HOME-MADE ALPHA-TRACK DETECTOR FOR RADIOACTIVE GAS: RADON

Marina Ionela CUCU[1], Daniel DUPLEAC[2]

Reference [1] gives the information that in Romania, the maximum allowed radiation concentration of the natural radon background is of 300 Bq/m^3. According to CNCAN values, the average concentration national level is of 145 Bq/m^3, and in Bucharest, it reaches 202 Bq/m3. There are several places in the country where this level exceeds the natural level. These are the areas where there are radioactive ore deposits, former ones.

Radon has been declared a carcinogenic factor and takes second place in the worldwide ranking top as a trigger for lung cancer, immediately after tobacco. To monitor the level of Radon that you have at home/workplace or any other closed spaces, you need to have adequate equipment to do it. The market nowadays offers you a large perspective of devices that can be used (passive or active detectors), but this paper aims to make possible, or at least to make us use our creativity to make a "Home-made non-expensive Radon detector", using cheap things around us: like a webcam, aluminum foil (used to cover food), duct tape.

Keywords: Radon concentration, Home-made Radon detector

1. Introduction

Radon is a radioactive gas of natural origins, coming from the disintegration of uranium from the soil, which concentrates in confined places. It is present in soils, water, building materials and can be transported through porous media, especially by convection and diffusion. Fig. 1 shows the disintegration series of U through which Rn appears. The Council Directive 59/2013/Euratom of 5 December 2013 laying down basic safety standards for protection against the danger arising from exposure to ionizing radiation addresses radon at workplaces and at homes. Radon is directly mentioned in the Basic Safety Standards Directive through Article 54 "Workplace Radon levels", also Article 74 is concerning about "Indoor Radon levels" and Article 103: "National action plan". The new Directive brings significant changes, with respect to the former Directive 96/29 EURATOM, in terms of protection measures related to exposures due to inhalation of Radon

[1] PhD Student, Faculty of Power Engineering, University POLITEHNICA of Bucharest; Engineer in NUCLEARELECTRICA National Company, subsidiary FCN Pitesti (Nuclear Fuel Plant), Romania, e-mail: mcucu@fcn.ro, marinaionela_cucu@yahoo.com

[2] Professor, Faculty of Power Engineering, University POLITEHNICA of Bucharest, Romania, e-mail: danieldu@cne.pub.ro

progeny not only in work environments but also in dwellings. Romania, having the status of a EURATOM/EU member, has to implement the directive requirements.

“Radioactivity”: is a physical phenomenon whereby the nucleus of an unstable atom, also called radioisotope, spontaneously transforms (disintegrates), releasing energy in the form of various radiations (alpha, beta, or gamma), into a more stable atom. The production of the three isotopes of radon (radon, thoron, and action) is directly related to the concentration of the parent isotopes: Ra^{226} ($T_{1/2}$ = 1620 years) for radon, Ra^{224} ($T_{1/2}$ = 3,64 days) for thoron, Ra^{223} ($T_{1/2}$ = 11 days) for action. [2]

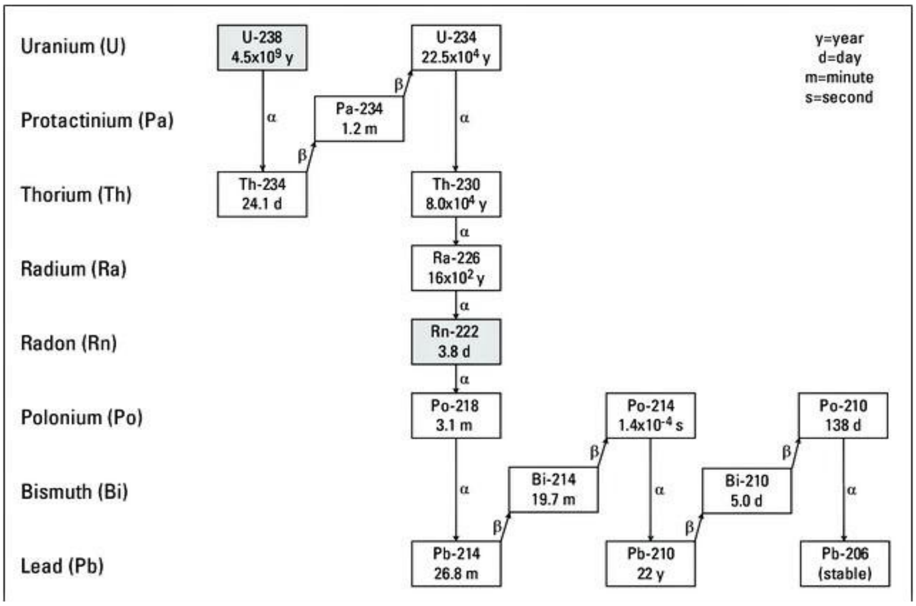

Fig. 1- Disintegration series for U^{238} [2], [11]

The principle of the experiment consists of modifying a webcam, in order to visualize alpha radiation. Modifying a webcam (high performance or not) is a cheap, easy, and accessible way for anyone to gain experience with CMOS image chips. The fact that the chip is integrated into the motherboard, accessible for those who want to experiment, makes webcams able to be used in the detection of radioactivity, in particular the alpha radiation emitted by Radium ^{226}, which is the "parent" of the $Radon^{222}$ isotope. An usual webcam (without any modifications) can detect high-energy particles. For what it means detecting low energy particles, such as alpha particles you need to change it. The minimal change means removing the glass protection filter from the sensor in order to have maximum efficiency. Removing the filter also makes the webcam sensitive to infrared and ultraviolet light. For some older webcams, the filter and protective glass on the sensor were separate, which made them easy to change. In the case of the Logitech C270 webcam, these are combined, which makes it much more difficult to separate the two elements.

2. Theory

Complementary metal–oxide–semiconductor (CMOS), also known as complementary-symmetry metal–oxide–semiconductor (COS-MOS). CMOS technology is used for constructing integrated circuit (IC) chips, including microprocessors, microcontrollers, memory chips (including CMOS BIOS), and other digital logic circuits. CMOS technology is also used for analog circuits such as: image sensors (CMOS sensors), data converters, RF circuits (RF CMOS), and highly integrated transceivers for many types of communication [3]. The light-sensitive element in the construction of the webcams is the CMOS. Each pixel includes a photodiode and a conversion circuit /amplifier that converts the charge originated in the photodiode into a voltage that is read, pixel by pixel, and subsequently digitized into a numerical value ranging from 0 to 255. The active element, sensitive to particles, is the photodiode, shown schematically in the image below.

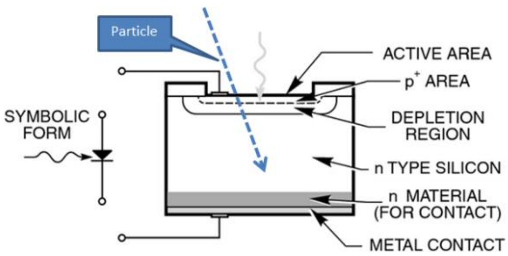

Fig. 2- CMOS [4]

The ionizing particle hits the sensitive area from the “top zone" and produces several hundred electrons/hole pairs in its passage, which are collected by the cathode/anode of the diode and produce the signal that is subsequently digitized. Reference [5] provides the following data on solid-state sensors:

- Silicon Bang Gap = 1,115 eV
- Couple Production Energy e/h (300°K) = 3,62 eV
- Electron ionization power = 80 e/µm

As a reminder: the CMOS sensor is not optimized for the detection of the particles (radiation field), and therefore the detection efficiency is rather low, especially due to the fact that the sensitive area which is the depletion layer of the junction is a very thin area. The alpha particles could not be detected of a “normal webcam”, because the sensor is (usually) protected by a layer of glass that completely blocks the alpha particles. Beta particles are partially absorbed by the surface protection, but a high percentage reaches the sensitive part and can be detected.

3. Process of the "home-made detector" making

In the process of transforming a usual webcam into a home-made detector, a Logitech C270 webcam was used, which has the following features [4]:
- Sensor Resolution = 3200 x 24000
- Pixel Dimension = 2,8 μm x 2,8 μm
- Sensor Dimension = 3,5 mm x 2,7 mm
- Sensor area = 9,45 mm2
- Image Resolution = 640 x 480
- Image Pixel Dimension = 5,6 μm x 5,6 μm

The first steps in the process of Modifying the Webcam are easy. First, the front cover (usual plastic or PVC) must be removed by levering with a screwdriver, then take apart the underlying base/ motherboard/base plate by removing the three small screws. The open webcam is shown in Fig. 3:

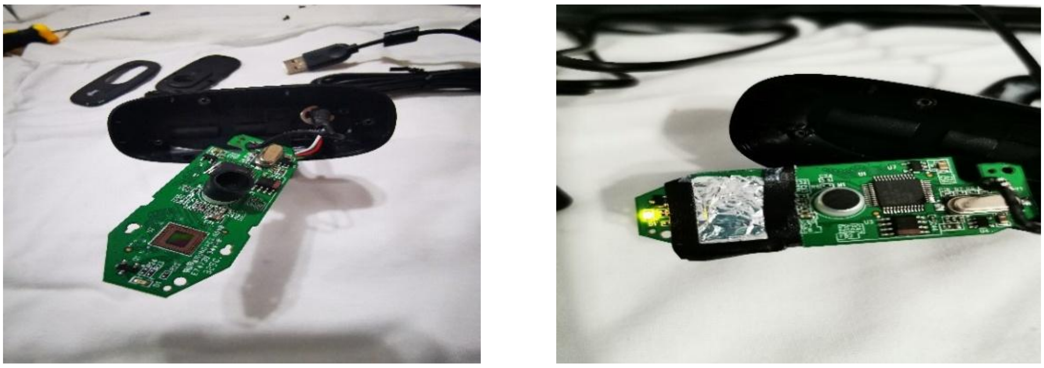

Fig. 3 – Open webcam

To prevent the light of the LED from reaching the CMOS sensor it is preferable to remove it/cut it or make sure it is very well covered with opaque material as in the picture above. To avoid that the CMOS sensor to be reached by the ambient light or any other source of light it is necessary to adequately shield it with an adhesive aluminum sheet/opaque plastic. At the end, the webcam can be mounted again, using the covers previously removed. Here it is what results:

Fig. 4- Closed webcam

4. Detector verification method

To capture the images recorded with the webcam, it has been realized the Theremino Particle Detector software. [6] The software simply performs the integration of the images to achieve “long exposure”. The particle tracks are not erased at every acquisition cycle, but accumulated frame by frame. The picture below is an example of a recording:

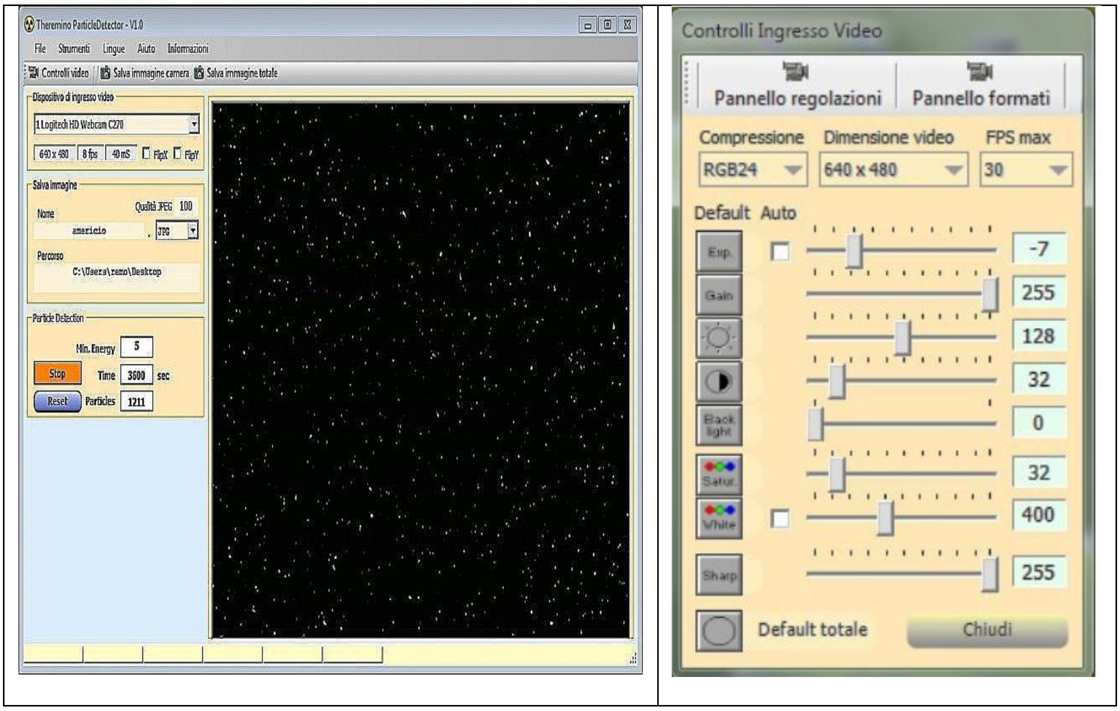

Fig. 5 Theremino specifications

The application is very easy to use. It features interactive buttons and easy to set. There are given the possibility to set the minimum energy ranged between 0 – 255 MeV in order not to count mistaken events caused by the noise of the CMOS sensor. By noise, one can understand any kind of light that reaches the sensor surface.

The START / STOP control button can start and stop-frame recording and events counting. The RESET control button can reset the integration time and the event counter. During frame recording the events which are caused by a particle detection are counted and shown in the box “Particles”, the total recording time is shown in the box “Time”. The ratio between these two values corresponds to the quantity “Counts per Seconds”, that is CPS.

Counts per second (abbreviated to CPS) are used for measurements when higher count rates are being encountered, or if handheld radiation survey instruments are being used which can be subject to rapid changes of count rate when the instrument is moved over a source of radiation in a survey area.

Taking into account the type of camera used, the manufacturers of Theremino software recommend using the following parameters in the setting of the webcam, in order to have the best quality of the obtained image.

It is indicated that the parameter "minimum energy" to be set to a value of about "5", this is used to exclude "noise" events that the CMOS sensor can receive and count, which would lead to erroneous counting and as the number of particles detected increases. By setting this threshold to values between 5 and 20, most of the noise can be canceled.

Source of radiation- Americium

Radon detection is based on alpha radiation detection of Ra element. Therefore, the method of verifying the functionality of the detector is based on the measurement of an alpha radiation source more precisely of an American source.
Americium-241 is an isotope of americium. Like all isotopes of americium, it is radioactive, with a half-life of 432.2 years. Am^{241} is the most common isotope of americium as well as the most prevalent isotope of americium in nuclear waste. It is commonly found in ionization type smoke detectors and is a potential fuel for long-lifetime radioisotope thermoelectric generators (RTGs). Its common parent nuclides are β− from 241Pu, EC from 241Cm, and α from 245Bk. 241Am is fissile and the critical mass of a bare sphere is 57.6-75.6 kilograms and a sphere diameter of 19–21 centimeters.[7].Since it was first offered for sale in 1962, its price, about US$1,500 per gram of Am^{241}, remains almost unchanged owing to the very complex separation procedure.[8]

The experiments performed used a calibrated source of Am^{241}. The source has the following characteristics:

- Maximum energies of alpha radiation and their probabilities: 5,388 MeV (1,4%) 5,4429 MeV (12,8%) 5,4856MeV (85,2%), which reinforces the idea of limiting the energies allowed by 5Mev, as mentioned in the previous paragraphs.

- Activity: 732 Bq with the uncertainty of the activity being: ± 44 Bq

Materials used

It is well known that a simple paper sheet is enough for alpha radiation to be stopped. Using such "protection" for the CMOS sensor would not be effective, stopping any alpha radiation. Also, it would be not effective from the point of view of passing LED's light. Starting from this, the first 2 attempts were made with common aluminum foil (with different thickness) then using Mylar foil. Mylar foil is commonly used in the Radioprotection field especially in dosimetric measuring equipment. Mylar is made reflective or metalized by sputtering a thin film of metal onto its surfaces. Mylar is less permeable to gasses and reflects up to 99% of light. [9]

5. Results

After hacking the webcam, 4 experiments were made using the same source of radiation, the same measuring time, but using different materials for covering the CMOS sensor. The synthesis of the measurements and the results are presented in Table 1 below.

Table 1

Results

Case	Source	Source activity [Bq]	Material used to cover CMOS	CPM of the source	Time of measuring (sec)	Counted Particles	CPS resulted	Bq resulted
1	Am^{241}	732	Aluminium foil, 17 microns	5000	3600	29	0,008	0,07
2	Am^{241}	732	Aluminium foil, 13 microns	5000	3600	47	0,013	0,015
3	Am^{241}	732	Mylar, 100 microns	5000	3600	781	0,22	2
4	Am^{241}	732	Mylar, 75 microns	5000	3600	3667	1,02	9

Note: Due to the features of aluminum foil, the number of particles in the first 2 cases could be from noises received by the CMOS and not really from any kind of alpha radiation.

Comparison

In order to make a comparison between a home-made device and calibrated radon detector, Corentium Home and Airthinghs Wave plus [10], the 2 detectors were left near the source of Am^{241} for 1 hour (3600 sec). Both detectors are small, yet powerful radon gas detectors. Radon sampling is made by passive diffusion chamber, detection method: alpha spectrometry (regarding alpha energies).

The values shown by the 2 detectors were 36 Bq and 41 Bq, values that by far exceed the values obtained with the experimental detector. It can be easily noticed that the last case from the experiments (number 4) is the closest to the real value of the measurement.

6. Conclusions

The numbers obtained after experimental measurements are not so concluding regarding the tracking of radon concentration in our homes or at our workplaces, but they are a base for other future experiments. The differences between common aluminum foil and Mylar foil into radiation have been again demonstrated. Mylar foil it's been used for so many years into the radioprotection field, especially for radioprotection measuring equipment.

Another point of interest is the size of the sensor that each of the detectors has, whether it's the home-made or the calibrated one. The home-made detector has a sensitive area of 9,45 square mm, almost half of the sensitive area of Wave plus, causing mis-tracking. For more experimental data, it would be helpful to recreate the electronic circuit using a larger sensitive area, similar to that of the calibrated detector, or, why not, even bigger, cumulated with finding another material with the same characteristics as Mylar foil for covering the CMOS, or to have another Mylar foil with a lower thickness than 75 microns.

R E F E R E N C E S

[1]***, http://www.cncan.ro/surse-naturale-de-radiatii-radon/ (accessed: March,2020)

[2] *C. Cosma, T Jurcut*, Radonul si mediul inconjurator (Radon and the Environment – in Romanian), Editura Dacia, 1996

[3] *R. Jacob Baker*, Circuit Design, Layout and simulation, IEEE Press 2011, chapter 1, page 1-56 and chapter 7, page 603-345

[4]***, http://physicsopenlab.org/2016/05/18/diy-webcam-particle-detector/ (accessed: February /March, 2020)

[5]***, https://www.clear.rice.edu/elec201/Book/basic_elec.html (accessed: February/March, 2020)

[6]***, https://www.theremino.com/en/downloads/radioactivity (accessed: February/March, 2020)

[7] *Dias, H.; Tancock, T.; Clayton, A.* "Critical mass calculations for ^{241}Am, ^{242m}Am and ^{243}Am".

[8]***, BREDL Southern Anti-Plutonium Campaign, Blue Ridge Environmental Defense League, Retrieved 28 November 2010 (accessed: March, 2020)

[9]***, https://www.techwalla.com/articles/uses-of-mylar (accessed: March, 2020)

[10]***, https://www.airthings.com/en/wave-plus (accessed: March, 2020)

[11]***, https://www.researchgate.net/publication/320504937, Occurrence of Uranium and 222 Radon in Glacial and Bedrock Aquifers in the Northern United States, 1993-2003 Scientific Investigations Report 2007-5037 (accessed: November, 2020)