PROTON RADIOSURGERY AT THE PNPI SYNCHROCYCLOTRON

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1. Introduction

Radiosurgery is a one-time exposure of small pathological formations to high doses of radiation. Since April 1975, it has been systematically carried out at the PNPI synchrocyclotron medical proton complex SC-1000. The exposure technique is described in detail in Refs. [1, 2]. In total, 1386 patients have received a stereotactic radiosurgery by January 1, 2013.

Several upgrades of the installation, as well as of its system to control the exposure parameters, have been performed during 40 years of operation of the Pilot Medical Proton Complex (PMPC). In 1990, a lock-head device of the third generation was built, and the process to control the exposure parameters was computerised. In 2002–2004, with the support of the Government of Leningrad region, the PMPC was upgraded. In particular, new systems for monitoring the supplied doses and scanning, as well as for controlling the proton beam parameters, were built, some worn-out elements were replaced, and the automation of the beam output was performed.

2. Modernisation of the medical proton complex

In the period after 2005, the worn-out measuring systems were replaced, the software was changed, and some work to ensure the reliability of the system operations was carried out. In particular, to ensure the stability against noise, a photocoupler isolation of the local manual control of the installation for the exposure of patients was added.

A new temperature control unit was fabricated in the installation for the thermoluminescence dosimetry, which also increased the reliability of its operation.

The performance of the TLD-100 detectors of the “Harshaw” company was studied with respect to the parameters presented below, with the aim to use these detectors in clinical dosimetry instead of LiF detectors.

2.1. Dependence of the light yield on the radiation dose

One can see in Fig. 1 that the obtained data are in good agreement with those in the literature.

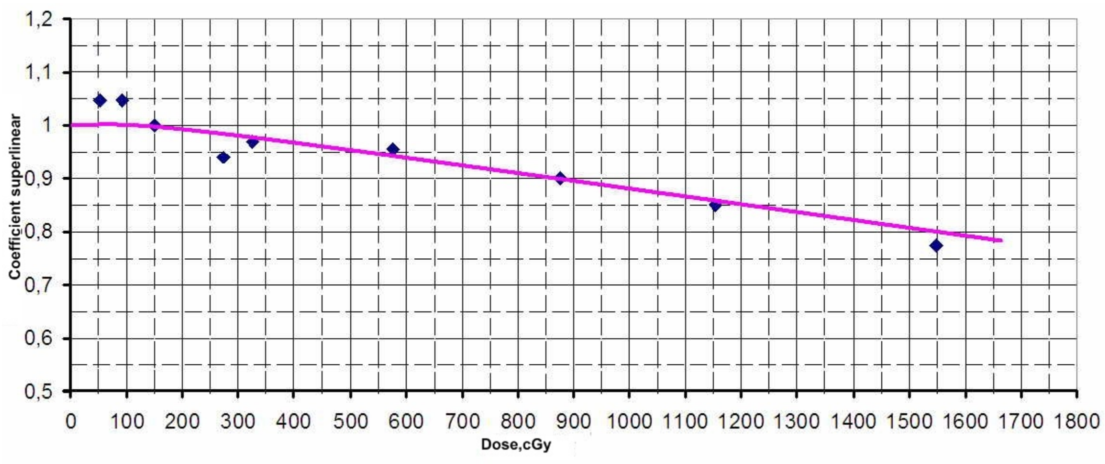


Fig. 1. Superlinearity curve for the TLD-100 detectors

2.2. Spontaneous loss of the information on the accumulated dose over time

Such a characteristic as the loss of the detector information (fading) is very important. While fading occurs even in normal conditions, its influence can be reduced by using special modes of the TLD preparation to reading, *e.g.*, by their pre-exposure to certain temperatures for a certain time. Providing that the reading regimes are standard and preparing them to be read, one can apply the corrections for fading, which is a function of the time passed after the previous reading or the moment of exposure. The results of the fading effect are given in Fig. 2.

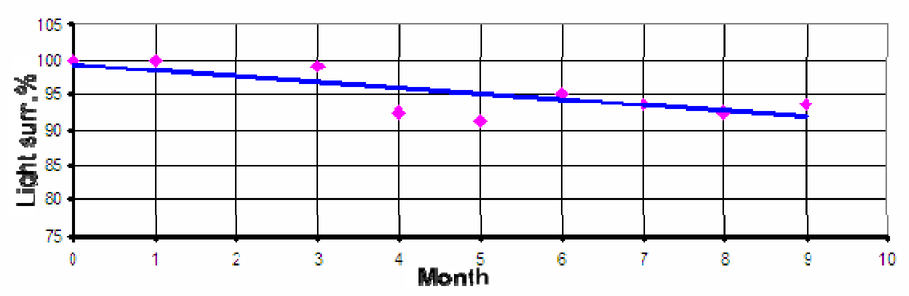


Fig. 2. Information loss of the irradiated TLD-100 versus the storage time

For the TLD-100, the fading for the first three months (the typical control period) was about 3 %. After the period of four months, the fading did not exceed more than 7.5 %. The obtained results are in good agreement with the published data on the dependence on the storage time of the information loss of the irradiated TLD.

2.3. Reproducibility of dosimeter readings

In clinical dosimetry, including the construction of dose distributions and fields, the reproducibility of the detectors – the ability of the dosimeters to show the same value of a dose in the same experimental conditions – is very important. For clinical dosimetry, the detectors are considered to be acceptable when the difference in readings of two measurements does not exceed 5 % (2 divisions on the device frame). The number of suitable TLD-100 detectors with the difference in readings between the first and the second measurement equal to 0, 1, 2 divisions was 155, or 78.7 % of the total number (197) of the detectors (Table 1).

Table 1

Reproducibility of dosimeter indications

Difference in the dosimeter readings between the 1-st and 2-nd measurements	Number of TLD	% of the total number
0	41	20.8
1	61	31
2	53	26.9
3	23	11.7
4	12	6.1
5	3	1.5
6	1	0.5
7	2	1
9	1	0.5
0–2	**155**	**78.7**

2.4. Dose measurements and construction of the dose fields and distributions

Two cassettes *XY* and *ZY* with the thermoluminescence detectors (by the “Harshaw” company) were prepared to measure the doses and to construct the dose fields. The measurements were performed using a homogeneous phantom of the human head made from plexiglass in the shape of a sphere of 160 mm in diameter. Before the irradiation, the phantom was centred on the rotation pole. During the period of the irradiation, the loch-device made 14 passes over ± 36º, the treatment table – 14 passes in one direction, the radiation dose being 6.56 Gy.

The calculations were made using Microsoft Office Excel, and the dose distributions and the dose fields were built in the PUSK application hosted inside MATLAB 5.5.0. The flowchart of the application used to build the dose distributions and fields is given in Fig. 3.

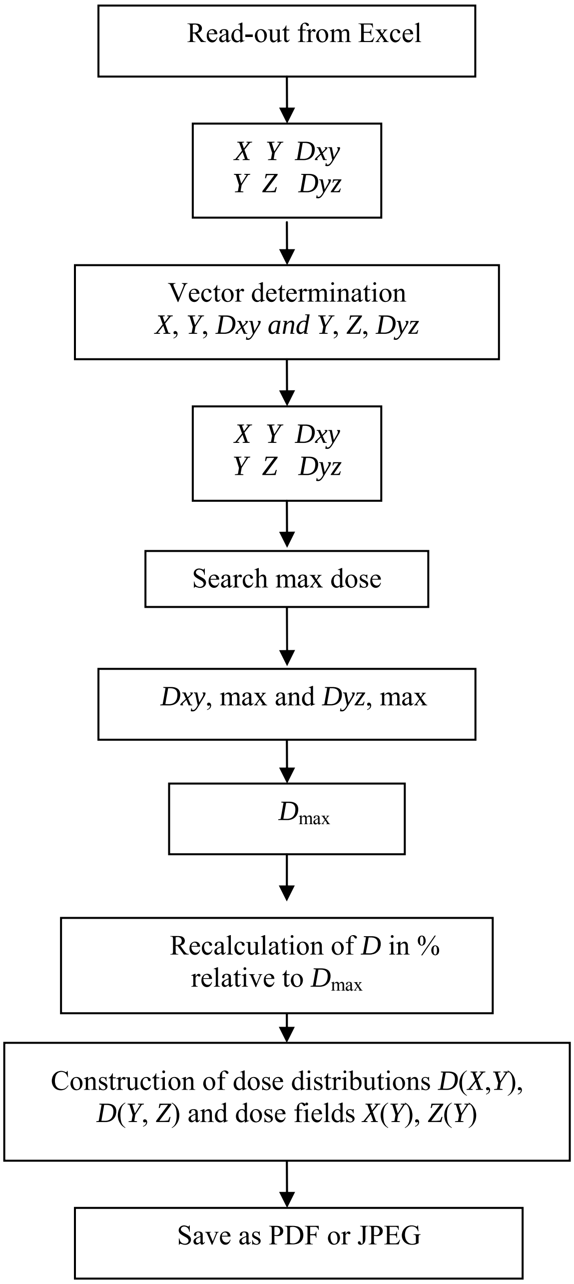


Fig. 3. The flowchart of the used application

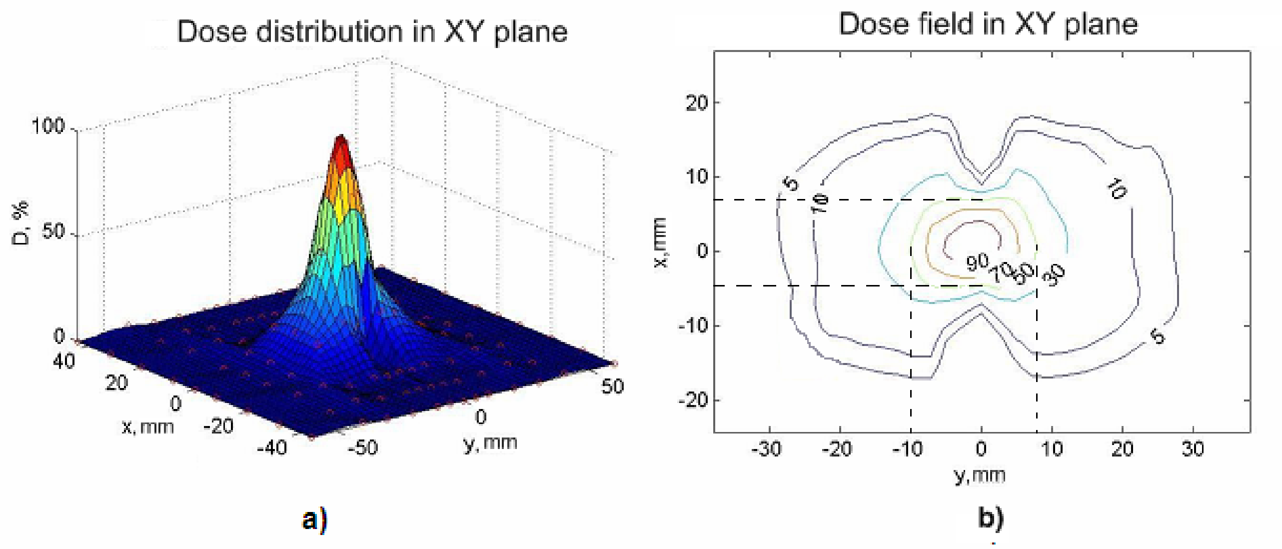


Fig. 4. Result of the PUSK application. a – the dose distribution and b – the field in the *XY* plane with mobile proton beam irradiation. The beam dimensions are $\Delta x = 12$ mm and $\Delta y = 18$ mm

The result of the PUSK application is presented in Fig. 4a, b, which shows the result of the connection to 50%-isodoses of two fields with the dimensions $\Delta x = 6$ mm, $\Delta y = 8$ mm, $\Delta z = 6$ mm. The docking of the fields is necessary for the irradiation of complex configuration targets, *e.g.*, cerebral ArterioVenous Malformation (AVM). The distance between the centres of the fields is selected according to the form and the size of the irradiation field, which was measured in a tissue-equivalent on the phantom and obtained at mobile proton beam irradiation with the dimensions $\Delta x = 12$ mm and $\Delta y = 18$ mm (50 % isodose). Note that the rotation pole and the phantom centre coincide. The measurements were performed with the thermoluminescent dosimeters that were 3 mm in diameter and 1 mm thick. Such a representation of the depth dose field clearly shows a high degree of localization of the absorbed energy in the centre of rotation.

3. Proton radiosurgery

The experience of proton radiosurgery performed at the SC-1000 is summarized in Table 2.

Table 2

Proton radiosurgery of FSBI RSCRST at the PNPI synchrocyclotron from 2007 to 2012

Irradiation of pituitary – hypophysectomy	50
Pituitary adenomas	12
Mammary cancer	18
Prostate cancer	20
Irradiation of brain	10
Arteriovenous malformation	10
Total Of these repeated	60 2

In detail, in the cases of prolactin-secreting adenoma, clinical remission was observed in 80 % of the patients and stabilization – in 15 % of the cases. 21 female patients could become pregnant and gave birth to healthy children (4 patients – twice). The complete clinical remission was observed in 92 % of the Icenko – Cushing's disease cases and, in the long-term period, this figure was equal to 96 %. This was manifested in disappearance of the diabetes, normalization of the blood pressure and regression of the pathological obesity. In the long-term period, the sustained recovery and full normalization of the growth hormone was observed in 86 % of the patients with acromegaly. In this case, the overwhelming majority of the patients were not marked by development of the secondary hormone deficiency. The clinical cure with hormonally inactive adenomas was 95 %. The treatment with the proton irradiation did not cause any serious threatening complications.

Figure 5 shows photographs of a patient before and after the irradiation. The patient had the Icenko – Cushing's disease causing obesity, diabetes, high blood pressure, calcium loss from bones, fractures, and impotence. The results of the proton therapy speak for themselves: 2 years after the therapy – the blood pressure became normal, there was no diabetes, the patient had daily 2 km runs; 3 years after the therapy – the patient got married; 4 years later – he became father.

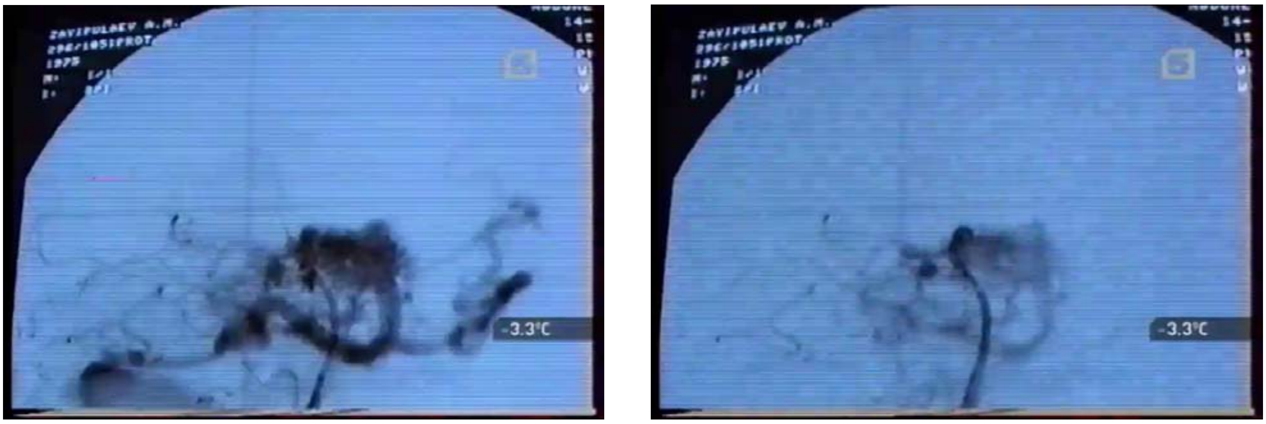
Fig. 5. Patient before (left) and after (right) the irradiation

Figure 6a shows the arteriovenous malformation of patient L., who previously had a stroke, before the Proton Therapy (PT) and 3 years after the PT. Figure 6b shows patient L. after the PT.

A year after the proton therapy, L. had a child and moved to a village to work as a postman. She drives a car and gives an interview to a TV reporter.

Our work is still in progess…

a)



b)

Fig. 6. a – the AVM of patient L. before the PT (left) and the AVM of this patient 3 years after the PT (right); b – patient L. several years after the proton therapy

References

1. N.K. Abrossimov *et al.*, Abstracts of XI Meeting on Applied Accelerators (ICAA 05), SPb. (2005).
2. N.K. Abrossimov *et al.*, Synchrocyclotron Journal of Physics: Conference Series **1**, 424 (2006).