the shield currents are positive. The zero voltage currents of RG-59 B/U and RG-62 A/U differ by a factor of more than 20, but the absolute difference between their respective shield and center conductor currents is small and practically the same for both.

2. Negative potentials applied to the off-ground conductor tend to increase the magnitude of the negative current signal as compared to the zero voltage signal. Positive potentials reduce the signal so as to reach zero at a finite voltage level, beyond which the signal becomes positive and increases with the further increase of the positive voltage.

3. The slope of the peak current-vs-voltage curve is greatly different for the different types of cable studied. If this slope is interpreted as a minimum of the temporary insulation resistance reached by the cable during the radiation pulse, these resistance values for the configuration studied here would range from 1,700 kohm for RG-59 B/U down to 60 kohm for RG-62 A/U.

4. Reverse cable polarity and individual leg measurements show that the response of both conductors in coaxial cables is greatly different. With applied voltage, the shield yields generally a much larger signal than the center conductor, and the minimum insulation resistance values drop to 38 kohm for RG-59 B/U and 13 kohm for RG-62 A/U.

Effect of Repeated Exposures

a. RG-59 B/U

The results of repetitive exposures for RG-59 B/U cable without an applied voltage are shown in Table 3. The major effect of the repeated exposure seems to be a significant reduction in the output pulse amplitude. In sample 59-13-138, the final level is reached in the fourth exposure if one disregards subsequent variations in magnitude and the occurrence of oscillatory pulses.

In the tenth shot, the measurement was made on the individual conductors. The center conductor repeats, although with increased amplitude, the oscillation of the preceding normal polarity measurement. The shield, however, shows a rather high negative current pulse ($-230\ \mu$a).

The other sample in which the individual conductors were measured, 59-16-146, resembles the behavior of 59-13-138 and 59-16-147 in that the center conductor values are of the same magnitude and show a comparable decrease from the first shot to the second shot. The shield value of this sample begins with a strong positive signal which decreases markedly in the second shot. It is not yet known whether this trend would continue and eventually lead to the negative value observed in the final exposure of sample 59-13-138. It is believed, however, that the difference between the response of the center conductor and that of the shield is real and significant.

The initial shot values of eight samples of RG-59 B/U exposed with an applied voltage of +268v fall within narrower limits than those of the samples without applied voltage (Table 4). Several samples yield oscillatory response signals. In the second shot the current pulse values split into two distinct groups, namely, those which show little change from the first shot response and those which increase strongly in magnitude and show positive polarity exclusively. The reason for this anomalous behavior is unknown. The one sample observed through seven shots reduced its pulse magnitude although somewhat erratically.

b. RG-62 A/U

Repetitive exposure of RG-62 A/U cable without an applied voltage results not only in a much stronger reduction in current pulse amplitude than that observed in RG-59 B/U, but also in a reversal of the current polarity from the initial negative to the positive flow direction (Table 5). Sample 62-13-137 reaches its final level in the third shot and sample 62-16-144 parallels this behavior in the first and second exposure.

In the individual conductor measurements, satisfactory agreement exists between the center conductor and the normal polarity results and between the shield and reverse polarity measurements. The shield response of sample 62-13-137 in the tenth shot is particularly interesting because it is practically identical with the corresponding result in RG-59 B/U cable. This is believed to be more than a coincidence since both shields are constructed identically; therefore, they should be expected to exhibit the same response, and it appears that this state is finally achieved by the "stabilizing" effect of repetitive exposure.

The other sample for which individual conductor measurements are listed, 62-16-145, falls close to the negative extreme of the pulse magnitude range in the first shot. In the second shot, however, the response of both conductors decreases drastically and it is quite likely that it would parallel the trend of 62-13-137 in further shots. The shield response decreases even more strongly than that of the center conductor and it is possible that it would duplicate the final values observed in 59-13-138 and 62-13-137 after receiving the same number of exposures.

Sample 62-22-148 reported in Table 5 exhibits an unusually high current pulse of $-15{,}000\ \mu a$. It differs from the remaining samples by its history. In the first three shots, it was exposed with +536v applied. In these exposures, its response had shown the normal amplitude reduction trend, namely, from $+4{,}000\ \mu a$ to $+2{,}800\ \mu a$ and finally to $+900\ \mu a$. In the fourth shot, the sample was exposed without an applied voltage, yielding the extreme pulse current listed above. Although this result will require confirmatory experiments, it seems to point rather clearly to a sensitization process of the cable occurring in the first shots.

With an applied voltage of +268v, the initial current values for RG-62 A/U cable range from $-6{,}500$ to $+5{,}500\ \mu a$. This spread is still widely overlapping the range of the predominantly negative signals observed with no applied voltage, but the mean value is shifted towards zero current, and in two samples the current pulse is positive. The second exposure brings all signals into the positive current field and four more exposures of sample 62-13-136 tend to confirm this behavior although the drastic increases in the fourth shot and the negative sign of the small final signal cannot be explained. It should be noted that the strong negative current flow in the first exposure is opposite to the leakage current flow direction governed by the applied voltage.

c. RG-81/U

As pointed out under the section on Measuring Methods, the data obtained on RG-81/U cable are not only limited in number but they are also possibly affected by causes unrelated to the intended test conditions (Table 7).

The data for sample 81-14-122, which was measured without applied voltage, are rather uncertain. In the first three exposures the magnitude of the current pulses can only be estimated to exceed 200 microamperes because the traces went off-scale. The current polarity was positive in the first two shots, negative in the third and fourth, and again positive in the fifth and sixth exposure. Beginning with the fourth shot the signal was very weak, thus conforming with the trend observed in the RG-59 B/U and RG-62 A/U cables.

The polarity is consistently positive for all measurements with an applied voltage of +268v and the trend of decreasing pulse magnitude is evident here too.

d. WD-1/TT

The results of measurements on WD-1/TT Field Wire are listed in Table 8. All samples were measured with one conductor off-ground and the other one grounded.* In the first and only exposure, sample WD-14-113 without applied voltage yields a rather strong signal with positive polarity. It is not known whether this is typical of this cable or whether the particular sample "strayed" into the positive current field as a few of the other cables have done.

With an applied voltage of +268v, the signals of all four samples measured are positive and roughly of the same magnitude as that of the no-voltage sample The signal amplitude appears to decrease in subsequent exposures; the high value of sample WD-13-110 in the fourth shot may be due to recovery, since there was a time interval of 258 hours between the third and the fourth exposure.

*This is the regular circuit shown in Fig. 2a; the distinction between "normal" and "reverse" cable polarity becomes meaningless for cables with equal conductors such as WD-1/TT and the TV cable.

e. TV Cable

The measurements on TV cable are reported in Table 9. Most of the samples were connected in the same way as the WD-1/TT cable, but in samples TV-16-112 and TV-22-103, the two conductors were measured individually.*

Regardless of this difference in measuring circuit, the current values of all four samples in the first exposure without applied voltage agree with respect to their order of magnitude and they all have negative polarity. Their behavior in the second shot does not point to a definite trend. Sample TV-22-103 was exposed in seven shots but measured for the first time during the eighth radiation pulse with the individual leg circuit. Both conductors exhibit positive signals. This behavior is reminiscent of the response of the RG-62 A/U center conductor of sample 62-13-137, shown in Table 5, Exposure #10. It is not known, however, whether the other four samples of TV cable would also reach positive polarity values if they were given the same number of shots as TV-22-103.

The one sample tested with an applied voltage +268v, namely, TV-17-102, maintained its initial positive polarity through five exposures, and shows a somewhat erratic trend of decreasing signal amplitude. Tested without an applied voltage in its sixth exposure, the signal fits in very well with the initial no-voltage signals of the four other samples.

The individual conductor measurements of the TV cable samples TV-16-112 and TV-22-103 are considered as strong evidence for the viewpoint that the radiation noise signal in an open cable is generated independently in the cable conductors. Since these are equivalent in the TV cable, the signals are equal in polarity and approximately equal in magnitude. Conversely, it is believed that the difference observed in the response of the center conductor and the shield in coaxial cables proves the inequality of the two conductors with respect to the conversion of radiation energy into electrical signals.

f. Comparison of RG-59 B/U, RG-62 A/U and TV Cable

In an attempt to syopsize the changes in the behavior of the individual conductors of various cables in eight or ten exposures without applied voltage, initial and final values taken from Table 3, 5 and 9 have been juxtaposed in Table 10 without regard to the fact that they were obtained from different samples. Assuming that these results can be confirmed in a future experiment on one and the same sample of each type, we note several facts about these data: (a) in all samples except perhaps one, the polarity of the signal reverses from the first to the nth exposure, regardless of whether it is first negative as in the single-wire conductors or positive as in the braided shields; (b) differences in absolute signal magnitude which approach two decades in the first exposure are practically wiped out in the nth exposure if one considers the single-wire conductors and the braided shields as different groups; (c) the absolute current magnitude in the nth shot is about five times greater in the shield than in the single wires; their difference, perhaps fortuitously, is about the same in the first and in the nth shot, namely about 200 μa.

g. Summary of Results in Repeated Exposure Experiments

1. In successive exposures the cable response signal tends to decrease, in some instances rather drastically, if the applied voltage is maintained at the same level throughout the series; usually the signal reaches its final level after about four or five exposures, and subsequent changes are relatively small.

2. Without applied voltage, and also within a certain range of applied voltages, the polarity of the signal reverses between the initial and the final shots; this appears also to be true for the response of both cable conductors individually.

*Circuit of Fig. 2b.

3. In RG-59 B/U and in RG-62 A/U, the response of the center conductor is definitely different from that of the shield; perhaps fortuitously, this difference amounts to about 200 μa and remains practically unchanged from the initial to the final exposure in spite of very large changes of the individual conductors.

4. A change in the applied voltage after several exposures may cause changes in the response signal. Under certain conditions the signal level was seen to increase far beyond that expected for the new applied voltage condition, thus suggesting a sensitization process.

Effect of Distance and Shielding in First Exposure: Applied Voltage: +268v

The results obtained in this experiment on cable type RG-59 B/U, RG-62 A/U, and RG-81/U are tabulated in Table 11, 12, and 13, respectively. For all three cable types, the data are so widely scattered that conclusions as to the influence of distance and shielding upon the generated signal are impossible.

For the RG-59 B/U cable, the total range of peak current values in all 28 samples of Table 11 is from −500 μa to +540 μa. This exceeds rather drastically the range from −150 μa to +150 μa occupied by the eight reference samples at zero distance and without shielding. It is not known whether the no-shield values at 6- , 24- , and 34-in. distance exceed those at zero distance only accidentally or whether the increase is real. At 60-in. distance the values are about equal to those at zero distance and at 96-in. distance the signal is the smallest of all as one might expect. With lead shielding, however, values exceeding the level of the reference samples are found at 34- , 60- , and even at 96-in. distance; the latter is actually the highest value of any RG-59 B/U sample. The samples shielded with polyethylene yielded data that cannot be definitely distinguished from the no-shield group.

For the RG-62 A/U cable (Table 12), the effect of distance and shielding is perhaps even more strongly masked by unknown contributing factors than in RG-59 B/U. With the exception of two samples at 34-in. distance, every sample regardless of distance and shielding falls in the same range as the data for zero distance, no shield. The total range of peak currents encountered in all 31 samples extends from −6,500 μa to 7,500 μa. The occurrence of the two positive maximum values at 34-in. distance is considered purely accidental.

In the case of the RG-81/U cable (Table 13), the data are even more fragmentary than those for the other cables. While the total range of current values, namely from −5 μa to +440 μa, is smaller than that for the RG-59 B/U and much smaller than that for the RG-62 A/U, there is no discernible effect of distance or of shielding.

From the results of the above measurements at various distances and under various conditions of shielding, it seems obvious that some of the underlying assumptions for this experiment must be revised. The fact that strong and even extreme signals are observed at a distance of 96 in. from the reactor shows that the radiation response is not solely dependent upon the dose rate of the incident radiation energy which decreases at least two orders of magnitude between the reactor surface and the 96-in. point. Whether this apparent equalization is caused by radiation reflected from the reactor room wall is unknown.

The unexpected insensitivity of the response to the distance variation may partially explain the absence of any detectable effect of the shielding. The contribution from the remote part of the sample that is exposed to scattered radiation is comparable or even larger than that of the very small part shielded by the relatively small lead or polyethylene blocks from the full gamma or neutron intensity.

Obviously, the above results also present a strong argument against the normalization of cable data with respect to exposed length (see the section under Measuring Methods).

SUMMARY

The most significant results of the work reported here can be briefly summarized as follows:

1. In the first exposure, the response of the various cable types tested is greatly different, with the RG-62 A/U cable signal exceeding those of the others by at least one order of magnitude. After four or five exposures under unchanged conditions, all cables appear to reach a greatly reduced common signal level.

2. Independent measurements of the individual cable conductors have clearly proved the fact that in coaxial cables the signals generated by the radiation pulse are different in magnitude and polarity for the center conductor and the shield, while in equivalent conductor pairs, e.g., TV cable, the response of both conductors is equal in polarity and closely comparable in magnitude.

3. Contrary to our expectation, the response of RG-59 B/U, RG-62 A/U, and RG-81/U was found to be virtually independent of the distance between the reactor screen and the sample. The cables were measured with an applied voltage of +268v and all measurements were made during their first exposure only.

CONCLUSIONS

Although the data obtained in this experiment exhibit considerable scatter and the results on some of the planned tests remained rather fragmentary, the findings are believed to be valuable for the understanding of the cable response mechanism, as well as for the minimization of spurious contributions from the cable when used as an accessory in other measurements.

The glaring difference in the response of the RG-62 A/U cable from that of all other cable types, and particularly from RG-59 B/U which it resembles so closely in dimensions and general construction, has been established beyond any doubt. Comparing the two cable types, one is almost forced to ascribe this difference to the only structural difference between them. In the RG-59 B/U, the polyethylene dielectric is directly extruded onto the center conductor, while in the RG-62 A/U, the center conductor and the dielectric are separated by a helically wound spacer filament which maintains an air-filled envelope around the conductor. If one attributes the extreme signal of RG-62 A/U cable to the ionization of this air envelope during the radiation pulse, one must invoke an additional mechanism for the drastic decline of the signals in the later exposure. This mechanism is as yet unknown but it is hoped that it can be identified by further experimental analysis.

The new finding that the individual conductors of coaxial and equivalent pair cables respond to the radiation pulse independently and with characteristic differences in magnitude and polarity of the generated signal is believed to be of practical importance for cable applications in radiation effect measurements. Once the data obtained during this experiment have been established in sufficient detail and with known tolerance limits, it seems possible to minimize the undesired cable signal by selecting the proper cable type, preaging treatment, and operating voltage. For differential measurements,the equivalent-pair-type conductor appears preferable because, ideally, the outputs from its two conductors would cancel. This is true only in a balanced circuit without applied voltage.

Further information is, therefore, needed on the effect of the applied voltage upon the individual conductor response of both the coaxial and the equivalent-pair-type cables.

Wherever possible, measurements of radiation effects on electronic circuits or components should be made by ac rather than dc methods. By placing the operating frequency sufficiently far above the highest frequency of the cable signal spectrum, the cable contribution can be suppressed almost completely by a high-pass filter, except for possible phase and amplitude changes caused by changes in transmission characteristics during the radiation pulse. This approach is being studied further.

ACKNOWLEDGMENTS

This experiment was conducted by a USAELRDL team at the Sandia Pulse Reactor Facility, Albuquerque, New Mexico, during the period from 2 April to 20 April 1962. The authors appreciate and commend the concerted effort and the individual contributions made by each team member towards the thorough preparation and precise execution of the experiment.

The following personnel participated in this task: Messrs. Joseph Newberg, Electronics Engineer, Joseph A. Key, Nuclear Physicist, Pfc. Robert Shakun, Physicist, and Anthony A. Allocca and William E. Mayo, Electronic Development Technicians.

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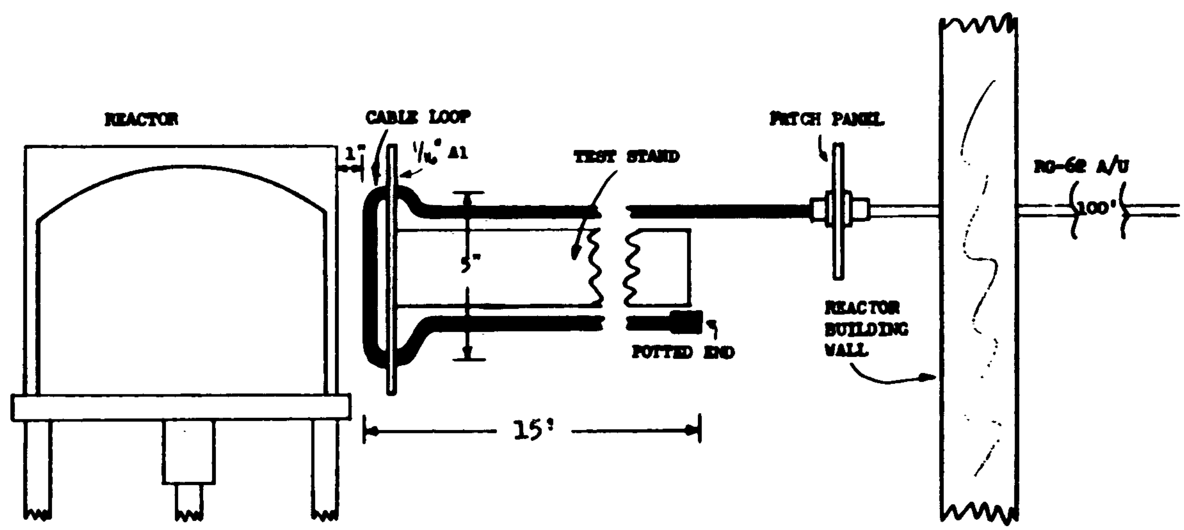
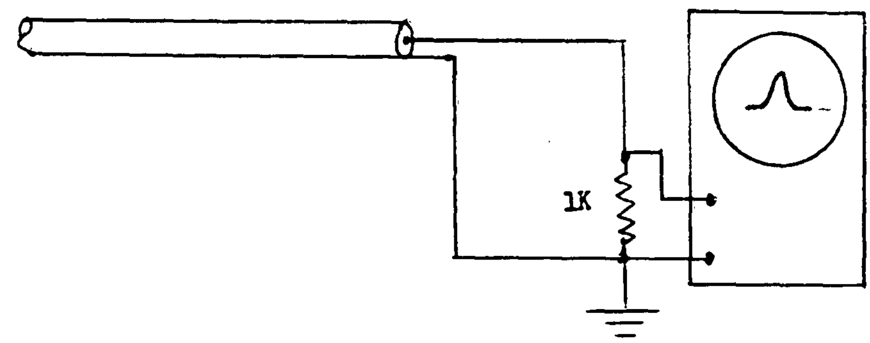
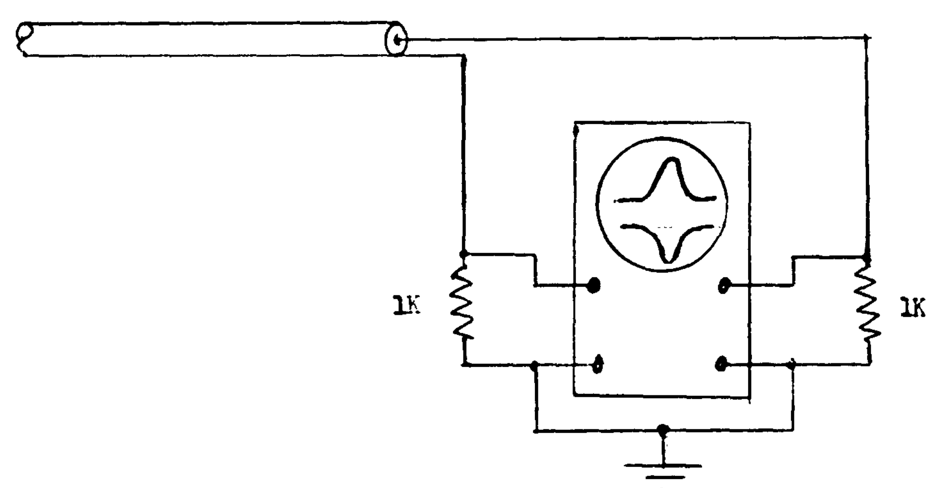


Figure 1
Arrangement of Test Cable Loop



a. Regular Circuit used for Measurements with

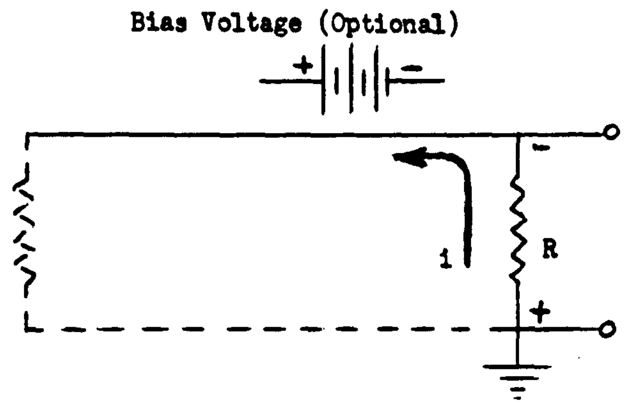
"Normal and "Reverse" Cable Polarity



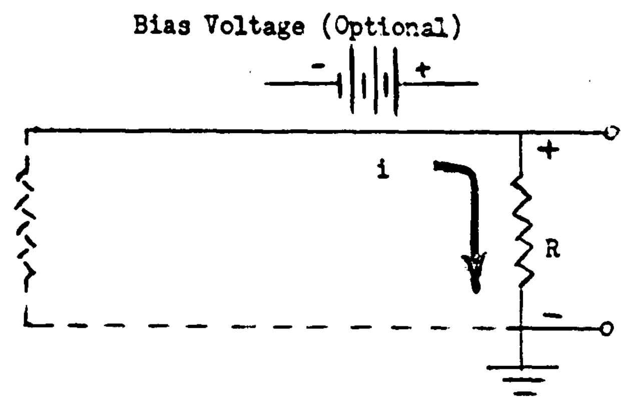
b. Special Circuit Used for Measurements of the Individual Conductors

Figure 2

Test Circuits for Cable Measurements



Positive Current Flow
(Electrons flowing to ground via measuring resistor R)



Negative Current Flow
(Electrons flowing into off-ground conductor via measuring resistor R)

Figure 3

Definition of Current Polarity

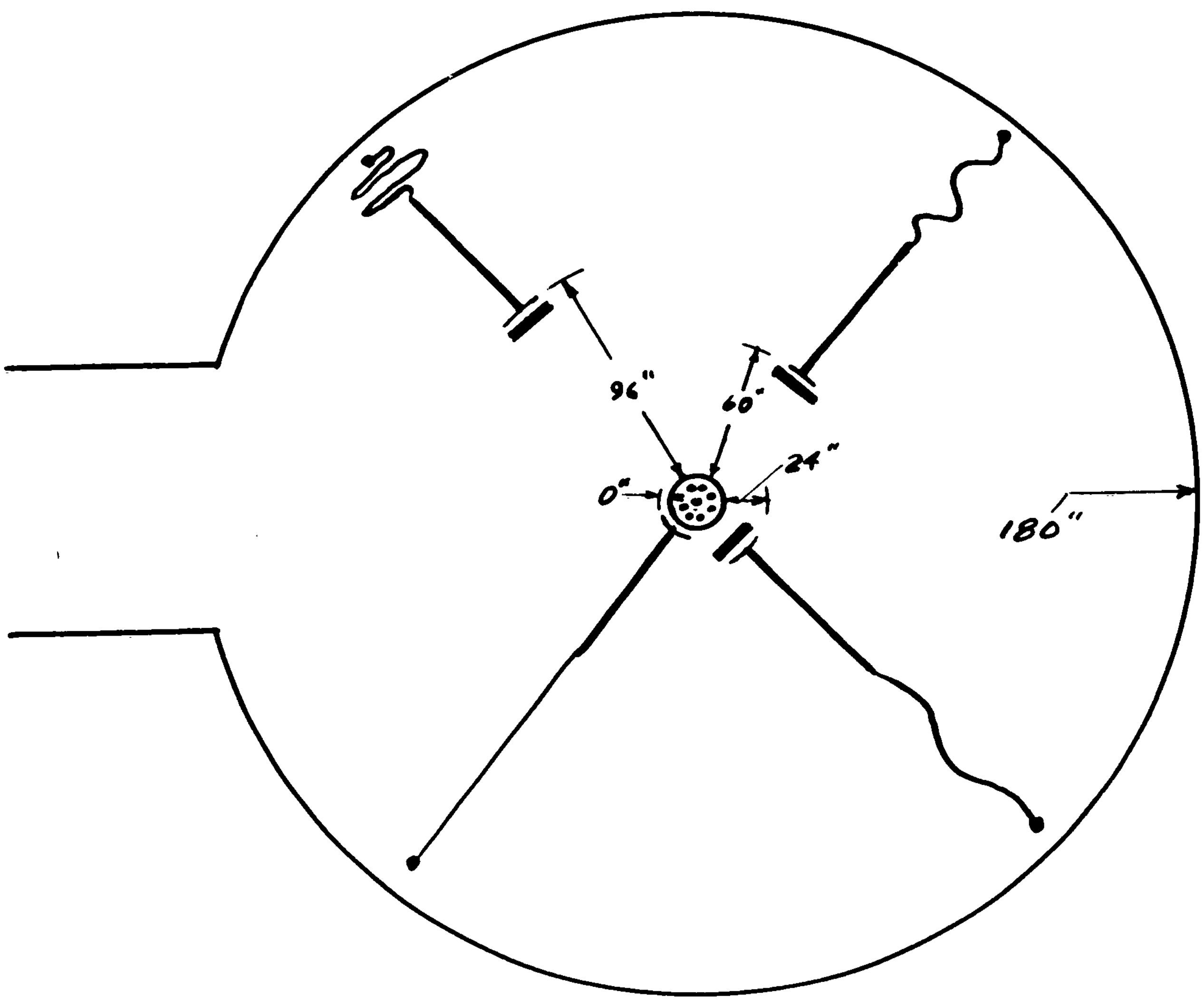


Figure 4 - Arrangement of Test Specimens About the Reactor (Schematic)

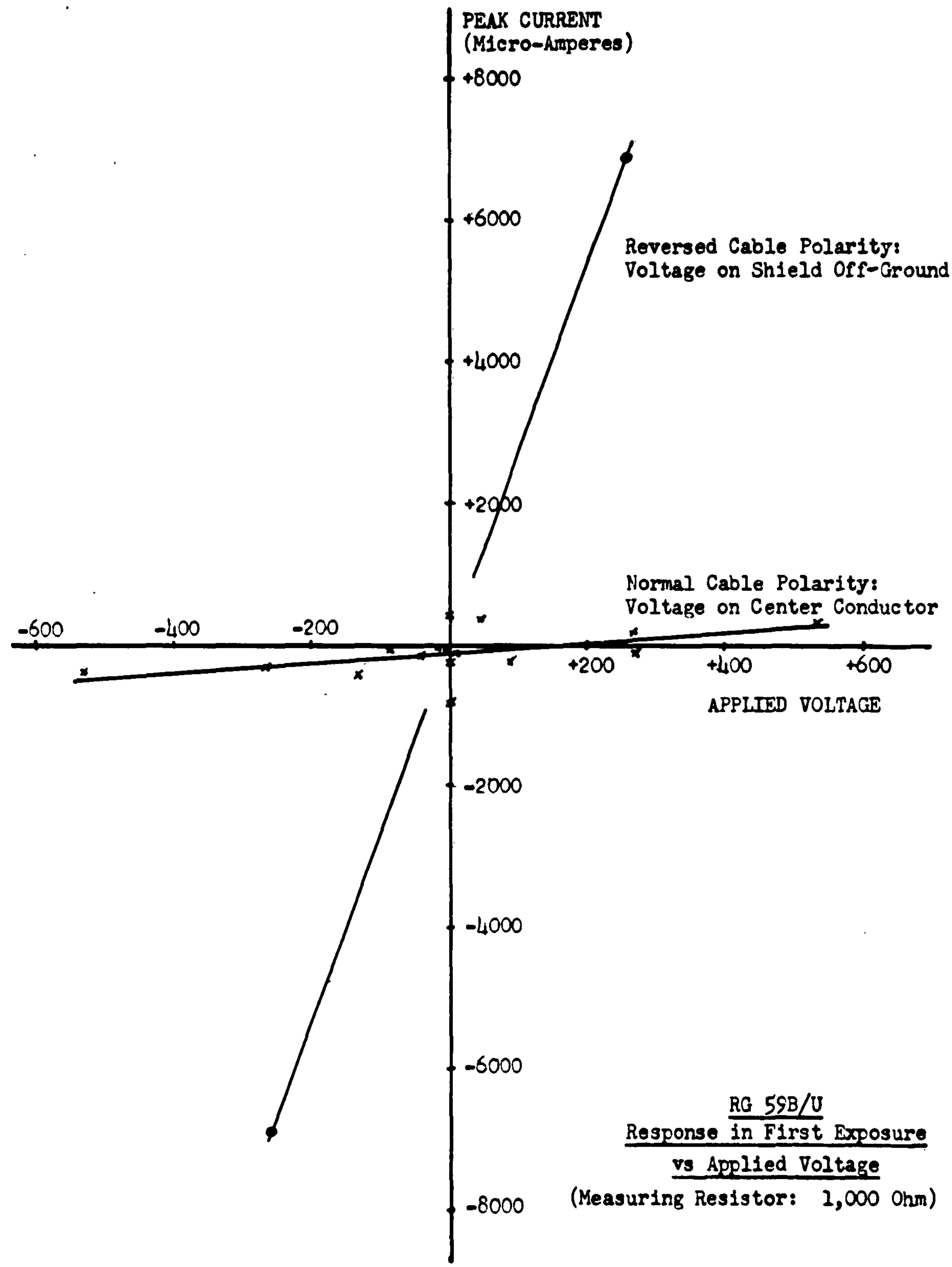

PEAK CURRENT
(Micro-Amperes)
+8000
+6000
+4000
+2000
-2000
-4000
-6000
-8000
-600
-400
-200
+200
+400
+600
APPLIED VOLTAGE
Reversed Cable Polarity:
Voltage on Shield Off-Ground
Normal Cable Polarity:
Voltage on Center Conductor
RG 59B/U
Response in First Exposure
vs Applied Voltage
(Measuring Resistor: 1,000 Ohm)

Figure 5

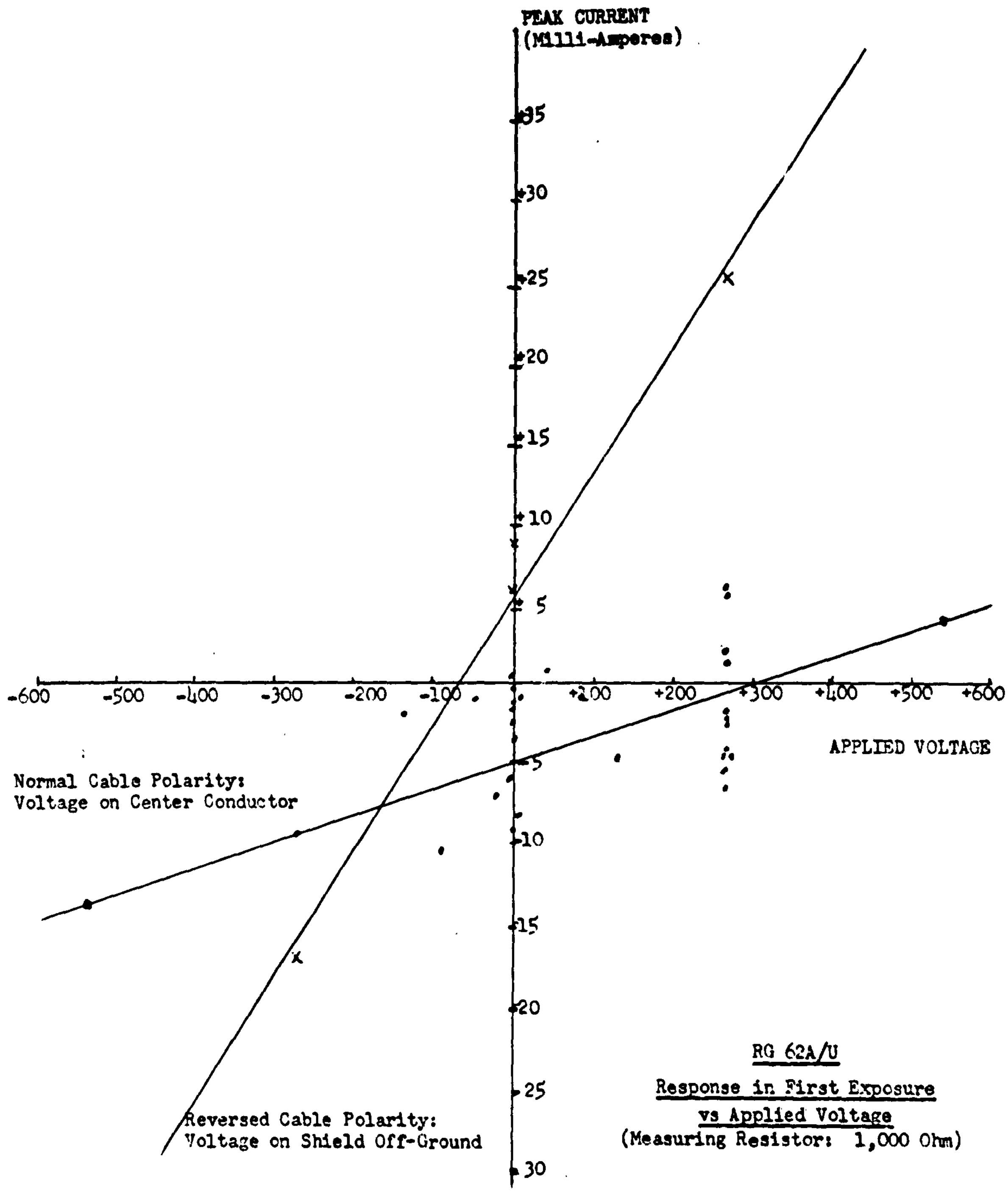
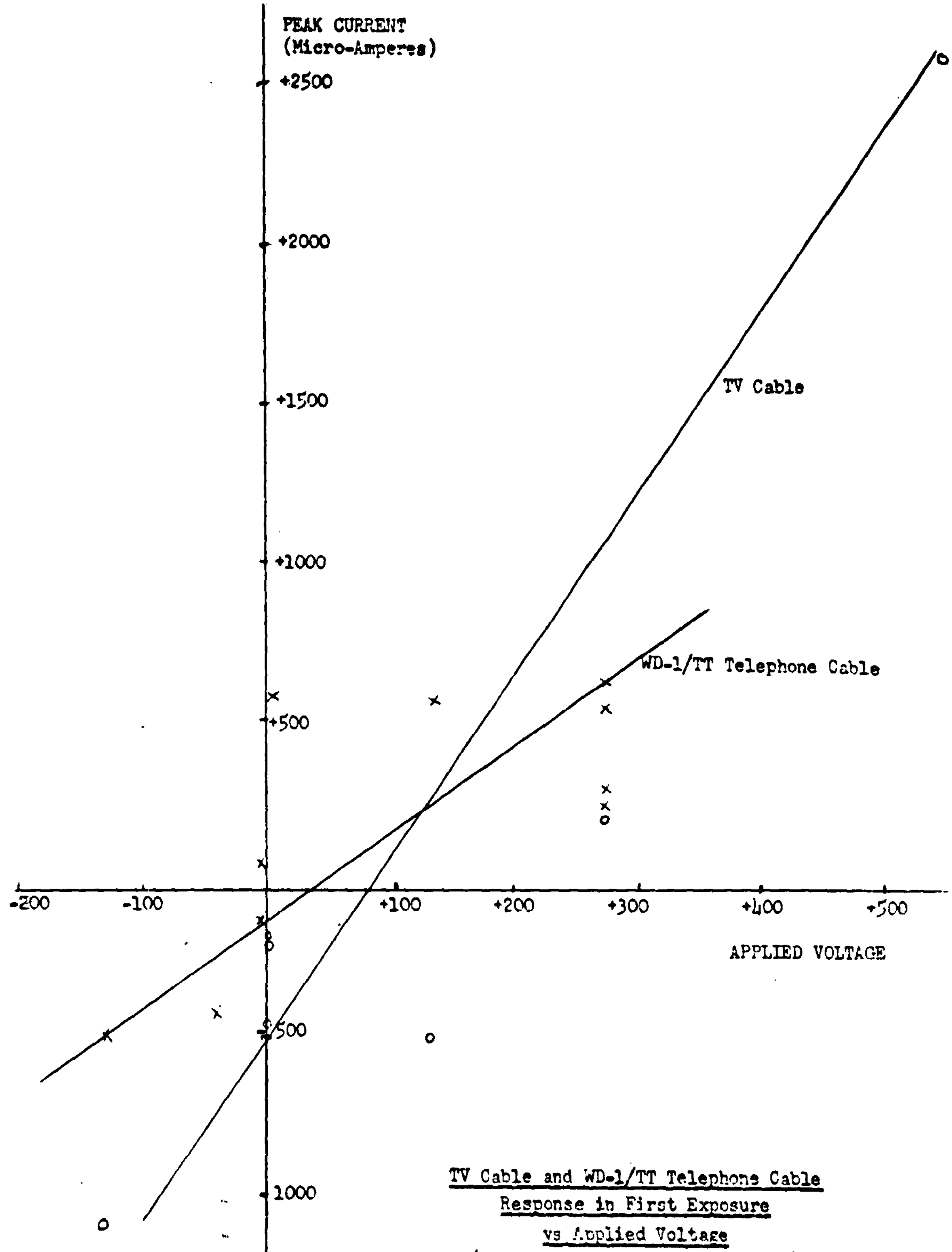

PEAK CURRENT
(Milli-Amperes)
+35
+30
+25
+20
+15
+10
5
-5
-10
-15
-20
-25
-30
-600
-500
-400
-300
-200
-100
+100
+200
+300
+400
+500
+600
APPLIED VOLTAGE
Normal Cable Polarity:
Voltage on Center Conductor
Reversed Cable Polarity:
Voltage on Shield Off-Ground
RG 62A/U
Response in First Exposure
vs Applied Voltage
(Measuring Resistor: 1,000 Ohm)

Figure 6



TV Cable and WD-1/TT Telephone Cable
Response in First Exposure
vs Applied Voltage
(Measuring Resistor: 1,000 Ohm)

Figure 7

TABLE I

Range of Peak Current Values in First Exposure

Cable Type	No Applied Voltage		Applied Voltage +268v	
	From	To	From	To
RG-59 B/U	-820	+390	-150	+150
RG-62 A/U	-9,000	+170) -350)	-6,500	+5,500
RG-81/U	–	–	+65*	–
WD-1/TT	–	+580*	+250	+580
TV Cable	-700	-180	+200*	–

*Only one sample measured.
Tabulated Values in Microamperes.

TABLE II

Minimum "Insulation Resistance" During Radiation Pulse
Calculated from Peak-Current-vs-Voltage Slope

Cable Type	Normal Cable Polarity	Reverse Cable Polarity
	kohm	kohm
RG-59 B/U	1,700	38
RG-62 A/U	60	13
RG-81/U	–	–
WD-1/TT	360	
TV	170	

TABLE III

Coaxial Cable, Radio-Frequency, RG-59 B/U
Effect of Repeated Exposure and Cable Polarity

Sample # 59	Exposure # 1	2	3	4	5	6	7	8	9	10
	Normal Cable Polarity (Shield Grounded)									
1-102	−50									
10-188	−500									
13-138	−100	−50	−25	−10	−10	−5	−3) +3)	−15	−5) +5)	C − 20) + 20)* S − 230)*
14-142	−820									
14-143	+390									
16-146	C − 80* S + 300*	C − 70* S + 160*								
16-147	−75	−60								
20-160	−60									
20-161	−140									
	Reverse Cable Polarity (Shield Off-Ground)									
22-166	+120) −50)									
22-167	+40) −320)									

(Voltage on Off-Ground Conductors: 0v; Measuring Resistor: 1,000 Ohm)
Tabulated Values in Microamperes; Values with Asterisk(*) are Individual Leg Measurements: C = Center Conductor, S = Shield.

TABLE IV

Coaxial Cable, Radio-Frequency, RG-59 B/U
Effect of Repeated Exposure and Cable Polarity

Sample #	Exposure #									
59	1	2	3	4	5	6	7	8	9	10
Normal Cable Polarity (Shield Grounded)										
1-101	−95	+480								
2-108	–	+21) −5)								
5-115	−85) +43)	+30								
6-121	+50	+75								
7-125	−50	+380								
7-170	−150	+360								
8-127	−85) +14)	−38								
13-137	−50) +10)	−15	No Reading +5)	+25) −5)	+15	+5(?)	+15			
20-158	+150									
Reversed Cable Polarity (Shield Off-Ground)										
23-182	+7,000 est.									

(Voltage on Off-Ground Conductor: +268v; Measuring Resistor: 1,000 Ohm)
Tabulated Values in Microamperes.

TABLE V

Coaxial Cable, Radio-Frequency, RG-62 A/U
Effect of Repeated Exposure and Cable Polarity

Sample #	Exposure #									
62	1	2	3	4	5	6	7	8	9	10
Normal Cable Polarity (Shield Grounded)										
1-102	– Off Scale									
10-185	+170 –350									
13-137	–1,200	–1,400	+50	No Reading	+100	+35	+35	+75	+25	C + 50* S – 250*
14-140	–9,000									
14-141	–6,000									
16-144	–1,600	+100								
16-145	C – 6,250* S + 6,000*	C – 1,200* S + 850*								
22-148	(+536 Volt applied in Exp. 1-3)			–15,000 est.						
Reverse Cable Polarity (Shield Off-Ground)										
22-156	+8,500									
22-157	+5,500									

(Voltage on Off-Ground Conductor: 0v; Measuring Resistor: 1,000 Ohm)
Tabulated Values in Microamperes; Values with Asterisk (*) are Individual Leg Measurements: C = Center Conductor, S = Shield.

TABLE VI

Coaxial Cable, Radio-Frequency, RG-62 A/U
Effect of Repeated Exposure and Cable Polarity

Sample #	Exposure #									
62	1	2	3	4	5	6	7	8	9	10
Normal Cable Polarity (Shield Grounded)										
1-101	−4,000	+750								
5-114	−2,400	+625								
6-120	−6,500	+1,500								
7-124	−1,900	+1,400								
8-126	−2,000	+1,100								
13-136	−5,500	+500) −100)	+200	+1,750	+200	−20				
20-152	+5,500									
25-176	+5,500									
Reversed Cable Polarity (Shield Off-Ground)										
23-173	+25,000 est.									

(Voltage on Off-Ground Conductor: +268v; Measuring Resistor: 1,000 Ohm)
Tabulated Values in Microamperes.

TABLE VII

Coaxial Cable, Radio-Frequency, RG-81/U
Effect of Repeated Exposure and Applied Voltage

Sample # 81	Exposure # 1	2	3	4	5	6
	No Applied Voltage					
14-122	> + 200 est.	> + 200 est.	> – 200 est.	–10	+5	+5
	Voltage Applied: 268v					
1-101	–	+460	+400	+100	+65	
8-113	+65	+100				

(Voltage on Off-Ground Conductor as Indicated: Measuring Resistor 1,000 Ohm)
Tabulated Values in Microamperes.

TABLE VIII

Electrical Telephone Cable WD-1/TT (Infantry Field Wire, Twisted Pair)
Effect of Repeated Exposure and Applied Voltage

Sample # WD-1/TT	Exposure # 1	2	3	4	5
	No Applied Voltage				
14-113	+580				
	Applied Voltage: +268v				
1-101	+250	+630			
5-105	+550	+550			
6-107	+580	+360			
13-110	+300	+140	+100	+500	

(Voltage on Off-Ground Conductor as Indicated; Measuring Resistor 1,000 Ohm)
Tabulated Values in Microamperes.

TABLE IX

TV Cable
Effect of Repeated Exposure and Applied Voltage

Sample # TV	Exposure # 1	2	3	4	5	6	7	8
	No Applied Voltage							
16-111	−180	−500						
16-112	−550* −700*	−500* −150*						
20-109	−450							
20-110	−200							
22-103	←	No Readings					→	+75* +50*
(17-102)						−300		
	Applied Voltage: +268v							
17-102	+200	+240	+50	+135	+40 - -	- - -		

(Voltage on Off-Ground Conductor as Indicated; Measuring Resistor 1,000 Ohm)
Tabulated Values in Microamperes; Values with Asterisk (*) are Individual Leg Measurements.

TABLE X

Effect of Repeated Exposure upon Magnitude and Direction of Current Flow in Individual Conductors

Conductor	First Exposure	nth Exposure (n = 8 or 10)
RG-59 B/U, Center	−80	−20) +20)
RG-62 A/U, Center	−6,250	+50
TV Cable, Leg "a"	−550	+75
TV Cable, Leg "b"	−700	+50) −25)
RG-59 B/U, Shield	+300	−230
RG-62 A/U, Shield	+6,000	−250

(Applied Voltage: 0v; Measuring Resistor: 1,000 Ohm)
Tabulated Values in Microamperes.

TABLE XI

Coaxial Cable, Radio-Frequency, RG-59 B/U
Effect of Distance and Shielding in First Exposure

Distance From Reactor Screen	No Shield		Lead Shield (γ)		Polyethylene Shield (n)	
	Sample #	Microamps.	Sample #	Microamps.	Sample #	Microamps.
0"	1-101	−95				
	5-115	−85) +45)				
	6-121	+50				
	7-125	−50				
	7-170	−150				
	8-127	−85) +15)				
	13-137	−50) +10)				
	20-158	+150				
6"	3-111	+200	3-109	−70) +70)	4-112	+47) −19)
	4-114	−40	10-134	−80		
	9-189	+140				
	10-188	−500				
24"	5-116	−55) +5)				
	8-128	+480				
34"	24-184	+250	24-186	+300	24-185	+150) −10)
60"	8-129	+10	3-110	+250	4-113	−10) +10)
	25-179	+15) −55)	10-135	−30) +10)		
	25-180	+30) −70)				
96"	25-181	−3) +5)	10-136	+540		

(Voltage on Center Conductor: +268v; Measuring Resistor: 1,000 Ohm)

TABLE XII

Coaxial Cable, Radio-Frequency, RG-62 A/U
Effect of Distance and Shielding in First Exposure

Distance From Reactor Screen	No Shield		Lead Shield (γ)		Polyethylene Shield (n)	
	Sample #	Microamps.	Sample #	Microamps.	Sample #	Microamps.
0"	1-101	−4,000				
	5-114	−2,400				
	6-120	−6,500				
	7-124	−1,900				
	8-126	−2,000				
	13-136	−5,500				
	20-152	+5,500				
	25-176	+5,500				
6"	3-110	−4,200	3-108	−4,200	4-111	+800
	4-113	−4,200	10-133	−600	9-130	−1,400
	9-186	+2,000				
24"	5-115	−1,500 est.				
	8-127	−3,600				
34"	24-164	+6,750	24-163	+7,500	24-162	+500
60"	5-116	−3,000 est.	3-109	−4,000	4-112	+3,000
	8-128	−2,200	10-134	−2,000	9-131	−2,000 est.
	25-177	+5,500				
96"			10-135	−1,900	9-132	−1,300
	8-129	−1,500				
	25-175	−3,800				

(Voltage on Center Conductor: +268v; Measuring Resistor: 1,000 Ohm)

TABLE XIII

Coaxial Cable, Radio Frequency, RG-81/U
Effect of Distance and Shielding in First Exposure

Distance From Reactor Screen	No Shield		Lead Shield (γ)		Polyethylene Shield (n)	
	Sample #	Microamps.	Sample #	Microamps.	Sample #	Microamps.
0"	8-113	+65				
	2-104	+420	10-116	−5 +15	2-103	+400
	5-111	−5 +45			4-108	+100 −100
					9-114	−5 +25
60"			3-106	+300	4-109	+60
96"			3-107	+300	4-110	+50
			10-118	+260	9-115	+440

(Voltage on Center Conductor: +268v; Measuring Resistor: 1,000 Ohm)

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Current transients generated in various types of electrical communication cables under irradiation from a mixed neutron and gamma pulse were measured as a function of applied voltage, repeated exposure, distance from source, and interposed shielding. Results are reported for coaxial radio-frequency cables RG-59 B/U, RG-62 A/U, and RG-81/U, electrical cable WD-1/TT, and parallel wire TV antenna cable. The radiation source was the bare critical assembly of the Sandia Pulse Reactor Facility. By individually measuring the transients in both cable conductors, the response of the coaxial cables was found to differ characteristically from that of the equivalent pair cables. Applied voltage exerts a strong influence on the magnitude and polarity of the response signal. Repeated exposures under unchanged conditions lead to marked or even drastic reductions of the transient signal level. For reasons yet to be determined, the anticipated signal attenuation by increasing the distance from the source and by interposing radiation shields could not be verified under the conditions selected in this experiment.

UNCLASSIFIED

1. Radiation Effects, Transient, Nuclear
2. Cable, RF, Coaxial
3. Cable, Telephone, Electrical
4. Gamma Rays
5. Fast Neutrons
6. Cumulative Effects
7. Individual Conductor Measurement
8. Driving Potential
9. Shielding

I. Both, Eberhard; Broemmer, Horst P.; Schlosser, William
II. Army Electronics Research and Development Laboratory, Fort Monmouth, N. J.
III. DA Task 3A99-15-003-01 and DASA Task 74-00-005-26

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Army Electronics Research and Development Laboratory, Fort Monmouth, New Jersey
TRANSIENTS INDUCED IN ELECTRICAL CABLES BY NUCLEAR RADIATION PULSES by Eberhard Both, Horst P. Broemmer and William Schlosser, September 1962, 29 p. incl. illus. tables, 9 refs. (USAELRDL Technical Report 2313) DA Task 3A99-15-003-01 and DASA Task 74-00-005-26) Unclassified Report

Current transients generated in various types of electrical communication cables under irradiation from a mixed neutron and gamma pulse were measured as a function of applied voltage, repeated exposure, distance from source, and interposed shielding. Results are reported for coaxial radio-frequency cables RG-59 B/U, RG-62 A/U, and RG-81/U, electrical cable WD-1/TT, and parallel wire TV antenna cable. The radiation source was the bare critical assembly of the Sandia Pulse Reactor Facility. By individually measuring the transients in both cable conductors, the response of the coaxial cables was found to differ characteristically from that of the equivalent pair cables. Applied voltage exerts a strong influence on the magnitude and polarity of the response signal. Repeated exposures under unchanged conditions lead to marked or even drastic reductions of the transient signal level. For reasons yet to be determined, the anticipated signal attenuation by increasing the distance from the source and by interposing radiation shields could not be verified under the conditions selected in this experiment.

UNCLASSIFIED

1. Radiation Effects, Transient, Nuclear
2. Cable, RF, Coaxial
3. Cable, Telephone, Electrical
4. Gamma Rays
5. Fast Neutrons
6. Cumulative Effects
7. Individual Conductor Measurement
8. Driving Potential
9. Shielding

I. Both, Eberhard; Broemmer, Horst P.; Schlosser, William
II. Army Electronics Research and Development Laboratory, Fort Monmouth, N. J.
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