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THE USE OF ION FLUX IN MEDICINE

Стаття представляє новий метод терапії, здійснюваної з іонною течією. Це - один з найменш агрессивній і, в той же час, найбільш ефективний метод для лікування новоутворених центрів. На прикладі фотонної голки, стаття надає інформацію щодо засобів і принципів дії іонної течії і описує проект апаратури, використовуваної для контролю цієї течії. Деяка увага також була присвячена вимірюванням стабільності іонної течії - один з основних параметрів, що визначають застосовність іонного променя в процесі радіотерапії.

Статья представляет новый метод терапии, осуществляемой с ионным течением. Это - один из наименее агрессивний и, в то же время, наиболее эффективный метод для лечения новообразованных центров. На примере фотонной иглы, статья предоставляет информацию относительно средств и принципов действия ионного течения и описывает проект аппаратуры, используемой для контроля этого течения. Некоторое внимание также было посвящено измерениям стабильности ионного течения - один из основных параметров, определяющих применимость ионного луча в процессе радиотерапии.

The article presents a new method of therapy carried out with ion flux. It is one of the least invasive and, at the same time, most effective methods for curing the neoplastic foci. On the example of photon needle, the article gives information on means and principles of operation of an ion flux and describes the design of an apparatus used for control of this flux. Some attention has also been devoted to the measurements of ion flux stability – one of the basic parameters determining the applicability of photon beam in the process of radiotherapy.

1 Introduction

Notwithstanding the permanently improving techniques of diagnosis and surgical treatment, the results of the treatment of primary brain tumours, especially the malignant glioma, and brain metastases are still bad. Special problem create the deep-seated tumours and tumours seated near the important functional centra. This is the reason why all neurosurgical medical departments are looking for more and more precise methods of the treatment, such that would provide tools for the removal of brain tumours with minimum degree of invasion and patient's mutilation [1, 2].

One of the most effective methods of the treatment of neoplastic foci is the treatment by ionising radiation, generally known as radiotherapy. In respect of the type of the emitted radiation, the techniques of radiotherapy are divided into two groups: brachytherapy and teleradiotherapy. In brachytherapy the source of radiation is placed directly in the body cavity, in the tumour itself, or in its close vicinity. Teleradiotherapy uses an external beam radiation.

Unfortunately, standard methods of brachytherapy and teletherapy are available in very few clinical centres only, mainly because of the very high cost of respective devices [3]. Hence the necessity of looking for cheaper means of the treatment, such – however – that, while being cost effective, could still offer high efficiency, low invasiveness and high precision, thus reducing considerably the time required for curing the post-surgical effects in patients. All these features seems to have the solution presented in this article, based on practical application of the X-radiation destroying the neoplastic tissues. The radiation is produced by an X-ray tube placed in a photon needle. The said method of practical application of the ion flux combines in itself the advantages of both brachytherapy and teleradiotherapy.

2 Scope and aim of the study

The aim of the study was to develop an innovative method of application of the ion flux (Polish photon needle) in post-surgical oncological treatment of brain tumours [4]. An important oncological problem in the treatment of brain diseases are, besides metastases, primary tumours of gliomatous proliferation character. Because of their tendency to infiltration, complete removal of the tumour during neurosurgical treatment is not possible. Therefore it is necessary to combine different techniques of the treatment, like brachytherapy, teleradiotherapy based on a stereotactic technique, or the use of gamma scalpel.

3 Methods of investigation

3.1 The design of ion flux generator

Photon needle (IF) is a miniature generator of the ion flux (X-radiation). The source of radiation is special X-ray tube provided with the, so called, needle-like anode. The anode is a thin tube of 3 mm external diameter. The anode tip is a beryllium cup on the bottom of which a target has been placed. In the target, bombarded by electrons, the flux of ions is produced. The maximum operating parameters of an X-ray tube are the following: anode voltage $U_a = 40$ kV, anode current $I_a = 40$ μA. To make the radiotherapy treatment safe to the patient, the photon needle is fed by a voltage of 12 V.

The photon needle comprises the following elements:

- X-ray tube,
- a system feeding high voltage to the focusing electrode and anode, and a control system for the electron gun,
- a low– voltage system for control and stabilisation of the anode voltage and anode current, a measuring

system, a microprocessor, and a data transmission system,

- deflector coils,
- beam monitoring system.

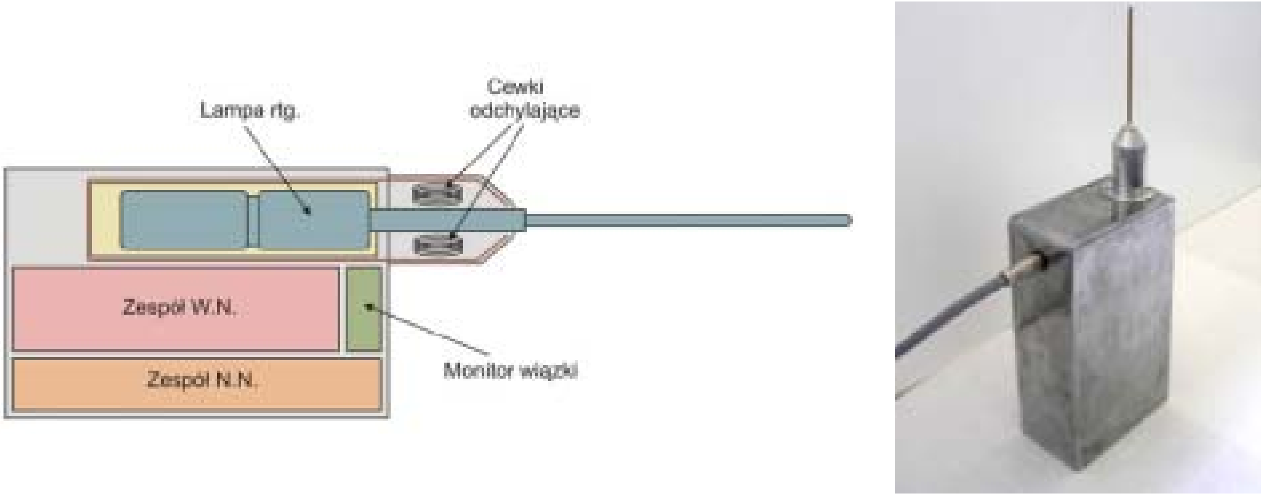


FIG. 1. THE ION FLUX GENERATOR (PHOTON NEEDLE)

The photon needle is connected to the control system via a cable, which feeds the needle and transmits control signals. Since photon needle produces a high voltage current, the cable feeding the needle has been designed for a low voltage only (up to 14 V).

3.2 Principle of operation

In photon needle, the source of X-radiation is a special X-ray tube provided with the, so called, needle-like anode. The X-radiation is produced by an anode beam bombarding the target placed in the tube. The beam of electrons is produced in an electron gun. The electrons are firat accelerated by the focusing electrode and anode potentials, to move next at a constant speed. When reaching the target, the beam of electrons has a diameter of about 0.3 mm (focusing of electron beam on the target is ensured by proper potential chosen on the focusing electrode). The target of the tube is a gold foil about 1 μm thick; it is deposited on the beryllium cup that ends the anode. Having a low atomic number Z, beryllium is poor absorber of the X-radiation.

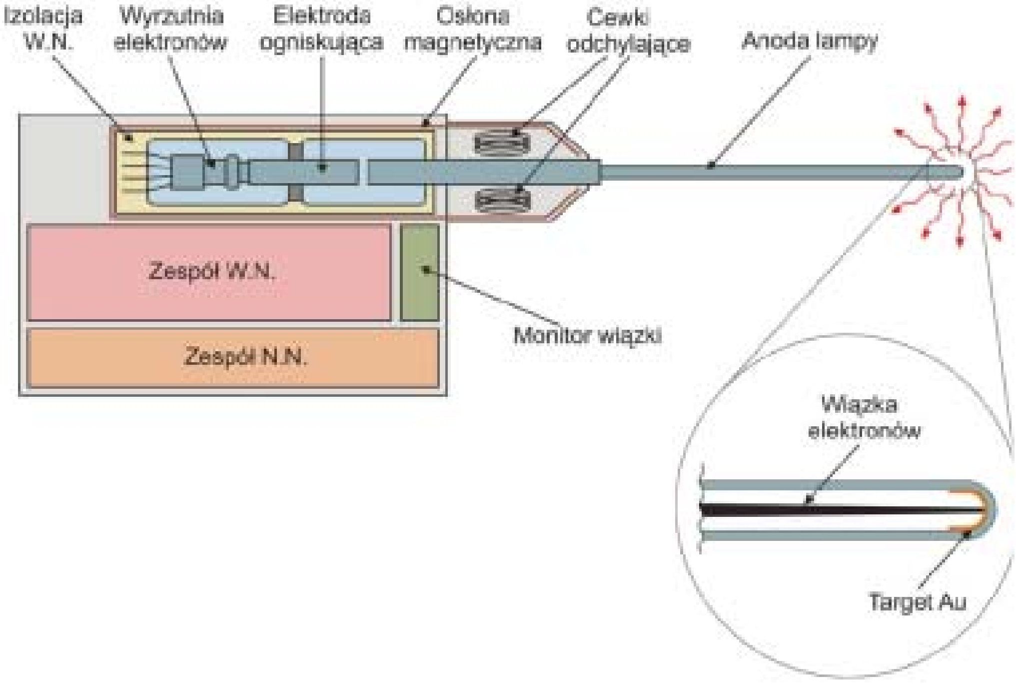


Fig. 2. Schematic diagram illustrating the operating principle of ion flux generator

Precise location of the electron beam in a central point of the target is ensured by properly chosen value of the constant voltage component feeding the deflector coils, while the variable voltage component is sweeping the electron beam along the target. The sweeping is done to produce an isotropic distribution of the X-radiation emitted by a photon needle.

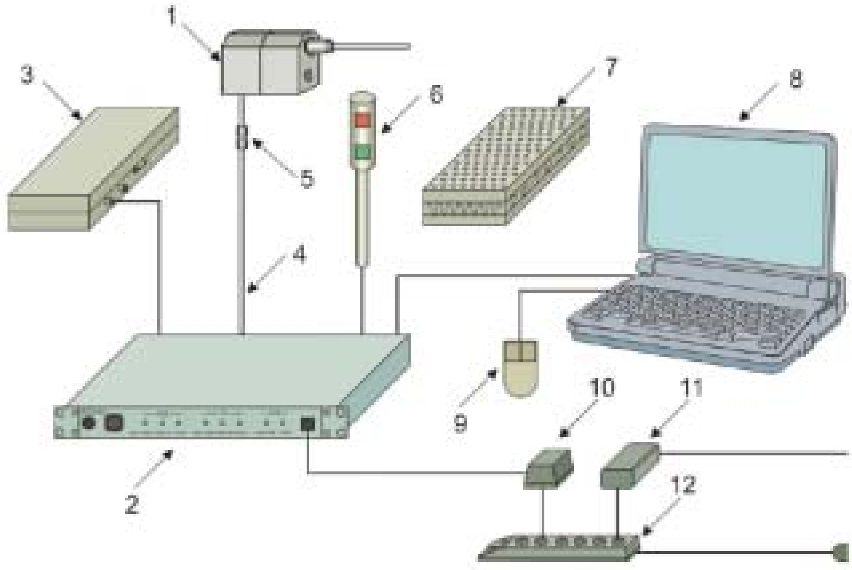
While passing the long distance of several centimetres, the electrons are exposed to the effect of external magnetic fields. This is the reason why the tube is placed in a magnetic sheath. The tube anode is made from a material characterised by high magnetic permeability.

The high voltage needed for the electron acceleration is produced by a high-voltage set (the W.N. set). The W.N. set also gives voltage for the gun operation control. The low-voltage set (the N.N. set) comprises a system that controls and stabilises the anode voltage and anode current, the measuring system, the microprocessor, and the data transmission system.

The beam monitor, which includes an X-ray radiation detector, exerts a real-time control over the X-radiation flux emitted by a photon needle.

3.3 Control of the device operation

The photon needle operation is controlled by a program installed on PC computer. The software communication with other elements of the set (photon needle, tester detector) is established through a driver.



ION FLUX CONTROL SYSTEM COMPOSED OF THE FOLLOWING ELEMENTS:

- **PHOTON NEEDLE – 1,**
- **PHOTON NEEDLE DRIVER – 2,**
- **TESTING CHAMBER – 3,**
- **CABLE FEEDING THE PHOTON NEEDLE– 4,**
- **INDICATOR OF OPERATING CONDITION – 5,**
- **EXTERNAL ELEMENT OF DRIVER OPERATION CONTROL – 6,**
- **STERILISATION VESSEL – 7,**
- **LAPTOP COMPUTER – 8,**
- **MOUSE – 9,**
- **DRIVER CHARGING UNIT – 10,**
- **LAPTOP CHARGING UNIT – 11,**
- **POWER STRIP WITH SWITCH – 12,**
- **PROTECTING SHEATH,**
- **TESTER OF PHOTON NEEDLE GEOMETRY.**

FIG. 3. A SYSTEM FOR ION FLUX CONTROL

The system has several programs, which exercise the irradiation, photon needle testing, and battery charging.

4 The results of investigation

4.1 The stability of radiation

The X-ray tube operating in the Polish photon needle provided with a needle-like anode is a two-member element (Fig. 4). In the first member, the electrons emitted by a cathode are collected and shaped into a narrow bundle running in the space along the geometrical axis of the tube and accelerated to intermediate energy Up × e (where Up is the voltage on intermediate electrode). In the second member, the electrons are accelerated to a required energy level

Ua × e (where Ua is the voltage on anode) and focussed on the target. Before the target is reached, the electrons are moving in a drift chamber (a tube made of acid steel of the Φ = 6 mm inner diameter and a tube from μ-metal – a magnetic sheath of the Φ = 2 mm inner diameter). The acid steel tube holds two pairs of coils which control the operation of electron beam. The component of DC voltage feeding the coils moves the electron beam to the centre of the target, while the AC component sweeps the beam along the target (to reduce the anisotropy of the X-radiation flux emitted by the tube). The stability of the X-radiation flux emitted by the tube results from the stability of voltage and current Ua, Up, Ia, the current on the coils (DC and AC components), and the feeding current.

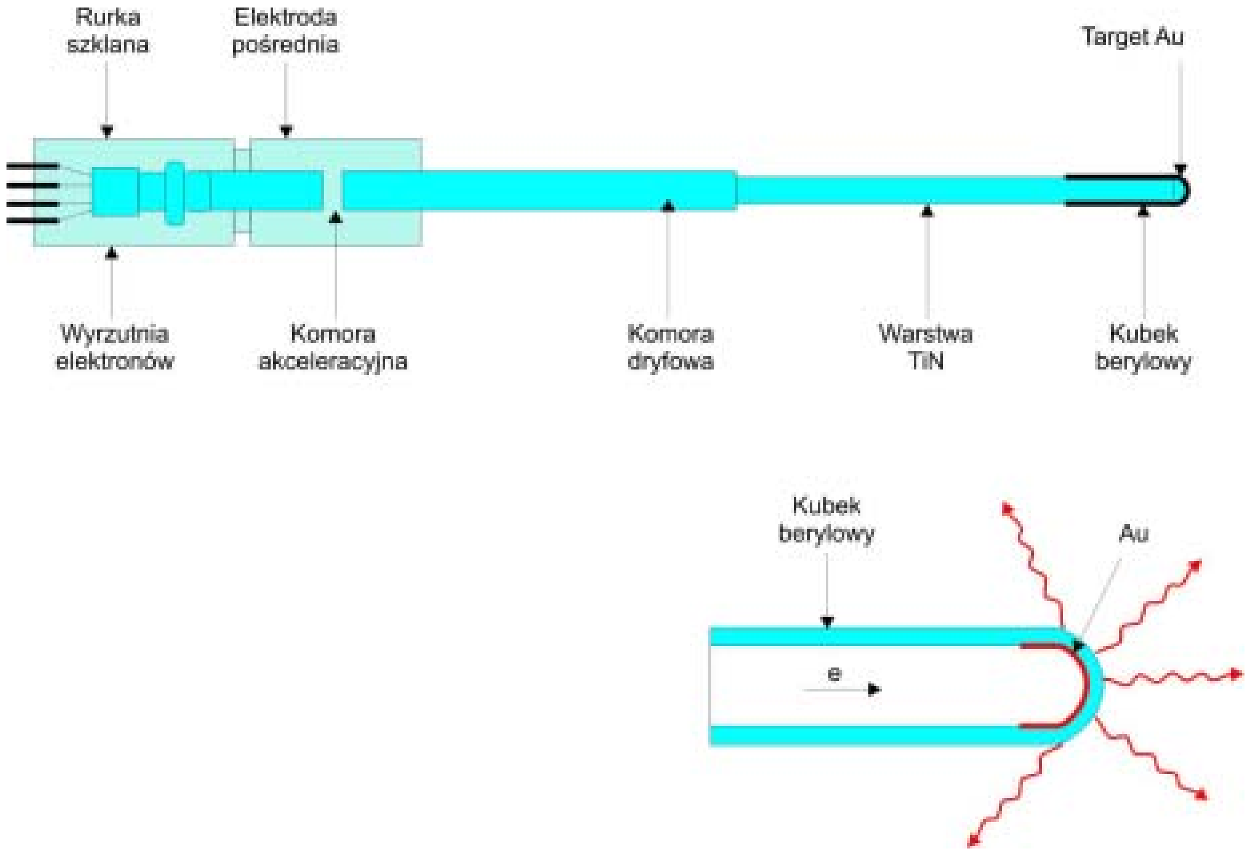


Fig. 4. Schematic diagram of an X-ray tube with needle-like anode.

Since the dose rate is proportional to the X-radiation flux emitted by the photon needle, the stability of this flux is one of the main parameters determining the applicability of the photon needle in a course of radiotherapy.

The stability of the X-radiation flux emitted by the Polish photon needle, designed by a team of the Polish scientists and assigned for radiotherapy of the brain tumours, was measured in a testing chamber of the set. The chamber ensures constant geometry of the photon needle-detector system. The radiation flux in the chamber is detected by an air ionisation chamber operating in DC system. The current leaving the chamber is proportional to the X-radiation flux (and hence to the dose rate). Therefore, by measuring in function of time the value of the current leaving the chamber, we can determine the stability level of the photon needle operation.

The batteries operating the driver of the photon needle (STZ) and the computer were charged to almost 100 %. The system was operating without external feeding (like in the true process of radiotherapy). The photon needle was running on the following parameters: Ua = 40 kV and Ia = 40 uA. Figure 3 shows as an example the result of one of the measurements.

During the measurement, which took the time of 90 minutes, the STZ battery was discharged in 80 %, while that of laptop – in 26 %. During that time, the instability of the X-radiation flux was ±1,4 %. The main cause of this instability was the slow drift of the flux observed after the lapse of 40 minutes. The instability counted for a time range of 0-60 minutes was ±0,8 %.

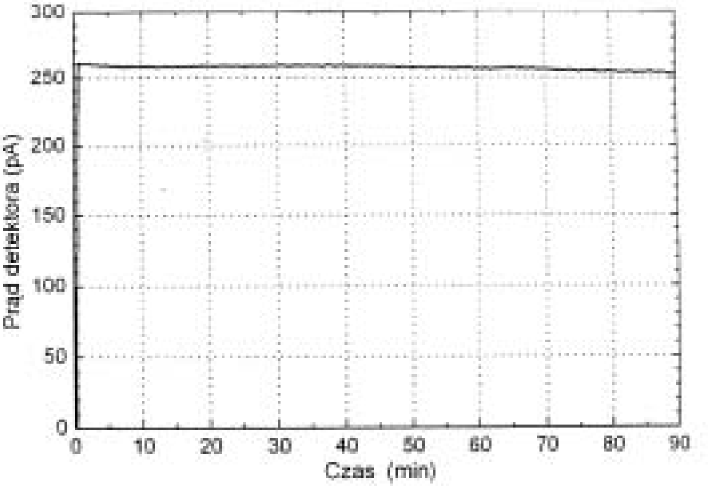


Fig. 5. Tester detector current vs time

4.2. The stability of radiation

Over the time of one week, a series of six measurements of the X-radiation flux emitted by the photon needle were taken. The photon needle was running on the following parameters: Ua = 40 kV and Ia = 40 µA. The time of each measurement was 90 minutes. Before each measurement, the driver and laptop batteries were charged to 100 %. Figure 7 shows the results of these measurements (the flux radiation measured in function of time).

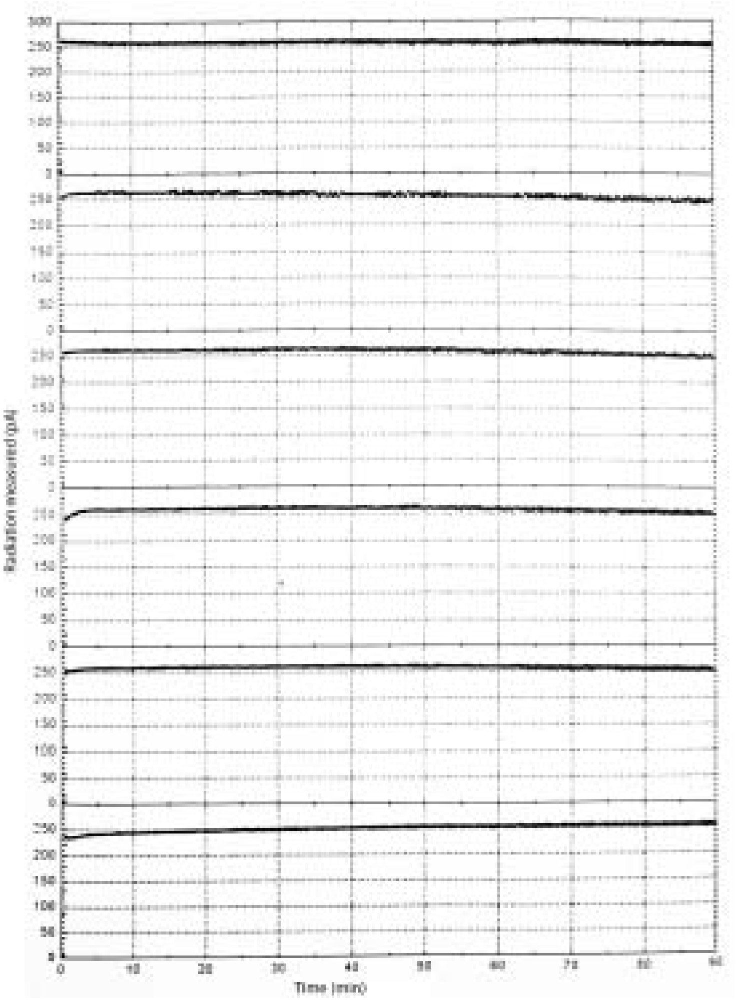


Fig. 6. The results of six measurements of the X-radiation flux

For each measurement, the detector current was integrated after time for the three ranges of time intervals, i.e. 0-30, 0-60, 0-90 minutes. Figure 8. shows, calculated by this technique, values of the charge. The charge calculated by this method is proportional to the dose. Therefore, the three integrated current values can be regarded as the three dose values. The repeatability of the dose will be the same as the repeatability of the charge presented in Fig. 8. For a series of six measurements, the scatter of the results was at a level of ±3 %.

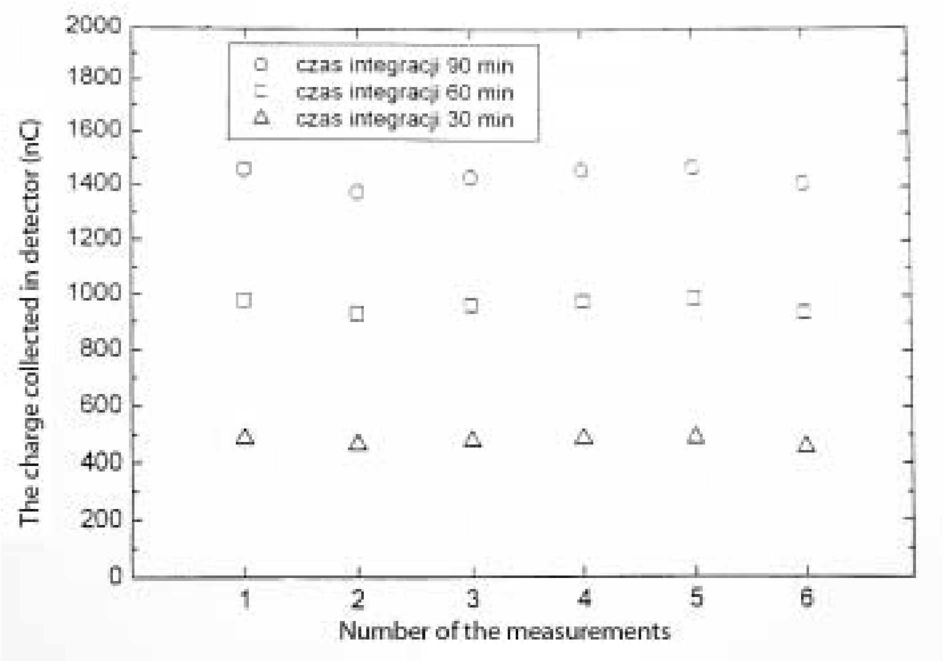


Fig. 7. The charge collected in detector for each of the six measurements

4.3. Work safety

Since the ion flux generator produces a high rate X-radiation dose, the safety regulations stated below should be closely followed in each respect.

The photon needle may be switched on (high voltage fed to the X-ray tube) only in the following cases and under the following circumstances:

- the photon needle is placed in a closed testing chamber, or
- the photon needle is protected by a radiation sheath, or
- the photon needle is in its operating position (the needle tip has been placed in the patient's skull).

Testing of the photon needle in a testing chamber and its control during radiotherapy (the needle is protected by a sheath) is fully safe (the dose rate on the surface of the testing chamber and on the radiation sheath has the level of natural background).

5. Conclusions

1. Compared with standard brachytherapy using isotope sources, the benefits of the radiotherapy using photon needle are the following:

- radiation is available only when the photon needle is switched on,
- easy change of the radiation hardness (i.e. penetration range) by changing the X-ray tube anode voltage.

2. Getting a certificate for the Polish photon needle used as a medical device opens the way to clinical tests, which will mean the next step in introducing the needle as a tool to standard intraoperational brachytherapy and sealed brachytherapy.

3. Relatively low cost of the Polish photon needle (estimated at 150 000 PLN) and the cost of the fixing system adaptation to different stereotactic devices available at the neurosurgery departments in Poland (10 000 PLN) should satisfy the expectations of patients who require radiotherapy. Radiotherapy should be more easily available at the national medical centres, which may notably improve the results of oncological treatment.

** The study uses some of the results obtained during the work on own research project 3 T11 E014 27.*

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