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Institute of
High Current
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Measurement and calculation of the absorbed dose during irradiation of the grain by a pulse electron beam with energy up to 160 keV

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Relevance

Application examples of electron accelerators with large cross section beams:

- *[Food radiation processing;]*
- *Sterilization of medical products;*
- *Pumping gas lasers;*
- *Curing of polymer coatings;*
- *etc.*

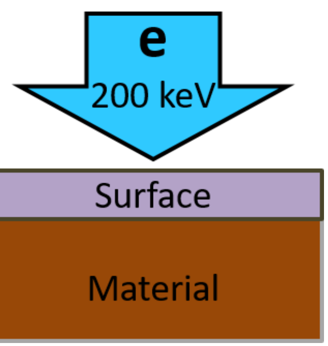


Fig. 1- Impact of a low-energy beam on the material surface

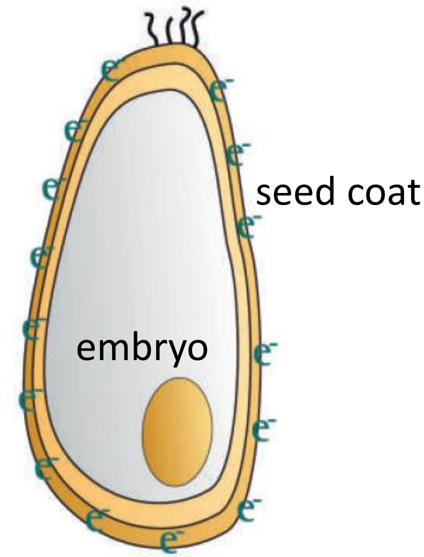
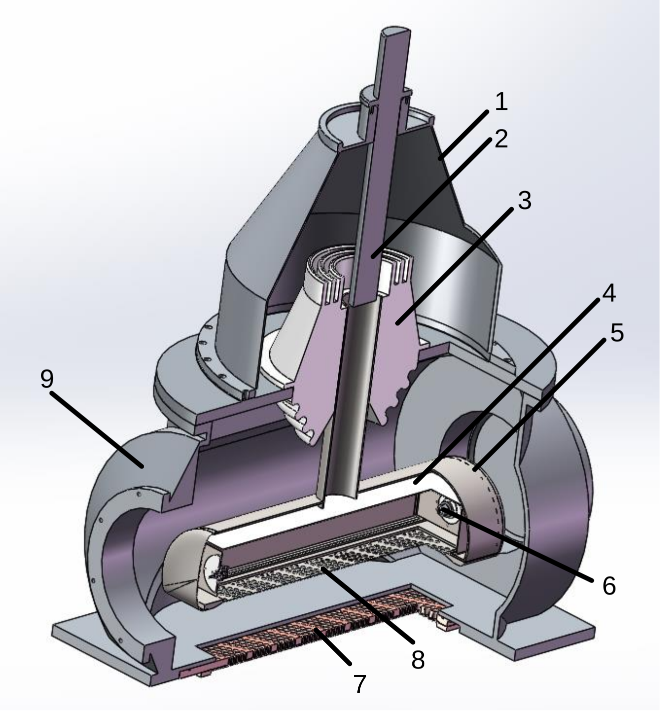


Fig. 2- Electron beam treatment of grain

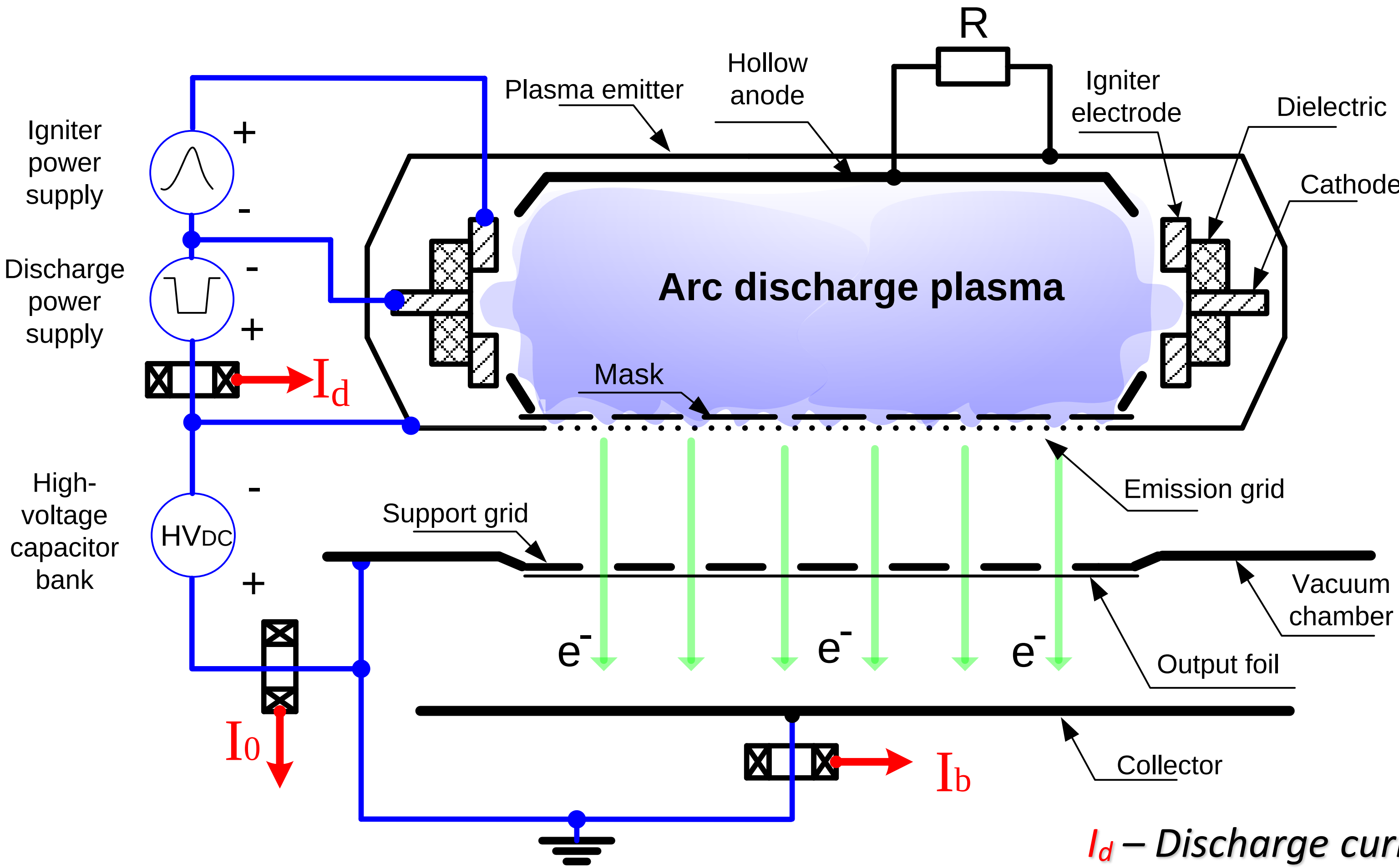
Appearance and parameters of the electron source «Duet»



Electron energy	(100÷200) keV
Beam current (in ambient atmosphere)	(2÷30) A
Pulse duration	(10÷250) μs
Pulse repetition frequency	up to 50 c^{-1}
Beam cross section	(15x75) cm
Heterogeneity of current density across the beam	±10%
Beam average power	4 kW
Efficiency	up to 80%

1 – high voltage insulator cap;
2 – high voltage cable;
3 – high voltage insulator;
4 – hallow anode;
5 – plasma cathode case;
6 – cathode assembly;
7 – output foil window;
8 – mask;
9 – vacuum chamber.

Structural diagram of the electron source «Duet»



I_d – Discharge current;

I_0 – Emission current;

I_b –Beam current in the ambient atmosphere

Dosimetric films SO PD (E)- 1/10

Range of absorbed doses, kGy	1-10
Power range absorbed doses, Gy/s	10^{-1} - 10^{5}
Radiation energy range, MeV for photon radiation for electron radiation	 0.66 - 1.25 0.3 - 10
Relative error measurements of the absorbed dose with using SO at P=0.95, not more, %	15

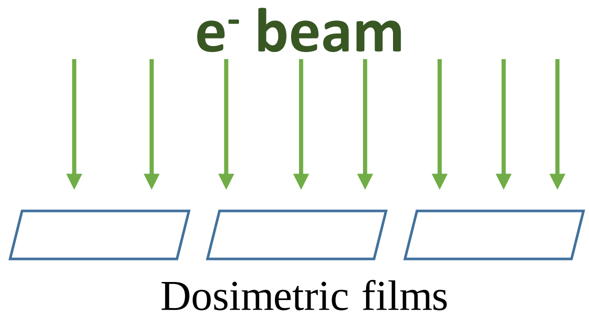
Fig. 3- Dosimetric films SO PD (E) – 1/10 for measure absorbed dose

Each film has a 100 µm thick lavsan base and a 30 µm sensitive layer

Measured absorbed dose

Number of pulses	Accelerating voltage, kV	Average optical density	Absorbed dose, kGy
1		0.40	3.3
2	100	0.78	6.5
4		1.21	>10
1		0.36	3
2	130	0.77	6.4
4		1.16	9.8
1		0.20	1.6
2	160	0.36	3
4		0.66	5.5

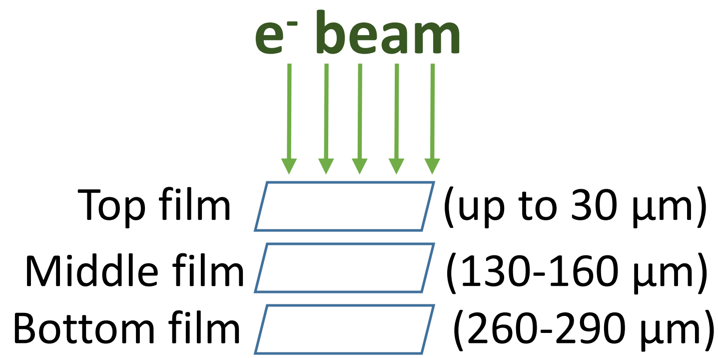
The optical density of films was measured using a SPEKS SSP 715-1 spectrophotometer at a wavelength of 550 nm.



The density of the extracted beam energy per pulse was 15 J/cm^2. An increase in the absorbed dose was achieved by varying the number of pulses.

Absorbed dose is proportional to the number of pulses, taking into account the measurement error of dosimetric films and the conditions of the experiment.
An increase in the accelerating voltage, and, accordingly, the electron energy, leads to the fact that a larger number of electrons are able to overcome the first film without interacting with it.

Measurement the depth distribution of absorbed dose



To measure the depth distribution of absorbed dose, a stack of three dosimetric films was irradiated. Since the electron energy is small, each film fixes the dose at a different thickness.

In a series of 20 pulses, the upper film darkens so much that the value of the optical density goes into saturation, but at the same time, a certain value of the absorbed dose is recorded in the middle film, which is not allowed to be recorded by a series of 2 pulses.

From this we can conclude the following: at accelerating voltages of 100 and 130 kV, the total dose introduced into the sample is concentrated at a depth of 130 μm; at an energy of 160 kV, the dose is distributed over a depth of up to 260 μm.

Number of pulses	Accelerating voltage, kV	Top film		Middle film	
		Optical density	Absorbed dose, kGy	Optical density	Absorbed dose, kGy
2	100	0.61	5.1	0.00	0
20		1.34	>10	0.02	<1
2	130	0.66	5.5	0.00	0
20		1.36	>10	0.01	<1
2	160	0.35	2.9	0.08	<1
20		1.35	>10	0.86	7.2

Simulation of absorbed dose into dosimetric films

The numerical code EPHCA2 used in this work allows simulating the passage of electrons, positrons and photons through various media (or a set of media) taking into account energy losses, elastic and inelastic scattering, generation of bremsstrahlung radiation, etc.

Simulations were performed to validate the measurements made with dosimetric films. Dose estimation in the simulation was carried out for a water layer of the same thickness as the sensitive film layer. The layers of water were separated by layers of lavsan.

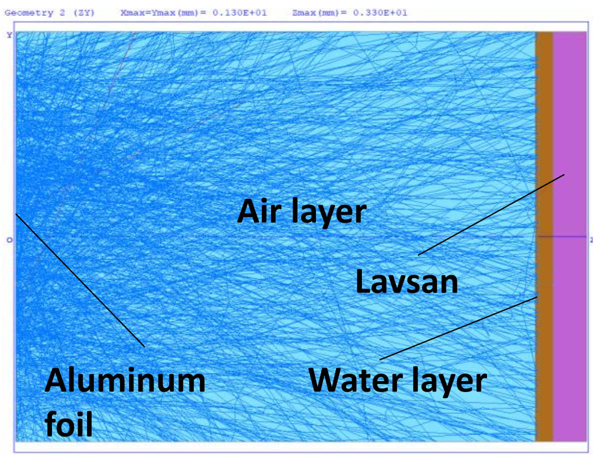


Fig. 4- Computational domain geometry

All doses per electron obtained from the simulation show the absorbed dose produced by an electron over an area of 1 cm^2.

To calculate the total absorbed dose D in the layer, we used the corresponding values from table and equation, in which j is the electron current density of the beam 10 mA/cm^2, D_e is the absorbed dose reduced to one electron, t_{pulse} is the pulse duration 90, 35 and 15 µs for energies of 100, 130 and 160 keV, respectively, q_e is the electron charge.

$$D = (j \cdot t_{pulse} \cdot D_e)/q_e \qquad (1)$$

Water layer (film number)	Electron energy, keV	Dose per electron, Gy	Total absorbed dose, kGy
1		$2.75 \cdot 10^{-10}$	3.1
2	100	0	0
3		0	0
1		$1.04 \cdot 10^{-9}$	4.55
2	130	$2.03 \cdot 10^{-12}$	0.01
3		0	0
1		$1.15 \cdot 10^{-9}$	2.16
2	160	$3.36 \cdot 10^{-10}$	0.63
3		0	0

Simulation of absorbed dose for grain

Simulation was carried out in a geometry consisting of several layers: aluminum foil 30 µm thick (closes the output window of accelerator), an air layer 30 mm thick (air gap between the output window and irradiated culture), a carbon layer 1 mm thick (imitates a solid single layer of grains). Simulation showed that the main part of electrons with an initial energy of up to 160 keV is absorbed in the outer layer less than 250 µm thick, and the main dose of absorbed radiation is also created there. In a real grain, this is the seed coat. The inside of the grain (endosperm) is less irradiated. The main source of dose in the inner part of the grain is X-ray bremsstrahlung generated in the outer shell of grain.

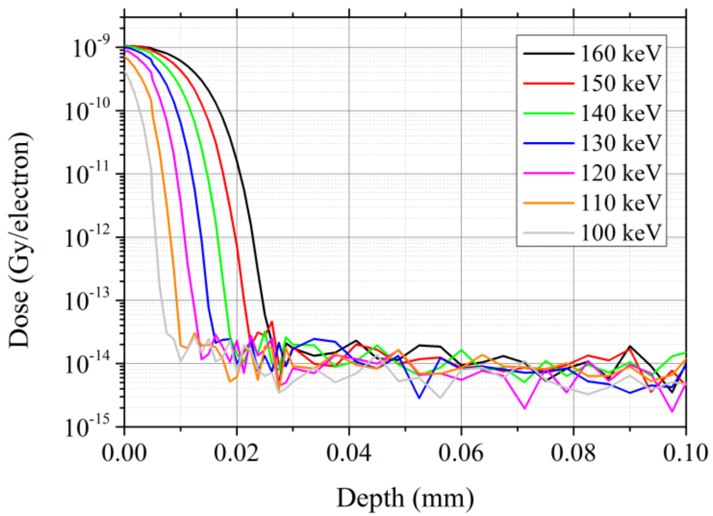


Fig. 5- Distribution of absorbed dose in the model layer of barley depending on the initial energy of electrons.

In addition to graphical data on the distribution of absorbed dose in grain, the numerical values of absorbed dose over the layer thickness are given. The obtained values make it possible to estimate the total absorbed dose in different layers of the barley grain at different electron energies using equation (1).

Layer depth, mm	Dose in selected layers, reduced to one electron Gy/electron						
	100 keV	110 keV	120 keV	130 keV	140 keV	150 keV	160 keV
0,0–0,05	$1{,}64\cdot10^{-10}$	$4{,}16\cdot10^{-10}$	$6{,}69\cdot10^{-10}$	$8{,}52\cdot10^{-10}$	$9{,}55\cdot10^{-10}$	$1{,}01\cdot10^{-9}$	$1{,}02\cdot10^{-9}$
0,05–0,25	$2{,}22\cdot10^{-13}$	$5{,}52\cdot10^{-12}$	$2{,}81\cdot10^{-11}$	$7{,}19\cdot10^{-11}$	$1{,}34\cdot10^{-10}$	$2{,}05\cdot10^{-10}$	$2{,}82\cdot10^{-10}$
0,25–0,75	$5{,}97\cdot10^{-15}$	$8{,}85\cdot10^{-15}$	$7{,}87\cdot10^{-15}$	$9{,}72\cdot10^{-15}$	$1{,}11\cdot10^{-14}$	$1{,}07\cdot10^{-14}$	$1{,}21\cdot10^{-14}$

Conclusion

Dosimetric studies were carried out to measure the absorbed dose using dosimetric films SO PD (E)-1/10. Also, the simulation of the experimental scheme was carried out, which confirms the nature of change and the value of absorbed dose. The obtained data make it possible to estimate the dose at different electron energies in the range from 100 to 160 keV. It follows from the experiments and calculations that the optimal solution to disinfect the grain and not inhibit its growth is the use of electron accelerators generating a beam with energies in the range of 100-130 keV. The embryo of a grain is located directly under the seed coat, the thickness of which does not exceed 150-200 microns, therefore, at an electron energy above 130 keV, it can be exposed to significant radiation, leading to the death of embryo. Nevertheless, the question of stimulating grain growth with radiation doses below the lethal dose remains open.

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Thank you for your attention

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