Comparison Between Super-High Dose Rate X-Ray Radiation and Static Gamma-Irradiation Effects on Human Lymphocytes in Vitro

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Abstract – There have been compared the biological effect of X-ray radiation with dose rate $7 \cdot 10^7$ Gy · s^{-1} from a small-size 1 MV ARSA accelerator and gamma-radiation from an isotopic source ^{60}Co (with dose rate $8 \cdot 10^{-3}$ Gy · s^{-1}) by using micronuclei test for lymphocytes in human peripheral blood in vitro. The dose/effect dependences have been obtained for each radiation kind. It has been found that for all dose values the mean percentages of cells with micronuclei are the same for irradiation conditions of the both types. It is shown that a small-size inexpensive and environmentally safe X-ray irradiator with a super-high dose rate can be used for radiobiological investigations instead of isotopic sources.

The goal of these efforts was to find out the effect of a super-high dose rate radiation on the results of micronuclei test for human peripheral blood's lymphocytes as compared to radiation with low dose rate in the isotopic source field.

A small-size ARSA accelerator [1] was a source of pulse X-ray radiation. It is a direct-action accelerator with ten-cascade 1 MV oil-insulated Marx generator. Its design includes a high-voltage unit with a sealed-off accelerating tube, a charging device and a control console (Fig. 1). The specific feature of Marx generator used in the device is pulse charging of storage capacitors. Commutation of current is performed using gas-filled cermet dischargers. The accelerator operates in single pulse and frequency modes.

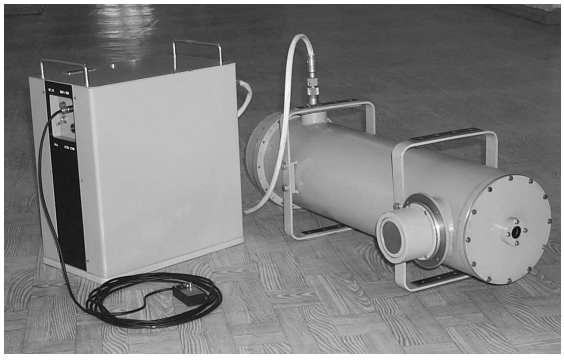

Fig. 1. A small-size ARSA accelerator

A sealed-off accelerating tube which is a vacuum diode with cold cathode is a source of electron or X-ray radiation. The edge-type cathode provides a uniform current density on anode and a uniform radiation field. A combined anode consisting of a 50 μm tantalum target, a 50 μm titanium foil window, and an aluminum filter absorbing electrons passed through the target and window is used in the accelerating tube.

Specifications of ARSA accelerator are as follows:

Maximum energy of quanta	1 MeV
Maximum dose of X-ray radiation	2 Gy
Maximum dose rate of X-ray radiation	$5 \cdot 10^8$ Gy · s^{-1}
Duration of radiation pulse	4 ns
Diameter of an X-ray spot on the window	10 mm
Pulse repetition rate	1 Hz
Mass of high-voltage unit	65 kg
Dimensions of high-voltage unit	∅220×800 mm
Power supply	220V/50 Hz
Power consumption	200 W

Figure 2 shows the dose field in air in the area nearest to the accelerating tube. The absorbed dose was measured using a thermoluminescent dosimeter DTU-01 with air-equivalent and tissue-equivalent detectors DTG-4 on the base of LiF monocrystal 5 mm in diameter and of thickness 1 mm. To reduce a random error of measurements, a series of experiments on irradiating a lot of detectors using a certified isotopic source was carried out, with providing the radiation dose to an accuracy of 2.5%. Selection of detectors resulted in the measurement error reduced from 12 to 5%.

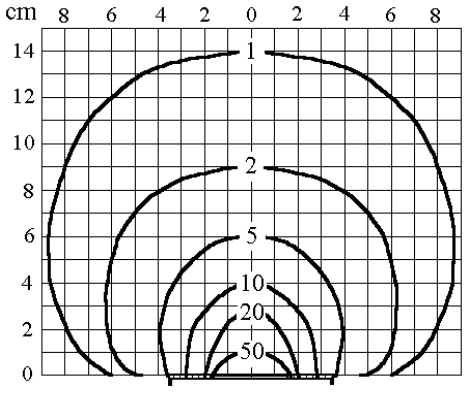

Fig. 2. Isodose surfaces in air (cGy per pulse) near the accelerating tube's window

During the experiment, blood was irradiated in plastic test-tubes 16 mm in diameter. To examine the absorbed dose distribution in blood under bilateral irradiation, a column of 14 detectors was placed inside a test-tube (see Fig. 3).

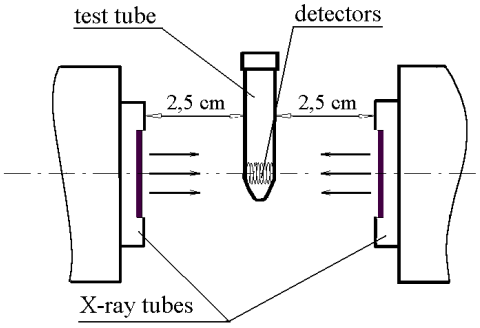

Fig. 3. The schematic drawing for bilateral irradiation of a test-tube

Figure 4 shows the distribution of the absorbed dose over the column of detectors inside the test-tube. One can see that non-uniformity of the absorbed dose distribution over the depth does not exceed 10%.

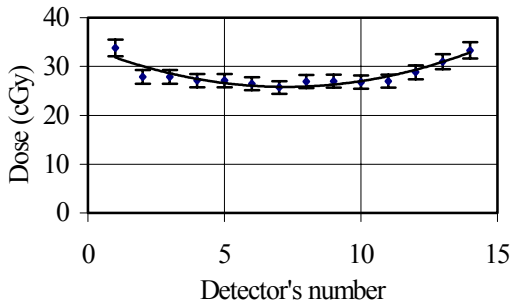

Fig. 4. The absorbed dose distribution over the column of detectors

The two ways of irradiating blood:

– ARSA accelerator. Under bilateral irradiation, the dose value per pulse was 28 kGy, the dose rate in pulse was $7 \cdot 10^7$ Gy·s^{-1}, the pulse repetition rate was 1 Hz.

– The certified isotopic source ^{60}Co with the absorbed dose rate $8 \cdot 10^{-3}$ Gy·s^{-1}.

Blood from five donors (men and women 23 to 53 years old), 2 ml per each person was irradiated under the conditions above with doses 0.5 Gy, 1 Gy, 2 Gy, 3 Gy. The irradiated and control non-irradiated blood preparations were examined by micronuclei test. The standard procedure (see [2]) with cytochalasin B was used. At least 1000 binuclei cells per dose were examined. The spontaneous percentage of cells with micronuclei was 2 to 5% in control samples.

Only survived cells were examined in compliance with the method used. The percentage of picnotic (lost cells) during irradiation with the above-mentioned doses using ARSA accelerator did not exceed this parameter value for the isotopic source ^{60}Co. The maximum picnosis percentage was achieved using ^{60}Co and comprised 42% with irradiation dose 3 Gy.

Figure 5 shows the dependence of the output of binuclei cells with micronuclei (MN) on the absorbed dose value for pulse and static irradiation. The assessment using Student criterion shows that with each dose value above the mean percentages of cells with MN coincide (with 0.05 significance level) for both types of irradiation conditions.

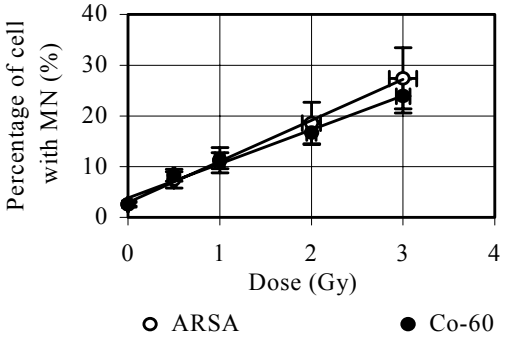

Fig. 5. The dose dependences of output of cells with micronuclei during irradiation on ARSA accelerator and isotopic source ^{60}Co

The results obtained allow us to conclude that an environmentally safe X-ray irradiator on the base of ARSA accelerator can be used for radiobiological research instead of isotopic sources, for example, to study individual sensitivities. Besides, it is evident that in case of extremely intensive irradiation with dose rate up to $\sim 10^8$ Gy·s^{-1} calibration dose dependences obtained using isotopic sources can be used for biological dosimetry. The results are consistent to those given in Ref. [3], where the authors examined the effect of pulsed ionizing radiation on the output of chromosomal aberrations in human blood lymphocytes with dose rate $5 \cdot 10^8$ Gy·s^{-1}.

References

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[3] T.V. Styazhkina, T.I. Khaimovich, Medical Radiology **5**, 68 (1982).