RADIATION RISKS, NUCLEAR ENERGY AND "THE DEVIL"

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1 INTRODUCTION

The "nuclear issue" is one of the most hotly debated social topics, with phases of varying intensity: the arguments, ranging from nuclear arms to nuclear energy, are in general focussed on the radiation risk discussion. Most of the information that drives the average public opinion is provided, at least in Italy, by the "media" (television, internet, newspapers, magazines, etc.), with the principal aim of developing emotional rather than rationally based reactions: technical aspects are therefore rarely presented, while a large space is given to the opinion of various "authorities". For teachers and students this is obviously negative from the educational point of view because, besides the frustration related to the lack of basic information about "facts", it induces the idea that, in order to understand a problem, the important thing to do is listening to the opinion of "authorities" rather than trying to build up a personal understanding. A few projects have been developed [1, 2], also by research or educational institutions/associations [3], in order to offer to students and teachers basic information and hints for an experimental approach. The aim of our project is essentially in the same direction. It has been developed with the collaboration of secondary school teachers, who have tested it in their classes; it is based on a few experiments, which can be done with rather simple devices, accessible also to a secondary school laboratory, safe and easy to handle, but sufficient to understand the basic physical ideas.

The core idea is to show to the teacher that

- the physical basis of the "nuclear problem" can be discussed at a reasonably deep level also with secondary school students,
- it is possible to integrate the theme in a natural way in the physics curriculum, because it is related to many fundamental physical concepts, which can thus be usefully reviewed;
- the mathematical tools needed to analyze the essential physical aspects (statistical errors and Poisson distribution), are extremely interesting.

As to the students, at the end of the experiment, they see that

- radiation is natural and there is a lot of radiation around us,
- there are different types of radiation, and ionizing radiations are just a particular type of radiation,
- ionizing radiations can be measured,
- and, finally, it is fun to discover and detect ionizing radiation in the environment.

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In the paper we will discuss how to start from classical and familiar types of radiation to understand the essential features of radiation which are important to understand the peculiarity of ionizing radiations; we will then present the experiments and discuss the analysis of data.

2 ABOUT RADIATION

One of the aspects that makes nuclear or in general ionizing radiations mysterious, and thus potentially dangerous, is the fact that they are invisible and only their negative effects are observed, often when it is too late to protect oneself. It is thus useful to start discussing radiation in more familiar contexts, to get used to this important concept. Indeed, radiation is an important physical concept not only because it is related to fundamental branches of physics such as optics and electromagnetism, but also because radiations are encountered continually in numerous everyday life phenomena, for example in phenomena which have to do with light (visible radiation), with infrared rays in remote control devices or detectors, with microwaves in cellular phones and in microwave ovens and, finally, with low frequency electromagnetic waves in television or radio communication. It is important to start from these familiar phenomena to recognize their common features, which are present also in ionizing radiations, and to understand what are the relevant parameters which differentiate the various types of radiation, in particular the ionizing radiations. The common features to underline are:

- all radiations *originate from a source*,
- *travel in space* (also in empty space),
- *can be revealed by a detector*,
- *different types of radiations* need different devices as sources and as detectors.

For example, the visible radiation from the sun (Fig. 1) is detected directly by our eyes, after travelling a long distance in empty space, while a cellular phone (Fig. 2) can be, at the same time, a source or a detector of microwave radiation, which travels in space from the nearest cell repeater to the phone or vice versa.

Figure 1 Light from sun.

Figure 2 Cellular phone.

Our eyes cannot detect the microwave radiation emitted by the phone, while the cellular phone does not detect the visible radiation (it emits and detects also in the dark!), so there is something peculiar in each type of radiation that determines the type of source and of detector needed to handle it. Teachers or students who have already studied optics will quote the frequency or the wavelength, which is certainly correct, but to our purpose it is more useful to refer to *energy* as the essential parameter that discriminates between different sources of radiation. The key ideas are that

- *radiation carries energy* through empty space from the source to the detector,
- energy is carried by single *quanta of energy* (E_γ),
- the *single energy quantum is very small*: for example the energy of a microwave quantum is $\approx 10^{-5}$ eV [4];
- the *number of energy quanta* in usual phenomena is enormous: for example a cellular phone which detects a microwatt signal receives $\approx 10^{18}$ quanta per second;
- the *different values of the energy quanta* determine the type of source and of detector needed;
- the source transforms other forms of energy into "radiant energy"; the detector transforms radiant energy into other forms of energy.

The important issue about radiation is thus **energy**, because, through radiation, energy is transmitted in empty space. With energy, also information can be transmitted: this is just what makes, for example, cellular phones so popular, because one can receive information at a distance without a cable to transmit the electrical signal!

3 EXPERIMENTS ON IONIZING RADIATION

The peculiar aspect of ionizing radiations is that their energy quanta are extremely large, much larger that the energy quanta of more common radiations, such as visible light. The starting point of the first experiment that we propose is to detect the background radiation with a simple Geiger detector as that of Fig. 3, which emits a short beep at each detection and counts the number of hits.

Figure 3 The Geiger detector used in the experiments.

After turning the detector on, the students immediately realize that this detector reveals *single hits* that are counted as shown in the liquid crystal window: this is important to start a discussion on the extremely large value of the energy quanta, which is so large that the single energy quantum can be detected [5]. This large energy is related to its "nuclear origin", because only in nuclear reactions large amounts of energy are released through transformation of "mass energy" into radiative energy [6].

3.1 Measurements on background radiation

Continuing the experiment, students are then asked to detect background radiation in different sites of the school or in the nearby zones in a given time interval (for example 5 minutes) and then come back and compare the results. This has two aims:

- to show that there is nothing "mysterious" about ionizing radiations, because they are diffused and very similar in all places,
- to raise the question of the uncertainty on this kind of measurements, which is essential for the comparison between different values of the count rate measured in different places.

The latter point is fundamental, because it is related to the intrinsically random time distribution of the "events", which originates from the probabilistic aspects of the nuclear interaction due to its quantum mechanical nature: there is no way to know *when* a given event will occur, but the average probability that it will occur in a given time interval is well determined. An interesting mathematical analysis can be done on this specific point, based, for example, on measurements taken every 10 s, as those shown in Fig. 4, compared with the predictions of Poisson distribution.

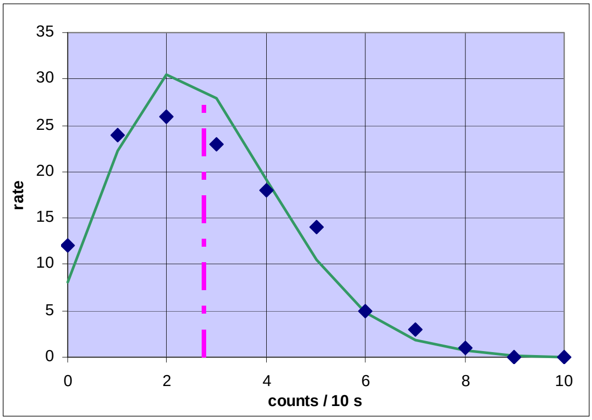

Figure 4 Distribution of the counts detected in 10 seconds for background radiation (diamonds) compared with Poisson distribution (continuous line); the dashed vertical line at 2.8 counts shows the average value.

This clearly shows that the number of counts observed in a 10 second time interval can be very different, ranging from 0 to 8 counts; however the average value of 2.8 counts is very stable and reproduced by repeating the measurements; also the statistical fluctuations around the average value are reproduced, confirming the relation that for N counts the fluctuation is $\pm N^{1/2}$.

In Fig. 5 we compare the average counts per second obtained in different schools of the Torino area: the overall average is 0.41 with an average spread of ±0.05, which shows that only the last measurement, taken in a school in the Alps, might be significantly above the average.

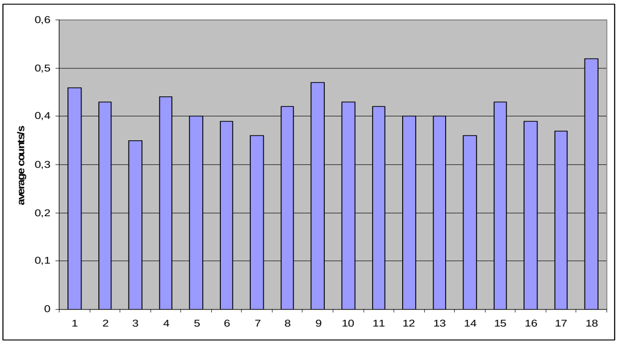

Figure 5 Average values of background radiation obtained in different schools of the Torino area.

3.2 Measurements with a "radioactive source"

The measurements with a weakly radioactive rock had the aims of discussing the *activity* of a source, the dependence of radioactivity on distance and the statistical significance of the radioactivity level. We show in Fig. 6 the counts/minute detected as a function of the distance from the detector edge, after the subtraction of the background illustrated in Fig. 5, which was measured to be 22 ± 2 counts/min. One clearly observes that the decrease with distance follows an approximate $1/d^2$ law and that, at a distance of 10 cm, the radiation level is already negligible. With a simple model the "activity" of the "source" can then be estimated, assuming an isotropic distribution.

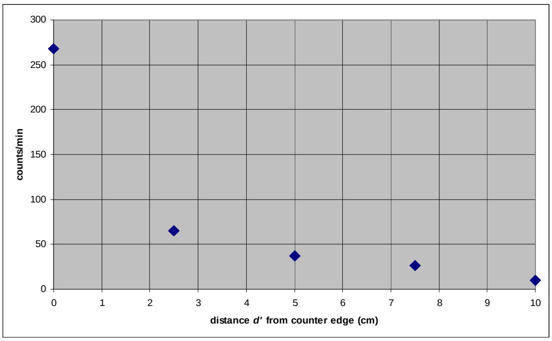

Figure 6 Counts/min as a function of the distance from the detector edge, corrected for background.

4 CONCLUSIONS

Our experience is that these simple activities proposed to students and teachers of upper secondary schools excite a strong interest and the desire to understand more deeply. This is, in our opinion, the encouraging aspect, because it opens the possibility to start talking about the nuclear problem on a more rational basis. We propose also, to classes particularly motivated, more complete experiments with the measurement of the energy spectrum, to appreciate, at a quantitative level, the amount of energy of the single quantum.

ACKNOWLEDGEMENTS

We gratefully acknowledge Flavio Marchetto of the Italian National Institute of Nuclear Physics (INFN) for helpful discussions and the Director of the Torino Research Unit of INFN, Dr. Angelo Maggiora for continuous support and encouragement.

Funding for part of the project was provided by the ENVIRAD-SPLAH project of Group V of INFN.

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[3] see, for example, Esposito A M, Ambrosio M, Balzano E, Gialanella L, Pugliese M, Roca V, Romano M, Sabbarese C and Venoso G, 2005, "The ENVIRAD project: a way to control and to teach how to protect from high indoor radon level", International Congress Series, Vol. 1276, p 242-244

[4] The "electronvolt" ($1\ eV = 1.6 \cdot 10^{-19}\ J$) is a measurement unity of energy more convenient, at the microscopic level, than the SI unity.

[5] The nice feature of the detector that we use, present also in many other detectors of the same, very reasonable, range of cost, is that it can be opened rather easily thus allowing to see the Geiger tube and its position close to the entrance window.

[6] We generally discuss simple nuclear reactions, as the alpha decay of U_{238}, which is very convenient from the didactical point of view, because energy conservation can be worked out in detail, showing directly the large value of the released energy.