FIRST RESULTS OF EXPERIMENTS WITH THE EXTRACTED CARBON BEAM AT THE U-70 ACCELERATOR

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Abstract

The scheme of the C ions beam production with energy 455 MeV/nucleon from the U-70 accelerator was described briefly. The equipment facilities for the radiobiology experiments were shown. Experimental parameters of the carbon beam were described. The first experimental results were shown.

INTRODUCTION

Carbon beam program at IHEP has been started at 2001. The goal is to create an Ion beam therapy Center. Project state. For today we have finished:

- Laser based carbon ions source;
- Acceleration of carbon ions in the I-100 linac;
- Transfer line between I-100 and U-1.5 booster;
- Modernization of U-1.5 and U-70 equipment;
- Stable acceleration of carbon ions in U-1.5 and U-70;
- Slow extraction of the carbon beam from U-70 with parameters appropriate for the medical practice;
- U-70 biological shielding was modified to build radiobiological extraction line (Channel #25) in the experimental hall;
- Magnetic elements for the head part of the Channel #25 mounting (four dipoles and four quadrupoles);
- Slow extraction of the carbon beam with 450 MeV/A energy into the temporary radiobiological setup (VRBS) at the Channel #25;
- Three runs of the VRBS with the carbon beam at 450 MeV/A.

Carbon ions are accelerated up to the 450 MeV/A in U-1.5 booster, and then are transferred into the U-70 synchrotron. Carbon beam is not accelerated in the U-70. Carbon ions are collected in the U-70 and then are transferred by means of slow extraction scheme into the VRBS region.

Parameters of the extracted carbon beam and background conditions were measured, and VRBS was qualified for the radiobiological studies.

EXPERIMENTS WITH EXTRACTED CARBON BEAM

Experimental studies with extracted carbon beam at VRBS were done during three last runs of U-70. Water phantom with 3D system of detector movement. This phantom is installed in the VRBS zone. It has 15 mm thick side walls and 30 mm front wall made from polycarbonate. Bragg peak position was measured in this phantom by means of:

- Clinical dosimeter with natural diamond detector;
- Clinical dosimeter with TM-30013 ionization chamber with graphite walls;
- Radiochromic film Gafchromic EBT3.

Thin ionization chambers were used to measure intensity of the extracted carbon beam. These chambers were designed and produced at IHEP. Chamber with 200x200 mm2 cross-section was used for general beam intensity measurements. To measure transversal distribution of the extracted beam density 2D multicellular chamber was used. One cell has 1x1 cm2 size, number of cells is 64 (8x8) wall.

Ionization chambers were calibrated with activation detectors data. Pure carbon discs 40 mm in diameter and 5 mm thickness were used as activation detectors. Detectors were placed on the flange of OM-1 magnet in between OM-1 and OM2 magnets. Measurements data are shown in Table 1.

Table 1: Activation detectors calibration

Date	Particles	Cycling	Intensity by cycle
30.03.2014	Proton E=1,3 GeV	7	$1{,}9x10^{10}$
04.04.2014	Proton E=1,3 GeV	7	$1{,}3x10^{10}$
04.04.2014	Carbon E=455 MeV/nucleon	7	$4{,}5x10^{8}$
21.04.2014	Carbon E=455 MeV/nucleon	7	$1{,}5x10^{9}$

Extracted beam composition was studied. For this goal detecting setup was combined from three 1 mm thick and 1 cm2 square scintillation detectors, dE/dx ion-implanted Si detector with 450 um thickness and 1 cm2 square, and full absorption BGO detector. Time-of-flight, amplitude analysis and 2D amplitude analysis methods were used. As a result of measurements it was found that extracted carbon beam at VRBS has 11% of admixtures, which corresponds to the amount of matter crossed by beam upstream of the VRBS.

ISBN 978-3-95450-170-0

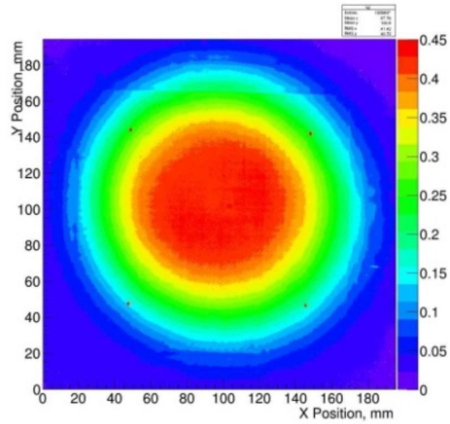

Figure 1: Dose distribution measured around the irradiation point.

For the radiobiological studies one needs to have heterogeneity of the carbon field not worse than 5% in the VRBS region. Method of the longitudinal transversely flat paraxial dose field production was developed for this. Carbon ions beam was slowly extracted during the lower plateau of the U-70 synchrotron magnetic field. Dose field is produced by compact electromechanical wobbler using rotating constant di-pole magnets. As a result we have got uniform irradiation field with diameter 60 mm for the first radiobiological experiments. Dose distributions around the irradiation point, measured by the radiochromic film Gafchromic EBT3, are shown in Fig.1.

Irradiation of the biological objects by carbon ions beam was performed. Culture of cells of the mouse melanoma B-16 was used as an experimental biological test-system. Cells were received from Moscow institute of medical ecology. Culture was cultivated in monolayer according by standard method and was irradiated in the late log-phase. Irradiation of the cells monolayer was done at a room temperature in vials totally filled with RPMI-1640 medium with addition of 2% of embryonic veal serum. There are three sets of irradiation were performed – through up to the Bragg peak ("on the cross"), in the Bragg peak and be-hind the Bragg peak. Positioning of the vials is shown in Fig. 2.

Doses of irradiation are shown in Table 2. Standard gamma-irradiation for the comparison was performed on the isotope gamma-setup "Luch" (Co60, E = 1.25 MeV) with dose rate 1.04 Gy/min. Residual clonogenic activity of cells was determined in standard way after irradiation. Experimental curves for "dose-effect" are shown in Fig. 3. Experimental data was approximated by the linear-quadratic model:

$$\log\left(\frac{1}{S}\right)=\alpha D+\beta D^2, \qquad (1)$$

where S is a fraction of survived cells, D – irradiation dose in Gy, α and β – coefficients equal to the probability of lethal damages in tracks of one or different particles.

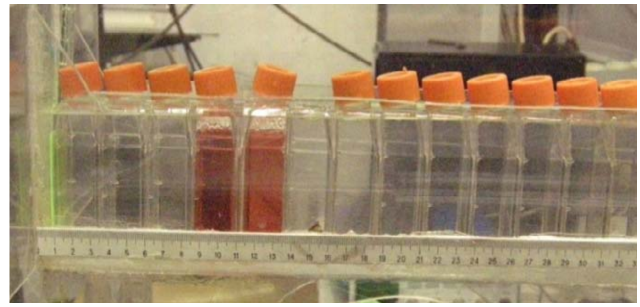

Figure 2: Irradiation of the vials with monolayer of melanoma B-16 in the region of the Bragg peak. First veal is sitting in the region of the peak, second – behind the peak. Beam is hitting from the right side.

Table 2: Radiation dose.

Namber	Dose , Gr	Errors	Cycling	Time
602	1,97	0,14	67	10 min.
603	1,53	0,11	52	6 min.
604	1,10	0,04	33	5 min.
605	0,54	0,04	14	2 min.
606	1,65	0,04	126	18 min.
607	2,55	0,07	133	19 min.
608	3,81	0,10	223	31 min.
609	5,05	0,15	251	33 min.

The coefficient of the relative biological effectiveness (RBE) was determined according to the level of 10% survival of cells:

$$\mathrm{RBE} = \frac{D_\gamma}{D_C}, \qquad (2)$$

where D_γ – dose of standard γ-irradiation, D_C – dose of the carbon beam irradiation. RBE value was calculated equal to 2.7 in the Bragg peak position and 1.7 at "on the cross" irradiation.

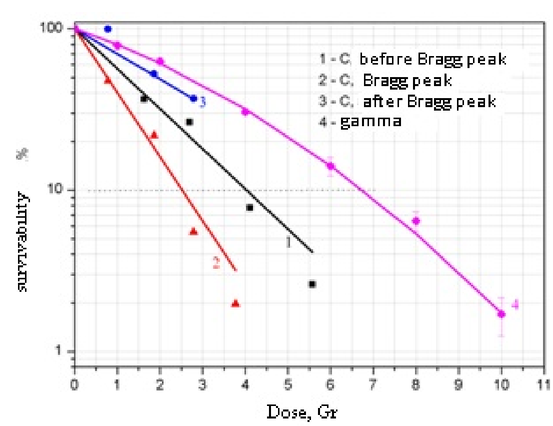

Figure 3: Survival probability curves for mouse melanoma cells B-16 after gamma-irradiation (4) and carbon irradiation (1 – 3).

ISBN 978-3-95450-170-0

Experimental date presented in the Fig. 3 does not contradict to the published date and support attraction of the carbon beams to goals of radiation therapy.

CONCLUSION

1. Carbon beam with parameters suitable for radio-biological studies was extractive into VRBS region.
2. Beam diagnostics equipment was tested.
3. Experimental data for the future development of wobbler magnet were obtained.
4. First irradiations of biological objects were performed.
5. Future development of dosimetry approaches is required.

ISBN 978-3-95450-170-0