Delayed emission of electrons in a photomultiplier.

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Two types of time correlation of noise pulses caused by the PMT photocathode and dynodes are established using the autocorrelation delayed-coincidence time spectrometer. Time distributions of noise pulses in the XP2020, XP2232B, XP1021, FEU–87, FEU–93, FEU–130 and R7600U-200 photomultiplier tubes are investigated. An exponential time component of noise pulses with a nanosecond scintillation time is found in some types of PMTs.

Any operating electronic detection device, including a PMT, generates noise. Sources of noise in photodetectors are analyzed in detail in [1]. When a PMT operates in the pulsed mode, the most significant sources of noise are thermal electron emission from the photocathode and dynodes, field electron emission from the electrodes, and emission caused by both external cosmic and internal radioactive radiation. These sources of noise can be regarded as primary sources, and the processes resulting in ionization of residual gas in PMTs or vacancies in dynodes can be regarded as secondary sources. The investigation of noise pulses is primarily aimed at finding not only their energy and intensity but also causes and places of their generation in the PMT. Since noise pulses are associated with the passage of electrons through the PMT, they are supposed to produce secondary pulses related to generation of either feedback ions or delayed-emission electrons from the dynodes. Accordingly, there should be time correlation between the noise pulses and secondary pulses. This is confirmed by the time correlation between the PMT illumination and occurrence of noise pulses in the range from microseconds to many hours. The purpose of our work was to search for the time correlation between noise pulses and secondary pulses in the nanosecond region and to clarify the role of the photocathode and dynodes in this process.

A source of noise like leakage currents in the PMT anode circuit will not produce any considerable effect on the pulsed-mode operation of the PMT. In our investigations we used the autocorrelation time scintillation spectrometer [2]. Measurements were carried out in two stages. First, the time spectrum of the noise was measured without illumination of the PMT photocathode by any source of light, and then the time spectrum of pulses was recorded with illumination of the photocathode by light pulses either from a light-emitting diode or from a sandwich-type radioactive source. Noise pulses were measured in the XP2020, XP2232B, Xp1021, FEU–87, FEU–93, FEU–130 and R7600U-200 photomultiplier tubes. Figures 1–7 show the time spectra measured with and without illumination of the of PMT photocathode. Time distributions were measured in the range from 0 to 3 μs. The fact that the time spectrum of the noise involves afterpulses from feedback ions [3] formed in the PMT focusing chamber leads to the conclusion that this kind of noise pulses is generated by thermal electrons emitted by the photocathode. When the intensity of noise pulses was low, time distributions were measured at an elevated PMT voltage or at a lower discriminator threshold.

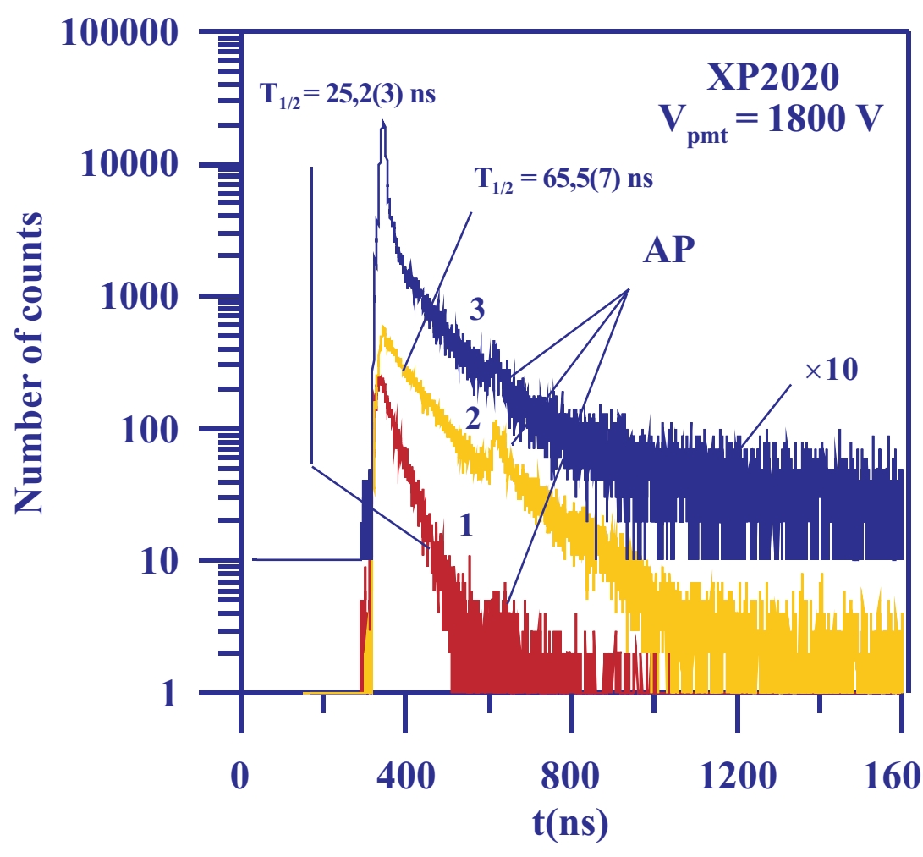

Fig.1. Time distributions of pulses in XP2020
1 – time distribution of noise pulses. Energy threshold registration V_d = 2keV.
2 – decay time of 59,5 keV state in ^{237}Np(V_d = 15 keV)
3 – time spectrum ^{241}Am(V_d = 2 keV)

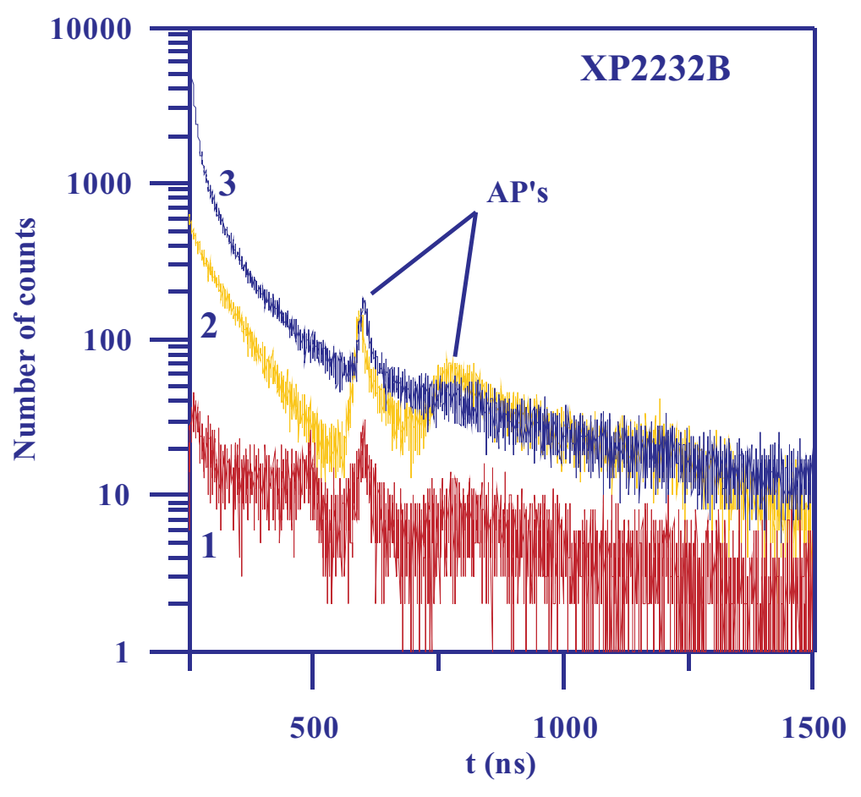

Fig.2. Time distributions of pulses in XP2232B (V_{pmt} = 1900 V)
1 – time distribution of noise pulses (V_d = 0.20 V)
2 – decay time of 59,5 keV in ^{237}Np(V_d = 1.00 V)
3 – time spectrum of afterpulses (V_d = 0.10 V_{pmt} = 1800)

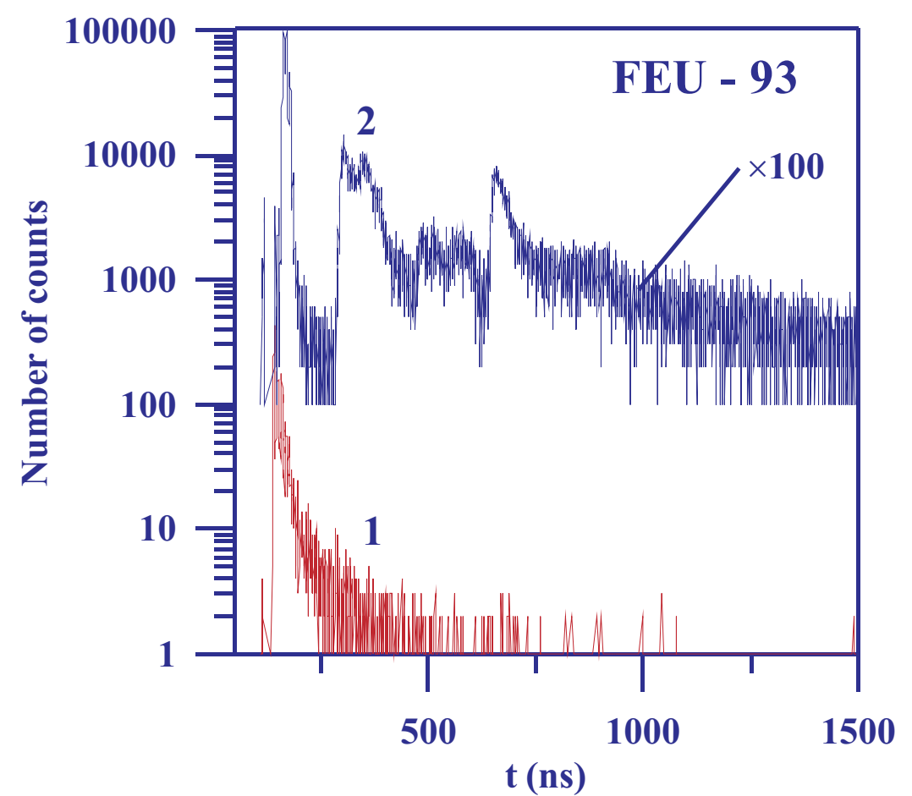

Fig. 3. Measured time distributions of pulses from the FEU–93 (V_{pmt} = 1800 V):
1. Noise spectrum (V_d = 0.08 V);
2. Afterpulse spectrum with the photocathode illuminated by the LED (V_d = 0.10 V).
The dynode material is CuMg.

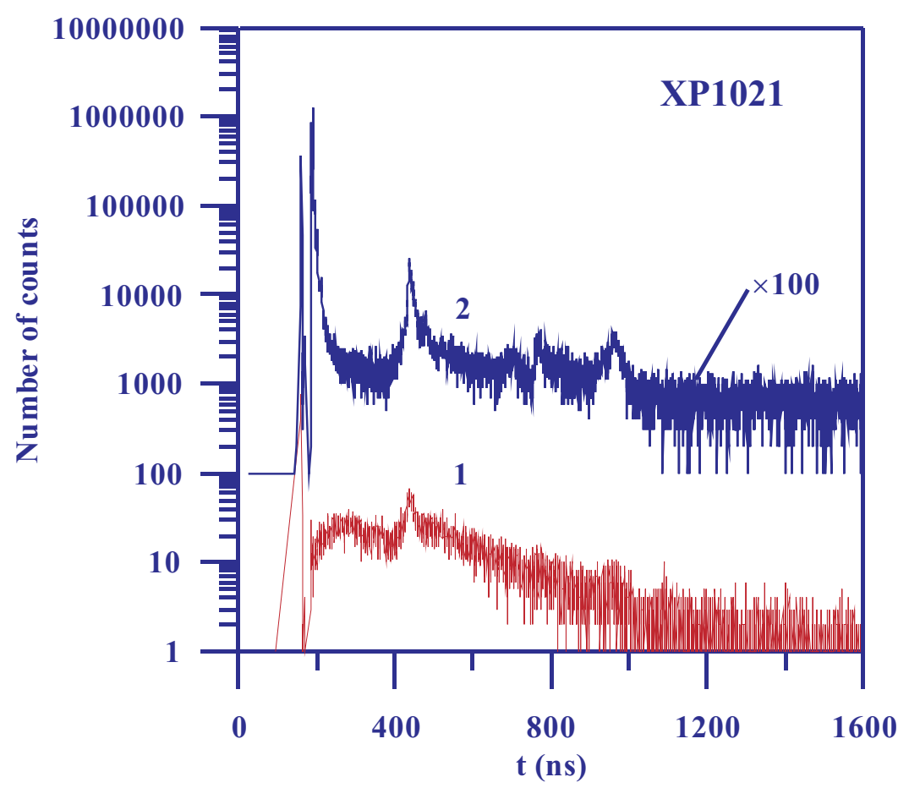

Fig. 4. Measured time distributions of pulses from the XP1021 (V_{pmt} = 1900 V):
1. Noise spectrum (V_d = 0.10 V);
2.Afterpulses spectrum (V_d = 0.10 V).

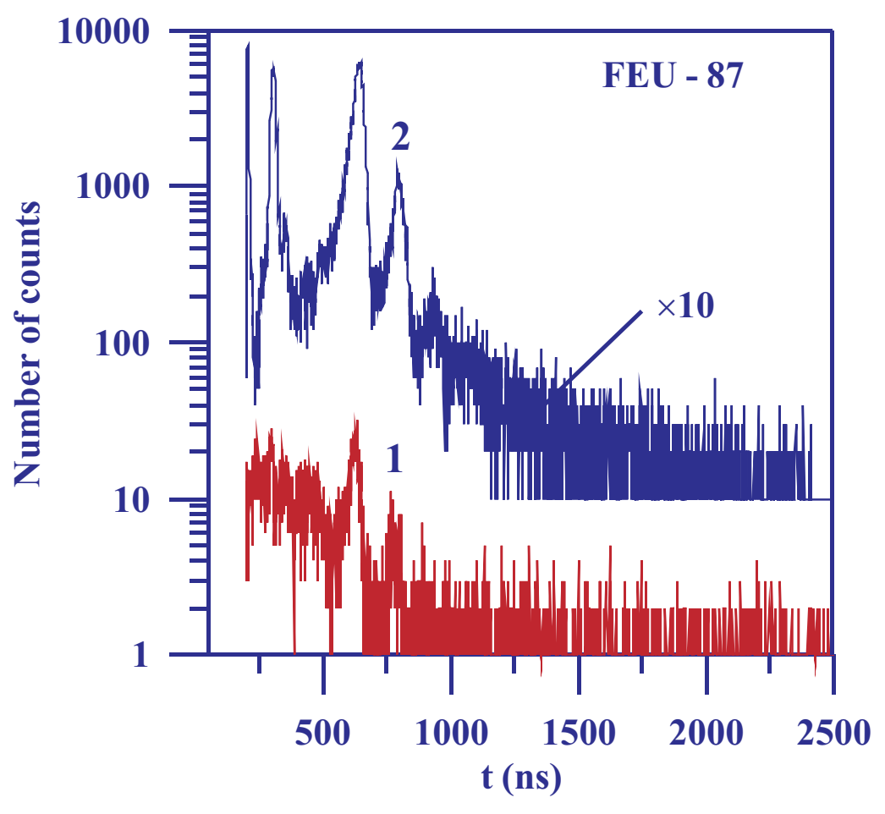

Fig.5. Time distributions of pulses in FEU-87:
1 – time distribution of noise pulses. (V_d = 0.08 V, V_{pmt} = 1900 V);
2 – spectrum of afterpulses (V_d = 0.10, V_{pmt} = 1800)

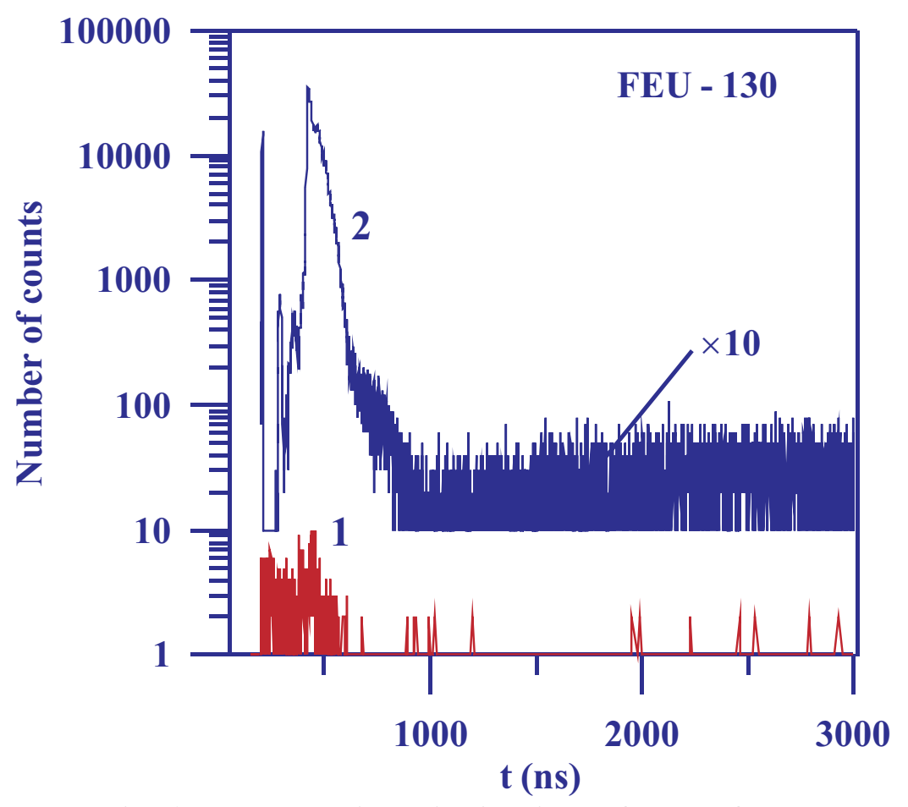

Fig. 6. Measured time distributions of pulses from the FEU-130:
1. Noise spectrum (V_d = 0.08 V, V_{pmt} = 1900 V);
2. Afterpulse spectrum (V_d = 0.10 V, V_{pmt} = 1700 V).
The dynode material is CuAlMg.

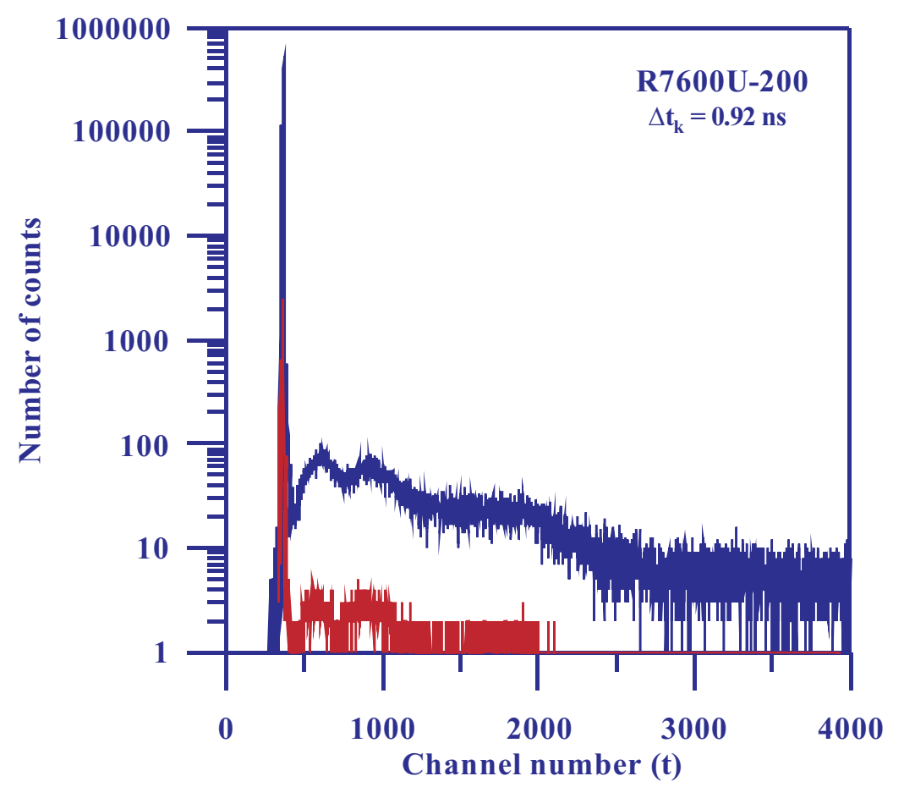

Fig.7. Time distributions of pulses in R7600U-200 (V_{pmt} = 800 V, V_d = 0.08 V)
1 – time distribution of noise pulses.
2 – spectrum of afterpulses from sandwich type radioactive sourse ^{60}Co.

Interestingly, exponential distribution in the nanosecond range was observed for some PMTs (Figs. 1–3) both in the noise spectrum and in the PMT illumination mode. This can indicate that metastable states are excited in the photocathode or dynodes, and their discharge after the detection of the primary electron results in emission of the secondary electron, which characterizes the metastable state deexcitation time. Thus, generation of noise pulses is obviously affected by two processes, thermal electron emission and excitation of metastable states. Since we have already established that the source of thermal electrons is the cathode, the second process mainly occurs in the PMT dynode system because the amplitudes of the exponentially distributed pulses are smaller than the amplitudes of the feedback ions, which is due to the lower gain of the pulses produced by the last dynode. Apart from the time spectrum of the noise, Fig. 1 presents the half-lives of the 59.5-keV state in 237Np measured at the discrimination thresholds ~2 keV and 15 keV. It is seen that the exponential distribution, which has nothing to do with deexcitation of the known isomeric state in the 237Np, is detected only at the low threshold.

As the radioactive radiation is detected, the exponential part of the time distribution of pulses considerably increases because the dynodes are affected by the intense electron flux. This can be evaluated from the ratio of the feedback ion afterpulse intensity to the exponential part intensity of the afterpulses in the XP2020 (Fig. 1). The exponential component of the noise observed only the XP2020, XP2232B, and FEU–93 photomultiplier tubes can probably be related to the material of the dynodes or the specific features of the processes used in production of these types of PMT. Similarity of the noise time spectra and feedback ion time spectra confirms that PMT photocathode is a source of one of the types of noise pulses that generated by thermal electrons emitted from the photocathode.

Two types of noise pulse time correlation are established in the course of investigations. One type is associated with emission of thermal electrons from the photocathode and ionization of residual gas in the PMT, and the other type is associated with excitation of metastable states in the PMT dynode system. The effect of these processes is eliminated by increasing the threshold of the detected radiation or operation in two detector coincidence mode with single scintillator.

1. S. S. Vetokhin, I. R. Gulakov, and A. N. Pertsev, in Single-Electron Photodetectors (Energoatomizdat, Moscow, 1984) [in Russian].
2. V. A. Morozov, N. V. Morozova, Yu. V. Norseev, et al., Nucl. Instrum. Methods Phys. Res., Sect. A, 484, 225–232 (2002).
3. V. A. Morozov and N. V. Morozova, Prib. Teckh. Eksp., No. 4, 26 (1997).