“Radiation Remote Laboratory” with two level diagnostics

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Abstract—The paper describes the remote experiment “Radiation Remote Laboratory” with two levels diagnostic system, built on ISES - Internet School Experimental System, accessible across the Internet and provided via the system REMLABNET (http://www.remlabnet.eu/), The remote experiment strives to provide the basic knowledge on γ radioactivity and/or γ radiation and its basic application laws, and parameters like its Poisson distribution, intensity dependence on distance from the point source and provides basic ideas about its absorption in various materials. Absorption in Cu on thickness of the Cu material is possible to examine in detail. Besides, this experiment serves to develop the basic knowledge for handling the radioactive materials in education and practice.

Keywords—ISES, remote experiment, diagnostic system, radioactivity, intensity, shielding effect, absorption.

1 Introduction

Research shows that many students misinterpret the physical principles behind radiation and radioactivity and are unable to apply scientific knowledge connected with radiation and radioactivity [1]. By addressing these issues “Radiation Remote Laboratory” provided via the Internet was developed. Students and interested may understand the basic concepts as source, radiation and detector model, similar as in [2]. They can then easily understand the concepts of absorption of radiation, radioactive decay and half-life of radioisotope.

The proposed “Radiation remote laboratory”, controlled as finite state machine and its core – Measureserver, provided by two level diagnosis for the purpose of the increased reliability is described in detail in [3]. The remote experiment is aimed at real measurement of the statistical distribution γ radiation, its point source properties, absorption power of Al, Fe, Pb materials and detailed dependence of absorption of Cu on thickness. As a point source of γ radiation Americium (Am^{241}) was used as the most prevalent isotope of americium in nuclear waste. Americium 241 has a half-life of 432.2 years, γ emission with energy of 59.5 keV [4]. The concept of γ radiation and its properties are important subject matter in contemporary industry and science in connection with the energetics, use in medicine and military applications [5]. As a teaching tool this experiment is contributing to teaching of radioactivity, because it is one of the first remote experiment dealing with the real measurements in the field of radioactivity [6].

2 Purpose and goals

The whole concept of the Remote Experiment "Radioactive Laboratory" experiment comprehended to enable demonstrating the basic concept of radioactive phenomena:

- The concept of basic properties of γ radiation source and its Poisson distribution of emission,
- To study the dependence of the intensity of radiation on the distance from the source,
- To study the absorption power of different materials in general,
- To study the absorption in Cu on thickness of the Cu shielding and the stopping power of Cu.

3 Short theory, the experiment setup and students result

3.1 Theory

Firstly, let us assume that the relative intensity of γ radiation of the point source is denoted by I [min^{-1}] (and expressed by number of registered events by Geiger-Műller tube), the intensity at x = 0 m is denoted by I_0, the absorption coefficient μ [m^{-1}] and the distance x [m].

Radiation intensity on the distance from the source

The radiation intensity of the γ radiation of the point source depends on the distance x from the source

$$I \sim \frac{1}{x^2}\,. \tag{1}$$

Absorption power of materials

The absorption of γ radiation in material depends on the material thickness x as

$$I = I_o e^{-\mu x}\,, \tag{2}$$

and the corresponding absorption coefficient μ [mm^{-1}] then is

$$\mu = \frac{1}{x}\,.\,(\ln\frac{I_0}{I}). \tag{3}$$

Poisson statistical distribution of γ radiation

The Poisson statistical distribution gives the prediction of the outcome of random and independent events [7]. The probability density function of the Poisson distribution is given by

$$P(X, \mu) = \frac{\lambda^k . e^{-\lambda}}{k!}, \quad (4)$$

where λ is the average number of events per interval and k takes values 0, 1, 2…. Poisson distribution Radioactive decay will be calculated with the help of radioactive decay can be calculated easily for small No of counts according [8].

3.2 "Radiation Remote Laboratory" - setup

The arrangement of the RE "Remote Radioactive Laboratory" is shown in the Fig. 1. As the source of γ radiation is used the certified school demonstration source DZZ GAMA Americium (Am-241). As detectors are used couple of ISES Geiger-Műller (GM) tubes. The first GM movable tube (GM1) is used for the background and source intensity–distance measurements, whereas the second, also movable (GM2) is used for absorption power of Cu, Al, Fe and Pb materials. The motion of GM tubes is by step motor drives. The whole setup uses the optical bench. Both the driving and measured signals are transmitted and collected by ISES standard hardware. The remote experiment "Radiation Remote Laboratory" is controlled by notebook FUJITSU with ISES USB module. The whole system is built on the Internet School Experimental System (ISES) components [9]. The whole experiment is organized as finite state machine and its core – Measureserver with PSC file controlling program and the web page were built using Easy Remote ISES (ER ISES) for compiling the control RE program [9]. The diagram shown in Figure 2 present the controlling web page of RE "Remote Radioactive Laboratory".

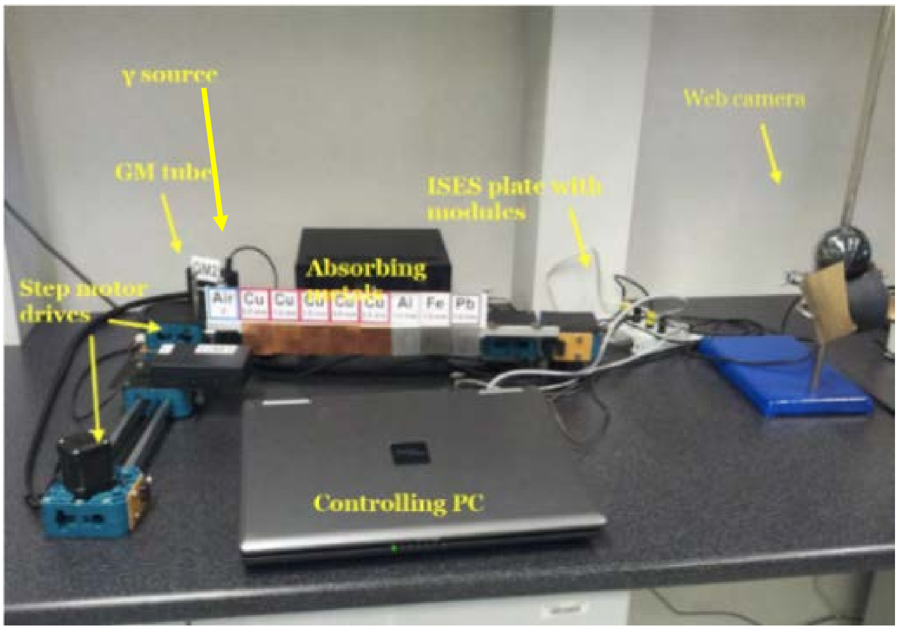


Fig. 1. View of the remote experiment "Radiation Remote Laboratory" with components described

In upper part there is the panel with the measured data output, below are the controls for adjusting the type of measurements and corresponding times, and in the lower panel is the transferred data for processing. The experiment is covered by the stream from web camera (right upper corner).

Fig. 2. Controlling webpage of the remote experiment "Radioactivity Remote Laboratory"

3.3 Two level diagnostic system

The first diagonistic system gives the feedback of the functionality of the experiment with the help of "traffic lights" [3]. (a) The green light indicates that the experiment is available to use, (b) the orange light indicates that the experiment is currently occupied and c) red light indicates that the experiment is out of oder. (see Figure 3).

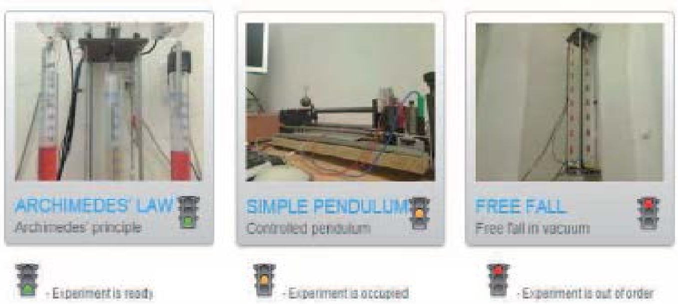
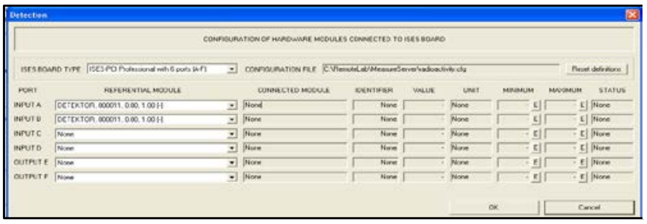


Fig. 3. Remote experiments **diagnostics I** - the "traffic lights" signal availability of the experiment (green) (a) occupation of the experiment, (orange) (b) and out of order experiment – not available(c)

Furthermore, the second system of diagnostics II is more sophisticated and watches for the proper functioning of all the components of the remote experiments. See Figure 4b, indication that it is running and further shows the continuous report regarding the functioning of the physical hardware. If all system and functions are working properly then they are indicated, but if the apparatus is either not working properly or their limiting function disrupted, then they are denoted by different colour. On issuing an error, the message will be sent to the experiment supervisor. The proper configuration and functioning of the remote experiment is inserted into configuration table – see Figure 4a [3].



[10:29:00] [Measureserver is running]
[10:29:30] [Measureserver is running]
[10:29:50] [Measureserver is running]

(A)
[10:30:30] [PORT: B, NAME: DETECTOR, ID:000001, UNIT: μWm^{-1}, MIN: -0, MAX: 10000,
STATUS: Connected with wrong reference]

[10:31:00] [Measureserver is running]
[10:31:10] [Measureserver is running]
[10:31:20] [Measureserver is running]

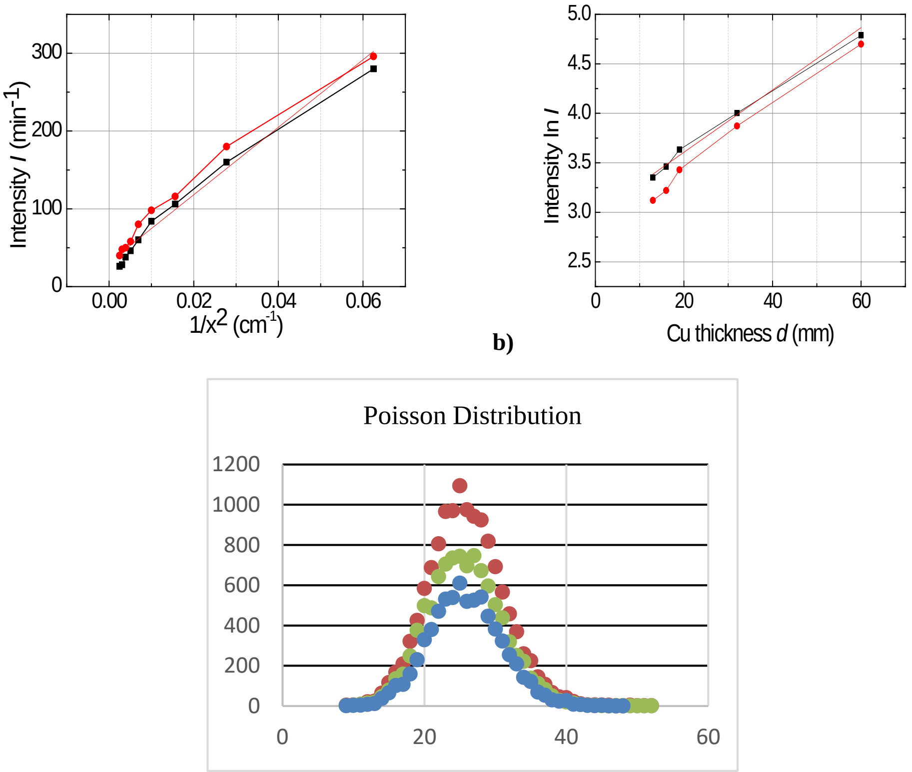
(B)
[10:32:00] [PORT: B, NAME: DETECTOR, ID:000001, UNIT: μWm^{-1}, MIN: -0, MAX:15000,
STATUS: Disconnected]

a) **b)**

Fig. 4. Reference list for configuration of Diagnostics II module (a), running report of diagnostics II module with proper functioning (green/light) and artificially introduced two faults (brown/dark)

3.4 Student's experimental results

The results of the radioactivity experiment measured by students are depicted in Fig. 1. Fig. 1a) gives the dependence radiation intensity of the γ radiation of the point source on the distance *x* (for collection time 30s) with fitting according to eq. (1) (where the upper (red) curve is with background pulses and the lower (black) one is without background pulses. In Fig. 1b) is the absorption in Cu, plotted as the transmitted intensity of γ radiation on Cu thickness *I*(*d*) with fitting by eq. (2) (here also the upper (black) curve is with background pulses and the lower (red) one is the without banground). In Fig.1c are the examples of the Poisson statistical distribution for different average number of events *λ*.



a) b)

c)

Fig. 5. Students results' of the γ radiation intensity of the point source on the distance $I(x)$ (for the collection time 30 s) with fitting by eq. (1) (continuous curve) a), the transmitted intensity of γ radiation on Cu thickness I (d) with fitting by eq. (2) (continuous curve) b), the Poisson statistical distribution for different average number of events λ.

In Tables 1-4 are given evaluations of the measured data.

Table 1. Intensity of the source

Eq. (1)	Intensity I	Value
$y = a\ 1/x^2$	Intensity at zero pos. I_0 [min^{-1}]	0.0625
	Coefficient a [cm^2s^{-1}]	4.31

Table 2. Absorption coefficient of copper (Cu)

<table>
<tr><th>Model</th><th>Eq. (2)</th><th>Intensity I</th><th></th><th>Standard Error</th></tr>
<tr><td>Equation</td><td>y = a exp $^{(-b\,x)}$</td><td rowspan="3">Fitting constant **a** (intensity at zero position I_0 [min^{-1}]</td><td rowspan="3">2.97</td><td rowspan="4">0.11</td></tr>
<tr><td>Reduced Chi-Square</td><td>0.0066</td></tr>
<tr><td>Adj. R-Square</td><td>0.98</td></tr>
<tr><td></td><td></td><td>Fitting constant **b** (absorption coefficient μ [mm^{-1}])</td><td>0.82</td></tr>
</table>

Table 3. Absorption coefficients for several metals

Materials	GM1 Value N	GM2 Background Radiation B	Interval t (s)	Corrected Pulse	Intensity I	Absorption coefficient μ [mm^{-1}]
Al (1mm)	111	9	30	102	3.40	0.26
Fe (1mm)	63	8	30	55	1.83	0.88
Pb (1mm)	8	12	30	4	0.13	3.5

Table 4. Sample of probability distribution without background pulses

Distance (X)	Mean	Cumulative	Probability Distribution
38	9	4	1
21	10	5	0.9993
21	11	8	0.997748
28	12	21	0.999977
29	13	24	0.999962

Also, with these tables, students can easily comprehend the radioactivity theory like the intensity-distance relationship, absorption phenomena of the material and also the randomness of radioactivity. The measured intensity value plot in Fig 5a with respect to distance after transferring it into logarithmic value. The linear fitting of the graph gives the zeroth position intensity value and constant coefficient value, see Table 1. The figures recorded in the tables, help to improvise the idea of intensity-distance relationship theory of radioactivity among the students. Also, the absorption coefficient of the material like Cu, Al, Fe and Pb (Table 2 and Table 3) can easily be calculated by using this experiment. This absorption coefficient value develops the idea of shielding property of the material among the users. They easily understand theoretical concept of it. This experiment helves the user to understand the probability of the randomness through the Poisson distribution calculation too. This paper built the practical idea of the theoretical knowledges and also provide the better acquaintance of the radioactivity properties.

4 Conclusions

From the results of measurements, it is obvious that:
- The measured intensity of radiation from point source decreases with the square of the distance as predicted by theory,
- Statistical approach helps us to limit the impact of errors on results of measurement.
- Results of absorption measurements give direct information on absorption power of various materials with respect to protection against harmful radiation,
- The results of measurements give evidence of Poisson statistical distribution of the events of emission in accordance with theory.

Along with the advantages in experimental analysis the advantages of the real remote experiment over virtual laboratories also increase the interest among the students for performing the radioactive experiments and accumulate the knowledge.

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References

1. H. M. C. Eijkelhof, Radiation and risk in physics education. CD 0B* Press, 1990.
2. F. Schauer, M. Gerza, M. Krbecek, and M. Ozvoldova, "'Remote Wave Laboratory' with embedded simulation–real environment for waves mastering," in Online Engineering & Internet of Things, Springer, 2018, pp. 182–189.
3. F. Schauer et al., "REMLABNET III—Federated remote laboratory management system for university and secondary schools," in Remote Engineering and Virtual Instrumentation (REV), 2016 13th International Conference on, 2016, pp. 238–241.
4. E. Holm and R. B. R. Persson, "Biophysical aspects of Am-241 and Pu-241 in the environment," Radiat. Environ. Biophys., vol. 15, no. 3, pp. 261–276, 1978.
5. O. B. Nwosu, "Comparison Of Gamma Ray Shielding Strength Of Lead, Aluminium And Copper From Their Experimental And MCNP Simulation Result," 2015.
6. F. Schauer, M. Krbecek, P. Beno, M. Gerza, L. Palka, and P. Spilakova, "REMLABNET-open remote laboratory management system for e-experiments," in Remote engineering and virtual instrumentation (REV), 2014 11th international 2014, pp. 268–273.
7. G. Arbia, D. Griffith, and R. Haining, "Error propagation modelling in raster GIS: overlay operations," Int. J. Geogr. Inf. Sci., vol. 12, no. 2, pp. 145–167, 1998.
8. S. Shamim, H. Hassan, and M. S. Anwar, "Natural Radioactivity and Statistics," Lab Monogr. Introd. Exp. Phys., p. 206, 2010.
9. M. Ozvoldova and F. Schauer, Remote Laboratories in Research-based education of real world phenomena. Frankfurt am Main: Peter Lang, 2015. - 183 pp., [9,44 AH]. - ISBN 978-80-224-1435-7. - ISSN 2195-1845.