A METHODOLOGY FOR SYSTEMATIC RADIATION TESTING OF ELECTRONIC COMPONENTS ON THE M-30 MICROTRON

V.T. Maslyuk[1]*, I.B. Turkin*[2]*, N.I. Svatuk*[1]*, O.M. Pop*[1]*, O.V. Liubimov*[2]*, M.I. Romanyuk*[1]*,*
Y.Y. Gainish[1]*, L.O. Volobueva*[2]
[1]*Institute of Electronic Physics of the NAS of Ukraine, Uzhhorod, Ukraine*
E-mail: volodymyr.maslyuk@gmail.com;
[2]*National Aerospace University “Kharkiv Aviation Institute”, Kharkiv, Ukraine*

The main stages of radiation testing for electronic devices are outlined, covering both the finished assembly and its components. These stages must take into account the nature of the irradiation field, the radiation-induced defects in the electronic components of the samples under study, and the effects on their electrophysical parameters. The article discusses issues related to accelerated radiation testing on the M-30 microtron, control of accelerator parameters and radiation dose, consideration of systematic and statistical errors in radiation testing, and data archiving tasks. The results of parameterization of irradiation conditions, in particular, segmentation of radiation field areas, are presented.

INTRODUCTION

One of the key stages in the life cycle of modern materials, structural elements, and electronic equipment designed to operate in conditions of ionizing radiation exposure is the conduct of full-scale ground-based radiation tests. Such tests enable assessment of the impact of ionizing radiation on sample characteristics and function, as well as the limiting conditions for its reliable operation in complex environments. It is at this stage that the scientific and technical basis for the further implementation of devices in the fields of space technology, aviation, nuclear energy, and the military-industrial complex is formed.

The world practice of radiation testing is based on the use of high-tech metrological stands, which are created based on nuclear-physical installations with the possibility of simulating the actual operating conditions of the electronic equipment. Test facilities must not only ensure the specified beam characteristics (energy, density, spectrum) but also provide means for reliable measurement of dose loads, ionization losses, and spectral composition of radiation.

It is common international practice to use so-called “model sources” of ionizing radiation for ground-based simulation of the operating conditions of space technology, medical devices, or industrial electronic systems. In this context, the M-30 microtron is a unique facility that generates monoenergetic beams of accelerated electrons in the range of 1…19 MeV, with the ability to vary their current from 1/10 to 20 μA [1]. Over the past decade, the microtron has been actively used for radiation testing of materials, photosensitive structures, scintillation crystals, plastic fibers, as well as individual blocks of aviation and space equipment.

The use of the M-30 microtron for radiation testing makes it possible not only to reproduce the operating conditions of materials – the spectral composition of the Earth's radiation belts – but also to implement an accelerated mode of radiation dose accumulation under low and high temperatures. It is also important to establish the uniformity of the radiation load on different areas of the samples under study, as well as the reliability of the absorbed dose accumulation. This task can be solved by metrological certification of the irradiation field, which means of controlling the parameters of the M-30 microtron: the current of accelerated electrons at the accelerator output, the irradiation area, and the establishment of the transfer function K.

1. IMPACTING FACTORS OF NUCLEAR PARTICLES ON MATERIALS

Ground-based radiation tests should reproduce the nature of damage to materials and equipment under the influence of nuclear particles during their service life. Such damage depends on many factors affecting nuclear particles as a means of action on matter: pulsed, continuous, their type: electrons (e), gamma (γ), and neutron (n) radiation, energy spectrum, flux density, as well as irradiation conditions: temperature, passive or active state of devices. The damaging factors of nuclear irradiation are realized during the passage of charged and neutral particles through matter as a result of energy losses during particle deceleration, ionization and excitation of matter atoms, the formation of radiation defects of various types (point, extended, areas of disorder), as well as the emission of secondary particles (γ, n, e^-). The main types of radiation damage in matter are point defects, such as vacancies (absence of an atom in a lattice node, Schottky defects), as well as interstitial atoms and Frenkel pairs: a vacancy and an interstitial atom that arise in matter simultaneously. The formation of such defects during the act of elementary interaction of a nuclear particle requires the transfer of energy to atoms with a higher binding energy in the material, approx. 20…50 eV. The transfer of energy greater than 100…200 eV to atoms causes a cascade effect, when the knocked-out atom interacts with the crystal lattice and forms cascades of disturbances and complex structural complexes: linear, planar, and volumetric defects. Complex defects are also distinguished as clusters of vacancies and interstitial atoms, or radiation damage combining point and volume defects. The system of radiation defects is a dynamic object: the generation of a mass of radiation defects under the action of nuclear factors is accompanied by processes of their annihilation and transformation into more complex defect complexes. In some cases, such interaction stimulates nuclear reactions and induced radioactivity in the substance. The final radiation damageability of the substance is determined by the processes of dynamic equilibrium of formation and annihilation/transformation of radiation defects. The ordering of the radiation defect system occurs in the time scale range of 10^{-10} to 10^{6} s. These processes are significantly influenced by the temperature and nature of the radiation exposure – pulsed or continuous – as well as whether the material is exposed to electromagnetic or mechanical factors. The physics of defect formation must be taken into account in radiation testing.

2. A METHODOLOGY FOR RADIATION TESTING ON THE M-30 MICROTRON

To test on a M-30 microtron-based radiation stand, it's important to know and control the metrological parameters of the electron beam on the plane where the sample is located. These parameters determine the conditions of sample irradiation, control the absorbed dose, and ensure the reproducibility of the results obtained. Such parameters include electron flux density, irradiation field uniformity, electron beam current stability, and their pulse characteristics. For practical application, knowledge of the permissible range of their variation, methods, and reliability of their determination is necessary, which is the subject of a special methodology used to control beam parameters during sample irradiation and for metrological verification of the installation's operation. The methodology is designed for dosimetric monitoring of electron beam irradiation of samples. It defines the characteristics of the radiation field, methods, and metrological parameters for their establishment. The methodology provides:

a) measuring the electron flux density φ_e with an error that is established during radiation certification for each distance and value of the M-30 microtron current;

b) determining the integral electron flux Φ_e with a specified error $\delta\Phi_e$;

c) measuring the uneven distribution of electron flux density η in the irradiation area;

d) determining the energy of electrons in the irradiation area.

To address these needs, a special methodology was developed, which is used to control the beam parameters during sample irradiation and perform metrological verification of the installation's operation [2]. The methodology establishes that the initial data for determining the microtron operating mode and irradiation geometry are: the absorbed dose F_{eni}, the electron beam energy E_e, their flux density φ_e, and the geometric dimensions of the area under irradiation. This initial data allows the determination of a distance from the microtron output window to the sample under study. If data on the heterogeneity of the irradiation field is available, the current of the secondary emission monitor (SEM) and the Faraday cylinder are calibrated to establish the correspondence coefficient K. Subsequently, the coefficient K is used as a basis for determining the irradiation fluence through the SEM current integrator.

3. METHOD OF NUCLEAR EXPERIMENT IN RADIATION TESTING

Radiation testing involves researching the radiation resistance of a electronic product in its actual size, fully assembled and under operating conditions, as well as by irradiating individual components that are important for its functioning. Component-by-component radiation studies can be conducted both in system experiments with individual parts and as part of a finished product assembly, by diaphragming areas of the radiation field.

This paper presents the results of special studies of irradiation field parameters related to the characteristics of irradiation field homogeneity and the establishment of the fluence of accelerated electron fluxes. Fig. 1 shows the dependence of the K coefficient for the different distances L from the M-30 output window.

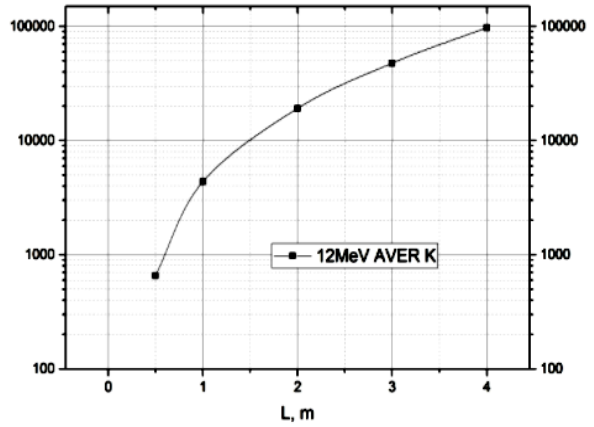
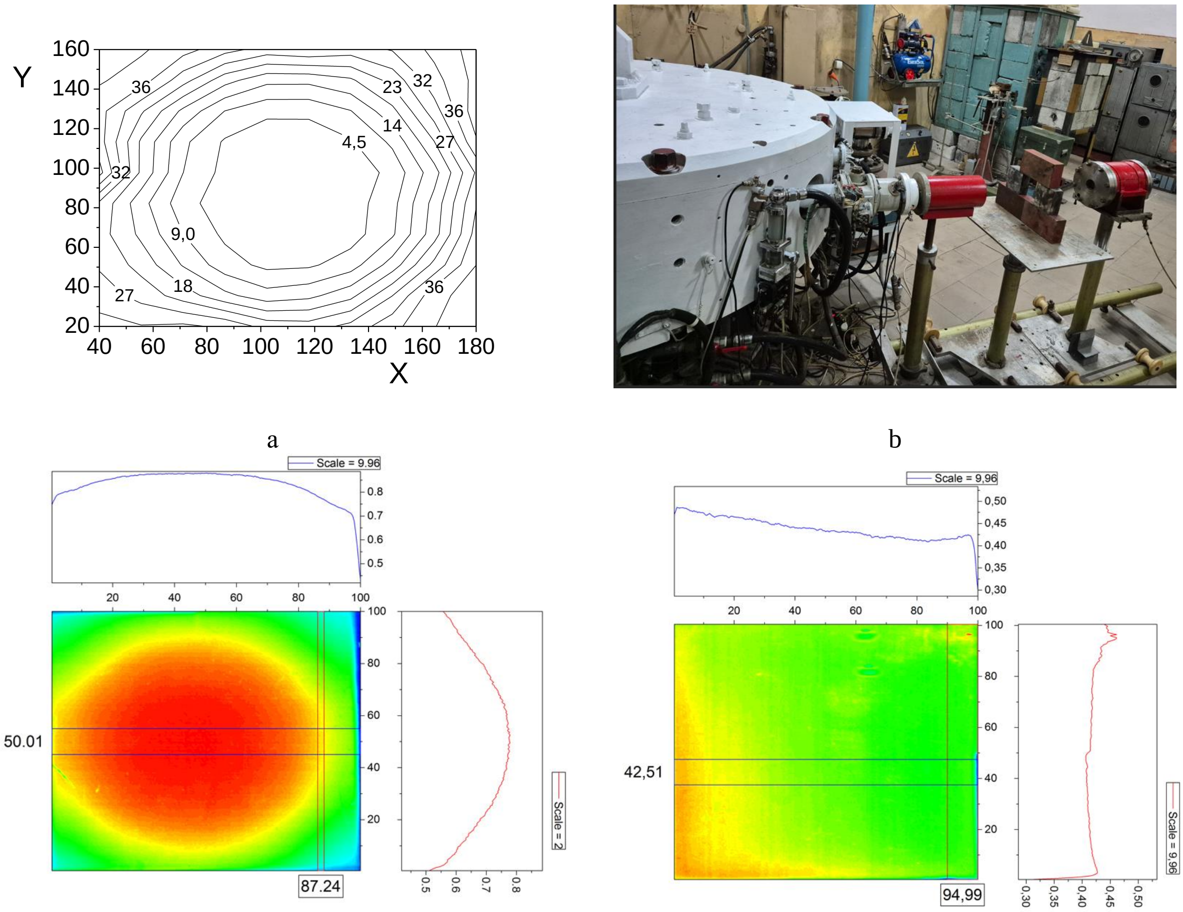


Fig. 1. Dependence of the averaged correspondence coefficient K on the distance L from the M-30 microtron, obtained for different values of the accelerated electron current in the range 0.5; 3 μA

Fig. 2 shows, as an example, the results of measurements of the spatial distribution of electron flux for electron energies of 12.5 MeV and a distance to the output window of L = 50 cm.



a

b

c

d

Fig. 2. Investigation of the uniformity of the M-30 microtron irradiation field for a selected segment: a – using a radiation field scanner; b – radiation experiment conditions; c and d – uniformity of the irradiation field of a 10x10 cm segment, determined by the darkening of a glass plate irradiated with electron beams and bremsstrahlung gamma radiation, respectively

Funding: The work was carried out with the support of the Ministry of Education and Science of Ukraine project D603-2/2026-P.

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МЕТОДОЛОГІЯ СИСТЕМНИХ РАДІАЦІЙНИХ ВИПРОБУВАНЬ ЕЛЕКТРОННИХ КОМПОНЕНТ НА МІКРОТРОНІ М-30

В.Т. Маслюк, І.Б. Туркін, Н.І. Сватюк, О.М. Поп, О.В. Любімов, М.І. Романюк, Й.Й. Гайніш, Л.О. Волобуєва

Розглянуто основні етапи проведення радіаційних випробувань електронної продукції, яка передбачає її тестування у складі як завершеної збірки, так і по компонентних елементів. Такі етапи мають враховувати характер характеристики поля опромінення, радіаційного дефектоутворення електронних компонент досліджуваних зразків, вплив на їх електрофізичні параметри. Обговорюються питання проведення прискорених радіаційних випробувань на мікротроні М-30, контролю параметрів прискорювача та дози опромінення, врахування систематичних та статистичних похибок при радіаційних випробуваннях, задачі архівування даних. Наведено результати параметризації умов опромінення, зокрема, сегментування ділянок радіаційного поля.