

# LABORATÓRIO DE FÍSICA DAS RADIAÇÕES E ATÓMICA

Mestrado Integrado em Engenharia Física Tecnológica

## O DETECTOR DE GEIGER-MÜLLER

### Operação e aplicações

#### 1. INTRODUÇÃO

O trabalho tem duas vertentes:

- A. Na primeira estudam-se as características do detector: seu princípio de detecção e modo de operação, tipo de partículas que detecta, taxa de contagem que suporta, eficiência na detecção dos diferentes tipos de partículas.
- B. Na segunda, estudam-se diversas aplicações: sobre medidas de radioactividade do meio ambiente, de natureza topológica e estatística.

As diversas partes do trabalho são:

- Estudo da curva de resposta do detector em função da tensão aplicada e escolha da zona de operação, usando uma fonte de  $^{204}\text{Tl}$  de  $0.5 \mu\text{Ci}$ . Medição do declive do patamar.
- Estudo da correcção à taxa de contagem do detector devido ao seu tempo morto (uso das fontes meia-lua de  $^{204}\text{Tl}$ ).
- Estudo da eficiência do detector a radiações  $\beta$  produzidas por uma fonte de  $^{204}\text{Tl}$ . A actividade da fonte era de  $0.5 \pm 0.1 \mu\text{Ci}$  em 1/4/08 (considere um erro de 10% para o tempo). As medições devem ser efectuadas com chapa metálica de  $\phi=7.25\pm0.05 \text{ mm}$ , que define uma eficiência geométrica mais precisa para a radiação  $\beta$ .
- Estudo da eficiência do detector a radiações  $\gamma$  produzidas por uma fonte de  $^{137}\text{Cs}$ . A actividade da fonte era de  $5 \pm 1 \mu\text{Ci}$  em 1/3/94 (use a fonte sem a pinta verde – janela fina e considere um erro de 10% para o tempo). As medições devem ser efectuadas com uma chapa de alumínio (a absorção dos  $\gamma$ s na chapa de Al é de 10%).
- Estudo da retrodifusão de partículas  $\beta$ , oriundas de uma fonte simétrica de  $^{204}\text{Tl}$ , causada por materiais de diferentes números atômicos.
- Estudo da lei de variação da taxa de contagem com a distância do detector à fonte de  $^{137}\text{Cs}$ , usando as prateleiras de 1 a 5.
- Estudo da dispersão estatística do número de contagens de 50 amostras obtidas com a fonte de  $^{204}\text{Tl}$ .

NOTA:

- Use todas as fontes viradas “para cima” e na prateleira do meio (nº 3).
- Faça sempre 2 aquisições de 60s, no caso do estudo da retrodifusão faça 2 aquisições de 90s. Depois de verificar a sua compatibilidade, **some** os resultados.

## 1.1 Discussion

In the study of radioactivity there are usually three parameters associated with an unknown source that are necessary to know. These are: 1) What kinds of particles is the source emitting, 2) What are the energies of these particles, and 3) How many particles per unit time is the source emitting. In this experiment, the Geiger-Mueller counter (called GM) will be used to help answer the third question. In subsequent experiments, the other two questions will be studied in great detail.

The GM tube is one of a variety of radiation detectors that take advantage of the fact that charged particles lose energy in a gas by creating electron-ion pairs. In air for example, an alpha particle will ionize from 50,000 to 100,000 molecules per cm of its path. The Geiger tube is simply a metal cylinder that is filled with some kind of counting gas. A thin window at one end of the cylinder allows the radiation to enter the counting region. The electron-ion pairs that are produced by the radiation are swept out and collected by an electric field that is maintained between a thin wire on the axis of the tube (anode) and the metal cylinder (cathode). The electric field between these two electrodes is high enough that the pairs produced by the initial radiation are accelerated and produce subsequent pairs. This chain reaction (secondary, tertiary, ..., ionisations) is called an avalanche.

In this experiment  $\beta$ s and  $\gamma$ s will be measured with one of these end-window Geiger tubes. In order to detect gammas with these detectors a two step process must occur. The gamma must first make a photoelectric or Compton interaction in the gas. The recoil electrons from these interactions then produce the ion-pairs that cause the avalanche. In the experiment, it will be seen that the GM tube is quite efficient for detecting beta particles and the voltage gradient across the tube will be such that any of these ionizing particles that enter the sensitive region will cause an avalanche. The output pulse is usually greater than one volt. The GM tube does not differentiate between kinds of particles or energies: it simply gives an output pulse when any ionizing particle triggers this avalanche. These output pulses are then recorded in a scaler which acts as an electronic adding machine.

## 2. DETERMINING THE OPERATING PLATEAU FOR THE GEIGER TUBE

### 2.1 Experimental Procedure

Figure 1 shows a typical voltage plateau curve for a GM tube. At low voltages there is no output. As the voltage is increased, a few counts will be recorded at the "starting voltage." As the voltage is further increased, the counting rate will change rapidly until the "knee" or threshold of the plateau is reached. From this point on, the counting rate is fairly constant for approximately 200 volts. This is called the plateau region. Shortly after the plateau region, the tube breaks down and goes into a continuous discharge. The operating voltage for the measurements in this experiment will be 25% of the plateau above the knee or threshold. Halogen quenched Geiger tubes, such as the Model PK-2 used in this experiment, are NOT harmed by a continuous discharge. Lower the voltage to the plateau level, and the GM tube will again operate normally.

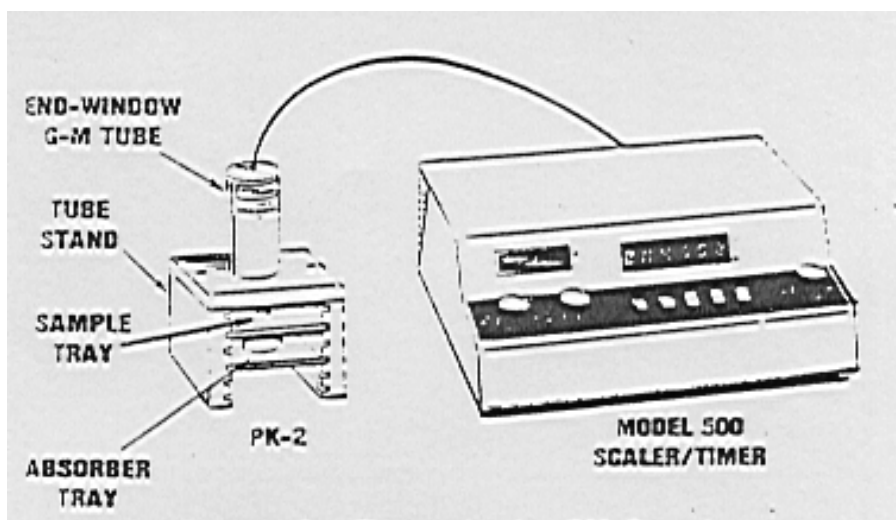


Figure 1. Electronics for GM Counting

1. Set up the electronics as shown in Figure 1.

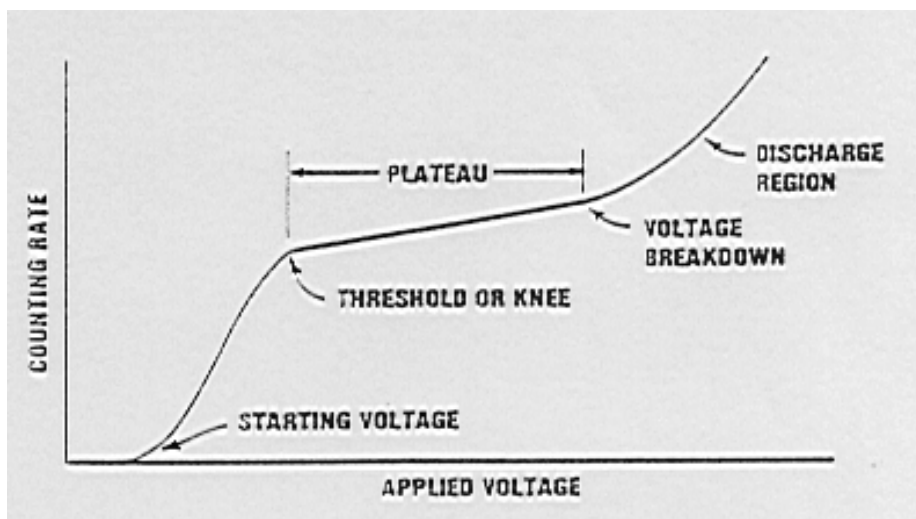


Figure 2. Typical Geiger-Mueller Characteristic Curve.

2. Place the  $^{204}\text{Tl}$  beta source on the second shelf of the GM stand. Set the timer on "manual" so that the voltage on the tube can be slowly raised and the student can observe all of the features of figure 2. Slowly raise the voltage until the starting voltage is reached. Record this value. Continue to increase the voltage until the counting rate levels off. This is the knee of the plateau. Record this value.

Continue increasing the voltage until the voltage breakdown region is reached. Record this value. This concludes the visual inspection of the curve.

- Now we will take data so that the plateau curve can be plotted and the operating voltage for the GM tube established. Go back to the value of the starting voltage and take 60 sec. counts in 25V increments until the breakdown point is reached. Fill in Table 1.

Table 1 Data for Constructing a Plateau Curve

Tensão	N (cts)	R (cts/s)
...		
...		
...		
...		
<b>700</b>		
<b>725</b>		
<b>750</b>		
...		
...		

## 2.2 Data Analysis

Plot a curve of counting rate versus voltage and determine the position of the knee and the voltage breakdown region. Record the operating point which is 25% of the plateau starting from the knee.

The plateau region rises with a gentle slope. Extract its value. From this measured slope obtain the intrinsic slope.

## 3. RESOLVING TIME CORRECTIONS

### 3.1 Discussion

In the earlier discussion it was mentioned that the Beta particle enters the GM tube through the window and loses its energy by creating electron-ion pairs. The electrons that are produced in the resulting avalanche are accelerated to the anode and collected in a short period of time. The positive ions, however, are more massive and make their way slowly to the cylindrical cathode. If their average transient time is called  $\Delta t_1$  the GM tube is busy, so to speak, during  $\Delta t_1$ . If another ionizing particle enters the GM tube during  $\Delta t_1$  it will not be counted. This time  $\Delta t_1$  is called the "dead time" of the tube. In this experiment the resolving time of the GM tube will be determined and the correction factor which can account for these lost events will be shown.

### 3.2 Experimental Procedure

1. Set the GM counter at its operating voltage. Obtain the split source from the instructor. This source is designed such that each half of the source can be counted separately without too many losses, but when both parts are counted at the same time, substantial losses occur. Count the first half of the source on shelf one for 60 sec. Calculate the counting rate and call this rate  $R_1$ . Repeat the exact measurement for the second half of the source and call this rate  $R_2$ . Now count both halves together for 60 sec and call this rate  $R_{12}$ .

### 3.3 Data Analysis

Calculate the resolving time of the GM tube which is given by:

$$T_R = \frac{R_1 + R_2 - R_{12}}{2R_1R_2} \quad (1)$$

The true counting rate  $R_v$  can be calculated from the observed counting rate ( $R_m$ ) by the following:

$$R_v = \frac{R_m}{1 - R_m T_R} \quad (2)$$

*Note:* Because of the solid state electronics used in the circuitry of modern instrumentation such as the scaler, the resolving time of these instruments is normally one microsecond or less. Therefore, only the resolving time of the GM tube affects the true count rate.

For the rest of the data taken in the experiment with the GM tube, eq. (2) should be used to correct the resulting counting rate.

Also, the radioactive sources should be moved away and a 60 sec background taken. This background rate should be subtracted from all measurements.

## 4. STUDY OF THE EFFICIENCY OF A GM COUNTER FOR GAMMAS AND BETAS

### 4.1 Experimental Procedure

1. Set up the GM system (Fig. 2) as we did in section 2. (Note: A GM radiation survey meter may also be used for this experiment). Adjust the voltage of the GM tube to its operating value.
2. Place the 1  $\mu\text{Ci}$   $^{137}\text{Cs}$  source on the third shelf and count for 1 minute. Record this value in Table 2 as Beta and Gamma and record the sum.
3. Place a 1/8 inch piece of aluminum on shelf between the source and the detector number 1. This thickness of aluminum is greater than the range of the 514 keV beta from  $^{137}\text{Cs}$  but will not appreciably attenuate the 662 keV gammas from the source (See the decay scheme fig.3). Make two independent 60 second measurements with this beta shield in place. Record the sum in Table 2 as gamma only.

Table 2 GM Relative Efficiency Data

Radiation	$N_1$	$N_2$	N
Beta and Gamma			
Gamma Only			
Beta Only			

## 4.2 Data Analysis

Subtract the *Gamma*s only from the *Beta and Gamma* count to get the actual number of Betas and record. Since the GM tube is nearly 100% efficient for betas, this number represents the number of betas that impinge on the window of the GM tube. How does this number compare to the theoretical number that you calculate from the  $^{137}\text{Cs}$  source activity and the geometry?

*Relative Efficiency of GM Tube for Gamma*s: This number is calculated by taking the ratio of gamma

counted to the theoretical number that impinge on the face of the tube. From this experiment the student should gain some familiarity with beta absorbers and GM efficiencies. The portable GM counter or survey meter is one of the basic instruments used in Health Physics monitoring.

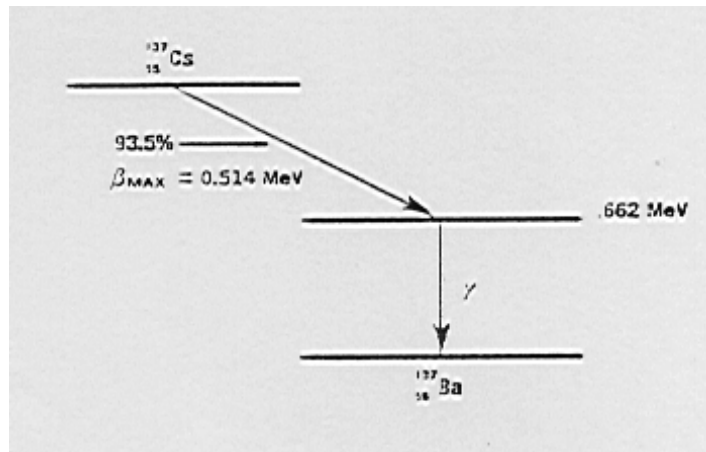


Figure 3. Decay scheme for  $^{137}\text{Cs}$  (simplified).

## 5. BETA BACKSCATTERING AS A FUNCTION OF ATOMIC NUMBER

### 5.1 Beta Radiation

The processes by which  $\beta$  particles lose energy in absorbers are similar to those for alphas. However, an additional process must be considered in dealing with  $\beta$  absorption. This is the process whereby electromagnetic radiation, called *bremstrahlung*, is produced.

A  $\beta$  particle has a very small mass and one-half the value of the charge on an  $\alpha$  particle. So, for a given energy, a  $\beta$  particle will have a much greater velocity than an  $\alpha$  particle. As a result of these and other factors, the  $\beta$  particle has a lower specific ionization which means that the penetration in any absorber will be much greater than that of an  $\alpha$  particle.

A 1 MeV  $\beta$  particle will travel about 10 feet in air. In order to penetrate the dead layer of skin, a  $\beta$  particle must have an energy of about 70 keV. Beta radiation is considered a slight external hazard.

The thickness and choice of material for shielding from beta radiation depends upon: (1) stopping the most energetic  $\beta$ s, and (2) *bremstrahlung*.

The shielding thickness which is necessary to stop  $\beta$  particles at a given energy will decrease with increasing density. For example, about 0.1 inch of aluminum ( $\rho = 2.7 \text{ g/cm}^3$ ) will stop 1.5 MeV betas, whereas only about 0.024 inches of lead ( $\rho = 11.34 \text{ g/cm}^3$ ) is needed for the same purpose.

However, the production of bremsstrahlung increases with increasing atomic number of absorber. A  $\beta$  source with  $E_{\max} = 1$  MeV will lose about 3% of its energy as bremsstrahlung when lead ( $Z = 82$ ) is the absorber. If aluminum ( $Z = 13$ ) is the absorber, the fraction is about 0.4 %. Therefore, low- $Z$  absorbers such as aluminum, plastics or even glass are effective  $\beta$  shields.

When you are trying to measure a beta-emitting source, the environmental surroundings are important. For example, let's assume that at a reactor site some beta activity has spilled on a steel pipe. The measurement that was made with a portable GM counter would have to be corrected for beta backscattering for Iron. This experiment is designed to give the student an overview of this backscattering phenomena and how it can affect the observed counting rate from the source.

## 5.2 Experimental Procedure

1. Use the same GM electronics (fig. 1) that was employed in the last experiments.
2. Place the  $^{204}\text{Tl}$  source (see fig.4 for its decay scheme) on the third shelf of the GM assembly. Count for 60 seconds and record in Table 2 as NONE.
3. Place the aluminum backscattering sheet from the backscatter kit (see Table 3) in contact with the source to enhance backscattering. Count for 60 seconds and record in Table 3. Repeat for the other materials in the kit and fill in the rest of the Table.

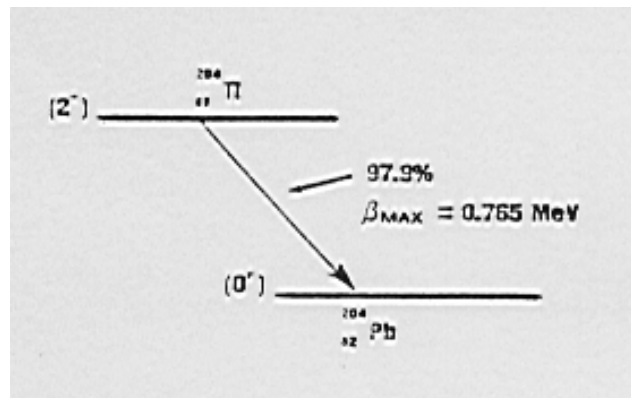


Figure 4 Beta decay scheme for  $^{204}\text{Tl}$ .

Table 3 Data for Beta Backscattering Analysis

Backscattering Material	Z	N <sub>1</sub> (cts)	N <sub>2</sub> (cts)	N(cts)	f <sub>bks</sub>
None					
Aluminum					
Iron					
Copper					
Cadmium					
Molybdenum					
Tungsten					
Lead					

### 5.3 Data Analysis

From the known activity of the  $^{204}\text{Tl}$  source and the fact that the GM counter is almost 100% efficient for a pure beta source, calculate the counts/minute that you would expect for the geometrical set up being used. How does your answer compare to the measurement made with no backscatter?

The backscattering factor ( $f_{\text{bks}}$ ) is defined be the ratio of counts with a scatterer, divided the counts without a scattering medium. Calculate this value for each of the measurements and fill in Table 3. Calculate the percent backscattering from your data and plot this value (y axis) as a function of the atomic number of the backscattering material. Figure 5 shows a plot of some typical experimental data.

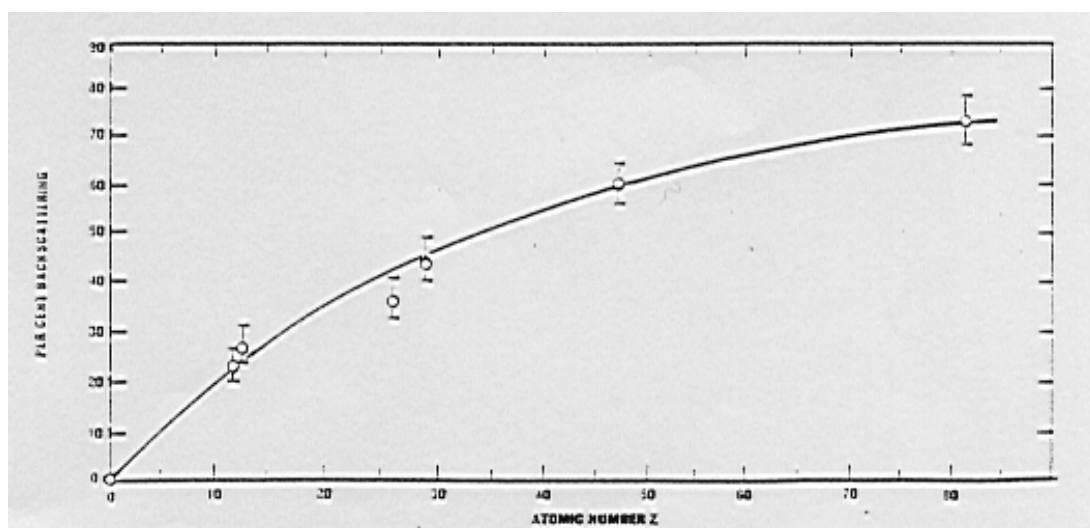


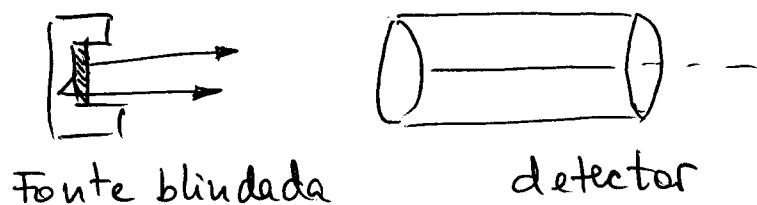
Figure 5. Percent beta backscattering as a function at the atomic number of the backscateting material.



## Retrodifusão de electrões

Os electrões sofrem difusões a grande ângulo na sua interacção com a matéria, devido à sua pequena massa (ao contrário das partículas  $\alpha$ ).

Então, numa montagem experimental do tipo:



o nº de electrões que chega ao detector depende também da capacidade de retrodifusão do material da blindagem.

Chama-se factor de retrodifusão (backscattering factor),  $f_{bs}$ , à razão entre as contagens com e sem blindagem.

A medida que se aumenta a espessura da blindagem,  $f_{bs}$  cresce até atingir a saturação;  $f_{bs}^{sat}$  obtém-se para espessuras de  $\sim 25\%$  do alcance dos electrões no material.

O factor  $f_{bs}^{sat}$  cresce com  $Z$  do material e é proporcional a  $\sqrt{Z(Z+1)/M}$  ( $M$ , massa do núcleo difusor).

Por isso, para detectar electrões, usam-se de preferência detectores semicondutores de silício em vez de germânio, devido ao mais baixo valor de  $Z$ , e portanto, menor retrodifusão.

## 6. THE INVERSE SQUARE LAW

### 6.1 Discussion

Most radioactive sources are isotropic in nature. This means that gammas (for a gamma source) are given off equally in all directions. There are some sources, however, where there is a correlation of one gamma relative to the other that is not isotropic. This angular correlation allow to predict some properties of the nuclear states that are involved in the decay of these isotopes. In the case of an isotropic source, it is a well known fact that the intensity of the source falls off as  $1/R^2$ . In this experiment, this  $1/R^2$  relationship for a  $^{137}\text{Cs}$  source will be verified.

### 6.2 Experimental Procedure

1. Set the voltage of the GM counter at its operating value. Determine the background counting rate.
2. For this experiment, use a  $^{137}\text{Cs}$  source. The betas from the source must be attenuated out, since air absorption of the betas will modify the results. This can be done by placing a thin piece (1/16") of almost any material between the source and the window. Place the  $^{137}\text{Cs}$  source in each shelf and count for a long enough period of time to get good statistics. Record this uncorrected counting rate in Table 4.

Table 4 Data for  $1/R^2$  Determination

Shelf	$N_1$	$N_2$	N
1			
2			
3			
4			
5			

### 6.3 Data Analysis

Study the  $1/R^2$  dependency.

## 7. STATISTICAL VARIATION OF DATA

### 7.1 Discussion

There is no way to predict when a person will have an automobile accident that does \$1000 worth of damage to the car. However, if a very large number of drivers are considered it is possible for an insurance company to predict with reasonable accuracy, how many accidents, costing \$1000 will occur this year. Insurance companies use large computers to store mounds of statistical data so they can accurately predict these probabilities from random events.

The radioactive decay of a nucleus is also a random event. There is no way to determine when a particular nucleus will decay. However the half-life can accurately be determined. If two identical counts are taken in sequence on a long lived radioisotope, the counts will almost always differ. If a large number of these individual counts are taken, the average count N can be determined. From this data, a predictable deviation of each count from this average can be calculated.

For this experiment, 35 independent measurements will be taken on the long lived isotope  $^{137}\text{Cs}$  ( $T_{1/2} = 30.2$  y) and with this data the predictable behavior of the measurements will be shown.

## 7.2 Experimental Procedure

1. Set the operating voltage of the GM counter to its recommended value. Place the  $^{137}\text{Cs}$  source at a distance such that 2000 counts can be obtained in 0.5 min.
2. Perform 35 sequential 0.5 minute acquisitions and record these uncorrected events ( $N$ ) in a Table similar to Table 5.

Table 5 Counting Statistics Data Table

Run No	$N$	$N - \bar{N}$	$\frac{N - \bar{N}}{\sigma}$	$\frac{N - \bar{N}}{\sigma}$ (rounded)

## 7.3 Data Analysis

Calculate the average of these 35 counts  $\bar{N}$ . Tabulate  $N - \bar{N}$  in the table. Note, the number  $N - \bar{N}$  can be positive or negative. If you will add up all of the  $N - \bar{N}$  in the table, the answer should be zero. Calculate the standard deviation,  $\sigma$ . Calculate  $(N - \bar{N})/\sigma$  and tabulate it in the data table. Now round off the value for each entry to the nearest 0.5. For example, if  $(N - \bar{N})/\sigma = +1.11$ , the rounded off figure would be +1, etc. Plot the frequency of rounded off events versus  $\sigma$  and a normal distribution curve should be seen. Sixty-eight percent (68.4 %) of the observed data should lie within the range of one  $\sigma$ . And ninety-five percent (95.5 %) within the range of  $2\sigma$ .

Figure 6 shows a normal distribution curve that should fit your calculations.

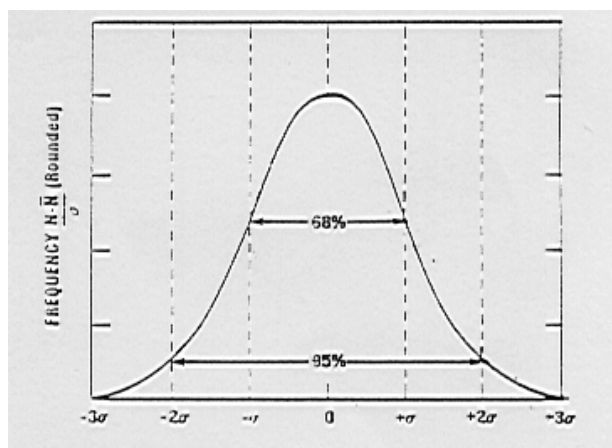
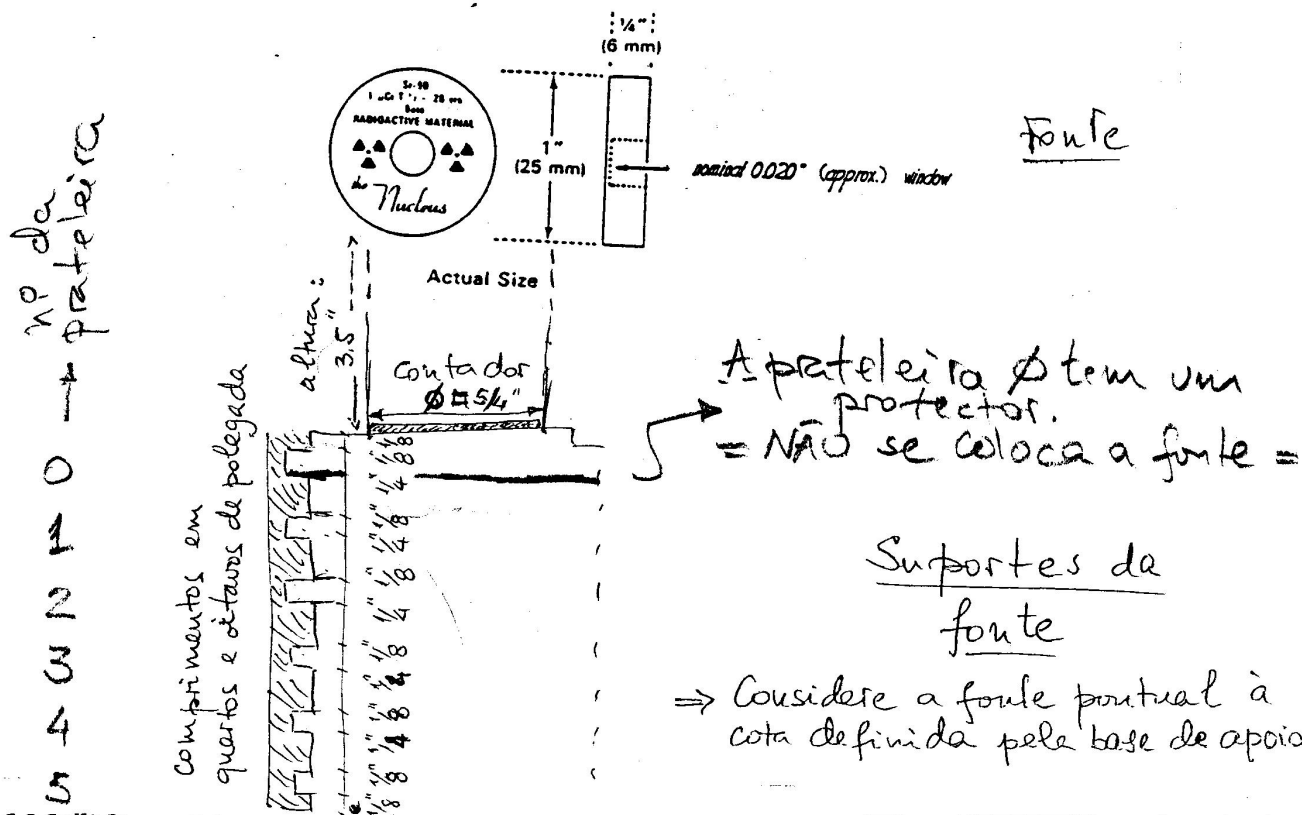


Figure 6. Typical Gaussian. Generated from an Extensive Set of Data.

# Experiência com Geiger - Müller

NOTA : Todas as montagens usam a prateleira 3.



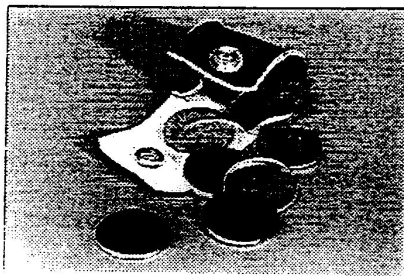
## S-9 Split Source Set

The S-9 split source set is best used for resolving time measurements to demonstrate the dead-time of a GM tube. The S-9 set includes two identical half-disc plastic-sealed sources containing 5  $\mu\text{Ci}$  of Tl-204 each. A third half-disc (nonradioactive) is included to give uniform geometry.



## S-10 Backscatter Kit

The S-10 is a favorite experiment kit to demonstrate the backscattering effects of beta radiation and determine the relative effects on atomic number, thickness of backing material and energy level of beta radiation. The kit includes seven backscatter materials (aluminum, copper, glass, lead, nickel-plated steel, plastic and stainless steel). A thin mylar-covered sealed source containing 0.5  $\mu\text{Ci}$  of Tl-204 is provided along with a leather storage pouch.



aco = ferro c/  $\approx 1\%$  de carbono; pode conter  
fraca percentagem de outros metais  
(Niquel, estanho, ...)

1 = Alumínio

2 = cobre

3 = vidro

4 = chumbo

(5 = aço niquelado)

6 = plástico

7 = aço

"8" = tungstênio (dado à parte)