BNWL-1325
UC-37, UC-80

2-
3-70

QUARTERLY REPORT
OCTOBER, NOVEMBER AND DECEMBER 1969
REACTOR ENGINEERING DEVELOPMENT
REACTOR ENVIRONMENTAL EFFECTS
ON SIGNAL CABLES

March 1970

AEC RESEARCH &
DEVELOPMENT REPORT

ROUTE TO	P.R. NO.	LOCATION	FILE NUMBER DATE

BNWL-1325

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

PACIFIC NORTHWEST LABORATORY

RICHLAND, WASHINGTON

operated by

BATTELLE MEMORIAL INSTITUTE

for the

UNITED STATES ATOMIC ENERGY COMMISSION UNDER CONTRACT AT(45-1)-1830

3 3679 00061 9025

BNWL- 1325

UC-37, Instruments
UC-80, Reactor Technology

QUARTERLY REPORT

October, November and December 1969

REACTOR ENGINEERING DEVELOPMENT
Reactor Environmental Effects on Signal
Cables

Principal Investigator
J. L. Stringer

Person In Charge
R. L. Gordon

March 1970

UNCLASSIFIED
DISTRIBUTION STATEMENT
MAR 24 '70

BATTELLE MEMORIAL INSTITUTE
PACIFIC NORTHWEST LABORATORIES
RICHLAND, WASHINGTON 99352

Printed in the United States of America
Available from
Clearinghouse for Federal Scientific and Technical Information
National Bureau of Standards, U.S. Department of Commerce
Springfield, Virginia 22151
Price: Printed Copy \$3.00; Microfiche \$0.65

CONTENTS

INTRODUCTION	1
SUMMARY.	2
GENERAL BACKGROUND INFORMATION	4
Radiation Induced Current.	4
Radiation and Temperature Dependent Electrical Noise	5
Radiation Induced Insulator Conductivity	6
DISCUSSION - PROGRESS DURING THE REPORTING PERIOD.	7
Radiation Induced Current.	7
Radiation and Temperature Dependent Electrical Noise	9
Radiation Induced Insulator Conductivity.	16
CONCLUSIONS.	16
ANTICIPATEDWORK FOR NEXT QUARTER	17
REFERENCES	18

QUARTERLY REPORT

October, November and December 1969

REACTOR ENGINEERING DEVELOPMENT

Reactor Environmental Effects on Signal Cables

Identity No. 12550

Budget Activity No. 04-40-03-01

Principal Investigator: J. L. Stringer

Person In Charge: R. L. Gordon

Solid State Physics Group
Applied Physics Department
Systems and Electronics Division
Pacific Northwest Laboratories
BATTELLE MEMORIAL INSTITUTE
Richland, Washington 99352

INTRODUCTION

The experimental investigations of this program are to (a) provide a better understanding of radiation induced currents so that maximum limits can be determined for the magnitude of the current induced in a specific radiation environment; (b) measure and study the noise generated in the metal oxide insulator used in signal cables as a function of radiation, temperature and applied voltage both as an aid in understanding the generation mechanism and in determining the noise limit for instrumentation

-2-

applications, and (c) provide bulk insulator conductivity data as a function of radiation and temperature for other powder insulation materials* presently available in signal cables for engineering design (i.e. SiO_2 , Al_2O_3 , ThO_2 , BeO , ZrO_2 and HfO_2).

SUMMARY

The analysis, design, assembly and testing was completed on the cable noise measuring system during the quarter. A brief analysis of the system is included in this report. The analysis showed that to make the cable noise source dominate over the other system noise sources it is necessary to make the input impedance as large as possible and use a minimum noise amplifier. The best way to achieve a high impedance with the large shunt capacitance of the cable is with a parallel tuned resonant circuit. At the resonant frequency the impedance is real and is Q times larger than the capacitive reactance at that frequency. Since the impedance at resonance is real it has an associated noise generator. The noise at the system output from the generator is proportional to the square-root of the impedance and the noise at the output due to the cable is proportional to the impedance. Thus, a circuit current sensitivity can be defined as the effective mean current required to give a noise contribution equal to the noise generated by the impedance. The measured and calculated noise system parameters are tabulated in Table II. In recent preliminary tests with cable 3E, there was sufficient change in the system output noise with application of radiation to conclude the anticipated noise increase did occur.

*The bulk conductivity of powdered MgO was measured in FFTF Task IC-16 and is reported in BNWL-1025 and BNWL-1148.

-3-

However, the power line noise was erratic and entering the system to the extent that quantitative measurements could not be made. The measurement system is being evaluated for shielding and grounding to determine how to correct the problem.

The induced current (dc) of the five cables selected for testing plus the control cable (5E) was measured in the ^{60}Co facility and tabulated with other measured cable parameters in Table I . When the data are plotted as a function proportional to the insulator cross sectional area ($b^2 - a^2$) and divided by the geometry factor $\ln (b/a)$ the data values fall near the straight line determined by other similar cables tested in FFTF Task IC-16. The data is shown in Figure 1 .

The furnace to be used for combined temperature and radiation measurements in the ^{60}Co facility detailed in Figure 2 has been fabricated and tested to 800°C , and is ready for use. The testing showed that the electrical power supply originally designated for the furnace was marginal. A higher capacity supply was purchased and was recently incorporated into the system.

Only a single partial bid has been received for the twelve cables to be used to measure the combined radiation and temperature dependance of the bulk conductivity of powdered metal oxide insulators other than MgO . The bid price received was a factor of four larger than the expected price of the total order. The expected cost was based upon past cable purchases. This problem will be resolved as quickly as possible, but will cause a delay in obtaining the cables.

-4-

GENERAL BACKGROUND INFORMATIONRADIATION INDUCED CURRENT

Induced current became a recognized problem for power reactor instrumentation cables with the application of self-powered in-core flux detectors. ⁽¹⁾ It has been necessary to study the parameters involved in the generation of the current so that magnitude limits can be predicted for specified cables and environments. These limits must then be considered in the design of sensors and instrumentation systems so that errors in the system output remain small.

Induced current can be loosely defined as the dc current which flows between two electrodes when the electrodes are maintained at the same potential and subjected to a nuclear radiation flux. In the definition the maintenance of the electrodes at the same potential is only necessary to determine the induced current magnitude. Experiments ⁽¹⁾ have shown that bias potentials up to the experiment limit of ± 50 Vdc have negligible effect upon the current magnitude. The analysis of the induced current in coaxial cables ⁽²⁾ has shown that for radiation to produce a current it must interact with the cable or surrounding material to place a high energy electron or other charged particle in the dielectric. The analysis also showed that the current measured is the magnitude difference between a current component due to the charged particles moving toward a specific electrode and the component due to the charged particles moving away from the same electrode. A parametric analysis ⁽²⁾ was made for each of these current components, when they are generated in a coaxial cable

-5-

by an external gamma-ray flux, and includes three constants for each current component. The evaluation of three constants from only the measured induced current (dc) and parameter variation is impossible. At this point **it** became apparent that since these two components are generated primarily by independent absorption events there should be an extra noise component from the cable which would be proportional to the sum of the two current components. Since the dc current results from the difference between the two components and the noise results from the sum, the magnitude of each component can be determined. Knowing the magnitudes may allow evaluating the constants for the gamma-ray exposure equation, but a more important aspect is that **it** may be possible to determine the contribution due only to the neutron flux in a mixture of radiation. With this information **it** should be possible to develop a parametric relationship to a magnitude limit for a given cable design in a postulated radiation environment with a minimum of two radiation tests, and as experience is gained perhaps no tests.

RADIATION AND TEMPERATURE DEPENDENT ELECTRICAL NOISE

One of the more immediate problems relating to cable noise is that of operating ^{10}B proportional counters or fission counters interconnected with a single metal oxide insulated cable at high temperatures. A large number of pulses originating in the cable have been observed,⁽³⁾ and the pulse rate was a function of temperature combined with the applied voltage. **It** is also expected that the pulse rate will be a function of the radiation intensity, since the insulator bulk conductivity under irradiation has

-6-

a temperature equivalent value.

Measuring the noise spectrum over the frequency range of 20 Hz to 100 kHz as a function of temperature, applied voltage and radiation will allow characterization of the noise so that magnitude limits can be determined and its effect can be reduced through cable design and further minimized by detector and electronic system design. The noise spectrum may also give information about the conduction mechanism causing the noise when it is combined with other measured electrical or process parameters being recorded by this and the insulator development program.

Another aspect of this part of the program is to measure the combined radiation, temperature and applied voltage breakdown of the insulator. Since voltage breakdown is related to the thermal carrier generation rate it is possible that radiation of the magnitude available in the ^{60}Co facility (3.85×10^7 R/hr) will tend to reduce the threshold voltage for the onset of breakdown. The measurements will determine how much reduction has occurred for specific radiation intensities.

RADIATION INDUCED INSULATOR CONDUCTIVITY

In FFTF Task IC-16 measurement techniques were established which allowed the bulk conductivity of powdered MgO insulator material to be measured in the coaxial cable in which it is used. It was found that the powdered MgO had two to three orders of magnitude smaller bulk conductivity than would be predicted from measurements made by Dau⁽⁴⁾ on flame sprayed Al_2O_3 in a similar radiation environment. The measurements made on MgO in both the ^{60}Co facility (2.3×10^7 R/hr.) and in the pulsed TRIGA

-7-

reactor at Washington State University (9×10^{10} R/hr. at pulse peak) showed a linear variation of the induced conductivity with dose rate. Tests with temperature and radiation combined in the TRIGA reactor showed that the bulk conductivity would approximately fit the theory developed by Dau⁽⁴⁾ with the appropriate constants changed. Tests with temperature alone on the powder insulator showed no significant departure of bulk properties from those of polycrystalline solids.

This part of the program is to supply engineering design data on other powdered insulator materials such as Al_2O_3 , ZrO_2 , BeO , ThO_2 , SiO_2 and HfO_2 . In addition the resulting data may isolate the process which gave powdered MgO a smaller radiation induced conductivity than would be predicted from other radiation data.

DISCUSSION -- PROGRESS DURING THE REPORTING PERIOD

RADIATION INDUCED CURRENT

Five MgO insulated coaxial cables remaining from the FFTF Task IC-16 were selected for testing in the tasks for radiation induced current and cable electrical noise. In addition cable 5E which is insulated with MgO and cables 17B & 17C with Al_2O_3 insulation which were tested in Task IC-16 are being used for control. Table I lists the physical and some of the electrical parameters for these eight cables. An average of the maximum induced currents per centimeter for the three control cables gave

-8-

the maximum dose rate in the ^{60}Co facility to be 3.85×10^7 R/hr.

Independent dose rate measurements made by the facility personnel using other techniques also measured 3.85×10^7 R/hr. Their measurement was made near 1 August 1969. Thus, there is good correlation between the present measurements and those made for IC-16 with the old ^{60}Co charge.

The induced current data for the test and control cables listed in Table I were normalized to 2.35×10^7 R/hr. and plotted as a function of $(b^2 - a^2)/\ln(b/a)$ in Figure 1. The straight line in Figure 1 was determined from data taken for similar cables in IC-16 and is included for comparison. Cable parameter a is the radius of the center conductor, and parameter b is the radius of the insulator outer boundary. The factor $(b^2 - a^2)$ is proportional to the cross sectional area of the insulator in the cable and the factor $\ln(b/a)$ comes from the coaxial geometry and allows cables with different dimensions to be compared. The data in Figure 1 indicates that the larger cables produce currents per unit length proportional to the insulator area. The scatter of the data points indicate influence of the metal in the sheath and center conductor and to a small degree the penetration of the sheath by electrons emitted from surrounding material by photo electric and Compton interactions of the gamma-rays. It is of interest also that the straight line, if extended, must go through zero since the induced current will be zero when there is no insulator.

While testing the noise measuring system in the noise environment of the ^{60}Co facility cable 3E was attached to the system and subjected to the gamma radiation. There was sufficient change in the system output noise with a rapid application of radiation to conclude that the anticipated

-9-

noise increase had occurred. However, power line related noise was entering the system and caused erratic readings. The noise system is being evaluated for shielding and grounding to determine how best to eliminate the problem.

RADIATION AND TEMPERATURE DEPENDENT ELECTRICAL NOISE

One of the important equipments for these measurements is the furnace to heat the cables in the radiation facility. The dry tube dimensions of the facility allowed the design used for the TRIGA reactor (IC-16) to be used. The furnace design shown in Figure 2 is for the TRIGA. The only difference between the two furnaces is that the present design uses only one spiral heating element. In tests with the furnace immersed in water within one inch of the top a temperature of 750°C was reached with 1.35 kilowatts of input power. This was the power limit of our power supply. The water immersion test is very severe, but approaches the condition expected in testing. A power supply capable of 1.8 kilowatts has been recently included in the system and should allow 800°C to be easily reached.

The noise measurement system is essential for the measurements to be performed in the task. Since it is necessary to understand the measurement system to understand the data to be obtained from it, it seems appropriate to include a brief discussion and analysis in this report rather than waiting to including it in a topical report.

An unbiased open circuit coaxial cable operated at frequencies less than one MHz which is short compared to a wavelength of the

-10-

frequencies in that band can be represented by a current noise source shunted by the parallel combination of the shunting resistance and capacitance as shown in Figure 3. The frequency spectrum of the noise

FIGURE 3

Noise In An Unbiased Open Circuit Coaxial Cable

source is a constant with magnitude $\frac{4kT}{R_c}$, where k is the Boltzmann constant, T is the absolute temperature (OK), R_c is the total shunting resistance and C_c is the total shunting capacitance. The noise source is the current equivalent of a Johnston noise source. When nuclear radiation is applied at room temperature a second current noise source is added in parallel

to the one shown in Figure 3. This second noise source $\left(\frac{\overline{i_R^2}}{\Delta f} \right)$ is assumed to have a frequency spectrum similar the first with a magnitude assumed to be given by $2\epsilon[I_+ + I_-]$ where ϵ is the charge of an electron, I_+ is the average positive induced current component and I_- is the average negative component. Other current noise sources are added in parallel with these two as the cable temperature is increased with a bias voltage applied. These current sources will be the subject of future reports.

To measure the magnitude and frequency distribution of the radiation caused noise source it is necessary to make that noise source predominate at the input of an amplifier system. Since most amplifiers

-11-

require a voltage at their input terminals, the impedance at the amplifier input must make a large voltage when combined with the current noise source. The cable capacitance combined with the amplifier input capacitance and the stray circuit capacitances reduce the input impedance of the amplifier. When the input capacitance is resonated with a high Q (low loss) inductor the resulting impedance at resonance is $|Z| \approx 2\pi f L Q$ and real. In the impedance f is the resonant frequency and L is the inductance. At resonance, either series or parallel when Q is large, the impedance of the total capacitance is equal to the impedance of the inductor thus, the circuit impedance at resonance is Q times larger than the capacitive reactance. This impedance represents the largest obtainable at the given frequency for a passive circuit.

The complete measurement system with all the input noise sources are shown in Figure 4. At the system input R_p is the total resistance shunting the input at resonance, C_p is the total capacitance shunting the input at resonance including the self capacitance of the inductor and L_p is the total inductance shunting the input at resonance including that inductance being cancelled by the self capacitance of the windings. The noise source $\overline{i_R^2}$ is due to the radiation applied to the cable, and is given by

$$\overline{i_R^2} = 2\epsilon [I_+ + I_-] B_1 \quad (1)$$

The components ϵ, I_+ and I_- have already been defined, and B_1 is the noise bandwidth of the input circuit. The noise source $\overline{i_p^2}$ is due to the

-12-

parallel resistance (R_p) and is given by

$$\overline{i_p^2} = \left(\frac{4kT B_1}{R_p} \right) \quad . \quad (2)$$

The noise source $\overline{i_a^2}$ is due to the mean grid leakage current (I_g) of the input amplifier tubes and is given by

$$\overline{i_a^2} = 2\epsilon I_g B_1 \quad (3)$$

The remaining noise source is due to the shot noise and $1/f$ noise in the amplifier, and is normally expressed as the equivalent input noise resistance R_e . The magnitude is given by

$$\overline{e_a^2} = 4kTR_e B_2 \quad . \quad (4)$$

In Equation (4) the factor B_2 is the noise bandwidth of the band-pass filters following the amplifier. If this series noise source was not present the band-pass filter preceding the true rms voltmeter would not be necessary. It is necessary that B_2 be much greater than B_1 so that the resulting noise at the input circuit remain undistorted.

The mean-square noise voltage at the amplifier input due to any of the current noise sources $\left(\overline{i_n^2} \right)$ is given by

$$\overline{e_n^2} = \left(\frac{\overline{i_n^2}}{\Delta f} \right) R_p^2 B_1 \quad . \quad (5)$$

-13-

Thus, the total mean square noise voltage at the amplifier input is

$$\overline{e_T^2} = B_1 \left[2\epsilon(I_+ + I_- + I_g)R_p^2 \right] + 4kTR_p + 4kTR_e B_2 \quad . \quad (6)$$

Equation (6) shows that to make $\overline{e_T^2}$ primarily dependent upon $(I_+ + I_-)$ it is necessary to find an amplifier whose equivalent noise resistance (R_e) and mean grid current (I_g) are as small as possible, and that R_p be made as large as possible since the voltage from the current is due to R_p^2 and the noise from R_p is only proportional to R_p .

The equivalent noise bandwidth for a parallel resonant circuit was shown by Bennett⁽⁵⁾ to be

$$B_1 = \frac{1}{4R_p C_p} = \frac{\pi}{2Q} \quad . \quad (7)$$

Combining Equation (6) and (7) and assuming that the noise components from R_e and I_g are negligible equation (6) reduces to

$$\overline{e_T^2} = \frac{\epsilon R_p}{2C_p} \left[I_+ + I_- \right] + \frac{kT}{C_p} \quad . \quad (8)$$

Equation (8) shows that the total mean-square noise voltage at the amplifier input is the noise due to the radiation induced current plus a constant due to the circuit. When the incremental measurement technique developed in IC-16 is used the constant noise sources are eliminated.

-14-

To get some idea about the required value for R_p we will assume that I_+ and I_- are approximately equal and each is about 10 times the measured total dc current for cable 3E exposed to the ^{60}Co facility. This gives a value of $[I_+ + I_-] = 6.4 \times 10^{-8}$ Ampere. If the system current sensitivity is defined as the current required to give a unity value for the signal noise to circuit noise ratio, then the value for R_p can be calculated from the right side of Equation (8) as

$$R_p = \frac{2kT}{e[I_+ + I_-]} \quad (9)$$

or evaluated

$$R_p = \frac{2.0 \times 1.38 \times 10^{-23} \times 3.0 \times 10^2}{1.6 \times 10^{-19} \times 6.4 \times 10^{-8}}$$

and

$$R_p = 0.81 \text{ M}\Omega$$

Unfortunately it is necessary to resonate the total cable capacitance with the inductor. The limited Q of the inductors available and the reduced inductance value do not allow this resistance value to be approached at the measurement frequencies of 20 kHz, 50 kHz and 100 kHz.

The measured and calculated system noise parameters at each spot frequency are given in Table II. The column headed "Measured System Noise" is referred to the amplifier input and includes only the circuit and shunt amplifier input noise sources (the short circuit noise has been subtracted).

-15-

The large value for the noise measured at 100 Hz is due to the low circuit rejection of the 120 Hz component from the amplifier power supply. This can be corrected by using a higher Q inductor, but will not be changed at this time. The next adjacent column in Table II gives the noise component calculated from the measured circuit parameters

$\left(\frac{kT}{C_p}\right)$. The mean-square difference between the two columns is the contribution due to the amplifier grid current (I_g). The column headed "Short Circuit Noise" is due to the series noise source of the amplifier and the noise bandwidth of the band-pass filters. The noise bandwidth of the band-pass filters is nominally 0.653 times the measurement frequency. The column headed "Current Sensitivity" is the current calculated by solving equations (1) and (5) for $[I_+ + I_-]$ as

$$[I_+ + I_-] = \frac{2C_p}{\epsilon R_p} (\overline{e^2})^{1/2}, \quad (10)$$

and using the measured system noise as $\overline{e^2}$. The remaining two columns give the 300°K measured values for C_p and R_p . When a test cable is added to the system the value of R_p differs from that shown in Table II at 50 kHz and 100 kHz due to losses in the cable.

Comparison of data in Table II shows that the performance of the Tektronix Type 1A7 plug-in amplifier in a type 132 power supply meets the noise requirements set by Equation (6). Provision has been made in the system design to apply up to 1000 Vdc on the test cable. In addition system gain, shunt resistance (R_p) and input circuit tuning can be

-16-

measured conveniently. The test results from the noise measurements indicate that the system is ready for cable testing.

RADIATION INDUCED INSULATOR CONDUCTIVITY

Specification were prepared for twelve coaxial cables and submitted for bid. These cables were grouped into 0.250 inch and 0.125 inch outside diameters. One cable from each diameter group is to be insulated with the same insulator material. The insulator materials selected are: Al_2O_3 , ZrO_2 , BeO , ThO_2 , SiO_2 and HfO_2 . Other than the variety of insulator materials the major difference between this and previous cable specifications was the addition of a sheath integrity test. This test was added in an attempt to get a longer shelf life for cables exposed to the room ambient.

To date only a single partial bid has been received for the twelve cables. The bid price received was a factor of four larger than the price expected for the total order. The expected price was based upon past cable purchases. This problem will be resolved as quickly as possible, but will cause some delay in obtaining the cables.

CONCLUSIONS

The performance tests on the noise measurement system and furnace for use in the ^{60}Co facility have shown that the system is ready to start noise testing the cables.

-17-

The radiation induced current measurement on the test cables showed that there is good correlation between the old and new ^{60}Co facility and that the cables selected for testing did not differ from those tested in Task IC-16.

Preliminary tests on cable 3E indicated an increase in system output noise when the cable was subjected to gamma-radiation.

ANTICIPATED WORK FOR NEXT QUARTER

The power line pick-up noise problem will be eliminated from the noise measurement system. Measurements will then be made to determine the 300°K gamma-ray only noise magnitude in each cable. Following these tests the radiation induced insulator conductivity will be measured at the ^{60}Co facility ambient temperature. When the above tests are complete the cables will be subjected to temperatures up to 800°C with an applied voltage. These tests will provide data to characterize the noise source frequency distribution causing trouble in pulse detector systems.

The problems with the cable order will be resolved and a purchase order will be placed.

-18-

REFERENCES

1. W. L. Bunch and M. R. Wood. Boron-11 Neutron Flux Monitors: Interim Report, BNWL-64, P. 10, Pacific Northwest Laboratory. Richland, Washington, April 1965.
2. J. L. Stringer and R. R. Bourassa. Nuclear Radiation Induced Currents in Coaxial Signal Cables, BNWL-749. Pacific Northwest Richland, Washington, June 1968.
3. C. N. Jackson. Unpublished Data. Pacific Northwest Laboratory, 1969. (Personal Communication)
4. G. J. Dau and M. V. Davis. "Gamma Induced Electrical Conductivity In Alumina". Nucl. Sci. and Engr. Vol. 25, pp 223-226. 1966.
5. W. R. Bennett. Electrical Noise, McGraw-Hill Book Company, Inc. New York, New York, 1960, P 16-17.

TABLE I - MEASURED CABLE PARAMETERS (MECHANICAL)

Cable #	Outside diameter inches	Sheath thickness inches	Insulator O.D. - 2b inches	Center conductor O.D - 2a inches	ln b/a
5E	0.248	0.018	0.210	0.030	1.95
3E	0.237	0.018	0.203	0.022	2.22
5D	0.178	0.025	0.128	0.027	1.56
4C	0.144	0.011	0.124	0.018	1.93
1B	0.122	0.009	0.102	0.010	2.32
6A	0.080	0.015	0.054	0.019	1.05
17B	0.090	0.011	0.068	0.022	1.17
17C	0.092	0.011	0.069	0.022	1.17

All mechanical data taken at room temperature $\sim 75^{\circ}\text{F}$, accuracy $\sim \pm 0.002$ inches

TABLE I - MEASURED CABLE PARAMETERS (ELECTRICAL)

Cable #	Current /cm $^{60}\text{Co} - 3.85 \times 10^7 \text{ R/hr}$ $\text{A/cm} \times 10^{-11}$	Insulator Conductivity 75°F $\sigma(\Omega - \text{cm})^{-1}$ $^{60}\text{Co} - 2.35 \times 10^7 \text{ R/hr}$	75°F Cable Total Resistance ohms	75°F Cable Total Capacitance Picofarads	Insulator Comments
5E	(-)11.7	5.27×10^{-13}	3.4×10^9	1088	MgO Control
3E	(-)7.65	*	$>1.0 \times 10^{11}$	853	MgO
5D	(-)7.26	*	5.0×10^{10}	1163	MgO
4C	(-)5.56	*	$>1.0 \times 10^{11}$	1103	MgO
1B	(-)4.53	*	$>1.0 \times 10^{11}$	853	MgO
6A	(-)3.81	*	4.0×10^{11}	1631	MgO
17B	(-)3.41	5.56×10^{-13}	6.0×10^9	1330	Al_2O_3 Control
17C	(-)3.68	5.40×10^{-13}	2.0×10^{10}	1325	Al_2O_3 Control

*No data at present time

TABLE II - SYSTEM NOISE AND CIRCUIT PARAMETERS

Freq. (kHz)	Measured System Noise (μV - rms)	Calculated Circuit Noise (μV - rms)	Short Circuit Noise (μV - rms)	Current Sensitivity (Amperes $\times 10^{-8}$)	R_p $T = 300^\circ\text{K}$ (Megohms)	C_p $T = 300^\circ\text{K}$ (Nanofarads)
0.02	0.404	0.404	0.17	1.64	3.13	25.3
0.05	1.25	1.01	0.42	1.05	7.50	4.05
0.10	12.1	0.99	0.21	121.0	6.39	4.22
0.20	1.65	1.15	0.59	2.58	4.10	3.12
0.50	1.17	1.13	0.17	4.36	1.23	3.21
1.0	0.77	0.72	0.16	6.76	0.87	7.92
2.0	1.71	1.44	0.18	2.95	2.45	1.98
5.0	1.65	1.46	0.23	4.30	1.54	1.94
10.0	1.48	1.30	0.28	8.04	0.82	2.42
20.0	1.61	1.43	0.37	14.8	0.44	2.01
50.0	1.59	1.46	0.50	23.8	0.26	1.95
100.0	1.52	1.44	0.64	51.2	0.11	1.99

FIGURE 1

Induced Cable Current as a Function of Cable
Parameters (a & b) @ 2.34×10^7 R/hr in the PNL
 ^{60}Co Facility

Figure 2
⁶⁰Co Facility Cable Furnace

FIGURE 4
Noise Measurement System

DISTRIBUTIONNo. of
CopiesOFFSITE

1	<u>AEC Chicago Patent Group</u> G. H. Lee
2	<u>AEC Division of Reactor Development and Technology</u> Special Technology Br. , RDT:RT F. C. Legler S. N. Ceja
6	<u>AEC Division of Technical Information Extension</u> UC - 37 (3) UC - 80 (3)
2	<u>Argonne National Laboratory</u> LMFBR Program Office J. Harrer H. Bryant
2	<u>Argonne National Laboratory</u> Reactor Engineering Division T. P. Mulcahey G. F. Popper
1	<u>Atomic Power Development Associates</u> 1911 First Street Detroit, Michigan 48226 C. Scott
1	<u>Atomics International</u> Division of North American Aviation P. O. Box 309 Canoga Park, California 91305 3. J. Flaherty

-26-

No. of
Copies

- 1 Babcock & Wilcox Company
Nuclear Development Center
Lynchburg, Virginia 24505
R. M. Ball
- 1 Combustion Engineering, Inc.
Prospect Hill Road
Windsor, Connecticut 06095
F. Bevilacqua
- General Electric Co.
Advanced Products Operation
310 Deguigne Drive
Sunnyvale, California 94086
G. R. Pflasterer
- General Electric Co.
Nuclear Instrumentation Department
175 Curtner Avenue
San Jose, California 95125
R. A. DuBridge
- Gulf General Atomic, Inc.
P. O. Box 608
San Diego, California 92112
D. E. Schwarzer
- 1 Idaho Nuclear Corporation
P. O. Box 1845
Idaho Falls, Idaho 83401
R. G. Morrison
- 1 Liquid Metal Engineering Center
P. O. Box 1449
Canoga Park, California 91304
R. W. Dickinson
- 2 Oak Ridge National Laboratory
Instrumentation and Controls Division
Oak Ridge, Tennessee 37830
D. P. Roux
R. L. Shepard

-27-

No. of
Copies

1 Reuter - Stokes Electronic Components, Inc.
 18530 South Fliles Parkway
 Warrensville Heights
 Cleveland, Ohio 44128

F. Reuter

Westinghouse Electric Corporation
 Advanced Reactors Division
 Waltz Mill Site
 Box 158
 Madison, Pennsylvania 15663

F. M. Heck

Westinghouse Electric Corporation
 Electronic Tube Division
 Elmira, New York 14902

W. H. Todt

ONSITE HANFORD

1 AEC Chicago Patent Group
 R. K. Sharp (Richland)

1 AEC Richland Operations Office
 C. L. Robinson

2 RDT Assistant Director for Pacific Northwest Programs

3 Battelle Memorial Institute

29 Battelle-Northwest

J. L. Bates
 T. R. Billeter
 R. R. Cone
 J. L. Deichman
 R. L. Gordon
 N. C. Hoitink
 C. N. Jackson
 R. R. Schemmel

W. G. Spear
 J. L. Strinaer (10)
 C. D. Swanson
 D. C. Thompson
 M. R. Wood
 Technical Information (5)
 Technical Publications (2)