THE PRACTICE OF ELECTRON AND PROTON ACCELERATORS UTILIZING FOR INDUSTRY, EDUCATION AND SCIENCE

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Abstract

Seven years' experience of Radiation Sterilization Center of Ural Federal University is presented. The main aspects of accelerators utilizing for industry, education and scientific research are described.

1. E-BEAM FACILITY AND DOSIMETRY SYSTEMS

Since 2015 in Ural Federal University the linear electron beam accelerator is functioning for the purposes of radiation sterilization and modification materials, scientific research and education. The organizing of Radiation Sterilization Center (RSC) started from 2013 after design qualification procedure was finished. Firstly, the reconstruction of the building (fig1, a) was performed, and equipment installed (fig1, b, c). Then the steps of validation procedure were realized that led for certification of accelerator facility and medical products irradiation conditions according to ISO 11137. The main parameters of accelerator are energy 8-10 MeV, nominal beam current – 1mA, beam scanning width – 40 cm. Conveyor system consists of 36 pallets with moving velocity 0,6 – 4 m/min. The disadvantage of this kind conveyor system is ineffective beam utilizing due to free areas between pallets that lead to absence of continuous products irradiation. From the other hand free areas allow to perform simultaneous irradiation of material samples for scientific research activity.

FIG 1. Stages of RSC organization

For absorbed dose measurements the optical and calorimetric dosimetry systems are used. For routine dose measurements during radiation sterilization polymer films (fig. 2, a) with phenazine coating (manufactured in RF by Russian metrological institute of technical physics and radio engineering (VNIIFTRI)) are used with dose ranges 1-10 and 5-50 kGy and 30-200 kGy depending on processed product. Dosimeters are traceable to national

standard of absorbed dose. To make dose measurements traceable to international standard of absorbed dose calorimetric polystyrene dosimeters (fig2, b) and polystyrene phantom were bought in RIS0 laboratory. Calorimeters allow to measure absorbed doses in 3-40 kGy dose range and perform irradiation of different dosimeters in the same conditions with using of phantom. Calorimeters were verified on conditions of irradiation in RSC. So, these dosimeters are used from time to time for routine measurements, to test optical dosimetry system and for IAEA intercomparision program realized from 2017. RSC took part twice in this program and by the results of the last step difference between established and delivered doses were not more 5%, that is the good result for e-beam facility. Next step of intercomparision program is realized during 2022 and RSC plan to take part. Also, calorimeters used for calibration curve preparation during training courses.

FIG. 2. Dosimetry systems used at RSC

2. INDUSTRY UTILIZING OF E-BEAM ACCELERATOR

Practically 90% of accelerator working time is used for industry purposes. RSC sterilizes different kinds of single used medical products (fig. 3, a, b, c) with sterility doses in region of 11 - 17 kGy for different products (blood test tubes, surgery sets and clothes, catgut suture material and other), processes polymer packages for juice and wine (fig.4 a) by dose 15 kGy with the goal of decontamination and shelf time extension, processes polyethylene tubes of different diameter with doses 100-120 kGy (fig.4 b) for thermoshrinkable isolation materials preparation.

FIG. 3. Medical single used production

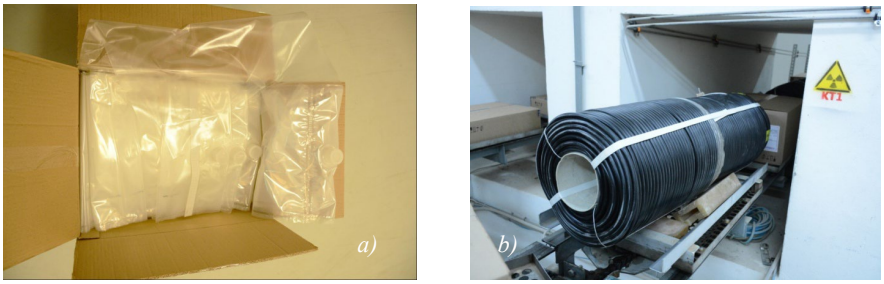

FIG. 4. Polymer production processed at RSC

The specific of medical goods irradiation validation (operation and performance qualifications) establishing of irradiation and packaging conditions in RF is attracting of licensed organization for realizing these procedures. This organization is VNIIFTRI that is carry out products dose mapping, determine minimum and maximum absorbed doses, establish the range of doses in control point and conveyor velocities. All received data with the information about type of product included in validation certificate. After PQ procedure all one type products sterilization is going according to validation certificate.

Polymer tube layout method (see fig.4 a) was suggested to customer by RCS and after dose mapping carried out by us it was showed that dose distribution is laying in the range 100-120 kGy that was is enough for cross-linking.

After six years of activity in this field we can define some critical points for successful operation of facility for radiation technology. The first one is technical condition of facility. Our efforts were applied in regular maintenance and modernization of all installation's modules needed to be done for reliability providing. During exploitation the decisions on modernization of vacuum, high voltage equipment, ventilation, remote-control and conveyor systems were taken and realized. This upgrading allowed us to increase reliability of equipment and provide RSC functioning without issues that were typical at beginning of accelerator complex exploitation.

The second critical point is strong necessity to perform radiation sterilization procedure according to standards of technology. According to national standard radiation sterilization performs on the base main document - technological regulation that is elaborated by RSC and signed by customer and Center. This regulation describes all the stages starting from initial control of delivered product (presence of packaging damages, dose indicators) continued by steps of auxiliary equipment and accelerator starting control, then radiation sterilization performing and dosimetry control, irradiated product storage and dose indicator changing color control. All this steps a detailly described in regulation with focusing on documentation provided sterility dose delivering that should be prepared for customer. Dose measurements are traceable for primary national standard through the calibration curve prepared by manufacturer of dosimeters - VNIIFTRI.

The third important moment is regular work with customers for the explaining how radiation sterilization procedure validation should be carried out. On the present day five main customers of radiation sterilization have a contract with RSC on processing medical and polymer production. Only one of them had knowledges about all the steps should be done before starting routine sterilization. This company firstly established sterility dose for their products and after performed OQ and PQ procedures at our facility with attracting of licensed organization for dosimetry measurement. All the other customers of sterilization needed to be trained by the stuff of RSC for right approach to start sterilization or processing of their product.

In principle that is well known steps but in the specific of countries and used facilities can be realized in different ways.

3. E-BEAM ACCELERATOR UTILIZING FOR EDUCATION AND TRAINING

3.1. Students' education

As usual more than one hundred students of bachelor, master and specialist education programs have more-less practice on the base of E-beam accelerator. Education starts traditionally from lectures on the basics of acceleration technologies and nuclear physics and continued by special courses on nuclear installations, metrology of dose measurements, applied nuclear physics, dosimetry, radiation action on microelectronic components and detectors. In each course the laboratory work on the base of accelerator is presented. For instance, measurement of electron beam energy is a standard laboratory work of metrology course where students get the experience of absorbed dose measurement with using of optical dosimeters, plotting absorbed dose curve, and determining of electrons range and calculating the energy. Irradiation action on detector course provides laboratory work on electrical properties of e-beam irradiated detectors measurements. Even student from biotechnological program have laboratories on studying of e-beam irradiated bio samples.

Another type of education work in our department is personal scientific research work where students take part in real R&D activity under scientific advising of teacher in the fields of physical, chemical and biological materials properties changing under the action of e-beam irradiation. Multiplicity of effects born under the action of irradiation gives a wide field of scientific challenges for scientists including students. The results of student's participation in research activity are real experience on working with complex equipment, studying investigations

methods, acquisition of scientific contacts and of course – publications. From the other hand taking part in R&D activity can be directed on studying and developing of radiation technologies that are realized at accelerator facility or can be launched. Students can apply themselves in modernization of equipment, improvement or starting radiation technology, new dosimetry system implementing etc. So, participation of student in R&D activity give the possibility of scientific or technological qualification formation.

As usual R&D activity realized by students during graduate work. In this case student have more complicated task in compare with personal scientific work. Not only make one or two measurements under advising, but independently formulate the goals and objectives of the work, master the techniques and take measurements, analyze the data and give explanations and conclusion. It can be scientific task, for instance, studying of luminescent properties changing in any compound under e-beam action or technological task – studying the dose distribution in any kind of production that planned to be processed at E-beam facility. The outcome of the work is assignment of bachelor's, master's degree or specialist qualification.

The last one type of education activity that is realized in RSC is industrial practice. It carried out in free of education time and allow students to take part in all steps of radiation technology of sterilization. They attracted for initial and post irradiation control of products, working with accelerator facility to start or close radiation process, dose measurements of routine dosimeters, controlling of beam parameters and dose distributions under stuff advising. As a result – enhancement of technological qualification in the field of applied using irradiation.

3.2. Training

Training courses at RSC were born because of close cooperation with IAEA. Starting this activity in 2011 with participation in training courses on dosimetry at gamma irradiation facility in 2015 it was continued in more closely. With increasing of our experience, it was suggested to Agency to make RSC as a place for training courses on E-beam dosimetry and after IAEA expert's visit the decision to start IAEA training program on this topic was taken. The interest of IAEA lays in possibility of attracting for participation colleagues for Former Soviet Union countries, that's why the first regional training course on dosimetry at electron beam facilities carried out at 4-8 of September 2017 (fig. 5) had official languages English and Russian. It was convenient for participants from Belarus, Uzbekistan and RF with poor knowledge of English. Also, participants from European countries – member states of IAEA took part in training. Training group was 16 people of that allowed to organize 4 groups for practical exercises. The program of the course was divided to theoretical part with lections and practical with exercises at E-beam facility. Theory includes presentations of IAEA expert on dosimetry systems and dosimetry measurements in procedures of validation (IQ, OQ and PQ) and performing (QC) radiation sterilization and presentations of RSC stuff on specific of dosimetry measurements at E-beam facility in RF. Practical exercises were measuring of E-beam energy, calibration curve of optical dosimeters, dose distributions on the surface of irradiated box, dose-conveyor velocity dependence, interruption procedure simulating, dose distribution in real medical product, routine control of products sterilization.

FIG. 5. IAEA Training Course on E-beam Dosimetry at RSC, 2017

Next one IAEA training with the same topic was carried out in August 26-30, 2019 (fig.6). Again, participants from Former Soviet Union countries have been presented also with European countries. At this training the presentation of main customer of sterilization at RSC facility - “Zdramedtech” company and excursion to plant of medical production were included in a program. It was successful addition that gave possibility to see all the chain from production of single used medical goods to sterilization and distribution of irradiated product to customers.

FIG. 6. IAEA Training Course on E-beam Dosimetry at RSC, 2019 with visiting of “Zdravmedtech” company

Took in account an experience of IAEA training courses organizing, increased skill in radiation processing of materials and huge education work experience RSC suggested to Rosatom corporation to organize the similar training with extended program including basics of dosimetry, radioactive sources and equipment for personnel dosimetry measurements additionally to lections and practical exercises on radiation processing and E-beam practical exercises. In November 2019 such first training program named “Multipurpose irradiation centre as a component in Centre of nuclear science and technologies”, supported by Rosatom Corporation have been successfully realized with participants from Europe, Africa, South America and Asia countries. Selection of participants conducted by Rosatom were directed on the countries – partners of Rosatom which have interest in implementing of radiation technologies. Finally, 16 candidates were chosen and took part in training (fig 7). The second one training course under Rosatom support was performed in October 2021 with the same geography of participants. Both events had good feedback from participants and positive outcome of IAEA and Rosatom as a customers of training programs.

FIG. 7. Rosatom supported Training Course at RSC, 2019

So, both programs under IAEA and Rosatom supporting gave us unique learnings and skill increasing in international training organizing, gave productive discussions with participants concerned of radiation technologies developing and implementing. We shared with our experience in radiation processing and got an assessment of our facility and radiation processing operation. Both training courses planned to be continued. IAEA supported training course planned to 2023 in frame or RER 1021 and Rosatom program planned to be carried out twice per year.

4. E-BEAM ACCELERATOR UTILIZING FOR SCIENCE

The construction of RSC allows to irradiate different materials by electrons directly under the beam and with step-by-step accumulation of absorbed dose with using of a conveyor. Moreover, irradiation could be done in parallel with the main process of radiation sterilization (fig.8, a). So, main implementation of accelerator is irradiation of different materials for investigation of physical chemical and biological properties changing. Through the water-cooling system, it is possible irradiate samples without essential increasing of its temperature under the direct electron beam. E-beam accelerator gives the possibility to irradiate materials by electrons with dose rates up to 1 kGy/s, by bremsstrahlung (using lead or tungsten converters) with dose rates up to Gy/s. The materials irradiated at RSC facility are solid states (polymers, dielectrics and semiconductors, microelectronic components, detectors, solar cells, powders for various purposes) and biological objects (food products, microorganisms, fungus). For example, in [1] investigation of irradiated GaAs detectors electrical properties have been conducted (fig.8, b).

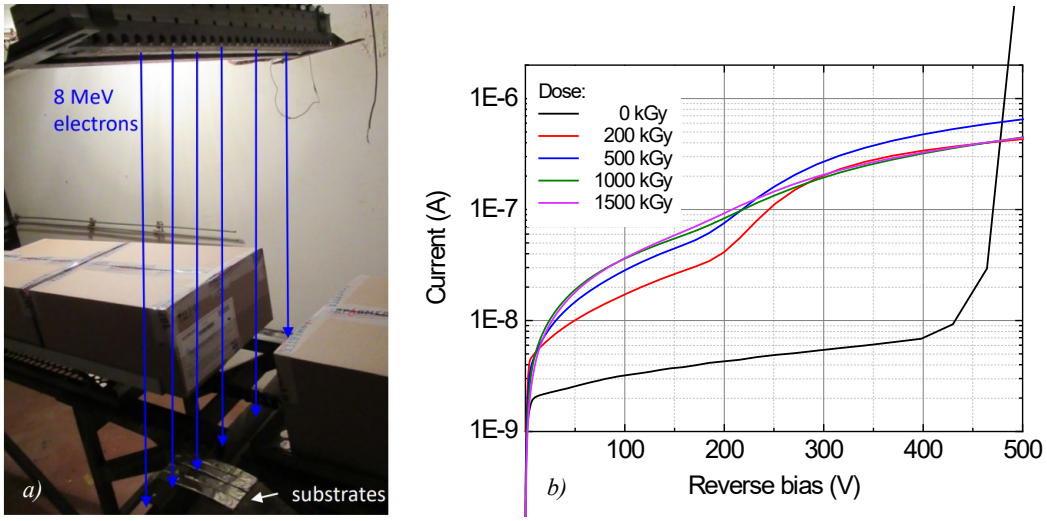

FIG. 8. Irradiation of GaAs detector under direct E-beam and electrical properties changing [1].

The same kind of work [2] were performed at RSC facility where photoluminescence spectra of glass solar cells on the base of ZnO/CdS/Cu2ZnSnSe4/Mo/ irradiated by 10 MeV were studied.

As an example of biological object investigation, the work [3] can be presented, where probiotic cultures were processed by E-beam with the goal of comparative chemical analysis to determine characteristics of amino acids, containing in whole cell and lysed by irradiation of the respective microbial cultures.

So, irradiation facility of RSC has a strong demand on irradiation performing with dose range from units of Gy up to MGy for scientific research. Some of this works lays in fundamental physics, others are directed for radiation technology developing.

5. CYCLOTRON FACILITY

The second project realized at experimental physics department is commissioning of TR-24 proton cyclotron with objective to organize radiopharmaceutical production. After rconstruction of the building cyclotron with equipment for radiopharmaceutical production was installed (fig.9). Nominal characteristics of accelerator are E_p - 18-24 MeV, beam current – up to 300 μA, dual beam configuration, external multi-CUSP ion source.

Radiopharmaceuticals production on the base of ^{18}F and ^{123}I are planned to start in 2022 using the first beam extraction channel and ^{68}Ge, ^{111}In, ^{99m}Tc two years later engaging second extraction channel. Also, experimental channel for samples irradiation is provided.

FIG. 9. Cyclotron and radiopharmaceutical production facility with analytical equipment

Finally at the present time stages of national licensing are carried out and GMP documentation started to form. Experimental channel is ready for using. Besides of industrial radiopharmaceutical production this facility is planned for using for R&D activity and education.

6. CONCLUSION

The experience of industrial irradiation facility integrated in university structure can be estimated as successful. E-beam facility installation and RSC organizing required less efforts in compare with cyclotron and Nuclear Medicine Center (NMC). Started both projects practically at the same time in 2012-2013 RSC has 7 years exploitation period whereas NMC on the stage of QMS documentation forming. The delay in Center commissioning deals with the long reconstruction of old building according to modern requirements of radiopharmaceuticals productions. Nevertheless, request on radiopharmaceuticals in our region is still high and MNC production should be in demand.

Benefits of industry accelerators university location lays in supporting of educational programs in nuclear physics, radiation technologies, radiochemistry, dosimetry etc., possibility of fundamental and applied research in radiation technologies. Accelerators as industrial facility provided by modern cooling and ventilation systems, electron and ion sources, automatic control systems, dosimetry and particle fluenses measurement equipment that gives extensive experience in servicing and maintaining of facility, developing of new electronics for improvement of irradiation process characteristics, dosimetry methodic preparation and measurements, research equipment production and etc. Acquired skills allows to organize educational and scientific tool platform for

students and distribute experience through training courses for the stuff of the same kind facilities in RF and countries – member states of IAEA and partners of Rosatom corporation.

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