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INDUCED RADIOACTIVITY AT THE IHEP PROTON SYNCHROTRON

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The strong-focusing proton synchrotron at the Institute of High Energy Physics is designed to accelerate protons to an energy of 70 GeV, at an accelerated beam intensity of 10^{12} protons/pulse and a repetition rate of 0.12 1/sec. The synchrotron injector is a 100 MeV linac. A detailed description of these accelerators is given in works /1, 2/. The basic materials used for the construction of the accelerator's main equipment were: stainless steel, mild electrical steel and aluminium. The accelerator's vacuum chamber is made of 0.4 mm stainless steel. The inside dimensions of the chamber are 115 x 195 mm. The annular magnet consists of 120 magnetic blocks composed of mild electrical steel sheets. The electromagnet's windings and busbar are of aluminium.

The accelerator was first operated for physics in October 1967. Towards the end of 1968 the accelerated beam intensity was increased to the design value of 10^{12} protons/pulse. The accelerator is at present operated for runs of 3-4 weeks, with intervals of two weeks for inspection and preventive maintenance of the equipment. The average beam intensity obtained during each run is 5-8 x 10^{11} protons/pulse.

During the initial period, the accelerator was operated without internal targets. The main areas of high induced radioactivity were, at that time, the region of beam injection into the annular accelerator and the region where the accelerated beam was projected onto an internal interception screen designed for localized beam dumping. Since the second half of 1968 /3/, two secondary particle channels with internal targets have been in operation: a positive particle channel, used to tune the physics equipment, and a negative particle channel. The accelerator now has four operative target stations in these different channels, and each of the stations contains two to six separate aluminium targets. The targets measure roughly 1-2 mm in diameter and 10-20 mm long. The accelerator programme provides both for combined operation of several targets and for the separate operation of any one target. The intensity distribution among the targets of the separate channels is dictated by the requirements of the physics experiment; as a rule, most of the intensity of the proton beam (95% and above) is taken up by the targets in the negative particle experimental channels.

The efficiency of target interaction with the accelerated beam at the target dimensions selected is approximately 30%. The elastically scattered protons which have not interacted on the targets move into new orbits and are precipitated in a zone behind the target, as shown in Figure 1.

Throughout the accelerator's operation period checks were made of the radiation levels of induced activity at several characteristic points, and the build-up rate of this activity was analysed. The most interesting aspect was that of the build-up of induced activity in the target station area. Figure 2 shows the curve of the variation in induced radioactivity on the target station of the negative particle channel during six consecutive runs made in 1968. The curve is composed of the experimentally obtained activity decay curves (continuous sections) and the calculated curves for the build-up (dashed lines). The observed growth in induced activity is linked with the increase in the accelerator's operating time (build-up of a long-lived component) and correlates with the increase in the average intensity of the accelerator. The same figure shows a time diagram of the accelerator's operation during the period under consideration and the main parameters of its operation in separate runs. The start of target station operation is also indicated. The level of activity, after six runs, is almost 10^6 times greater than it was before the target station was brought into operation.

Figure 3 shows curves for the decay in induced activity, and these are typical of the target station of the negative particle channel. It shows the decay in activity during the first 150 secs., 15 minutes, 15 hours and 15 days after the machine was switched off. All the curves have been normalised to the target station switching off time, after 216 hours' operation at an average intensity of the accelerated beam of 8 x 10^{11} protons/pulse.

Figure 1 shows the distribution of induced activity along the annular accelerator after a 250-hour run with an average intensity of 8×10^{11} protons/pulse. The figure also shows the location of the internal targets of the secondary particle channels. The dose rates indicated were measured in the straight sections of the annular magnet on the surface of the vacuum chamber.

The distribution of the induced radioactivity along the annular chamber cannot provide sufficient grounds for authorizing the maintenance staff to start working on the chamber. To determine correctly the degree of radiation danger it is essential to know the spectral composition of the gamma-radiation, the variation with time of the hardness of the spectrum, the contribution of beta-radiation and the configuration of the radiation field in the work area. To study the spectral distributions of gamma-radiation special samples were prepared, measuring 40 mm in diameter and 0.4 mm thick, from the vacuum chamber material. The gamma-spectra of the irradiated samples were measured on a spectrometer with a NaJ(Tl) crystal, 40 mm x 40 mm, by means of a multi-channel AI-100 analyser. The gamma-spectra were examined in the 0-600 keV and 0-2000 keV energy ranges. The isotopes were identified by their half-life and the energies of the gamma-quanta. The half-life was determined according to the count rate variation below the peak of total absorption in the gamma spectrum.

Figure 4 shows the gamma spectrum of a sample irradiated for 200 hours. The spectrum was recorded in the 0-2000 keV range after a holding time of 5 hours. Figure 5 shows the spectral distributions of gamma radiation in the 0-600 keV range, measured for various holding times after irradiation. The upper curve in figure 5 corresponds to a decay time of 5 hours; the middle curve is for 96 hours and the lower one, 970 hours. By carefully studying the gamma-spectrum over a long period it was possible to identify with sufficient certainty the main radioactive isotopes whose $T_{1/2} > 20$ min, and determine their relative contribution to the total radiation dose. The results of this work are given in Figure 6. The average energy of the radiation spectrum of the vacuum chamber is, according to these data, 930 keV. The error in measuring the dose, due to the contribution of unidentified isotopes, does not exceed 10%.

By using the data given in Figure 6, it is possible to assess the error due to underestimation of the soft part of the spectrum of induced radioactivity when measurements are made with the standard radiation monitoring equipment. In view of the thinness of the vacuum chamber walls, - 0.4 mm, - the self-absorption of gamma quenta can be disregarded. If the spectral distortion during scattering on the chamber walls is also ignored, the contribution of the soft part of the spectrum can be estimated directly from the data obtained from a spectral analysis. With this type of estimate the contribution of gamma quanta, whose energy is less than 300 keV, to the total dose does not exceed a few percent, i.e. it is within the limits of measurement error and can be ignored.

When use is made of radiometric equipment for measuring induced activity and analysing decay curves, an important consideration is the variation in the hardness of the gamma radiation during decay, and its effect on the readings given by the instruments. To characterise this variation it is convenient to adopt the dose value which corresponds to a unitary flux of gamma quanta. To determine the dependence of the dose for the unitary flux of gamma quanta on the holding time, measurements were made of the spectra with an activated sample, with various holding times. During each measurement of the spectrum the overall dose and relative contributions of identified isotopes to the dose were determined. The results are given in Figure 7. It can be seen that the fluctuations in the dose for the unitary flux, due to a redistribution of the contributions of identified isotopes, do not exceed $\pm$ 5% and can be ignored for most practical purposes.

In order to take into account the contribution of beta-radiation to the overall dose, the identified isotopes were subjected to a detailed analysis. All isotopes except Mn^{56} radiate positrons;

the value of the beta dose is determined by the Mn^{56} and by the unidentified isotopes. The contribution of annihilation quanta was taken into account in the total dose of gamma radiation. A direct measurement of the contribution of electron and positron radiation to the total dose was not made since it is difficult to assess the error due to the influence, during the gamma radiation measurements, of the complex spectral composition. Taking into account the percentage contribution of Mn^{56} to the total gamma dose, self-absorption in the chamber walls and the geometry of the radiation emitters, we estimated the contribution of beta-radiation to the dose on the chamber surface to be 50% of the total gamma dose, for a holding time of 5 hours.

As the dose, in roentgens, for a unitary flux of gamma quanta practically does not depend on the holding time, the contribution of beta-radiation with time will decrease in proportion to the decay rate of Mn^{56}, i.e.

$$D_\beta (t_{hold.}) = D_\beta (0)^{-\frac{0.69 \cdot t_{hold.}}{2,6}} \qquad (1)$$

where $D_\beta (0) = 50\%$.

$t_{hold.}$ is the time, in hours, after the accelerator has been switched off.

The target stations of the secondary particle channels are the sections with the highest levels of induced activity, and consequently necessitate a detailed study of the space distributions of the fields of induced activity. Measurements of the space distributions, a chart of which is given in Figure 8, were made with individual pen-type dosimeters in the plane of the beam equilibrium orbit. The measurement results are given in the form of iso-dose curves, normalized to the maximum radiation level on the surface of the vacuum chamber.

This analysis of the composition of induced radioactivity radiation, both in terms of its components and energies, and the space distribution of the radiation provide a sufficient basis from which to approach the determination of the degree of radiation danger to which personnel working in fields of this type are exposed, and predict the future build-up rate of induced activity.

References

A.A. Naumov. Vestnik AN USSR No. 8 58-65, 1968

A.L. Mints, Vestnik AN USSR No. 8 66-67, 1968

R.M. Sulyaev, Vestnik AN USSR No. 8 76-81, 1968

Manuscript received by publications
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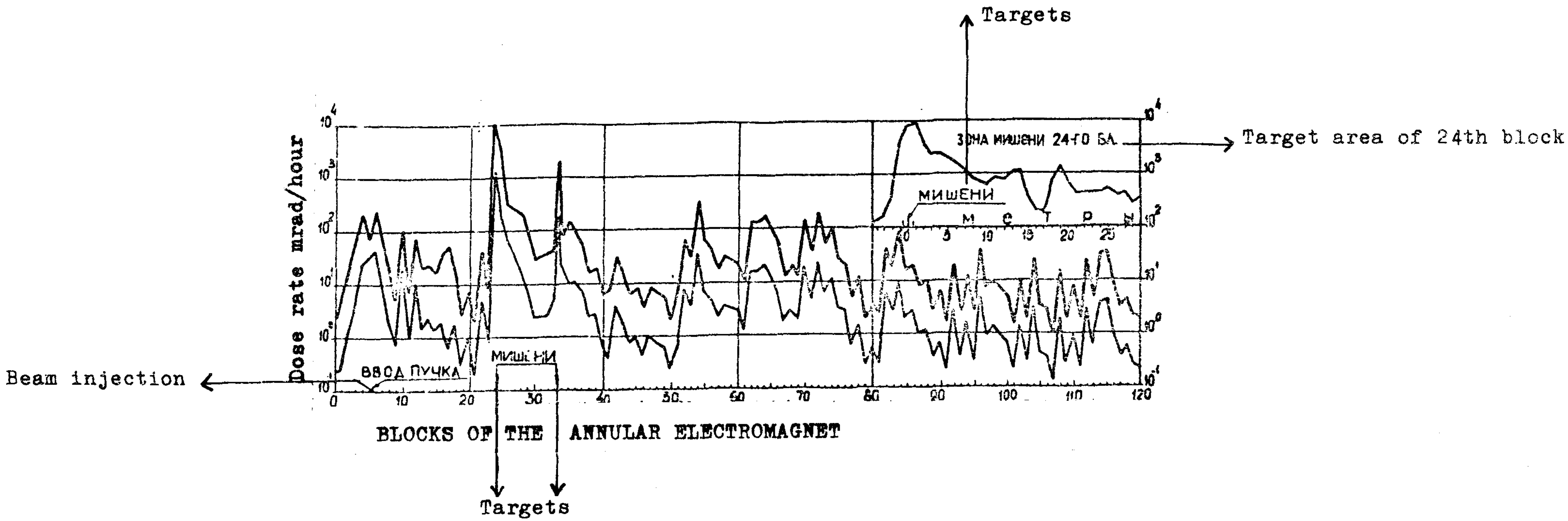

Fig. 1. Distribution of induced radioactivity along the annular accelerator.

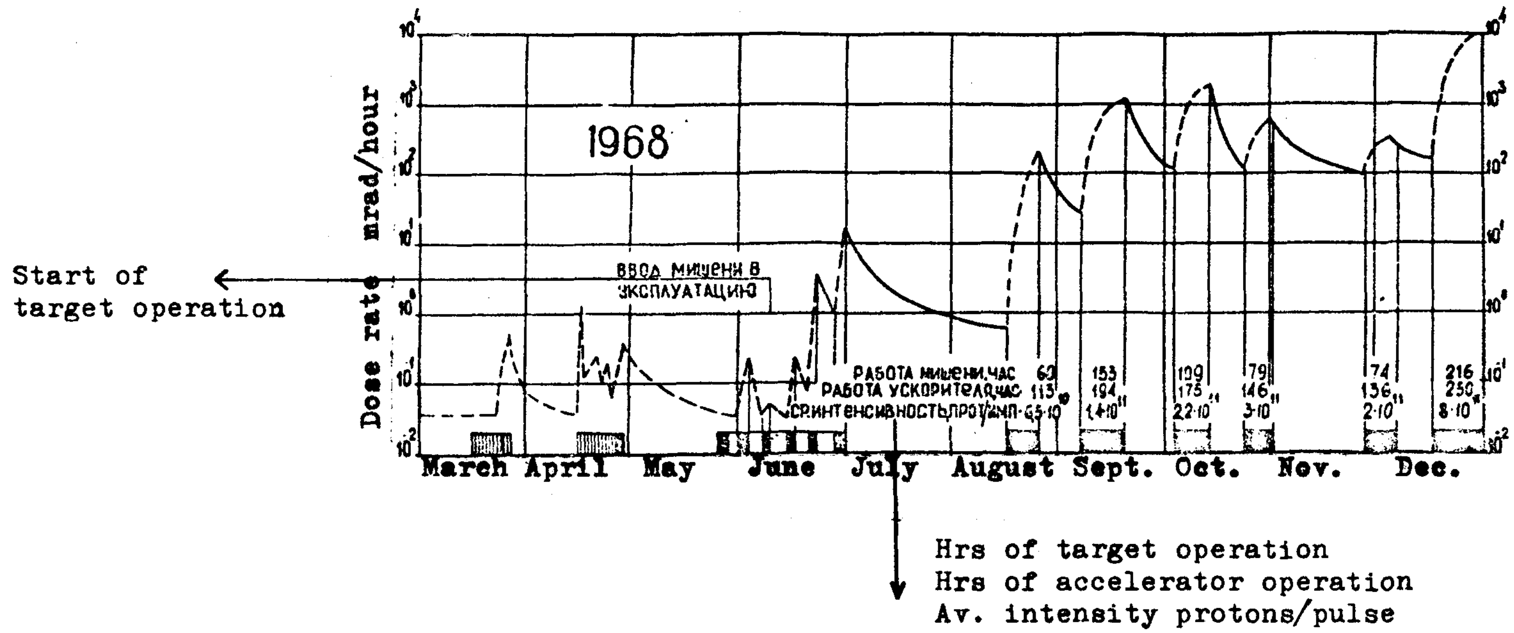

Fig. 2. Build-up of induced radioactivity in the target station area of N° 2 secondary particle channel.

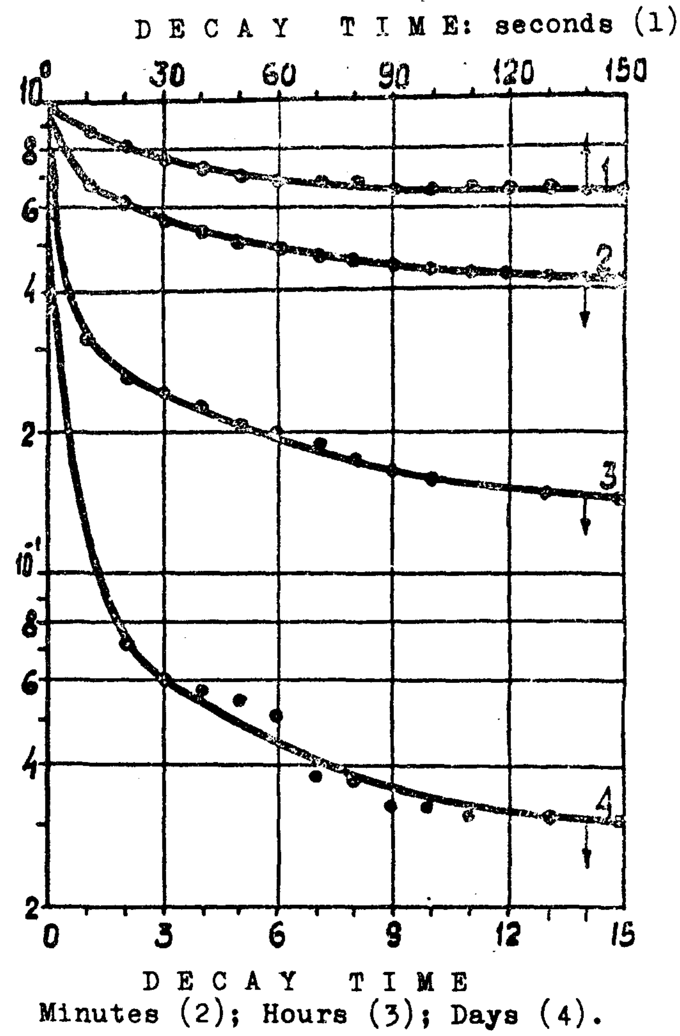

Fig. 3. Curves showing the decay in induced radioactivity.

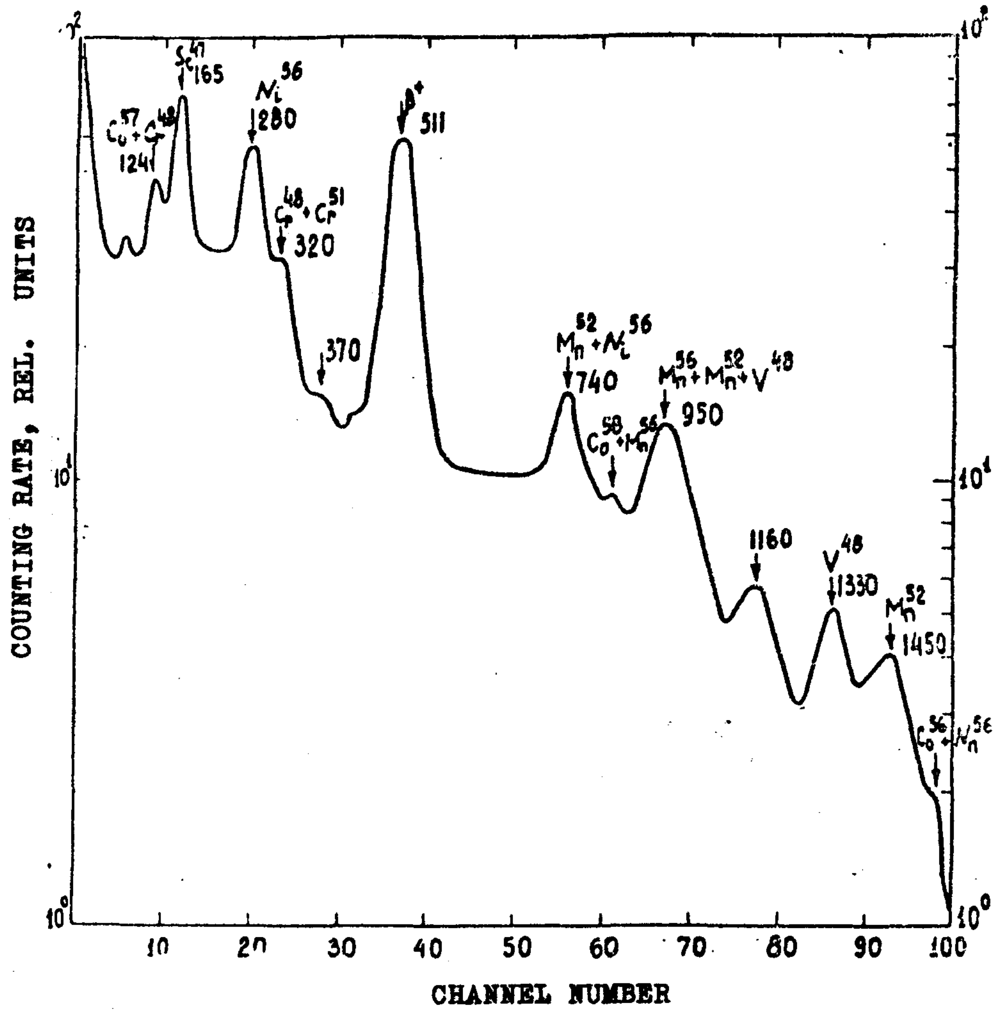

Fig. 4. Gamma-radiation spectrum for the vacuum chamber.

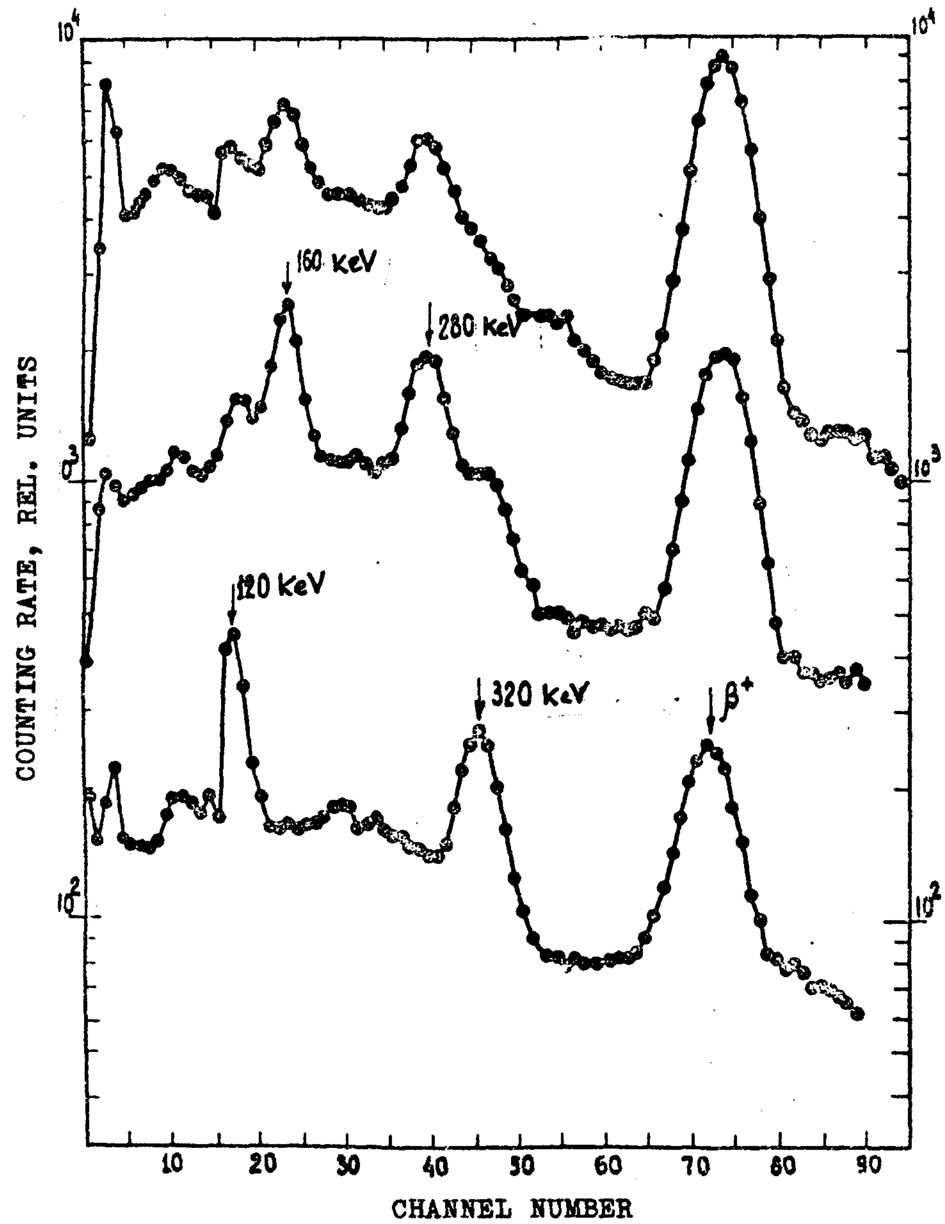

Fig. 5. Gamma radiation spectra for the vacuum chamber in the soft region for various holding times (5 hours, 96 hours, 970 hours, reading from top to bottom).

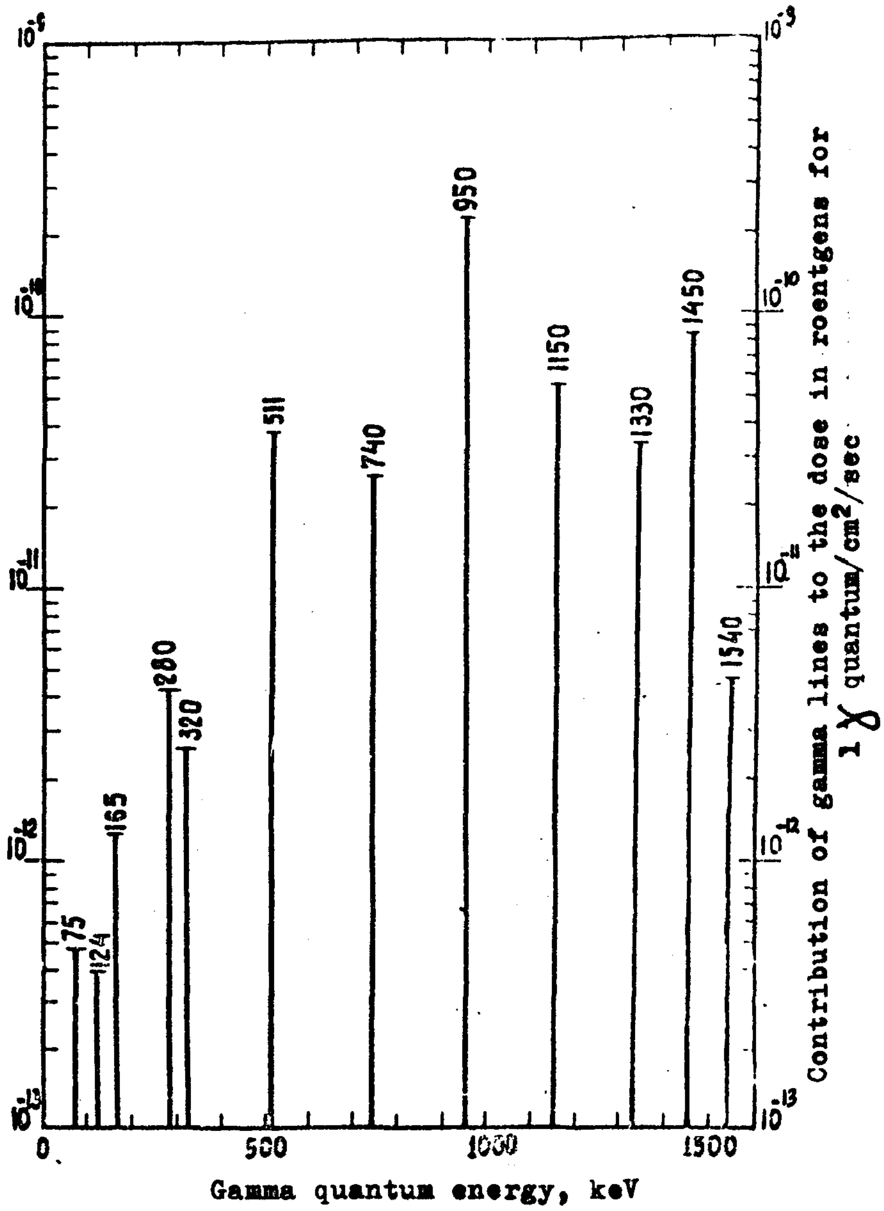

Fig. 6. Contribution of identified isotopes to the gamma radiation dose.

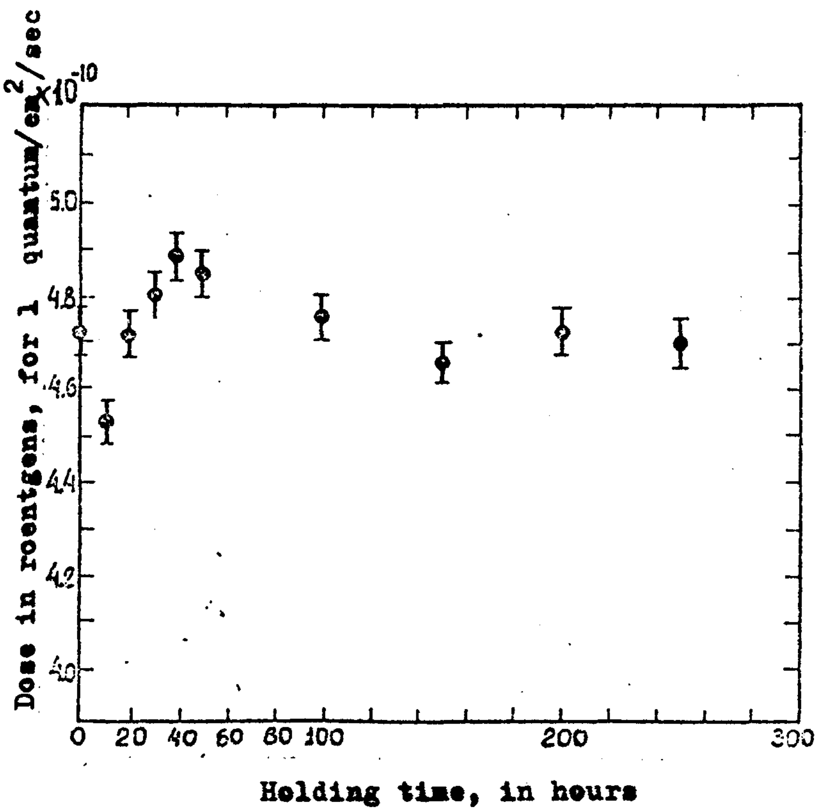

Fig. 7. Dependence of dose for a unitary flux of gamma quanta on the exposure time.

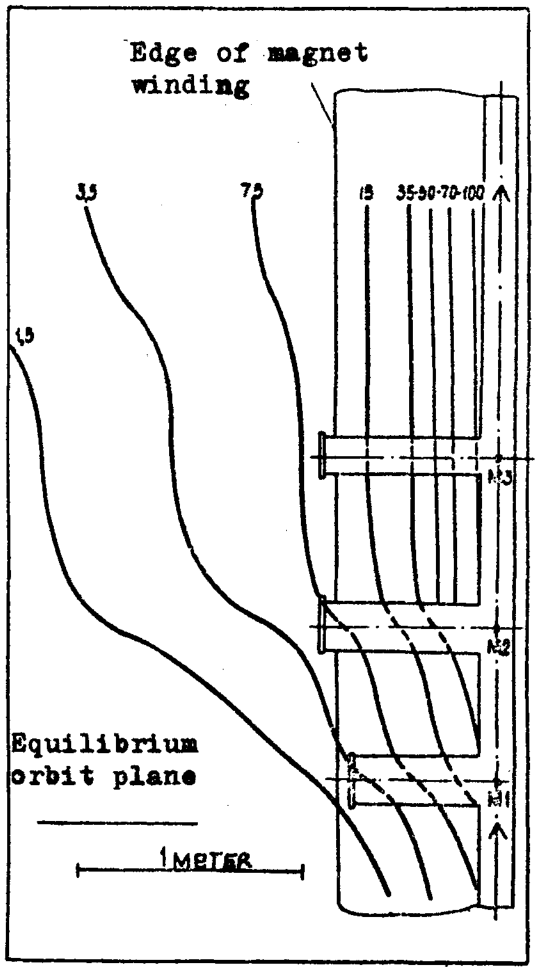

Fig. 8. Isodose curves of induced radioactivity in the area of the target station of N° 2 secondary particle channel.