# Educational technology for laboratory experiments in Nuclear Physics and related sciences

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## ABSTRACT [1]

In this work, we present a prototype of a Nuclear Radiation Counter simulator, targeted to laboratories teaching Nuclear Physics and related sciences, both in universities and high schools. Its usage is also possible in research centers, for personnel ramp up and training. This equipment simulates data based on real experiments for the elaboration of representative characteristic curves corresponding to different radioactive sources, allowing to experiment without manipulating real radioactive elements. By incorporating this simulator in the multidisciplinary teaching and learning processes in STEM fields, it is possible to run these tests in a simple manner using non-radioactive materials. This, in turn, eliminates the risks inherent to the manipulation of radioactive sources, and reduces the costs and complexity of doing these experiments. Doing experiments allows theoretical contents to be applied in practical situations that lead to involvement in the research, interpretation, integration and communication processes of the obtained results. Simulating the experiments enables to obtain the same experiences for both the student and the professor, especially in situations where it would be significantly more difficult to do the real experiment. This will facilitate sharing knowledge of Nuclear Physics beyond the local scope of the university.

**Keywords**: Learning, Technology, Experiments, Simulator, Nuclear Energy.

## 1. INTRODUCTION

Laboratory experimentation on Science, Technology, Engineering and Mathematics (STEM) subjects allows students, professors and professionals to apply interdisciplinary concepts where the theoretical aspects of scientific developments can be applied to a real-life activity. In these experiments, schools, scientific communities and the industry come together as a cohesive unit.

At the same time, the usage of simulators in teaching and personnel training is becoming wider in all stages of academic and/or professional career developments, especially on fields where the experiments are either complex, expensive or dangerous. Simulating these experiments transforms them into simple, cost-effective and safe experiments, through the use of the data obtained from real experiments. By doing this, the student can qualitatively and quantitavely verify the scientific laws that interact with the real world, in an environment with the aforementioned benefits [1].

Nuclear physics, in particular, is one of those fields. Most of the experiments involve the manipulation of radioactive material, which means that experiments must

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be done on nuclear laboratories with the proper protection to use them.

This poses an accesibility problem for schools and universities who do not have a nuclear laboratory and want to teach about Nuclear Physics, as they would be unable to provide a valuable laboratory experimentation for their students.

In the upcoming sections, we present a project of a Geiger counter simulator, as a part of a broader project [2]. This simulator puts the user in a similar environment as the real experiment environment, where the user can develop skills, learn operative procedures, and reinforce knowledge of theoretical and practical aspects from the real experiments. All of the simulations can be done an unlimited number of times, which also allows to adjust to the user's own learning process.

## 2. BACKGROUND

Geiger counters are instruments used for detecting and measuring ionizing radiation. They consist of a Geiger Müller tube, a cylinder filled with ionizing gas, and electrical components that count the amount of ionizing pulses that come from inside the tube. A basic scheme of the Geiger counter can be seen on figure 1.

Whenever a charged particle (such as $\alpha$ or $\beta$ particles) goes into the detector, the gas gets ionized. This produces a chain reaction that lasts for a fraction of a second which, in turn, produces a pulse, which is processed by the pulse counter. The pulse occurs due to the power supply, as it forces electrons to accumulate on the anode, and positive iones on the cathode.
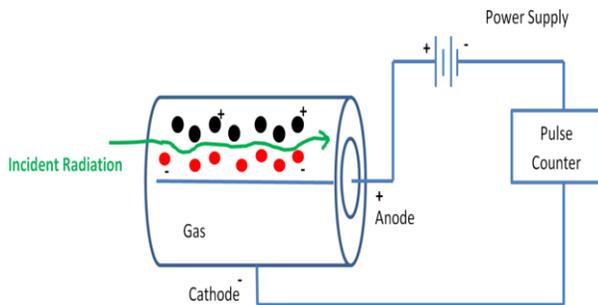


Figure 1: Geiger counter description

## 3. SIMULATOR DESCRIPTION

This section explains in detail the different laboratory experiments and how the user should operate the simulator in order to obtain the results from each experiment. The simulated elements include the electrical supply voltages of the Geiger counter, radioactive sources, absorbent elements and particle dispersers. These values are used to determine the Plateau curve of the aforementioned instrument and the values of the absorption and backscattering of charged particles by different materials exposed to the selected radioactive source.

### 3.1 Laboratory 1: Determining the plateau curve of the Geiger Counter

The plateau curve indicates the appropiate supply voltage for a Geiger counter. If the voltage is too low, radioactive activity will not be equally distributed along the cathode; if the voltage is too high, the tube may be damaged by the continuous discharges. An appropiate supply voltage will be in a zone from the curve in which the amount of counts per minute grows linearly when increasing voltage, with the optimal point being in the middle of this zone, to reduce the effect of variations in the voltage [3]. The graph shown in figure 2 shows a graphical representation of the plateau curve.

In order to experimentally obtain the aforementioned curve, the user would need to vary the supply voltages used on the tube, measuring on every variation the amount of counts per minute returned by the pulse counter. Using this data, the user will be able to plot the curve and graphically determine the optimal supply voltage.

In the simulator, the user is able to select the supply voltage from a set of pre-loaded data on the simulator, which has been obtained from doing the real experiment.

### 3.2 Laboratory 2: Absorption

The next laboratory focuses on two aspects of nuclear experimentation: on one hand, determining which radioactive material is acting as the radioactive source (that is, to determine whether the source is Cobalt-60, Sodium-22, etc.); on the other hand, determining the minimum thickness of an absorbing material so that it can block incoming radiation from the radioactive source.

To block incoming radiation, the required material depends on the type of radiation that the user would want to block.

$\alpha$ radiation is blocked by paper, $\beta$ radiation by metals and $\gamma$ radiation by concrete and/or lead. This laboratory focuses on blocking $\beta$ radiation.

In order to obtain the minimum thickness of the radiationabsorbing metals, the student will have the superficial density of the piece of metal, and the density of the metal, which is always constant. Using these data, it is possible to obtain experimentally the thickness of the absorbing metal.

On a real experiment (as shown on figure 4), the required elements include a $\beta$ particle source, absorbers of various thicknesses, and a Geiger counter [4].
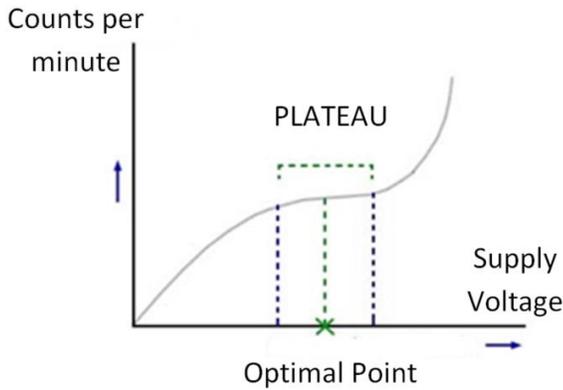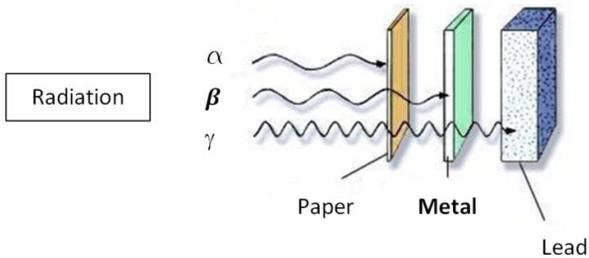
Figure 2: Geiger counter description



Figure 3: Radiation types and blocking materials



Figure 4: Real absorption experiment setup

The simulated elements are shown on figure 5. The simulator returns activity count values corresponding to the radioactive source and the thickness and type of the absorbing material being simulated, with the radioactive source being on the third slot of the tower, and the absorbing material being on the second slot.



Figure 5: Simulated absorption experiment setup

The user of the simulator should take note of the activity count values displayed by the simulator. These values can then be plotted and, through and approximation technique (on most cases, minimum squares), it is possible to obtain an exponential fit to the obtained data. An example of this curve is shown on figure 6. The fit of the curve will be of the form $y = a\, e^{(-bx)}$ , where the absorption coefficient can be calculated by obtaining the value of b [5].
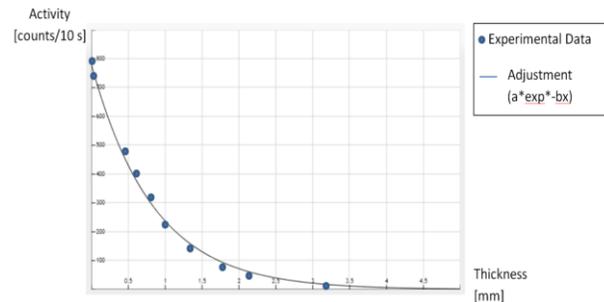


Figure 6: Simulated absorption experiment curve fitting

The next step on the experiment is to obtain the maximum energy before β-decay. This can be done using the thickness of the material that resulted in the lowest amount of counts per second, and then mathematically obtaining the maximum energy with this data.

Finally, comparing the maximum energy with known β-decay patterns (as shown on figure 7 [3]), the user can determine the radioactive being used.
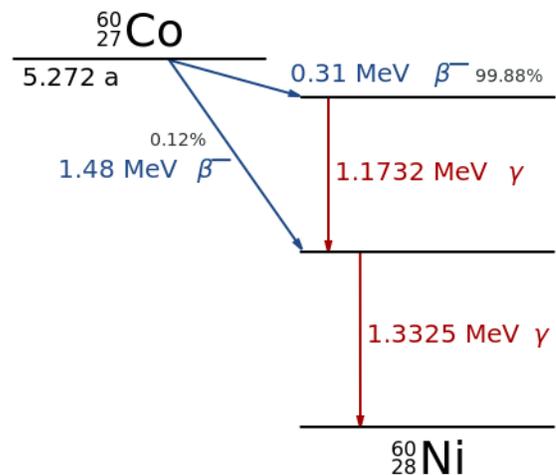


Figure 7: β-decay of Cobalt-60

## 3.3 Laboratory 3: β-backscattering

This laboratory experiment analyzes the radiation from the radioactive source when the incident beta radiation scatters when going through different materials. In particular, this experiment shows that the materials used as scattering materials exhibit this behavior, and that the scattering effect is more prominent on materials with a higher atomic number.

When a β particle coming from a radioactive source interacts with a material, its trajectory may deviate depending on its initial energy. This produces a dispersion effect on the particle. Depending on the relative orientation of the impact between the β particle and the core of the material's atoms, there is a chance that the β particle exits the material on the same spot where it entered the material. This phenomenon is called backscattering.

In this experiment, the user first measures the radiation activity count when there is no scattering material in between. After that, the user adds different materials at the end of the source and measures the activity count once again. The difference between the two allows to determine which is the scattering material being used. A schematic of the experiment setup is shown on figure 8. In the simulator, the setup is shown in figure 9. The different simulated elements (the radioactive source and the backscattering material) are placed in a tower similar to the one used on the previous experiment. The position of the simulated elements resembles the real experiment.
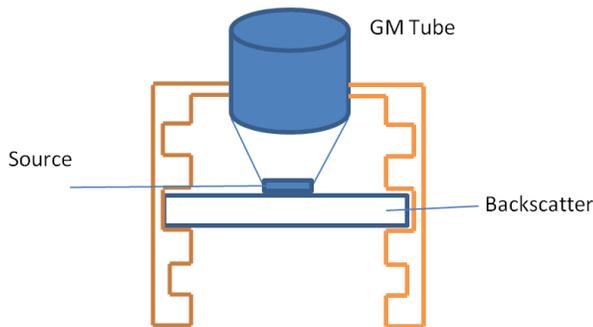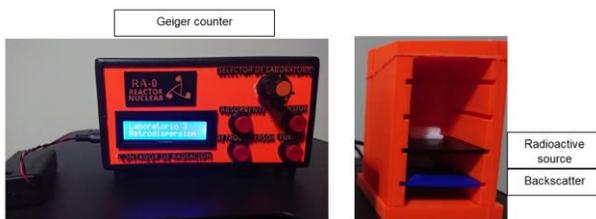


Figure 8: Backscattering experiment schematic setup



Figure 9: Backscattering experiment simulated setup

## 4. VALIDATION AND RESULTS

In order to evaluate how effectively the simulator, the prototyped simulator was used in a graduate university course.

Specifically, this simulator was used on late 2019, on a course of "Methodology and Application of Radionuclides", taught by the University Center for Nuclear Technology (CUTeN), of Faculty of Exact, Physical and Natural Sciences, part of the National University of Cordoba, Argentina.

The course consisted of 30 students, where as part of the laboratory practice exercises, they used the presented simulator. At the end of the corresponding exercises, the students were asked to answer a survey that focuses on the effectiveness and the overall reception of the simulator and the experiments conducted with it.

The table 1 indicates the questions asked to the students on the survey, and the figures 10 and 11 indicate the results obtained from the survey. The first two questions refer to information about similarity to the real experiments and understanding the real phenomena; the other three questions ask the user to rate the degree of learning that they have achieved of various concepts taught with the help of the simulator.

The results from the survey indicate that students perceived positive effects on the learning process of different topics related to the usage on the simulator, and they also showed a high degree of acceptance of the tool.

| Question | Options |
|---|---|
| Q1: The simulator is similar to its real counterpart | Greatly agree, Agree, Slightly agree, Do not agree |
| Q2: Using the simulator helped me understand the physical phenomena | |
| Q3: Rate your learning achievement of the working mechanisms of the instruments | Achieved, Partially achieved, Not achieved |
| Q4: Rate your learning achievement of radioprotection (distance-time-protection) | |
| Q5: Rate your learning achievement of the behavior of radionuclides (decay, half-life period) | |

Table 1: Questions and possible answers asked on the survey
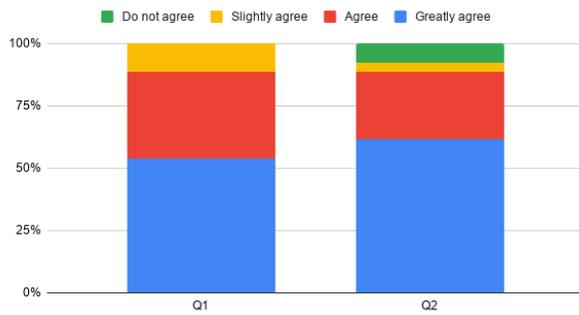
## Questions 1 and 2



Figure 10: Answers to Questions 1 and 2
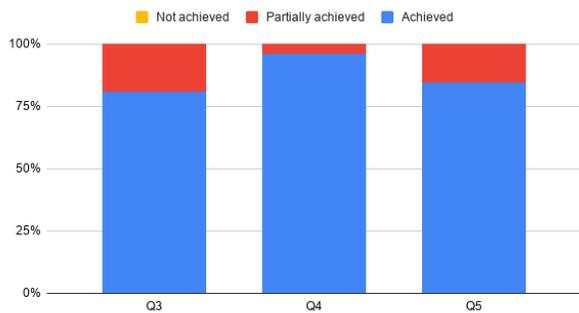
## Questions 3 to 5



Figure 11: Answers to Questions 3 to 5

## 5. FUTURE WORK

This simulator is part of a broader project. As part of the scope of the extended project, it is planned, in the near future, to upgrade the prototype of the simulator to allow usage both physically and remotely through the internet.

We also plan to make the values returned by the simulator non-static, that is, to make the values variate according to known statistics for them [6].

Another feature under consideration is to add new tables for the radioactive activity values for other radioactive sources, absorbent materials and dispersers.

## 6. CONCLUSION

The simulator presented in this article has as its main objective to improve laboratory activities on schools, universities and laboratories.

This prototype of a simulator of a nuclear radiation counter was designed and built having as main purpose allowing to obtain real data using simulated elements. This simulator has three modes related to real-life experiments: obtaining the plateau curve that shows the basic behavior of a Geiger counter; obtaining curves that show the radioactive activity in relation to the thickness of the absorption materials which can, in turn, be used to

estimate the energy of the particle-emitting source; and finally, evaluating the behaviour of radiation as it goes through dispersers.

As the radioactive activity data provided by the simulator is based on real experiment, the usage of this simulator allows to manipulate radioactive sources, absorbing materials and particle dispersers in a safe, simulated environment that resembles the real world experiments.

## 8. REFERENCES

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