CrossMark

Dostępne online www.journals.wco.pl/los

Zeszyty Naukowe WCO, Letters in Oncology Science 2019;16(4):137-145

Letters in Oncology Science
ISSN 2543-6724
ZESZYTY NAUKOWE WIELKOPOLSKIEGO CENTRUM ONKOLOGII

Artykuł / Article

Rozwiązania i modyfikacje konstrukcyjne układów dozymetrycznych akceleratorów elektronowych

Solutions and constructional modifications of dosimetry systems of electron accelerators

Agnieszka Misiarz[1], Bożena Malesa[1],
Wasyl Markopolskyi[1], Ewa Jakubowska[1], Jerzy Wysokiński[1]

[1] *National Centre for Nuclear Research, Otwock, Poland*

Abstract

The study is designed to present a method of dosimetry system solution in electron accelerators manufactured at the NCBJ Nuclear Equipment Division (HITEC). Two special cases of accelerator applications have been presented - the first using a high-efficiency electron beam in material research and the second using a low-efficiency photon beam in cargo inspection at borders. The article presents constructional modifications of the standardly used ionization chamber, which successfully enabled proper dose measurement in both of the above-mentioned cases.

Keywords: dosimetry system, ionization chamber, electron linear accelerator

Introduction

Linear accelerators of electrons are devices that generate ionizing radiation by accelerating particles (electrons) in the electric field. The source of radiation in accelerators are electron guns - diodes or triodes. The electrons emitted from the gun are accelerated by microwave power in the accelerating structure. A useful beam is an electron beam or a photon beam with energies above 1MeV and various dose rate (depends on the radiation source efficiency).

Although accelerators were invented for elementary particle physics, they are also used in other branches of science, as well as in industry and medicine. Linear accelerators are used in factories for polymerization of plastics, waste utilization and food sterilization, as well as in radiotherapy.

Non-destructive testing is a well-developed branch of accelerator applications. Accelerators have also been used to inspection bulky goods such as air containers, trucks or railway wagons at borders. Such research, like NTD (Nondestructive Testing), allows to see the inside of the load, without the need to stop and time-consuming searching.

Regardless of the type of radiation source used its intensity (dose rate) is regulated in the feedback loop (Figure 1).

Adres do korespondencji
Agnieszka Misiarz
National Centre for Nuclear Research, 05-400 Otwock, Świerk, Poland
Telefon. +48 22 273 21 10
e-mail: agnieszka.misiarz@ncbj.gov.pl

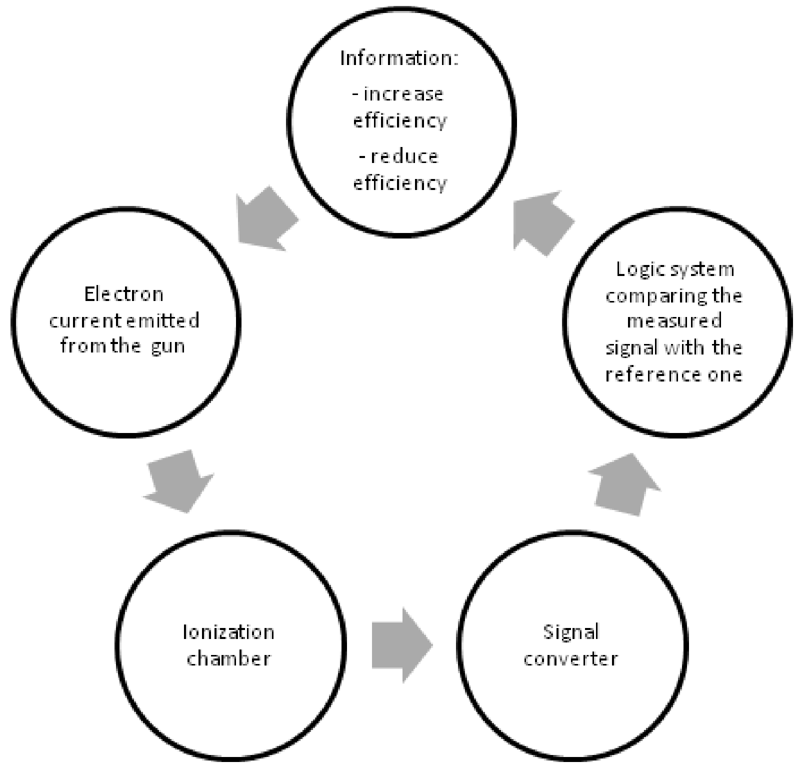

Figure 1.Diagram of feedback regulation of the radiation beam intensity in electron accelerators.

The loop includes a dosimetry system consisting of an ionization chamber and electronic and logical circuits for processing signals from the chambers into a useful signal. Thanks to that the current of electrons emitted from an electron gun can be regulated. In accelerators used in radiotherapy the dosimetry system needs to be duplicated.

Materials and methods

- **Dosimetry system description**

The ionization chamber is a device for measuring and recording radiation causing gas ionization (nuclear radiation, X-rays, elementary particles). Ionization chambers are those radiation ionization detectors in which the charge collected on the electrodes is created only as a result of ionization by the registered particles (primary ionization) [1].

Open ionization chambers are used in linear electron accelerators manufactured at the NCBJ Nuclear Equipment Division (HITEC). The air is the working gas in such a chamber.

According to the technological specificity and location of the ionization chamber in the accelerator (Figure 2), the material for this subassembly must meet the following conditions:

1. be resistant to ionizing radiation (located in the main beam);
2. be almost transparent to radiation (it cannot affect the dispersion or absorption of radiation in the primary beam);
3. must have a modular structure. Due to the fact that electrodes are made of it, it must be a material that connects conductive and non-conductive material with each other;
4. the metallic material must be easily etched from the surface of the non-conductive material - for the electrical separation of the chamber electrodes.

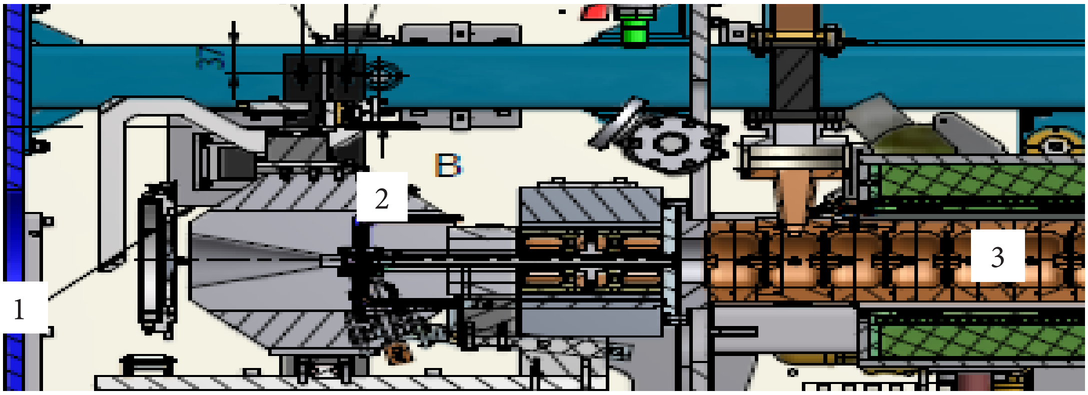

Figure 2. Location of the ionization chamber in the industrial accelerator 1 – ionization chamber; 2 – primary collimator; 3 – linear accelerator structure [8].

A material that meets all of the above conditions is aluminum sputtered kapton.

Kapton is a polyimide film developed in the late 1960s that remains stable over a wide range of temperatures, from -269 to +400 ° C (-452 to 752 ° F; 4 to 673 K) [2] [3].

The thermal conductivity of Kapton at temperatures from 0.5 to 5 kelvin is rather high for such low temperatures, $\kappa = 4{,}638^{-3}\, T^{0{,}5678}\, Wm^{-1}K^{-1}$. [4] This, together with its good dielectric qualities and its availability as thin sheets have made it very popular. Kapton is regularly used as an insulator in ultra-high vacuum environments due to its low outgassing rate.

Kapton is also commonly used as a material for windows of all kinds at X-ray sources (synchrotron beamlines and X-ray tubes) and X-ray detectors. Its high mechanical and thermal stability and high transmittance to X-rays make it the preferred material. It is also relatively insensitive to radiation damage [5].

To be maximally transparent to radiation, the thickness of the kapton is 25um and aluminum sprays are minimum 100nm. For the chamber to work properly, the cover must be uniform.

- **Chamber - standard solution**

In the linear accelerator manufactured at NCBJ split ionization chambers have been used for the main device. In accelerators it is very important to measure dose and dose rate of the beam, but not only. It is also important that the dose distribution across the radiation field is uniform [6]. That is why the divided chambers are used. The chamber consists of two independent systems - two ionization chambers D1 and D2. Each chamber is divided into two parts (D1 - D11 and D12; D2–D21 and D22). The chambers are located one below the other and the semi-circles of chamber D2 are rotated 90 degrees relative to the semi-circles of chamber D1. (Figure 3).

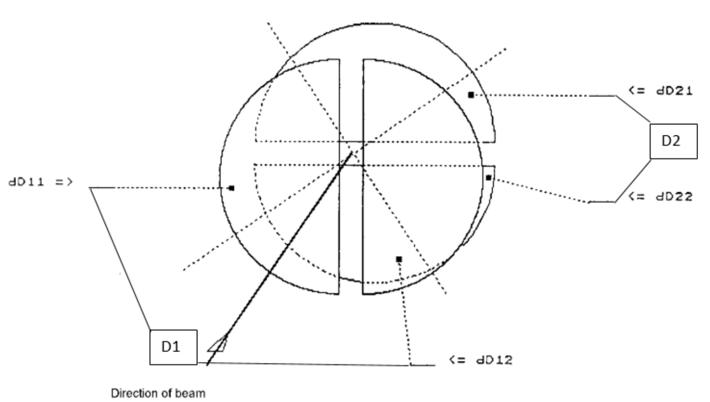

Figure 3. Schematic dual chamber configuration for linear accelerators.

The ionization chamber monitors the beam of the linear particle accelerator. The chambers are used for routine dose determination and radiation centering in the accelerator collimator. The electronic assemblies cooperating with the chamber correct the beam path, calculate the dose rate and the dose and switch off the beam when the set point is exceeded or in the event of irregularities indicated by the chamber. The chamber must protect against exceeding the set dose [6]. Therefore, its reliability and operation accuracy are important. Both these properties are guaranteed by the appropriate chamber structure, double electronic track of signals.

The saturation current in voltage range corresponding to the ionization chamber is given by the formula:

$$I = eVN \quad (1)$$

e - elemental charge;
V - active volume;
N - the number of ion pairs produced by ionizing radiation in 1 ccm within 1 s.

Ionization chambers work in the voltage range corresponding to the saturation range. This means that for a given active volume V, the saturation current I depends only on the number of N ion pairs generated by the radiation beam [7]. It is 300V for chambers used in NCBJ.

Each of the chambers has 2 voltage electrodes and 1 split current electrode. In the primary chamber plates are aligned along the radial axis of the beam; in the secondary chamber plates are aligned along the transverse axis. Dividing the chamber into two increases certainty of correct dose measurement, because the signal from each chamber is recorded by a separate electrometer.

In the production of the beam, internal plates are completely inside the beam, so their combined output current is proportional to the dose rate.

Even if track 1 is damaged the accelerator will switch off irradiation after reaching the set dose through track 2.

Results

- **Chamber - modification for high - efficiency electron beam**

The first modification of the standard ionization chamber for high - efficiency electron beam shows figure 4.

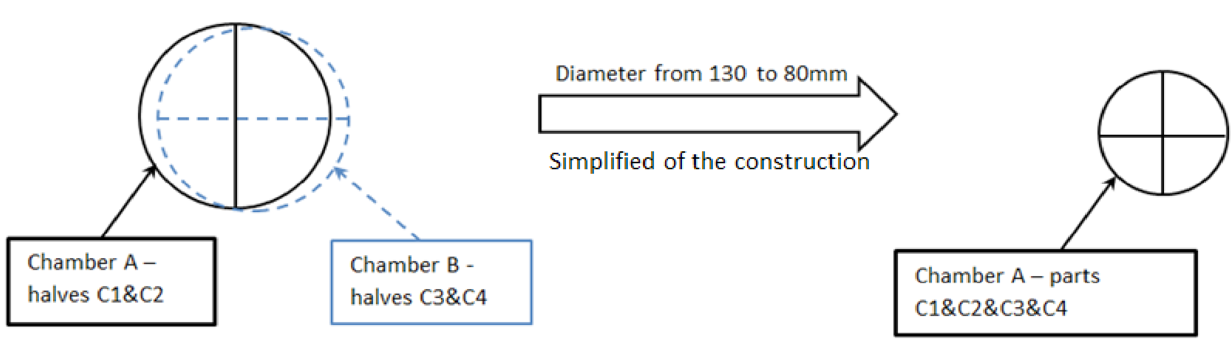

Figure 4. Schema of the first modification the standard ionization chamber.

The first modification focused on reducing the dimensions of the chamber. Its construction was also simplified - the division into two chambers was eliminated. The first chamber was divided into 4 parts to be able to check the dose distribution on the surface of the tube.

However, a very large dose rate caused mechanical destruction of the chamber material. The chamber in this situation did not properly fulfill its function.

The next step of the modification was to eliminate the material that is subject to destruction. The modification is shown in the figure 5.

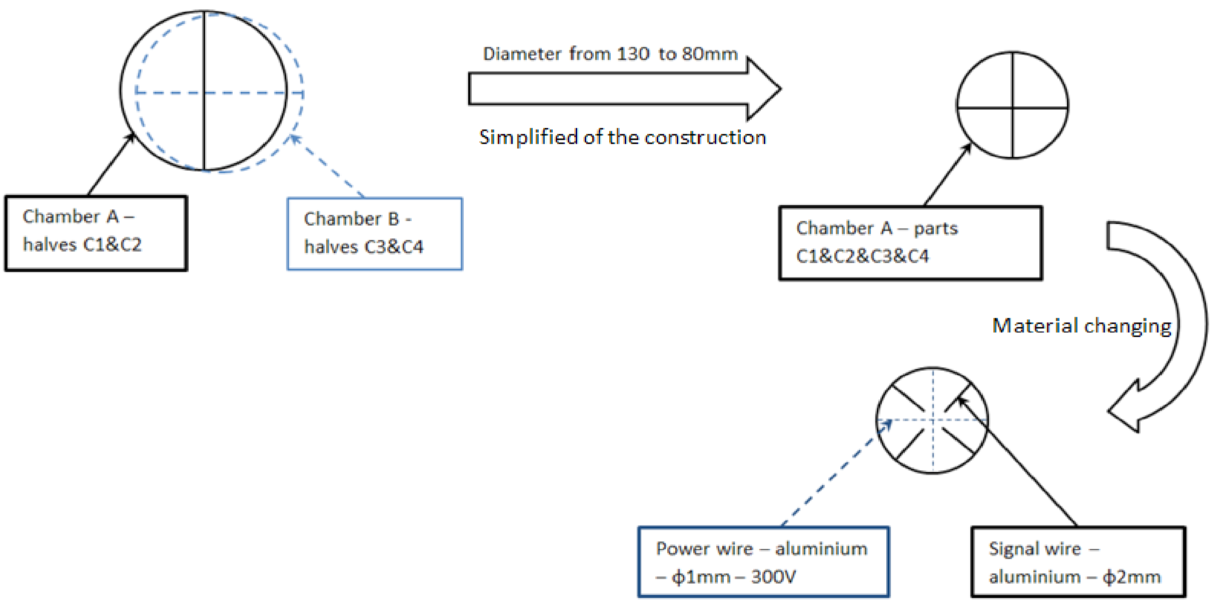

Figure 5. Schema of the second modification the standard ionization chamber.

By using power wires, the entire active area of the chamber was divided into 4 equal parts. Distribution of equidistant four electrodes in the form of signal wires with a diameter of 2mm has eliminated the risk of material damage and loss of connection of the electrodes. Wires and 1mm diameter did not significantly affect the dose distribution. Aluminum material also does not undergo radiation destruction. Thanks to this modification, the device could be changed with the existing chamber without additional change of signal processing electronics.

Useful signals read from the electrodes are presented on drawings 6 and 7.

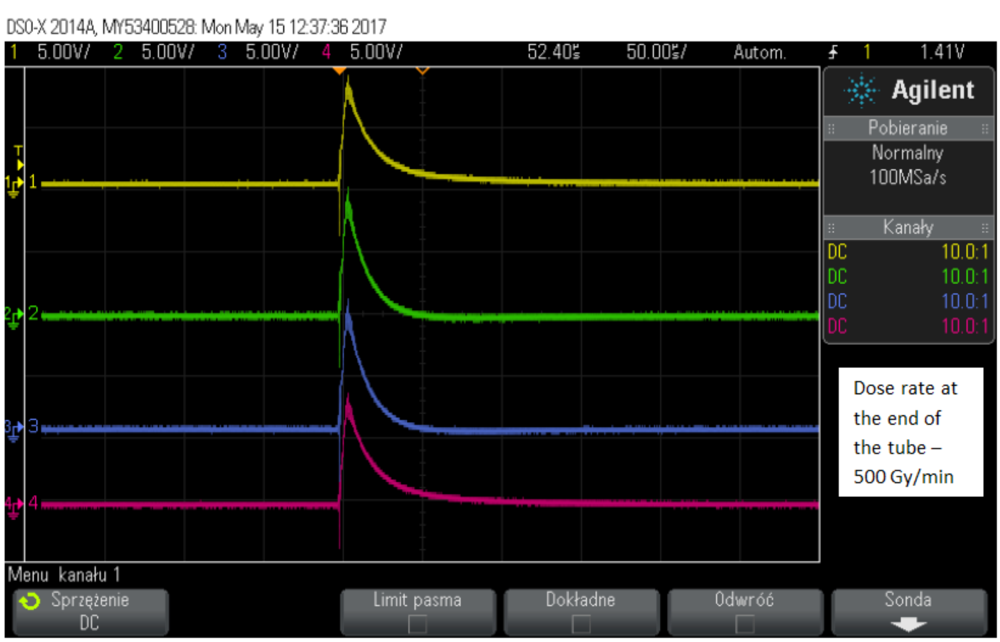

Figure 6. Useful signals read from the electrodes for 500Gy/min at the end of the tube.

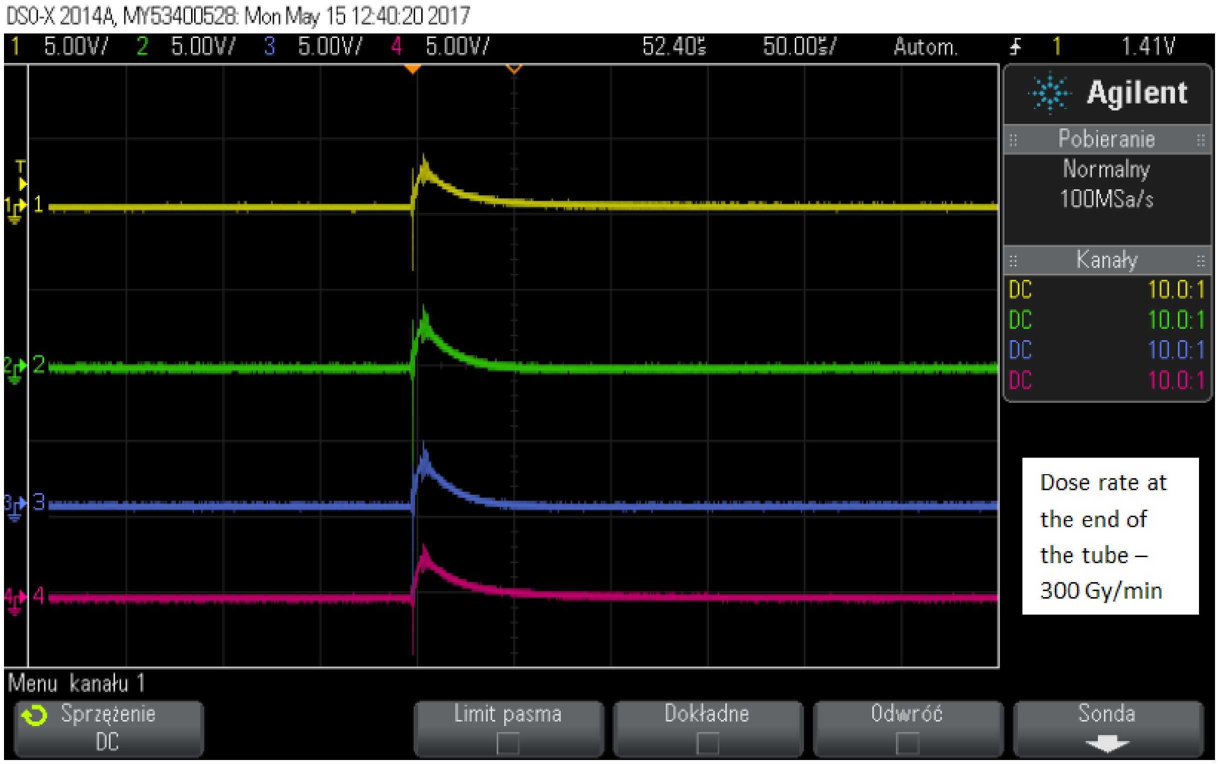

Figure 7. Useful signals read from the electrodes for 300Gy/min at the end of the tube.

It is clearly seen the change in signal height along with the change in dose rate. A change in the signal from any electrode to a higher one compared to the previous one shows a change in the uniformity of the dose distribution in the tube.

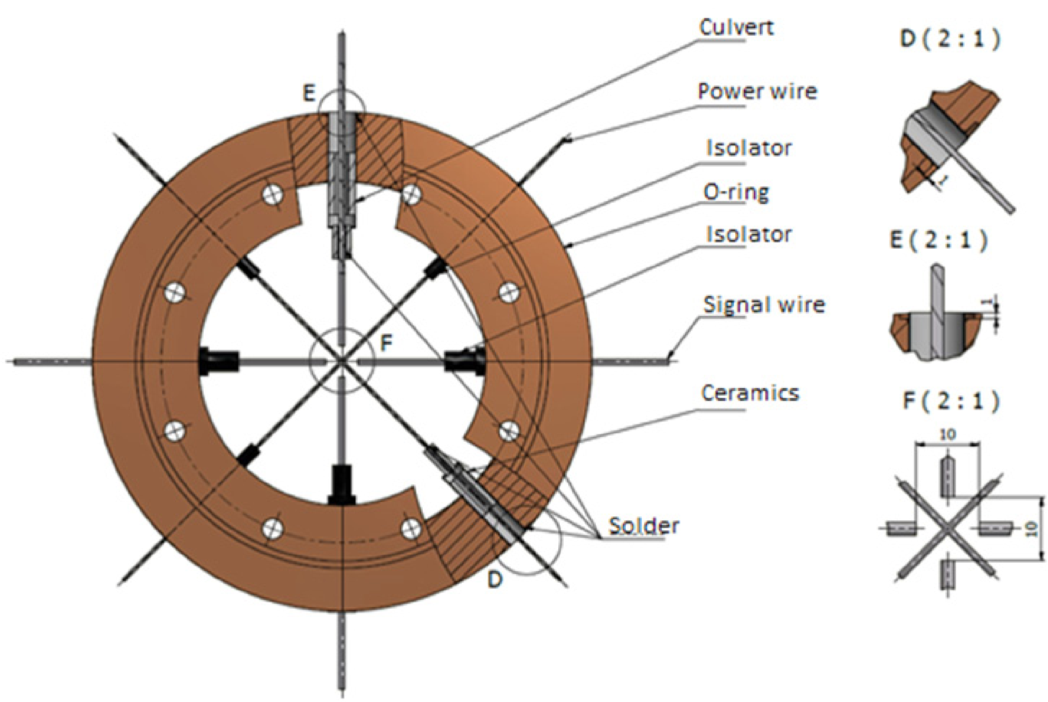

Figure 8. Dosimetry device PDD – mechanical construction

The device (Figure 8) has been mounted and works correctly in the system installed at Nondestructive Testing Laboratory at Wroclaw Technology Park since 2017.

- **Chamber - modification for low-efficiency photon beam**

For low-efficiency photon beam the measuring chamber is used to stabilize the dose rate only. For this purpose 1 collecting chamber and 1 dosimetry track are enough.

The non-split ionization chamber consists of 3 electrodes: 2 voltage electrodes (E1 and E2), 1 collecting electrodes. The modification shows figure 9.

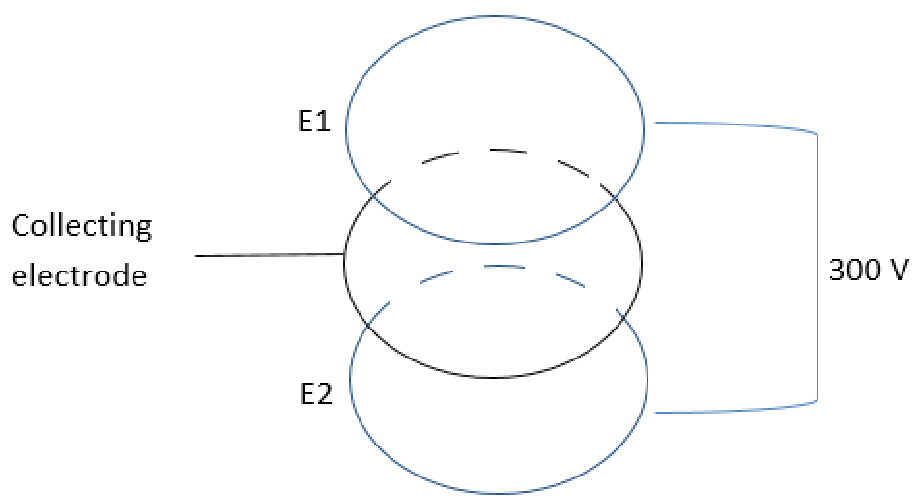

Figure 9. Schematic diagram of the electrode configuration in the ionization chamber.

The modification of the chamber was carried out in the direction of simplifying its construction, increasing the total active surface, due to the low dose intensity. According to formula 1, as the active volume of the chamber increases, its sensitivity increases.

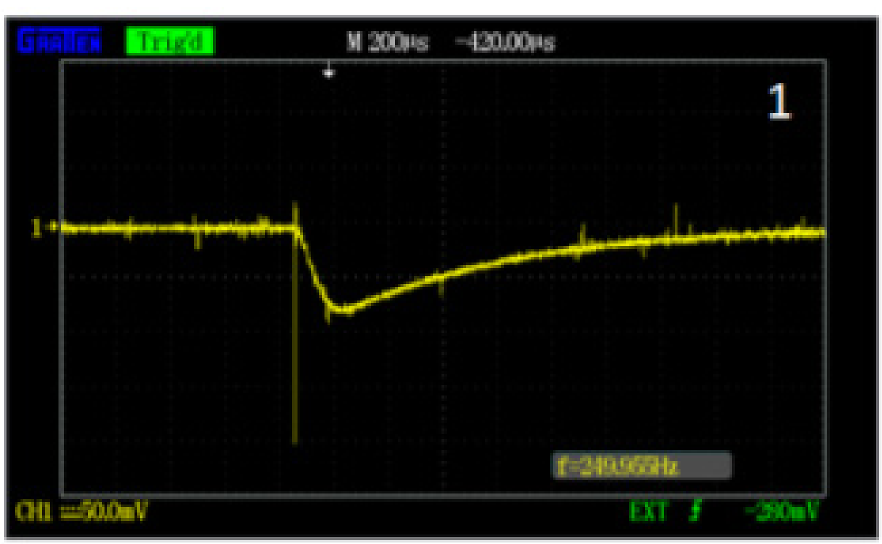

Figure 10. Measurement of chamber signal amplitude for the dose rate expected in the accelerator for cargo x-rays - approx. 0.5 Gy / min

The 0.075 V signal amplitude is measurable (Figure 10). The signal from the chamber is a signal useful in determining the radiation dose rate.

To further increase the measuring capabilities of the chamber, it will be further modified. New ionization chamber consisting of five electrodes: voltage electrode E1 (300V), collecting electrode 1, voltage electrode E2 (300V), collecting electrode 2 and voltage electrode E3 (300V). The signal from collecting electrodes will be added together –together – see figure 11.

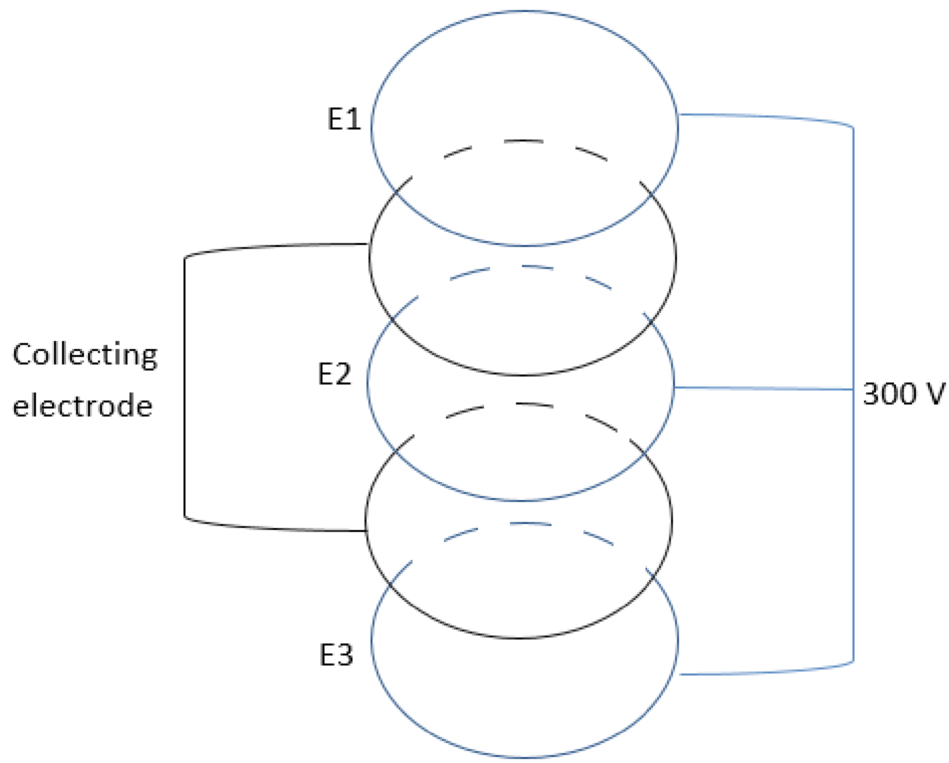

Figure 11. Schematic configuration of the electrodes in ionization chamber – finale design for low-efficiency photon beam.

The new chamber design allows the measurement of very low beam intensities, which will meet the requirements of the dosimetry system in the specific application of the accelerator.

Conclusions

Electron accelerators are widely used in oncology, modern industry and defense. The wide energy spectrum and range of efficiency of both electron and photon beams requires the use of an individually customized dosimetry system.

Modifications to the mechanical construction used in the special purpose accelerators manufactured at the NCBJ Nuclear Equipment Division (HITEC) enabled the system to be precisely adapted to the application.

Bibliography

[1] https://pl.wikipedia.org/wiki
[2] November 15, 2013. Retrieved 2015-05-28. DuPont invented Kapton® polyimide film over 45 years ago
[3] Navick, X.-F.; Carty, M.; Chapellier, M.; Chardin, G.; Goldbach, C.; Granelli, R.; Hervé, S.; Karolak, M.; Nollez, G.; Nizery, F.; Riccio, C.; Starzynski, P.; Villar, V. (2004). «Fabrication of ultra-low radioactivity

detector holders for Edelweiss-II». Nuclear Instruments and Methods in Physics Research Section A. 520: 189–192

[4] Peter Kittel (30 September 1998). Advances in Cryogenic Engineering. Birkhäuser. pp. 1366–. ISBN 978-0-306-45807-1. Retrieved 29 April 2012.

[5] Janez Megusar (1997). «Low temperature fast-neutron and gamma irradiation of Kapton polyimide films». Journal of Nuclear Materials. 245 (2–3): 185–190.

[6] Anna Natalia Kowalik „Ocena ryzyka, kontrola jakości i bezpieczeństwa w radioterapii w świetle doniesień konferencyjnych 3rd ESTRO Forum w Barcelonie”. Zeszyty Naukowe WCO, 2016; 13(4) 73-78.

[7] Układy elektroniki Front-End, Kazimierz Korbel, Kraków: Wydaw. Akademii Górniczo-Hutniczej im. Stanisława Staszica, 2000.

[8] Dokumentacja konstrukcyjna akceleratora LILLYPUT ver.6/9 NCBJ Zdaj, 2017