NA-69-609

FINAL REPORT ON A RUGGEDIZED GAMMA RADIATION DETECTOR

PREPARED UNDER

CONTRACT NUMBER

NAS8-20840

DCN 1-7-40-79262

FOR THE

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

GEORGE C. MARSHALL SPACE FLIGHT CENTER

HUNTSVILLE, ALABAMA

LOS ANGELES DIVISION OF NORTH AMERICAN ROCKWELL CORPORATION

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SERIAL NO. 13

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ON A

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T. E. Carrell, Program Manager

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FOREWORD

This report, Ruggedized Gamma Radiation Detector, was written in accordance with the requirements of EXHIBIT "A", part IV E of the National Aeronautics and Space Administration contract number NAS8-20840. The purpose of this report is to document technical effort associated with the development of a prototype gamma radiation detector to meet the technical requirements established within this contract.

ABSTRACT

Presented in this report is a description of the design, fabrication, and testing effort conducted to provide a prototype gamma radiation detector capable of operating in the severe environment that will be encountered in the vicinity of a nuclear powered rocket engine. The technical discussion centers on the theory of detector operation, specific details of fabrication and the results of performance qualification testing.

The ruggedized gamma radiation detector is designed to measure gamma radiation intensities in the range of 10^5 to 10^7 roentgens/hour in a space, ambient and liquid helium environment. It is a self powered device that is capable of operating in a high neutron field, and under extreme conditions of shock and vibration. The three prototype detectors developed under this contract have successfully demonstrated compliance with all of the technical requirements of this contract.

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INTRODUCTION AND SUMMARY

This report provides a discussion of the work carried out by the Los Angeles Division of North American Rockwell under the National Aeronautics and Space Administration contract No. NAS8-20840. The objective of this effort was to develop a prototype gamma radiation detector to be used for instrumentation of the Nuclear Ground Test Module and any flights which may utilize a nuclear powered engine. Significant technical aspects of this development program were the design, fabrication, and testing of a gamma radiation detector capable of operation in a space, ambient, or liquid hydrogen environment and also capable of withstanding shock loads up to 50 G's. The gamma radiation detector developed by the Los Angeles Division to meet these requirements and described herein is unique in its ruggedness, simplicity of design and operation, and in the fact that it requires no power for operation.

In section I of this report is presented a basic description of detector operation based upon experimental evidence compiled by the Los Angeles Division in research associated with this type of detector. Section II presents significant aspects of detector fabrication which could adversely affect the performance characteristics of the detector. Section III contains a detailed discussion of the performance tests that were conducted to demonstrate compliance with the technical requirements. The results of this test program demonstrate the ability of this detector to measure gamma radiation dose rates over the range of 10^5 to 10^7 roentgens/hour with an accuracy of better than $\pm 10\%$. This performance can be expected over a temperature range from $-269^{\circ}C$ to $60^{\circ}C$ and in the presence of a neutron flux fields greater than 10^{12} neutrons/cm^2-sec. The detector continued to perform without degradation after exposure to a neutron fluence levels exceeding 10^{16} neutrons/cm^2 and after being subjected to shock testing at a level of 50G's. The repeatability of the response was demonstrated to be better than $\pm 3\%$ and the response time is considerably faster than the two seconds specified.

Section I

THEORY OF OPERATION

A variety of gamma radiation detectors have been developed to measure gamma radiation dose rates. Although the basic principles of operation of each type are substantially different, they have in common the fact that operation is dependent upon the ionizing properties of gamma radiation. Another characteristic common to most detectors is the fact that they could not be designed to meet the severe environmental requirements of the National Aeronautics and Space Administration as presented in Appendix D of this report. The detector developed by the Los Angeles Division of North American Rockwell and described in this report is unique in its ability to meet and surpass these severe environmental requirements. Since this detector is also different from other gamma ray detectors in its operation, it is considered appropriate here to discuss observed principles of operation based upon experimental evidence obtained prior to and during this contract effort.

There are two basic approaches that can be applied in developing an operational theory for the self powered detector described herein. One approach is to relate the observed output signal of the detector to the polarization effect that will occur as a result of the motion of electrons in a dielectric media. The other approach is to consider the magnitude of the replacement currents that must be provided as a result of gamma ray ionization. Although both processes are undoubtedly involved, the experimental evidence developed by North American Rockwell Corporation indicates that the latter phenomena predominates. Therefore, this discussion will be restricted to this approach.

The self powered gamma radiation detector described in this report derives its operation from the interaction of gamma radiation with a dielectric media. Thus, if two metal parallel plates separated by a dielectric such as plastic are acted upon by a steady gamma radiation field as shown in Figure 1a, a charge transfer will take place between the plates. This charge transfer results primarily from the Compton scattering process by which the gamma radiation energy is absorbed by the parallel plate system. At the first plate encountered by the gamma radiation, gamma ray interaction with the plate produces high energy primary electrons. The major component of motion of the electrons will be in the same direction as the gamma radiation. From Compton interaction with this plate, electrons will be scattered from the plate into the dielectric resulting in a net positive charge on this plate. The movement of electrons across this boundary constitute a current density (J_1) that is proportional to the input radiation level. The proportionality constant is dependent upon the absorption coefficient of the plate, the range of the primary electrons in the plate, and upon the thickness of the plate. Compton absorption of the gamma ray energy by the dielectric contributes to the current density that is created between the two plates. The expected distribution of this current density in the dielectric is illustrated in Figure 1b. At position 1, the current density is equal to

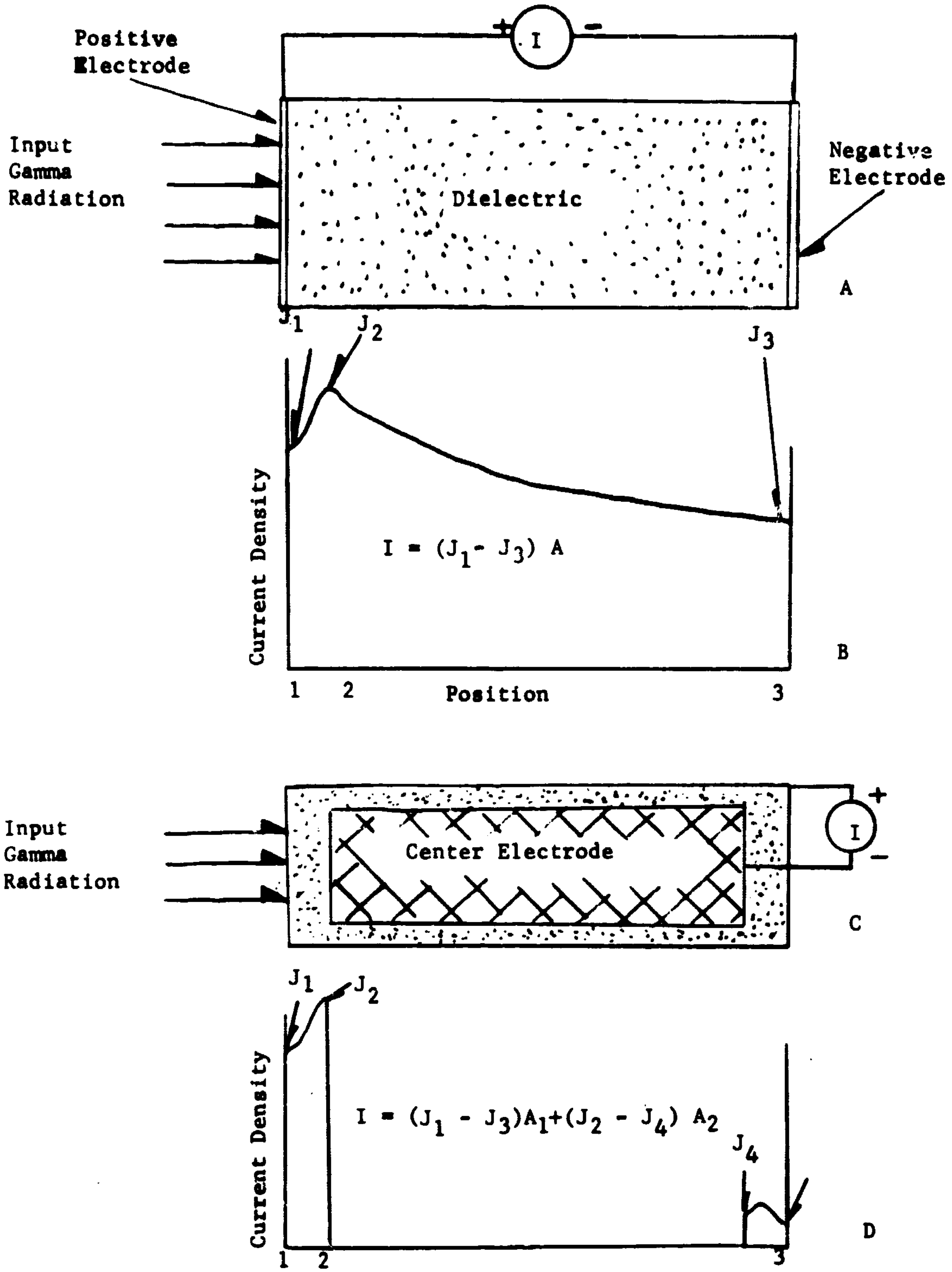


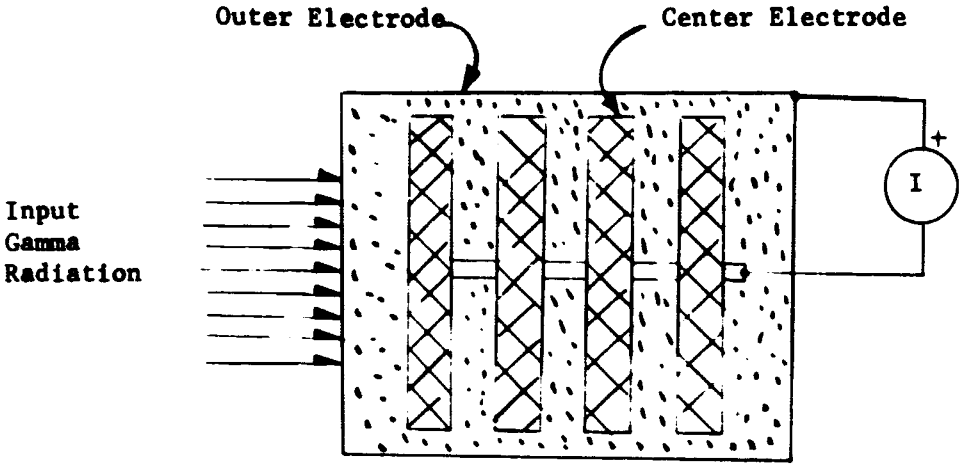
Figure 1. Sketch of basic detector operational concept.

the electrons escaping the first plate. Since the primary electrons have a finite range in the dielectric, the current density in the dielectric will increase (assuming a very thin plate) in value until an equalibrium level (J_2) is reached at about three times this range. At any selected cross-section beyond this point in the dielectric, the current density will decrease in proportion to the decrease in gamma radiation resulting from attenuation in the dielectric. At position #3 primary electrons will be scattered into the second plate resulting in a negative charge build-up on this plate approximately equal to the current density J_3. A meter connected between the plates would measure a current equal to $J_2 + J_3$ multiplied by the area of the system being irradiated, provided care is taken to eliminate leakage paths between the plates during irradiation. Since the output current is proportional to the input gamma radiation, the parallel plate system illustrated in Figure 1 constitutes a radiation detector. Maximum output would be achieved if the second plate were placed at position #2.

Electrons trapped in the dielectric of the parallel plate system could produce undesirable effects such as the creation of a space charge that would limit or cut-off the detector output, or an extremely poor response time might be expected due to the slow mobility of the electrons in the dielectric. Such effects have not been observed in practice. This is attributed to the fact that the primary electrons in dissipating their energy in the dielectric create numerous low energy electrons along their path. The motion of these electrons is perpendicular to the path of the primary electrons. Although a few of the electron-hole pairs thus produced will immediately combine, a cylindrical path of electron-hole charges is created. Because the density and the area of influence of the holes is relatively large, recombination in the dielectric is greatly enhanced both during irradiation and after termination of the incident gamma radiation. Thus, response time is a function of the input gamma ray intensity.

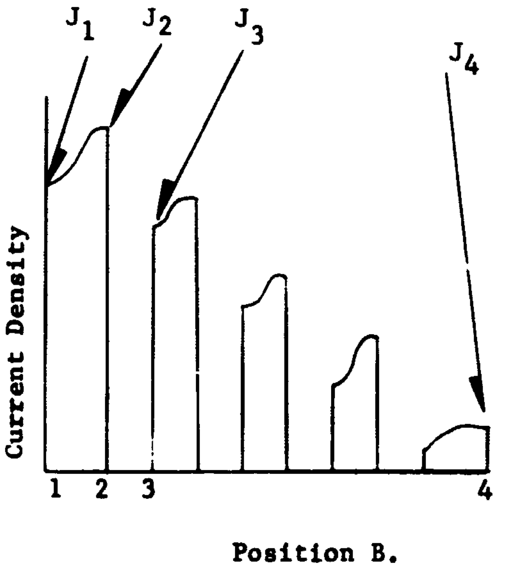
Figure 1C illustrates a detector developed using the basic principles described previously for the parallel plate detector. The outer metal shell of this detector forms one electrode (positive) of the detector in addition to providing a detector housing and protection against leakage paths during irradiation. The center electrode (negative) is made of a material having a high atomic number. The center electrode is surrounded with a dielectric material. The expected current density distribution is illustrated in Figure 1D. It is obvious here that the reason for the heavy center electrode is to reduce the number of electrons entering the outer electrode on the side of the detector away from the incoming radiation to a minimum since these charges constitute a reverse current opposite to that realized at the front of the detector. The output of this detector is equal to $(J_1 - J_3)\ A_1 + (J_2 - J_4)\ A_2$, where A_1 and A_2 are the areas of the outer and inner electrodes perpendicular to the path of the incident gamma radiation.

Although the detector configuration illustrated in Figure 1C will produce output currents at nominal dose rate levels sufficient to drive many high input impedance amplifiers, the major disadvantages of this detector is that a major portion of the energy content of the incident radiation is expended in the center electrode without producing useful output signal and the weight and size of the detector is prohibitive in many applications. One approach



A.

$$I = (J_1 - J_4)\, A_1 + (J_2 - J_3)\, A_3 + \ldots (J_i - J_k)\, A_2$$



B.

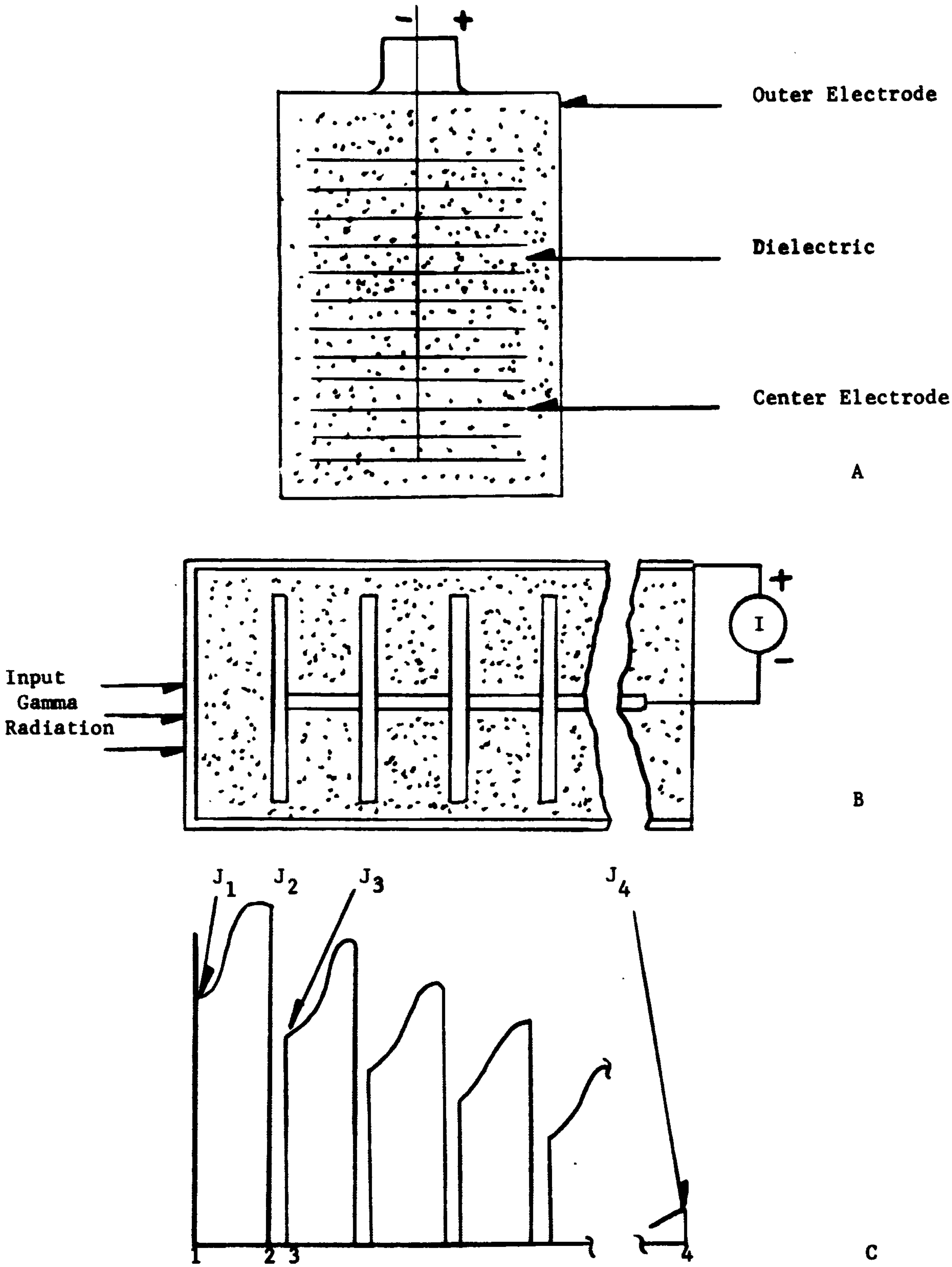
Figure 2. Sketch of multiple plate detector.

to provide a reduction in detector weight and yet maintain an approximately equivalent output signal is illustrated in Figure 2a. The center electrode of the previously described detector is replaced with a series of plates made of the same high atomic number material. The expected current density distribution in the dielectric for this type of detector is shown in Figure 2b. At positions 1 and 2 the current density will be the same as in the previous detector. However, at position 3 a large current density (J_3) will exist due to the large number of Compton electrons created in the plate which have sufficient energy to enter the dielectric at this point. The electrons leaving from this plate subtract from the signal current in the plate that was realized by electrons entering. Successive center electrode plates will add to the current signal of the center electrode with the detector output current approximately equal to the following:

$$I = (J_1 - J_4) A_1 + (J_2 - J_3) A_2 + . . . + (J_i - J_k) A_2.$$

By giving appropriate consideration to the basic principles of detector operation that have been discussed and which govern the operation of this detector, it is possible to effect much greater reductions in the detector size and weight and at the same time improve the overall operational performance characterisitcs of the generator. The detector illustrated in Figure 3a has demonstrated this accomplishment. Although a complete comprehensive theory of operation of this detector is beyond the scope of this effort, a very basic operational theory can be described as follows: The outer (positive) electrode of the detector is made of a thin light material such as aluminum. The center (negative) electrode is made of stacked electrically connected metal plates having properties that will be discussed later. The center (active volume) of the detector is filled with a dielectric material. The properties of the dielectric material are dependent upon the intended detector application. Figure 3b is an expanded view of this detector and 3c illustrates the expected current densities in the dielectric. The current densities J_1 and J_2 will be the same as in the previously discussed detectors. At the first plate of the center electrode, primary electrons will be scattered into this plate from the dielectric. If the plate is sufficiently thick, all of the electrons from the dielectric will be stopped resulting in a negative charge on this plate. At the reverse side of this plate electrons will be scattered back into the dielectric which will offset the charge accumulation on the plate. However, if the electron range in the plate is considerably shorter than in the dielectric, then all electrons entering the plate and some of those freed in the plate will be stopped. Since it requires three electron range distances to establish an equalibrium current density and if the plate is only one mean range in thickness, then the current density leaving the plate will be significantly less than that entering the plate. Thus, the signal current on the plate is equal to $J_2 - J_3$. Successive plates will add to the signal current in a similar manner. However, at each successive plate the current density will be less due to the attenuation of the gamma radiation. Any current density appearing at the back wall of the detector will reduce the output signal. For optimum signal output, the separation of the plates should be sufficient to insure electron equalibrium.

An analogy similar to that described previously for the detector illustrated in Figure 3 can be carried out for gamma radiation entering from a



$$I = (J_1 - J_4)\ A_1 + (J_2 - J_3)\ A_2 + \ .\ .\ .\ (J_i - J_k)\ A_2$$

Figure 3. Sketch of prototype detector concept.

direction parallel to the center electrode plates. However, in this case the minor component of electron motion is in the direction of the center plate which results in a smaller number of electrons entering the plates. At the same time, the surface area presented by the center electrode to the gamma radiation is greatly reduced resulting in fewer electrons being scattered from the center electrode into the dielectric. Thus, a properly designed detector will not exhibit significant directional dependence.

The theory of operation presented in this section is not intended to imply a conclusive result of this contract, but rather is intended to provide a basis for understanding the final design parameters which are considered essential in the end product of this contract. The actual optimization of the prototype detectors was achieved as a result of consideration of the experimental evidence. The most significant aspect of this optimization effort is the fact that it is not necessary to create an asymetrical condition in the detector using a heavy center electrode. In fact, an improved output response was achieved using an extremely light center electrode, thus allowing a significant reduction in the size and weight of the detector.

Section II

DETECTOR DESIGN AND FABRICATION

Figure 4 is a photograph of the ruggedized prototype gamma radiation detector designed by the Los Angeles Division of North American Rockwell to meet the requirements of this contract. Figure 5 presents some of the detector characteristics that were observed during testing of the prototype units. Its operation is extremely simple in that the detector directly converts input gamma radiation into a proportional output voltage without requiring a supply of power. Its design is simple in that there are no close tolerances involved and very few purchased parts. However, there are significant fabrication aspects that must be adhered to if the detector is to operate successfully in the specified environment. It is the purpose of this section to delineate these aspects of fabrication. Detailed design characteristics are contained in drawings L7300001.

OUTPUT IMPEDANCE

The detector operation described in Section I of this report is a high impedance constant current source with a current signal output that is directly proportional to input dose rate. For this contract it was necessary to convert this signal to an output voltage covering the range of 10^5 to 10^7 roentgens/hour with a minimum voltage of one millivolt.

To accomplish the current to voltage conversion and at the same time provide the temperature stability that is implied by the requirements, it was decided to use a temperature compensating resistor internally connected across the output terminals of the detector. Current measurements indicated the value of this resistor would be ten megohms.

Tests conducted early in the program effort indicated that there would be no problem in accomplishment of temperature compensation. A previously tested resistor of this value was available off the shelf. Another supplier was also found and both types of resistors were purchased. Initial tests indicated that the resistors would operate over the temperature range of -269°C to +60°C. During final testing of the prototype detectors, it was found that repeated cycling over this temperature range produced 100% failures in this type of resistor. Since the resistors were wirewound and potted, it was not possible to identify the exact mode of failure. Several obvious fixes were attempted without success before it was decided that the resistor would have to be redesigned for operation in this environment.

The output resistor that is used in the final prototype detectors has been designed to eliminate all possible thermal stress points. In its present configuration, extreme care must be exercised in handling this resistor during fabrication since at this point it has very little mechanical strength. Once installed, the potting compound used in the detector provides the necessary mechanical strength.

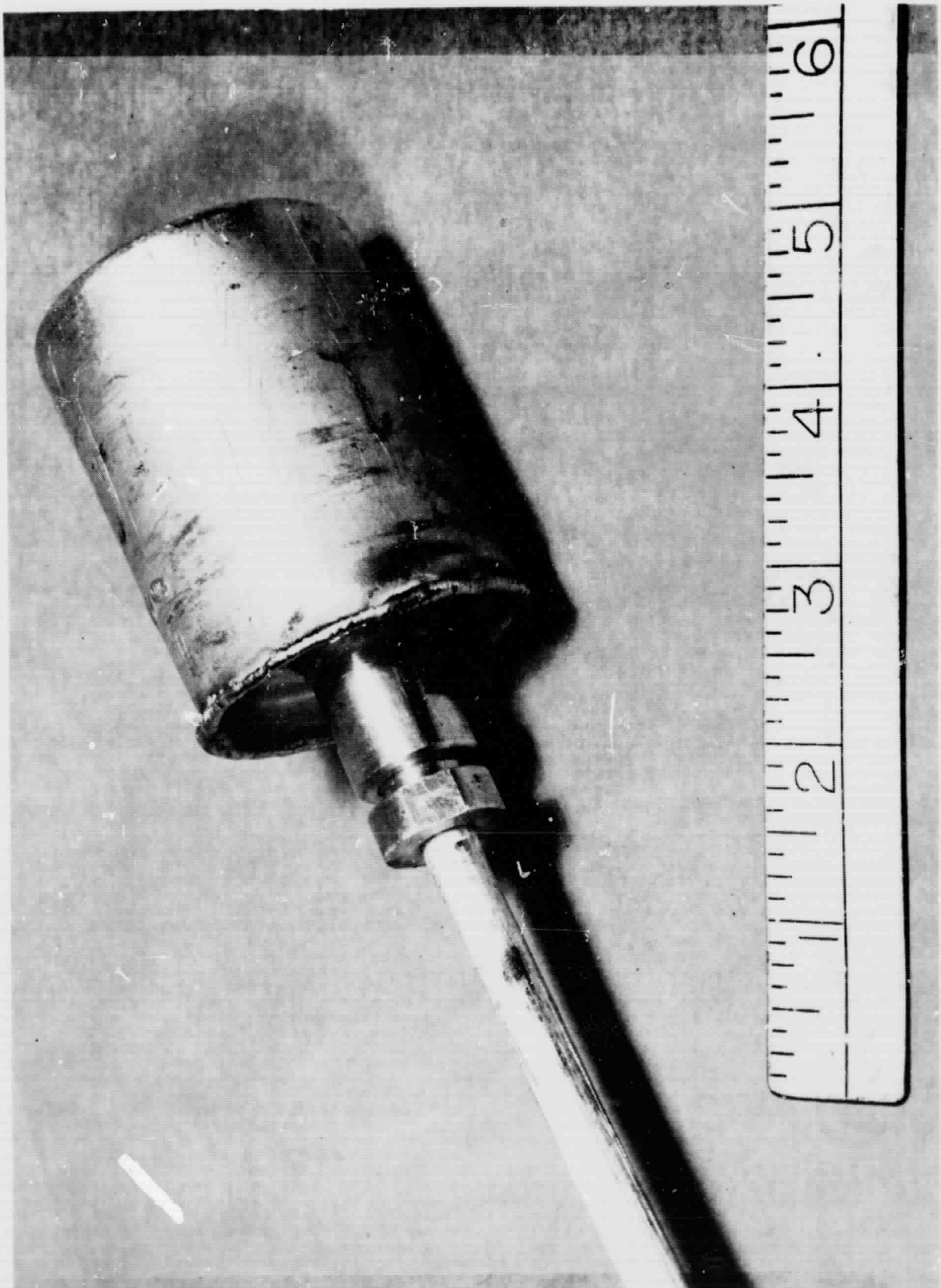
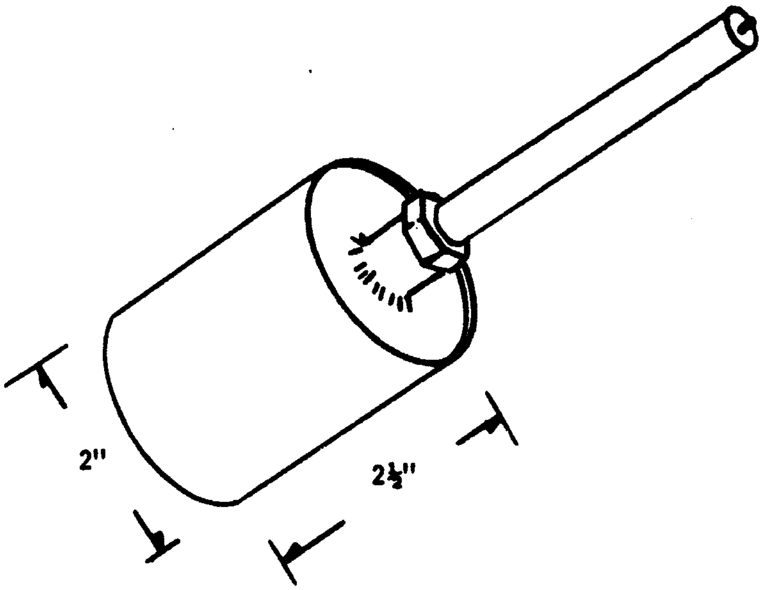


Figure 4. Photograph of prototype detector.



General Characteristics

• Power Requirements	None
• Temperature Range	-269°C to +60°C
• Intensity Range	10^5 to 10^7 R/Hr.
• Shock	Tested to 50 G's.
• Response Time	Less than 2 sec.
• Neutron Sensitivity	None
• Accuracy	± 10%
• Repeatability	± 3%
• Weight	12 ounces

Figure 5

General characteristics of prototype detector.

The resistor is fabricated by Rich Industries, Santa Clara, California in accordance with North American specifications. The resistor is a single non-reversed winding on a bobbin specially treated to allow slippage of the winding during thermal stress. It is housed in a thin walled epoxy shell, however, contact of the winding with the epoxy is avoided. The winding is soldered to the axial leads with ample slack left at the ends to allow for thermal expansion and contraction.

MATERIAL SELECTION

The two significant materials used in this detector are the metals used in the electrodes and the epoxy dielectric. In the case of the electrodes, aluminim was selected;however, the type of aluminum used is not critical. A heat tempered aluminum was used in the prototype detectors.

The selection of the dielectric material to be used in the prototype detectors was based solely upon its cold temperature characteristics. Emerson-Cummings epoxy, 2850 GT, was found to be the most acceptable of those tested for operation in liquid hydrogen. However, it also was found to absorb moisture readily, especially after being subjected to low cryogenic temperatures. Consequently, it is essential that the detector be completely weld sealed during fabrication since absorption of moisture by the epoxy will effect the output impedance characteristics of the detector. It is also important that no air paths exist between the inner and outer electrodes or output cable connection since ionization of the air produces leakage paths which will alter the performance characteristics.

CABLE SELECTION

No specifications were provided under this contract relating to handling of the output signal. Initially,it was expected that a connector would be used at the output of the detector. However, because of the moisture absorbing properties of materials immediately after being subjected to liquid nitrogen and liquid helium environments, it was decided that a connector could not provide adequate sealing.

To insure adequate detector sealing a coaxial cable was selected having a solid outer wall of aluminum. The actual selection of this cable was not based upon optimization of the detector configuration but rather upon availability, cost, and lead times at that particular point in the contract effort.

Technically, the selection of the output cable should be based upon the following considerations:

1. The insulation should be polyethylene since it is less susceptable to radiation damage.

2. The inner and outer conductors must be of identical type materials to avoid thermocouple effects at the extreme environments.

3. On a purchase of 2000 feet minimum, it is possible to purchase this type of cable in a variety of sizes which could effect a considerable weight reduction and also provide more flexibility in designing for various installations.

There are numerous cable suppliers at the present time capable of providing this type of cable given the required lead time. Reconfiguration of the cable entrance into the detector to accept a different size cable should present no technical difficulties.

DETECTOR SEALING

As pointed out previously in this section, avoidance of air conduction paths between the inner and outer electrodes and the elimination of moisture leakage paths to the dielectric inside the detector are important considerations in detector fabrication. Although the prototype detectors were fabricated in the laboratory and construction techniques were not necessarily representative of what might be employed in a production assembly, a discussion of the techniques of fabrication will provide an indication of what was considered to be critical in the fabrication of the prototype detectors.

Filling the center of the detector with dielectric (Emerson and Cuming Epoxy-2850 GT) was accomplished in three steps to avoid the formation of large air pockets inside the detector and to protect against internal electrical shorting of the inner and outer electrodes. The center electrode was potted separately to insure total filling between the plates. At the same time the bottom of the detector can was filled to provide an insulating support base for the center electrode. Prior to potting, the temperature of the epoxy was elevated to lower the viscosity of the epoxy and to assist in the elimination of air bubbles. After the potting compound has set, the center electrode is potted in place. The final step consists of making necessary electrical connections, potting the detector to a depth that is consistant with the recessed depth of the cover of the detector, and placing the cover in place. Care must be taken to avoid getting epoxy on surfaces between the cover and the detector wall, since this will make subsequent welding of the detector difficult.

The detector is sealed against external moisture by welding arround the top and at the junction between the cover and the output cable. Since welding cannot be accomplished in the vicinity of epoxy or polyethylene, it was necessary to recess the cover approximately 3/8" below the weld joint. Also, it is necessary to remove approximately ½" of polyethylene from the cable to accomplish a weld where it joins the top. During potting of the detector, this section of the cable must be refilled with the potting compound.

On a production basis, it would be possible to improve considerably upon the construction techniques employed in the fabrication of the prototype detectors. Placing the detector in a vacuum immediately after potting would enhance the flow characteristics of the epoxy and assist in the elimination of air bubbles. Weld joints should be checked for leakage by placing the detector under water in an evacuated chamber and watching for air bubbles. It is believed that the uniformity of fabrication that would be achieved on a production run would reduce significantly the costs that would be required for subsequent detector calibration. How significant a reduction can be expected can only be determined from an analysis of an initial production run.

Section III

PERFORMANCE TESTS

This section describes the test procedures that were employed and the observed test results in the performance of tests required to demonstrate that the three prototype detectors meet the various environmental and accuracy requirements presented in Appendix D. Included in this section are the results of tests to determine the linearity response, temperature dependence, neutron sensitivity, shock and vibration, pressure, repeatability, and response time of the three prototype detectors.

REACTOR CALIBRATION

Important to any test is the method used to perform instrument calibration. Because of the number of variables involved and the limited number of instrument types available with sufficient accuracy to perform as transfer standards, calibration of radiation fields is a very critical aspect of testing. In the performance of the following tests involving radiation measurements, thermoluminescent dosimeters (TLD) were employed in gamma dose rate measurements while activation foils were used to measure the neutron flux.

Since the TLD has a limited range ($3X10^5$ roentgens), it was necessary early in the program effort to develop a method of calibrating the reactor in terms of gamma dose rate over the required range of interest. This was especially true since the TRIGA reactor is primarily used for neutron exposures in radiation effects work and consequently the gamma flux receives little or no attention from a calibration standpoint. A discussion of the calibration technique used and the results obtained is presented in Appendix A of this report. Figures 6, 7, and 8 present in graphical form the calibration values obtained and which, unless otherwise stated, will be used in this report. Although some of the data used to support these calibration curves was obtained early in the program, subsequent point checks indicate that the values are subject only to the operators ability to repeat power settings on the reactor and this has been observed to be within the tolerance of the TLD measuring devices.

LINEARITY RESPONSE TESTS

Linearity response tests were conducted to demonstrate the output voltage response of the prototype detectors to input dose rate levels over the range of 10^5 to 10^7 roentgens per hour. It was also the purpose of this test to demonstrate that this response is linear within a tolerance of $\pm$ 10%. Output voltages from the detector were made with a Keithley Electrometer, Model 601, which has a specified accuracy of $\pm$ 1% of full scale on its voltage ranges.

The dry exposure room of a TRIGA Mark F reactor was used to produce the required input dose rate levels. Figure 9 presents a sketch of the test set-up. With the prototype detectors positioned at 1/4" from the exposure

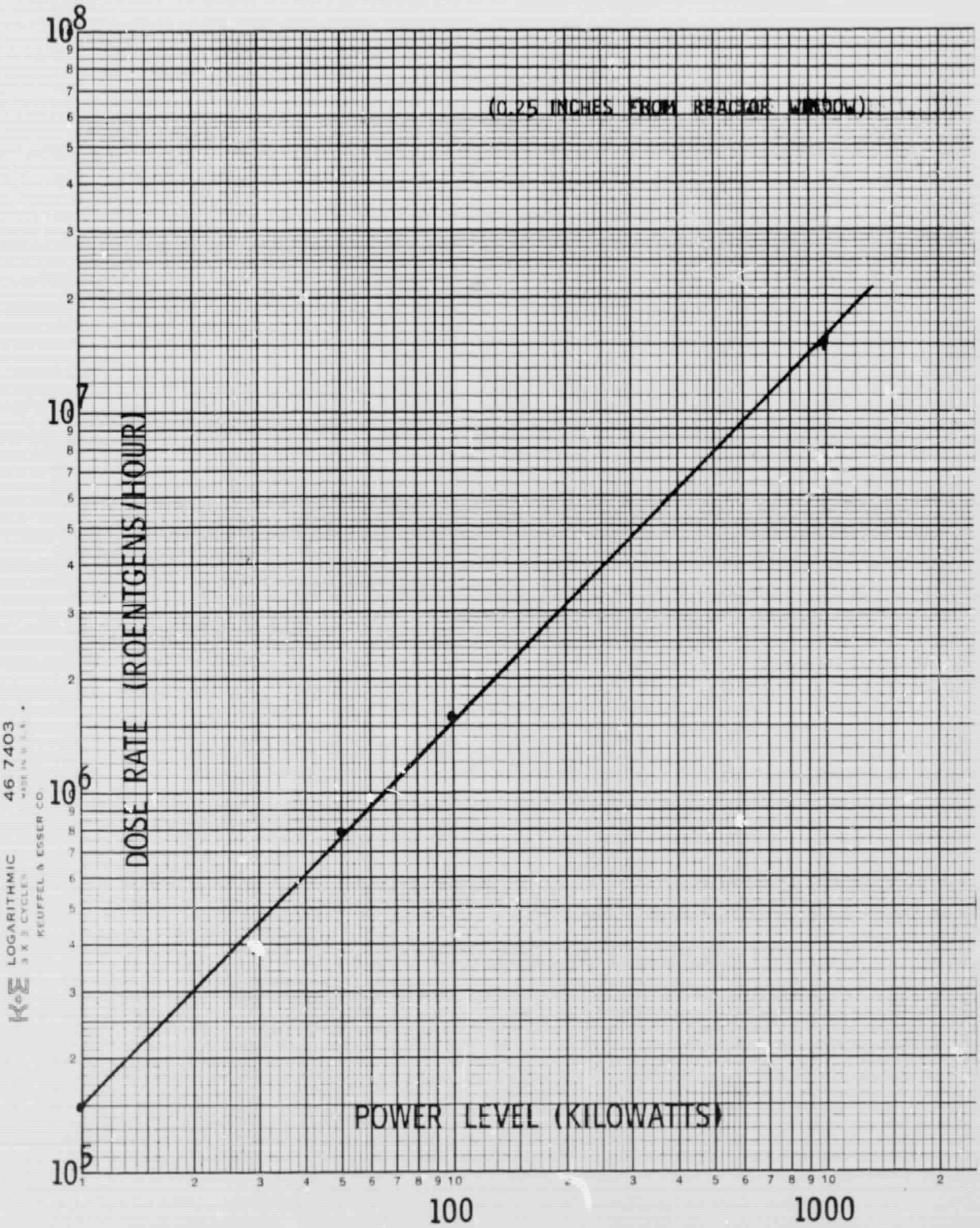


Figure 6 Reactor calibration, power level versus dose rate.

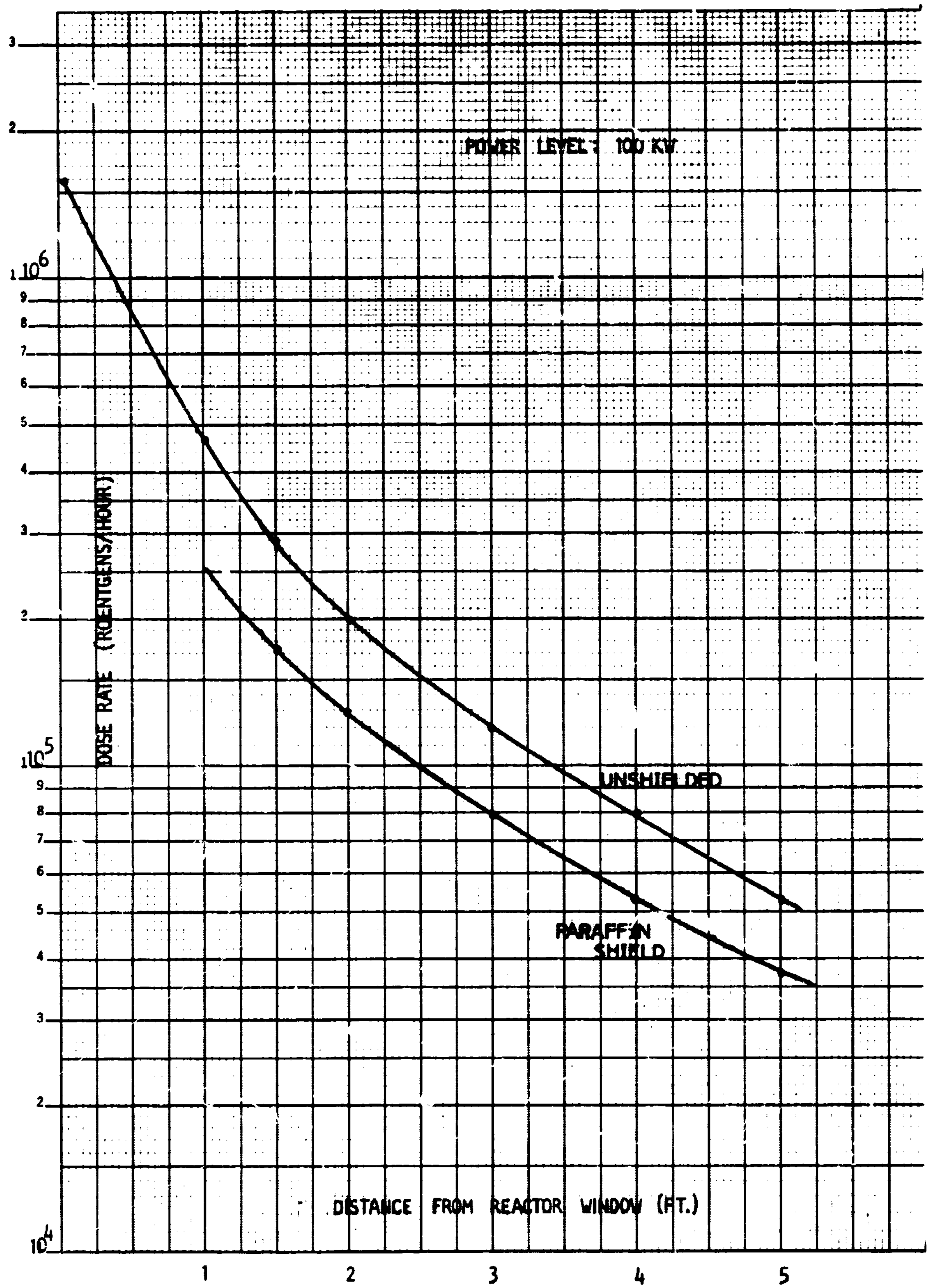


Figure 7. Reactor calibration, dose rate versus distance.

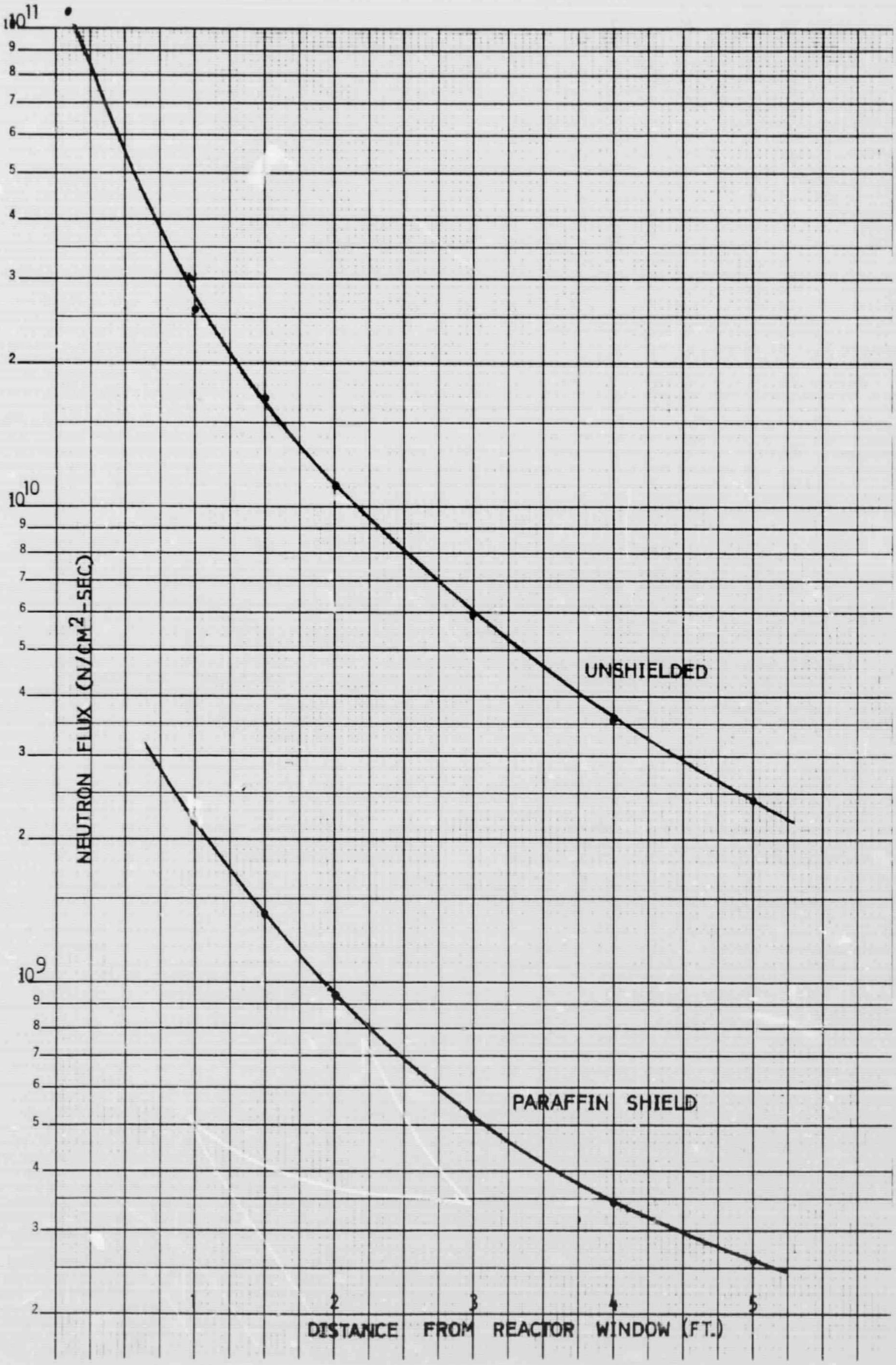


Figure 8. Reactor calibration, neutron flux versus distance.

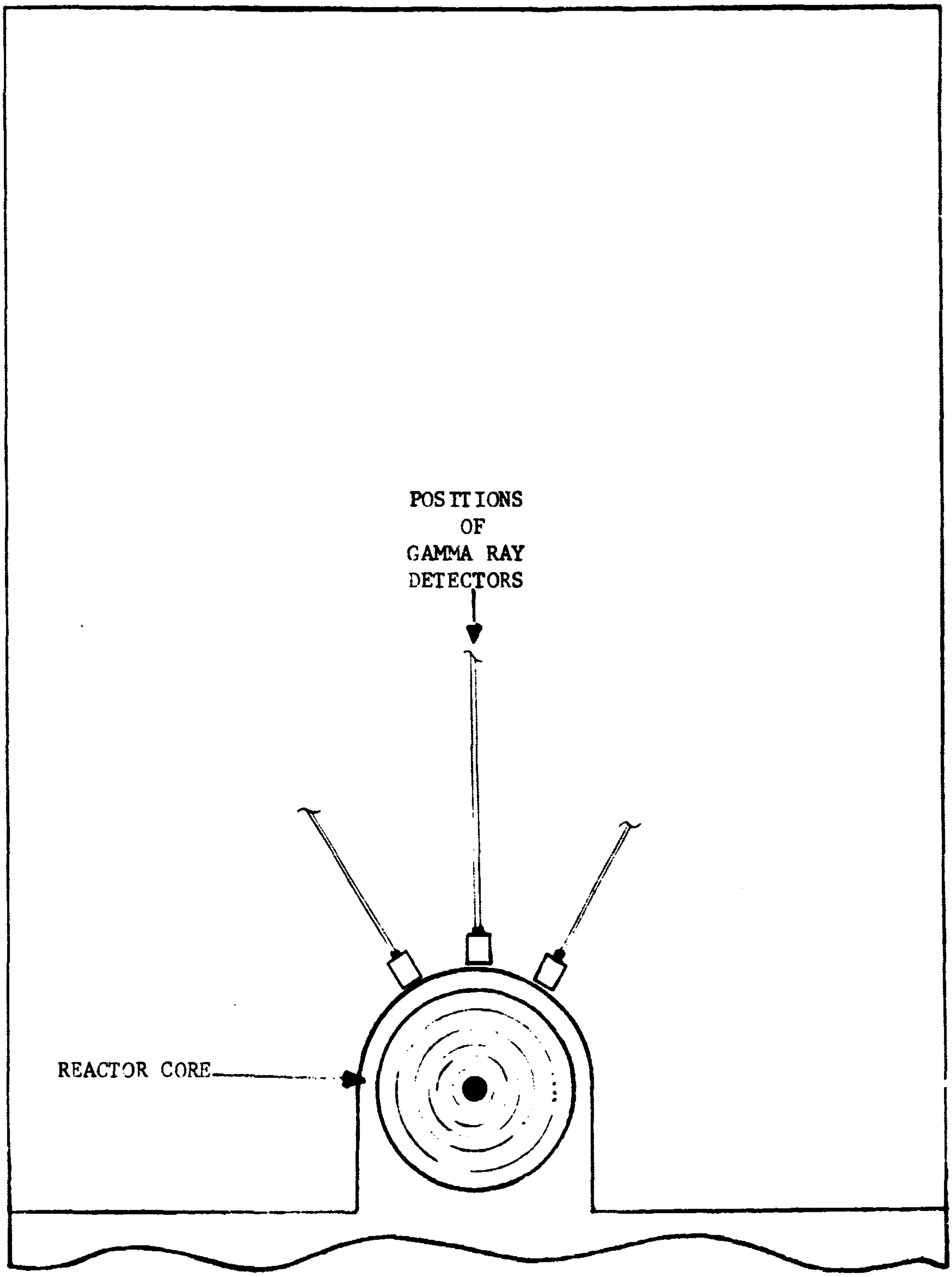


Figure 9. Dry exposure room, TRIGA Mark F nuclear reactor.

window, the power level of the reactor was raised to provide the input dose rates with a dwell time at each level of ten minutes to insure the stability of the power level and the detector response. Table I presents the resulting data while Figures 10, 11, and 12 give a graphical presentation of the demonstrated linearity. The dashed lines indicate ± 10% tolerance limits.

The results of this test demonstrate the excellent linearity and accuracy that can be obtained with this type of detector. All readings were well within the ± 10% tolerance levels. The fact that the linear response line does not cross the one millivolt level at a dose rate input of 10^5 is accounted for by the improved conversion efficiency that has been achieved in the detector since the selection of a ten megohm resistor value. If it were desirable to have this occur, then a 6.8 megohm resistor would be a better choice.

Another interesting aspect of this data is the fact that the output voltage characteristics of the three detectors versus input dose rates are very close to identical. Since these three detectors were fabricated in a research laboratory, it is believed that on a production basis where tolerances would be better maintained, much closer agreement in output responses would be achieved. This would considerably decrease the calibration costs.

One additional item to be noted in the linearity test is the high neutron fluence to which the detectors were exposed. As shown in Figure 8, at 100 kw the neutron flux (> 10 kev) is 1.1×10^{11} n/cm^2-sec. Thus, at 500 kw it is approximately 5.5×10^{11} n/cm^2-sec. and 1 mw it is 1.1×10^{12} n/cm^2-sec. Therefore, the total neutron fluence for ten minute runs at these levels is 10^{15} n/cm^2. Earlier models of this detector have been exposed to neutron fluence levels of over 10^{16} n/cm^2 with no apparent degradation in performance.

TEMPERATURE DEPENDENCE TESTS

Temperature tests were conducted to demonstrate operation of the prototype gamma radiation detectors over the range of -253°C (liquid hydrogen) to 60°C. Since it was not feasible to put liquid hydrogen in the reactor which was used in the performance of this test, it was decided to use liquid helium, thus extending the temperature range to -269°C.

The temperature tests were conducted in two parts with the overall objective of the test to demonstrate the relative response of the detectors over the required temperature range. The low temperature test was conducted in the dry exposure room of the reactor. This was necessary in order to expose the detectors to a sufficiently high radiation level while operating in dewars containing liquid helium and liquid nitrogen. High temperature tests were conducted using a Co60 source.

Figure 13 shows a sketch of the test set up for the low temperature tests along with the observed test results. Since it was not possible to place TLD's directly on the detectors, it was decided to monitor only the average level at eighteen inches from the reactor window. This is consistent with determining only the relative response of the detectors to temperature.

REACTOR POWER LEVEL	DOSE RATE (R/Hr)	OUTPUT VOLTAGE (mv)		
		#1	#2	#3
10 kw	14.8×10^4	2.2	2.35	2.7
50 kw	8.0×10^5	10.6	10.5	11.8
100 kw	1.6×10^6	20.7	21	23.5
500 kw	7.6×10^6	91	89	95
1000 kw	1.5×10^7	180	180	180

Table I. Linearity Response Data

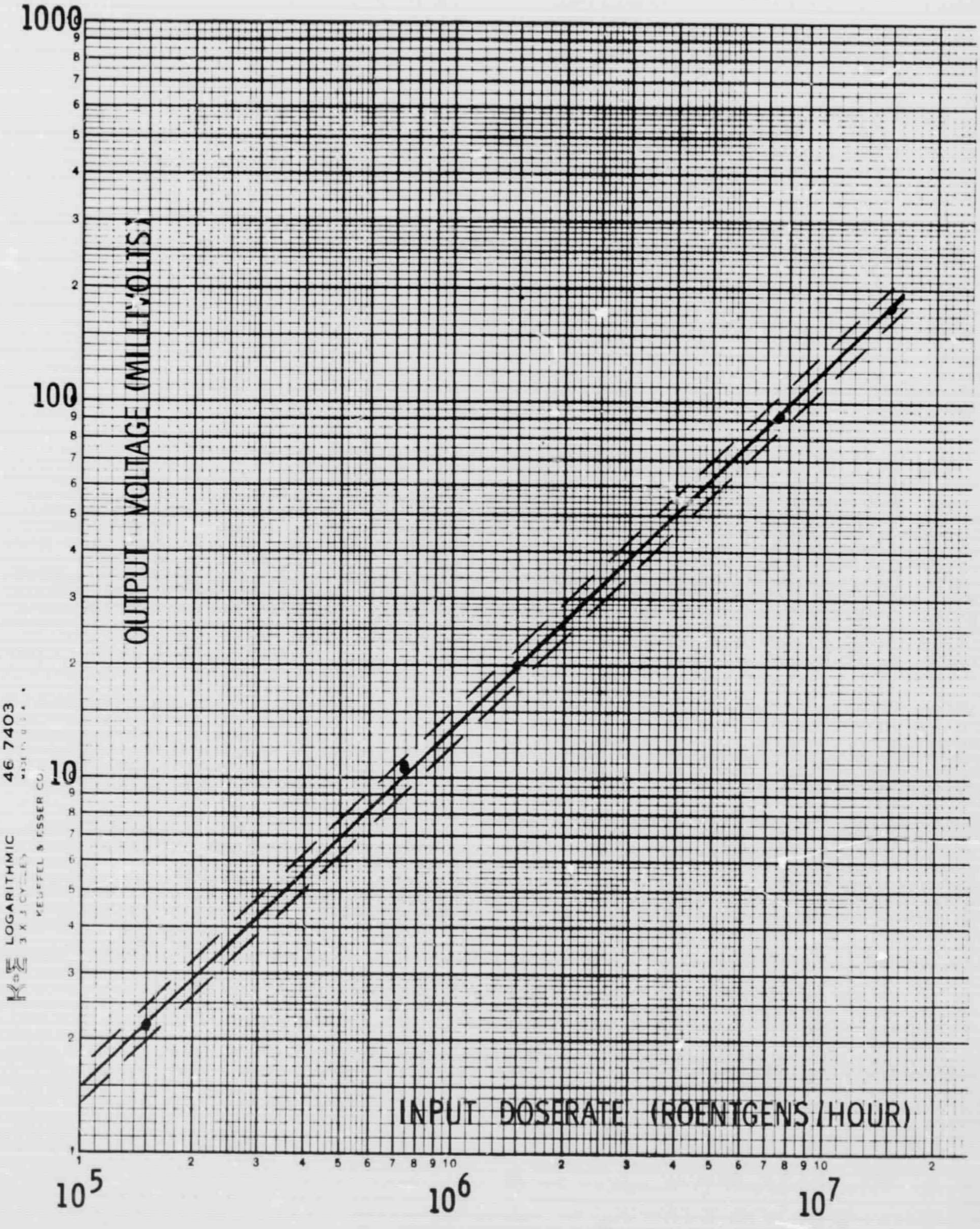


Figure 10. Dose rate linearity response of detector #1.

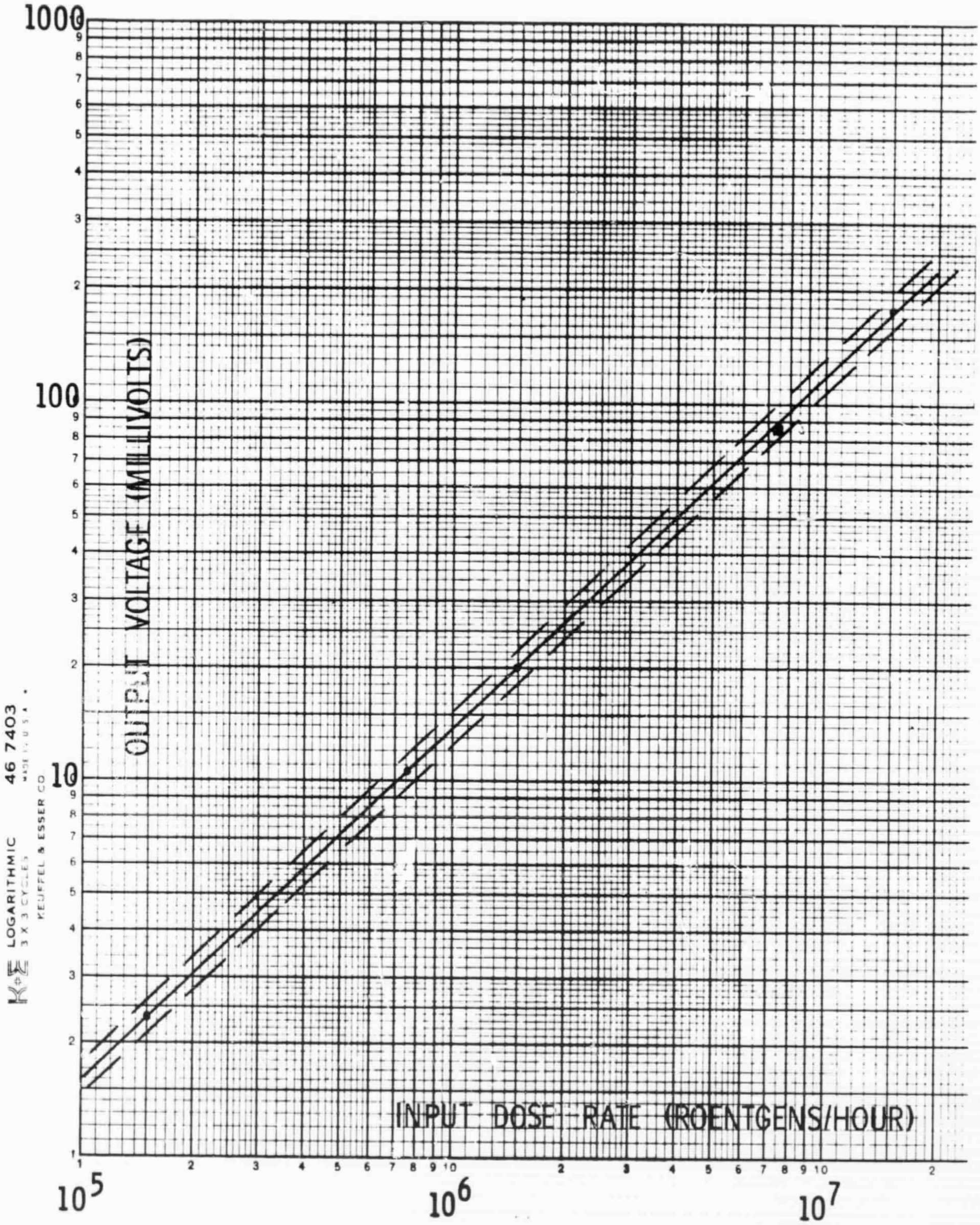


Figure 11. Dose rate linearity response of detector #2.

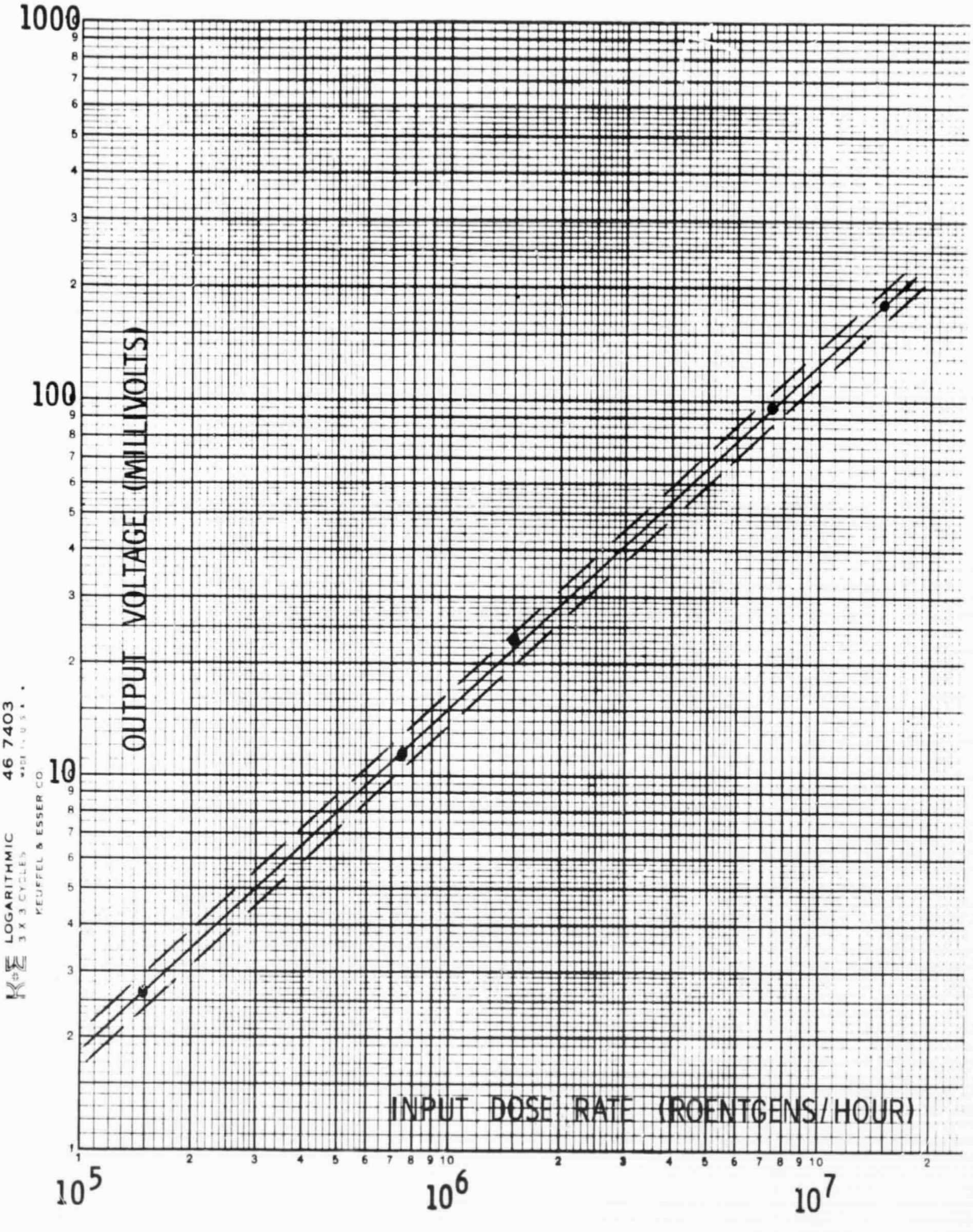
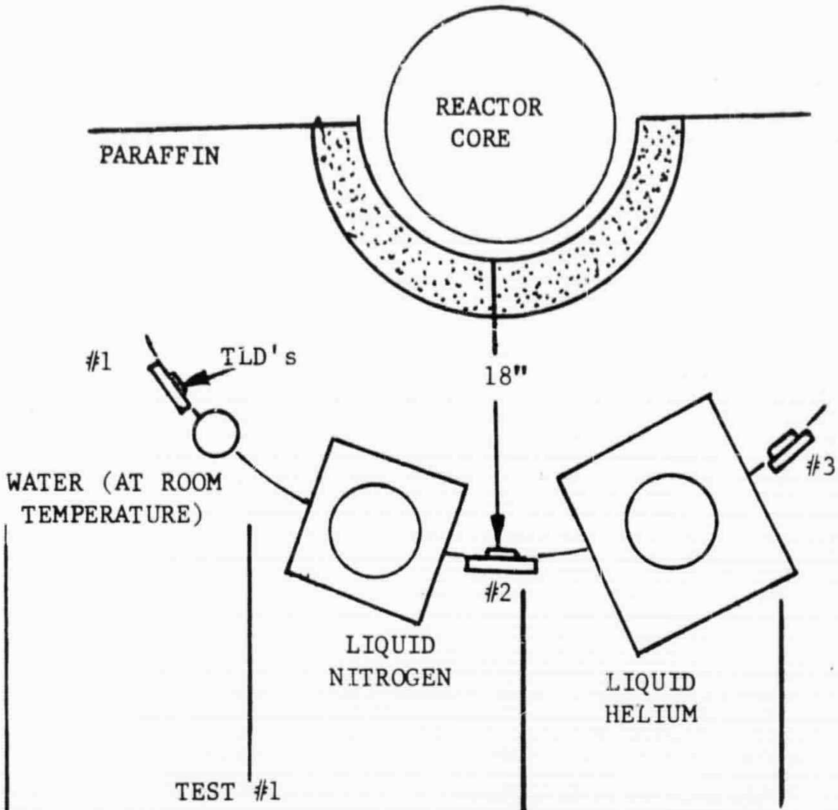


Figure 12. Dose rate linearity response of detector #3.



TEST #1

DETECTOR NUMBER	2	1	3
OUTPUT VOLTAGE (mv)	3.7	3.4	3.4
MEASURED DOSE RATE (R/HR)	1.62×10^5	1.62×10^5	1.62×10^5
NORMALIZED OUTPUT VOLTAGE (mv)	3.7	3.5	3.5

TEST #2

DETECTOR NUMBER	1	3	2
OUTPUT VOLTAGE (mv)	3.4	4.1	3.7
MEASURED DOSE RATE (R/HR)	1.64×10^5	1.64×10^5	1.64×10^5
NORMALIZED OUTPUT VOLTAGE (mv)	3.4	4.1	3.7

TEST #3

DETECTOR NUMBER	3	2	1
OUTPUT VOLTAGE (mv)	4.4	3.8	4.1
MEASURED DOSE RATE (R/HR)	1.68×10^5	1.68×10^5	1.68×10^5
NORMALIZED OUTPUT VOLTAGE (mv)	4.3	3.7	4.0

Figure 13 . Low temperature test data.

The two large glass vacuum dewars indicated are six inches in diameter and were surrounded with insulating materials to help hold the cryogenic liquids. The smaller dewar is three inches in diameter and was filled with water to simulate the radiation scattering that will occur in the larger dewars. The three prototype detectors were placed in these dewars with the main axes in the vertical direction. The detectors were then alternated between dewars to obtain the indicated test data.

The gamma radiation dosimetry report is contained in Appendix A, Table AI . In figure 13 , the indicated measured dose rate levels are the averages obtained during each test run. The differences in observed dose rate levels are the result of error involved in differences in power level settings. To normalize this data to equivalent radiation input levels, it is first necessary to determine the average value of the three tests. If A equals the measured output voltage, then the normalized value of A is given by

$$\text{Normalized A} = \frac{\text{Measured Input Dose Rate}}{\text{Average Input Dose Rate}} \text{ X A}$$

In the conduct of high temperature test a Co-60 source was used which provided an input dose rate of approximately 7×10^4 roentgens/hour. The detectors were heated to approximately 70°C and allowed to cool to room temperature in this radiation field. The output voltage was monitored during this test and the end points noted.

Table II presents the results of these tests. The normalization of the values to one was accomplished by first dividing each output voltage reading obtained during cold temperature tests by the average reading. Then, the voltages obtained during the high temperature tests were multiplied by a constant (necessary to make the room temperature equivalent) and divided by the same average value.

Figure 14 is a graphical presentation of this data. The observed values do not exceed ±10%. One of the important aspects of this data presentation is the fact that there is no observable correlation between observed output voltages and temperature. This is attributed to the fact that experimental errors at cold temperatures were sufficiently significant as to overshadow thermal effects. First of all, dosimeter accuracy is placed at ±5%. Second, placement of detectors at a given distance is fairly critical. How critical can be determined by observing the slope of the dose rate versus distance curve shown in figure 7. A two inch error in placement could result in an error of approximately ±8%. Since liquid helium and liquid nitrogen tests were conducted in closed vessels in order to conserve these cryogens during the test it was not possible to maintain accurate predetermined distances from the reactor window. Thus, the true temperature response is much better than that indicated by these test results.

TEMPERATURE (°C)	RADIATION SOURCE	MEASURED VOLTAGE (MV)	NORMALIZED VALUE
-269	Reactor	4.0	1.08
-196	Reactor	3.5	0.95
25	Reactor	3.4	0.92
25	Co 60	0.79	0.92
60	Co 60	0.82	0.96
Detector #1			
-269	Reactor	3.7	1.00
-196	Reactor	3.7	1.00
25	Reactor	3.7	1.00
25	Co 60	0.92	1.00
60	Co 60	0.89	0.98
Detector #2			
-269	Reactor	3.5	0.90
-196	Reactor	4.1	1.05
25	Reactor	4.3	1.10
25	Co 60	1.0	1.10
60	Co 60	1.0	1.10

Detector #3

Table II. Normalized values of observed temperature response

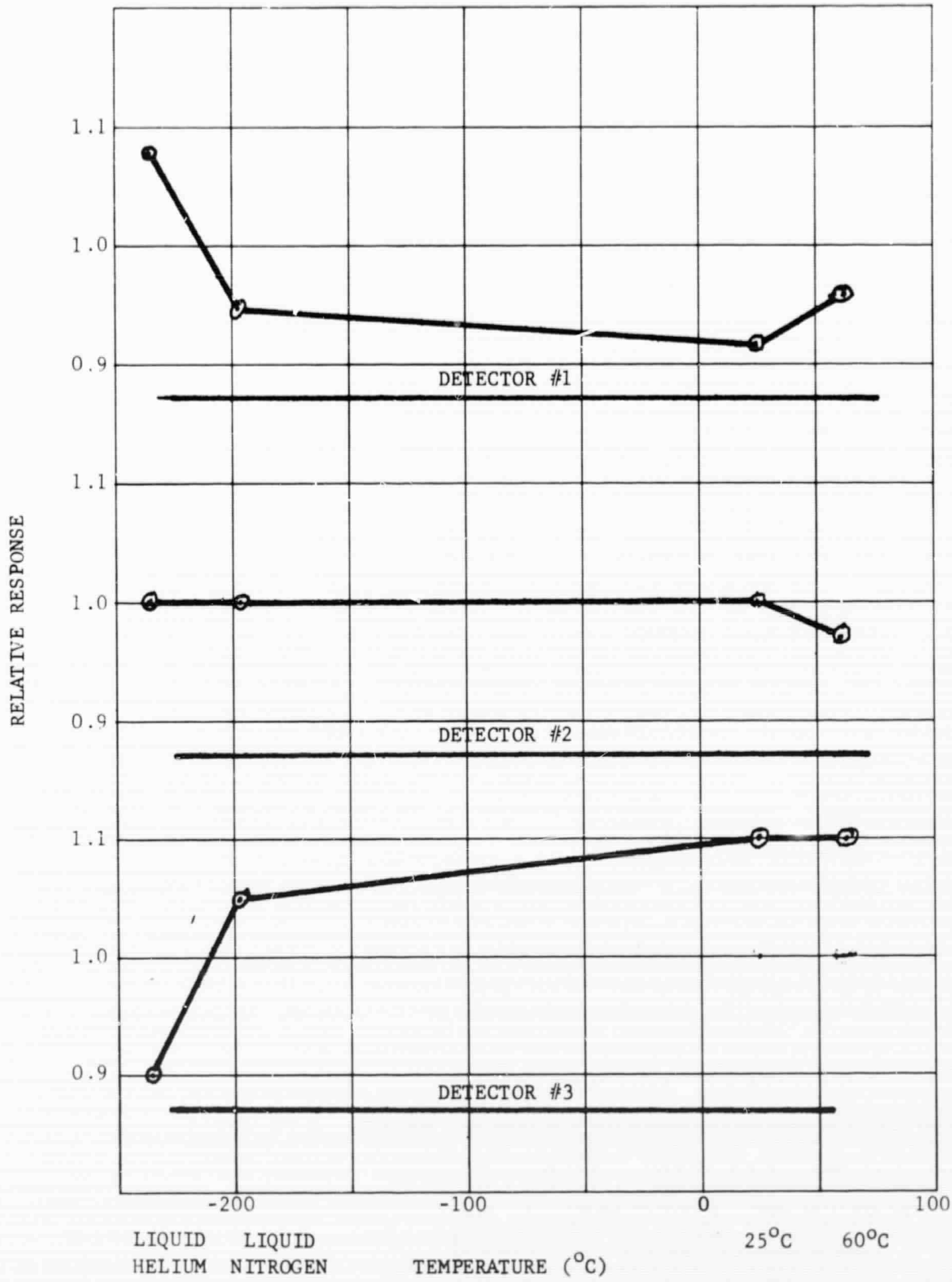


Figure 14 . Relative temperature response.

It is important to note that during the conduct of these tests, the detectors were maintained at the liquid helium and liquid nitrogen temperatures for a minimum of thirty minutes. Two of the detectors were left in liquid nitrogen for more than twenty-four hours with no degradation of performance.

NEUTRON SENSITIVITY

Although at the start of this program it was predicted that the detector would be insensitive to neutron fluxes of the magnitude specified, it was essential to confirm this prediction experimentally early in the design effort. At that time, linearity tests conducted in a reactor environment were compared to similar tests conducted using an x-ray machine to produce the input radiation. Within the accuracy limits of the test, the results indicated no observable response to neutrons. These results are further confirmed by the test data obtained during the testing of the prototype detectors.

If neutrons do not contribute significantly to the detector response to radiation in the reactor environment, then the calibration curve established for the detector should be capable of predicting the output voltage that will result from exposing the detector to a known gamma radiation field from a Co60 source.

To conduct this test a 260 curie Co60 source was employed. The dose rate level at one quarter inch from this source was measured with a Landsverk R-meter, and was found to be $6X10^4$ roentgens/hour. Detector #2 was placed at this point and the voltage output was measured to be 0.92 millivolts. The results of this test are presented graphically in Figure 15. The plotted line is a continuation of that presented in Figure 11 . Data point A is that obtained using the Co60 source. The results indicate that the neutron contribution to the detector response is negligible.

DETECTOR RESPONSE TIME

At the beginning of this contract concern was expressed with regard to the ability of this type of detector to respond to step increases in gamma radiation within the required two seconds. Ideally, to demonstrate that the detector response is considerably better than this, tests would be conducted on the reactor. However, it was found early in the program that this was not possible. The induced activity in the vicinity of the reactor core is sufficient to produce a significant residual gamma dose rate level. Consequently, it was decided to use a Co60 source in the performance of this test.

Figure 16 is a sketch showing the test procedure that was used to establish that the detector response time is less than two seconds. A signal referenced to opening of the source is provided by the switch on the source lever arm. Both this signal and the detector output signal were simultaneously recorded on a Brush (model 280) recorder. Although the dose rate level was only $6X10^4$ R/hr., the response time of the detector can be expected to be faster at higher dose rate levels as is the case in other types of radiation detectors.

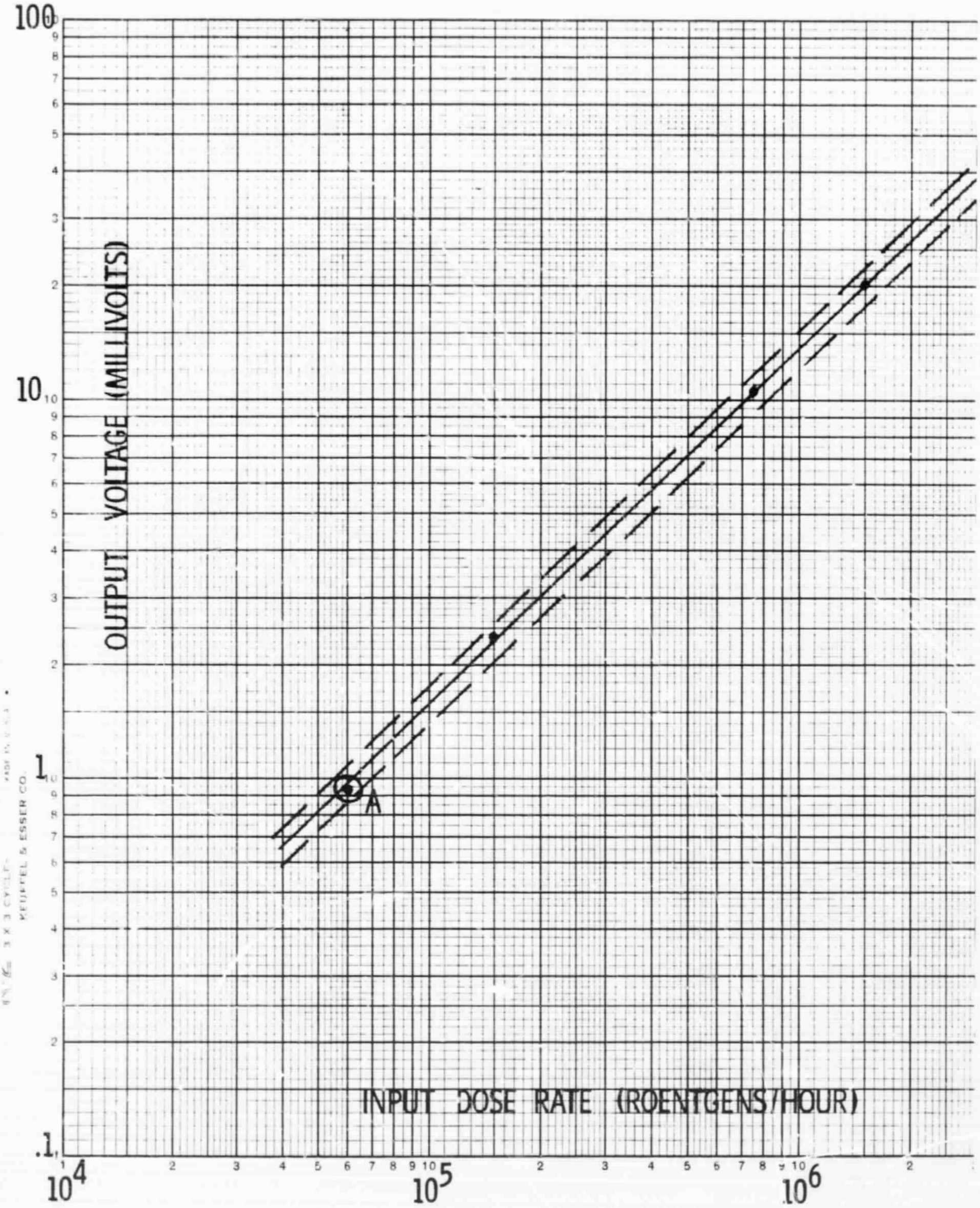


Figure 1¯. Results of neutron sensitivity test.

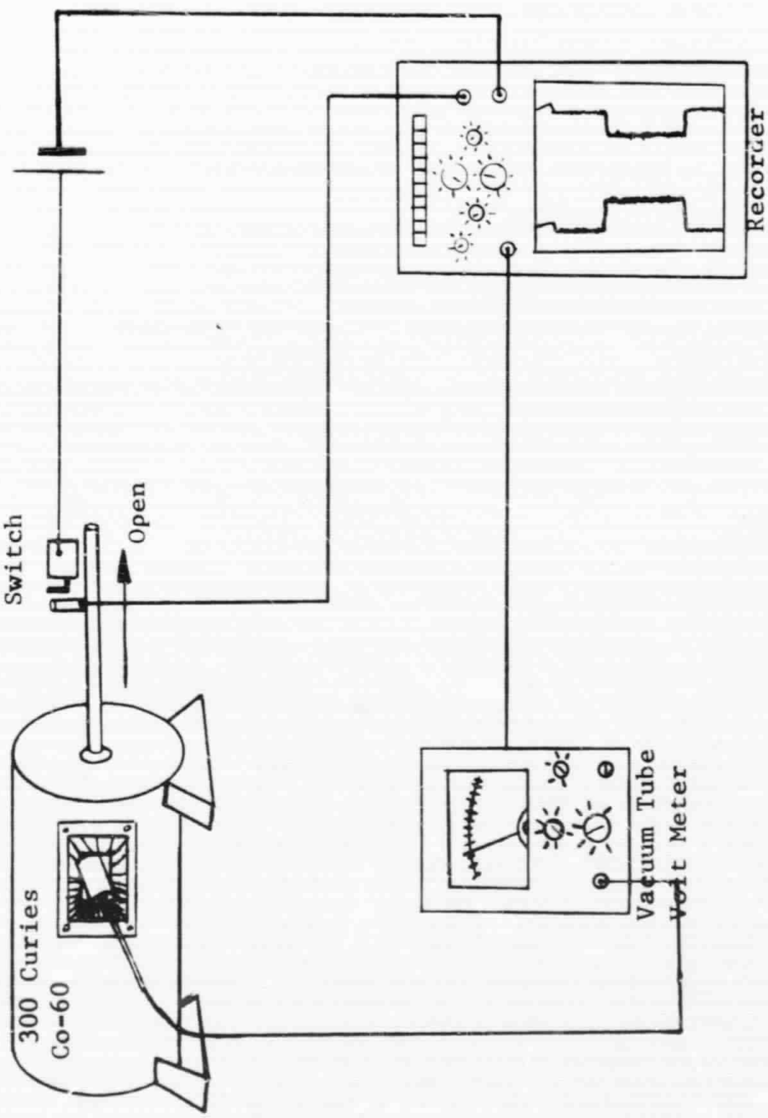


Figure 16. Sketch of response time test setup.

Figure 17 is a sample recording made during this test. Although no effort was made to align the switch to exactly reflect the time that radiation is applied to the detector, the results indicate that the response time is well under one second. The shape of the knee at the top of the step function of the detector response is attributed to the fact that the source was manually opened with a slowing action at the end. Thus, the actual response time would appear to be faster than five-hundred milliseconds.

VIBRATION, SHOCK, AND PRESSURE TESTS

The vibration, shock, and pressure tests were conducted by the Approved Engineering Test Laboratories, Los Angeles, California. These tests were conducted in accordance with the North American test specification, TFD-68-35-1 which is included as Appendix B of this report. A certified report describing test procedures that were employed, test equipment, and instrument calibration used by the test laboratory in compliance with this specification is provided in Appendix C of this document.

Shock tests were conducted first in this series of tests. Detector #1 was subjected to six shocks of eight milliseconds duration (sine wave) of 50 G in two of the three major axis. The test was repeated for the other two detectors at a 25 G level. After each test, a visual inspection and functional test was made. No damage to the detector was noted.

Each prototype detector was subjected to sinusoidal vibration tests in two of the three major axis at the following levels:

a. 5 to 20 hertz at 0.5 inches D.A.
b. 20 to 100 hertz at 10G's peak
c. 100 to 160 hertz at 0.019 inches D.A.
d. 160 to 2000 hertz at 32 G's peak

During these tests a continuous D.C. signal was applied to the detector and monitored by North American Rockwell. No failures were experienced during these tests.

In the conduct of pressure tests, the detectors were placed in a test chamber and the pressure was varied over the range of $3.1X10^5$ newtons /meter^2 to 10^{-4} Torr. At the completion of pressure tests, functional tests were performed and no apparent damage was observed.

REPEATABILITY TEST

The objective of this test was to demonstrate that the detectors response to repeated inputs of a given radiation level would not vary by more than $\pm$ 3%. This test was accomplished by applying an input radiation intensity of $6X10^4$ roentgens/hour from a Co60 source. Without moving the detector, this field was removed and reapplied several times. No change in detector response was observed.

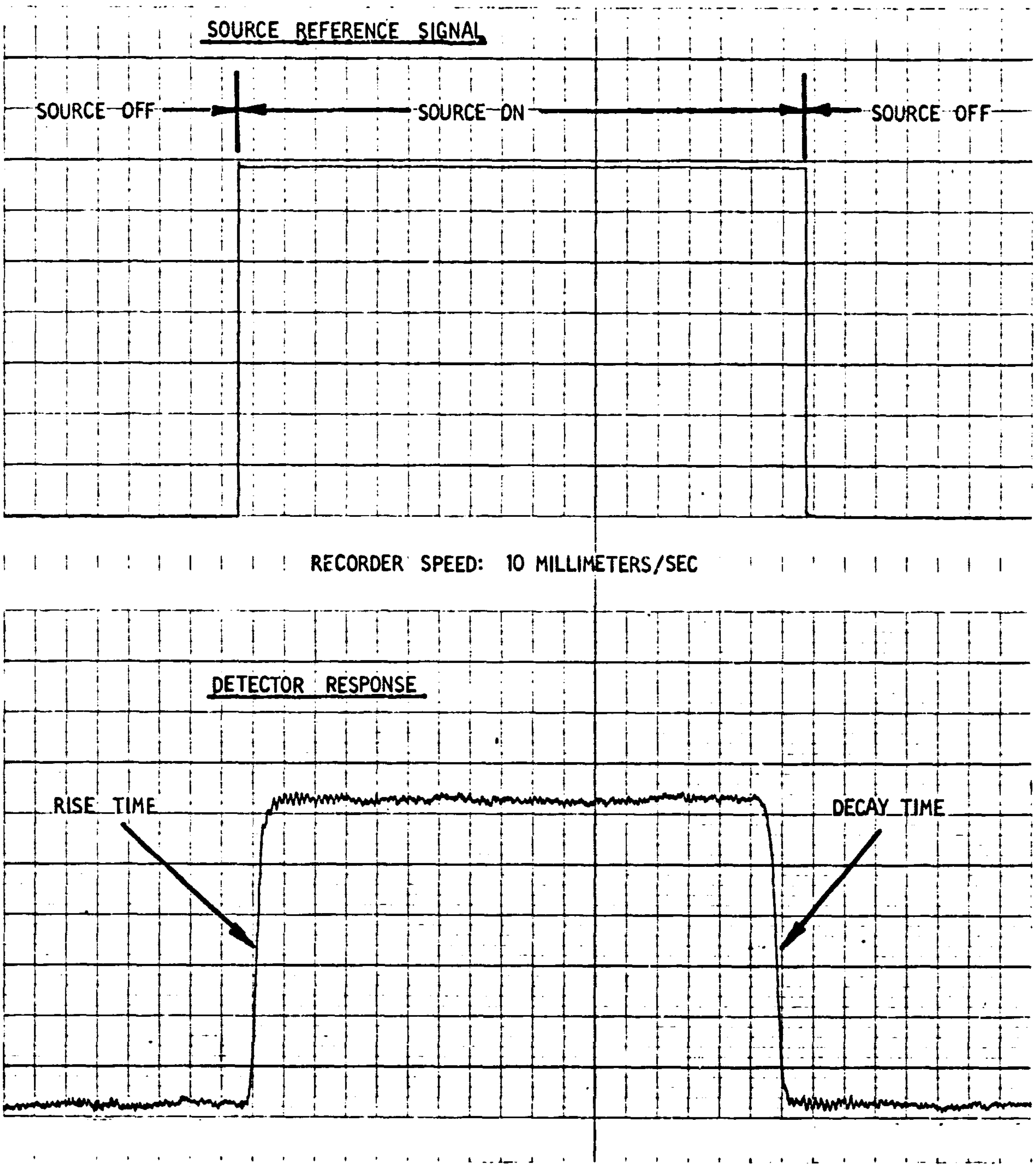


Figure 17. Results of response time test.

A more significant indication of repeatability is provided by the data presented in Table III. Prior to initiation of tests described in this section, the detectors were placed in a $6X10^4$ roentgen/hour field from a Co60 source and the output voltage measured. This test was repeated upon completion of all tests. The results indicate the excellent repeatability of this detector even after subjection to the extreme environmental conditions delineated in this section.

DETECTOR NUMBER	25 JUNE 1969 OUTPUT VOLTAGE (mv)	21 JULY 1969 OUTPUT VOLTAGE (mv)
1	0.80	0.82
2	0.90	0.89
3	1.10	1.05

INPUT DOSE RATE: $6X10^4$ R/HR.

SOURCE: Co60

Table III. Repeatability test data.

Appendix A

REACTOR CALIBRATION

Important to section IV of this report is the calibration of the TRIGA Mark F reactor which was used to accomplish most of the testing under this contract requiring high intensity gamma and neutron radiation. This appendix presents the dosimetry techniques employed in calibration of the reactor, dosimetry data and supporting dosimetry analysis. Thermoluminescent dosimetry (TLD) was used to measure the gamma radiation while activation foils were used for neutron measurements. Calibration standards traceable to the National Bureau of Standards were used.

Thermoluminescent dosimeters have a useful linear range up to approximately 3 x 10^5 roentgens. At 10^7 roentgens/sec. they would saturate in such a short period of time that an accurate determination of gamma dose rate would be impossible. At lower dose rate levels the accuracy of the TLD is excellent. Therefore, early in the program a calibration technique was developed to make the TLD reading useful over the entire range of interest in the TRIGA Mark F reactor tests, and to establish a calibration of this reactor that could be easily updated for subsequent tests.

The calibration procedure was to make both gamma and neutron measurements 0.25 inches and 5 feet from the reactor. Thus, the data could be used to establish the basic assumptions that the gamma radiation intensity is directly proportional to the reactor power level and to the neutron flux. The dosimetry results are provided in tables A-2 and A-3, while table A-1 presents the results of the analysis of the dosimetry data.

There are three ways in which the dosimetry data can be extrapolated to yield the high intensity dose rate levels above the operating range of the TLD's. If

A = Gamma dose at the exposure window
B = Gamma dose at 5 feet from window
C = neutron fluence at window
D = neutron fluence at 5 feet from window

then the ratios A/B, A/C, A/D establish approximate ratios that can be accurately determined at low power levels, and if linearity can be assumed, can be applied at the higher power levels to determine gamma exposure and dose rate levels. Thus, at any power level (P_n)

$$A_n = B_n K_1$$
$$A_n = C_n K_2$$
$$A_n = D_n K_3$$

where K_1, K_2 and K_3 are the constants of proportionality whose validity is established by the agreement achieved by the actual evaluation of these ratios. Also, the best statistical estimate of K_n is provided by the

POWER LEVEL (KW)	MEASURED VALUES**				CALCULATED RATIOS			CALCULATED DOSE			AVERAGE
	A (R)*	B (R)	C (n/cm^2)	D (n/cm^2)	A/B	A/C ($R/n/cm^2$)	A/D ($R/n/cm^2$)	K_1B (R)	K_2C (R)	K_3D (R)	$\bar{A}$
10	3.6×10^4	1×10^3	9.5×10^{12}	2.1×10^{11}	36	3.7×10^{-9}	1.8×10^{-7}	3.6×10^4	3.6×10^4	3.8×10^4	3.7×10^4
50	2.0×10^5	5.6×10^3	5×10^{13}	1.1×10^{12}	35.8	3.8×10^{-9}	1.8×10^{-7}	2.1×10^5	1.9×10^5	2.0×10^5	2.0×10^5
100	-	1.3×10^4	9.7×10^{13}	2.2×10^{12}	-	-		4.6×10^5	3.6×10^5	3.8×10^5	4.0×10^5
500	-	5.7×10^4	4.3×10^{14}	1.1×10^{13}	-	-		2.1×10^6	1.6×10^6	2.0×10^6	1.9×10^6
1000	-	1.2×10^4	8.1×10^{14}	2.1×10^{13}	-	-		4.3×10^6	3.3×10^6	3.8×10^6	3.8×10^6
					$35.9 = K_1$	$3.75\times10^{-9} = K_2$	$1.8\times10^{-7} = K_3$				

*R = roentgens

**All values are for 15 minute exposure

Table A-1 Power Level Versus Gamma Radiation Calibration

19-20 Feb. 1962
DHR:ek

Table A-2
GAMMA DOSIMETRY

Dosimeter No.	Dosimeter Location	Distance from Exposure Room Window	Run No.	Power Level	Time	Roentgens
255	On Boral ℄, Left	1/4 inch	2255	10 Kw	15 min.	3.6×10^4
263	" , Right	"	"	"	"	3.6×10^4
257	Wall Reference	5 feet	"	"	"	1.0×10^3
273	On Boral ℄, Left	1/4 inch	2256	50 Kw	"	2.0×10^5
278	" , Right	"	"	"	"	2.0×10^5
294	Wall Reference	5 feet	"	"	"	5.6×10^3
258	On Boral ℄, Left	1/4 inch	2257	100 Kw	"	3.1×10^5
271	" , Right	"	"	"	"	3.2×10^5
283	Wall Reference	5 feet	"	"	"	1.3×10^4
*	On Boral ℄, Left	1/4 inch	2258	500 Kw	"	1.9×10^6
*	" , Right	"	"	"	"	1.9×10^6
274	Wall Reference	5 feet	"	"	"	5.7×10^4
*	On Boral ℄, Left	1/4 inch	2259	1 Mw	"	3.5×10^6
*	" , Right	"	"	"	"	3.5×10^6
282	Wall Reference	5 feet	"	"	"	1.2×10^5

*At power levels of 500 Kw and 1 Mw, the gamma dose at the boral screen exceeds the useful range of the gamma dosimeter. The gamma dose was calculated by determining the ratio of the gamma dose at the boral screen to the neutron fluence at the wall reference point for power levels of 10 Kw, 50 Kw, and 100 Kw. The average of these ratios was applied to the wall reference neutron fluences measured during the 500 Kw and 1 Mw runs to calculate the corresponding gamma doses at the boral screen.

Table A-3
NEUTRON DOSIMETRY

Dosimeter No.	Dosimeter Location	Distance from Exposure Room Window	Run No.	Power Level	Time	Neutron Fluence $n/cm^2 > 3$ Mev	Neutron Fluence $n/cm^2 > 10$ Kev
76	On Boral ℄, Left	1/4 inch	2255	10 Kw	15 min.	1.29×10^{12}	1.00×10^{13}
77	" , Right	"	"	"	"	1.22×10^{12}	9.47×10^{12}
78	Wall Reference	5 feet	"	"	"	2.76×10^{10}	2.14×10^{11}
79	On Boral ℄, Left	1/4 inch	2256	50 Kw	"	6.50×10^{12}	5.04×10^{13}
80	On Boral ℄, Right	"	"	"	"	6.46×10^{12}	5.01×10^{13}
81	Wall Reference	5 feet	"	"	"	1.44×10^{11}	1.12×10^{12}
82	On Boral ℄, Left	1/4 inch	2257	100 Kw	"	1.29×10^{13}	1.00×10^{14}
83	On Boral ℄, Right	"	"	"	"	1.21×10^{13}	9.39×10^{13}
84	Wall Reference	5 feet	"	"	"	2.77×10^{11}	2.15×10^{12}
85	On Boral ℄, Left	1/4 inch	2258	500 Kw	"	5.62×10^{13}	4.36×10^{14}
86	On Boral ℄, Right	"	"	"	"	5.42×10^{13}	4.21×10^{14}
87	Wall Reference	5 feet	"	"	"	1.43×10^{12}	1.11×10^{13}
88	On Boral ℄, Left	1/4 inch	2259	1 Mw	"	1.05×10^{14}	8.15×10^{14}
89	On Boral ℄, Right	"	"	"	"	1.03×10^{14}	8.00×10^{14}
90	Wall Reference	5 feet	"	"	"	2.71×10^{12}	2.10×10^{13}

relationships:

$$K_1 = \frac{A_1/B_1 + A_2/B_2 \ . \ . \ . \ n}{n}$$

$$K_2 = \frac{A_1/C_1 + A_2/C_2 \ . \ . \ . \ n}{n}$$

$$K_3 = \frac{A_1/C_1 + A_2/C_2 \ . \ . \ . \ n}{n}$$

The results of this analvsis, presented in table A-1, show a greater dispersion of points for the **calculated** 15 minute gamma exposure levels occurring in the TLD data and the neutron dosimeter that was placed 1/4 inch from the reactor window. Dosimetry readings taken close to the reactor window will tend to show greater variation due to the geometrical relationships which make positioning of the dosimeter highly critical. TLD readings would tend to be high at the higher power levels due to the large amount of residual gamma radiation after reactor shutdown. Thus, the measured neutron fluence at 5 feet from the window would present the most representative data. However, to take advantage of the large number of data points observed, the average (A) of the three calculated values of A is selected. A recent check at 1/4" from the reactor window at the 100 KW power level gave the result of 4.8×10^2 roentgens/sec which is within ±5% of the value shown in table A-1 and is consistent with the published accuracy of TLD's.

In the performance of tests involvi the reactor, only two measured distances from the reactor window were ed. These were 1/4 inch and 18 inches. At the 18 inch distance, a inch shield of paraffin was used. Although only these two distances w used, it is important to show the relationship of gamma dose rate ve distance in order to indicate how critical placement of the dos eters is. Table A-4 provides gamma dose rate and neutron flux data that was either taken under this contract or provided by Northrop Corporation. Table A-5 is dosimetry data taken during the conduct of low temperature tests with the six inch paraffin shield in place.

Since thermoluminescent dosimeters were used in all tests where accurate measurement of gamma radiation was involved, it is important to consider some of the more important characteristics of these devices. In a batch of 750 instruments, a manufacturer has found that the average sensitivity difference less than 6% with the following details.

AVERAGE DEVIATION: 5.8%
DOSIMETERS WITH DEVIATION LESS THAN 5%: 44.7%
DOSIMETERS WITH DEVIATION LESS THAN 10%: 81.6%
DOSIMETERS WITH DEVIATION LESS THAN 15%: 95.5%

Distance From Window (Inches)	No. Shielding Gamma Dose Rate (R/Hr)	Neutron Flux (n/cm² sec)	6 Inches of Paraffin Gamma Dose Rate R/Hr	Neutron Flux n/cm²-se
1/4	$1.6x10^6$	1.1×10^{11}	-	-
12	4.7×10^5*	2.6×10^{10}*	-	2.2×10^9*
18	2.8×10^5*	1.7×10^{10}*	1.7×10^5	1.4×10^9*
24	2.0×10^5*	1.1×10^{10}*	1.4×10^5*	9.2×10^8*
36	1.2×10^5*	6.0×10^9*	8.0×10^4*	5.3×10^8*
48	8.0×10^4*	3.6×10^9*	5.4×10^4*	3.4×10^8*
60	5.2×10^4	2.4×10^9	3.6×10^4*	2.6×10^8*

* Northrop Published Value

xx 10 Kev

Table A-4 Radiation Intensity Versus Distance From Reactor Window (Reactor Power Level = 100 kw)

330-69-376
DHR:ek

3401 West Broadway, Hawthorne, California 90250

NORTHROP CORPORATE LABORATORIES

Telephone (213) 675-4611

27 June 1969

North American Rockwell Corporation
Los Angeles Division
International Airport
Los Angeles, California 90009

Attention: Mr. W. Crego, Dept. 291

Gentlemen:

The following table is a summary of the dosimetry for the tests conducted at the Northrop Reactor on 26 June 1969. The experiments were conducted within the Northrop Reactor dry exposur room with the 1/4 inch boral, 6 inches paraffin and .020 inch cadmium screens in position around the exposure room window.

Table A-5

GAMMA DOSIMETRY

Dosimeter Number	*Dosimeter Location	Distance from Exposure Room Window	Run Number	Power Level	Time	Gamma Dose Roentgens
101	Board #1	18"	3421	100 Kw	10 min	2.7×10^4
103	" #2	"	"	"	"	2.7×10^4
105	" #3	"	"	"	"	2.7×10^4
107	" #1	"	3423	"	"	2.7×10^4
109	" #2	"	"	"	"	2.7×10^4
111	" #3	"	"	"	"	2.8×10^4
113	" #1	"	3424	"	"	2.8×10^4
115	" #2	"	"	"	"	2.7×10^4
117	" #3	"	"	"	"	2.9×10^4

*See attached sketch for dosimeter locations.

NORTHROP CORPORATE LABORATORIES

D H Rusling

D. H. Rusling
Northrop Reactor

The linearity response to gamma radiation to 5×10^3 R is much less than 5% while the reproducibility error is less than 2%. The energy response could produce significant errors depending upon the material and its construction. For the tests conducted under this contract, calcium floride dosimeters were used.

APPENDIX B

Specification of the Vibration, Shock Testing, and Pressure Testing of a Gamma Ray Detector

TFD-68-35-1

SERIAL NO.

VIBRATION, SHOCK TESTING, AND

PRESSURE TESTING

OF A

GAMMA RAY DETECTOR

T. E. Carrell
Program Manager

DATE 13 May 1968

NO. OF PAGES 4 + 1

LOS ANGELES DIVISION OF NORTH AMERICAN ROCKWELL CORPORATION
INTERNATIONAL AIRPORT • LOS ANGELES, CALIFORNIA 90009 • TELEPHONE 213/670-9151

TABLE OF CONTENTS

1.0 TEST PROGRAM

This test program is intended to demonstrate that the equipment meets particular test requirements. The equipment shall be operating and functional tests performed during and after vibration testing. The equipment shall not be operating during the shock test, but shall be visually examined and functionally operated after each shock impact. The equipment shall not be operating during the pressure test but shall be examined and functionally operated after the pressure test.

2.0 EQUIPMENT

Figure 1 illustrates the gamma ray detector as fabricated by the Los Angeles Division of North American Rockwell Corporation. This detector will weigh approximately 14 ounces.

3.0 APPLICABLE SPECIFICATIONS

This document forms the only specification of interest to the testing agency.

4.0 TESTS

4.1 Functional Tests

The functional tests will be performed by North American Rockwell Corporation test engineers who are witnessing the tests. This test will consist of simulating the output signal by passing a current through the detector (no radiation sources are required). All test equipment required for these functional tests will be furnished by North American Rockwell Corporation. The total time for this test is approximately ten (10) minutes.

4.2 Vibration Tests

The equipment to be tested is defined in paragraph 2.0 above. The following sinusoidal vibration in two of the three major axes shall be used:

a. 5 to 20 hertz (Hz) at 0.5 inches double amplitude displacement
b. 20 to 100 hertz (Hz) at 10 G's peak
c. 100 to 160 hertz (Hz) at 0.019 inches double amplitude displacement
d. 160 to 2000 hertz (Hz) at 32 G's peak

The frequency shall be swept logarithmically from 5 Hz to 2000 Hz and from 2000 Hz to 5 Hz at the rate of one octave per minute for the first detector. Two additional detectors will be tested at a rate of two octaves per minute.

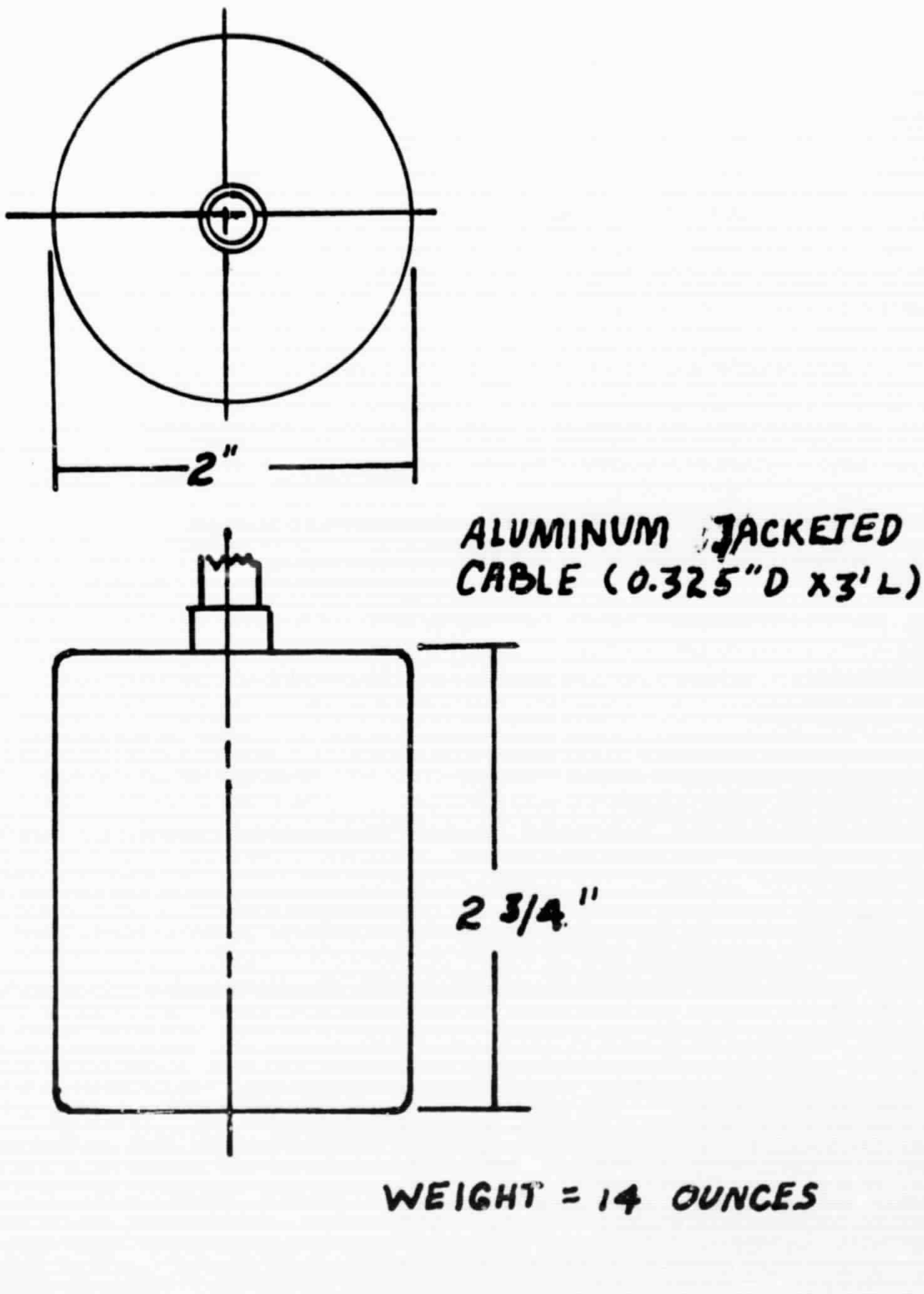


Figure 1. Dimensional Data, Gamma Ray Detector Unit

At least the input vibration level as well as that experienced by the detectors shall be automatically recorded and submitted to North American Rockwell Corporation. The purpose of this is to ascertain and document that the proper input vibration had been applied to the test program.

The equipment shall be operated during this test by North American Rockwell Corporation engineers.

It is requested that one accelerometer be employed to monitor the level of vibration on the detector.

4.3 Shock Tests

The equipment to be tested is defined in paragraph 2.0 above. The first detector shall be subjected to six (6) shocks of either 10 (triangular wave), 8 (sine wave), or 6 (square wave) milliseconds duration of 50 G in two of the three major axes. The test shall be repeated for two additional detectors at 25 G's.

The equipment shall not be operated during this test. A visual inspection and a functional test shall be performed after each shock impact.

4.4 Pressure Test

Three detector units shall be placed in a test chamber and the pressure shall be increased from ambient to 3.1×10^5 newtons/meter^2. The chamber pressure shall then be lowered to ambient and a visual inspection and functional test performed. The test chamber pressure shall then be lowered to 10^{-4} Torr and then raised to the ambient level. A visual inspection and a functional test shall be accomplished at this time to complete the test.

5.0 DATA REQUIREMENTS

5.1 A test report is required that includes:

a. Test Proceedure - The test proceedure shall consist only of reference to specific paragraphs of this TFD.

b. Test Results - Those that pertain to vibration, shock and pressure test, not the functional test.

c. Test Set up Photos - One reproducible photo per test (i.e. one for vibration, one for shock, and one for pressure).

d. Notarized Certification of Tests.

APPENDIX C

Test Report of the Vibration, Shock, and Pressure Testing of the Gamma Ray Detector

Originator's Report No. 5330-7664-1

Revision

Report of Test on: Three (3) Gamma Ray Detector identified as Specimens #1,#2, and #3 in this report.

TEST AUTHORIZED BY

NORTH AMERICAN ROCKWELL
LOS ANGELES DIVISION
INTERNATIONAL AIRPORT
LOS ANGELES, CALIFORNIA 90009

Purchase Order No.: L8F0-DM-170097

TEST PERFORMED BY

APPROVED ENGINEERING TEST LABORATORIES
5320 West 104th Street
Los Angeles, California 90045

NAS8-20840

	Date	Signature	Stamp
Test Initiated	7-8-69		
Test Completed	7-9-69		
Report Written By	7-10-69	Joyce Peterson	
Test Engineer	7-10-69	[illegible]	
Project Supervisor	7-10-69	[illegible]	
Quality Control	7-10-69	[illegible]	[illegible]
Lab. Director	7-10-69	[illegible]	
DCASR/LA			
Source Inspection			
Final Release	7-10-69	Joyce Peterson	

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TABLE OF CONTENTS

APPROVED ENGINEERING TEST LABORATORIES
LOS ANGELES, CALIFORNIA
AETL

1.0 GENERAL REPORT SUMMARY

1.1 Component/Part Name: Gamma Ray Detector

1.2 Program or Weapon System: Unknown

1.3 Type of Test Performed: Qualification Test

1.4 Test Initiated: 7-8-69
Test Completed: 7-9-69

1.5 Originator's Report Title: Qualification Test Report

1.6 Originator's Report Number: 5330-7664-1

2.0 SCOPE

2.1 The purpose of this test program was to demonstrate compliance of three (3) Gamma Ray Detectors to the Qualification Test requirements of References 6.1 and 6.2 as required by Reference 6.3 of this test report. The test procedures employed and the results obtained, are presented herein for evaluation.

3.0 DESCRIPTION OF TEST SPECIMENS

3.1 Three (3) Gamma Ray Detectors, no identifying part number or serial numbers, were submitted for testing. The test specimens were manufactured by North American Rockwell, Los Angeles Division, International Airport, Los Angeles, California 90009.

4.0 DISPOSITION OF TEST SPECIMENS

4.1 At the conclusion of the test program, the test specimens were returned to North American Rockwell, Los Angeles Division, International Airport, Los Angeles, California 90009.

5.0 TEST SEQUENCE AND TEST SUMMARY

5.1 The test specimens were subjected to the following sequence of testing, in accordance with References 6.1 and 6.2, as required by Reference 6.3 of this test report.

Para. No.	Test
9.1	Shock Test
9.2	Vibration Test
9.3	Pressure-Vacuum Test

5.2 The test procedures employed during the performance of this test program and the results obtained, are presented in this test report for evaluation.

6.0 REFERENCES

6.1 Approved Engineering Test Laboratories Test Report No. 5330-7058, dated 20 June 1968. See Notice of Deviation No. 1 of this report.

6.2 North American Rockwell Corporation Test Procedure No. TFD-68-35-1, dated 13 May 1968.

6.3 North American Rockwell Corporation Purchase Order No. L8F0-DM-170097, dated 081668.

7.0 TEST CONDITIONS

7.1 Unless otherwise specified herein, all tests required by the specifications were performed at room ambient conditions, defined as an atmospheric pressure of 29.92 ± 0.5 inches of mercury absolute, a temperature of 70° ± 20°F, and prevailing relative humidity of less than 85% RH.

8.0 TEST EQUIPMENT AND INSTRUMENTATION

8.1	Instrument:	Shock Test Machine
	Manufacturer:	Barry Controls
	Model No.:	VP-150
	Type:	Free-Fall Drop
	Range:	0 to 1500 g's
	Wave Forms:	Sawtooth, 1/2 sine, or square
	Calibration:	Prior to each use.
8.2	Instrument:	Vibration Exciter
	Manufacturer:	M. B. Electronics
	Model No.:	C-60
	Serial No.:	119
	Type:	Sine or Random
	Range:	6000 force-pounds: 5-5000 cps: 120 g's; 1 inch total displacement
	Calibration:	Prior to use
8.3	Instrument:	Amplifier
	Manufacturer:	M. B. Electronics
	Model No.:	T452
	Serial No.:	148
	Range:	17.5 kva
	Accuracy:	± 1.5% (30 to 3000 cps); ± 3% (10 to 30 cps and 3000 to 5000 cps)
8.4	Instrument:	Accelerometer Integrator/Amplifier
	Manufacturer:	M. B. Electronics
	Model No.:	N504
	Serial No.:	934
	Range:	5 to 10,000 cps (amplify position) 5 to 3,000 cps (integrate position)
	Accuracy:	± 1.0 %
	Calibration:	Three months

8.5	Instrument:	Accelerometer
	Manufacturer:	Endevco Corporation
	Model No.:	2252
	Serial No.:	NH28
	Type:	Piezoelectric
	Range:	.1 to 7000 cps, 0-5000 g
	Accuracy:	± 3%
	Calibration:	Three months
8.6	Instrument:	Shock Amplifier
	Manufacturer:	Endevco Corporation
	Model No.:	2118
	Serial No.:	PA 53
	Type:	Charge
	Range:	0 - 50,000 g
	Accuracy:	± 1.5%
	Calibration:	Three months
8.7	Instrument:	Accelerometer
	Manufacturer:	Endevco Corporation
	Model No.:	2213 M5
	Serial No.:	EC 48
	Type:	Piezoelectric
	Range:	Vibration: 0-10,000 peak g's Shock: 0-16,000 peak g's Frequency: 5-10,000 cps Output: Approx. 30 mv/peak g
	Accuracy:	± 3%
	Calibration:	One month
8.8	Instrument:	Peak Holding Meter
	Manufacturer:	Endevco Corporation
	Model No.:	2954
	Serial No.:	PA 16
	Type:	Peak Reading
	Range:	0 - 50,000 g's
	Accuracy:	± 2%
	Calibration:	Three months

8.9	Instrument:	Automatic Vibration Exciter Control
	Manufacturer:	B & K for M. B. Electronics
	Model No.:	N572-73
	Serial No.:	117
	Range:	5 cps to 10 kc; 0 to 1000 g's Scanning Speed variable from 3.1 to 315 degrees per minute
	Accuracy:	Frequency, ± 1%; Acceleration, Displacement and Velocity, ± 4%
	Calibration:	Three months
8.10	Instrument:	Pressure Gauge
	Manufacturer:	Ashcroft Guage Co.
	Model No.:	1082-AXED
	Type:	High and low electrical contacts
	Range:	0 to 60 psi
	Accuracy:	± 0.75 with contacts; 0.25% without contacts
	Calibration:	Three months
8.11	Instrument:	CEC Helium Mass Spectrometer Leak Detector
	Serial No.:	8295
	Calibration:	Daily
8.12	Instrument:	Storage Oscilloscope
	Manufacturer:	Tektronix
	Model No.:	549
	Serial No.:	000845
	Type:	Dual Channel
	Range:	Time Base: 0.1usec/cm to 5 sec/cm External Input: 0.2 volts/cm,dc to 350 KHZ Vertical Sensitivity: 5 mv/cm to 1A1 plug in
	Viewing Time:	Up to one hour
	Calibration:	Three months

8.13	Instrument:	Oscilloscope Camera
	Manufacturer:	Hewlett-Packard
	Model No.:	196B
	Serial No.:	215-00300
	Lens Opening:	f1.9 to f16 shutter speed: Time exp. to 1/100 second
		Object/Image Ratio: 1.0 to 0.9

9.0 TEST PROCEDURES AND TEST RESULTS

9.1 Shock Test (Ref. 6.2)

9.1.1 The test specimens, individually, were rigidly mounted to the shock test machine, the following results were obtained:

Specimen No.	Drop Height	Amplitude (G)	Duration (MS)	No. of Drops	Axis
#1	9.7	50	8.0	6	X
	9.7	50	8.0	6	Z
#2	4.1	25	8.0	6	Z
	4.1	25	8.0	6	X
#3	4.1	25	8.0	6	X
	4.1	25	8.0	6	Z

The wave shape was approximately half-sine. Drops were made against rubber to achieve the desired amplitude.

9.1.2 At the completion of each drop in each axis the test specimens were visually examined for evidence of damge.

9.1.3 The test specimens complied with the specification requirements in all respects. No damage was noted as a result of the Shock Test.

9.1.4 See Figure 1 for axis identification.

9.2 Vibration Test (Ref. 6.2)

9.2.1 The test specimens were installed on the vibration exciter and subjected to sinusoidal cycling for a period of 8.6 minutes for Specimens #1 and #2, and 17.2 minutes for Specimen #3, in the X and Z axes only, as shown in Figure 1 of this report. The frequencies and vibratory levels were as follows:

Frequency (cps)	Vibratory Level
5 - 20	0.5" D.A.
20 - 100	± 10 g's
100 - 160	0.019" D.A.
160 - 2000	± 32 g's

During the above cycling, the specimens were being monitored by North American Rockwell personnel.

9.2.2 At the completion of vibration in each axis, the test specimens were visually examined for evidence of damage or deterioration. The test specimens complied with the specification requirements. There was no evidence of damage or deterioration noted as a result of vibration testing.

9.3 Pressure-Vacuum Test (Ref. 6.2, Para. 4.4)

9.3.1 Each test specimen, in turn, were placed in the test chamber and the pressure increased from ambient to 3.1×10^5 (or 44.5 psi) newtons/meter^2. The chamber pressure was then lowered to ambient and a visual inspection and functional test was conducted by North American Rockwell personnel.

9.3.2 The test chamber pressure was then lowered to that of liquid hydrogen (LH_2) vacuum,(or 1×10^{-4} torr.) and then raised to the ambient level. A visual inspection and functional test was conducted by North American Rockwell personnel. The specimens were then removed from the chamber.

9.3.3 No damage was noted as a result of the Pressure-Vacuum Test.

APPROVED ENGINEERING TEST LABORATORIES
LOS ANGELES, CALIFORNIA
AETL

Report No.: 5330-7664-1

Date: 7-10-69

NOTICE OF DEVIATION

CUSTOMER North American Rockwell

Job No. 5330-7664-1

Part No.

Purchase Order No. L8F0-DM-170097

Serial No.

N.O.D. No. 1

Date 7-8-69

Notification Made: To Doug Stevens

By Bill Crego

Date & Time 7-8-69

How Verbal

Test Title: Shock And Vibration Testing

Test Procedure NA-68-35-1 Paragraph 4.4

Requirements

Description of Deviation Conduct shock and vibration test in accordance with AETL Job #5330-7058 dated 6-20-68.

Disposition of Test Specimen Proceed with test.

By Bill Traw

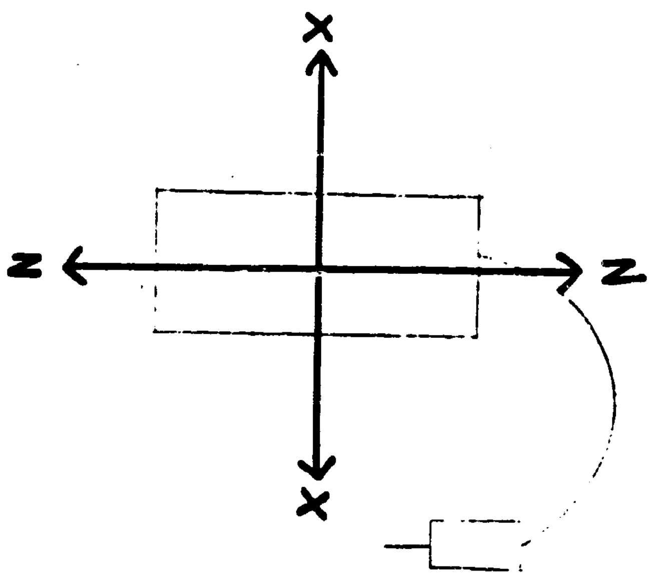
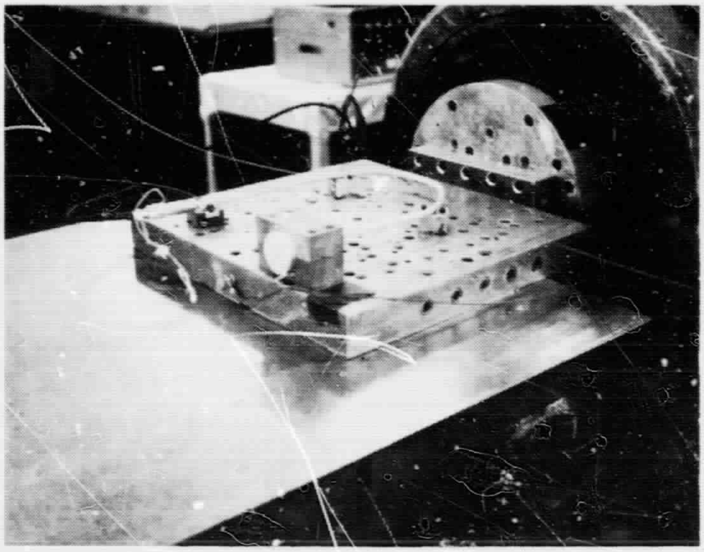


FIGURE 1

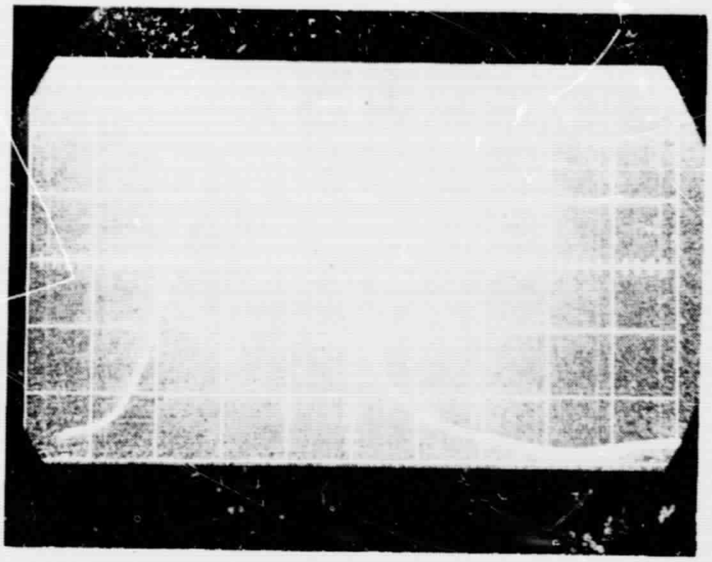
AXIS IDENTIFICATION

PHOTOGRAPHS OF THE
VIBRATION TEST PARA.9.2



SPECIMEN #1

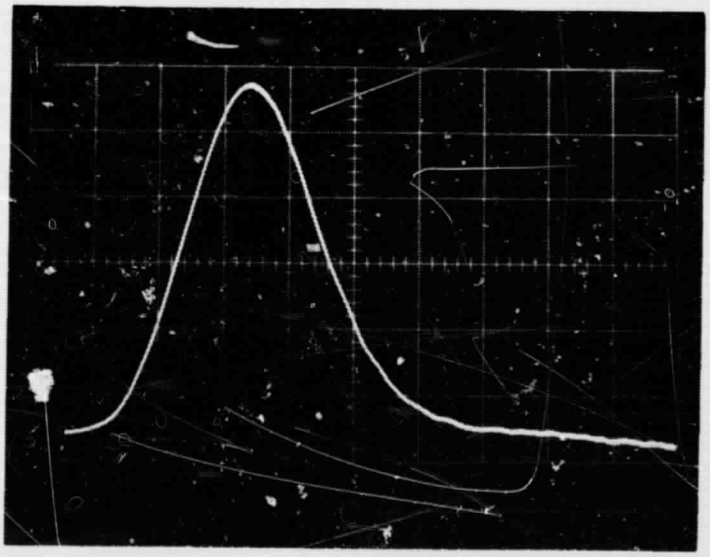
X Axis



Vertical Sensitivity: 10 G/Div.

Horizontal Sensitivity: 2 MS/Div.

Z Axis

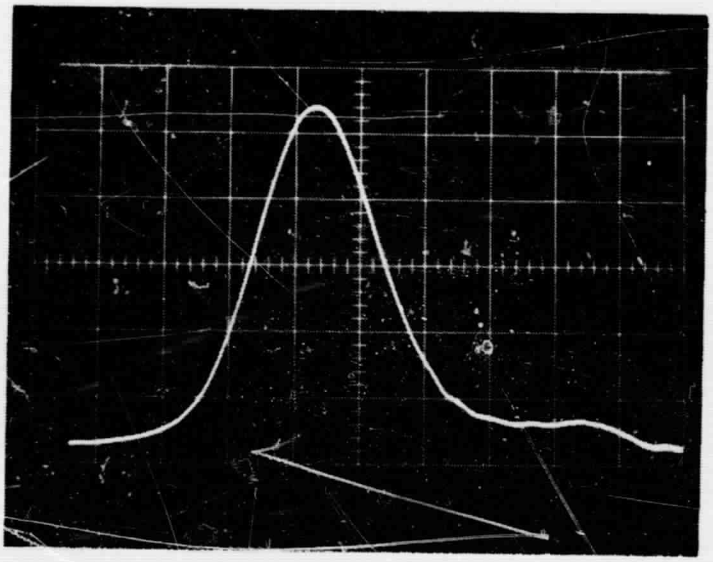


Vertical Sensitivity: 10 G/Div.

Horizontal Sensitivity: 2 MS/Div.

SPECIMEN NO. 2

X Axis



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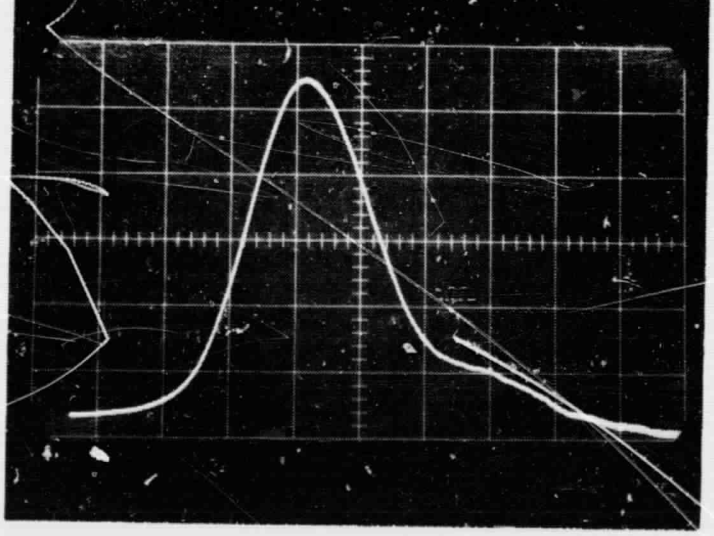
Horizontal Sensitivity: 2 MS/Div.

Z Axis

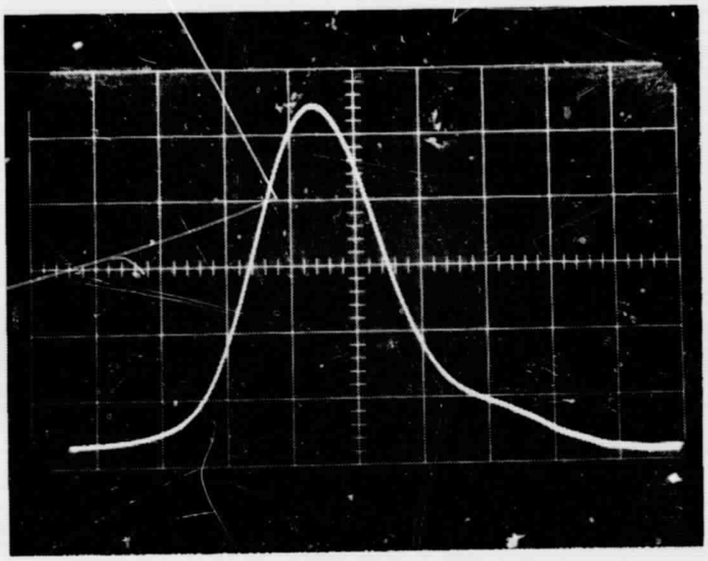


Vertical Sensitivity: 5 G/Div.

Horizontal Sensitivity: 2 MS/Div.

SPECIMEN #3

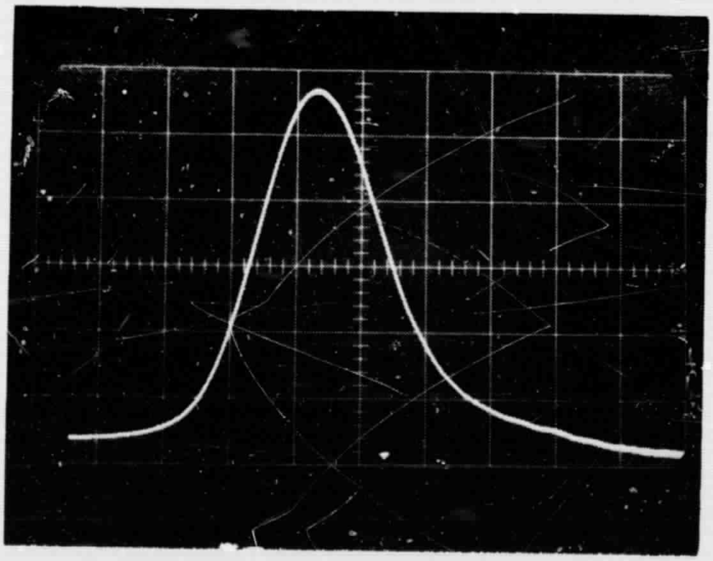
X Axis



Vertical Sensitivity: 5 G/Div.

Horizontal Sensitivity: 2 MS/Div.

Z Axis



Vertical Sensitivity: 5 G/Div.

Horizontal Sensitivity: 2 MS/Div.

APPENDIX D

TECHNICAL SPECIFICATIONS

A. General

This procurement is for a detector or detector system which will provide continuous monitoring of gamma radiation in and about a liquid hydrogen propellant tank. The instrument must be compatible with the liquid hydrogen environment, especially if a preamplification system is necessary to obtain the desired output characteristics given in the specifications below. It is intended for this item to be used for instrumentation on the Nuclear Ground Test Module and any flights which may utilize a nuclear powered engine.

B. Specifications

The measuring device developed for this application must meet the following requirements:

(1) Measuring Capabilities and Accuracies: The measuring device shall be capable of measuring the gamma dose rate in a mixed neutron and gamma radiation environment with at least a ±10% accuracy of the actual value. The repeatability of the system shall be within ±3%.

(2) Media: Liquid hydrogen, ambient, and space environments.

(3) Response Time: Two (2) seconds or less.

(4) Size and Weight: The measuring device shall be designed for minimum size and weight.

(5) Temperature: The measuring device shall be capable of operating without failure during and/or after being subjected to an environmental temperature varying from plus 60°C to - 253°C.

(6) Vibration: The measuring device shall be capable of operating without failure during subjection to the following sinusoidal vibration in each of the major axes:

a. 5 to 20 hertz (Hz) at 0.5 inches D.A. Displacement.
b. 20 to 100 Hz at 10 G's peak
c. 100 to 160 Hz at 0.019 inches D.A. Displacement
d. 160 to 2000 Hz at 32 G's peak.

The frequency shall be swept logarithmically from 5 Hz to 2000 Hz and from 2000 Hz to 5 Hz at the rate of one octave per minute.

(7) Shock: The measuring device shall be capable of operating without failure after being subjected to six (6) shocks of either 10 (triangular wave), 8 (sine wave), or 6 (square wave) milliseconds duration of 50 g in each of the three major axes.

(8) Pressure: From 3.1 x 10^5 Newtons - meter minus 2 to vacuum and include sea level pressure - air, LH^2 vacuum

(9) Radiation environment: Gamma, 1 x 10^5 to 1 x 10^7 Roentgens/hour Fast Neutrons, 1 x 10^{11} neutrons/cm^2-sec. maximum, Thermal Neutrons, 1 x 10^{11} neutrons/cm^2- sec. maximum

(10) Input voltage: 28 ± vdc.

(11) Output signal: The output signal of this detector will be a voltage (minimum of 1 millivolt to 100 millivolt positive signal) proportional to the gamma ray exposure dose rate from 1 x 10^5 to 1 x 10^7 roentgens per hour shown. The output resistance of this detector may be greater than one (1) megohm, although an output resistance equal to or less than 4000 ohms is desirable.

(12) Power Consumption: Held to a minimum.

(13) Grounding Procedure: The following circuits shall be isolated from each other: 28 Vdc, minus; signal output, minus; signal input; transducer excitation voltage, and case ground.

(14) Safety: The measuring device must be compatible with liquid hydrogen, and outgassing characteristics should be considered.