SYNCHROPHASOTRON BEAMS FOR RADIOBIOLOGICAL EXPERIMENTS

S.Avramenko, Y.Belikov, A.Golokhvastov, I.Issinsky, J.Lukstins, S.Novikov, V.Volkov,
JINR, Dubna, Moscow Region, 141980, Russia
S.Druzhinin, B.Fedorenko, Institute for Biomedical Problems, Moscow, Russia

Abstract

The Institute for Biomedical Problems in collaboration with the Laboratory of High Energies, JINR, has been carrying out biological experiments to solve problems of the radiation safety during long-term manned space flights. For this purpose investigations of the influence of accelerated charged particles, which are similar to different components of the space radiation, are carried out with laboratory animals, and model biological experiments are going as well. It required to improve the Synchrophasotron beam transportation and diagnostic equipment for proper exposure of biological objects and dose measurements. The new system has allowed one to obtain the required experimental conditions and data on intensity, contamination and spatial characteristics of beams extracted from the accelerator. The results of the performed research have been used to estimate the space radiation hazard, as well as for drawing up the State Normative Documents (GOST) for radiation safety of the manned space flights.

1 INTRODUCTION

Pioneering Outer Space is connected with continually increasing distance and duration of manned space missions. Under these conditions the effects of space radiation on cosmonauts become more serious. Calculations have shown that the equivalent dose of a crew after one-month flight on the earth orbit at the altitude of 200-300km does not exceed 1 or 2 cSv. An increase in flight altitude of up to 400-500km and its duration up to 3 months result in 10-fold increase of the absorbed dose [1]. Therefore as studies of this field advance, new problems are encountered of space radiation danger assessment and of maintenance of radiation safety for crews. Now particle accelerators at large nuclear centers have become the main source of obtaining this information due to high costs of the experiments on the effects of ionizing radiation on biological objects directly in Space.

The purpose of the investigations conducted is to provide close-to-real radiobiological conditions simulated by using accelerated particle beams, which enable the researcher to study the effects resulted from the space particles of high energies. Now the accelerator complex of the JINR Laboratory of High Energies makes it possible to generate beams of protons with the energy range from 1GeV to 9 GeV, ions of helium, beryllium, carbon and other light nuclei with energies from 100MeV/nucleon to 4GeV/nucleon. The dose power of charged particles can reach 0,02 cGy/s to 1,2 cGy/s. Thus, the linear energy transfer values of the accelerated nuclei are ranged from 0,23 keV/μm to 50,6 keV /μm. Spectroscopic measurements have shown that it is possible to achieve a "pure" enough content and energy spectrum of nuclear beams necessary for radiobiological experiments.

2 BEAM TRANSPORT LINE FOR BIOLOGICAL EXPERIMENTS

The Resonance Slow Beam Extraction provides the channel for medical and biological experiments in the energy range from 0.1GeV/amu up to 4 GeV/amu. The obtained intensity (ppp) of the accelerated ions is for protons 4.10^{12} , deuterons 2.10^{12} , helium 5.10^{10} , carbon 1.10^{10}. There is an opportunity to accelerate (at the lower level of intensity) ions of nitrogen, oxygen and neon.

The beam transport line is directed to the Main Experimental Hall. The area for irradiated objects is located at the distance of 30 meters from the accelerator and has a space of about 10sq.m. (Fig.1) An 8-meter concrete wall shields the place from the accelerator background. The cross section of the beam here can be formed by means of four quadrupoles in the limits from $30x30\ mm^2$ to $100x100\ mm^2$.

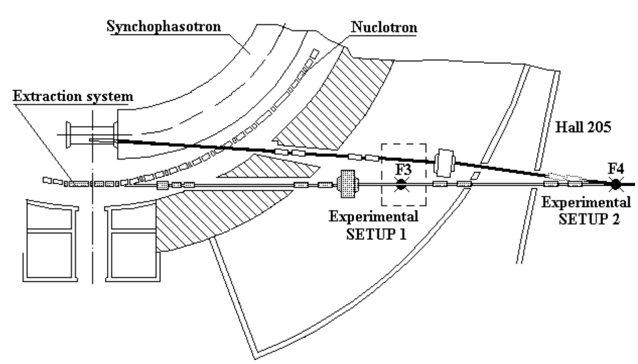

Figure 1: Layout of the beam transport line.

3 BEAM DIAGNOSTICS

Four analogue mode MWPC (multi-wire proportional chambers) are used as profile monitors in the range of intensity from 10^6 to 10^{11} pps. One MWPC consists of two orthogonal signal wire planes. Each plane has 32 golden tungsten wires 25 µm in diameter separated by 2 to 6 mm. High voltage cathode planes are fabricated of Be-Cu wires 100 µm in diameter. The anode-cathode gap is 6 mm. The chamber is filled with gas mixture of Ar (80%) and CO_2 (20%). The current-to-voltage converters with adjustable sensitivity, sample-and-hold amplifiers and a multiplexer are placed close by a MWPC. A timer/synchronizer, a 40 kHz buffered ADC of a 10-bit resolution and a multiplying scaling DAC are arranged in the processing centre at a distance of 300 m.

The plane parallel ionisation chamber filled with argon is used as a detector to measure the absolute beam intensity. It consists of 4 signal and 5 high voltage copper electrodes 180 mm in diameter separated by 10mm. The main module of the intensity measurement apparatus is an ionisation current integrator with 3 ranges of current to voltage conversion. The intensity measurement error is about 5% in the range from 10^5 pps to 10^{12} pps. The calibration of the detector was carried out by a scintillation counter.

Linear Energy Transfer (LET), determined as L= dE/dl, is one of the most essential parameters characterising interactions of the ionising radiation with the matter, in particular, with biological objects.

In the experiments carried out with accelerated elementary particles (protons, pions) all relevant values (charge, mass, momentum) are determined to obtain the LET value. In case of full-stripped ions, nuclei, uncertainty can appear. In general, there are possible situations when different nuclei can be accelerated simultaneously during one cycle: for example, when different nuclei, such as carbon, oxygen and sulphur have distinction of the z/A ratio inside the 0.2% limits. Nuclear beams can contain this kind of contamination by lighter nuclei with similar z/A ratio due to beam interactions in windows, tuning of an ion source, etc. Moreover, the contamination can appear during the accelerator cycle as the nuclei fragmentation at their interactions with residual gas molecules inside the vacuum chamber. It means, that in case of heavy nuclear beams one should have a possibility to determine the composition of the beam for calculating LET separately for all ingredients with a subsequent estimate of their distribution inside the beam.

The measuring system developed contains scintillation counters, a charge measurer and computer programs, recognizing nuclei spectrum in the beam. Measurements of the light output from scintillation or Cherenkov counters (the choice of the counter depends on the beam energy) is used to determine LET value. Since the light output is proportional to Z^2 peaks from different types of nuclei, they can be easily separated. The program calculates the number of events under each of peaks, proportional to the intensity of all beam fractions and then, using the known machine energy, it calculates LET within the errors of 1%.

At the beginning of the accelerator run the counters and charge-digital converters (CDC) should be calibrated. We use the following method. At a short distance from the counters a thick target, where 30-40% of the beam particles interact, is inserted to produce fragments of the accelerated nuclei. Signals from the beam nuclei and fragments are displayed as a number of peaks, where the incident nuclei are shown as the right hand edge peak (Fig.2). All peaks follow rule Z^2, which in case of large charges can be distorted by nonlinear effects in counters and amplifiers. The neural network approach provides identification of all selected peaks according to carbon, oxygen, etc. If the number of peaks is large, a part of the left hand peaks overlap and the system is calibrated using only well separated peaks.

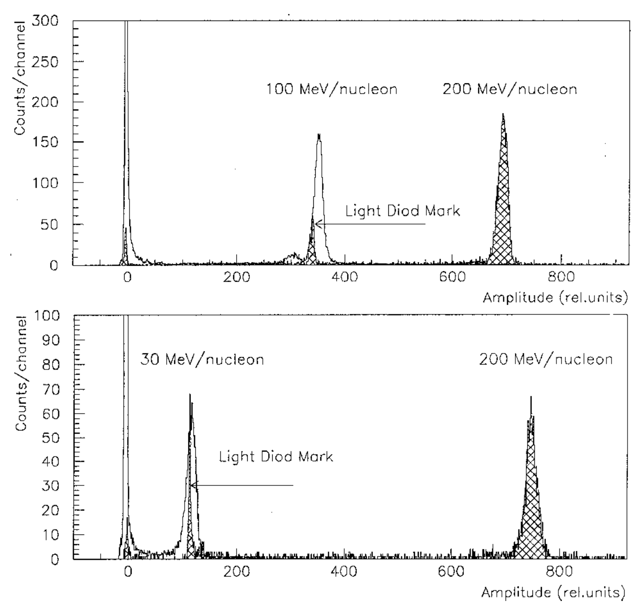

Figure 2: Signals from the beam nuclei and fragments as a number of peaks.

After the calibration procedure the target is removed and the system operates to collect the spectrum of beam particles. The number of the registered particles is quite enough to calculate the LET value for nuclear beam using the following dependence:

$$L = \Sigma \eta_i L_i \ ,$$

where L_i refers to the registered type of the nuclei and η_i is its fraction in the beam. LET for the nucleus pass through the matter can be calculated by using Bethe-Bloch formula [3].

The system provides an opportunity at the beginning of the run to check whether the scheduled nuclei are accelerated and to control the beam purity during the machine operation. So, while acceleration of the carbon nuclei up to the energy of 200MeV/amu, the beam was transported to the setup with contamination of less than 1%, and at the energy of 100MeV/amu the beam contained the admixture of lighter nuclei at the level from 5% to 7%.

4 OPERATION

To meet new requirements to radiation safety provision during long-term space missions, numerous studies have been performed on biological effectiveness of different accelerated nuclei as components of the space radiation. These studies have been done using small laboratory animals, human peripheral blood lymphocytes and other biological objects. Radiobiological damage has been examined at the cells, tissue and organism levels in acute and distant periods of time after irradiation with accelerated particles. In particular cytological, cytogenetical and morphological lesions in mammalian cells and plant objects as well as carcinogenesis and cataractogenesis were studied. Relative biological effectiveness (RBE) values have been calculated, which varied in a wide range depending on linear energy transfer (LET), biological objects' radiosesivity and other factors. RBE values for accelerated nuclei appear to be higher then those for gamma-radiation.

The results obtained are taken into consideration by the radiation safety service to justify permissible dose limits and either to develop or modify State Normative Documents (GOST) of Russia.

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