3. Demonstrations and laboratories using MX-10

In the following chapters we will deal with experiments that can be performed with weak, for a school easily accessible radiation sources without significant constraints. The chapters are sorted mainly according to the used sources, and focus on the primary radionuclides first. Let us show the differences between different radionuclides by visualizing the radioactivity of uranium, thorium, and potassium. Let us also compare the energies of emitted particles.

3.1 Demonstration of uranium glass radioactivity

The nuclei of primary radionuclides were formed along with stable nuclei of elements by thermonuclear synthesis in the cores of stars, or by nucleogenesis during supernovae explosions. If these nuclei had a short half-life (compared to the age of Earth), they decayed and are not present in the environment any more. Only those whose half-life is at least 10^8 years can be found around us. The most important primary radionuclides are potassium ^{40}K (half-life of 1.26×10^9 years), thorium ^{232}Th (half-life of 1.40×10^{10} years), uranium ^{238}U (half-life of 4.47×10^9 years) and uranium ^{235}U (half-life 7.04×10^8 years). Thorium and uranium have formed three decay series, potassium does not form a series.

The sources of the natural radioactivity originating from the primary radionuclides can be rocks in the Earth's crust that contain isotopes of uranium. Such source of ionizing radiation (IR), which one may encounter in everyday life, is called uranium glass, used to produce decorative objects such as glasses or beads. Using the MX-10 we will demonstrate that uranium glass is a weak source of IR. According to the shapes of the detected tracks we will also determine which kind of IR is detected.

3.1.1 Visualization of the tracks of different types of IR (Uranium)

The tracks of particles emitted by uranium glass can be visually separated into three categories matching the alpha, beta, and gamma radioactivity. The following experiment is focused primarily on familiarizing with the shape of the tracks caused by radioactivity originating from uranium glass. We are going to capture 60 frames with an exposure time of a single frame equal to 1 s, and we will enlarge these tracks and describe them in more detail.

Experiment type:	Demonstration			
Duration:	4 min			
Equipment:	MX-10 camera and computer, mounting rails, uranium glass in a holder.			
Settings:	*Radiation source:*	Uranium glass	*Exp. count:*	60
	Mode:	Spectrometer	*Exp. time:*	1 s
	Analysis type:	Basic	*Min. level:*	0
	Bias voltage:	20 V	*Max. level:*	20
	Continuous m.:	No	*Colormap:*	Hot
	Integral mode:	No		

Instructions: Mount the MX-10 detector on the mounting rails. Fix the uranium glass bead into the holder, mount it on the rails and bring it as close to the detector as possible (Fig. 11).

After starting the measurement, we observe several tracks caused by the impact of IR particles in each one-second-long frame. After the end of the measurement, we can combine all frames into a single integral frame (*Tools → Integral frame*) and we can take a snapshot of the measurement (*Tools → Snapshot*).

In the integral frame (Fig. 12) three types of tracks can be seen. Quite rare are large, almost round tracks (called blobs) caused by the impact of alpha particles (enlarged track on Fig. 13 a). More often are present long, usually curved ("wormlike") tracks caused by beta radiation (Fig. 13 b). The third type are small, usually one pixel large tracks caused by radiation of gamma or sometimes beta (Fig. 13 c).

The table *Analysis* shows us how the Simple preview program analyzed individual tracks based on their shape and ranked them in the category of alpha, beta, gamma. Differences of the tracks caused by the impact of alpha, beta or gamma particles stem from the differences of the interaction of heavy and light charged particles and photons with silicon sensor. Heavy particles (such as alpha particles) have high ionization effects, quickly lose their energy and therefore have a short mean linear range. For example, energy of the alpha particle from the Fig. 13 a was 4022 keV which corresponds to the mean range of 14 µm in silicon. The generation of free electrons and holes took place close below the upper surface of the silicon sensor (thickness is 300 µm) and free charges were then moving to the electrodes. During the motion of the holes toward the bottom cathode they penetrated multiple adjacent pixels due to diffusion (Fig. 14), and the track looks like a circular "blob". From the layout of colors, we can see that more energy was absorbed in the center and less at the edge of the "blob".

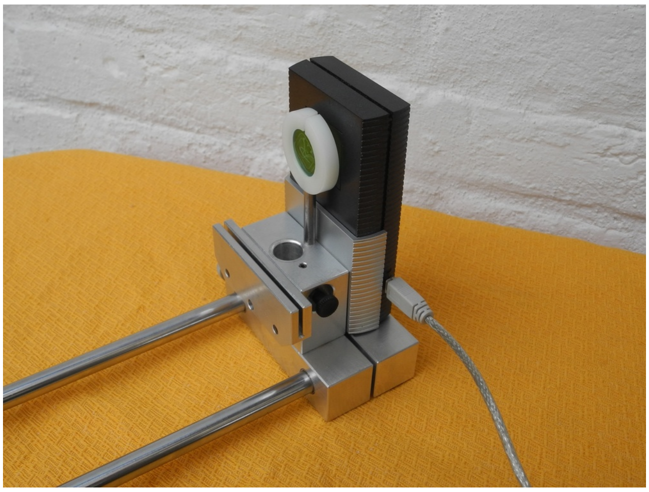


Figure 11: Setup for measurement of uranium glass radioactivity. The glass bead is fixed in the holder and brought as close to the sensor as possible.

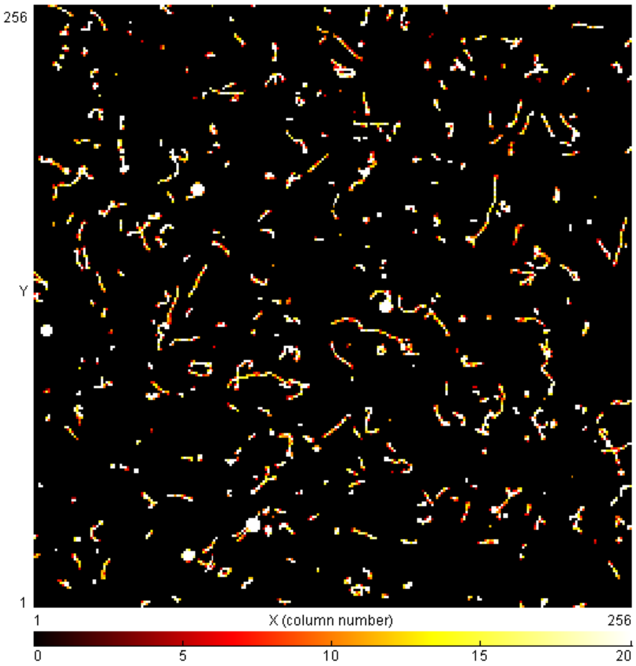
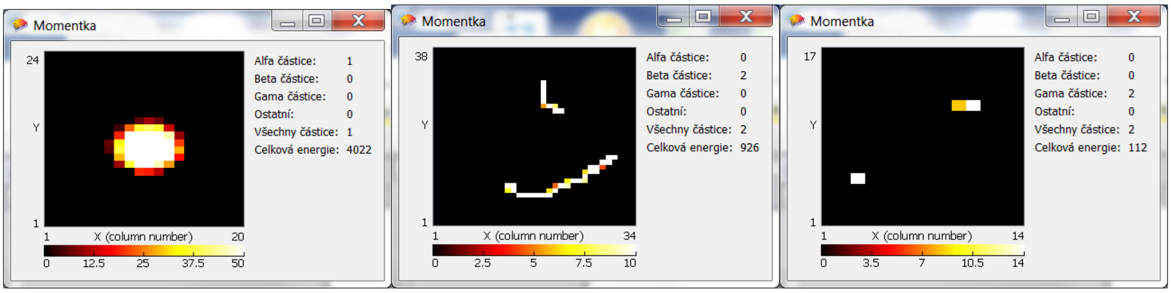


Figure 12: Based on the detected tracks we can distinguish between three types of radioactivity (alpha, beta, and gamma) of the uranium glass.



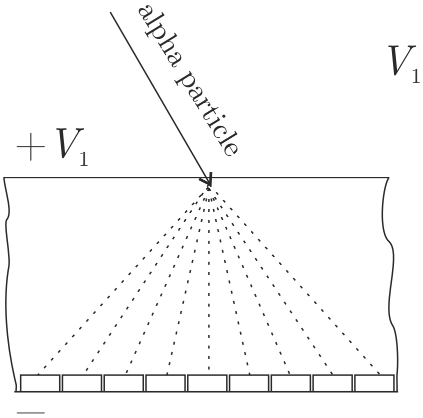
Alfa částice: 1
Beta částice: 0
Gama částice: 0
Ostatní: 0
Všechny částice: 1
Celková energie: 4022

Alfa částice: 0
Beta částice: 2
Gama částice: 0
Ostatní: 0
Všechny částice: 2
Celková energie: 926

Alfa částice: 0
Beta částice: 0
Gama částice: 2
Ostatní: 0
Všechny částice: 2
Celková energie: 112

(a) Alpha particle track *(b) Tracks of two beta particles* *(c) Two gamma particle tracks*

Figure 13: Tracks of particles emitted by uranium glass.



$V_1 < V_2$

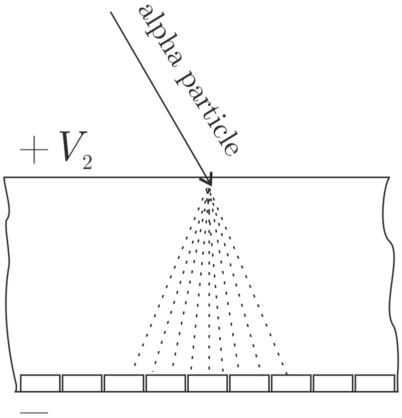


Figure 14: Diffusion of charges into adjacent pixels after an alpha particle penetrates the sensor. Left and right subfigures show the dependence of track size on the bias voltage. Bias V_2 on the right image is higher than bias V_1 on the left image. Therefore, charge collection is faster on the right side and the charges there are spread to a lower number of pixels than on left side.

Beta radiation is high energy electrons, or positrons, which create completely different tracks inside the sensor than alpha particles do. An electron loses gradually its energy in collisions with electron in silicon atoms electron clouds and ionizes them. At the same time, the electron is due to collisions randomly deflected from its original direction causing a signal in a few neighboring pixels. The result is a curved trajectory of high energy electrons corresponding to Fig. 13 b. The motion of an electron in a silicon crystal can be thought of as a random motion of a light elastic ball among significantly heavier elastic balls.

A photon with an energy of units to tens of keV can inside the sensor interact with an electron, that is due to the interaction freed from the electron cloud and subsequently ionizes other atoms. The energy of freed electrons, however, is low, and so they generate only a small charge, which is detected as a measurable signal usually only in one, two or three pixels. Such track will be included in the “analysis” table in the category gamma. A similarly weak signal is created after an impact of electrons (beta) with low energy. From the shape and energy of these small tracks, it is not possible to decide which kind of particle has created them.

Pure uranium emits only alpha and gamma radioactivity, however, all chemical elements belonging to its decay series can be found in uranium glass, that’s why we observe significant beta radioactivity. The uranium decay series ends with the stable isotopes of lead ^{206}Pb, respectively ^{207}Pb, and so in substances containing uranium the content of uranium decreases over time and the amount of lead increases. From the ratio of the count of uranium atoms and lead atoms contained in a sample it is possible to calculate the age of the substance (“the age of rocks”) and thus actually determine the age of the Earth.

3.1.2 The kinetic energy absorbed in the sensor and particle speeds (Uranium)

A particle impacting on the silicon sensor of MX-10 may be absorbed inside the sensor and depose there all of its the kinetic energy E_{k} (this occurs for all alpha particles originating from radioactivity and for low-energy beta particles), or may pass through the sensor and depose there only a portion of its kinetic energy.

The energy of the particle is given by the Einstein relation $E = E_0 + E_{\mathrm{k}}$, where E is the total energy, E_0 is rest energy and E_{k} the kinetic energy. After substituting $E = \frac{E_0}{\sqrt{1-\frac{v^2}{c^2}}}$ we can