COMPACT X-RAY IRRADIATOR ON THE BASE OF PULSED ACCELERATOR ARSA IN MEDICINE AND BIOLOGY

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ABSTRACT

ARSA is a compact pulsed accelerator on the base of a ten-cascade Marx generator with voltage of 1 MV, developed in the Russian Federal Nuclear Center - All-Russian Scientific Research Institute of Experimental Physics (RFNC-VNIEEF). It is successfully used in physical research. An accelerating tube (a sealed diode vacuum cold-cathode tube) is the source of electron and X-ray radiation. The maximum dose per impulse with duration 10ns is 3×10^4 Gy and 3 Gy, correspondingly. The mass of the high-voltage assembly is about 50 kg. A compact X-ray irradiator on the base of the ARSA accelerator can be used for irradiation of donor blood and for research of biological effects of super-powerful radiation, as well as for solving other problems of radiobiology and medicine. The irradiator is equipped with biological protection, monitor-dosimeter and control panel. The irradiator is ecologically safe, mobile and easy to operate.

INTRODUCTION

There is a problem in medicine concerning a secondary disease (graft-versus-host) which appears after transplantation, particularly bone marrow transplantation, as well as in treating of inborn and acquired immunodeficiency syndromes, hemolythic disease of newborns, leukemia, other oncological and hematological diseases. The problem is being solved by irradiating donor blood and its components by gamma- or X-rays. While blood absorbs the required total dose (15..30Gy), lymphoid cells which may cause the secondary disease are depressed.

Blood and its components are usually irradiated in facilities with isotopic sources. A drawback of the GAMMACELL-1000 facility with isotope Cs-137 (Canada) is its ecological hazard and, therefore, possible radiation accidents. The radioactivity of the isotopic source is very high (from 600 to 2400 C depending on modification). The GAMMACELL-1000 requires special premises, trained personnel and periodical control of radioactive contamination. Also the problem of burial of radioactive waste exists. The facility is unwieldy and expensive (~70000 $ U.S.A.). These facilities are used to some extent in clinics in the U.S.A. [1]. There is only one GAMMACELL-1000 in use in Russia.

Required values of absorbed doses can be provided within several minutes by X-ray radiation using the ARSA compact accelerator, developed in the Russian Federal Nuclear Center. The advantage of the blood irradiator on the base of the ARSA accelerator is its ecological safety. Use of the accelerator in the RFNC-VNIIEF during several years has indicated its high reliability and the stability of its parameters.

ACCELERATOR DESIGN

ARSA is an accelerator of direct action with a ten-cascade Marx generator of 1 MV voltage with oil insulation [2]. It consists of a high-voltage assembly with an accelerating tube, a charging device and a control panel (Figure 1). An essential feature of the Marx generator used in the unit, is pulsed charging of storage capacitors. Current is commutated by discharges of high pressure.

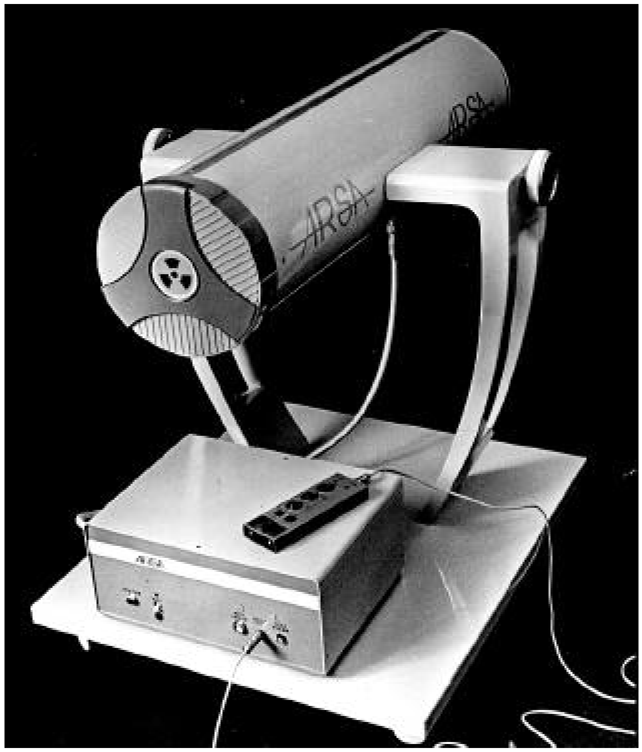

Figure 1 ARSA Accelerator

The main accelerator's element is a sealed accelerating tube working as a source of electron and X-ray radiation. The tube's dimensions are: 70 mm diameter, 100 mm length. It is a vacuum diode cold-cathode through-target tube. The blade cathode provides uniform current density and a homogeneous radiation field. The electron tube window is made of titanium foil 50 μm thick for electron beam output. The X-ray tube's anode is a combined one. It contains a tantalum target with thickness of 50 μm, titanium window (50 μm) and beryllium or aluminum filter for absorption of electrons that have passed the target and window. The X-ray tube is changed for the electron one rather easily.

MEASUREMENTS AND CALCULATION OF CHARACTERISTICS

The ARSA accelerator is equipped with a set of measuring devices which allow it to obtain the required data on radiation fields.

Voltage on the accelerating tube is recorded by a liquid-resistive divider based on a solution of blue vitriol with 1kΩ resistance of a liquid stage. Pulses of electron beam current are measured by the Faraday cup and low-inductance shunt. The form of the X-ray radiation pulses is recorded by a semiconductor or diamond detectors. High-speed oscillographs are used for measuring pulsed electric and radiation parameters.

Maximum energy of the electron beam is measured according to the electron path in a stack of polymer dosimetric films, which change color under irradiation. The error in measurement of the maximum energy is of ±50 keV, that is defined by the dosimetric film thickness.

The absorbed dose of X-ray radiation is measured by thermoluminescent dosimeters based on alumino-phosphate glasses and lithium fluoride (the error is ±15%). The absorbed electron radiation dose is evaluated with a colored film dose indicator or is measured by film dosimeters.

Table The main parameters of the ARSA accelerator

Main parameters	X-ray radiation	Electron radiation
Maximum energy of electrons, quanta, keV	1000	1000
Maximum dose in air per pulse, Gy	3	$3*10^4$
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	

While using the accelerator in radiation research (physical, biological, medicine), knowledge of the spectrum of energy radiation is needed and a profile of energy release in objects under radiation. Spectrometry of pulsed X-ray radiation is a rather complicated task, therefore, spectra of electron and X-ray radiation are calculated by the Monte-Carlo method using oscillograms of current and voltage. Results of energy release calculations in air for X-ray and electron radiation agree well with those of dosimetric measurements. The calculated distribution of the dose of X-rays absorbed in air is shown in fig. 2.

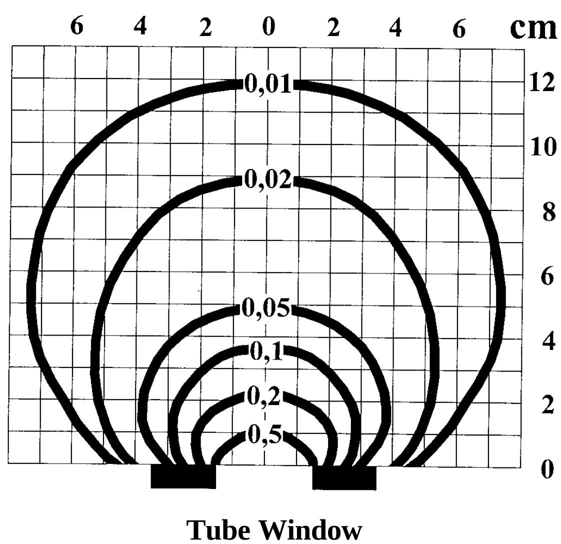

Figure 2 Dose map (Gy) of X-rays in air.

POSSIBLE APPLICATIONS

Stable parameters of the accelerator radiation, its small dimensions, low cost, ecological safety, and possible calculation of absorbed energy in any object under radiation, allow it to be used in medical and radiobiological research, as well as in clinics.

X-ray radiation of the accelerator can be used for irradiation of donor blood and its components, which is recommended for bone marrow transplantation. Usually blood is irradiated in plastic bags (hemacons). A spot with a diameter of 12 cm (hemacon size) is rather uniform at the distance of 9 cm from the X-ray tube window. The dose from the center to the edge of the spot is reduced not more than by 50%. If the hemacon with blood is disposed within this 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 double-sided irradiation the uniformity of the absorbed dose in blood increases, and the radiation time decreases.

The ARSA accelerator's electron radiation sterilizes surfaces and thin samples, in this case the sterilization dose in the vicinity of the tube window can be obtained over one pulse. We performed a calculation-experimental work on sterilizing surgical stitch material [2].

A sealed polyethylene bag (50x60 mm) with polyester wicker surgical thread enclosed was located in a homogeneous spot at the distance of 50 mm from the electron tube window. To simplify calculations of the absorbed dose the stitch material was simulated by lavsan with the thickness of 2 mm. Calculations showed that a dose of 1 kGy/pulse and more was established in a layer at the depth from 0.3mm to 1mm. Double-sided irradiation of the stitch material will provide more uniform distribution of the absorbed dose over the hank of surgical thread and reduce sterilization time.

The proposed electron irradiator-sterilizer may be used in clinics, applied for sterilization of micro-surgical and stomatological tools, small artificial organs, stitch materials , etc.

CONCLUSIONS AND PERSPECTIVES

At present a transportable irradiator on the base of the ARSA accelerator with double-sided irradiation of objects and compact biological protection is being developed. The control panel is combined with the monitor-dosimeter intended for prompt control of the dose and switching off the unit once the preset dose is achieved. This irradiator is compact, relatively cheap and ecologically safe. The X-ray irradiator can be used for solving applied tasks, for example, developing a 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.

ACKNOWLEDGEMENT

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KEY WORDS

Pulsed accelerator, X-ray radiation, electron beam, irradiation of blood, sterilization, irradiator.