A novel high-voltage voltmeter for medical x-ray apparatuses has been designed on the principle of x-ray spectrometry [1, 2]. The advantage of the device is its ability for contactless measurement of voltage. Because access to live high-voltage circuits of x-ray apparatuses is problematical, the advantage of the voltmeter is rather significant. The RIVN x-ray spectral high-voltage voltmeter consists of two basic units: a detector unit and a multichannel analyzer. The two units are connected by a cable. The detector is placed directly in the output radiation beam, and the analyzer records the radiation spectrum. Then, from the measured bremsstrahlung spectral edge, the x-ray tube voltage can be estimated with high accuracy by a special embedded program and printed out.

The OChG semiconductor sensor is used in the detector unit (resolving power not worse than 0.5% at radiation energy of 100 keV), and the Afora LP4900B multichannel analyzer (Finland) is used as the analyzer unit. The results of measurements can be processed either by the integral processor of the analyzer or by an external personal computer (PS 2, model 30), which can be connected to provide higher speed data processing. The borders of the bremsstrahlung spectra and values of sought voltages are calculated by the procedure developed by Zubkov and Potapov and described elsewhere [3]. Major causes of measuring errors and approximate values of the errors were also considered in [3]. These errors were taken into consideration when selecting the measuring conditions for the present study.

The RIVN experimental device was designed on the basis of a RUM-20 x-ray diagnostic apparatus equipped with a high-voltage stabilizer. The voltage applied to the x-ray tube is stabilized with 0.02% accuracy. The circuit of the device and control instruments are shown in Fig. 1.

The output radiation beam of the x-ray tube (1) is limited by the copper collimator (2) with 1-mm passage diameter, and the x-ray tube itself is shielded by the lead plates (3) to reduce intensity of stray radiation. The detector (5) is aligned along the axis of the output radiation beam using a special telescopic system (4). The detector and the forerunner stage of the preamplifier are placed into a Dewar flask (6) and cooled with liquid nitrogen to provide better resolution. The distance from the output collimator edge to the input window of the detector is 450 mm; the diameter of the nonattenuated radiation beam at the input window does not exceed the input aperture of the detector.

Copper filters (7) of various thickness are placed before the input window of the detector, the thickness of the filters depending on the measured voltage to provide equal measuring conditions. For example, at 40 kV the thickness is 0.6 mm, and at 110 kV it is 2.2 mm. The input signal frequency of the multichannel analyzer (8) during measurements did not exceed 10,000 pulses/sec (not more than 3-4% by the “dead time” indicator). The Ch3-36 frequency meter (9) is used to monitor the frequency. Signal shape and baseline shift are monitored by an S1-114 oscilloscope (10). In addition to the analyzer, unit (8) (see Fig. 1) may also incorporate a personal computer and a printer.

DNO-100 reference dividers (11 and 12) of precision class 0.05 are connected to the anode and cathode output arms of the stabilizer (13). V7-34 digital voltmeters (14 and 15) are used to measure low-voltage output voltage, the x-ray voltage being determined from the sum of the low-voltage voltmeter readings. The S1-69 double-beam oscilloscope (16) connected to the same outputs is used for high-voltage pulse monitoring. The intensity of the output radiation is regulated by varying the x-ray tube current as performed from the control panel of the RUM-20 apparatus.

Before measurements, the scale of the multichannel analyzer was calibrated in absolute units of radiant intensity. Reference sources of gamma-radiation are used for this purpose, the radiant energy of the sources being known with the accuracy of one thousandth of one percent. The reference peaks of the $^{57}$Co and $^{139}$Ce radionuclides were used in the studied
range of high voltage. Only isolated single peaks were selected to provide better accuracy, and even well-resolved doublets were discarded. For example, cobalt peaks with energy of 14.4127, 122.0614, and 136.4743 keV and a cerium peak with energy of 165.857 keV were used. Precision determination of the reference peak centers was conducted using a special program, the effect of peak contour asymmetry and the presence of spectral "tails" being accounted for and corrected. Then, a calibration curve is found by the least square method from the determined energy of peak centers. The calibration curve obeys the following equation:

\[ U = A_0 + A_1 \cdot X, \]  

where \( U \) is voltage (kV), \( X \) the analyzer channel recordings, \( A_0 \) the proportionality constant (in kV), and \( A_1 \) the proportionality constant in kV/channel.

The values of the proportionality constants \( A_0 \) and \( A_1 \) were averaged from several calibration runs. In the experiments described below, the values of the constants were taken as \( A_0 = 0.067 \) kV and \( A_1 = 0.02139 \) kV/channel.

Control of RIVN against the DNO-100 reference dividers connected to the anode and cathode arms of the x-ray tube of the RUM-20 x-ray apparatus was performed at four points within the specified range of voltages (40, 65, 87, and 110 kV).

There was a "drift" in the x-ray tube high voltage of the RUM-20 apparatus during the reference testing, although the "drift" during one measurement did not exceed 0.02%. The duration of one measurement was automatically set by the analyzer, and it was not less than 1000 sec. The time interval was selected in accord with the recommendations given in [3]. The interval was sufficiently long to accumulate a significantly large number of readings near the bremsstrahlung spectral edge and to provide high accuracy of experimental measurements and calculations of the sought values of voltage. The dependence of expected measuring error of the x-ray spectral voltmeter on the number of readings near the bremsstrahlung spectral edge determined in