The Geiger Müller counter

# Introduction

## What is radioactivity?

Radioactivity is a property of certain atoms to spontaneously emit particle or electromagnetic wave energy. The nuclei of some atoms are unstable, and eventually adjust to a more stable form by emission of radiation. These unstable atoms are called radioactive atoms or isotopes. Radiation is energy emitted from radioactive atoms, either as electromagnetic (EM) waves or as particles. When radioactive (or unstable) atoms adjust, it is called radioactive decay or disintegration. A material containing a large number of radioactive atoms is called either a radioactive material or a radioactive source. Radioactivity, or the activity of a radioactive source, is measured in a unit equivalent to the number of disintegrations per second (dps) or disintegrations per minute (dpm). The SI unit for activity is called the Becquerel (Bq) and one Becquerel is equal to one disintegration per second.

1 Bq = 1 dps = 60 dpm

Another unit of measure commonly used to denote the activity of a radioactive source is the Curie (Ci) where one Curie equals thirty seven billion disintegrations per second corresponding to the activity of 1 gram of radium (Ra).

1 Ci = 3.7x1010 dps = 2.2x1012 dpm

## What is the origin of Radiation?

Radioactive materials that we find as naturally occurring were created by:

1. Formation of the universe or in stellar nucleosynthesis processes, producing some very long lived radioactive elements, such as uranium and thorium.
2. The decay of some of these long lived materials into other radioactive materials like radium and radon.
3. Fission products and their progeny (decay products), such as xenon, krypton, and iodine.

Man-made radioactive materials are most commonly made as fission products or from the decays of previously radioactive materials. Another method to manufacture radioactive materials is activation of non-radioactive materials when they are bombarded with neutrons, protons, other high energy particles, or high energy electromagnetic waves.

## Types of radiation

The radiation one typically encounters is one of four types: alpha radiation, beta radiation, gamma radiation, and x radiation. Neutron radiation is also encountered in nuclear power plants and high-altitude flight and emitted from some industrial radioactive sources.

**Alpha Radiation**   
  
Alpha radiation is a heavy, very short-range particle and is actually an ejected helium nucleus. Some characteristics of alpha radiation are:

Most alpha radiation is not able to penetrate human skin.

Alpha-emitting materials can be harmful to humans if the materials are inhaled, swallowed, or absorbed through open wounds.

A variety of instruments have been designed to measure alpha radiation. Special training in the use of these instruments is essential for making accurate measurements.

A thin-window Geiger-Mueller (GM) probe can detect the presence of alpha radiation.

Instruments cannot detect alpha radiation through even a thin layer of water, dust, paper, or other material, because alpha radiation is not penetrating.

Alpha radiation travels only a short distance (a few inches) in air, but is not an external hazard.

Alpha radiation is not able to penetrate clothing.

Examples of some alpha emitters: radium, radon, uranium, thorium.

**Beta Radiation**   
  
Beta radiation is a light, short-range particle and is actually an ejected electron or positron. Some characteristics of beta radiation are:

Beta radiation may travel several feet in air and is moderately penetrating.

Beta radiation can penetrate human skin to the "germinal layer," where new skin cells are produced. If high levels of beta-emitting contaminants are allowed to remain on the skin for a prolonged period of time, they may cause skin injury.

Beta-emitting contaminants may be harmful if deposited internally.

Most beta emitters can be detected with a survey instrument and a thin-window GM probe (e.g., "pancake" type). Some beta emitters, however, produce very low-energy, poorly penetrating radiation that may be difficult or impossible to detect. Examples of these difficult-to-detect beta emitters are hydrogen-3 (tritium), carbon-14, and sulfur-35.

Clothing provides some protection against beta radiation.

Examples of some pure beta emitters: strontium-90, carbon-14, tritium, and sulfur-35.

**Gamma and X Radiation**   
  
Gamma radiation and x rays are highly penetrating electromagnetic radiation. Some characteristics of these radiations are:

Gamma radiation or x rays are able to travel many feet in air and many inches in human tissue. They readily penetrate most materials and are sometimes called "penetrating" radiation.

Sealed radioactive sources and machines that emit gamma radiation and x rays respectively constitute an external hazard to humans.

Gamma radiation and x rays are electromagnetic radiation like visible light, radio waves, and ultraviolet light. These electromagnetic radiations differ only in the amount of energy they have. Gamma rays and x rays are the most energetic of these.

Dense materials are needed for shielding from gamma radiation. Clothing provides little shielding from penetrating radiation, but will prevent contamination of the skin by gamma-emitting radioactive materials.

Gamma radiation is easily detected by survey meters with a sodium iodide detector probe.

Gamma radiation and/or characteristic x rays frequently accompany the emission of alpha and beta radiation during radioactive decay.   
Examples of some gamma emitters: iodine-131, cesium-137, cobalt-60, radium-226, and technetium-99m.

## Is Radiation Dangerous?

Everyone on the face of the Earth receives background radiation from natural and man-made sources. The major natural sources include radon gas, cosmic radiation, terrestrial sources, and internal sources. The major man-made sources are medical/dental sources, consumer products, and other (nuclear bomb and disaster sources).

Radon gas is produced from the decay of uranium in the soil. The gas migrates up through the soil, attaches to dust particles, and is breathed into our lungs. The average yearly dose in the United States is about 200 mrem[[1]](#footnote-1)/yr. Cosmic rays are received from outer space and our sun. The amount of radiation depends on where you live, lower elevations receive less (~25 mrem/yr) while higher elevations receive more (~50 mrem/yr). The average yearly dose in the United States is about 28 mrem/yr.

Terrestrial sources are sources that have been present from the formation of the Earth, like radium, uranium, and thorium. These sources are in the ground, rock, and building materials all around us. The average yearly dose in the United States is about 28 mrem/yr. The last naturally occurring background radiation source is due to the various chemicals in our own bodies. Potassium (40K) is the major contributor and the average yearly dose in the United States is about 40 mrem/yr.

Radiation doses can also be received from man-made sources. The most common is the radiation from medical and dental x-rays. There is also radiation used to treat cancer patients. The average yearly dose in the United States is about 54 mrem/yr. There are small amounts of radiation in consumer products, such as smoke detectors, some luminous dial watches, and ceramic dishes (with an orange glaze). The average yearly dose in the United States is about 10 mrem/yr. The other man-made sources are fallout from nuclear bomb testing and usage, and from accidents at nuclear power plants such as Chernobyl or Fukushima. The average yearly dose in the United States is about 3 mrem/yr.

Adding up the naturally occurring and man-made sources, we receive on average about 360 mrem/yr of radioactivity exposure.

**You can used the attached chart to estimate your own annual radiation dose. Compare it to your colleagues. Are they very different?**

# The Geiger-Müller Counter

Geiger-Müller (GM) counters were invented by H. Geiger and E.W. Müller in 1928, and are used to detect radioactive particles ( αand β) and rays (γ and x). A GM tube usually consists of an airtight metal cylinder closed at both ends and filled with a gas that is easily ionized (usually neon, argon, and halogen). One end consists of a “window” which is a thin material, mica, allowing the entrance of alpha particles. A wire, which runs lengthwise down the center of the tube, is positively charged with a relatively high voltage and acts as an anode. The tube acts as the cathode. The anode and cathode are connected to an electric circuit that maintains the high voltage between them.

When the radiation enters the GM tube, it will ionize some of the atoms of the gas. Due to the large electric field created between the anode and cathode, the resulting positive ions and negative electrons accelerate toward the cathode and anode, respectively. Electrons move or drift through the gas at a speed of about 104 m/s, which is about 104 microseconds after they are created, while the positive ions take a few milliseconds to travel to the cathode. As the electrons travel toward the anode they ionize other atoms, which produces a cascade of electrons called gas multiplication or a (Townsend) avalanche. The multiplication factor is typically 106 to 108. The resulting discharge current causes the voltage between the anode and cathode to drop. The counter (electric circuit) detects this voltage drop and recognizes it as a signal of a particle’s presence. There are additional discharges triggered by UV photons liberated in the ionization process that start avalanches away from the original ionization site.

These discharges are called Geiger-Müller discharges. These do not affect the performance as they are short-lived.

# Experiment #1: Measurement and Characterization of the Background radiation

Objective

The students will investigate background radiation, learn how to measure it, and compensate for it. Additionally, in this experiment, the students will investigate the statistics related to measurements with a Geiger counter, namely, the Poisson distribution.

## Introduction

Radiation that is around us every day of our lives. Normally we do not even think about it. However, every living organism contains a radioactive isotope of carbon, Carbon-14. Whenever you watch TV or look at any object, you receive the light waves, which are electromagnetic radiation. Cell phones also transmit via are electromagnetic radiation. It is all around us and we can’t escape from it. But we are lucky because the power and dosage in everyday life is so small there are no immediate biological effects.

The GM tube we will use is just like a human; it is being bombarded by radiation constantly.

That extra radiation shows up in our GM tube as a count, but it is impossible to determine the origin of the count as being from the radioactive source being investigated or background. This causes an erroneous sample count. The error can be very high, especially when the counts are low. Therefore, the background count must be determined and the sample’s counts must be corrected for it. It is not a difficult process and is rather straightforward.

Moreover, statistics is an important feature especially when exploring nuclear and particle physics. In those fields, we are dealing with very large numbers of atoms simultaneously. We cannot possibly deal with each one individually, so we turn to statistics for help. Its techniques help us obtain predictions of behavior based on what most of the particles do and how many follow this pattern. These two categories fit a general description of mean (or average) and standard deviation.

A measurement counts the number of successes resulting from a given number of trials. Each trial is assumed to be a binary process in that there are two possible outcomes: the trial is a success or the trial is not a success. For our work, the probability of a decay or non-decay is a constant every moment in time. Every atom in the source has the same probability of decay, which is very small (you can measure it in the Half-life experiment). The Poisson distribution is the one that will be used in this experiment.

## Equipment

* Geiger Muller tube PASCO SE7998
* PASCO's classic data acquisition system interface
* Right angle clamp
* Base and Support Rod
* Desktop computer

## Procedure

1. Set up your lab station:
2. Make sure the power switch for the interface is on. 4.
3. The G-M counter should be clamped vertically so that it is about 3 cm (or 1 inch) from the surface of the watch glass source holder. (Place watch glass on table directly under the sensor.)
4. Plug the power cord into an outlet of the G-M counter.
5. Plug the flat, grey cable into digital channel one in the SW 750 Interface.
6. Open up Data Studio Document "Radioactivity" at this time to make sure that everything is ready and running.
7. Go to the **Setup Timers** menu to set the **Sample rate** to 20 s. This will tell the software to collect data each 20 s.
8. Go to **the Sampling options** tab and on the **Automatic Stop** option set it to 1800 s (30 min.)
9. Start the background measurement by clicking start in Data Studio
10. Once the measurement id done. Export the data to a text file. To do that, click on the data table, then go to the **Display** menu and click on **Export Data.** Save the file on the Desktop with the name **Background.txt**.

## Data Analysis

1. Open the **Background.txt** file you just saved with Excel. The data you collected will be presented in two columns, one with the time and other with the counts registered on each time interval.
2. First, we will calculate the average and the standard deviation of the data by using the functions AVERAGE and STDEV. To do so, click on an empty cell and type **=AVERAGE(.** Excel will require you to insert a set of numbers to calculate the average. To provide it, just highlight the data in the second column by dragging with the mouse. Then close the parenthesis and press **Return.** The number that will appear in the cell is the average of the number of counts each 20 seconds. Repeat the same process to get the Standard deviation. Remember to use **STDEV.**
3. Produce a histogram of the number of counts per run. Use the function **FREQUENCY** to obtain the frequencies of each number of counts. The arguments of the **FREQUENCY** function are the array of data, which are exactly the same you used for the average and standard deviation, and the bins you want to use to calculate the frequencies. To do the binning, just type the numbers from the minimum of counts to the maximum in a column which you will label as Bins. Label the next Column as Frequency. Then select the cells on the right on the bins and type in the formula bar **=FREQUENCY( .** Select the data range, type a comma (**,**) and select the Bin column (See Figure 1). Close the parenthesis and press **CMD**+**Return (on Mac) or CTRL**+**SHIFT**+**Return (On PC).** This will fill the Frequency Column with their corresponding values for each of the bins

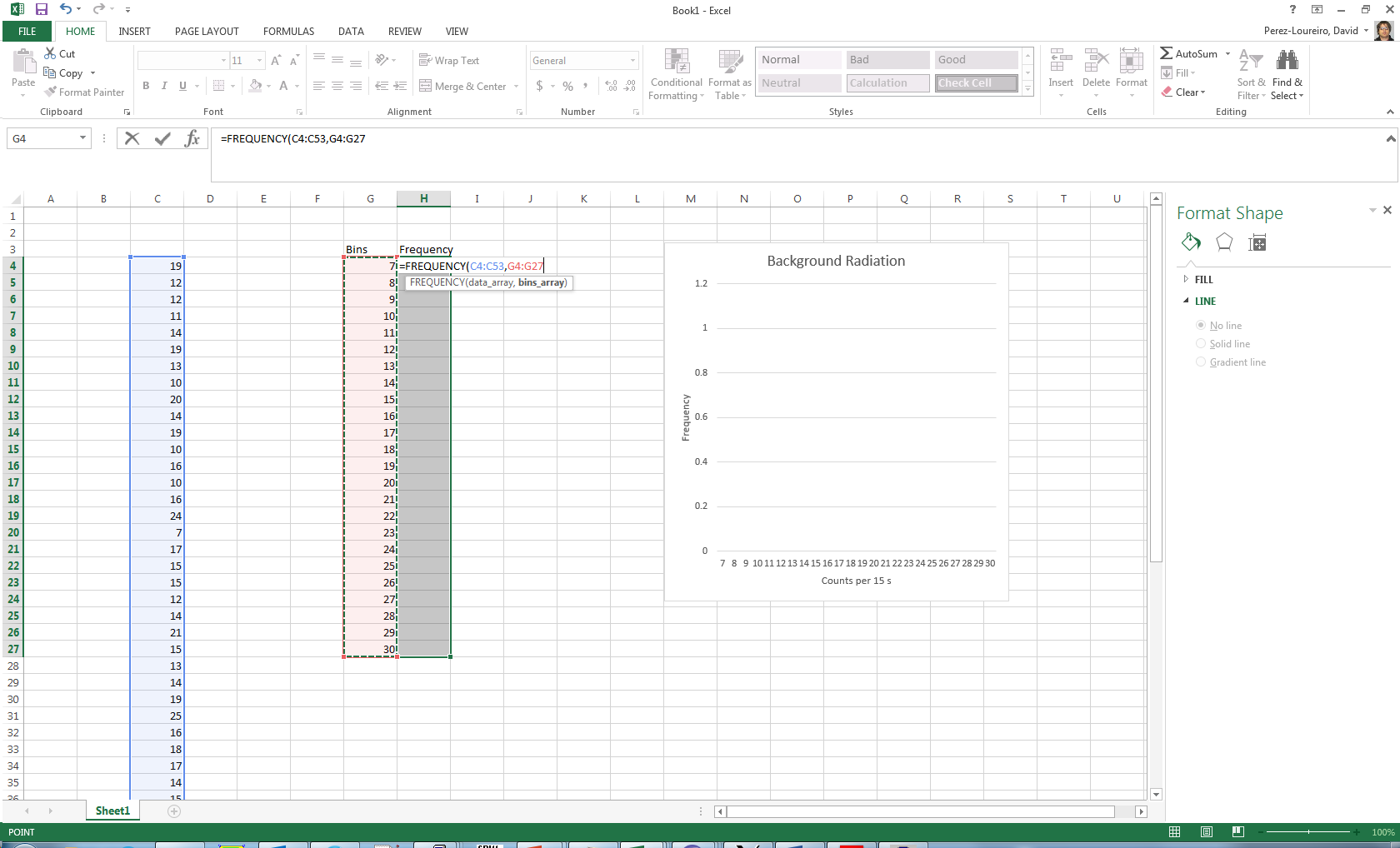


Figure 1: Example of use of the FREQUENCY function in Excel

Now you can produce a Bar Chart with the frequency per bin and then number of counts in the X axis. To do so follow the appendix instructions.

Now we will compare our histogram of the frequency distribution with the probabilities to obtain a certain number of counts given by the Poisson distribution.

1. Calculate the Poisson distribution for the average. Use the function **POISSON.**  The arguments of the **POISSON** function are, X, mean and cumulative. In our case the X value is the number of counts of each bin, the mean is the average you obtained before, and set cumulative to **FALSE**. Close the parenthesis and multiply by the number of runs **90** in this case (See Figure 2). Copy this formula in all the cells down to the las bin number. Remember to keep the value of the mean constant. In order to do so, just add dollar signs ($) to the row and column numbers, e. g., if the average is in cell E4, type $E$4. (See Fig. 2)

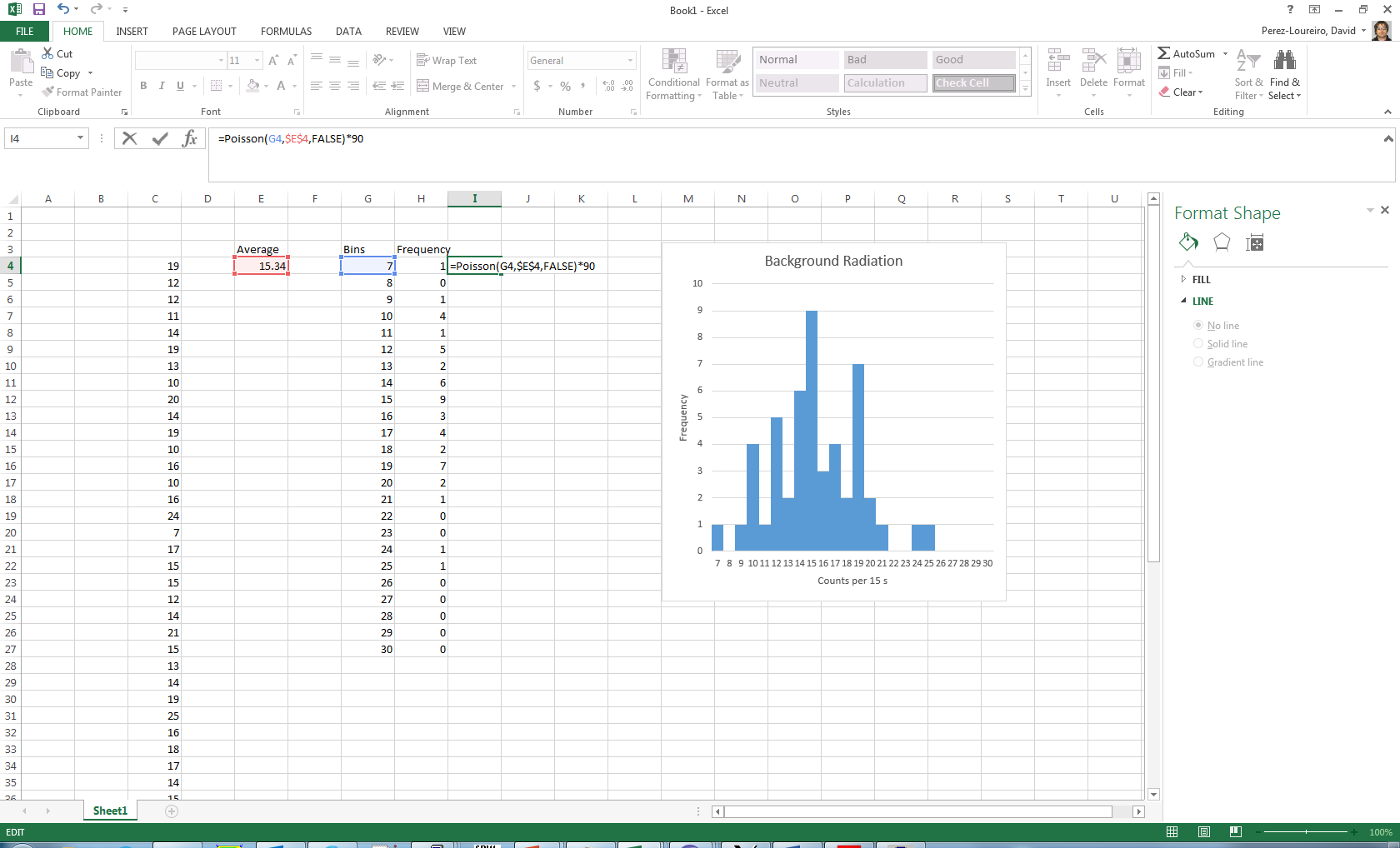


Figure 2: Example of use of the POISSON function in Excel

1. You can now plot the new series of data in the same chart and compare the results. Are they very different?

## Post-lab Questions

1. Is there any way to eliminate background radiation?
2. What is your prediction for the number of background radiation counts that your body would receive? (Hint: find the value for counts per minute, cpm, and multiple by the number of minutes in one day.) How many counts per year?
3. Are all the background measurements exactly the same number of counts?

Is there a systematic cause for this?

# Experiment #2: Half-Life of 137mBa

Objective

The students will measure the half-life of metastable 137Ba.

## Introduction

The decay of radioactive atoms occurs at a constant rate. The rate of decay is also a constant, fixed rate regardless of the amount of radioactive atoms present. That is because there are only two choices for each atom, decay or don’t decay. Thus, the amount of radioactive atoms we have on hand at any time is undergoing a consistent, continuous change.

The change in the number of radioactive atoms is a very orderly process. If we know the number of atoms present and their decay constant (probability of decay per unit time), then we can calculate how many atoms will remain at any future time. This can be written as the equation

|  |  |  |
| --- | --- | --- |
|  |  | (1) |

Where N(t) is the number of radioactive atoms that will be present at time t, N0 is the number of atoms present currently, λ is the decay constant, and t is the elapsed time. If the number of radioactive atoms remaining is plotted against time, a curve like the one shown in Figure 3 can be obtained.

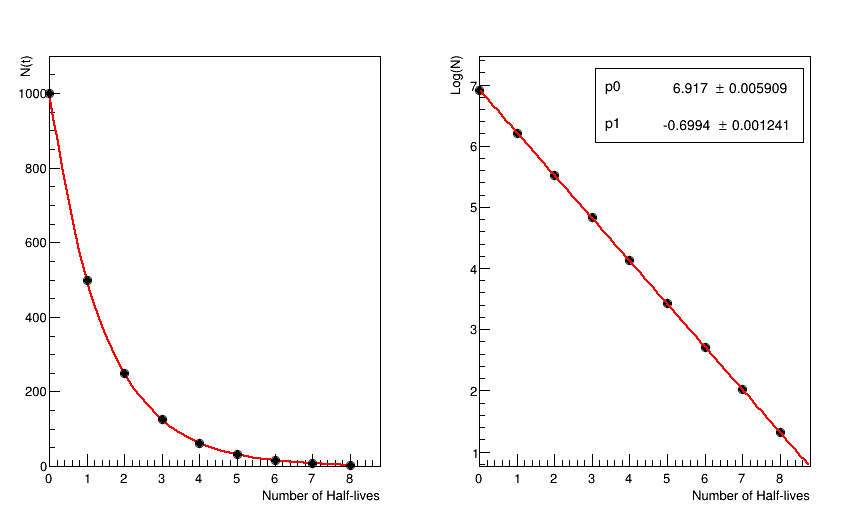


Figure 3: Left Panel: Exponential decay curve. Right panel: Logarithm of the activity vs time.

If we take the logarithm in Equation (1):

|  |  |  |
| --- | --- | --- |
|  |  | (2) |

And rearranging terms

|  |  |  |
| --- | --- | --- |
|  |  | (3) |

This equation corresponds to a straight line whose slope is directly the decay constant λ (Right panel on Fig. 3)

A more common way of expressing the decay of radioactive atoms is the **half-life (t1/2)**. The half-life of a radioactive isotope is the time required for the disintegration of one-half of the atoms in the original sample. For example, if 1000 atoms were present at t = 0. At the end of one half-life, 500 atoms were present. At the end of two half-lives, 250 atoms were present, one-quarter of the original sample, and so on.

Since the observed activity of a sample as detected by a Geiger counter is proportional to the number of radioactive atoms, it is not necessary to know exactly how many atoms are present to determine either the half-life or the decay constant. Any quantity of sample providing a suitable activity may be used.

## Equipment

* Geiger Muller tube PASCO SE7998
* PASCO's classic data acquisition system interface
* Right angle clamp
* Base and Support Rod
* Desktop computer
* 137Ba isotope generator (milk source)
* Syringe
* Eluting Solution
* Watch glass

## Procedure

1. Setup the Geiger counter as you have in the previous experiment. Be sure that the sampling rate is 20 s.
2. The instructor will draw up at least 1mL of the eluting solution with the syringe at your table.
3. The instructor will take the isotope generator carefully removing the top and bottom caps, note where the arrow is pointing.
4. Your instructor will insert the fluid filled syringe into the top hole and drain as close as possible to 1mL of the solution through the container onto the watch glass. ***DO NOT TOUCH THE SOLUTION AS IT IS RADIOACTIVE***. The leftover solution in the syringe can be put back into the bottle from whence it came.
5. Place immediately the watch glass with the radioactive liquid directly under the G-M counter. Click Start in data studio, and take data for 30 minutes.
6. After your measurement you should dump the watch glass into the hazardous waste bottle provided. Use a paper towel and wipe the liquid off of the watch glass. Try not to spill any liquid on the table. Put the paper towel in the radioactive waste container immediately.
7. After all measurements and clean-up is complete, remove gloves and dispose of them in the waste bin.
8. Once the measurement id done. Export the data to a text file. To do that, click on the data table, then go to the **Display** menu and click on **Export Data.** Save the file on the Desktop with the name **Half\_Life.txt**.
9. You may wish to do a second trial if time allows.

## Data analysis

1. Open the **Half\_Life.txt** file you just saved with Excel. The data you collected will be presented in two columns, one with the time and other with the counts registered on each time interval.
2. Make a graph of Natural Log (Ln) of Counts vs. Time. From this graph, you will be able to see the true exponential nature of the decay and also be able to estimate approximate half-life.
3. Calculate the natural logarithm of the number of counts for each run. Use the **LN** function.
4. Make another graph, except this time use the Natural Log (Ln) of Counts vs. time. Add a linear trend line and show the equation (See appendix).
5. Now, you will perform a linear regression over three different sets of numbers. A linear regression finds the slope and y-intercept for the best-fit line through the data chosen. The function you have to use is **LINEST**. Additionally to the fit parameters already obtained form the trend line, this function will provide the errors of the fit parameters. To use the **LINEST** function, select a matrix of 2x2 cells and type in the formula bar **=LINEST(.** Select the logarithm of the number of counts column, then type a comma (**,**) and select the time column, type another comma and add **TRUE,TRUE**. Close the parenthesis and press **CMD**+**Return (on Mac) or CTRL**+**SHIFT**+**Return (On PC).** This will fill the matrix you have selected with the fit parameters (first row) and their errors (second row). See Figure 4.

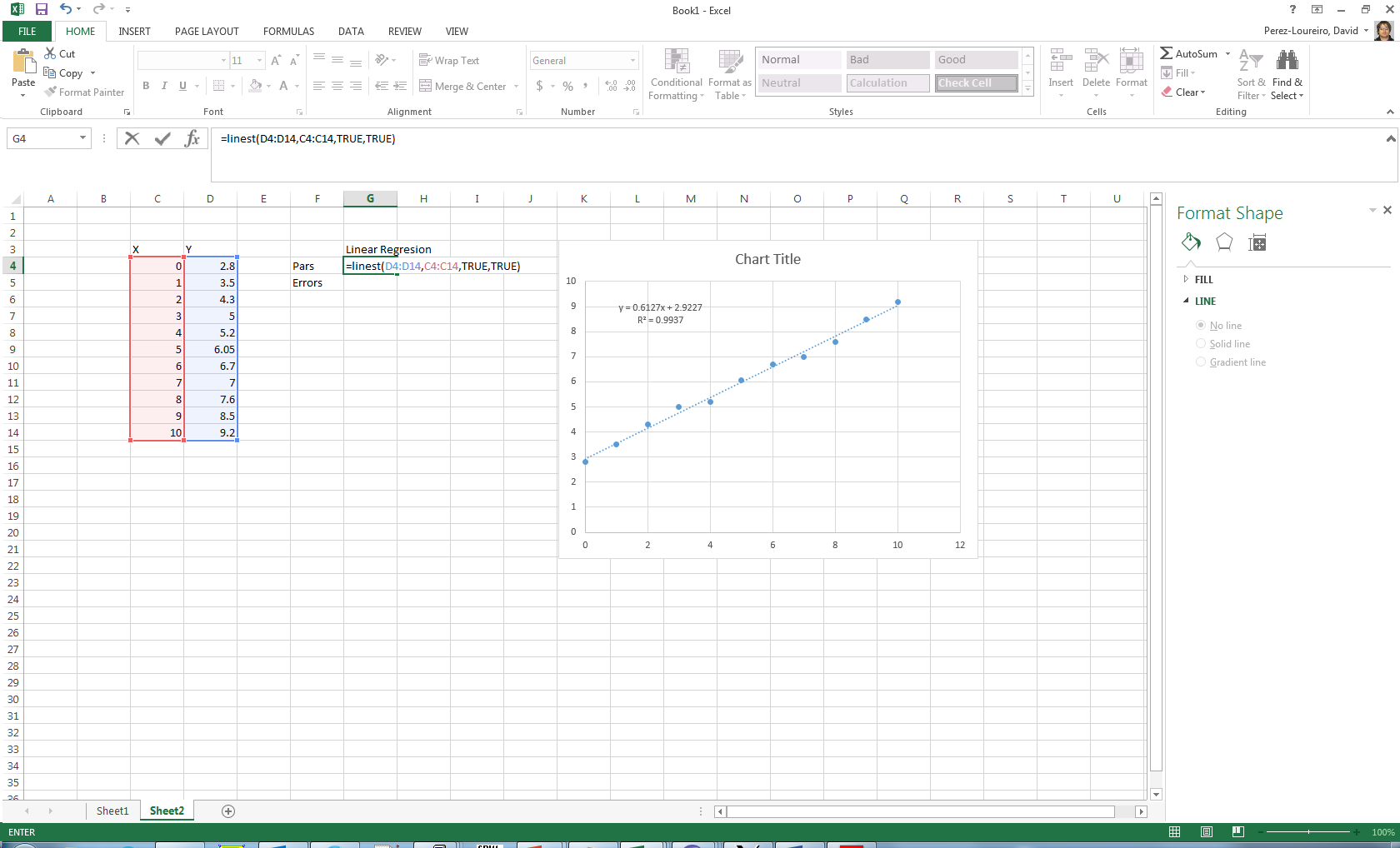


Figure 4: Example of the use of **LINEST** function in Excel

1. For the first linear regression, choose the first half of data points under **Natural Log of activity** for the **Y-Values.** Now, for the **X-Values** choose the first half of time values.
2. For the second linear regression, choose the other half of the data points.
3. For the third linear regression, choose all points. Does the slope for this linear regression match the slope from the first graph?
4. From the slope, we can obtain directly the decay constant λ, which is related to the half-life according to the following equation:

|  |  |  |
| --- | --- | --- |
|  |  | (4) |

1. In order to calculate the error of the half-life, we have to propagate the error of the slope:

|  |  |  |
| --- | --- | --- |
|  |  | (5) |

## Post-lab questions

1. Write your result with the error, i.e. 153 s ± 1 s. Is this result (statistically) good? (Recall that any value judgements must be justified.)
2. Which of the three results is better? Why?
3. How can the situation in #2 be resolved so that a linear regression over all the data give a more valid result? (How can you combine the halves of the data?)

# Nuclear Safety Guidelines

PLEASE READ CAREFULLY ALL OF THESE!! - All work with radioactive materials in the laboratory must be supervised by an instructor.

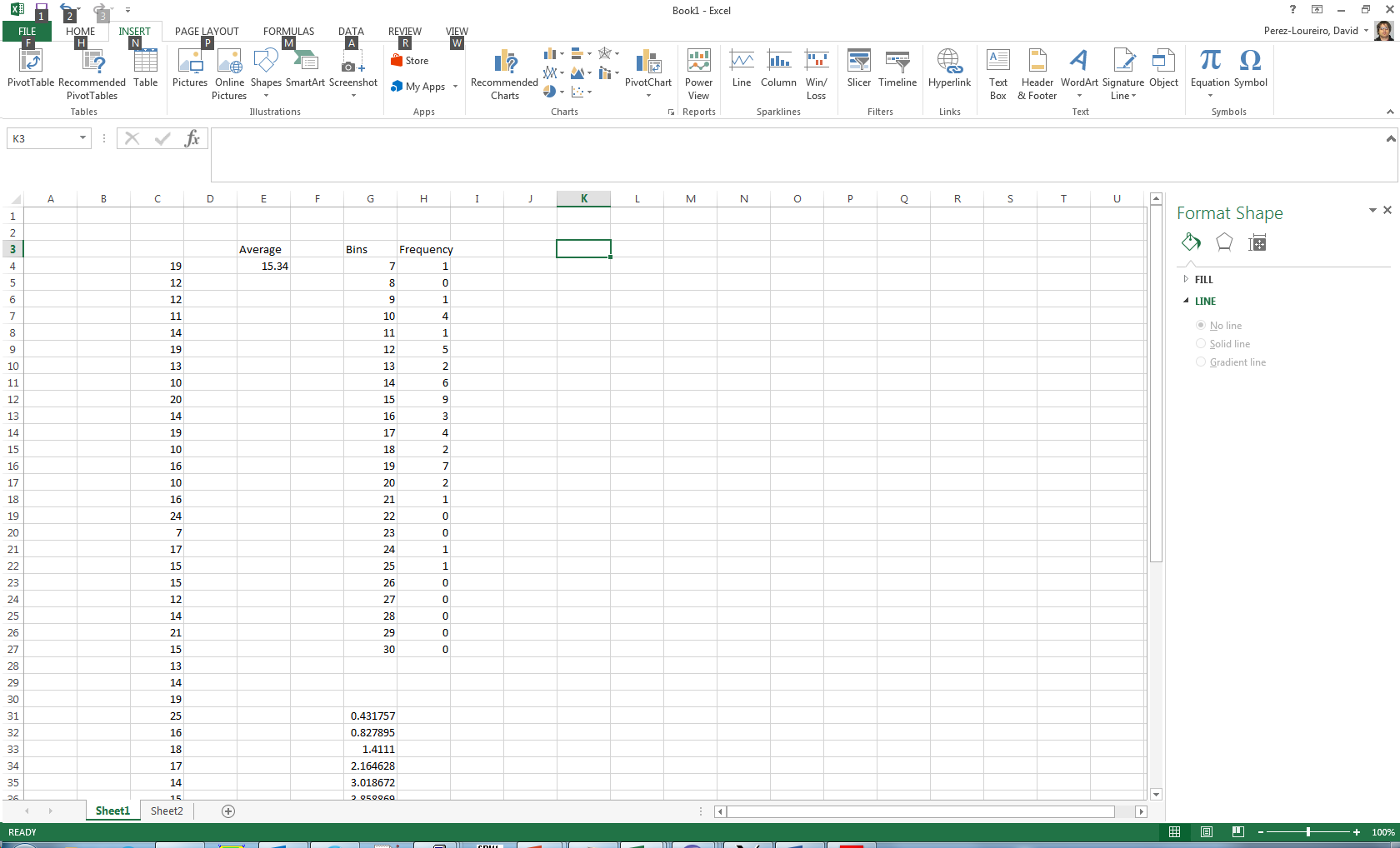
1. Special care should always be taken to avoid unnecessary handling of the sources, contact with the skin, and close proximity of sources to the eyes.
2. Eating, drinking, smoking, using cosmetics, and chewing gum are strictly forbidden.
3. Protective gloves should be worn whenever an instructor or student is handling or transferring a radioactive liquid.
4. When radioactive sources are not in use, they should be stored in an appropriately labeled container and kept in a place of limited access.
5. A survey should be promptly conducted when suspicion that an area, clothing, or hands have been contaminated. A portable radiation counter is available. The radiation you are working with is low in intensity and has a short lifetime. Small spillage is not dangerous but should be cleaned up promptly.
6. Should an accident occur, it should be reported immediately to the lab instructor.
7. Upon completion of the experiments, sources are to be returned to their designated storage containers. No sources are to be removed from the laboratory.
8. Everyone who any contact with the samples should thoroughly wash their hands before leaving the laboratory.
9. Dispose of all waste in the designated radioactive container.
10. Enjoy the experiments!

# Appendix: Using Excel for Plotting data

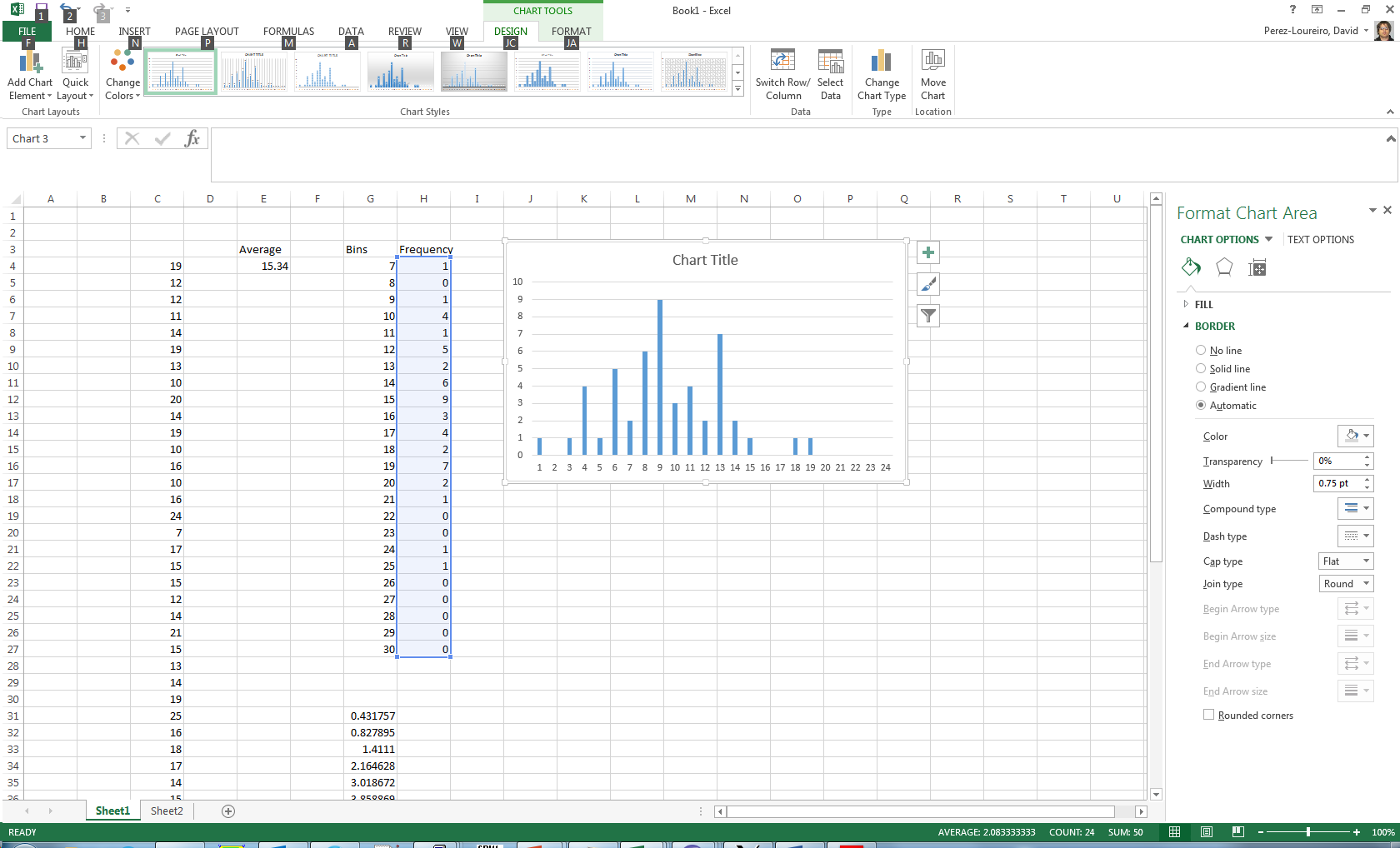
The following tutorial includes basic instructions for using Microsoft Excel 2011for Mac to make two types of simple graphs: column-bar, which will be used for the first experiment, and graphs and line (XY) graphs. This latter ones, will allow us to show the exponential decay and extract the half-life of 137mBa.

## Column/Bar Graphs

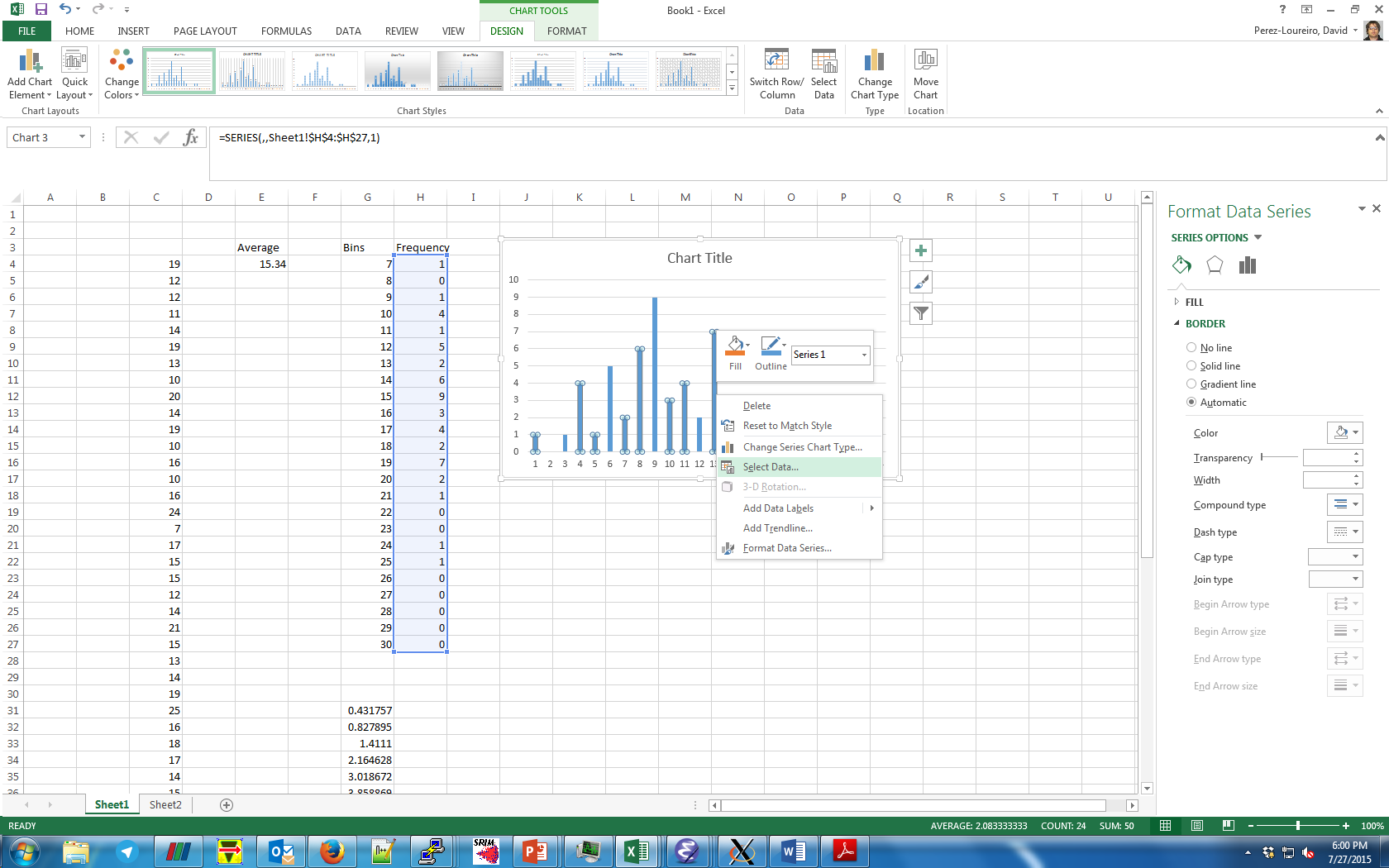
Use the mouse to highlight the data you want to plot. Then click the **Insert** tab**.** Then select in the Chart Section the 2D Column Icon



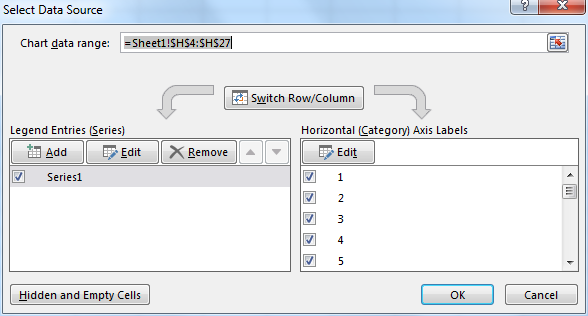
When you click in the Chart type you want, Excel automatically creates a draft of the chart and it pastes it into the worksheet, like this:



Then you have to add the right labels to the X axis, in our case the bin numbers. To do so, right-click on the Chart and select **Select Data…**

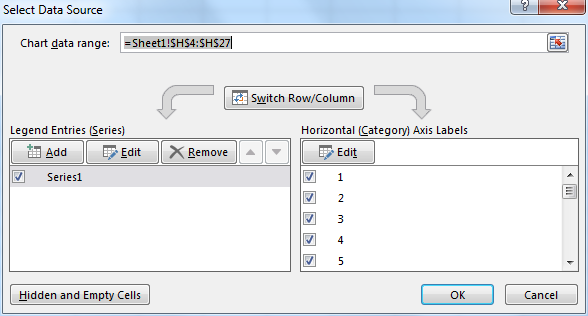


The following window will pop-out



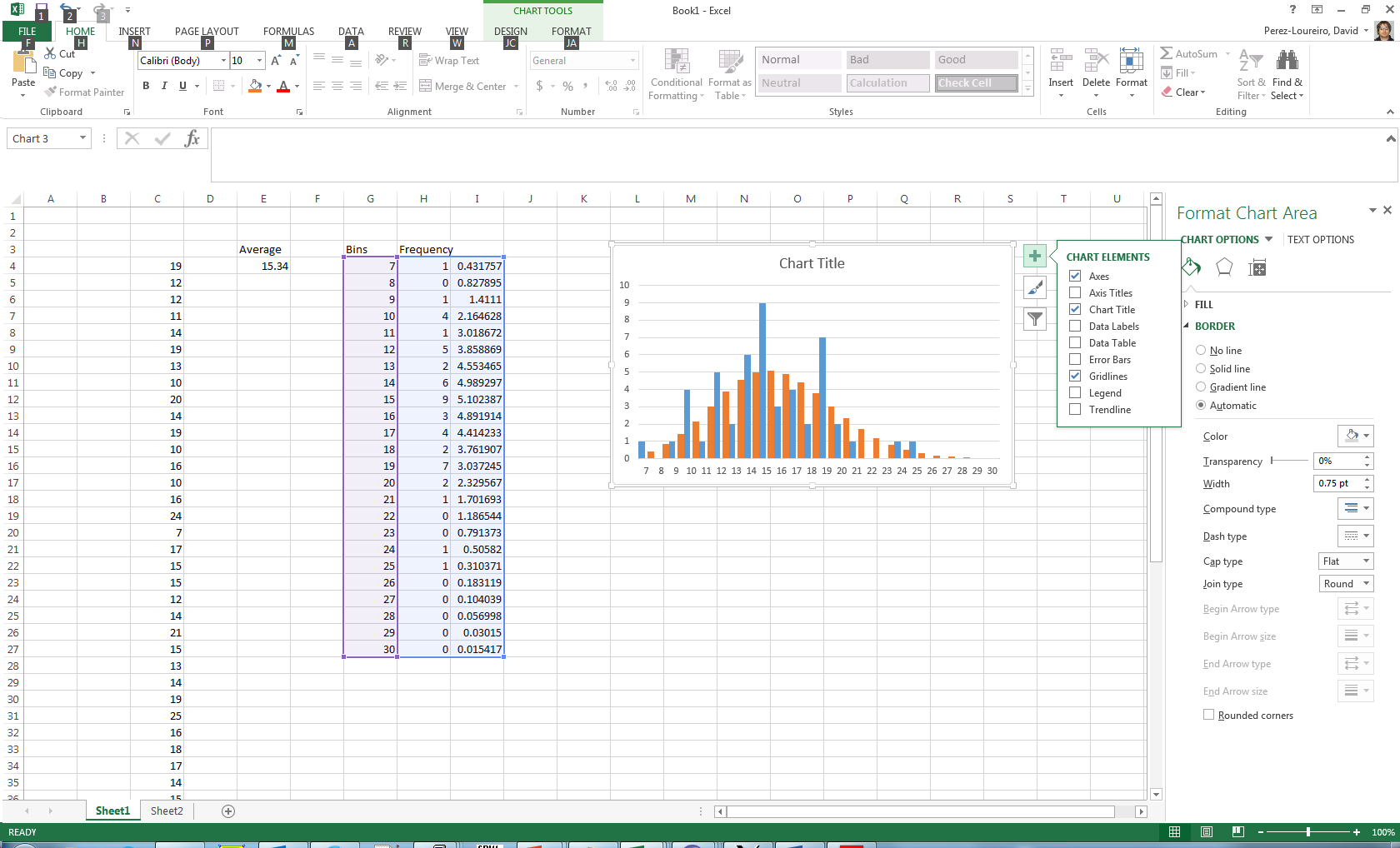
Now on the Horizontal Axis labels, click on Edit. Now select the Bin column and click **OK** when you are done. Click **OK** again, your chart should show the right labels

If you want to add a new series of data, just go to the **Select Data…** option again and add a new series to the left column by clicking on **Add**



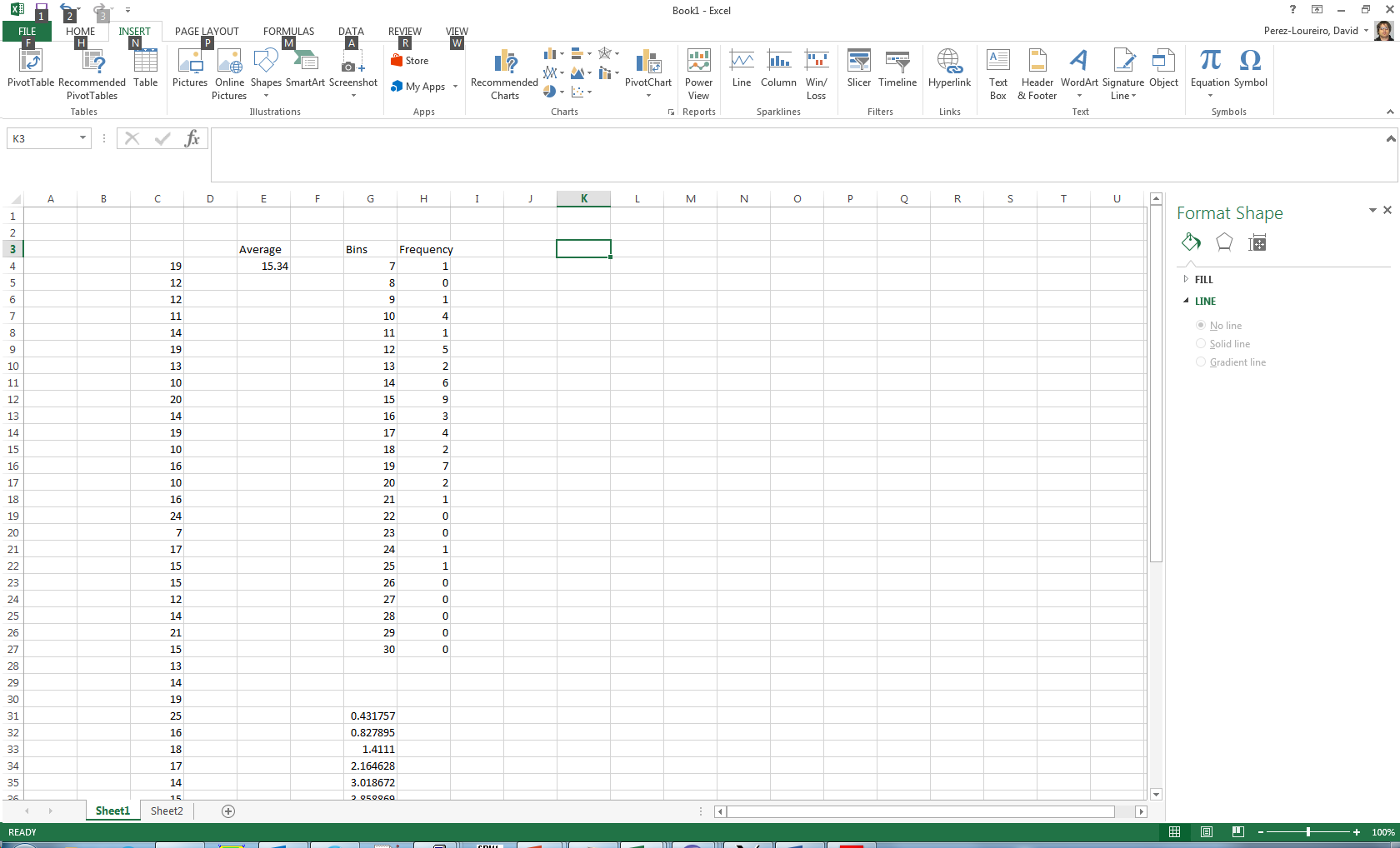
You will have to select your new series and click OK, same as before. Your chart will look like that

If you need to add labels to the axis, legends …, just click on the **+** on the right of the chart



## Scatter (XY) Graphs

The procedure is very similar to the one for column graphs. Use the mouse to highlight the data you want to plot. Then click the **Insert** tab**.** Then select in the Chart Section the Scatter option

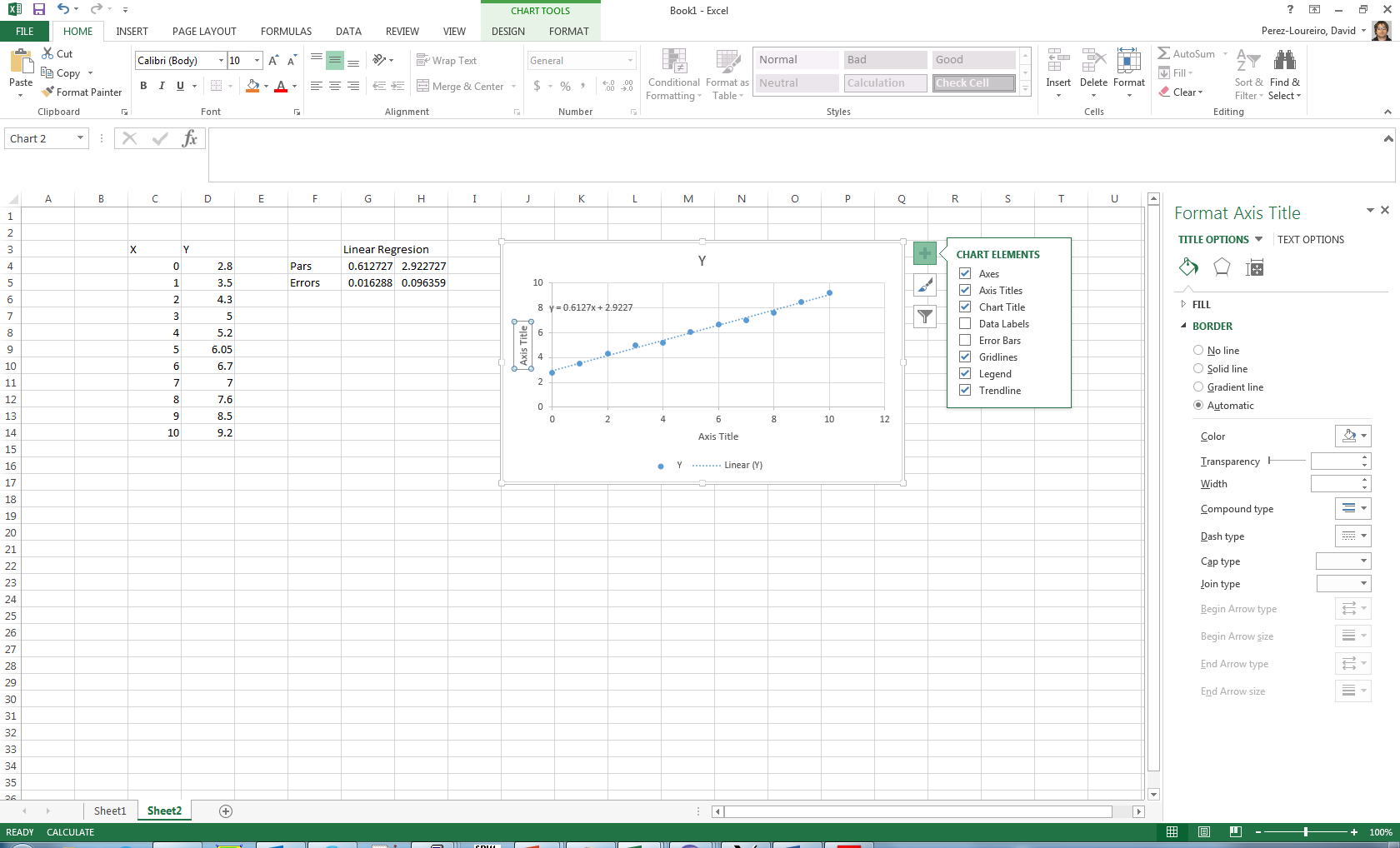


When you click in the Chart type you want, Excel automatically creates a draft of the chart and it pastes it into the worksheet, like this:

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Again, to add labels to the axis, legends …, just click on the **+** on the right of the chart and click on any of the chart elements you want to add. You can edit each element by clicking on it.

To add the trend line, the procedure is the same as any other chart elements. You will have to choose which kind of trend line you want, e.g. linear, exponential, polynomial …, You can also select to display the equation on the graph as well as the correlation factor R2.

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1. mrem (millirem) is a unit used for the equivalent dose of radiation.. These quantities are a complex weighted average of absorbed dose, which is a clear physical quantity measured in rads (Absorbed energy per mass unit). [↑](#footnote-ref-1)