MONITORING SYSTEM FOR PROTON BEAM TRANSPORT TO THE IRRADIATION FACILITIE

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A monitoring system online controls a proton beam passage from Linac to the experimental units by measuring a secondary neutron radiation from the beam losses. The system consists of the neutron detectors in the transport path and terminal controller connected to the computer. Monitor system allows to determine the beam losses and to detect instability of the formative elements.

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INTRODUCTION

When transporting the proton beam of the linear accelerator portion of the beam is lost in the beam line and the elements forming tube in the transportation channels. As a result of the beam loss is formed multicomponent secondary radiation that provides the background radiation. Nuclear reactions are activated ion guide elements. High proton beam losses can cause thermal damage to the vacuum system.

In control systems of the accelerator beam losses commonly used monitors secondary gamma radiation. However, the weakening of the gamma-ray structural materials and background X-rays distort the information received from the monitors.

At intermediate energies, the main component of the secondary radiation from the proton beam loss is fast neutrons [1]. The main part of the secondary radiation makes up the evaporation neutrons with approximately isotropic distribution (Fig. 1). The share of cascade neutrons of higher energies is less than 10% [2].

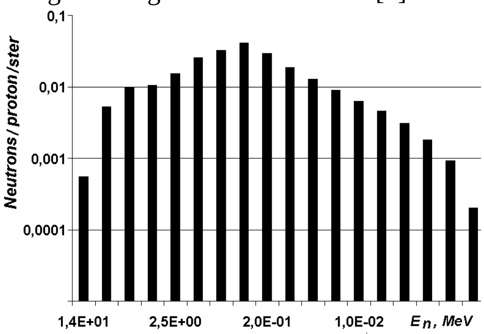

Fig. 1. The evaporation neutron yield per lost proton

One lost proton creates approximately one fast neutron. Fast neutrons in the transport channels can be registered with help of fast neutron detectors. Forming elements which create the beam losses are determined by measuring the induced activity.

The components of the secondary neutron and gamma radiation were investigated by using the automated radiation control system (ARCS) of INR Experimental complex during transportation proton beam to RADEX irradiation facilities, the pulsed neutron source IN-06 and the proton therapy facilities [3, 4]. It was found that the level of background radiation of secondary neutrons is order of magnitude larger than the secondary gamma radiation at the proton energy from 70 to 209 MeV.

With the help of UDBN-02R neutron detectors of ARCS system was investigated intensity of secondary neutron radiation in the transport channels in dependence on the current beam of protons on target irradiators. In [5] obtained a linear dependence of the radiation background in the transport path of the beam on the current value of the proton beam on RADEX.

In the future, such studies have been conducted in the channels of transportation to other proton beam irradiation facilities at the beam energy up to 209 MeV and a beam current up to 50 mA. The intensity of the neutron radiation *D* (mSv/h) in the transport channels depending from the proton beam current I_p (mkA) shown in Fig. 2. The neutron radiation intensity in the transport channels registered with the help of UDBN-02R detectors № 5, 25 и 45.

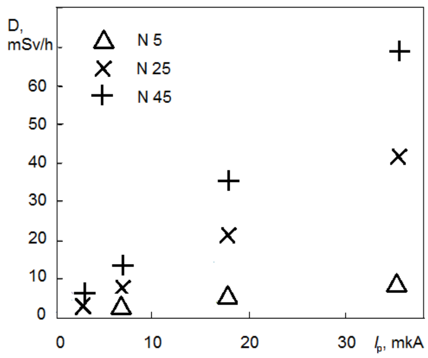

Fig. 2. The intensity of the secondary neutron radiation D (mSv/h) in the transportation channels

On the basis of the investigations have been established the system monitoring the secondary neutron radiation and the proton beam loss during beam transport from Linac to RADEX facility, the neutron source IN-06, the lead slowing-down neutron spectrometer LSNS-100 and the proton therapy (PT) facility).

The small-sized neutron monitors are used in the measurement of beam losses at high current accelerator, Oak Ridge National Laboratory, USA. These monitors have been designed at INR Linac Complex.

1. MONITORING SYSTEM

The control system of transportation proton beam from a linear accelerator to irradiators is based on fast neutron detectors UDBN-02P, located in the beam transport channels (Fig. 3).

The system monitoring the beam transport includes a terminal controller, which is connected to the computer. The neutron detectors are located along the ion guide, near the formative elements of the transport channels and near the target irradiation facilities (RADEX, IN-06, LSNS-100, the proton therapy facility). The detectors in the transport channels are used for the beam loss measurements. The detectors near the irradiation facilities are the monitors of neutron beams and can be used to monitor the proton beam intensity.

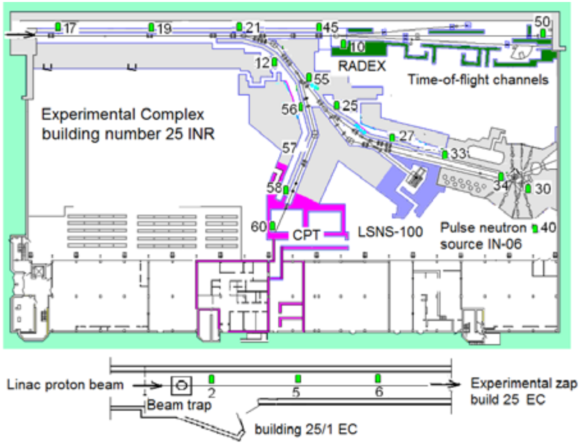

Fig. 3. Layout of neutron detectors of the system monitoring the proton beam transportation

Software module monitoring system determines and shows the dose power of the secondary neutron radiation in real time.

Fig. 4 shows the level of neutron radiation in the proton transporting channel to IN-06 source, as measured by the UDBN detector № 55 near the 1MS3 magnet at a frequency pulse current of the proton beam from 1 to 50 Hz, and corresponds to the average beam current of 0.7 to 35 mA.

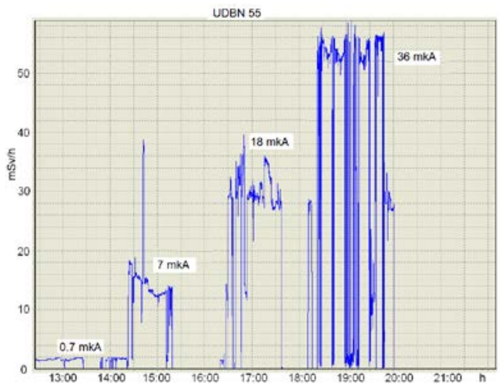

Fig. 4. Diagram of the neutron radiation dose power measured in the beam transport channel for IN-06 near the bending magnet 1MS3

As can be seen from the timing diagram of the average neutron dose rate is proportional to the average proton beam current proton. This is observed in almost all parts of the beam transport. The information about the neutron radiation intensity allows you to determine beam loss in different parts of the transport channel. To determine the main elements of the ion guide creating the greatest beam loss beam is measured induced activity along the beam transport channels [6].

The intensity of the secondary neutron radiation (I_n) from the proton beam losses can be estimated by the formula:

$$\eta = 4\pi r^2 \frac{D_n k}{i_p I_n \chi}, \tag{1}$$

where 4π – solid angle of the isotropic emission of fast neutrons; r – distance from the activated ion guide element to the neutron detector in cm; D_n – the power dose of the neutron radiation in mSv/h; k – coefficient quality of fast neutrons (10^3 s^{-1}·cm^{-2}·mSv^{-1}·h) [7]; i_p – the average current of the proton beam, in mkA; I_n – intensity of fast neutrons at 1 mkA ($0.6\cdot10^{13}$ s^{-1}·mkA^{-1} for the proton energy of 209 MeV); χ – absorption coefficient of fast neutrons in the forming element. This factor can be calculated or determined experimentally.

The value of the beam loss on the main elements forming the transport channels are shown in Table. There's also the numbers of neutron detectors, measuring levels of the neutron radiation close to those elements.

The key elements of the transportation channels, No. neutron detectors, the beam current, the level of the measured neutron radiation, the estimated beam losses on the forming elements

Channel element	Det. №	Beam, mkA	Radiation, mSv/h	Beam loss, %
Linac trap	1	0.7	1	100
For trap	2	36	2.5	0.001
MBB2	5	36	5.6	0.01
MBB4	6	36	1.8	0.003
2MC2	21	36	0.07	10^{-4}
RADEX target	50	36	8.6	100
2M1	12	18	11.5	0.04
1MC3	55	18	32	0.4
2MC4	25	18	15	0.08
PE2I	27	18	15.5	0.12
PE4I	33	18	45	0.1
3B17	34	18	7.5	0.2
IN-06 target	30	18	4	4
IN 06 target	40	18	6	100
PT target	58	2	5	100

χ coefficient close to 1 to determine the proton beam loss on the beam line. To the proton beam trap at the facility RADEX this ratio is $8\cdot10^{-3}$ in the direction of the horizontal channel spectrometer time of flight (SVPN). To the proton beam trap at the 83 rd axis of the Linac χ factor close to $1\cdot10^{-3}$. For neutron monitor of the proton therapy facility fast neutron absorption coefficient is about 0.01. The proton beam losses for the beam traps and the target facility are 100%.

The beam losses in the first approximation are independent of the average beam current and are determined by the parameters of elements forming the beam transportation channels.

2. MONITORING BEAM INSTABILITY

The system monitoring the proton beam transport temporal variations of the beam intensity in local areas transporting channels. These changes arise are due to changes in operating mode of the channels or instability of the elements forming the beam transport channels.

The neutron radiation intensity changes in the medical channel and in the PT procedural caused by blocking the beam covering the beam emergency workers or shutter. The monitoring system allows you to monitor this process using neutron detectors № 58 and 60 (Fig. 5).

The diagrams clearly observed correlation between the levels of neutron radiation in both sections of the proton beam transport due to the presence or absence of the beam in the procedural of proton therapy.

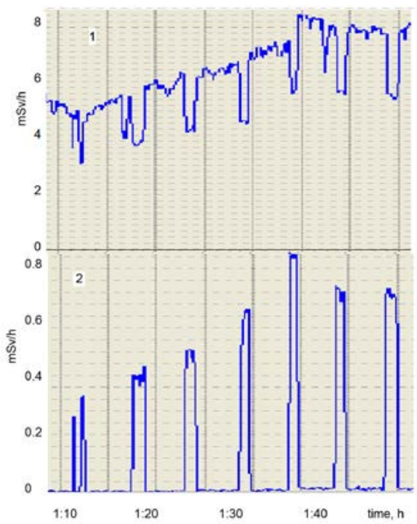

Fig. 5. The profile of the intensity level of neutron radiation in the medical channel (1) and in the procedural of proton therapy (2)

An example of changing the intensity of the beam of protons due to the unstable form of the elements in the area with a magnet 2M2 and lenses L78-81, L61 in the transport path of the beam on the target neutron source IN 06 is shown in Fig. 6.

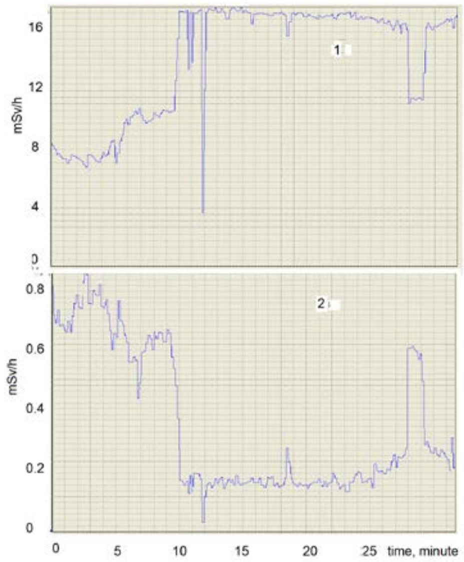

Fig. 6. Diagram of the neutron radiation intensity in the beam transport channel for source IN 06: 1 – neutron background in the area of the 2M2 magnet; 2 – neutron flux in the neutron channel of IN 06

The time dependence of the radiation intensity at the site in front of the magnet 2M2 repeats depending on the intensity of the preceding sections of the channel. Time instability of the secondary neutron radiation may be due to the instability of the formative elements in the area near PE2I profilometer and 2M2 magnet.

CONCLUSIONS

Join the neutron component of the secondary radiation can significantly improve the accuracy of measurements of beam losses.

Measured levels of secondary neutron radiation in the transport path of the proton beam is proportional to the average beam current and beam losses in the value of the measured sections of ions noprovoda.

The monitoring system allows rapid control of the beam transport and significantly reduce background radiation and activation equipment.

Neutron radiation measured by the monitoring system can receive timely information about the losses of the beam and correction of operational parameters which form the transport channel devices to improve the quality of beam.

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СИСТЕМА МОНИТОРИРОВАНИЯ ТРАНСПОРТИРОВКИ ПУЧКА ПРОТОНОВ НА ОБЛУЧАТЕЛЬНЫЕ УСТАНОВКИ

В.М. Скоркин, С.В. Акулиничев

Мониторная система в режиме реального времени контролирует прохождение пучка протонов линейного ускорителя до экспериментальных установок по вторичному нейтронному излучению от потерь пучка. Система состоит из детекторов нейтронов в канале транспортировки и терминального контроллера, соединённого с компьютером. Мониторная система позволяет определять потери пучка и контролировать работу формирующих элементов транспортного канала.

СИСТЕМА МОНІТОРУВАННЯ ТРАНСПОРТУВАННЯ ПУЧКА ПРОТОНІВ НА УСТАНОВКИ ОПРОМІНЕННЯ

В.М. Скоркін, С.В. Акулінічев

Моніторна система в режимі реального часу контролює проходження пучка протонів лінійного прискорювача до експериментальних установок за вторинним нейтронним випромінюванням від втрат пучка. Система складається з детекторів нейтронів у каналі транспортування і термінального контролера, сполученого з комп'ютером. Моніторна система дозволяє визначати втрати пучка і виявляти нестабільність роботи формуючих елементів транспортного каналу.