COMPACT PULSED ACCELERATOR ARSA FOR APPLICATION IN MEDICINE AND BIOLOGY

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Abstract

RFNC-VNIIEF has developed and successfully applied in physical research a small-size pulsed accelerator ARSA built upon a ten-cascade Marx generator of 1 MV voltage. An essential feature of the Marx generator is pulse charging of capacitors. Current switching is provided by high-pressure spark gaps. The accelerating tube which is a cold cathode sealed vacuum diode serves as source of electron or X-ray pulses. The dose at the output window is $3{\cdot}10^4$ Gy and 3 Gy, respectively, in a 10 ns shot. A blade-type cathode provides both uniform current density and radiation field. The high-voltage unit is about 50 kg weight. The ARSA accelerator incorporates a package of measurement equipment to obtain the required information on radiation fields. Stability in performance, small size, low cost, environmental safety with the capability of Monte-Carlo method calculation of energy deposition in any irradiated sample - all these make the device applicable in health research and clinics. The small-size bilateral X-ray irradiator using the ARSA accelerator can be useful for donor blood irradiation to prevent the secondary «Graft-Versus-Host» disease due to bone marrow transplantation.

1 ACCELERATOR DESIGN

RFNC-VNIIEF has been producing miniature ARSA accelerators for generation of nanosecond electron and X ray pulses` RFNC-VNIIEF has been producing miniature ARSA accelerators for generation of nanosecond electron and X-ray pulses. It is beneficially employed in the physical research. Due to its stable characteristics, compact design, low cost and environmental safety it can be widely used in medicine and biology.

ARSA accelerator comprises three units: a high-voltage unit, a charging unit and a programmed console. The high-voltage unit components (a generator, a pulsed transformer and a sealed accelerating tube) are located in the sealed metallic cylinder casing filled with capacitor oil. The accelerator is operatable at any orientation of the high-voltage unit. It can be equipped with a rotatory mechanism, a biological shielding.

ARSA is a direct action accelerator based on 1 MV Marx generator. Marx generator peculiarity employed in the facility is a pulsed charging of storage capacitors. The capacitors are powered through charging inductances with a pulse transformer which primary winding includes 2 μF capacitance at 10 kV voltage. The secondary winding achieves 100 kV at 4 μs charging pulse. As storage capacitors, commercial capacitors are used. The capacitance is 70 pF in a discharge. High-pressure gas-filled gaps serve for current commutation. The generator is loaded to the accelerating tube which is a vacuum diode with a cold cathode.

The tube cathode is manufactured in the form of tantalum foil blades providing a uniform density of electrons incident on the anode. The anode in the electron-beam tube is made of thin (25-50 μm) titanium foil. The X-ray tube has a composite anode: a tantalum foil target (50 μm), a titanium output window (50 μm) and a berillium or aluminum filter, which absorbs electron passed through a target and a window.

2 MEASUREMENTS AND CALCULATION

ARSA accelerator is equipped with a set of measuring devices which allow to obtain the required data on radiation field. Accelerating tube voltage is recorded by a built-in capacity divider or a liquid resistance divider on a blue vitriol basis. Electron beam current pulses are recorded with Faraday cup and low-inductive shunt. Maximum energy of the electron beam is measured according to electron path in a stack of polymer dosimetric films, which change the color under irradiation. The form of X-ray radiation pulses is recorded by semiconductor or diamond detectors. High-speed oscillographs are used for measuring pulsed electric and radiation parameters.

The integrate absorbed dose of X-ray radiation is measured by thermoluminescent dosimeters on the base of alumino-phosphate glasses and lithium fluoride. The absorbed electron radiation dose is evaluated with color film dose indicator or is measured by film dosimeters operating at high (to10^{12} Gy/s) dose rates.

Researches and operations at the pulsed accelerators demand knowledge of not only dose and time characteristics, but also angular and energy spectra of electron and X-ray radiations, dose distribution in the irradiated object. Pulsed X-ray radiation spectrometry is a rather complex problem, so the electron and X-ray spectra are computed by Monte-Carlo technique based on simultaneously recorded oscillograms of current and voltage. Dose spatial distribution is also calculated. Absorbed energy computation validity for different materials is reaffirmed experimentally.

The main characteristics are presented in Table 1.

Table 1: ARSA accelerator parameters.

Parameter	X-rays	Electrons
Maximum energy of electrons, quanta, keV	1000	1000
Maximum dose in air per pulse, Gy	3	$3 \cdot 10^4$
Duration of radiation pulse, ns	10	10
Pulse frequency, Hz	0,1...1	
Dimensions of high-voltage assembly, mm	∅250×800	
Mass of high-voltage assembly, kg	50	

3 POSSIBLE APPLICATIONS

Electron radiation of ARSA accelerator sterilizes surfaces and thin samples [1], in this case the sterilization dose in the vicinity of the electron-beam tube window can be obtained over one pulse. The electron irradiator-sterilizer may be applied for sterilization of micro-surgical and stomatological tools, small artificial organs, stitch material and etc just in clinics.

X-ray radiation of the accelerator can be used for irradiation of the donor blood and its components which is recommended for bone marrow transplantation. Irradiation of blood for transfusion reduces the risk of Graft Versus Host disease in patients with severely weakened immune systems [2]. If the plastic bag with blood is disposed within uniform X-ray spot, then the required average absorbed dose of 15 Gy is achieved over about 10 minutes at the pulse repetition rate of 1 Hz. For bilateral irradiation the uniformity of the absorbed dose in blood increases, and the radiation time decreases.

At present a transportable irradiator on the base of ARSA accelerator with bilateral irradiation of objects and compact biological protection is being developed. The control panel is combined with the monitor-dosimeter intended for prompt control of dose and switching off the unit upon the preset dose is achieved. This irradiator is compact, relatively cheap and environmentally safe. The X-ray irradiator can be used for solving applied tasks, for example, while developing the method for specifying professional fitness of personnel by the ionization factor. In future the irradiator can be used for investigation of peculiarities of biological effect of super-powerful radiation, as well as for solving other problems of radiobiology.

4 REFERENCES

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[2] K.C. Anderson, L.T. Goodnough, M. Sayers, P.T. Pisciotto, S.R. Kurtz, T.A. Lane, C.S. Anderson and L.E. Silberstein, «Variation in Blood Component Irradiation Practice: Implications for Prevention of Transfusion-Associated Graft-Versus-Host Disease», Blood, vol. 77, issue 10, pp. 2096-2102, 1991.