PECULIARITIES OF FORMING THE RADIATION SITUATION AT AN AREA OF NSC KIPT ACCELERATORS LOCATION

A.N. Dovbnya, A.V. Mazilov, M.V. Sosipatrov

National Science Center "Kharkov Institute of Physics and Technology", Kharkov, Ukraine
e-mail: mazilov@kipt.kharkov.ua

A general problem that determines the prospects of developing the accelerator technique is to study and evaluate the influence of radiation factors on the environmental safety and biological objects. The present paper considers a complex of problems related to analysis of experimental data and investigation of the radiation situation created by NSC KIPT charged particle accelerators at an area of their location, as well as estimation of different radiation effects and their influence on the personnel and environment.

PACS: 28.41.T, 87.50.Gi

1. INTRODUCTION

Appearance of ionizing radiation fields in elements of accelerator constructions and outside them is caused first of all, by beam losses at different stages of the operating cycle. Charged particles escaping from the beam volume because of casual or inevitable events come onto the wall of accelerating sections. In this case there appear nuclear-electromagnetic cascades, the components of which may possess a significant penetrability leading to formation of instantaneous radiation fields. These fields affect the accelerator equipment and environmental air and a result of this effect there appears the induced radioactivity of construction elements in accelerators, shielding, targets, and of the air in the working zone. Besides, in the case of interaction between high-energy (accelerated) charged particle beams and targets being irradiated, the powerful fluxes of gamma-neutron irradiation of a wide energy spectrum are formed. As a result of nuclear reactions such as (γ,n), (γ,pn), $(\gamma,2n)$ etc., the radioactive nuclides with different half-life periods are formed. A part of them in the form of radioactive gases and aerosols can be ejected into the atmosphere by creating an additional radiation source and thus increasing the total radiation level in the area of accelerators' location.

Radiation monitoring at the NSC KIPT accelerators (outboard the Center) includes a schedule control and a special control. The schedule control is conducted for obtaining the operative information about the state of the radiation situation, its change and emergency probability. A special control is necessary to obtain new information about the emergency situation required for defining or specifying a volume of radiation-dosimetry control.

2. SPECTRAL COMPOSITION OF GAMMA-NEUTRON RADIATION ON THE OUTSIDE OF THE SHIELDING

One of the results of the special control were experimental studies of a spectral composition of gamma- and neutron radiation on the outside of the shielding of the accelerator LUE-2000 at different electron beam parameters [1]. To know the spectral composition is necessary for determining methods and means of the radiation monitoring.

The spectral composition of gamma-radiation was studied in the energy range from 0.1 to 30 MeV using a NaJ (Tl) detector of 300 mm in diameter and 150 mm in thick. Measurements were performed in the instant of electron beam passage (Fig. 1), as well as, through the whole time interval (Fig. 2). On the vertical axis plotted is a number of photons in the given energy range normalized for an average current, detector area and time. On the horizontal axis the photon energy is plotted. It is seen that in the instant of beam passage the photon energy reaches 20…25 MeV. The presence of gamma-quanta in the interval between current pulses is due to deceleration and capturing thermal neutrons with a subsequent gamma-quantum emission. The shape of the spectrum in this case does not depend on the electron beam parameters and shielding thickness. Analysis of measurement results has showed that the main contribution into the equivalent dose rate on the outside of the shielding is determined by photons formed as a result of radiation capturing of thermal neutrons on nuclei of a shielding material.

The spectral composition of neutron radiation is studied in the energy range from 0.5 to 100 MeV with the use of the Bohnar spectrometer comprising a set of balls-degraders made of unitized polyethylene of a density (0.92 … 0.04) g/cm^3, and a ^{6}LiJ(Eu) crystal detector of thermal neutrons. Taking into account that the radiation intensity is changing with time the spectrometer comprises the ball-degraders of 5 inches in diameter. To measure the thermal neutron fluence we have used the indications of two detectors in the ball-degraders with a cadmium coating and without it.

Fig. 3 shows reproduced neutron spectra at different electron beam parameters. On the vertical axis plotted is a number of neutrons in the energy interval of 1 MeV per one reading of the monitor multiplied by their energy and normalized for an average current, detector area and time. It has been found that the intermediate neutrons of the energy between 0,5 eV to 0.2 MeV make the main contribution (more than 80%) into the neutron flux. The contribution of super-fast neutrons (of the energy more than 20 MeV), depending on the measurement point, is varying from 1 to 9%.

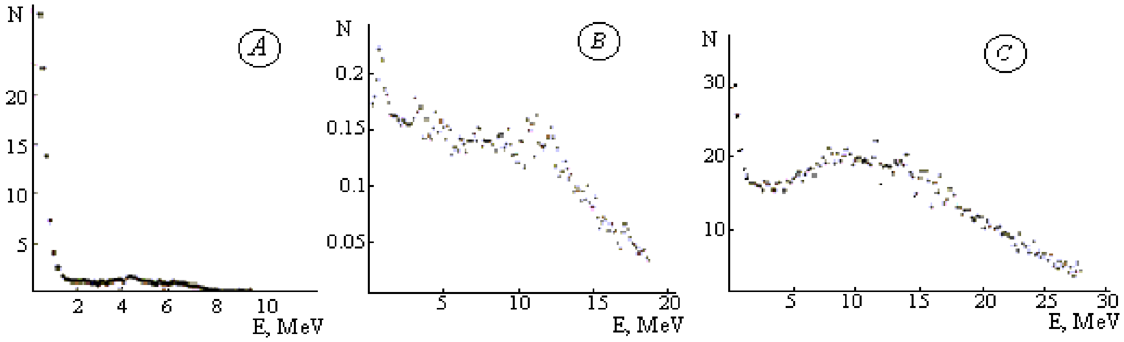

Fig. 1. *Spectral composition of the gamma-ray on the outside of the shielding at a moment of electron beam transmission: A: energy of 1.5 GeV, current of 1 μA; B: energy of 250 MeV, current of 50 μA; C: energy of 250 MeV, current of 0.6 μA*

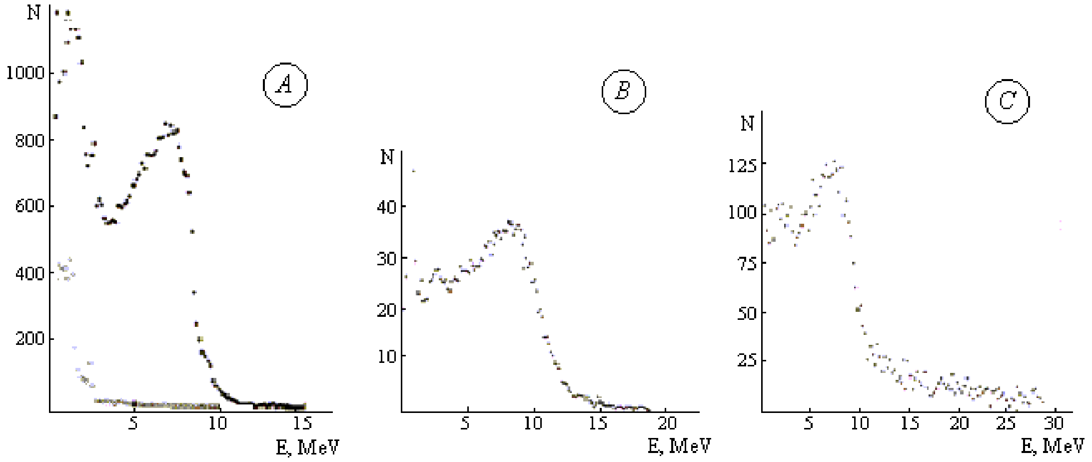

Fig. 2. *Spectral composition of the gamma-ray on the inside of the shielding: A - •- energy of 1.5 GeV, current of 1 μA; ○ – background when the accelerator is off; B – energy of 250 MeV, current of 50 μA; C – energy of 250 MeV, current of 0.6 μA*

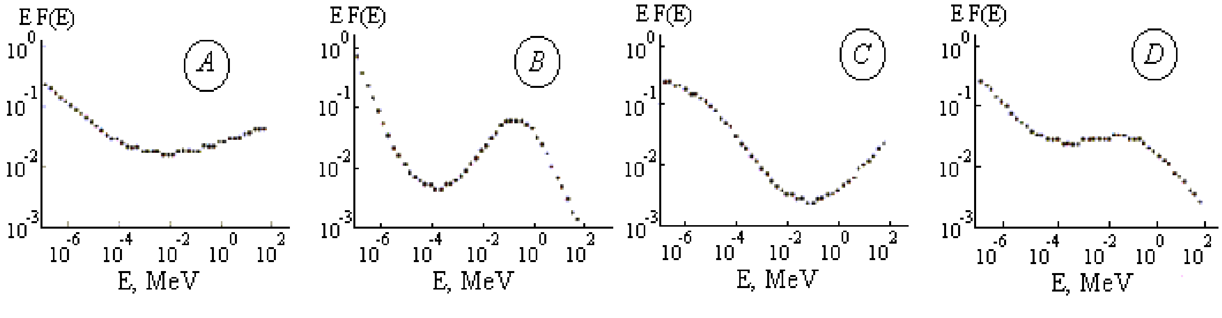

Fig. 3. *Reproduced neutron spectra: A – energy of 250 MeV, current of 5 μA, direct beam, klystron room; B – energy of 250 MeV, current of 5 μA, direct beam, experimental room; C – energy of 250 MeV, current of 2 μA, once- turned beam, outboard of the building (15 m from the building); D – energy of 250 MeV, current of 2 μA, twice-turned beam, outboard of the building (15 m from the building)*

3. INDUCED RADIOACTIVITY

Very important are the results of an experiment on studying the induced radioactivity, and on the gas and aerosol components of the radioactive air that is formed under long-term (10^3 hours and more) irradiation with high-energy electrons from different targets. The experiment was performed at the accelerator LUE-2000 in the framework of the program “Luch” [2] (electron energy of 300 MeV, average current of 54 μA). The scheme of the experiment is given in Fig. 4. The target (iron 60%, chromium 16%, nickel 15%) is made of 208 plates being 0.3 mm in thick. The taking of an air sample has been carried out simultaneously in two points: in the region of the target being irradiated (space between the point of sample taking and the target is of about 1.5 m), and in the place of a ventilation system location (distance from the target of about 35 m). The isotope composition of radioactive aerosols deposited onto the Petryanov filter was determined by the method of taking the curve of chamber gas decomposition and subsequent dividing it into components by half-life periods. It has been established the following.

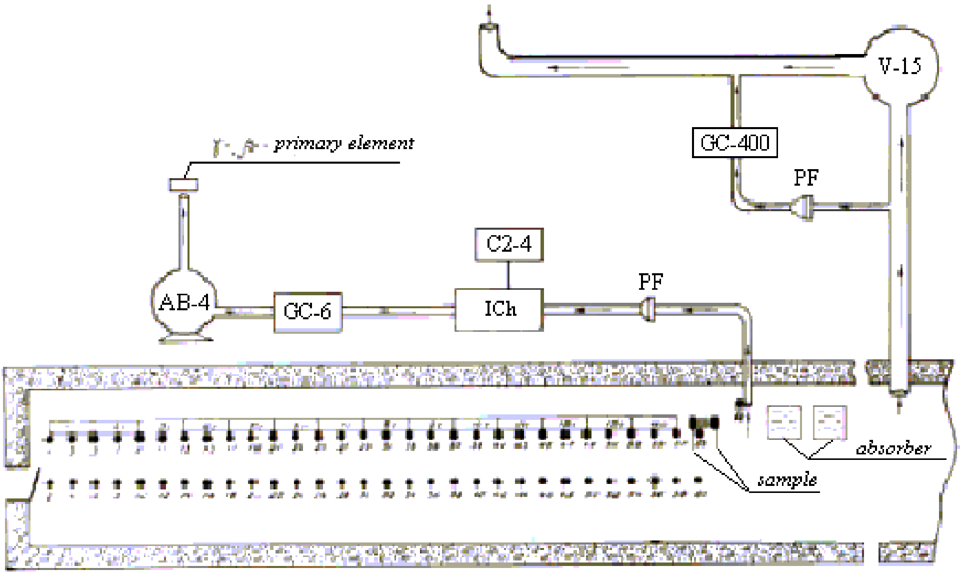

Fig. 4. *Layout of experimental equipment: V-15 – ventilation system; AB-4 – air blower; GC-6 and GC-400 – gas counters; ICh – ionization chamber; C2-4 – counter; PF – Petryanov filter; 2c…14c, 20c – accelerating sections; ● – points of measuring the induced radioactivity on construction elements of the accelerator and the shielding; ○ – points of measuring the induced radioactivity on the sample*

The air ejected from the accelerator’s working zone into the atmosphere has no essential influence on the value of the radiation background in the region of accelerator location and in the sanitary-defense and inspected zones. In this case the concentration of radioactive gases and aerosols in the air ejected does not exceed the background values. In the immediate vicinity to the target under irradiation the aerosol concentration is higher approximately by a factor of 5 than in the ventilation system, but is remaining by 3-4 orders of magnitude lower than permissible concentrations for the air in working rooms.

The radioactivity of gases, formed near the target, is due to isotopes ^{15}O, ^{13}N, ^{11}C. The isotope ^{15}O with a half-life period of 2.05 min makes a predominant contribution into the radioactivity. A total contribution of radioactive gases into the value of induced radioactivity in the accelerator’s working zone is insignificant.

The induced radioactivity of the target and construction elements of the accelerator and shielding leads to significant levels of gamma-radiation in the accelerator’s working zone, but does not influence, practically, on the radiation situation in the rooms where the personnel usually takes place.

4. CARTOGRAM OF A DOSE FIELD

To obtain the clearly evident and maximally objective information about the levels of distribution of ionizing radiation generated by accelerators in the NSC KIPT premises we have drawn up a detailed cartogram of a dose field. It is based on results of multiple measurements with the use of thermoluminescent detectors made of fluorine lithium DTG-4 and aluminum oxide TLD-500K. The detectors were calibrated before and after exposition individually, and every of detectors have had a proper calibration coefficient. Cassettes were light-and-moisture tight. In every cassette 4 detectors with aluminum filters can be placed. Measurement data processing has been performed in accordance with “General requirements to analysis, calculation rules and comparison of results”, Field Standard 95, 925-82. The measurement error was not higher than 5%. For measuring the radiation background levels at the boundary of the NSC KIPT territory along the Center perimeter, 125 dosimeters were installed with a space of about 25 m between them and at a height of 1.2 m from the ground so that all the perimeter be passed over. 4 dosimeters were installed at a distance approximately 10 km from the perimeter, 3 dosimeters were placed into a lead container having walls of 4 cm thick. The exposition time was 90 days.In Fig. 5 the background radiation levels for the operating accelerator (autumn-winter period) are presented in the form of a histogram. On the horizontal axis plotted is the length of the perimeter in the form of a direct line with corresponding supporting points, on the horizontal axis plotted is the dose rate in μSv/h. In the upper right-hand angle the diagrammatic plan of the Center with the largest accelerating installations is shown.

From the above given figure it follows that:

- the mean value of the dose rate at a distance of 10 km from the perimeter was 0.100±0.003 μ Sv/h;
- the dose rate measured inside the lead container was 0.048±0.004 μSv/h;
- the dose rate along the Center boundary is varying about the value 0.100 μSv/h;
- there is a boundary section of a length near 250 m with a dose rate up to 0.155 μSv/h.

In Fig. 6 presented are the background radiation levels in case of non-operating accelerators (summer period). Here the mean value of dose rate at a distance from the Center was approximately 0.110±0.003 μSv/h; the radiation background levels are varying about this value over all the perimeter. The value of dose rate increased approximately by 0.010 μSv/h in this case as compared to the above one is related, probably, to the season.

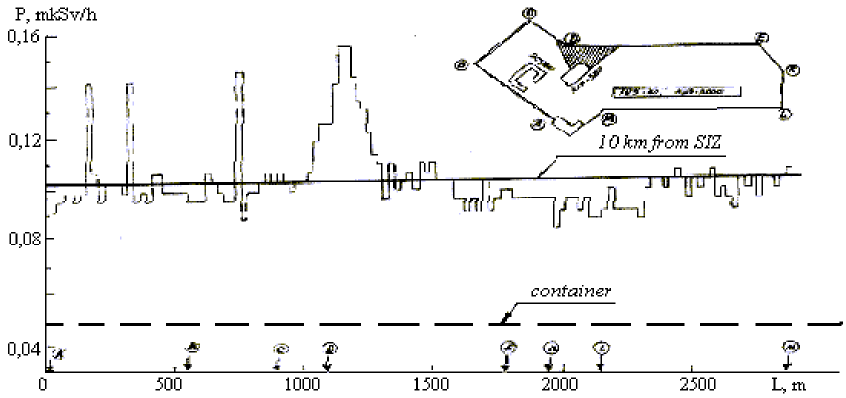

Fig. 5. Background radiation at the boundary of the sanitary-inspected zone for operating accelerators

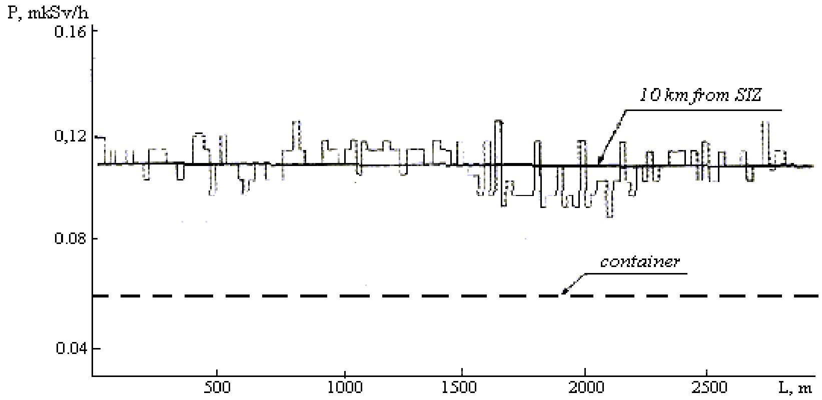

Fig. 6. Background radiation at the boundary of the sanitary-inspected zone for non-operating accelerators

Measurements of the radiation background at the Center territory (inside the perimeter) were performed in nodes of a rectangular spatial net with dimensions of about 60 x 70 m**.** The maximum deviation of nods in a real net of dosimeter seats, as compared to that in the case of an ideal geometrical net, did not exceed ±10 m. So, 100 dosimeters were disposed (one dosimeter in every point). Figs. 7 and 8 show the distributions of measured dose rate levels at the NSC KIPT premises for operating and non-operating accelerators, respectively. Lines of dose rate levels (isolines) as a function of two spatial variables are plotted with the use of smooth filling up (spline-interpolation) on the rectangular net.

The data presented evidence that in the case of operating accelerators there is the increase of a mean (for period of 90 day) value of the dose rate up to 0.30 μSv/h at some areas of the industrial site. The most significant contribution into the man-caused background radiation is made by the accelerators LUE-2000 and LUE-300. Thus, it may be argued that the gamma-radiation created during the accelerator operation made approximately 50% contribution to the man-caused radiation background

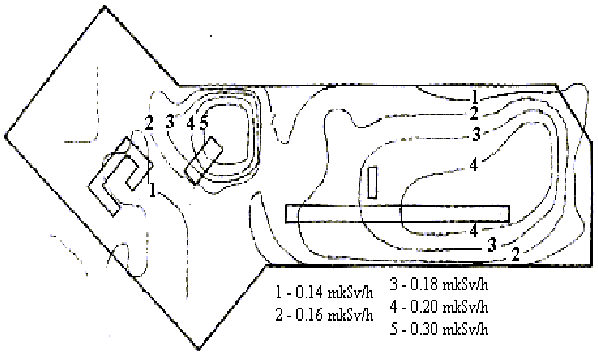

Fig. 7. Background radiation levels on the NSC KIPT territory for operating accelerators

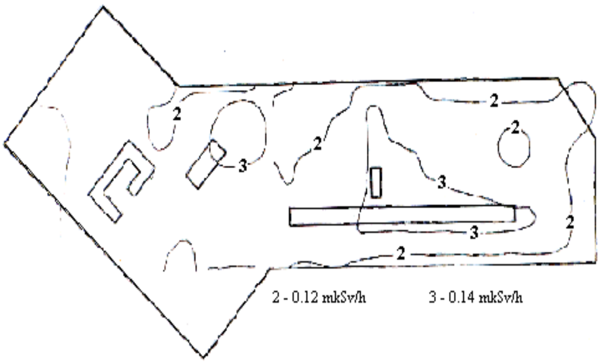

Fig. 8. *Background radiation levels on the NSC KIPT territory for non-operating accelerators*

of the sanitary-inspected zone. In the case of non-operating accelerators (Fig. 8), also the insignificant increase of the dose rate (up to 0.12…0.14 μSv/h) is observed that can be caused by the induced radioactivity on the construction elements of the accelerator of shielding.

5. DOSES OF RADIATION EXPOSURE TO PERSONNEL

Fig. 9 presents the results of analysis on individual radiation exposure to the NSC KIPT personnel for the last 11 years by the groups: heavy charged particle accelerators, electron accelerators, thermo-nuclear (plasma) installation and the NSC KIPT on the whole. It is shown that during last years the most probable value of the annual individual dose is of about 2.0 μSv. 90% of this value is conditioned by the gamma-radiation (Fig. 10), about 8% is contributed by fast neutrons, and approximately 2% - by epithermal neutrons. During the recent few years the neutron radiation contribution has been reduced nearly to zero.

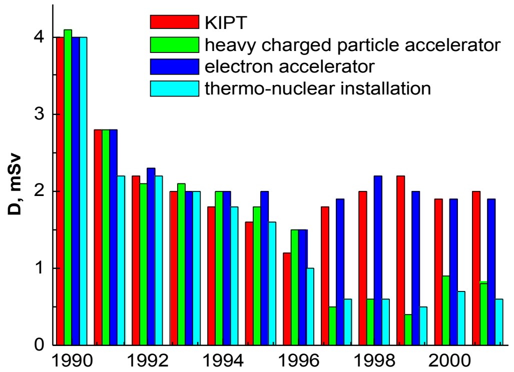

Fig. 9. *Exposure doses for the NSC KIPT personnel by groups*

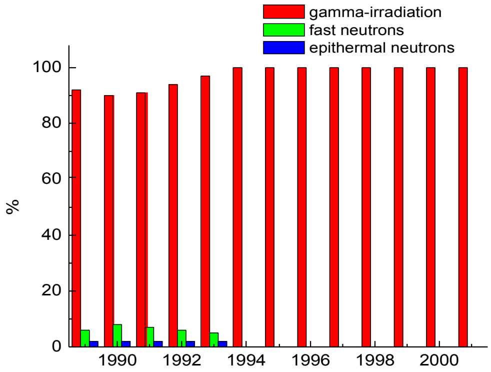

Fig. 10. *Contribution of gamma-irradiation, fast and thermal neutrons into the yearly average exposure dose for the personnel*

In conclusion the authors express their sincere gratitude to the Doctor of Sc. G.D. Kovalenko, which created at the NSC KIPT in 1982 the Laboratory of Radiation Studies and Environmental Safety that made it possible to carry out the research work in the field of dosimetry, protection, and environmental safety. The authors are thanking to the Doctors V.I. Vit'ko, I.G. Goncharov, B.N. Razsukovanyi, and I.P. Svetlichnaya, participating in carrying out the measurements.

REFERENCES

1. V.I. Vit'ko, G.D. Kovalenko, A.V. Mazilov et al. *Spectral composition of the gamma- and neutron radiation outboard the shielding of the electron accelerating installations*. Preprint: KIPT 86-10. Kharkov: KIPT AS Ukr. SSR (in Russian).
2. I.G. Goncharov, G.D. Kovalenko, A.V. Mazilov, I.P. Svetlichnaya *Effect of the Irradiation Program "Luch" on the radiation situation and environmental safety:* Preprint KIPT 90-27, Kharkov: KIPT, 1990, 15 p. (in Russian).