IAEA Coordinated Research Project on Development of Harmonized QA/QC Procedures for Maintenance and Repair of Nuclear Instruments

Test Procedure for Geiger-Mueller Radiation Detectors

PROCEDURE Nº MRNI-501
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Instituto Nacional de Investigaciones Nucleares
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CONTENT

1.- OBJECTIVE AND SCOPE

1.1.- Objective

The objective of this procedure is to describe the steps to verify the electrical characteristics and the radiation response of Geiger–Mueller detectors.

1.2.- Scope

This procedure is applicable only to Geiger-Mueller detectors.

2.- NOTATION AND DEFINITIONS

2.1.- Notation

GM — Geiger-Mueller detector.

2.2.- Definitions

2.2.1. Detector
A device that converts the energy of a photon or incident particle in an electric pulse.

2.2.2. GM Detector
A gaseous radiation detector that is designed specifically to operate in the Geiger–Mueller Plateau region.

2.2.3. Geiger-Mueller Plateau Region
Voltage range where the number of pulses generated in a GM detector is independent of the applied voltage for the same irradiation conditions.

2.2.4. Detector Background Counting
Counting that is present even without a radiation source, when the detector is biased, typically with some hundred volts.

2.2.5. Activity
Number of disintegrations per second of a radioactive source, the unit of activity is the Becquerel (Bq) that corresponds to one disintegration per second. The Curie (Ci) is also used and equals to 3.7×10^{10} Bq.

2.2.6. Sensitivity
It is the ratio between the number of counts per unit of time obtained in a GM detector and the exposure rate for a given radiation source. The employed isotope must be specified.

2.2.7. Dead Time
Time interval after the occurrence of a pulse when the detector remains insensible to the radiation.

2.2.8. Recovery Time
Elapsed time between a pulse and a second pulse with an amplitude of 50% of the normal size.

2.2.9. Exposure Rate
Amount of radiation measured as its capability to ionize the air. The utilized unit is the Roentgen/hour (R/hr).

3.- DEVELOPMENT

The sequence of steps to verify the electrical characteristics and radiation response of GM detectors is described in the next paragraphs. A flux diagram of the process is shown in Annex I.

3.1- Generalities

Whenever possible, refer to the test conditions recommended by the detector manufacturer in the sheet of specifications.

A technical report about the verification of the electrical characteristics and the response to radiation of the GM detectors must be elaborated, including the circuit diagram, environmental conditions, geometry of the testing set-up, count rate, isotope employed and details of the test instruments.

3.1.1.- First of all, make a physical inspection of the detector, looking for damages in the body and electrodes, strikes, integrity of the window, corrosion, oxidation.

3.2.- Test Instruments

All the instruments employed in the tests must be calibrated and with a valid calibration certificate.

3.2.1 Detector Bias Power Supply.

Generally it is a high voltage power supply with enough current capacity to feed the detector without any loose in regulation. The ripple should be less than 100 mV.

3.2.2 High impedance Voltmeter.

A high impedance voltmeter ($\geq 10M\Omega$) or an electrometer should be used to measure the high voltage applied to the detector, the use of an attenuated probe is recommended.

3.2.3 Oscilloscope

Use a digital oscilloscope with a high voltage coupling capacitor when needed.

3.2.4 Counter or Scaler

The number of counts per unit of time is measured with a counter or scaler for nuclear pulses, it generally includes a voltage discriminator to block low amplitude noise pulses. The input pulses to the counter or scaler must be positive.

3.2.5 Rate Meter

The average number of counts per unit of time is measured with a rate meter for nuclear pulses. The input pulses to the rate meter must be positive.

3.3.- Test Conditions

3.3.1 Background Radiation

Be sure that the only contribution to the detector counting is the natural background, avoiding the contribution due to any additional radioactive source.

3.3.2.- Temperature

Some characteristics of GM detectors are temperature dependant, a reference temperature between 20º C and 25 °C is recommended.

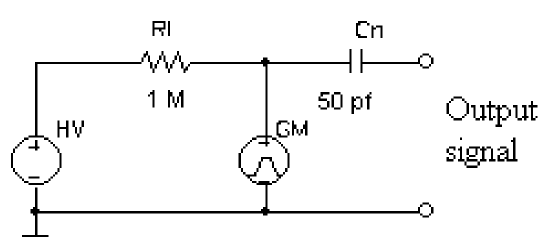
3.3.3.- Radioactive source employed

Generally, a γ radiation from a Co-60 source is specified to characterize the GM detectors. A source with an activity of around 37000 Bq (1 μCi) could be used.
The response of GM detectors to α and β radiation can be reported under specified special conditions.

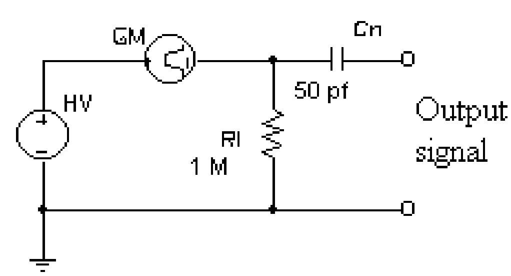
3.4.- Test Circuits

Whenever it could be possible, refer to the test conditions recommended by the manufacturer in the specifications sheet, if it is not available, use one of the diagrams shown in Fig. 1.
In any case, specify the value of the following components:

- Rl : limiter resistor (any value between 1 MΩ and 10 MΩ)
- Cn : coupling capacitor (any value between 50 pF and 1 nF)
- Counting circuit employed (oscilloscope, counter, etc.), kind of preamplifier or equivalent circuit (Input Resistance and capacitance) which could affect the shape of the pulse.



a) High voltage coupling capacitor is needed.



b) High voltage coupling capacitor is not needed.

Fig.1.- Circuits employed for the measurement of GM detectors.

The interaction of the radiation with the detector gas generates an output signal in the circuits shown in Fig. 1. If and oscilloscope is connected in the output port, we could see a pulse.
Fig. 2 shows a circuit in which a preamplifier is employed, the amount of pulses delivered by the GM detector is measured in a nuclear discriminator-counter, in this case, the discriminator eliminates the electric noise, a clock in the counter fixes the counting time at the experiment.

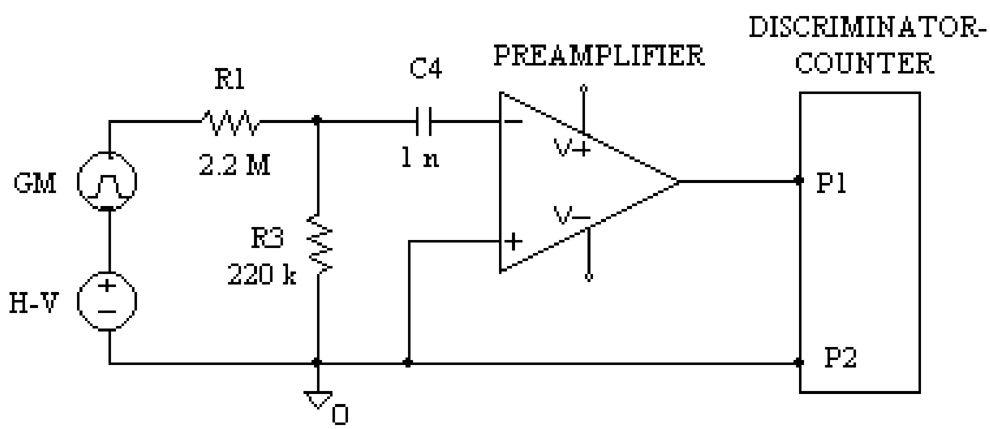


Fig. 2.- Circuit used to count the pulses from the GM detector.

If a preamplifier is not available, it is still possible to count the pulses from the GM detector by connecting the discriminator-counter directly to the output of the circuits shown in Fig. 1.

3.5.- Measurements

In this paragraph, the parameters of the GM detector are defined, considering that the detector is operating in the more adequate operating point, this optimal operating point is obtained from the response graph of the detector as function of the applied voltage.
In this example, the values for the LND 719 detector are obtained, however, these values could vary widely depending on the detector model and mark.

3.5.1 Response graph as a function of applied voltage.
Use one of the circuits shown before to measure the number of counts in a counter, place a Co-60 source at a fixed distance from the detector and vary the bias voltage. Be sure that the counts in the plateau be less than 20 times the maximum average counting of the detector to avoid dead time effects. The maximum average counting is calculated as the inverse of the dead time specified in the detector data sheet, if this data is not available, make a measurement with a pulse repetition rate less than 5000 counts per second. See Fig. 3.

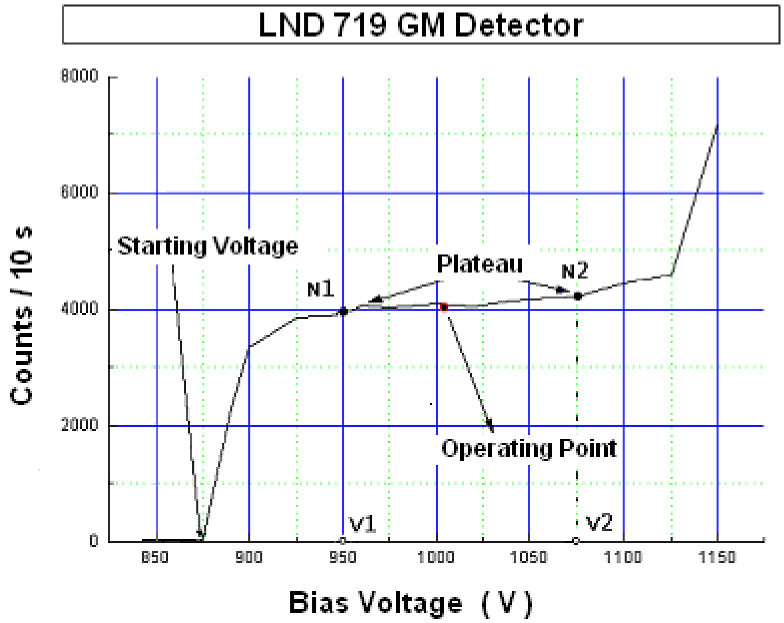


Fig. 3. Response of the GM detector as function of applied voltage.

If it is required, a similar graph can be built for α or β radiation, in that case, the radioactive source and geometry used in the measurements must be specified .

From Fig. 3, several detector parameters are derived:

- Starting voltage.
  In this example, 875 V.
- Plateau or Geiger-Mueller Region.
  In this example, from 950 to 1075V
- Plateau lenght. In general, it must be more than 100 V.
  In this example, 1075V – 950V= 125 V
- Optimal operating point.
  The optimal operating point is selected just in the middle point of the plateau.
  In this example, 1013 V
- Slope. The slope in the plateau, P, is calculated in % per every 100 V, with the following expression:

$$P = 100\left(\frac{N2-N1}{V2-V1}\right)\left(\frac{100}{(N1+N2)/2}\right)$$

In general, the value of the slope must be less than 15 % to consider that the detector is in good conditions.

In this example.

$$\mathbf{P = 100}\left(\frac{4200-4000}{1075-950}\right)\left(\frac{100}{(4000+4200)/2}\right)$$

P = 3.9 %

3.5.2 Measurement of the background with shielding.

Obtain the background reading in counts per minute, utilizing a circuit similar to the one shown in Fig.2, use a shielding on the detector (50 mm of lead in the outer shield plus 3 mm of aluminum in the inner shield).

In this example, **75 c.p.m.**

3.5.3 Sensitivity Measurement.

The sensitivity, S, to γ radiation is defined as the ratio of the number of counts per second, N, obtained and the exposure rate, $\bar{X}$.

$$S \equiv \frac{N}{\bar{X}}$$

Generally, it is specified for a Cobalt-60 source.

Use a circuit similar to the one shown in Fig.2.

For a defined distance *r* in cm, the source produces an exposure rate $\bar{X}$ in R/hr given by the equation:

$$\bar{X} \equiv \Gamma \frac{A}{r^2}$$

where: $\Gamma = 13.2 \frac{cm^2}{mCi}$ for Co-60

A : is the activity of the source in mCi

The sensitivity can vary widely, between 0.2 cps/mR/hr and 240 cps/mR/hr, depending on the detector model.

In this example: **S=90 c.p.s. /mR/hr**

3.5.4 Hysteresis.

When a hysteresis effect could be important, obtain the graph of Fig. 3 increasing the bias voltage and then repeat the measurements but in descending order of bias voltage, and compare the results obtained.

3.6.- Pulse Characteristics

The pulse characteristics can be measured in one of the circuits shown in Fig.1, an oscilloscope is connected in the output port, the detector is biased at the optimum operating voltage.

3.6.1 Amplitude

Is the voltage measured from the base line to the maximum value of the pulse. For this example, 75 V. See Fig. 4.

3.6.2 Rise Time

Elapsed time from 10% to 90% of the maximum value, measured in the leading edge of the pulse. It must be less than 1.5 μs. In the example, **1 μs.** See Fig. 4.

3.6.3 Dead Time

The dead time, DT, is the elapsed time between the beginning of one pulse and the closest next pulse available. The radioactive source must be placed very close to the detector to increase the counts, in this condition, the dead time effect can be noticed more easily. The DT can vary between 20 μs and 200 μs, depending on the detector model. In the example, DT **= 130 μs.** See Fig. 4.

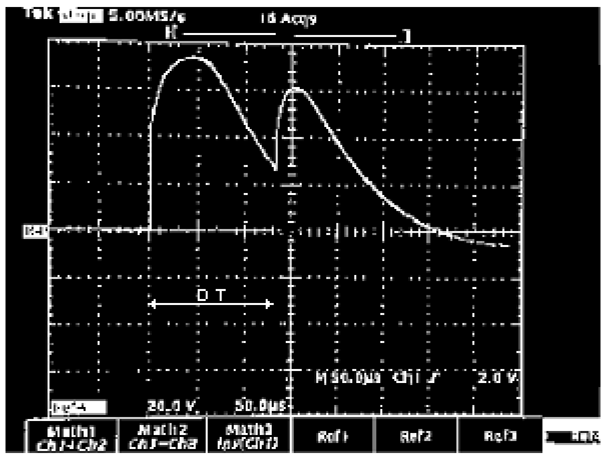


Fig. 4.- GM detector pulses as seen in the Oscilloscope screen to determine the dead time. The settings of the instrument are: 20 V/div and 50 μs/div

3.7.- Detector Aging.

The aging of GM detectors affects its detection characteristics and parameters. With respect to the functionality, the more important effects are:

- Drastic reduction of sensitivity
- Increase of counts respect to the expected value of sensitivity. This effect is true for old tubes due to a gas leakage.
- Increase of background counts.
- Notorious reduction of the plateau region.
- Increase of the slope in the plateau region.
- Drastic change in the optimum operating voltage.

3.8.- Advanced test

There is a limitation on the response of the GM detector for high values of exposure rate, in fact in the limit the detector could loss all its detection capability. Fig. 5 shows, for example, the experimental results for high exposure rates, notice that after 120 mR/hr the detector reduces its response drastically.

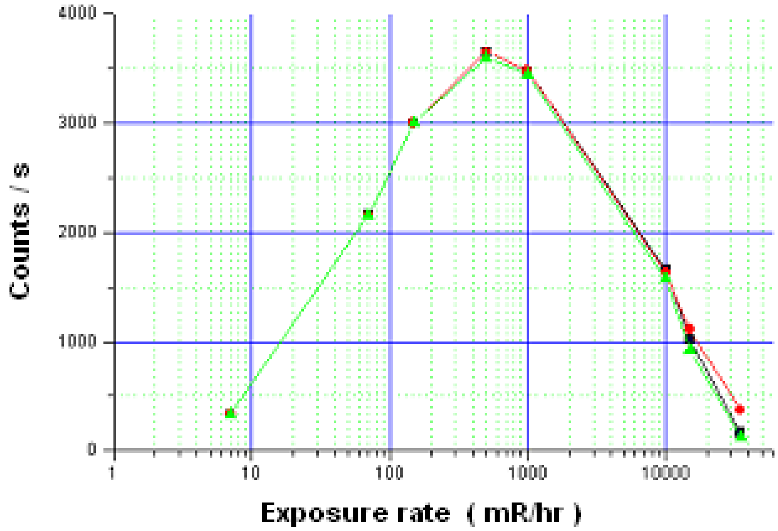


Fig. 5.- Counts per second obtained in a G-M detector for γ radiation and different exposure rates.

In order to get the counting values of the Fig. 5, very high radiation fields are required, thus, if this kind of measurements are required, great care need to be taken to avoid a high radiation exposure of the operative personnel. The help of the radiation protection personnel should be desirable.

4.- ADMINISTRATION OF THE TECHNICAL REPORTS

4.1 Numbering of the reports.

All the generated technical reports must have a unique and consecutive number.

4.2.- Personnel.

The test of GM detectors must be done by trained personnel.

4.3.- Test Report.

4.3.1 The results of the test of GM detectors must be registered in a unique technical report, stating the description of the GM detector, mark, model, serial number, and all the test conditions, including the name of the person who made the tests.

4.3.2 All the technical reports must be classified and keep in a folder for future consult.

5.- ACTION IN CASE OF NON CONFORMITIES.

5.1 Technical Report.

Even in the case that results of the test are not as expected, a technical report has to be elaborated, indicating the non conformities and how far are the measured characteristics from the ideal ones.

5.2 Labelling.

The components or equipments that are not under specifications or with a failure have to be marked with a label indicating: **OUT OF SPECIFICATIONS** and **FAILURE** respectively.

6. RESPONSIBILITIES

6.1.- Head of the Department.

Supervise that all the activities for testing of GM detectors follow the established procedure.

6.2.- Area Responsible.

6.2.1 Assure that all the electronic test equipment be in good operational conditions and with a valid calibration certificate.

6.3.2 Verify that all the activities for testing of GM detectors follow the established procedure

6.2.3 Verify that the technical reports contain all the details of the testing of GM detectors.

6.2.4 Maintain a register and control of the technical reports for all the GM detectors tested in the laboratory.

6.3 Operative Personnel.

6.3.1 Verify that all the electronic test equipment be in good operational conditions and with a valid calibration certificate.

6.3.2 Follow the steps established in this procedure for the testing of GM detectors.

6.3.3 Elaborate the technical report of all the tests of the GM detector.

6.3.4 Inform to the Area Responsible of any anomalous condition encountered during the test procedure.

7.- BIBLIOGRAPHY

1.- ANSI/IEEE Std. 309-1999/N 42-3-1999 (R2006) "IEEE Standard Test Procedures and Basis for Geiger–Mueller Counters" U.S.A. 2006.

2.- Knoll, Glenn F. "RADIATION DETECTION AND MEASUREMENT", Third Edition, John Wiley and Sons. U.S.A. 2000.

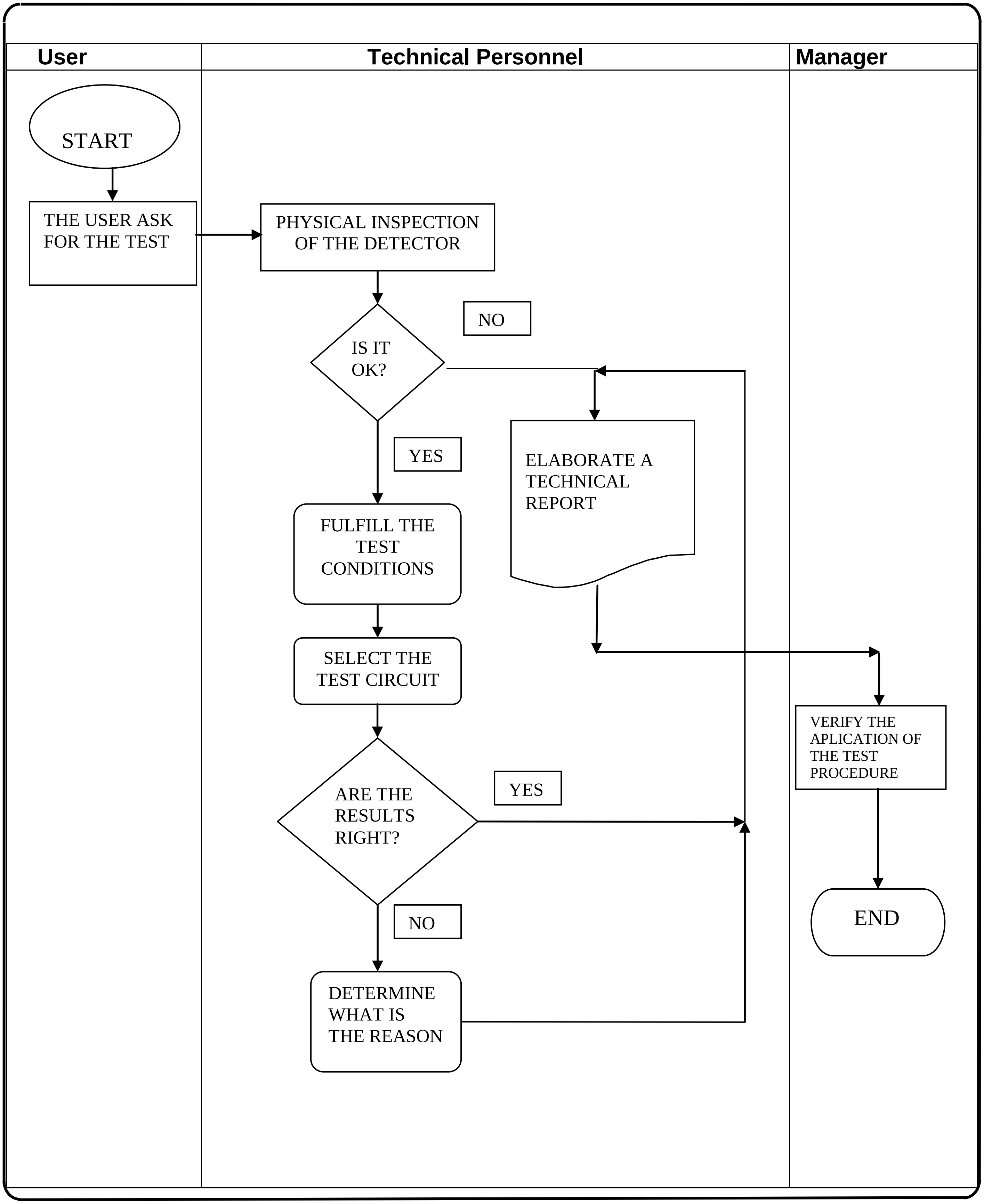
3.- Philips "GM Tubes, General Information" Electronic Tubes , Book T6, 1986

4.- LND Inc., home page available on the web: www.lndinc.com

8.- ANNEXES

Annex I

Flow Chart.



User
Technical Personnel
Manager
START
THE USER ASK FOR THE TEST
PHYSICAL INSPECTION OF THE DETECTOR
IS IT OK?
NO
YES
ELABORATE A TECHNICAL REPORT
FULFILL THE TEST CONDITIONS
SELECT THE TEST CIRCUIT
ARE THE RESULTS RIGHT?
YES
NO
DETERMINE WHAT IS THE REASON
VERIFY THE APLICATION OF THE TEST PROCEDURE
END

Annex II

Test report

TEST REPORT Nº GM-______

Geiger Mueller detector number:____________

Mark:____________ Model:_______________
Serial Number:____________Window:_______

Physical Revision

Condition	YES	NO
Damage in the Body		
Damage in the electrodes		
Strikes		
Integrity of the window		
Corrosion		
Oxidation		

Instruments Employed

Instrument	Mark	Model	Serial number
High Voltage Power Supply			
Voltmeter/Electrometer			
Oscilloscope			
Counter, Scaler			
Clock, Timer			
Rate Meter			

Environmental Conditions

Background	Temperature

Radioactive Source

Source	Energy	Activity	Date

Test Circuit

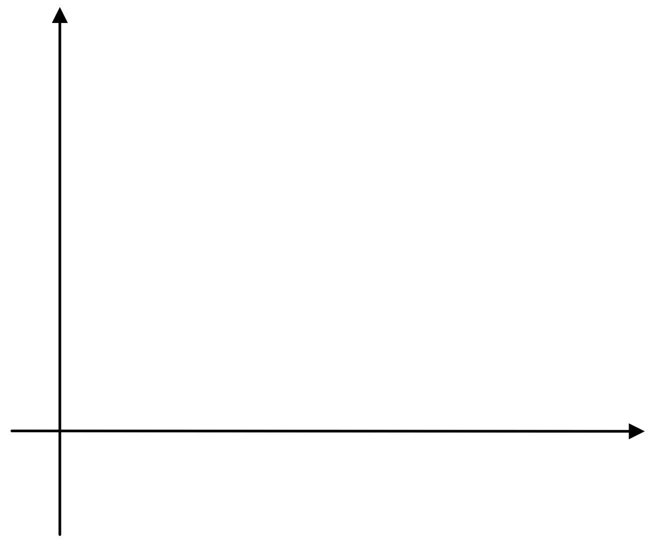
Fig. 1.a	
Fig . 1.b.	

R1(MΩ)	
Cn (pF)	

Response as a function of applied voltage

F.GC-1.b/2/12

Bias Voltage	Count/100s



Starting voltage (V)		
Plateau from (V) to (V):		
Plateau length (V)		
Optimal Operating voltage (V)		
Slope in the plateau (%)		
Background with shielding (Counts/minute)		
Isotope:	Sensitivity (cps/mR/hr)	
	Pulse amplitude (V)	
Rise time (ns)		
Dead time(μs)		

Diagnostic or Comments:

Tested By:	
Date:	