Gamma-spectroscopy-based survey of the devices activated by proton beams from the K150 cyclotron

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Setup of the LBC-detector-based station for gamma-ray radiation survey of the RTF-customer devices exposed to cyclotron beams is now completed and the system is fully calibrated and operational. (LBC stands for lanthanum bromochloride, while RTF refers to the Cyclotron Institute's Radiation Testing Facility, also known as SEE-line [1].) Details can be found in the collection of reports from the previous reporting period [2-4]. In this reporting period the system was used several times, as described below.

Fig. 1 shows gamma-ray energy spectra (using the standard energy scale [4], corresponding to the 643.7 V detector bias) of a RTF-customer device taken immediately after the end of their K150 proton irradiation run (shown in black) and about two weeks later (shown in red). At the time the latter spectrum was taken it was already safe to ship the device back to its owner, as determined from a measurement performed using a pancake-shaped Geiger counter placed at the closest possible distance from the surface of the device. Therefore, there was no need for an elaborate analysis of these spectra.

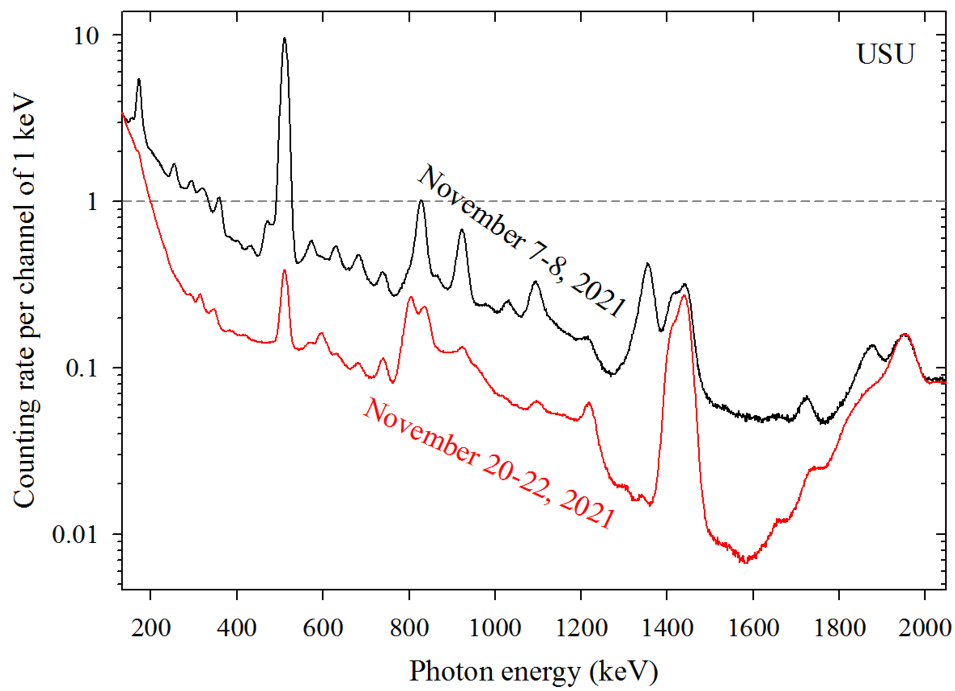

Fig. 1. Photon energy spectra of a RTF-customer device taken immediately after the end of their run (shown in black) and about two weeks later (shown in red).

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The spectrum shown in black was measured with the LBC detector placed about 30 cm away from the surface of the device. Such a large distance was selected in order to limit the counting rate. The spectrum shows a large number of gamma-ray peaks, but it is dominated by the 511 keV peak, which is due to positron annihilation. This was found to be typical right after irradiation by the K150 cyclotron protons. Since the Geiger counter has much higher efficiency for positrons than for gamma-rays, the 511 keV peak can be used to estimate the time it will take the overall activity to decrease to a shipping-safe level. It was found that the shipping-safe level corresponds roughly to the counting rate of 1 per second or less in the centroid-containing channel of the 511 keV peak (as indicated by the dashed line in Fig. 1), in a spectrum measured at the closest possible distance between the LBC detector and the device, provided that the 511 keV peak still dominates the gamma-ray energy spectrum. Example of such a spectrum is the one shown in red in Fig. 1.

It should be noted that the spectra shown in Fig. 1 start at about 130 keV. This is because at lower energies the spectrum was dominated by the background radiation produced by the ion sources and the cyclotrons, even though the measurement was performed within lead shielding built around the LBC detector and the device [2]. Typically, the background radiation is not steady and it is not practical to reduce it by turning off its sources. Furthermore, the peaks at 1440 keV and 1950 keV are due to radiation originating from within the LBC detector [2].

Fig. 2 shows energy spectra of the gamma rays emitted from a ZnSe window after it was irradiated by protons from the K150 cyclotron, measured two days after the irradiation (shown in black)

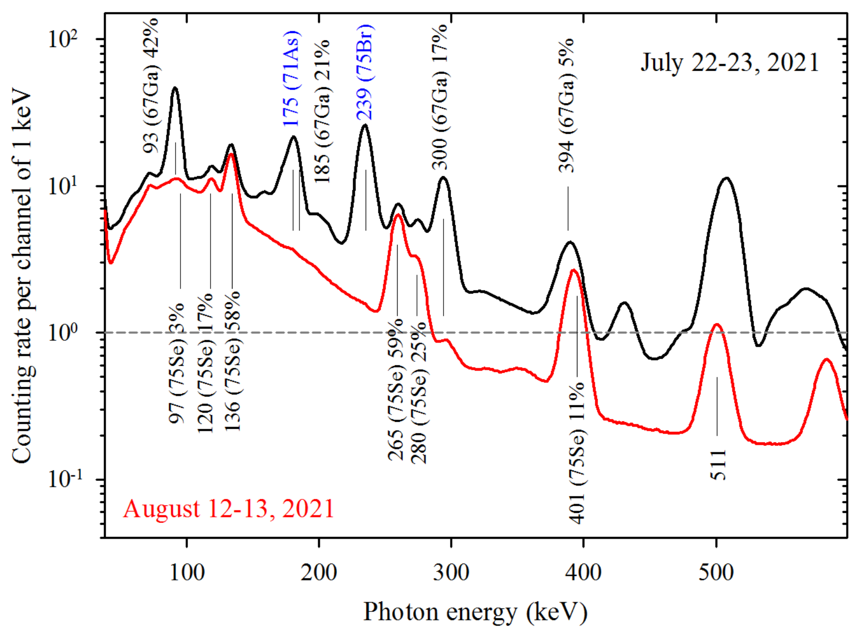

Fig. 2. Energy spectra of gamma rays emitted from a zinc selenide window after it was irradiated by protons from the K150 cyclotron, measured two days after the irradiation (shown in black) and about three weeks later (shown in red).

and about three weeks later (shown in red). This transparent, highly stable optical window was located on the cryostat that contained the target device. It was chosen for its extremely low absorption in the infrared region of the electromagnetic spectrum and high resistance to thermal shock. Its activity after proton irradiation was initially dominated by ^{71}As (65.3 h) [175@82%, 1095@4%], then by ^{67}Ga (3.26 d) [93.2@42%, 185@21%, 300@17%, 394@5%] and ^{77}Br (57h) [239@23%], and later by ^{75}Se (120 d) [97@3%, 120@17%, 136@58%, 265@59%, 280@25%, 401@11%]. It is estimated that it will be safe to ship the window back to its owner in August 2022, at which time the effect of proton irradiation on the ZnSe infrared transparency will be studied.

It should be noted that the energy spectra were recorded daily, for about 24 hours each, so that the half-lives (listed above in the parenthesis) could be verified for each isolated peak. The two numbers in the square brackets above refer to the photon energy in keV and the nominal intensity fraction. All four nuclides listed above decay by electron capture with 100% branching ratio.

In the same experiment an aluminum collimator was used to reduce diameter of the beam before it hit the ZnSe window. As a result, the collimator was activated. The main contributor to the collimator activity is 22Na (2.6 y), as illustrated in Fig. 3, where multiple spectra were shown to demonstrate that the peaks correspond to half-life much longer than 24 h. For comparison (and a more accurate energy calibration) spectra of gamma rays emitted from a 207Bi calibration source are also shown. Activity of ^{22}Na is estimated to drop below the background level in about 7.5 years.

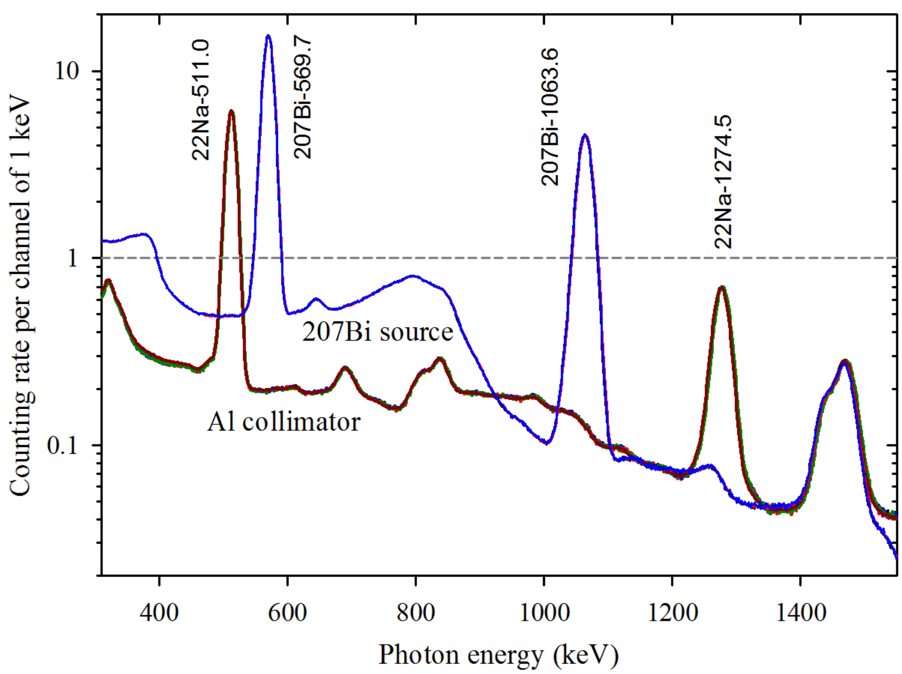

Fig. 3. Multiple energy spectra of gamma rays emitted from an aluminum collimator and from a Bi-207 calibration source.

Finally, the LBC-detector-based system was used to measure activity of a device exposed to proton beams from the K150 cyclotron and heavy-ion beams from the K500 cyclotron. Somewhat unexpectedly, the activity after irradiation was found to be dominated by ^{60}Co (1925 d) and ^{137}Cs (30.1 y), which was verified by taking a spectrum of gamma rays from a source known to contain ^{60}Co and ^{137}Cs. A comparison of the results is shown in Fig. 4. Due to the long half-life of these nuclides and the fact that owner of the device does not have a license to possess radioactive material, the device will have to be kept at the Cyclotron Institute indefinitely.

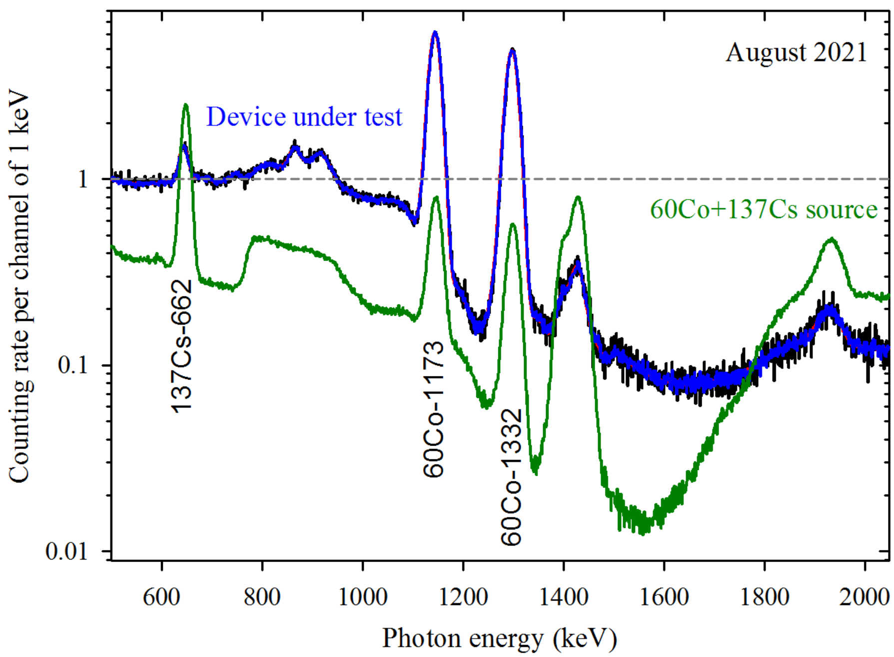

Fig. 4. Energy spectra of gamma rays emitted from a SEE-customer device and from a source containing ^{60}Co and ^{137}Cs.

[1] https://cyclotron.tamu.edu/see

[2] V. Horvat, H. L. Clark, B. Hyman, *Progress in Research*, Cyclotron Institute, Texas A&M University (2020-2021), p. V-26.

[3] V. Horvat, *Progress in Research*, Cyclotron Institute, Texas A&M University (2020-2021), p. V-29.

[4] V. Horvat, *Progress in Research*, Cyclotron Institute, Texas A&M University (2020-2021), p. V-34.