Some results of working process of proton therapy complex “Prometheus” for clinical purposes

Alushta, Crimea, 7 September 2017

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Abstract

In November 2015, the proton therapy complex "Prometheus", developed at PTC LPI RAS, started being used for the clinical treatment of patients with head and neck cancer. This complex consists of a compact zero gradient synchrotron, which is able to accelerate protons to energies of 330 MeV. In this paper, there are some key parameters of the extracted beam, the working process of the complex and the results of treatment received during the first year of using the accelerator in therapeutic purposes (treatment was carried out on 82 patients).

Keywords:

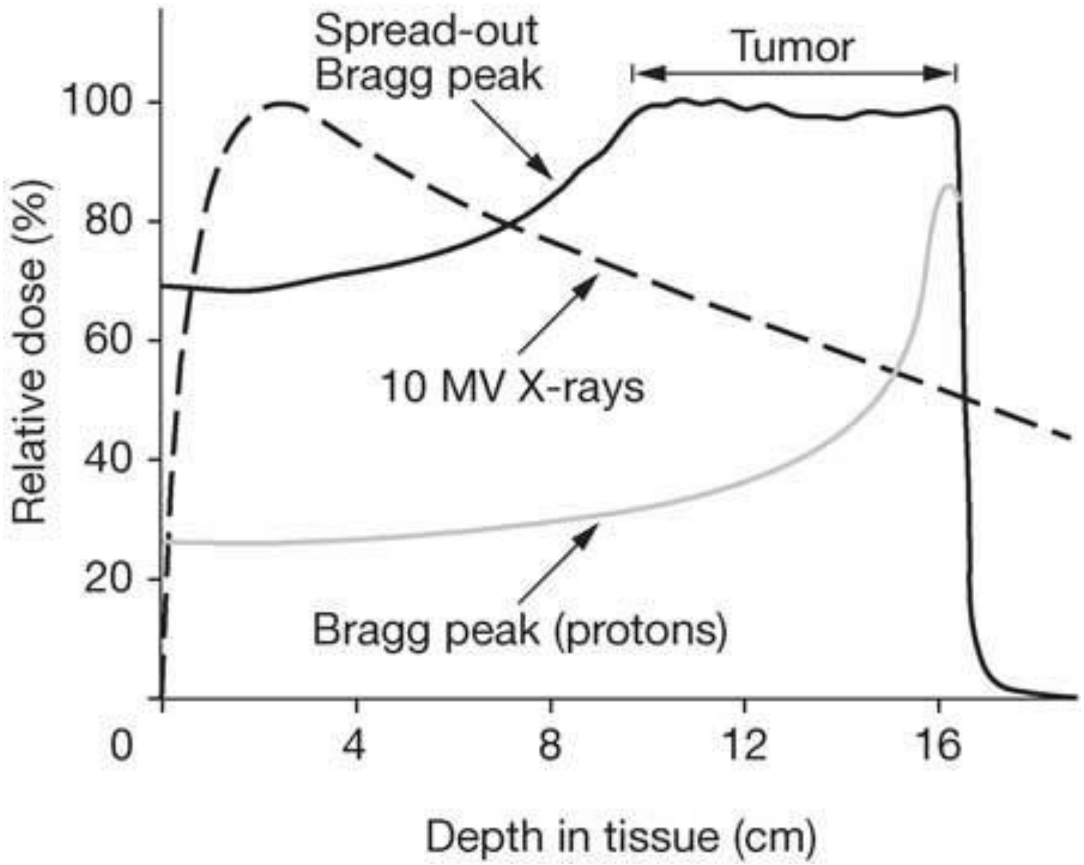
Proton therapy, medical accelerators, proton synchrotron, active proton beam scanning, Bragg peak.

Report structure

INTRODUCTION

Introduction

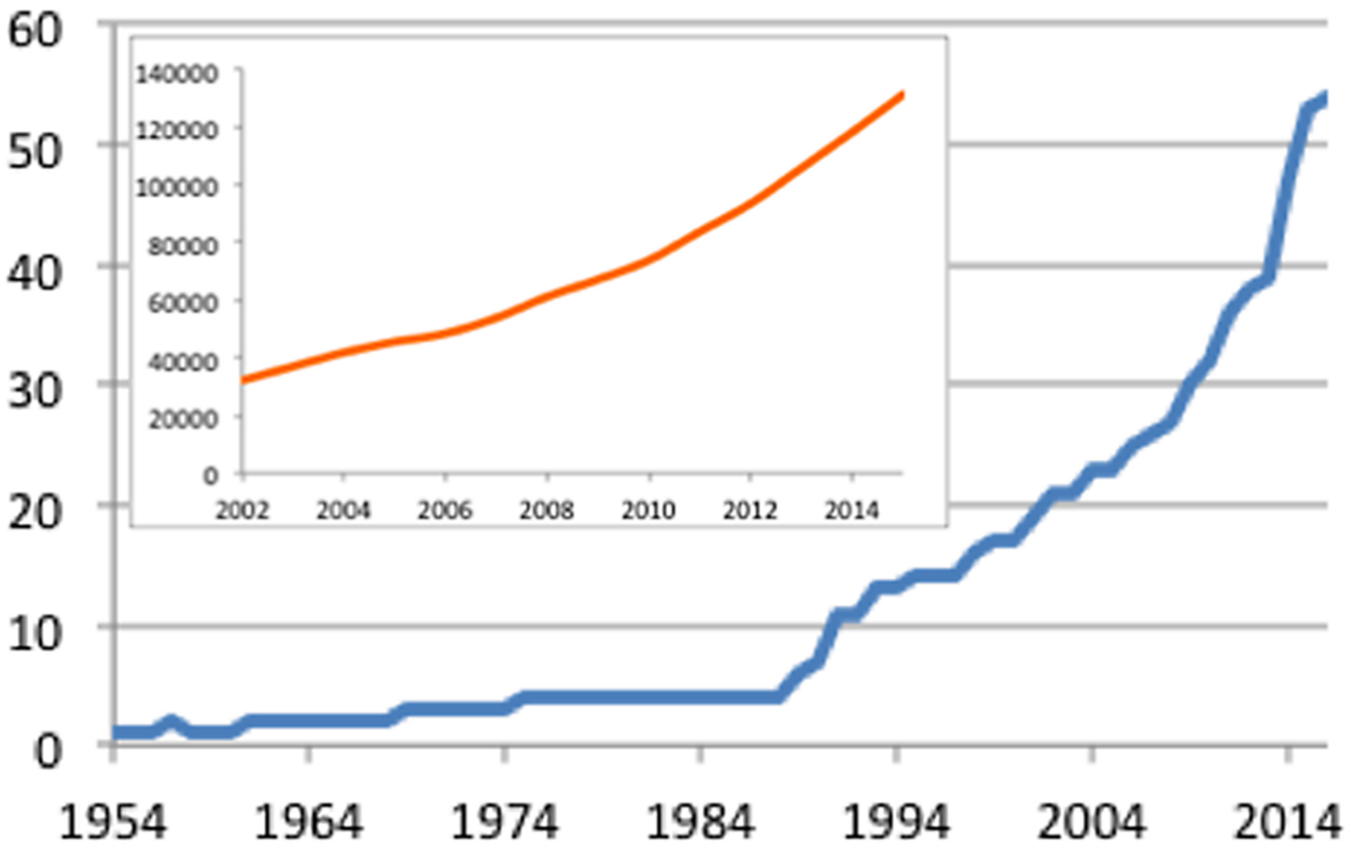
Proton therapy (PT) is one of the most accurate and modern methods of radiotherapy and radiosurgery. [1-2]. Protons can reduce the radiation load on surrounding tissues up to 30-50% in comparison with gamma rays. The use of a proton beam for tumors located near critical organs, such as the brain stem, optic nerves, etc are particularly effective. Therefore, in cases of head and neck cancer, proton therapy is the most advantageous of the available types of treatment for many patients.



Introduction

In the world, active work is being carried out aimed at increasing the accuracy of dose delivery to the tumor, reducing the time that patients stay under the influence of radiation and increasing the availability of this method for a larger range of patients. New proton accelerators [4], as well as more cost-effective and accurate immobilization systems [5] for patients are being developed for these purposes.

Introduction



Orange line – number of proton therapy centers in the world.

Blue line – number of treated patients in the world.

There is an increase of PT centers around the world [3].

Introduction

According to statistics, PT can be assigned to 50 thousand patients per year in Russia [6]. Unfortunately, in recent years, insufficient attention has been paid to this problem. Apart from the Medico-Technical Complex JINR, which started its work in 1967 [8] and annually irradiates several dozen people, only two PT centers are being built in Dimitrovgrad [9] and in Saint Petersburg. These centers are going to work using foreign setups, not Russian ones. The proton therapy complex “Prometheus” was developed and successfully implemented in the PTC LPI RAS in conjunction with Protom ltd. The complex is a Russian development and is fully produced within the territory of the Russian Federation. At the moment, there are two such complexes - in the city hospital of Protvino and in the A. Tsyb Medical Radiological Research Centre (MRRC). PTC LPI RAS and Protom ltd. along with MRRC have accumulated a year of experience in the usage of the complex under clinical conditions.

1. THE PROTON THERAPY COMPLEX «PROMETHEUS»

1.1. General Properties of the Complex

Table 1. Main properties of the clinical setup

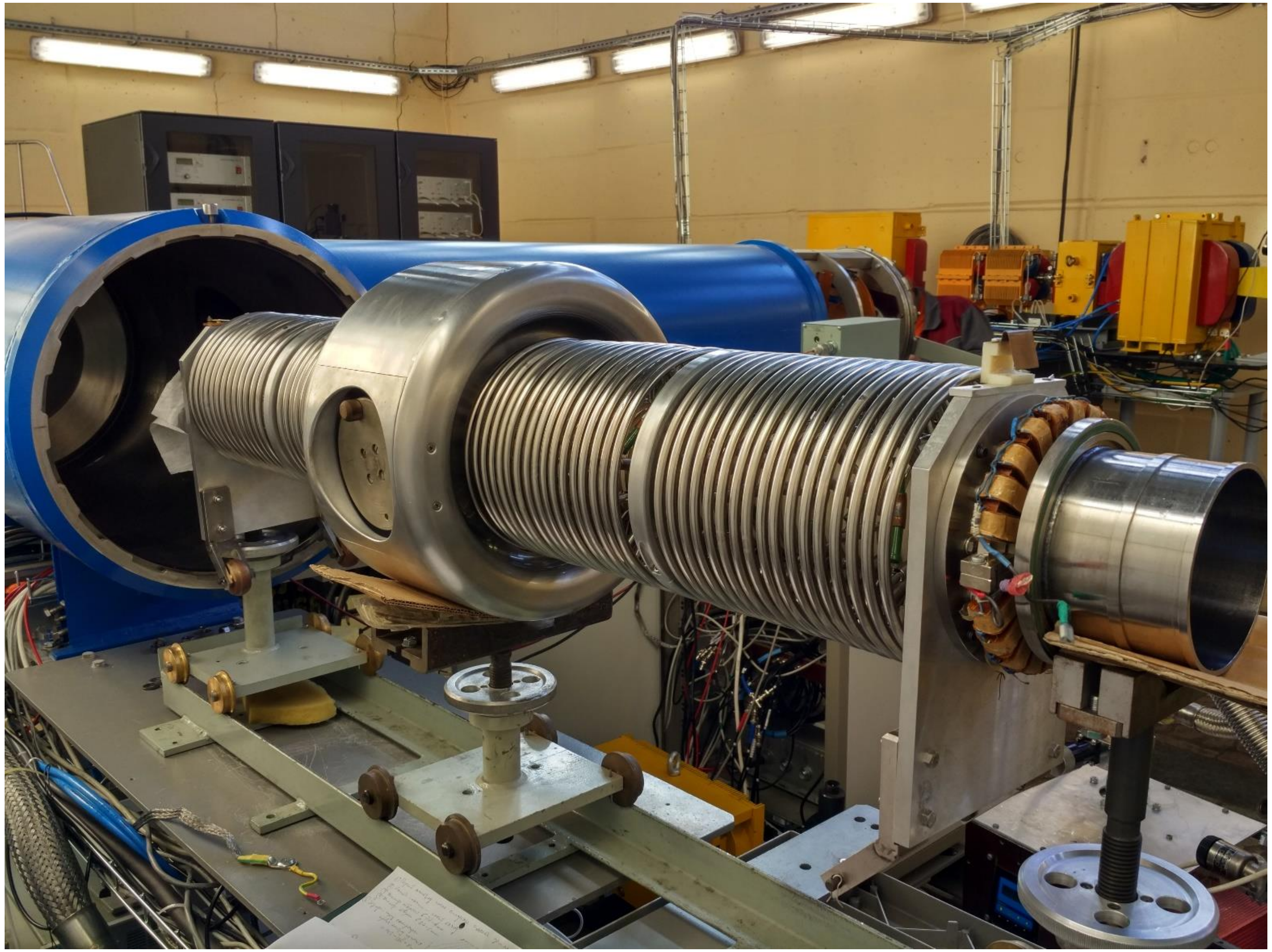
The range of accelerated proton energies, MeV	30 - 330
Magnetic field at injection, mT	80.66
Maximum magnetic field, T	1.8
Outer diameter of the ring, m	5
Weight of the accelerator, t	15
Average current of the extracted beam, prot\cycle.	$5 \cdot 10^8$

1.2. The Injection Channel

The injector is designed for the initial production of protons and their acceleration to the energy of approximately 1 MeV.

The injector consists of a pulsed arc source of ions with a pulsed hydrogen inlet, electrostatic lenses, a tandem high-voltage accelerator and a 630 kV voltage source. With the help of a pulse valve, hydrogen enters the ion source, an electric arc is ignited, which leads to the formation of plasma. The electrostatic lens draws negatively charged hydrogen ions and electrons from the plasma. Electrons are discarded by a separator. Hydride ions enter a tandem accelerator, where they are recharged on a carbon film. Then, protons accelerated to 1 MeV are injected into the synchrotron. The voltage for the tandem accelerator is produced by a cascade generator.

1.2. The Injection Channel



1.3. The Synchrotron

The synchrotron serves to accelerate the proton beam from the injection energy to the required energy in a given range. The synchrotron provides a high rate of particle acceleration equal to 250 MeV per 0.5 s.

The magnetic system of the synchrotron is formed by four identical quadrants, separated by large free gaps. Each quadrant is formed by four C-shaped iron blocks with parallel poles. Four magnets with a homogeneous field of each quadrant are arranged in a pairwise common winding.

1.3. The Synchrotron

To simplify the design of the accelerator and reduce its dimensions, separate focusing elements are excluded from the magnetic synchrotron system, and edge focusing is introduced into the rotary magnets, which is provided by cuts of magnets from the side of the free gaps. One of the main advantages of this magnetic system is the low power consumption compared to analogues.

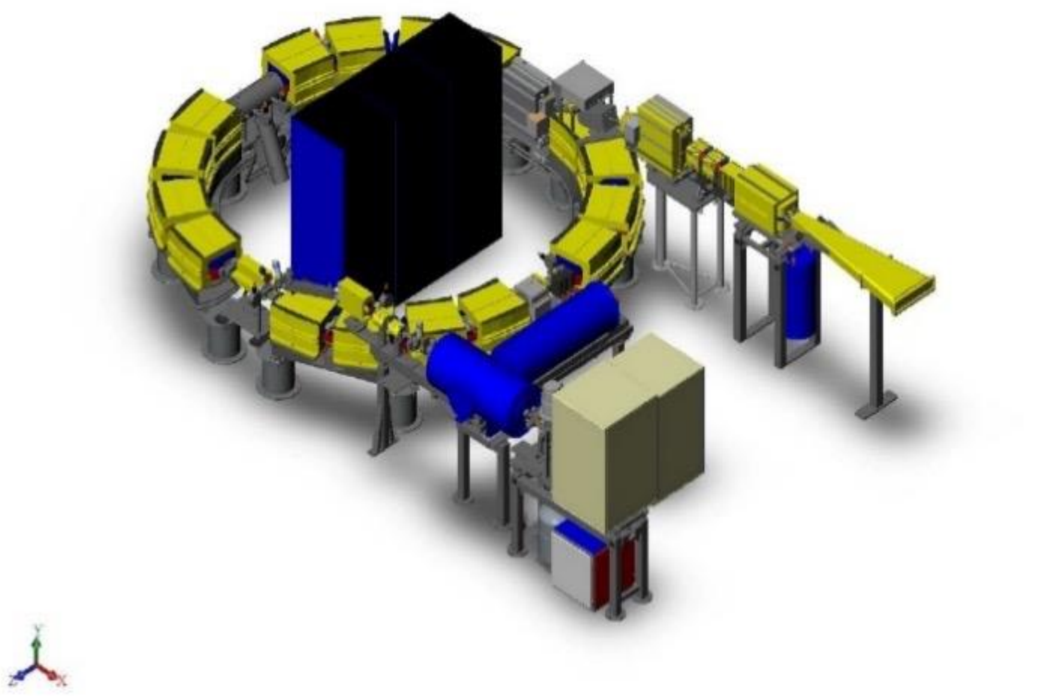


Fig. 1. The proton therapy complex “Prometheus”

1.3. The Synchrotron

During the calculation period, measurements of the power consumed by the magnetic system were made. The average value is 30 kW. The results integrated for each patient are shown in the diagram (Fig. 2). The average value of the energy consumed for the full course of treatment of one patient is 56.8 kW·hr.

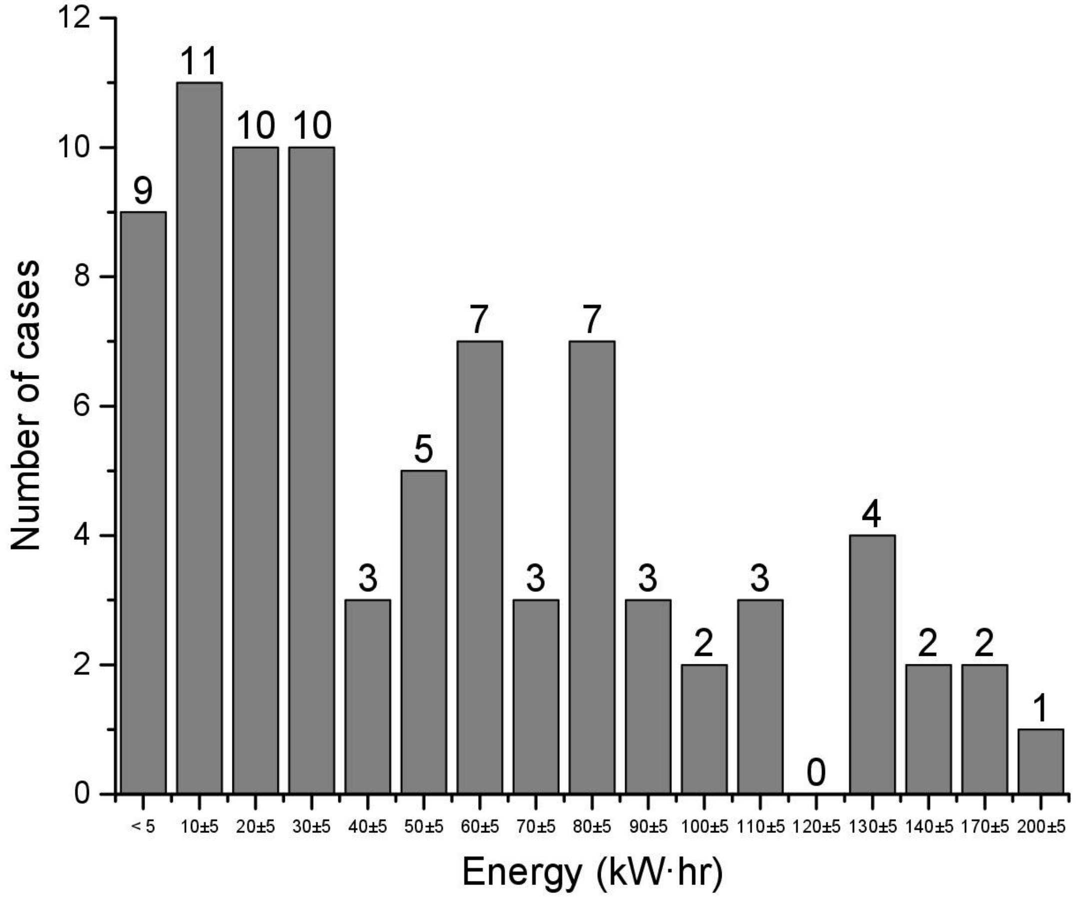
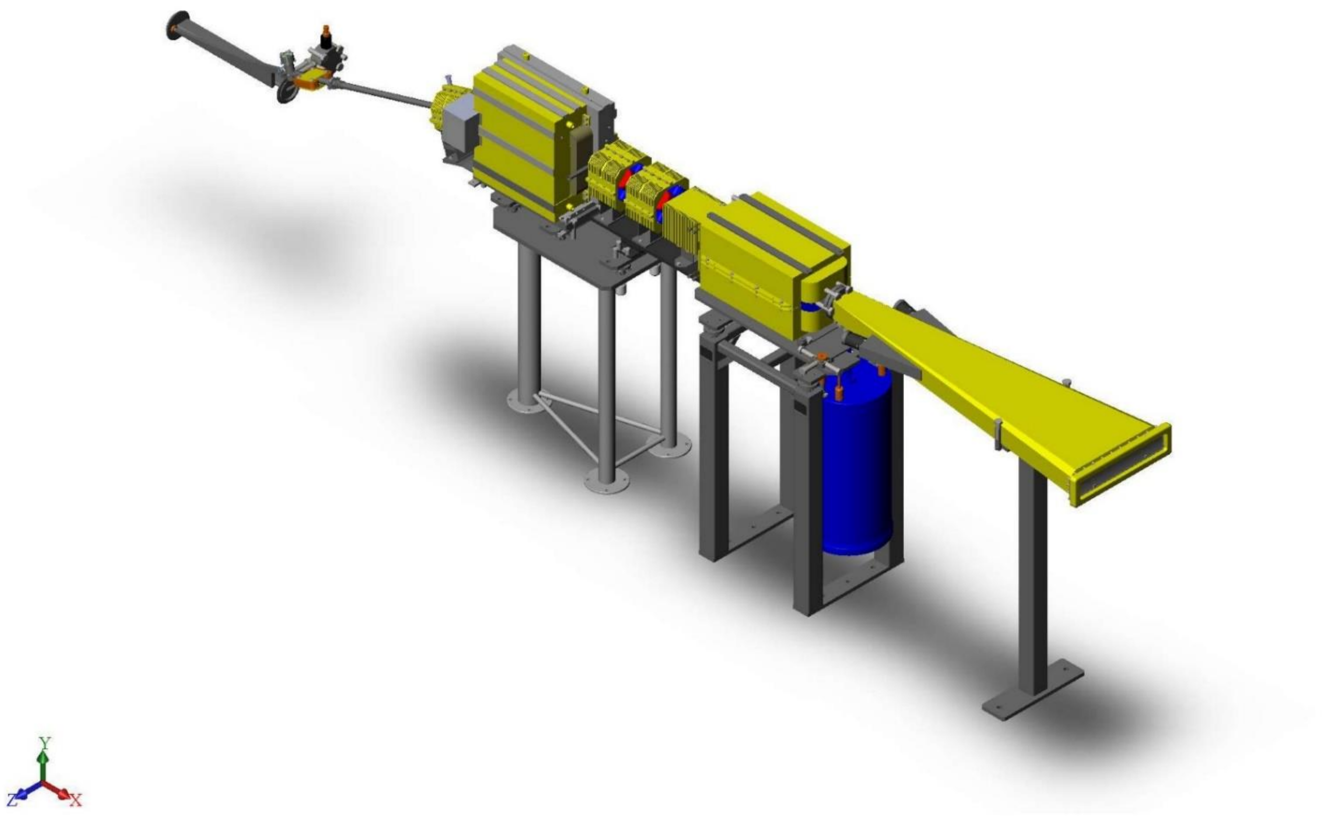


Fig. 2. The diagram of the consumed energy for the complete treatment course of one patient

1.3. The Synchrotron

1.4. The Extraction Channel

The beam extraction from the synchrotron occurs according to the following scheme: the buildup of betatron oscillations is initiated with subsequent scattering by the internal target, the beam enters the electrostatic deflector from the changed orbit, where it is radially thrown from into the discharge magnet. In the channel, the focusing lenses and the position correcting magnets are installed. Observation of the beam is carried out from the phosphor-coated screens using the system of visual control. The area of active beam scanning on the target is 90 mm × 700 mm.



1.5. The Patient Immobilization System

The system includes an armchair designed to fix the patient and move him to the irradiation zone, an x-ray unit represented by a small-dose X-ray tube and a digital X-ray panel (detector). With their help, the X-ray photographs are taken with a subsequent process of reconstructing them into a three-dimensional image for subsequent irradiation planning. The individual radiograph mode has been put into place in order to verify the patient's position before the start of the treatment.

1.5. The Patient Immobilization System

Fig. 3. Patient Immobilization System.

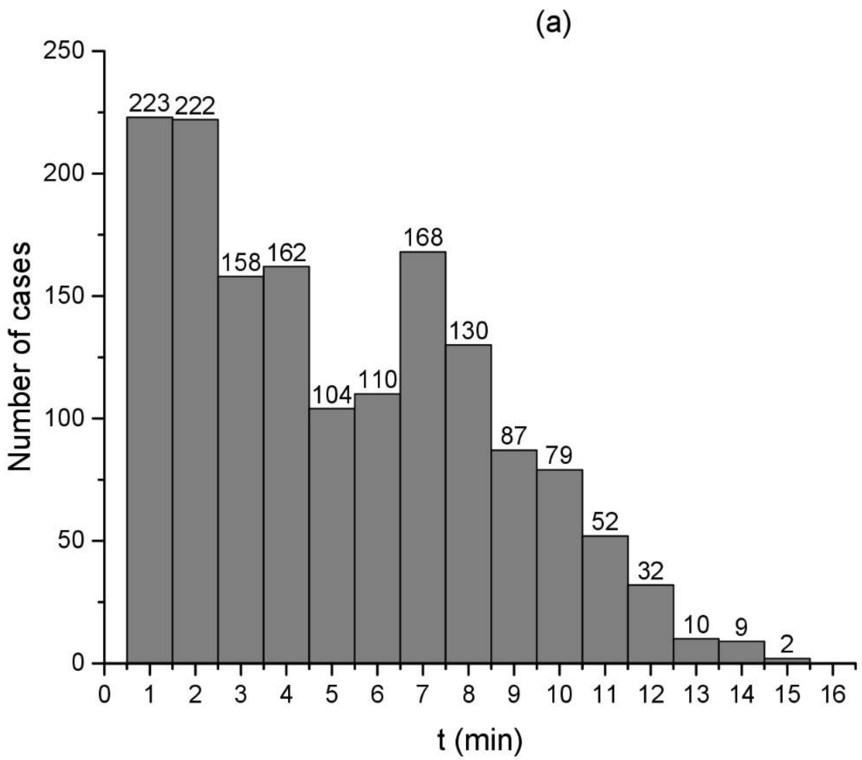
1.5. The Patient Immobilization System

2. SOME CHARACTERISTICS OF THE TREATMENT PROCESS

2.1. The Irradiation Time of a Patient.

An important characteristic of PTC is the presence of the patient in the immobilizing device. It is believed that the duration of a single therapy session should not exceed several minutes in order to minimize accidental patient movements. In real conditions, the irradiation time has not exceeded 15 minutes, and the average time was 5 minutes 39 seconds, which easily meets the accepted standards. There were 1548 fractions for 84 patients.

2.1. The Irradiation Time of a Patient.



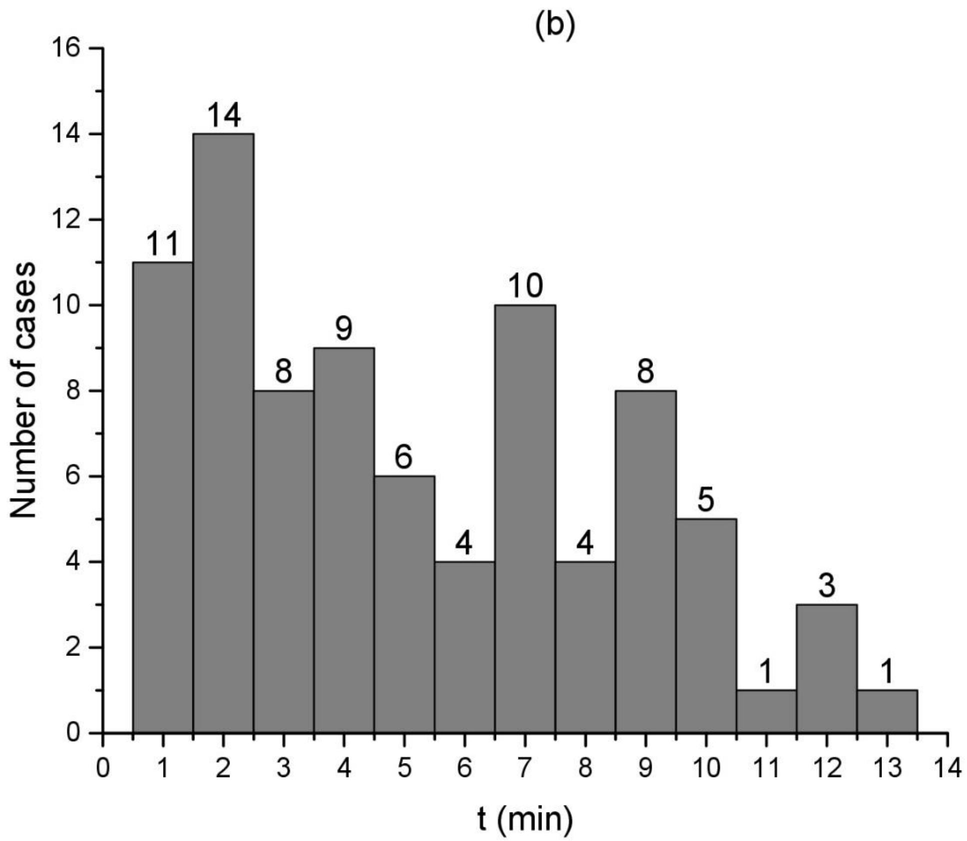
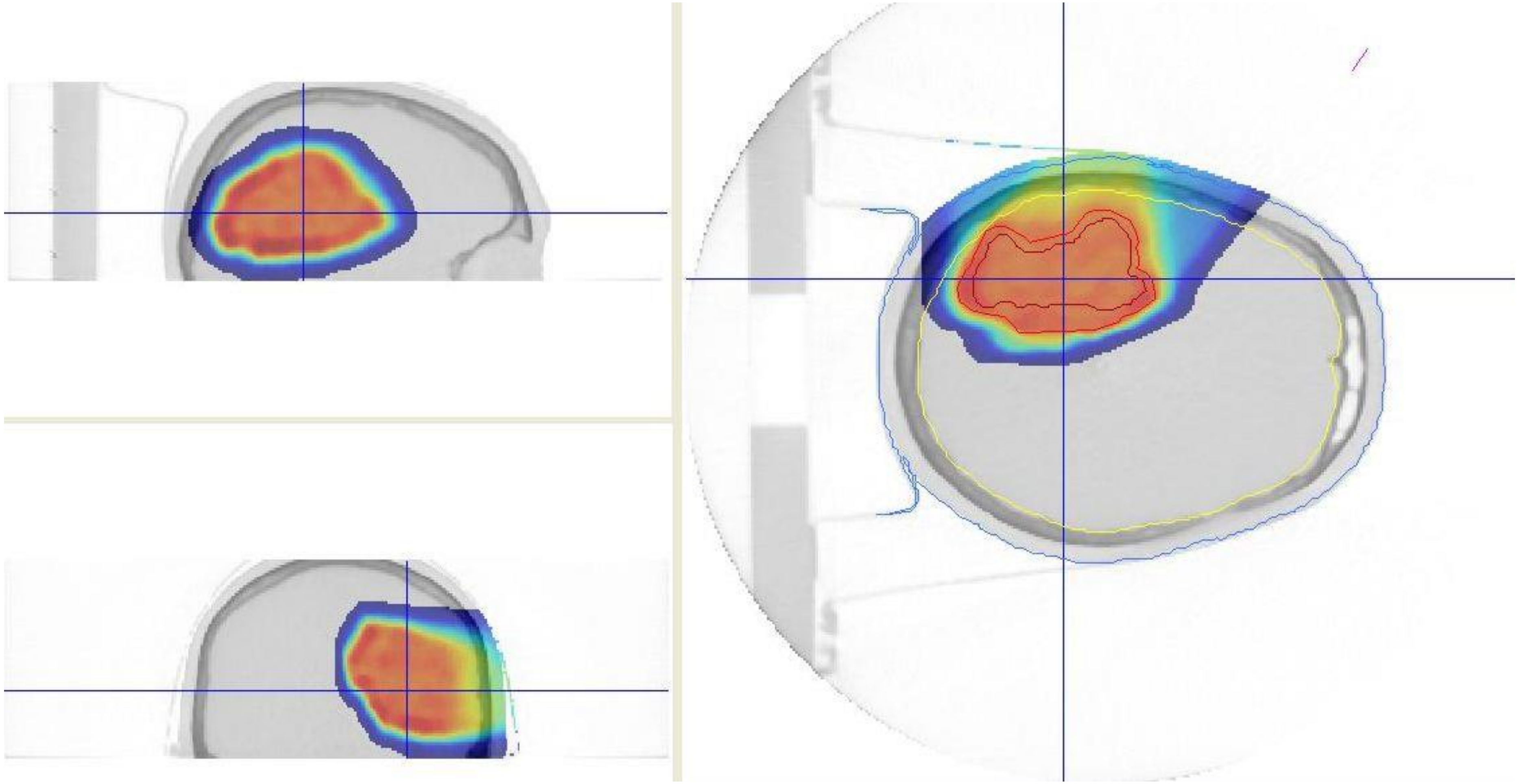


Fig. 4. Diagram of the irradiation time of one fraction (a).
Diagram of the average patient irradiation time (b).

2.1. The Irradiation Time of a Patient.



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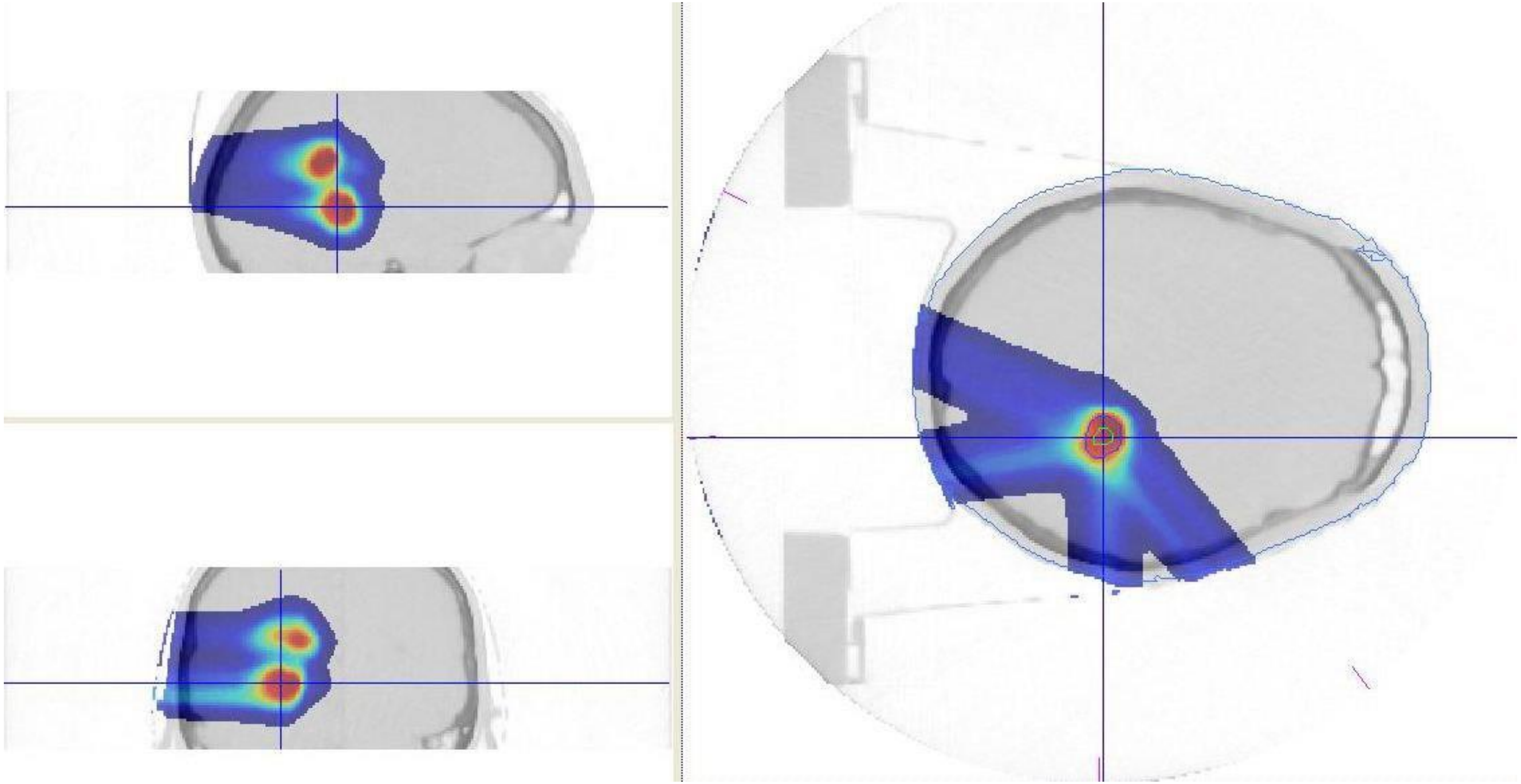
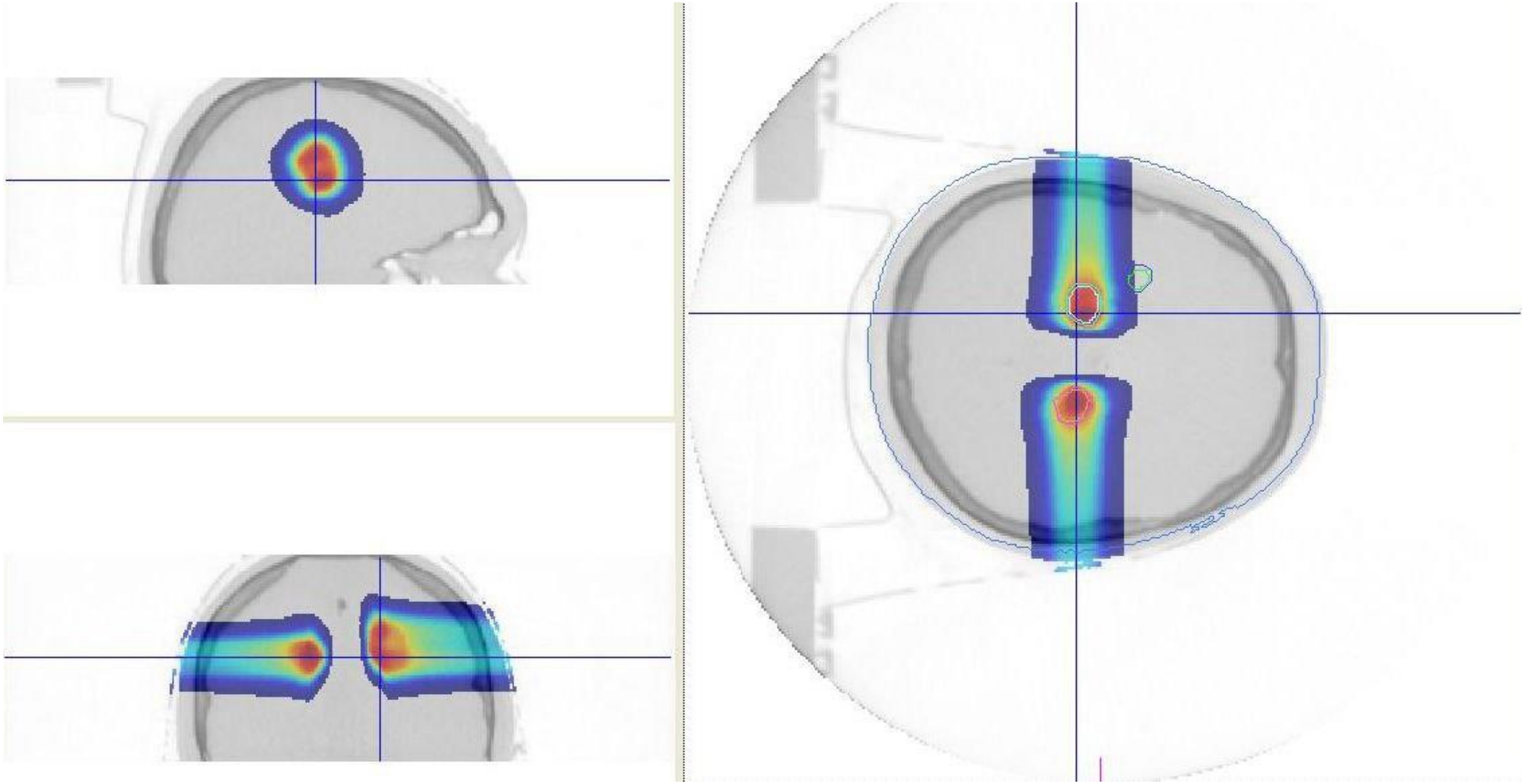


2.1. The Irradiation Time of a Patient.



2.2. Number of particles per one irradiation session

At first, it was necessary to prove that, in comparison with cyclotrons, the low intensity of the beam in the ring would be sufficient to conduct a radiotherapy session within the necessary time. Due to the high efficiency of the beam output from the accelerator, it was possible to achieve an average current value on the target for the entire energy range 0.3 - 1.1×10^9 prot./cycle. The standart cycle time is 2 s. The actual number of particles delivered to the tumor for each patient on average is shown in Fig. 5.

Average number of protons per one session is 9.1×10^{10}

2.2. Number of particles per one irradiation session

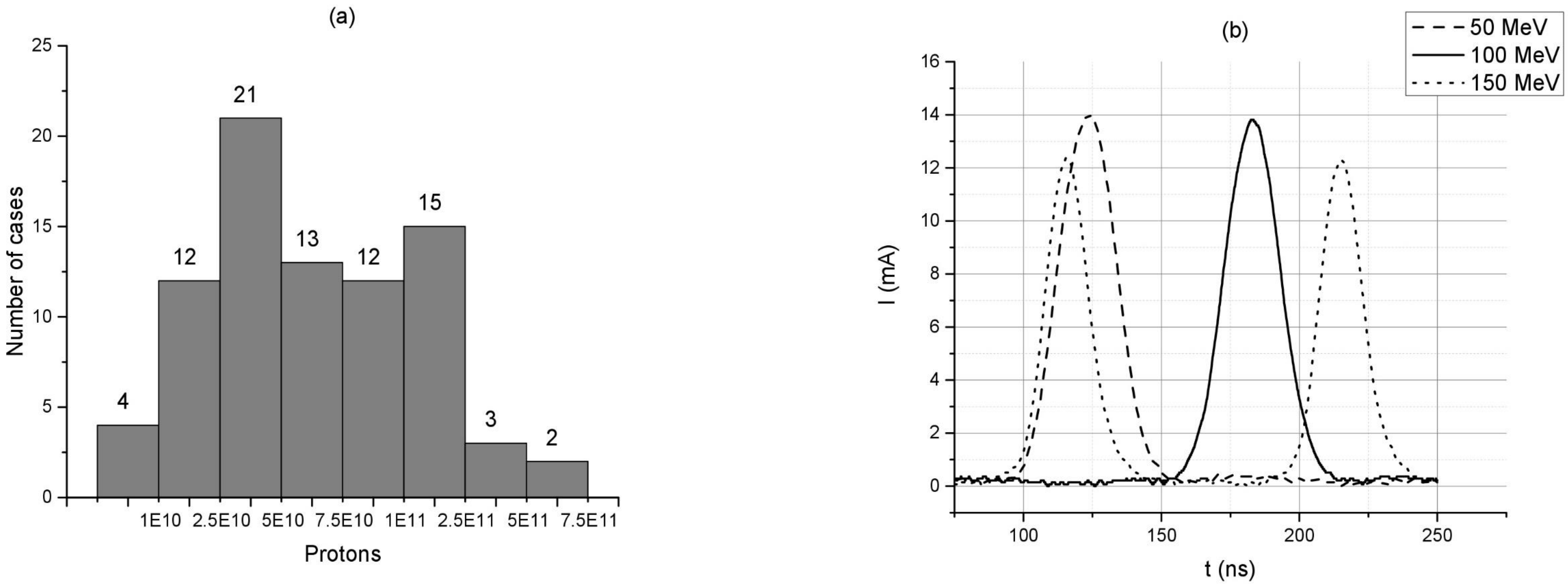
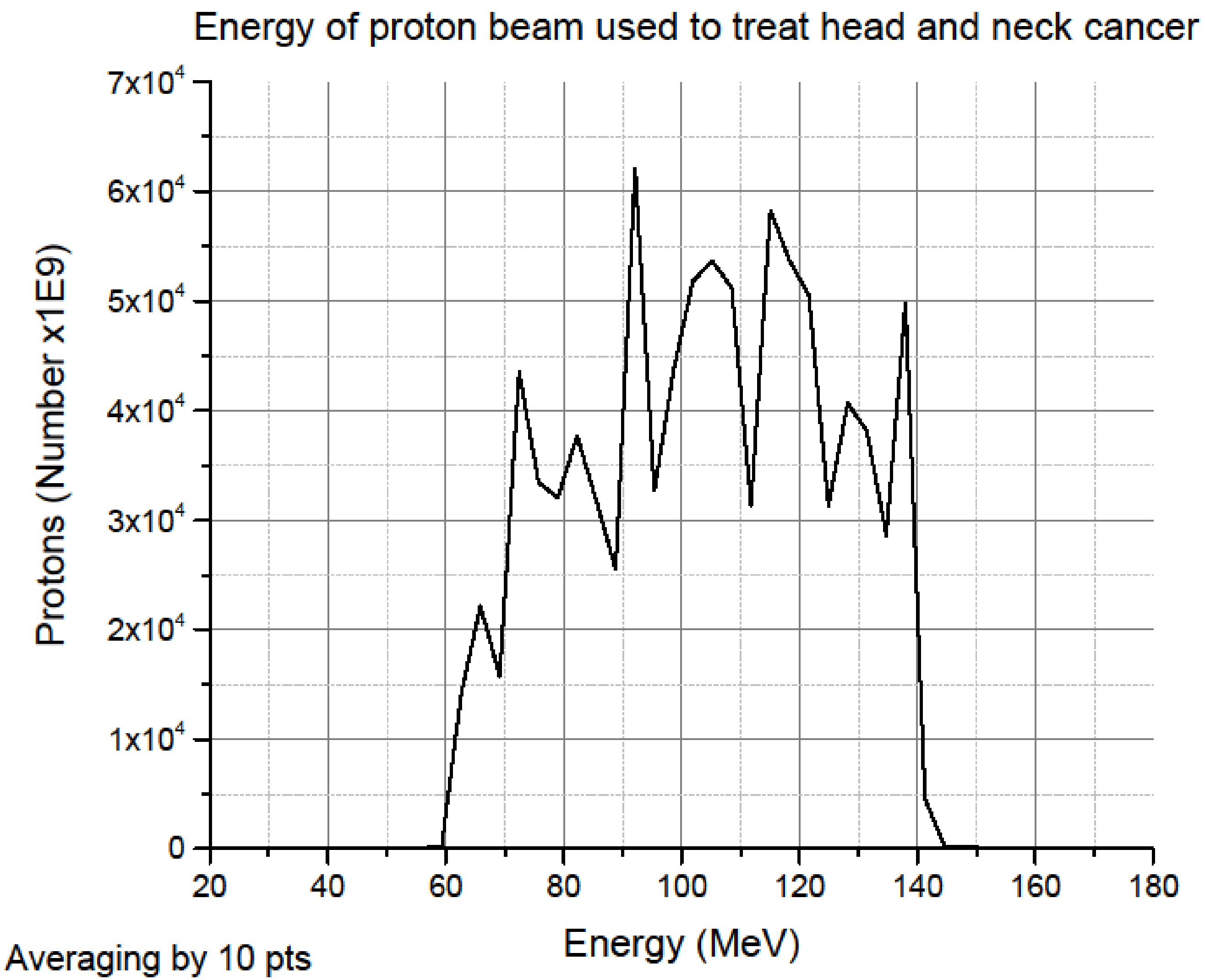


Fig. 5. Number of particles necessary for one fraction (a). The beam current in the accelerator at the time of inference (b).

2.2. Number of particles per one irradiation session



Averaging by 10 pts

2.3. Tumor volumes in case of head and neck cancer

It is believed that proton therapy is mainly used on neoplasms of small volumes (several dozens of cubic centimeters). Experience gained on PTC allows us to state the efficiency of the complex for the treatment of tumors of a much larger size. The average size of tumors was 155 cm^3.

2.3. Tumor volumes in case of head and neck cancer

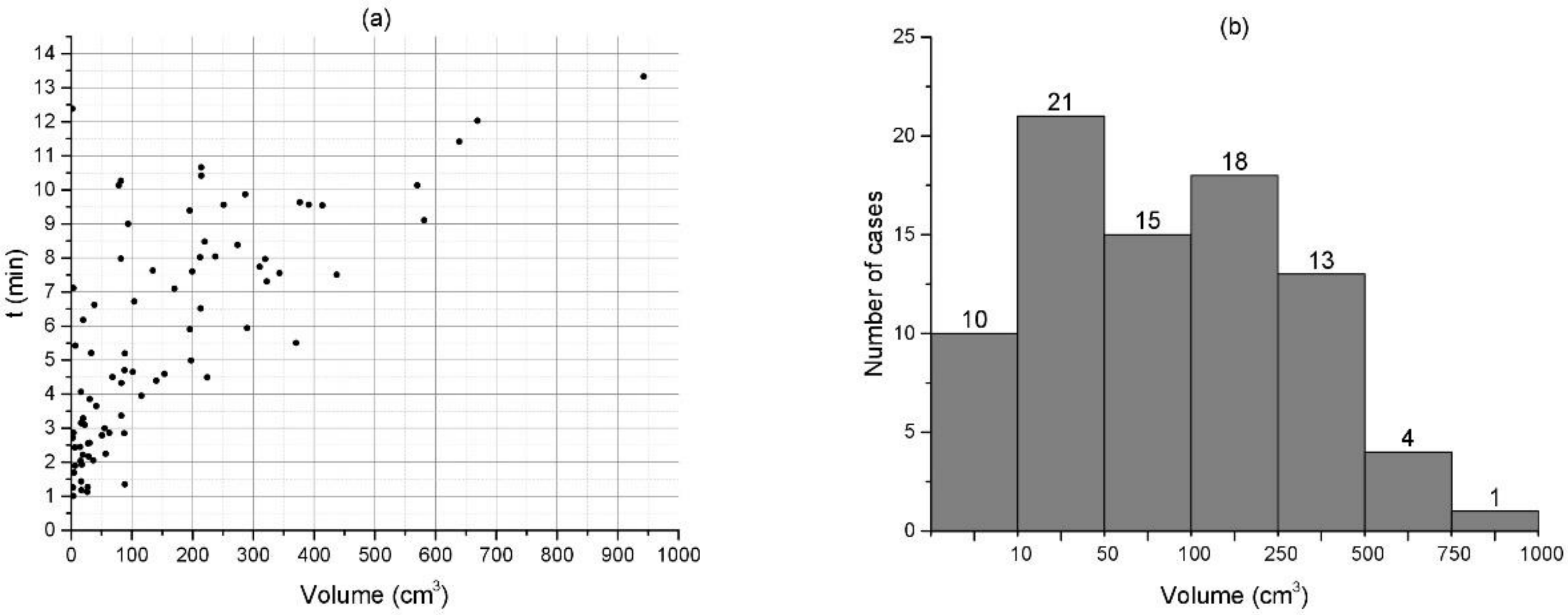
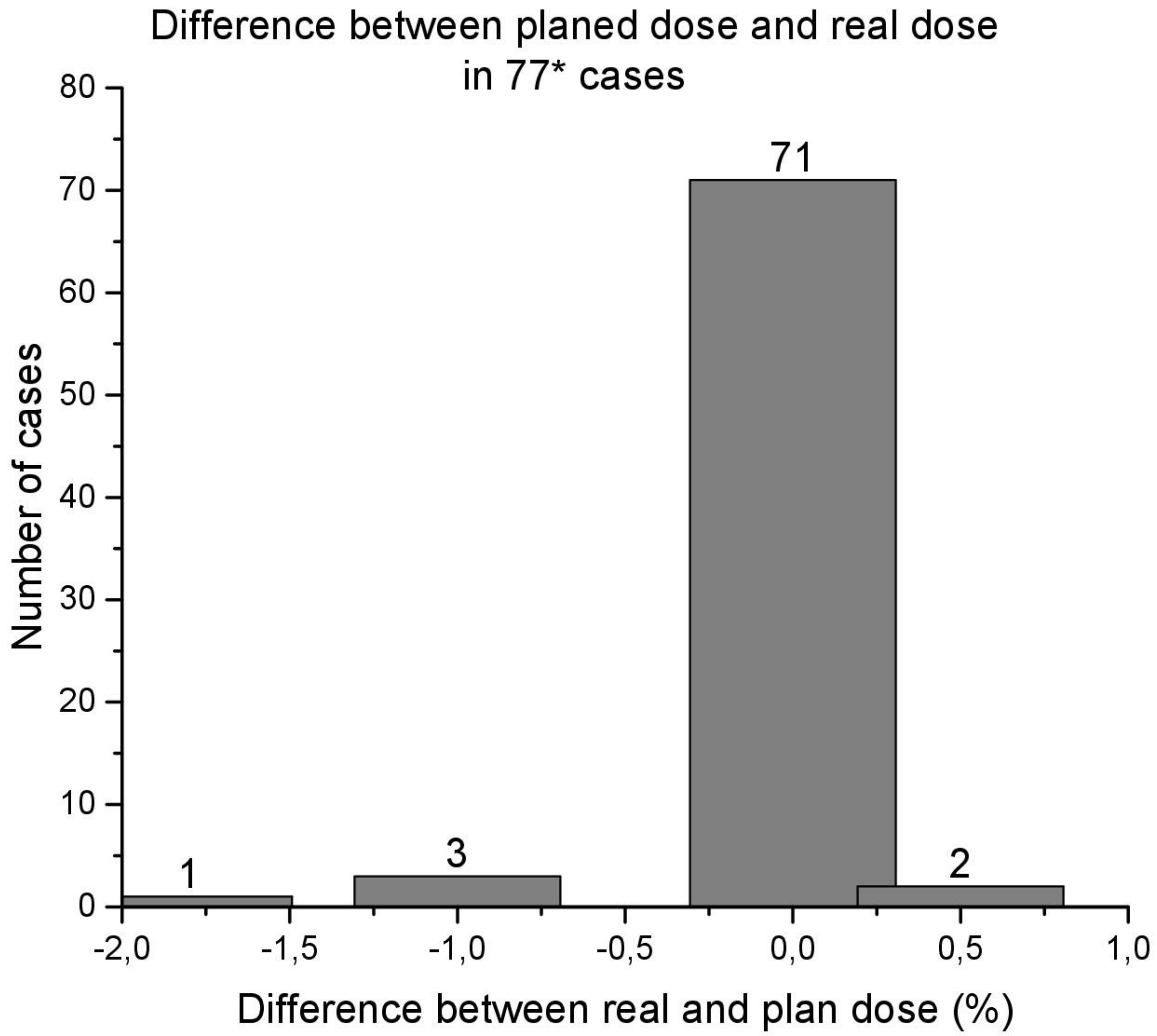
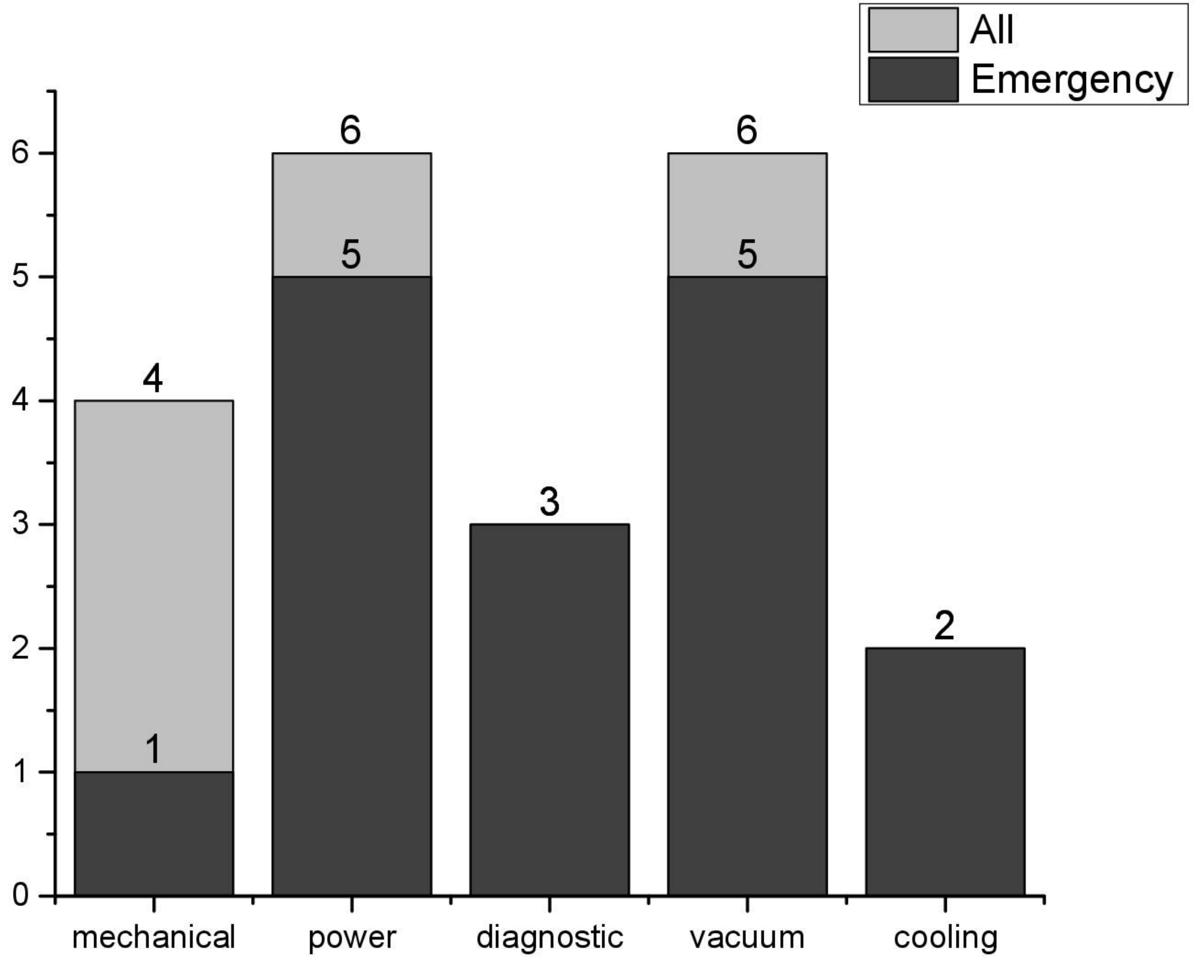


Fig. 6. Volume-time distribution (a). Diagram of the volumes of tumors that underwent the therapy (b).

2.4. The accuracy of dosing



2.5. Repair schedule



- 2 cases of cancellation of treatment
- 2 cases of delayed treatment

3. ANALYSIS OF THE RESULTS OF TREATMENT

Analysis of the results of treatment

About 40 patients have a follow-up of sufficient duration (from 3 to 10 months) necessary for making preliminary conclusions about the results of the therapy. Acute radiation toxicity has not exceeded degree II (radiodermatitis III, mucositis I-II).

Analysis of the results of treatment

Table 2. Treatment results for 40 patients.

Change in tumor volume after a course of PT			Number of cases
CR	Complete response	Decrease >70%	25%
PR	Partial response	Decrease 20-70%	27,5%
SD	Stable disease	Decrease <20%	37,5%
PD	Progression disease	Increase	10%

Analysis of the results of treatment

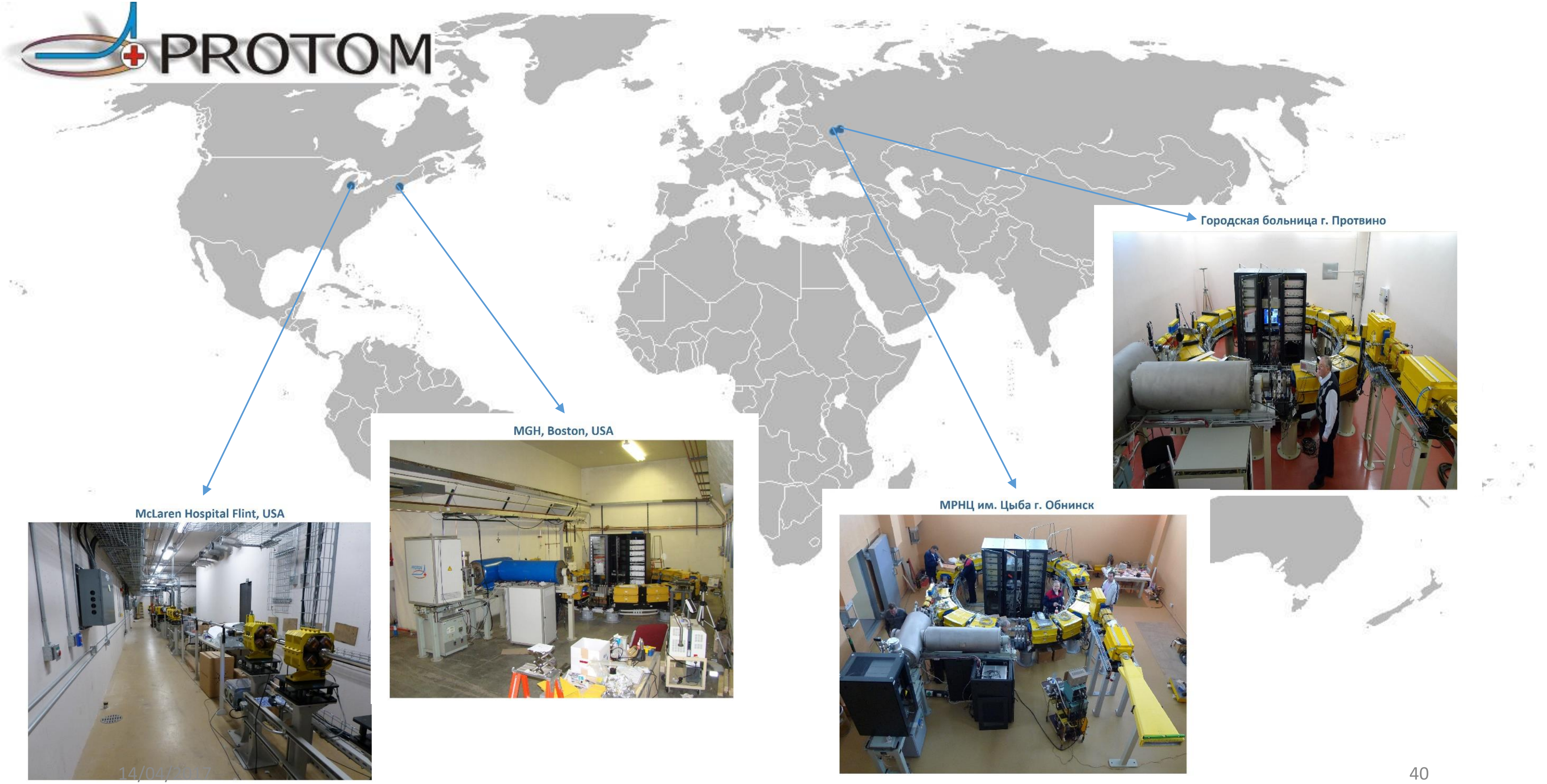
Table 3. Types of tumors affected by PT.

Types of tumors	Results of treatment			
	CR	PR	SD	PD
Meningioma	1	3	10	
Metastases	1		1	
Glyoblastoma		1		3
Neurostezioblastoma	1			
Astrocytoma	1	2	1	1
Adenocarcinoma	3			
Estesioneuroblastoma		1		
Hemangiopericytoma	1			
Skull Base Chordoma			2	
Pituitary adenoma		2	1	
Cancer of the salivary gland	1	1		
Flat cell carcinoma head and neck	1	1		
Total:	10	11	15	4

SUMMARY

Summary

Thus, PTC "Prometheus" has proved to be efficient and reliable in the year of clinical use in the treatment of head and neck cancer. If there is a developed infrastructure, the capacity of the facility can go up to more than 700 people a year. The low weight, low power consumption and compact dimensions of the complex allow it to be placed in ordinary hospitals, without constructing separate buildings. In addition to that, PTC “Prometheus” was licensed to irradiate the entire human body in March 2017. Therefore, this complex is by far the only Russian development capable of solving the problem of proton therapy at the country level.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Thank you for your attention

And many thanks to my colleagues for helpful input:

V. Balakin, A. Bazhan, T. Shchepchuk, D. Korobov, N. Strelnikova.

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BACK-UP SLIDES

PTC