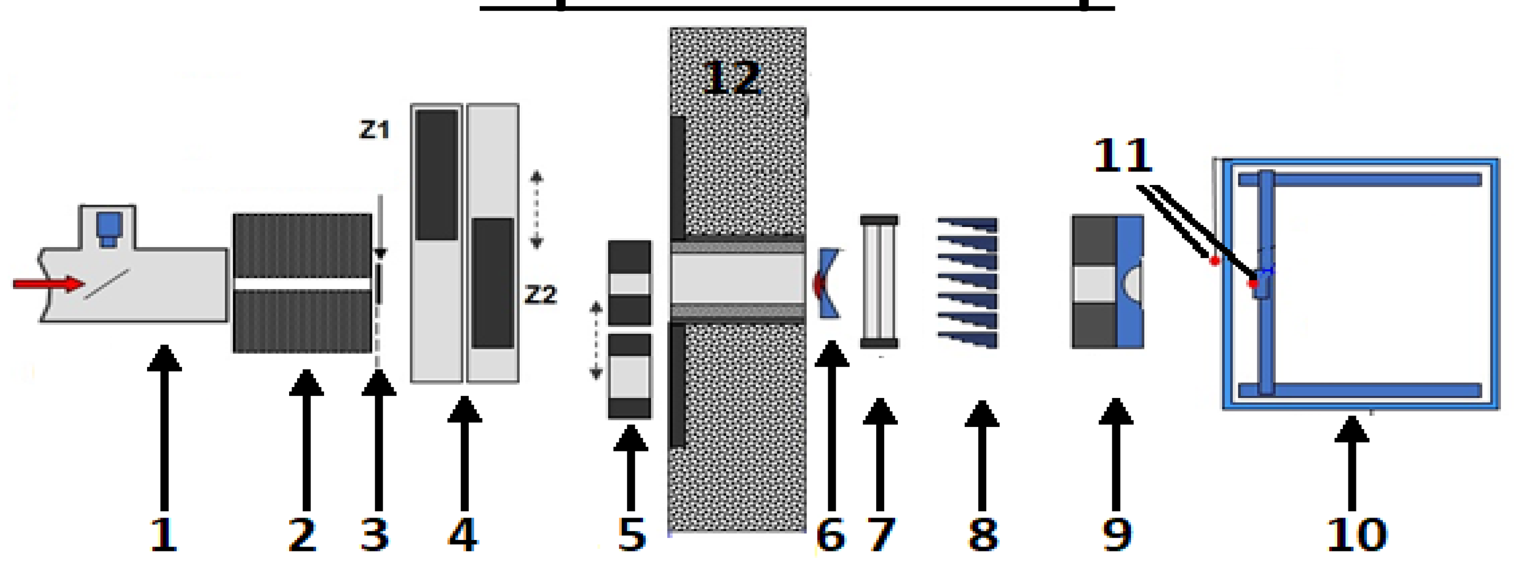
Designing the medical set-up of the proton beam of the Institute for Nuclear Research of the Russian academy of sciences

S. V. Akulinichev, Yu.K. Gavrilov, I. A. Yakovlev
INR RAS, Moscow (Troitsk)

Introduction

The Institute for nuclear research (INR) of the RAS is conducting research on methods for creating **a system of therapeutic dose formation** on the basis of a proton linac. This accelerator is very promising for the research of a new effective technology of irradiation – flash therapy [1,2], when the tumor is irradiated with ultrashort powerful pulses of radiation. For example, our linac allows to reach values of pulse dose rate of the order of 1 MGy/s. The existing beam formation system of the INR is based on **passive proton scattering**. The profile, energy spectrum and depth-dose distribution of the therapeutic beam are determined by a **double scattering system**, as well as a set of **collimators**, **boluses** and proton **energy modulators** [3]. The calculation of the forming devices is made by analytical methods with subsequent verification of the beam tracing by programs that implement algorithms of the Monte Carlo method. On the basis of one of these programs – SRNA [3] we developed an original program for the calculation of designs of energy modulators - **ridge filters**. As a result of the research, a beam formation installation was assembled, which allows to adjust to the current parameters of the initial beam of the INR linac. The system of formation of a therapeutic proton beam in a wide range of parameters of these beams was tested. The results of the experiments showed their good compliance with the preliminary calculations.

Experimental set-up



1 – proton channel;
2 – graphite collimator;
3 – first scatterer (S1);
4 – beam locks;
5 – beam aperture collimators;
6 – secondary scatterer (S2);
7 – ion chamber;
8 – ridge energy filter (REF);
9 – individual collimator & bolus;
11 – ion chambers in a water phantom (10);
12 – shielding;

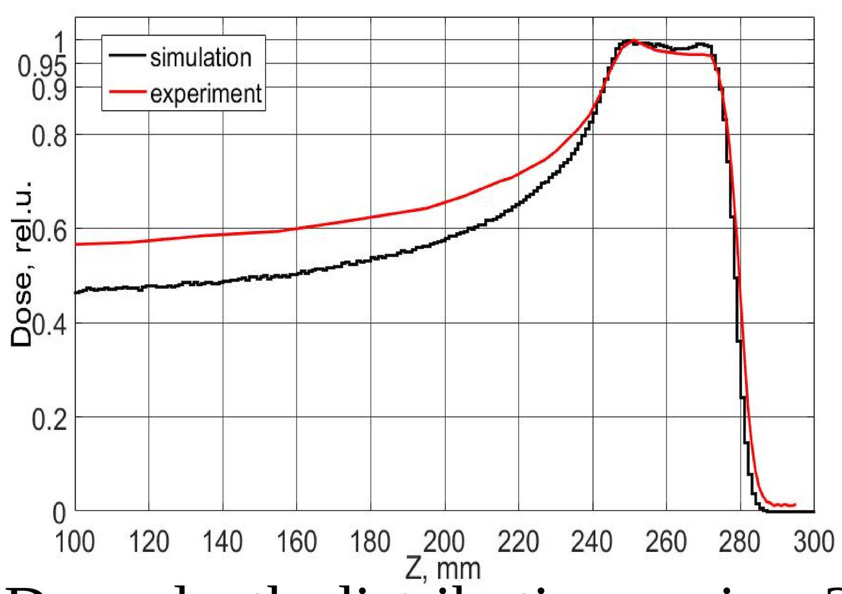
General view of the installation

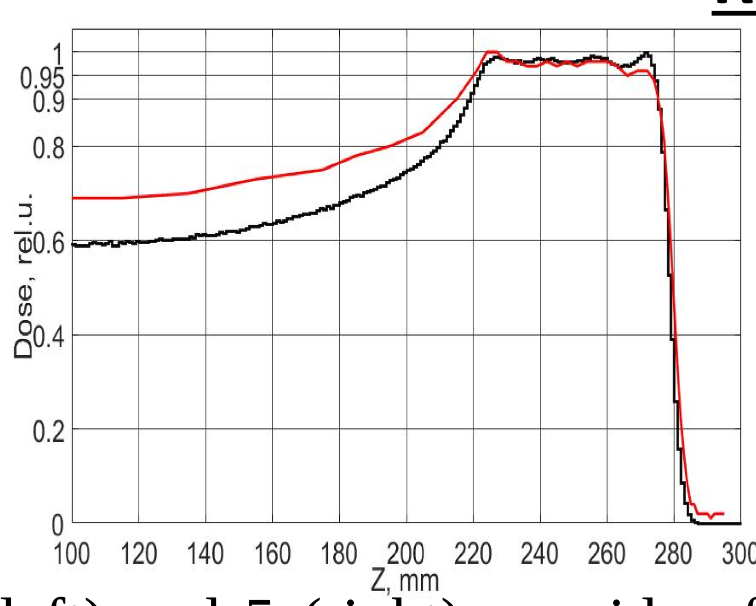
Methods

The system for the formation of a therapeutic beam is conventionally divided into three stages.

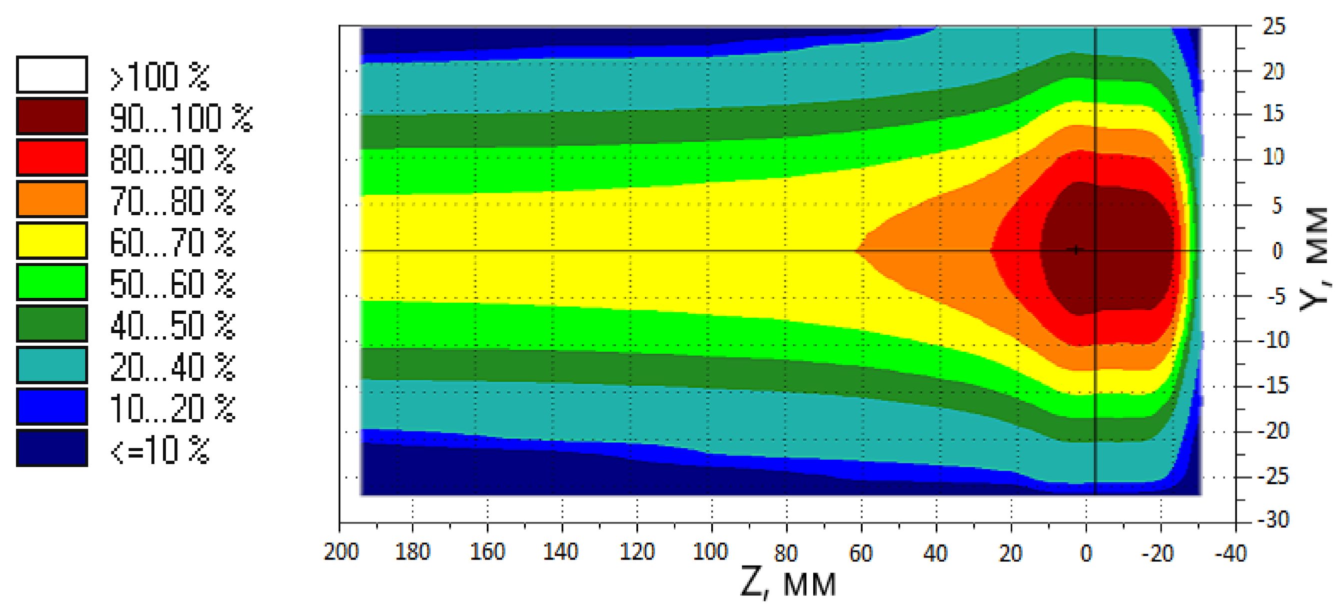
1. At the first stage, the initial narrow monoenergetic beam is expanded by passing through a double scattering system consisting of two scatterers combination. To calculate these elements, the NEU [4] program was used.
2. At the second stage, the beam already formed along the width passes the next element of the system - a ridge energy filter, which changes the energy spectrum and spreads out the narrow Bragg peak of the depth dose distribution uniformly. To calculate the design of the ridge energy filter, the FilterCalculus program was developed and tested. The program uses a mathematical model of beam propagation to determine the geometry of the device and takes into account corrections based on the calculation of the SRNA [3] proton transfer program using the Monte Carlo method;
3. At the last stage, the individual collimator and bolus shape the spatial distribution of the dose.

Results





Dose depth distributions using 3 (left) and 5 (right) cm ridge filters for 209 MeV protons. The calculated distributions obtained as a result of filter simulations in the SRNA program are marked in black. Red color shows the experimental dose distributions.



Spatial dose distribution in the phantom after passing three stages of formation.

Conclusions

The INR linear proton accelerator is a unique tool for research of a new promising irradiation technology-proton flash therapy.
The developed and tested system of passive dose formation allows to obtain uniform dose distributions with the required parameters for biological and medical experiments and with record dose rates.

Literature cited

[1] Favaudon V., Caplier L., Monceau, V. et al, Ultrahigh dose-rate flash irradiation increases the differential response between normal and tumor tissue in mice. Sci.Transl. Med.;6:245ra93 (2014).
[2] Patriarca A., Fouillade C., Auger M. et al, Experimental Set-up for FLASH Proton Irradiation of Small Animals Using a Clinical System, Radiation Oncology; /Volume 102, Issue 3, P. 619–626(2018).
[3] S.V.Akulinichev, R.D.Ilich and I.A.Yakovlev , Conformal proton therapy with passive scattering, Radiotherapy &Oncology (Elsevier) v. 118 (2016), page S2.
[4] Gottschalk B., Techniques of Proton Radiotherapy: Transport Theory, Harvard University arXiv:1204.4470