

## Remote simulator for Inverse Square Law experiments in nuclear physics

Kouichi Julián Andrés Cruz<sup>1</sup>, Gustavo Lazarte<sup>2</sup>, Alejandra Lucia Pérez Lucero<sup>3</sup>, Norma Adriana Chautemps<sup>4</sup> and Walter Miguel Keil<sup>5</sup>

*<sup>1,2,3,4 & 5</sup> Reactor Nuclear RA0, Facultad de Ciencias Exactas Físicas y Naturales, Universidad Nacional de Córdoba, Argentina*

### Abstract

In this work, we present a prototype of a simulator of the Inverse Square Law for nuclear radiation, targeted to laboratories teaching Nuclear Physics and related sciences, both in universities and high schools. This simulator provides a way for schools, training centers and universities to provide their students with the possibility of performing experimentation on this physical property, especially for those that do not have access to a laboratory with the adequate radioprotection for the experimenters. The equipment simulates data based on a real experiment that validates the Law, thereby allowing users to visualize the effects of it without manipulating real radioactive elements, in a safe, cost-effective and simple way. In this way, users can do laboratory practices that allow them to integrate theoretical concepts and their practical counterparts, without having to be concerned about the risks inherent to performing the real experiment. The simulator was designed with remote access in mind, allowing end users to perform these experiments regardless of their location, as many times as they like to, in order to successfully understand the applications of the Law in practical environments. In addition, this also facilitates sharing knowledge of Nuclear Physics beyond the local scope of the university.

**Keywords:** teaching, experiments, remote, simulator, inverse square law

### 1. Introduction

Laboratory experimentation on subjects relating to Science, Technology, Engineering and Mathematics is an integral part of the students' learning process, as it allows them to form a link between the theoretical concepts and the real life phenomena.

There are some cases where making students perform these experiments is not possible due to a variety of reasons, the most common being either high costs or high risks on making the experiment. In these cases, the usage of simulators for teaching in schools and in personnel training is steadily increasing as a simple, cost-effective and safe alternative to the real experiment. The learning process stays unmodified because these simulators are based on real-life data, allowing the student to qualitatively and quantitatively verify the scientific laws that

interact with the real world, in an environment with the aforementioned benefits (Pérez Lucero et al., 2015).

One field in particular where the usage of simulators has become particularly important is in the area of Nuclear Physics, as these experiments require manipulation of radioactive elements. Consequently, experimentation on this area can only be done by laboratories which have a properly insulated space and can afford the radioprotective gear for the people who perform the experiment. It should come as no surprise that this poses an accessibility problem for most schools and centers that wish to provide this valuable learning experience for their students.

In the upcoming sections, we present a project of an Inverse Square Law for nuclear radiation simulator. This work is part of a broader project (Lazarte et al., 2016) and it builds upon previous work on the area of simulators (Lazarte et al., 2020). This simulator, as it was the case with our previous one, puts the user in a similar environment as the real experiment, where the user can learn and reinforce their knowledge of the Inverse Square Law in a practical way. All of the simulations can be done an unlimited number of times, which also allows to adjust to the user's own learning process. Unlike the previous one, however, this simulator was designed to support remote access, enabling users to perform these experiments regardless of their location.

## 2. Methods

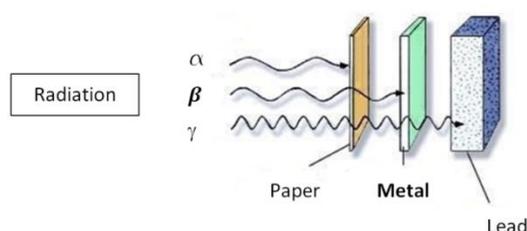
### 2.1 Theoretical background

This section focuses on the concepts that are being used on this simulator. These parts will provide context of the experiment being simulated

#### 2.1.1 Radiation types

There are three types of radiation:  $\alpha$ ,  $\beta$  and  $\gamma$  radiation, each of them being different on their nature ( $\alpha$  and  $\beta$  involving atomic particles being emitted,  $\gamma$  being electromagnetic) and in how they can be blocked ( $\alpha$  with paper,  $\beta$  with metals like aluminum,  $\gamma$  with lead; this is shown on Fig. 1). The experiment in this paper focuses on a property of  $\gamma$  radiation.

Figure 1: Radiation types and their blocking materials



#### 2.1.2 Inverse square law for $\gamma$ radiation

The Inverse Square Law is a physical property that established that the intensity  $I$  of a quantity at a distance  $d$  from the source of said quantity is inversely proportional the square of the distance. This is shown in Eq. 1.

$$I \propto \frac{1}{d^2} \quad (1)$$

This law follows a geometrical property for point sources that emit quantities on a three-dimensional space. Some examples of its applications include Newton’s law for gravitation (Halliday et al., 2018), Coulomb’s law (Tipler & Mosca, 2008), and in acoustics (Serway & Jewett, 2018).

Similar to those examples, there are multiple applications of this property for  $\gamma$  radiation. In this project we focus specifically on measuring the *dose rate*, which is defined as the quantity of radiation being absorbed per unit time (Knoll, 2000). The value can be calculated following the Inverse Square Law using the formula shown in Eq. 2.

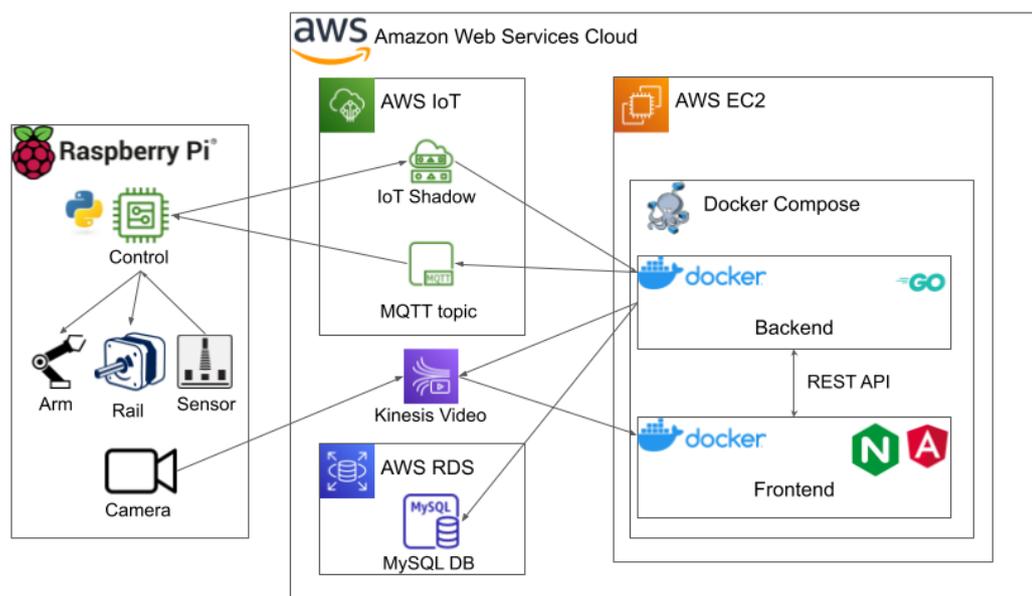
$$\dot{E} = T \frac{\alpha}{d^2} \tag{2}$$

where  $\alpha$  is the source’s activity,  $d$  is the distance between the source and the point of measurement, and  $T$  is defined as the *equivalent dose constant*<sup>1</sup>, which is a value specific to the radionuclide that is being used as the source (Cobalt-60, Cesium-137, etc.). These values are defined experimentally and are used as constants, measured in  $\frac{Sv \cdot m^2}{h \cdot Bq}$ . Based on this constant, the quantity  $\dot{E}$  is measured in  $\frac{Sv}{h}$ .

## 2.2 Simulator description

The simulator was implemented using the schematic diagram shown in Fig. 2.

Figure 2: Schematic description of the simulator



<sup>1</sup> Some authors denote this value with the letter  $\Gamma$ . As this letter is used for another constant, we use the letter  $T$  to avoid confusion

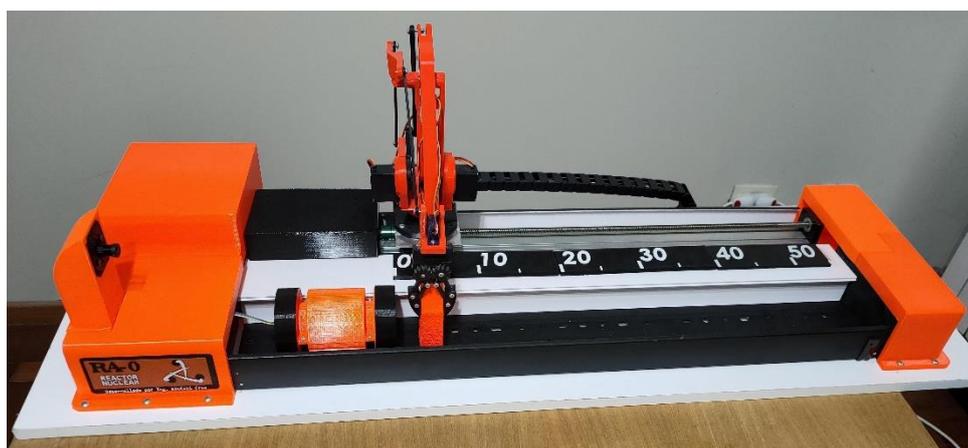
The simulator is composed of two distinct, well-defined modules: the *hardware* module that performs the simulated experiment, and the *cloud* module that provides users a way to interact with the hardware, and does the processing of the hardware's data for the user to see.

The hardware part is composed of multiple parts that simulate the components of the real experiment. Instead of using a dose rate counter, a radioactive source, and manually moving around the radioactive source at different distances from the counter, we use a distance sensor (replacing the Geiger counter), a plastic object with similar dimensions to a radioactive source, and a robotic arm built over a rail, which simulate a real arm moving the source around. These elements simulate the action of moving the source to a different distance, and measuring the dose based on it. The hardware also contains a camera that provides a live feed of the experiment to the end user whenever they are performing the experiment.

For the experiment, the distance sensor is positioned at a fixed location, with the simulated source being the object that is moved around by the robotic arm and the rail. The source can be positioned anywhere in the range of 3 to 50 centimeters from the distance sensor, in increments of 1 centimeter. This way, the user can test freely multiple positions and get measurements with custom resolutions.

The *cloud* module refers to the infrastructure that allows end users to communicate with the hardware and control it during the simulated experiment. This part is further divided into two parts, a web server that serves as an entry point for the user through its graphical interface, and other middleware services that implement the interaction between the web server and the hardware.

Figure 3: Hardware of the simulator



### 2.3 Simulator usage

In short, the procedure of the real experiment is to measure the dose rate of various radioactive sources positioned at various distances from the point of measurement. The simulator follows that experiment by allowing those two as inputs. In other words, the user of the simulator can control a variety of simulated radioactive sources (the same ones that are available to use for the real experiment on this University), and variate the distance at which to position the simulated radioactive source.

To select the source being used, the user can select which is the radioactive source from a dropdown bar. Each one of them is made of a different radionuclide and with different activity levels. This way, the user can test this property for multiple radiation sources that follow it, similarly to how it would be done in the real experiment.

To control the source's positioning, the user issues a command from the screen to move it in increments of 1 centimeter, or to move it to either the start position (at 3 centimeters from the distance sensor) or the end position (at 50 centimeters of the distance sensor). At each position, the distance sensor will relay information of the current distance of the simulated source to the cloud service, which will then simulate a dose rate measurement using the distance and the selected source as inputs. This simulated measure is then passed onto the graphical interface, which will be displayed to the end user as the measurement made by the sensor.

The measurements provided are calculated as the sum of a fixed and a variable component: the fixed one is obtained by using the theoretical formula explained in Eq. 2.; the variable one is obtained by generating a random number with a Gaussian distribution, with zero mean and variance proportional to the source's activity level. By doing this, the measurements made are not constant, but constantly changing, much like in real life. To further display this effect to the end user, a new simulated measurement is generated each second, with the latest measurement being displayed on the screen.

As the user keeps moving around the simulated source, the simulator will show on the screen a graph with the average measurement at each distance for the selected radioactive source. This is another resource available to the user to visualize the effects of the Inverse Square Law in a graphical way.

At all times, the graphical interface will also show the live feed of the camera from the hardware. This way, the user can see how the object is being moved by the robotic arm and the rail, reinforcing the idea of how the real experiment is done.

Finally, the user is given the option at any time to download as a CSV all of the simulated measurements done during their session of usage of the simulator; this helps the user keep track of any measurements obtained, and provides raw data to be used for further analysis should it be required.

As a final note, the interface also implements an exclusivity system, to prevent two different users from running into concurrency issues, as they might give contradicting commands to the simulator's hardware. To avoid this potential issue, the system requires users to log in to be able to use the system. Whenever a user logs in, they are entitled to use it for 30 minutes, with access from other users being denied by the system. During that time period, the user is able to perform the experiment on the simulator. After that time passes, the user logs the user out, giving them a final opportunity to download the raw data that they have obtained. This is done as a defense mechanism to prevent users from monopolizing the usage of the service.

Figure 4: Graphical interface of the simulator



### 3. Results

To validate the effectiveness of the simulator, we used it on a graduate university course in nuclear physics, 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 simulator was used by these students in August 2021, consisting of 14 students. These students were requested to perform laboratory practice exercises remotely using the simulator implemented here. After the exercises are completed, the students were then given a survey that asks them questions about their background, their opinions of the usage of the simulator from a functional standpoint, and their opinions of its usage from a learning standpoint.

The first questions, shown with their answers in Tab.1. contain the results of the background questions that were asked.

Table 1: Survey results for background questions

Questions	Answered "Yes"	Answered "No"
Have you ever used a simulator of any experiment (related or not to nuclear physics)?	7	7
Have you ever used a simulator of any experiment related to nuclear physics?	7	7
Have you ever done a nuclear physics experiment using real elements (in other words, not simulated)?	7	7

For the usage of the simulator, we gave the users questions where they should answer their agreement or disagreement with statements regarding their usage of the simulator, using the Likert scale<sup>2</sup>. The results from their answers are shown on Tab.2.

Table 2: Survey results for simulator usage questions

Questions	Average	Std. deviation	Median
It's easy to access the simulator	4.786	0.578	5
It's easy to make the experiment on the simulator	4.571	0.756	5

<sup>2</sup> 1: Completely disagree; 2: Disagree; 3: Neither agree nor disagree; 4: Agree; 5: Completely agree

The simulator shows similar results as the theoretical results	4.5	0.941	5
The simulator shows the information in a clear way	4.429	0.852	5
The simulated environment is similar to the real experiment's environment	4.143	0.949	4

Finally, we gave the students questions that provide self-assessment of their knowledge and comprehension of the concepts of the Inverse Square law, and how important is for their comprehension to have used the simulator. These results are shown on Tab.3.

From these results, we can see that there was a high acceptance of the simulator between the students, who perceived that they could use the simulator to great effect for their learning process.

Table 3: Survey results for comprehension questions

Questions	Average	Std. deviation	Median
I understand the foundations of the Inverse Square Law	4.786	0.426	5
I understand how to utilize the materials involved in the Inverse Square Law experiment	4.571	1.089	5
I understand which are the steps to repeat the Inverse Square Law experiment	4.643	0.633	5
The usage of the simulator has helped me to understand these concepts	4.571	0.756	5
The usage of the simulator has helped me to validate the Inverse Square Law in a practical way	4.571	0.756	5
I consider that I have to use the simulator more in order to better understand the experiment	3.714	1.267	3.5

## 4. Conclusion

The simulator presented in this article has as its main objective to improve laboratory activities on schools, universities and laboratories. This simulator of the Inverse Square Law experiment was designed and built having as main purpose allowing to obtain real data using simulated elements. By adding a noise factor onto the measurements, we provide further relation with the noisy measurements that happen during the real experiment.

As this simulator was designed having remote access in mind, it will provide potential users from all over the world a way of performing this experiment in a safe, simulated environment that resembles the real experiment.

## Acknowledgment

The authors would like to thank all of the students that participated on the survey, providing invaluable data for our research. This study was able to be conducted thanks to them.

## References

Halliday, D., Resnick, R. and Walker, J. (2018) *Fundamentals of Physics*, 11th ed., Wiley.

Knoll, G. (2000) *Radiation Detection and Measurement*. 3rd ed. Wiley.

Lazarte, G., Cruz, K. J. A., Pérez Lucero, A. L., Chautemps, N. A. and Keil, W. M. (2020) “Educational technology for laboratory experiments in Nuclear Physics and related sciences” *Journal on Systemics, Cybernetics and Informatics: JSCI*, vol. 18 number 5, pp. 16-20.

Lazarte, G., Pérez Lucero, A. L., Chautemps, N. A. and Díaz, L. C. (2016) “Simulador Prototipo de Contador de Radiación Nuclear”, *XI Congreso de Educación en Tecnología y Tecnología en Educación*

Pérez Lucero, A. L., Chautemps, N. A., Bertone, R., and Diaz, L. C., (2015) “Simuladores aplicados en laboratorios de energía nuclear”, *XXI Congreso Argentino de Ciencias de la Computación*.

Serway, R. and Jewett, J. (2018) *Physics for Scientists and Engineers with Modern Physics*, 10th ed., Cengage Learning.

Tipler, P. and Mosca, G. (2008) *Physics for Scientists and Engineers with Modern Physics (extended version)*. 6th ed., W. H. Freeman and Company.