RADIATION TECHNOLOGIES

Changing the nature of industries and the quality of life

RUSSIA 2012

PROSPECTS OF RADIATION TECHNOLOGIES DEVELOPMENT

FORESIGHT: 2012-2020

The publication is made within the framework of the "Radiation Technologies Foresight" project. The project was initiated by the Nuclear Cluster of the "Skolkovo" Foundation.

Within the scope of the report's preparation the experts of the Nuclear Cluster and the Center for Strategic Research "North-West" Foundation have analyzed the current state and development trends of non-energy radiation technologies applications. Some aspects of the future radiation technologies development are reviewed on the basis of the received data. Sections of the report cover perspectives of changes in technological, organizational and market development of radiation technologies at the new stage (years 2012-2020), as well as positions of Russia in the sphere of radiation technologies.

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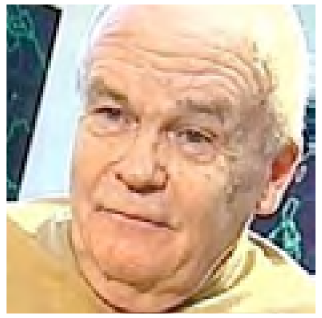


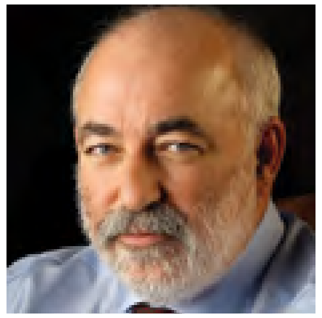
Y.P. Velikhov, Academician

For many years that I have devoted to research and development in plasma physics and controlled thermonuclear fusion, I got used to the fact that my work and the work of my colleagues can lead to really unexpected results. Development of technologies based on the ionizing radiation follows this scenario that is so familiar to many scientists. However, the success reached by radiation technologies (beam, laser, plasma technologies) is unusual for non-mainstream pathways. The backlog received in the Soviet Union in understanding measurement methods, in processes and technologies of the radiation technologies controlling provided the possibility to currently effectively use particle beams and electromagnetic fields in nuclear medicine, in semiconductor industry, in transport security systems and other industries.

When the Nuclear Technology Cluster suggested that the Advisory Scientific Council of the "Skolkovo" Foundation makes radiation technologies the major activity direction and supports new businesses creation within it, this idea was supported both by me and Professor A. Bement from Purdue University, and by academicians V.Y. Fortov and V.Y. Panchenko, as well as by other members of the ASC.

I am extremely pleased that my young colleagues start their way to forming a new industry from the analysis of the current technological and economic situation, and systematization of their predecessors' experience. The report presented to the public is full of topics for hot discussions. However, today it allows to get a fresh view at the perspectives of the applications of ionizing radiation. I hope that it will give a new impulse to the development of radiation technologies both in Russia and worldwide.

OPENING STATEMENT OF THE PRESIDENT OF THE "SKOLKOVO" FOUNDATION



V.F. Vekselberg

Dear readers of the report! A year ago in the discussions devoted to the strategy of the Nuclear Technology Cluster of the "Skolkovo" Foundation we developed two criteria for defining priorities for its activity. These criteria were, first, to support technologies that make their input into long-term global development and, second, to support technologies with high potential for launching startups in the growing markets. Therefore, we decided to concentrate on radiation technologies.

The markets of applications for radiation have already become comparable to the market of nuclear energy and are inseparable from our lives. They include modern methods of diagnostics and therapy in medicine, security systems on transport, new means of purification of air and water. Not less important is using radiation technologies for industrial development: in microelectronics, light industry, metallurgy, in fuel production, industrial waste processing etc.

Being an entrepreneur myself, I mean it. Even before the "Skolkovo" project was launched I had already developed my attitude to the radiation technologies as possessing high potential. I plan increasing investment volume for this sector – investing both into nuclear medicine market that enters the new stage of development and into other growing directions.

Over the last 60 years of the radiation technologies development, Russia has accumulated great potential in this field. It has not been fully commercialized yet, thus it is attractive for launching new businesses. The "Skolkovo" Foundation does not only support startups in this area, but also acts as the Coordinator of the national technological platform "Radiation technologies". The technological platform is a critical mechanism for creating environment for successful commercialization of the new technological solutions, a communications forum for customers, manufacturers and developers of the radiation technologies.

I hope that the presented report will be of great interest both to the professionals in radiation technologies and to the entrepreneurs and investors following the global technology trends and markets emerging as a result of technology development.

OPENING STATEMENT OF THE MANAGEMENT OF THE NUCLEAR TECHNOLOGY CLUSTER OF THE “SKOLKOVO” FOUNDATION

A.D. Fertman

D.A. Kovalevich

To dot all the “i”s from the beginning, let’s answer the most important question: why would the two of us, very different indeed – a researcher and a manager – start analysis and development of the radiation technologies industry. There are two answers to this question. First, we are sure that radiation technologies have a great chance to become a technological basis for many modern industries in the nearest future, like microelectronics 50 years ago or nanoscale materials design in the last ten years. Second, our interest is supported by the challenges and problems that we meet daily in the process of realization of the radiation technologies development program. There are no evident answers to these challenges and questions – mostly due to the fact that we are one of the first travelers who took this path.

The decision on founding the Nuclear Technology Cluster at Skolkovo was initiated during the “nuclear energy renaissance” period and based on traditionally strong positions of Russia in nuclear science and industry. However, even the first discussions of the activity priorities for the “Skolkovo” Nuclear Technology Cluster with our friends and colleagues from the State Atomic Energy Corporation ROSATOM, from the National Research Center “Kurchatov Institute”, from the institutes of the Russian Academy of Science have shown that there is no basis for rapid growth of small business in the nuclear energy sector. As a result of these discussions, we came to an agreed conclusion to focus the Cluster activity on developing technologies and equipment developments that commercialize ion emission (radiation technologies).

There is no doubt that nuclear medicine is the most well-known RT application. It is a standard of a healthy life for a modern person. However, even the brief analysis of the application opportunities of the radiation technologies lets us see how widely RTs are presented in other markets: global security and microelectronics, metallurgy and instrumentation technology, minerals mining and processing, ecology. Integral elements of these industries are accelerators, neutron generators, particle and emission detectors, high- and superhigh frequency systems. In the process of estimating the current level of RT penetration and the variety of the technological solutions, we have come to understanding that RTs represent not a fragmented group of applied solutions, but a process of establishment of the new technological platform. This understanding became a basis for our decision to organizationally shape research and development conducted in Russia in the sphere of RT into the national technological platform, and create within this framework special mechanisms for supporting profile companies and research centers.

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SHORT SUMMARY AND MAIN THESES OF THE REPORT

Solutions for industry based on radiation technologies make substantial input into the development of the world economy. Currently total volume of the applications of the radiation technologies constitutes about 200 billion USD

Historically, development of nuclear technologies (mainly – of energy technologies) demanded conduction of interdisciplinary research that represented a platform for close interaction between specialists in physics, chemistry, mathematics, engineering design and other spheres of science. This mode of nuclear sector development as well as high-level requirements for the technological solutions created great potential for transferring nuclear technologies to other sectors of economy and forming new industries. Radiation technologies (RT) became one of these directions, suitable for non-energy applications and based on the usage of ionizing radiation and electromagnetic fields. Non-energy RT are currently connected with hi-tech accelerators, laser-beam, plasmatic and magnetic equipment, isotopes and methods of irradiation of the living beings and non-living objects.

By now, due to more than 100-year exploration period of the interaction between ionizing radiation (IR) and substance, and scaling technological solutions that are based on various effects taking place due to their impact on living and non-living systems, there was received a range of technologies for emission control, production of emission sources as well as a number of services and products - both for end users and in a form of intermediate links for technological chains in various industries.

200

billion USD is the current total volume of the applications of the radiation technologies

POPULARITY AND DIVERSITY OF RT THAT ARE BASED ON COMMON PRINCIPLES OF PHYSICS ALLOW TO SEPARATE THEM OUT INTO A SINGLE TECHNOLOGICAL PLATFORM

According to the expert's estimates, the potential volume of these markets is up to 400-500 billion USD over the next decade. Currently, radiation technologies enjoy great global demand. More than 20% of top-100 global corporations use them in production and technological processes, for example, in medicine – for diagnostics and therapy of oncology diseases, sterilization of medical products and materials; in transportation safety – for creation of screening systems for passenger control and luggage control; in automobile industry – for increasing tyre wear resistance and car painting; in food-manufacturing and cosmetic industry – for disinfection and shelf life prolongation of goods; in production of materials - for changing their proprieties; in geological exploration and mining, as well as in other sectors.

THE 1890s

X-ray emission was discovered

THE CURRENT STAGE OF RADIATION TECHNOLOGIES DEVELOPMENT WAS PRECEDED BY THREE STAGES:

The stage of fundamental and applied research: starting with the discovery of X-ray emission in 1895 and discovery of radioactivity, and approximately up to the end of the 1950s.

The stage of "pilot" implementation and fine-tuning of technological solutions: within the 1960s-1980s, introducing commercial prototypes of the equipment, expanding spheres of application, first experiences in scaling of the solutions. During this stage the processes of irradiated production certification have been launched at the national levels.

The stage of «fragmented» technology scaling: the 1990–2010s were marked with the beginning of widespread usage of radiation technologies in several sectors - manufacturing, medicine, security, agriculture. Under the aegis of IAEA within the framework of sustainable development concept, the international community started active promotion of radiation technologies in developing countries (isotope hydrology, radiology, agriculture). «Fragmented» (in certain sectors) character of implementation was caused by limitations in economics and limited availability of solutions (costs, safety, and ease of usage). Besides that, necessary and cheap sources of emission were missing.

CURRENTLY RADIATION TECHNOLOGIES ARE AT THE THRESHOLD OF THE FOURTH STAGE OF DEVELOPMENT, BROUGHT TO LIFE BY A NUMBER OF MARKET AND TECHNOLOGY FACTORS:

Increase in demand for radiation technologies in the developed and developing countries. For instance, currently OECD countries (the USA, Canada, EU countries, Japan, Korean Republic) experience increase of consumption in "expensive" industries of economy connected with radiation technologies. Besides, there is observed a significant growth of radiation technologies application markets in developing countries, primarily in BRIC countries. Progressive increase of medical costs, intensive industrial growth, increase in food consumption in developing countries creates effective demand for the corresponding radiation technologies applications.

«Close» readiness for introduction into the market the new (more effective) generations of existing RT-systems, including those connected with the development of component base.

Technological development of the related sectors (for instance, development of imaging technologies, creation of the new types of detectors, application of the new materials, combination of different nuclear physics methods within one system, automation and robotization).

Possibilities for integration into dynamically developing, new spheres of applications (nanomedicine, development and production of new constructional and functional materials, etc.).

THE NEW STAGE OF RADIATION TECHNOLOGIES DEVELOPMENT CAN BE CHARACTERIZED BY SEVERAL CORE CHANGES:

Transition from energy to non-energy applications of the radiation technologies. This transition has been going on for the last 30 years and was especially noticeable in the 1990s, when a range of RT products was introduced into the market, first of all – the new diagnostic devices (PET) and corresponding radiopharmaceuticals. For example, as early as in the mid-2000s only in Japan the volume of non-energy RT investments was practically equal to energy investments.

THE 1990s

Widespread usage of the radiation technologies in the certain industry sectors began

Beginning of the transition from purely radiation technologies to convergent technologies due to the necessity to combine different technologies within joint systems and technological complexes. This process included changes in market structure (acquisitions of small and medium-sized businesses that had necessary competencies; creation of consortiums), and changes in forms of research organization and production activities.

Geographical transformation of RT markets is happening, that is primarily explained by rapid economic development of Asian and Latin American countries. Consumption centers move to China, India, Brazil; national market players appear in RT equipment markets.

THE PROCESSES DESCRIBED ABOVE CREATE A BASIS FOR A NEW WAVE OF INVESTMENT INTO NON-ENERGY RADIATION TECHNOLOGIES (R&D AND PRODUCTION)

MAIN DIRECTIONS OF THE RADIATION TECHNOLOGIES DEVELOPMENT DURING THE NEW STAGE ARE THE FOLLOWING:

Optimization of costs of the existing solutions, significant contribution to which will be made by engineering and construction solutions, such as implementation of modern systems of life cycle management, usage of the new materials for creating security systems etc.;

Smaller size and higher mobility of the systems, creation of user-friendly interfaces that allow users of average qualification to operate the equipment;

Commercialization of the "scientific" applications of the radiation technologies. For instance, one of the clusters of the promising technological solutions is connected with scaling of emission creation technologies that so far have been applied in research only and had no commercial application. Main goals of the conducted research and development are to create smaller-sized equipment and cheaper beams, to develop new generations of equipment for creation of "not-yet commercialized" or less commercialized types of emission – neutron, proton and synchrotron;

Development of technical and technological solutions for expanding the spheres of RT applications (specialized equipment for various sectors);

A new cycle of fundamental research, inter alia connected with the dynamics of nuclear power development (similar to the first stage of RT development) and with the whole range of closed nuclear fuel cycle technologies (radiochemistry, accelerator driven systems and other substance transformation technologies).

Dynamics of commercial and technological development of the radiation technologies will depend significantly on the level of cooperation and/or integration between the companies that are competent in radiation technologies and the companies of a new type that possess the so called "opening" technologies. We mean here biotechnological companies; companies connected with the production of new materials (primarily semiconductors), producers of electronics; IT-companies (4D-visualization technologies, automated data processing, user interfaces); engineering companies.

IN THE 2000s

there started a transfer from the purely radiation technologies to the convergent technologies due to the necessity of joining different technologies within common systems and technological complexes

Despite the leading position of Russia in RT research during the 1970s-1980s, severe economic crisis of the 1990s made Russia to actually skip the stage of mass commercialization of the technological advancement in RT sector (lack of possibilities for financing the certain sectors was burdened by the fact that the nuclear industry, bound with the issues of defense capacity and non-proliferation of nuclear technologies, was restricted and "out-of-bounds").

RUSSIA IS FACING A NUMBER OF BIG ISSUES IN RT DEVELOPMENT

Among them, there is a task to provide commercialization of the significant technological advancement and to collect the missing parts of the competence puzzle (ICT, biotechnologies) for creation of the world-class breakthrough products.

01

STAGES OF THE RADIATION TECHNOLOGIES DEVELOPMENT

"Earlier the accelerators were created, as a rule, for research purposes, to analyze the structure of substance. However, ionizing radiation offers great variety of applications."

G.I.Budker, Academician, 1969

1.1 1895-THE 1950S: THE FIRST STAGE – FUNDAMENTAL RESEARCH

Basic, exploratory stage of RT development, at that stage mostly in the energy applications, lasted from the discovery of the X-ray emission and radioactivity in 1895 and approximately up to the end of the 1950s. At that period large-scale government investments into the corresponding fundamental studies became the driver for RT development. They were also initiated by military/defense institutions, similar to many other high technologies that originated from nuclear, military and space projects of the developed countries.

The 1950s were marked by the beginning of mass creation of nuclear research institutions and infrastructure: experimental and development laboratories, research-and-development reactors, regulatory and legal framework. The first nuclear power plants founding, government support of major research projects created a positive image of the civil use of the nuclear technologies and gained broad support for their innovative applications.

THAT PERIOD WAS CHARACTERIZED BY THE FORMATION OF "PRIMARY COMPETENCE" CENTERS IN RADIATION TECHNOLOGIES BASED AT THE RESEARCH INSTITUTIONS. THE CENTERS ALLOWED RECEIVING KNOWLEDGE ABOUT THE NATURE OF INFLUENCE OF ALL TYPES OF EMISSION ON LIVING BEINGS AND NON-LIVING SUBSTANCE

ENERGY APPLICATIONS OF ALL TYPES OF RADIATION TECHNOLOGIES WERE THE PREDOMINANT DIRECTION OF THE FUNDAMENTAL RESEARCH

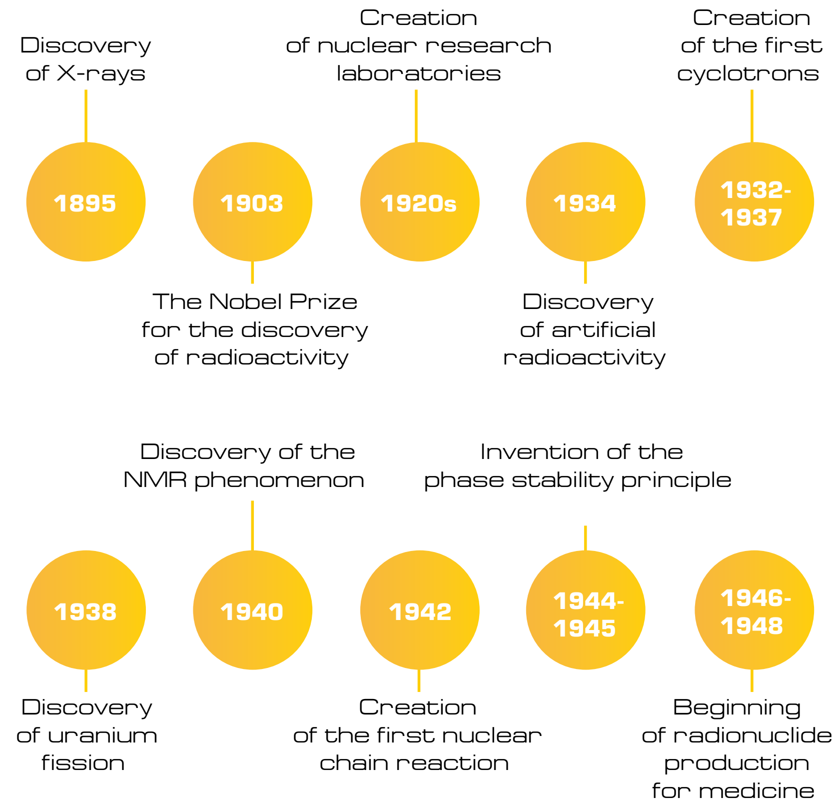
Wilhelm Conrad Roentgen discovered X-rays in 1895

What concerns non-energy radiation technologies, the key directions of works at this stage became:

Studying the main principles of generation and transportation of charged particle beams, and studies of the physics of interaction of electrons and protons with the substance. Further on, these principles became the basis for non-energy applications of RT;

Accumulation of experience and gaining competencies in creation and control of new emission sources, varying in strength. The only in-beam technology that appeared in the market at this stage was implemented in X-ray machines.

Figure 1 *The first stage of RT development timeline*



1.2 THE 1960-1980-S: THE SECOND STAGE – INTRODUCING THE FIRST GENERATION OF NON-ENERGY NUCLEAR TECHNOLOGIES

During the 1960-1980-s the first cycle of mass implementation of non-energy RT was performed. It was accomplished, firstly, due to development and implementation of the first commercial prototypes of emission sources and technological equipment and, secondly, due to the expansion of the application areas of RT.

RT DEVELOPMENT AT THIS STAGE WAS HAPPENING DUE TO THE URGENT NEED TO SOLVE MAJOR SOCIO-ECONOMIC PROBLEMS IN VARIOUS FIELDS:

Demographic transition led to the necessity of health services development and created demand for improvement of the effectiveness in agriculture and food supply systems;

Revolution in chemical synthesis and transit to polymer synthesis presumed demand for effective polymerization technologies (besides cracking) and for operations with polymers. Radiation-induced crosslinking of polyolefins and elastomer vulcanization, and later - other technologies of polymer creation and processing became a technological core for mass industrial realization of "polymer revolution"[1]. Further on, in the same way mass implementation of ion implantation took place in production of beddings for silicon cards in electronics;

In that period, after the oil crisis of the beginning of the 1970s, the problem of energy effectiveness of manufacturing operations arose for the first time. It became one of the main reasons to develop RT. The energy needed to cover surfaces with the help of electron acceleration is only 7% from the energy needed for the same thermal process. This factor gave a start for changing thermal processes (for example, in pasteurization of food) to radiation technologies.

Demand provided possibility for the introduction of the first generation

1 In the early 1970s the first devices (UV, electron accelerators) for polymer radiation processing appeared in the developed countries; one of the most important processes performed with the help of RT was radiation cross-linking of polyolefins. Up to the middle of the 1970-s all key suppliers of polyethylene and polyvinylchloride products used RT in their production chains. There appeared raw material suppliers especially for this technological process. Up to the beginning of the 2000s about 200 accelerators for polymer treatment were installed in Japan only.

emission sources and of the equipment connected with RT (medical accelerators, X-ray therapy equipment – "cobalt guns", radioisotope therapy; in the 1970s – equipment for manufacturing of electronics, including equipment for lithographic processes).

At that time there also started investment into research of the applications of different RT types in medicine (hadron, neutron, neutron capture, proton therapy, clinical research that had finished by the early 1990s) and in materials production.

THE 1970s

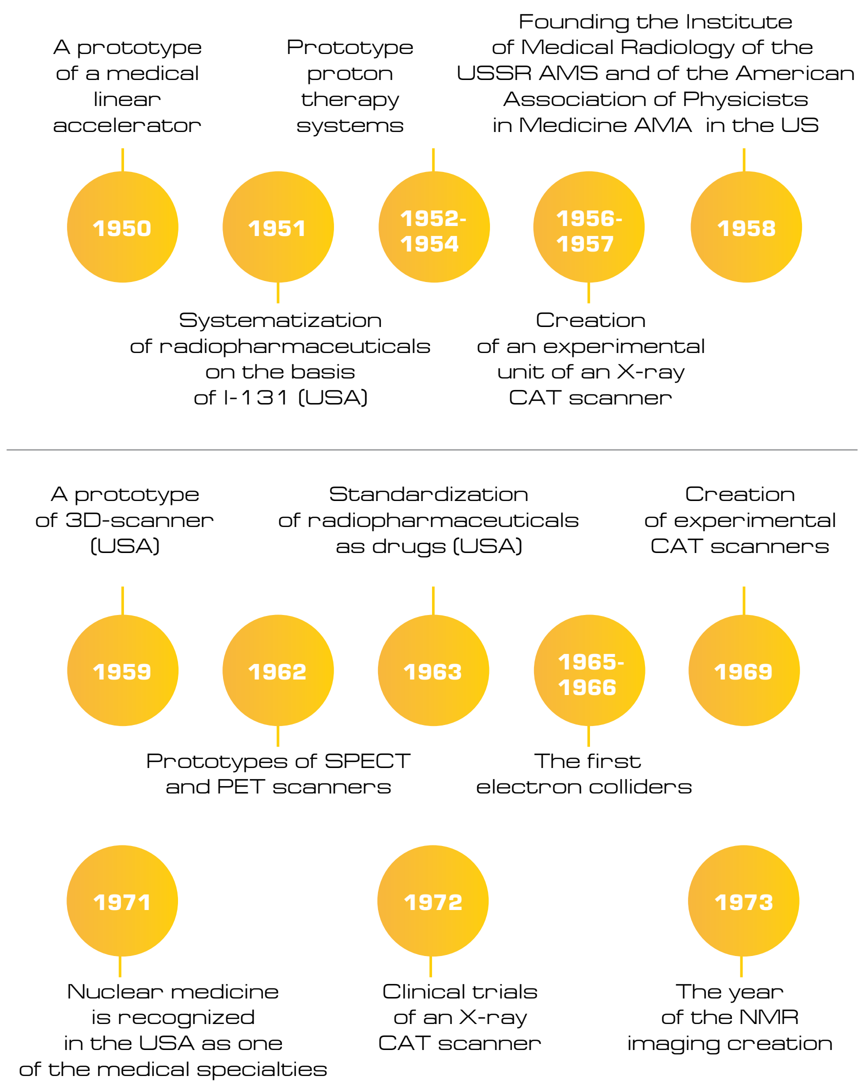
radiation technologies substituted thermal processes

THE LEADERS AT THE SECOND STAGE OF RT DEVELOPMENT BECAME THE COUNTRIES THAT EARLIER HAD CREATED FULL-SCALE RESEARCH INFRASTRUCTURE AND WERE CAPABLE OF STARTING PRODUCTION OF EXPERIMENTAL AND COMMERCIAL PROTOTYPES OF EQUIPMENT FOR THE SHAPING MARKETS OF RT APPLICATIONS

While in the USSR the government was both the developer and customer of R&D, in the USA, in Japan and Western European countries (France, Germany, Great Britain, Belgium, the Netherlands) RT were financed by private hi-tech concerns that later, at the third stage, would become leaders of the RT equipment markets. National markets of the developed countries became the basis for RT development – among them medicine (X-ray diagnostics, external beam radiotherapy and medical radioisotopes), agriculture (agricultural products irradiation) and industry (non-destructive examination of large-sized items in different spheres of industry, demand for the new materials).

The end of the second stage of RT development coincided with Chernobyl NPP accident. The latter became a reason for the "nuclear pause" (the pause in nuclear energy development) that lasted for 15 years and, partly, became a reason for redirection of attention from energy applications of RT to non-energy applications.

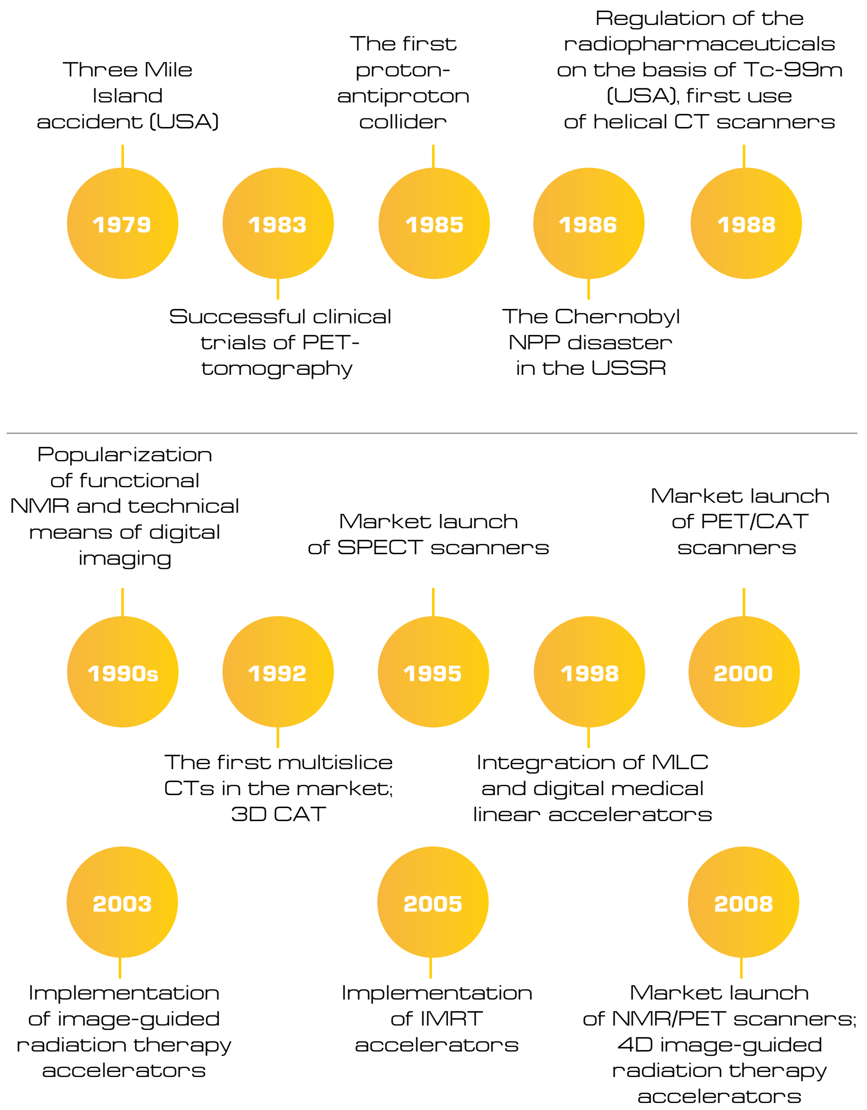
***Figure 2** The second stage of RT development timeline (illustrated by dynamics in nuclear medicine)*



1.3 THE 1990S–THE 2010S: THE THIRD STAGE – MATURITY OF «TRADITIONAL» RADIATION TECHNOLOGIES

During the third stage of RT development (the 1990s–2010s) there took place scaling of non-energy RT applications in medicine, in many types of non-destructive examination, in production of the new materials and in agriculture.

Figure 3 *the third stage of RT development timeline*



HIGH DYNAMICS OF DEVELOPMENT OF THE RT APPLICATIONS MARKETS DURING THIS STAGE WAS PROVIDED BY THE FOLLOWING FACTORS:

Globalization and high growth dynamics of the key markets of applications, first of all - of the most competitive markets of electronics, food production, medical technics, polymer products etc.;

Inclusion of separate systems and services into national medical insurance programs and into the programs of national security systems development that were important for the corresponding socio-oriented markets;

Acceptance of the international system of measures directed at promotion of the radiation technologies. In that period under the aegis of IAEA and within the framework of sustainable development concept the international community started active promotion of radiation technologies in developing countries (isotope hydrology, radiology, agriculture). Not only the programs were financed and the specialists educated, but also the expert assistance took place to those countries that were developing necessary national legislation;

Accumulation of research knowledge base and reliable positive results of RT applications in various fields, formation of the effectual demand for the new, especially socially important, directions of these applications.

These factors have predetermined dynamic development and large-scale commercialization of the ready technological solutions of the previous stage.

ACTIVE GROWTH OF THE MARKETS INCREASED COMPETITION THAT, IN TURN, LEAD TO THE FAIRLY RAPID CONSOLIDATION OF THE MARKET AND PROVIDED INVESTMENTS INTO MODERNIZATION OF THE TECHNOLOGICAL SOLUTIONS

It happened due to optimizing innovations and introducing ICT process control systems and new imaging technologies.

For non-energy RT this stage became the time of the "nuclear pause" that finished only by the early 2000s.

1.4 THE 2000S: TRANSITION TO THE NEW FOURTH STAGE OF RT DEVELOPMENT

Currently a new stage of radiation technologies development is starting. The end of the third and the beginning of the fourth stage of RT development were connected with the creation of radiation sources and equipment of the new generation (compact neutron generators, compact accelerators) and with the beginning of commercialization, and also with the optimization of the existing RT equipment.

Within this new stage of development a new cycle of the mass RT applications is expected. It should happen both due to introduction to the market new generation radiation technological systems and due to their integration into dynamically developing new spheres of applications (nanomedicine, development and production of the new constructional and functional materials etc.).

THERE EXIST THE FOLLOWING KEY ISSUES FOR ENERGY APPLICATIONS OF RT AT THIS STAGE:

Scaling of the nuclear energy industry on the basis of modern project engineering technologies, construction and production processes management (within the framework of an "old" market structure);

Selecting the fuel cycle model, creating new models of reactors according to it, as well as construction of the back-end market. Currently the possibilities for starting a new wave of investments into fundamental R&D are being formed. These R&D are connected with non-energy RT applications and the so-called nuclear renaissance (the second large cycle of development of the nuclear power industry, that is in turn connected with the new wave of investments into energy power and networks). Radiochemistry may become one of the major directions of these studies (the market of back-end and closed nuclear fuel cycle) that can result in the new generation of non-energy RT within the perspective of 15-20 years.

Gersh Itskovich Budker, Academician, 1969

Earlier the accelerators were created, as a rule, for research purposes - to analyze the structure of substance. However, ionizing radiation offers great variety of applications. The feature of the particles that allows them to pass any barriers, sometimes several meter in thickness, is used for the introscopy or internal vision. Radiation chemistry, a new and perspective science, is based on the capability of high-energy particles to stimulate and break the molecules of substance that brings to emerging of the new materials. Certain doses of radiation kill bacteria and insects, and it can be used for disinsection and disinfection of grain, sterilization of medications, conserving food, decontamination of wastewater. Radiation emission is a true assistant for doctors and biologists when they aim to stimulate the cell processes that are right for the cell and slow down the wrong ones. A well-focused beam that is carrying a huge concentration of heat energy can be used for cutting and melting of metals, drilling of rocks.

Table 1 *Main features of the stages of the radiation technologies development*

Feature	1st stage	2nd stage	3rd stage	4th stage
Basic activity	Prototyping	Research and development	Mass RT commercialization (scaling) Prototyping of the convergent technologies	Optimization, size reduction, design, RT engineering Convergence and commercialization of technologies
The essence of technological development	Creation of research infrastructure (studies of all emission types)	Expansion of non-energy RT applications (on the basis of knowledge received during the 1st stage)	Borrowing the breakthrough innovations from related industries (ICT)	Borrowing the optimizing innovations from related industries R&D for creation of essentially new technological platforms
Institutions	Creation of IAEA and the system of international RT regulation	Creation of the national normative and regulatory systems for non-energy RT Creation of the national programs and strategies of RT development	Creation of the international RT standard systems	Creation of systems and methodology of regulation for new RT applications
Market structure	Commercialization of separate segments (X-ray devices, defense and energy applications)	The market is fragmented Two segments of RT are formed: medicine (X-ray devices) and industry (industrial accelerators) Consumption takes place in the developed countries	The market undergoes active consolidation (mergers and acquisitions) Growth due to RT consumption in the developed countries Market leaders are hi-tech companies of the USA, EU, Japan Approximate volume of RT-equipment is 200 billion USD in 2010	The market is consolidated Intensive acquisitions of small innovative companies from related areas take place Growth due to the geographic expansion of the markets (BRIC countries) Appearance of the national companies in RT in the developing countries Forecast volume of RT-equipment markets is up to 500 billion USD up to 2020
Drivers	State investments into megaprojects (nuclear, space) and research infrastructures	A complex of socio-economic problems (health care reforming etc.) Revolution in petrochemistry (demand for polymerization technologies)	Globalization and creation of new industries Creation of legislation for RT, incl. introduction of the corresponding medical procedures into medical insurance programs Innovations in microelectronics and imaging.	Global trends: industrial revolution (materials engineering, project engineering), new medicine, ecology concerns Economic growth in the countries of Asia and Latin America Increased competition between producers (price/quality concerns)

02

KEY CHARACTERISTICS OF THE NEW STAGE OF RADIATION TECHNOLOGIES DEVELOPMENT

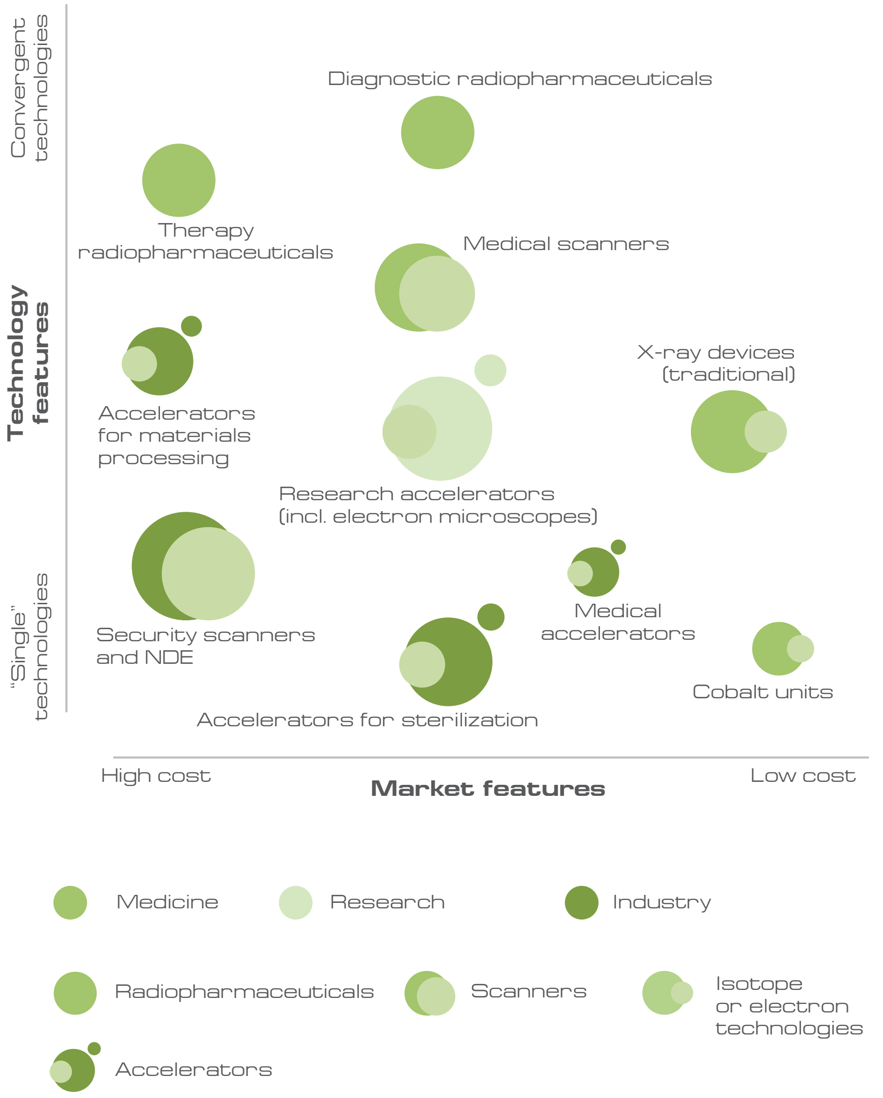
"Only by providing high quality we can gain trust to technology, to methods and approaches of the radiation medicine". Prof. Werner Burkhart, IAEA, Deputy Director General, Nuclear Science and Applications before 2010

2.1 TECHNOLOGICAL DEVELOPMENT

Basic market requirement to the equipment that will determine further development of RT will be cost reduction of the radiation sources and the equipment. Currently cost is a critical factor for mass expansion of RT, including expansion to the developing countries. Among other requirements are creation of the co-financing system that would increase radiation equipment availability (leasing, beneficial lending systems), reaching optimal parameters of emission (accuracy of the dose, reduction of time period, optimization of geometry), "ecological compatibility" in the broader sense (improving safety features, reducing potentially harmful effects of irradiation). These requirements will be essential for all areas of RT application.

AT THE FOURTH STAGE, SEVERAL FEATURES WILL BE CHARACTERIZING TECHNOLOGICAL DEVELOPMENT OF THE RADIATION TECHNOLOGIES, AMONG THEM COMBINING TECHNOLOGIES, IMPLEMENTING INNOVATIONS FROM THE RELATED SPHERES, ETC

Figure 3 *Factor scheme of radiation technologies development*



Source: CSR "North-West"

The main feature of the technological development during the fourth stage will be wide spreading of convergent radiation technologies[1].

1 Convergence is the process of mutual influence and interpenetration of technologies that leads to emerging of essentially new technologies and spheres of knowledge within the framework of cross-disciplinary work.

2.1.1 CONVERGENCE OF TECHNOLOGIES

THE MAIN FEATURE OF THE NEW FOURTH STAGE OF RT DEVELOPMENT IS ONE OF THE BASIC TECHNOLOGICAL TRENDS OF THE FIRST HALF OF THE 21ST CENTURY – INTENSIFICATION OF CONVERGENCE (OR INTERPENETRATION) BETWEEN VARIOUS TECHNOLOGIES, AND GRADUAL ERASING OF BORDERS BETWEEN DIFFERENT TECHNOLOGIES AND FIELDS OF KNOWLEDGE

As the development of radiation technologies initially took place, among other things, due to convergence (for instance, dramatic advancements in the sphere of nuclear medicine became possible due to achievements in biology, chemistry, physics and computer science), we can expect that this trend will also significantly influence the next cycle of RT development.

THE MOST LIKELY ARE THE FOLLOWING FOUR DIRECTIONS OF DEVELOPMENT:

Convergence with biotechnologies (in medicine). New ways of transporting isotopes totumors that developed with the use of modern nano- and biotechnologies, will allow to increase effectiveness of radioactive treatment and diagnostics. In particular, there are clinical trials that are aimed at discovering new methods of transportation of the emission source (rhenium-186) by liposomes with cross dimension

100 n.m. to brain tumor. Due to the low energy of the emitted electrons, rhenium is not encapsulated, and low energy of the particles allows practically pinpoint irradiation, as the depth of emission penetration into the tissue is negligibly small. Such approach allows tumor treatment with incomparably higher radiation doses — 20–30 times higher than today and without any damage to healthy brain tissue. In this case convergence is complex with nano- and biochemical methods of synthesis in relation to radio-resistant isotope bio-carriers — the liposomes.

Convergence with robotechnics. Industrial robots applications will grow rapidly. Even now the key areas of RT application in the industry simultaneously represent the major markets of robots – besides automobile construction, they include electronics (20%), chemical industry (10%), automotive industry and metallurgy. Robotization is also considered to be one of the most prospective directions of medical technics. It also includes RT applications: in particular, in 2010-2011 there were initiated projects for identifying advantages and disadvantages of robotic radio-surgical systems in comparison with the traditional equipment for X-ray treatment – with gantry[2].

3D

printers use electron-beam melting

Convergence with materials processing technologies. One of the most important examples of such convergence is RT applications in **3D-printing**. One of the technologies used in 3D-printers is electron-beam melting. It is used in production of all-metal details out of powder metal. Taking into account the expected rate of growth of the corresponding market (from 1.4 billion USD in 2011 up to 3 billion USD in 2016[3]) and growth in precision of RT-devices, we can expect significant development in this direction. Indirect relation to the trend of merging different technologies within the framework of the unified complex brings a principal change of approach to the design of factories, hospitals, laboratories. There are being designed not the separate devices but the technological cycles that use certain type of emission as a factor.

Finally, cognitive technologies will become «cross-linking» technologies for the convergence (6D-modelling that allows taking into account different components of the end product and their development with time).

2 For example, the research "Robotic Compared to Fixed Gantry Radiosurgery for Brain Metastases (TRICK)" sponsored by the U.S. National Institute of Health.

3 Source: research of IBISWorld.

Case study

COMPETENCIES OF RUSSIA

NATIONAL RESEARCH CENTER «KURCHATOV INSTITUTE» DIRECTOR OF THE CENTRE, CORRESPONDING MEMBER OF THE RAS, M.V. KOVALCHUKK

«The logic of the scientific development itself has brought us from narrow specialization to interdisciplinary work, then to the above-disciplinary work, and further on, in fact, to the need of merging of different sciences. However, it should result not in simple geometric addition, but in synergy effect and interpenetration.

At the first stage, it means unification of the four global directions of today science and technology: NBIC. "N" stands for nano, a new approach to customized materials design by nuclear and molecular construction; "B" stands for bio, for introduction of the biological part into the non-organic materials design and thus receiving hybrid materials; "I" is for information technologies that give us an opportunity to combine the above mentioned hybrid material or system with an integral scheme and receive an essentially new intellectual system, and "C" means cognitive technologies that are based on exploring mind, cognition, thinking process, behavior of live beings and first of all of a man – both from the neurophysiological and molecular-biological point of view, and from the humanities point of view.

Adding cognitive technologies gives a possibility to develop algorithms based on the studies of brain functions, cognitive mechanisms, live creatures' behavior. These algorithms, in fact, "animate" the systems that we create and give them something similar to the thinking functions. The sense of creating NBIC-center at Kurchatov Institute was in forming this infrastructure basis for convergence of sciences and technologies. The core around which the Kurchatov NBIC-center is built is the unique combination of world-class megaplants – sources of synchrotron and neutron emission. Kurchatov NBIC-center includes a new building for nanotechnology, modernized and reconstructed IR-8 neutron reactor, data processing and storage center on the basis of a supercomputer. In the Center there is collected unique X-ray equipment, atomic force and electron microscopes, various technological equipment for nanobiotechnologies and microelectronics, cleanroom spaces and many. It is necessary to mention that the largest part of this unique equipment is developed and produced by Russian companies.

The main objective of the convergence of these four directions is to create a new technological culture aimed first of all at designing hybrid materials and systems based on these materials. Here we speak about the essentially new generation of anthropomorphous bionic systems that copy the constructions we meet in nature – or biorobototechnical systems. For these purposes, in the Kurchatov NBIC-centre we have created a scientific and technological platform with the code name "HYBRID".[1]

1 Source: M.V. Kovalchuk, Russian Nanotechnology, January-February 2011 vol. 6, № 1-2, «Convergence of sciences and technologies – a breakthrough to the future"

2.1.2 TECHNOLOGICAL COMBINATION (INTEGRATION OF DIFFERENT METHODS WITHIN THE FRAMEWORK OF A SINGLE TECHNOLOGICAL COMPLEX)

ONE OF THE KEY FEATURES OF THE NEXT-GENERATION TECHNOLOGICAL SOLUTIONS BASED ON RT IS COMBINATION OF DIFFERENT NUCLEAR-PHYSICS METHODS IN ONE SYSTEM WITH THE TRADITIONAL TECHNOLOGIES

This trend is the most evident in medicine: such systems as Image Guided Radiotherapy and Sonolith I-Sys are already being used. In addition, integration of different nuclear-phycics methods with extending their functions took place in some industrial methods using RT, for instance, in coating systems. The respective equipment often integrates different technologies: ion-plasma and magnetron spraying.

Only by providing high quality we can gain trust to the technology, to methods and approaches of the radiation medicine. A firm and strong system will provide safe and effective usage of the technology at the technical level, and will allow maintenance staff not to doubt when explaining to the patients the good of radiation for them. New technologies represent progress, better opportunities for diagnostics and treatment.

Prof. Werner Burkhart, IAEA, Deputy Director General, Nuclear Science and Applications before 2010

INTEGRATION OF DIFFERENT TECHNOLOGIES PROVIDES NEW POTENTIAL FOR QUALITATIVE CHARACTERISTICS OF RT USED IN DIFFERENT SPHERES:

In the sphere of medical diagnostics the limits of accuracy in defining topography and metabolism of tumors and other pathologies by certain methods have been already reached, and further progress in accuracy can be obtained only by complementing and combining several research methods in one system. The highest potential lies in the sphere of combining different diagnostic RTs (PET/CAT, PET/NMR, SPECT/CAT). Research in the most promising direction (PET/NMR integration) has been going since the mid-2000s – in particular, by joint project teams of different corporations and research centers[4]. Moreover, in 2011 a team of researchers from Peking University[5] launched a project on designing a multipurpose diagnostic unit which would integrate CAT (X-ray tomography), PET, SPECT and FMT (fluorescent molecular tomography).

In addition, in the medical sphere combination of technologies will affect the very processes of therapy and diagnostics in the first place; in particular, combination provides opportunities for development of the so called **"theranostics"** (integration of diagnostics and therapy processes, even at the level of one medicine that can be simultaneously diagnostic and therapeutic)[6];

4 In particular, in 2007 a group of representatives from Laboratory for Preclinical Imaging and Imaging Technology (Werner Siemens Foundation), Siemens Preclinical Solutions, University of California (Department of Biomedical Engineering), Max Planck Institute for Biological Cybernetics, Eberhard Karls University (Department of Medical Biometry), etc. conducted a big set of surveys.

5 Representatives of Tsinghua University, Shanghai Jiaotong University, South Medical School, Hebei University, PKU Founder Group, Hospital 301, Shanghai Ruijin Hospital, PKU Health Science Center, PKU First Hospital, and PKU Third Hospital.

6 It should be understood that the potential for improving quality of medical services related to radiology also lies in the combination of different medical methods. For example, in the so called 'combined therapy' neutron therapy is conducted first to remove radio resistance of the tumor, and then it is followed by traditional gamma-ray therapy. In the meanwhile, such methods are not directly related to the characteristics of RT equipment.

Similar integration of different technological processes in RT will also be characteristic for RT usage in **security industry**. At the moment the principal problem in this area is to create technically and organizationally efficient security systems based on combination of different methods having their own advantages and constraints. Minimizing constraints can be reached by the optimal combination of these methods. One of such efficient combinations, for example, is neutron analysis used together with radioscopy in developing screeners for cargo, transport (except examination of people) and methods of non-destructive material control.

Combination of RT-processes in visualization will allow to operate 4D-images, reflecting both structural and functional features of the examined object in medical diagnostics (PET/NMR/CAT) and security systems (X-ray, neutron technologies, magnetic fields of adjustable intensity).

ENHANCEMENT OF THE EXISTING FUNCTIONALITY OF THE EQUIPMENT CAN BECOME A SEPARATE DIRECTION FOR RT DEVELOPMENT

For example, for accelerating equipment such enhancement can be reached by generating different emission types by one accelerator. Back in the mid-1990s there were created first specimens of medical and industrial accelerators that radiated soft X-ray (6MeV), hard X-ray (10-20 MeV) and a whole spectrum of electron beams (up to 10 specifications within the range from 6 to 20 MeV)[7].

7 Source: American Association of Physicists in Medicine

2.1.3 IMPLEMENTATION OF OPTIMIZING INNOVATIVE SOLUTIONS

Intensive production and implementation of innovations in various fields (life science, new materials, energy, etc.) will stimulate transformation in many other high technological areas, including non-energy radiation technologies. The following technological drivers can bring RT to the new level of development and ensure their competitiveness:

New materials. Applying nanotechnologies in the modules for radiochemical production and creating materials with high index of absorption will considerably simplify the problem of infrastructure security (shielding materials and walls) for the majority of units that use ionizing radiation. New materials are the basis for appearance of the next generation of the radiation-resistant and highly sensitive detectors, including detectors for the new types of medical diagnostic scanners (PET, SPECT, NMR, etc.). One of the most promising directions is development and mass production of quantum-sensitive detectors based on compound semiconductors doped with ion beams. Currently the most popular among binary and ternary compounds are GaAs, CdTe and CdZnTe[8].

Composite materials with high reflection factor and unique magnetic qualities can become a separate direction related to the new materials in RT. They can be used for creation of micro-accelerators on an essentially new technological basis. Thus, in the years 2010-2011 it was announced about a series of research aimed at minimizing the size of charged particles accelerators[9];

Superconductivity technologies. Superconductors have already been used in accelerating equipment: in magnet construction (Nuclotron in Joint Institute for Nuclear Research in Dubna, Large hadron collider, etc.) and in construction of particle detectors in high-energy physics, in research units for thermonuclear fusion, in nuclear-magnetic spectrometers for material structure studies, in medical magnetic resonance tomographic scanners. **Superconductors can become the technological basis for improving widely applied cryogenic methods** in large research and medical accelerators, as well as for enhancing efficiency and reducing the size of accelerating systems for therapy of malignant neoplasms and for production of radioisotopes. Great expectations are connected with the applications of superconducting magnetic systems for synchrotron development: superconductivity allows to reduce the radius of the ring and to considerably decrease the consumed power (in particular, American

8 The last two stand closer to prospective materials because of their high price and absense of mass production technology.

9 In particular, Cornell University conducts research in close collaboration with SonicMEMS Laboratory – department of the university which studies problems of micro-electromechanical systems (including materials and micro power-sources).

project SSC for the energy with 20 GeV per beam is designed using this principle).

New-energy technologies. Developing different types of autonomous power supply systems (RITEGs, fuel isotopic cubicles, etc.) and energy storage systems can become the basis for the whole range of principal changes in RT. It can provide higher mobility of the equipment (mobile PET and SPECT units, accelerators, different types of X-ray units, mobile screeners, etc.), as well as smaller sizes of the equipment.

2.1.4 SIZE REDUCTION: FROM BIG TO SMALL

Introduction of the revolutionary innovations from related spheres, improvement of engineering and production technologies, and necessity to maintain competitiveness of products by price and functionality make it possible to design RT-equipment of any size: from ultra-big technological systems (such as screeners for cargo containers) to ultra-small RT-units, first of all, diagnostic units for medical and industrial diagnostics and accelerators.

Size reduction has already influenced the most widespread (and commercialized first) type of RT diagnostic equipment – X-ray units. Mobile X-ray units have been produced since the end of the 1960s. Nowadays compact units are widely spread and are used in dentistry, veterinary medicine, 'field' medicine (in defense and emergency departments), and in industrial diagnostics for the method of non-destructive control (for pipelines).

In the mid-2000s research and development of compact[10] and ultra-compact (micro) accelerators were launched.

10 Thus, on 25th of October 2011 Siemens Company announced that it started collaboration with Science and Technology Facilities Council of Great Britain; one of the targets of this collaboration is to develop a cheap compact modular accelerator – Direct Current Electrostatic Accelerator.

BASIC IDEAS FOR DESIGNING MICRO-ACCELERATORS WERE ACTUALLY TAKEN FROM THE "NEW MATERIALS SCIENCE", THAT IS RELATED IN THE FIRST PLACE TO MICROELECTRONICS PRODUCTION (COMPOSITE MATERIALS WITH HIGH REFLECTION FACTOR SUITABLE FOR PRODUCTION OF MICRO- AND NANOTUBES)

Some of the potential application fields for such accelerators are medicine (a scalpel based on a proton beam, high precision radiation therapy), cosmetology, all types of sterilization, fundamental research (a possibility to use high energy with smaller-sized accelerators, portable electronic microscopes) and others.

Size reduction (along with specialization – moving from the units that scan the whole body to the specialized units that scan thorax or cervical spine) is an important trend for all types of medical tomographic systems (PET, SPECT and other)[11].

11 Source: Elaine H. Wacholtz, «The History and Development of PET» (Enterprises for Continuing Education Inc.).

2.1.5 DEVELOPMENT OF DATA PROCESSING AND DATA PRESENTATION

Development of all modern medical diagnostic equipment and security systems was closely related to appearance and quick development of computer technologies. New data formats and data processing systems will provide a whole range of possibilities for future progress at the fourth stage of RT development:

Further improvement of **image processing technologies** (from 3D-images construction in real time to data storage systems[12]) will make possible developing of the new application of RT. Moreover, it will push further wide spreading of the next-generation equipment: image-guided radiation therapy, more accurate and reliable screeners, devices for non-destructive control of buildings and construction of outstanding by importance objects (for example, nuclear reactors);

Development of communication technologies and creation of common storage systems (of the regional, national, international level) and systems of processing medical information, together with usage of cloud systems and virtual working space systems will provide a whole range of new opportunities for RT-equipment usage. Among them there can be access via Internet, flexible system of installing and maintaining radiation equipment, remote data processing, data output to the end-user machines, integration of products and services between the main platforms. Similar solutions are already being implemented for synchrotron radiation sources – the latter have a vast user network in different parts of the world;

New data analysis and storage systems will open opportunities for **virtual (digital) designing of processes** related to RT (beam control, mapping of real radiation doses) and for the processes that take place in organic and inorganic substance under ionizing radiation (controlled transformation with gaining certain qualities or effects). Simulation mathematical models related to ionizing radiation will be embedded in basic software tools for sophisticated engineering, in the first place, in new materials, nanotechnologies, biotechnologies, life support systems, medicine[13]. In this connection, a separate important direction is modeling of diagnostic processes[14] on the incoming data stream received from traditional non-sophisticated diagnostic systems (chemical analysis data, ultrasound, etc.).

12 For example, in 2011 Acuo Technologies introduced into the market Universal Clinical Platform (UCP3) based on DICOM Services Grid which is designed for diagnostic pictures and images control. This system is designed for managing the whole life-cycle of an image (from transmission of visual data and its analysis to archiving and on-line storing).

13 In particular, from the mid-2000s integrated medical databases and Minerva class of systems (multimodal cancer treatment systems) have been developed. They will allow fulfilling oncological diagnostics and complete cycle therapy by efficiently choosing among different therapy methods (RT, chemotherapy, surgery) that depend on incoming information – diagnosis, individual information about the treatment course, organism response to the therapy, etc.

14 For example, processes «in silico» (undertaking a biological experiment on a computer)

At last one of the most evident contributions of ICT to the development of radiation technologies will become creation of **efficient user interfaces** – the pre-programmed operation regime modes that depend on the tasks of radiation sources control. The goal is to withdraw from the "manual control" of the units. It is supposed that they will be transformed into devices operation of which does not require unique competence (nowadays RT and the related equipment are so sophisticated that on average it takes about 4-5 years to prepare competent operators who are able to operate this equipment and know these technologies – even after they have graduated from a special university). Making operation of the equipment easier is a principle point for RT market expansion.

2.1.6 NEW DESIGN AND PRODUCTION TECHNOLOGIES

In the nearest 10-15 years the key market requirement for the suppliers of hi-tech radiation equipment (in terms of production management and ensuring market competitiveness) may become implementation of life cycle management systems and 6D design as the most efficient technologies for production process optimization:

Life cycle management concept has already become the basis for optimization of engineering of the industrial objects/projects with the following characteristics: super complicated (up to 10 million parts), geographically distributed (up to 1000 contractors), interindustry (including requirements to manufacturing flexibility). Nowadays the concept of life cycle management is implemented in design, construction and maintaining of the most hi-tech and complex objects with long service life (for example, nuclear power plants);

Modern design and quick prototyping. The concept of 6D design changes the traditional scheme of product creation, sets new challenges for personnel and requires systematic innovations in management. 6D design means that three more elements - time (product scheduling), equipment (configuration, kitting and supply of materials and units), resources (labour, financial and other) – are added to the traditional design in three dimensions (3D). Quick prototyping technology, in turn, allows to promptly create prototypes or working models of systems for demonstration to the customer or checking the possibility of its realization. It considerably accelerates implementation of research and development results into industrial production.

A separate factor that increases demand for 6D-design and optimization of RT production processes is the progressive growth of cooperation in research and development, as well as further development of open innovation. At the pre-market level the cooperating companies solve scientific issues and, in our case, they estimate the prospects of the radiation processes usage, get principal technical solutions and create prototypes of the end products (sources, units). After the prototypes have been made, major competitive efforts begin at the stage of organizing the most efficient and cheap production possible, in other words –

COMPETITION SHIFTS INTO PRODUCTION ENGINEERING, INCLUDING PRODUCTION ENGINEERING OF THE EQUIPMENT FOR RT

Taking into account the emerging research consortiums formed by the companies that possess competences in RT area (for example, consortium Siemens-Varian in radiation therapy and diagnostics) and a range of cluster projects in this sphere (Atlanpole Biotherapies, clusters in materials science and others), we can expect widespread use of 6D design and life cycle management systems at the new stage of RT development.

2.2 EFFECTS AT THE NEW DEVELOPMENT STAGE OF RADIATION TECHNOLOGIES

2.1.1 COST REDUCTION OF THE EQUIPMENT

The most important result of radiation technologies development at the fourth level from the commercial point of view will be considerable cost reduction of the equipment due to its size reduction (thus saving expensive space), adopting innovations from the related areas, optimizing production processes, etc.

THERE CAN BE MENTIONED THE FOLLOWING SOURCES FOR COST REDUCTION OF THE RT EQUIPMENT:

The first source (by importance) will be its **size reduction** with maintaining full or almost full functionality of the prototypes. An obvious example of cost reduction potential is an X-ray unit. A fixed X-ray device costs up to 150 thousand USD, the average price of a mobile device (which has slightly inferior characteristics) is from 500 to 1000 USD;

One more source for the RT cost reduction is **complexation of the equipment**. The cost of a complex unit (for example, combined PET/CAT) is comparable with the total cost of separate units. For instance, PET/CAT unit costs up to 4 million USD, PET scanner costs up to 3 million USD, CAT scanner costs up to 160 thousand USD, and the price of one procedure at PET/CAT unit is considerably lower than the total price of two procedures – at PET unit and CAT unit. So, PET/CAT scanning costs up to 10.5 thousand USD, PET scanning costs up to 10 thousand USD, CAT scanning costs up to 6 thousand USD.

An important resource for RT cost reduction will be the **implementation of "cost-cutting innovations"** including the ones borrowed from other areas. An obvious example of "cost-cutting innovation" is the essentially new low-cost plastic scintilloscope SCINTIREX developed by Teijin Chemicals Limited. According to the developers, using this scintilloscope will allow to reduce the production price of plastic scintilloscopes more than 10-fold compared to analog products, and thus will help to reduce general cost of dosimeters and registration units in medical diagnostics, screening systems etc.;

Besides that, additional cost reduction of RT equipment can be gained due to **cost reduction in "related" technologies**, in particular, in digital visualization technologies: an X-ray unit with digital visualization system costs about 120 thousand USD, while a unit with traditional Polaroid film technologies costs from 15 to 25 thousand USD. A separate process that can reduce the cost of RT equipment is the trend for cost reduction for microelectronics. However, it is worth mentioning that in some cases the cost of "accompanying" industrial equipment (beam scanning systems, production line systems and different types of radiation monitoring systems) is comparable with the cost of the emission source itself. That is why cheaper production technologies reduce the cost of the whole radiation unit.

COST REDUCTION OF RT EQUIPMENT WILL CONSIDERABLY INFLUENCE A RANGE OF MARKETS AND INDUSTRIES RELATED TO THE USAGE OF THE IONIZING RADIATION:

Medicine. Firstly, there will take place geographical market expansion, and RT equipment will become affordable to developing countries (including the countries which have only the state medicine). Secondly, cost and size reduction of accelerating equipment (for example, proton accelerators) will make the corresponding equipment and services more affordable and in turn will raise the demand for them.

Food treatment. Under conditions of the continuously increasing food export (consumption center is moving to Asian countries, in the first place to China) and improvement of the quality standards for food at the international level, cost reduction of accelerating equipment for pasteurization/disinsection/disinfection will make RT treatment mandatory in the infrastructure of the "food hubs" (large transfer points where quality control of food products should take place among other activities - agricultural holdings; port facilities for grain logistics, etc.)[15]

Environmental safety. Cost and size reduction of accelerating equipment allows to widely use accelerators in the area of environmental safety. An R&D complex in this area has been already completed; there are separate projects using RT[16]. As a matter of fact, high price for such RT units is the only obstacle for using RT in mass recycling of solid household and medical waste, fuel gas refining and water refining (both for drinkable water and waste water).

Industrial modification of rubber and polymers. According to Japanese companies reduction by 1% of the radiation treatment cost of radial car tyres in order to increase their strength and enhance mileage allows to save over 50 million USD per year. Japanese market volume is 2.5 billion USD, the US market volume is over 5 billion USD.

The potential of cost reduction in security and other industrial applications of RT is not so substantial as in the four areas described above.

An important factor for providing easier access to radiation equipment and technologies is designing the system of beneficial financing for their development and purchasing (beneficial bank loans, withdrawal of customs fees, leasing and a range of other financial and legal measures,

15 *Even today radiation processing of food is competitive in price with other methods of disinfection and extension of the product shelf life (cold disinfection, pasteurization, etc.). According to American Nuclear Society, low-dose radiation processing of 1 ton of products costs from 10 to 15 USD, high dose processing costs from 100 to 250USD. In particular, in fruit processing the cost of radiation processing is 10-20% less than the cost of an alternative method – processing with high temperature vapor.*

16 *In Japan there exist pilot facilities at the plant for recycling solid household waste with an RT unit for tyre treatment; there exist working radiation units for refining of fuel gases (a more well-known example is the same unit in coal power plant in Pomorzany, Poland); in different parts of the world there is conducted research and development related to water refining (both drinking and waste water).*

Modern accelerator technologies have made one more step forward. Additional possibilities of their usage are available now. While in the preceding decades particle beams for cancer therapy and superconductive magnets for tomography have been introduced, the hopes for the future are based on superconductive linear accelerators. They provide a low-cost opportunity for receiving power currents, energy and power. The potential of these technologies for the society is huge, from production of medical isotopes and recycling radioactive waste from nuclear power plants to creation of the new industry for production of the pure energy at highly subcritical thorium reactors controlled by proton beams.

Vladimir Dmitrievich Shiltsev, Director of Accelerator Physics Center, Fermilab. Chicago, USA

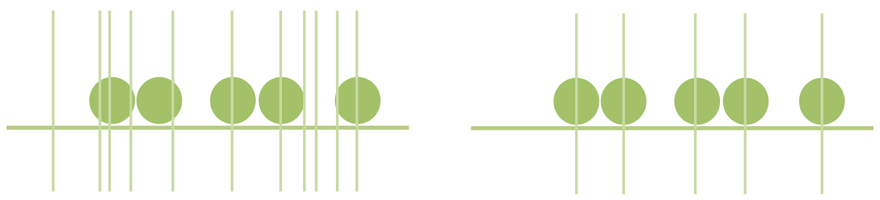
including those based on the new international agreements). It will allow stabilizing the long-existing markets, opening markets of the developing countries and thus globalizing radiation equipment and technologies markets.

2.2.2 IMPROVEMENT OF CORRECTNESS AND PRECISION OF ALL OPERATION TYPES CONDUCTED WITH THE HELP OF RT EQUIPMENT

Improvement of service correctness and needed radiation parameters accuracy while using RT equipment with ionizing radiation will be provided in the following directions:

Improvement of **beam control technologies** for receiving necessary characteristics. The main result of more accurate beam aiming and configuration is the possibility to radically reduce radiation doses and simultaneously to work with organic and inorganic materials at the cellular level and, in perspective, at the molecular level. Micro- and nanobeams will be first spread in the industries that already use beam technologies, including production of new materials, medicine, etc.

Figure 4 *Characteristics of a traditional beam and a microbeam of particles*



Improvement of **technologies of the emission identification** (detectors, sensors). The problem of providing higher resolution will be solved by a range of the following measures:

- Using detectors of smaller size (thus adding to scanner sensitivity);
- Using new materials in detectors (including the compounds with rare-earth elements (LSO, GSO, LYSO), «multi-layer» crystals, compounds of CdTe/CdZnTe and others) as an alternative to traditional crystals based on bithmus germinate (BGO);
- Combination of different technologies in the framework of one system (as mentioned in 2.1.2.). Radioactive emission precision will be improved due to complementing and combining different research methods in one system;

Improvement of **"targeting technologies"** due to the development of biotechnologies and new means of delivery (bio-radiopharmaceuticals that use for delivery monoclonal antibodies, peptides, etc.). As a matter of fact, development and application of biochemical markers along with the active usage of accurate PET-diagnostics and visualization is the technological basis of this concept.

IMPROVEMENT OF ACCURACY IN RT-EQUIPMENT USAGE WILL CHANGE CHARACTERISTICS OF MANY PRODUCTS AND SERVICES THAT ARE CREATED WITH THE HELP OF IONIZING RADIATION:

In microelectronics and new materials production. Creating technologies for generation of micro- and nanobeams (ideally the one-particle-width beams) will lead to appearance and mass production of the new generation equipment for materials modification. Similar units are already used in some areas: in production related to nano-materials the FIB-units (fine-focus ion beam) are used. They allow to generate a beam of several tens of nanometers. The main application of this equipment is producing microelectronics by ion lithography method; prototyping and direct designing of nano-structures by implanting ions in different materials; extracting nano-size samples from the materials for analysis.

In medicine (therapy). The main area related to higher accuracy of beam delivery to the place of exposure is INMR - Intensity modulated radiotherapy. It allows changing intensity of the beam, size and shape of the dosing area depending on location, size and shape of a tumor. On one hand, this technology allows steady irradiation of a tumor (or another target), which can be of an irregular shape, and on the other hand, allows to minimize the radiation dose for the tumor-surrounding tissues (provide «radiation selectivity») and mitigate the risk of further complications including the oncological ones. Among vivid examples of the systems using the complex of modern achievements are TomoTherapy Hi-Art and Cyberknife CyberKnife VSI (Accuray Company) or RapidArc (Varian medical systems companies);

In medical diagnostics development of the new generation equipment is oriented at the improvement of sensitivity of the registration systems and improvement of quality of image recognition (providing higher image spatial resolution), at the reduction of radiation doses for the patients and reduction of time taken by the procedures. Thus, complex units like PET/CAT, PET/NMR, SPECT/CAT allow to simultaneously visualize and analyze functional and morphological features of tissues and organs. In addition, considerable improvement of detector sensitivity will allow in full realize potential of the diagnostics at cellular/molecular level (molecular imaging);

In security. The critical success factor for further development of security systems is improvement of the resolution of RT units used for detecting dangerous substances (shell-less explosives, drugs, radioactive materials) by space and atomic number of the chemical elements compounding the object under examination.

2.2.3 «QUALITATIVE» DEVELOPMENT OF RT MARKETS

Reducing the cost and increasing precision of RT equipment together with the complex processes of integration and convergence will lead to qualitative transformation of RT markets, in the first place, at the established markets. Meanwhile, the changes taking place in production and science will create new niches and new markets for radiation technologies.

At the established markets where radiation technologies are already present it **is important to expand areas for RT applications**. Main directions of the RT applications growth at the existing markets are the following:

Increasing applications in medicine. New generation of the equipment for remote radiation therapy allows surgery both on brain tumors that were non-operable before and on other organs.

RADIATION TECHNOLOGIES ARE BEING USED MORE FREQUENTLY IN ALLERGOLOGY, TRAUMATOLOGY, PEDIATRICS, IMMUNOLOGY, HEPATOLOGY, PULMONOLOGY, HAEMOTOLOGY AND ENDOCRINOLOGY

In the recent years there have been conducted series of research and clinical trials on radionuclide therapy applications for rheumatoid arthritis and other joint diseases treatment, cardiac diseases treatment, lung cancer treatment, large intestine, prostate, pancreas diseases treatment, meningitis and AIDS treatment.

Expanded RT applicatios in pharmaceutics and biochemistry. Merck, Glaxo, Pfizer, Bristol-Myers-Squibb, Genentech, Johnson&Jonson and many other pharmaceutical companies have launched individual or joint programs of using radiation visualization in drug research and development. Accurate visualization is needed both in pharmacokinetics by marking the desired medicine molecules and in pharmacodynamics due to visualization of the key processes (for example, glycolysis, proliferation and hypoxia).

Expanded RT application areas in the processes related to modification of materials surface. Together with the traditional ion doping and etching in semiconductor industry, ionic technologies are being increasingly used to improve protection and strength features of products used in mechanical engineering. Usage of ions allows improving strength, tribological characteristics of the surface layers and their corrosion resistance. Usage of computer modeling in order to forecast the characteristics of the generated coatings will allow moving to production of coatings with programmed characteristics.

RT applications actively expand to the new parts of traditional application areas such as **sterilization, decontamination or aseptic treatment of food and organic substances.**

COMBINED STERILIZATION OF ORGANIC AND INORGANIC SUBSTANCES TAKES PLACE – FOR EXAMPLE, STERILIZATION OF COSMETICS, BABY DIAPERS AND OTHER CONSUMER GOODS, BLOOD STERILIZATION

It is possible to use RT for receiving new features of biomaterials and some organisms[17], and also for improving flavor of some food products[18];

17 For example, inducing delay in crop growth, improvement of germination capacity, mutations for selecting species resistant to certain impacts or species that produce larger volumes of biofuel.

18 An example of practical application of RT in food industry is shown by the experiments of Chinese researchers: they conducted experiments with irradiation of food and found out that under radiation the young wine gets properties of the aged wine.

An important direction of RT applications expansion is mass introduction of **radiation analysis methods** for materials (construction[19] and other materials, geological prospecting[20], etc.);

Current trends in development of many industries and knowledge fields form **absolutely new markets** of RT applications with the following important directions:

New niches and sub-markets in medicine related to the concepts of personalized medicine (boost in complex diagnostics and biochemical research)[21], preventive medicine (need for genetic analysis with the help of RT equipment)[22], nanomedicine;

Rapid increase of research and development (and their commercialization) is observed **in life science**. Niches for RT are being formed due to: 1) the growing demand for biocompatible materials (one of the basic technologies for biomaterials production is ion implantation)[23] – in 2008 the volume of biocompatible materials market made up 25.6 billion USD, forecast for 2015 is 64.7 billion USD; 2) the development of bioengineering (ion implantation is already used in one of the main areas of bioengineering – in genetic engineering[24]).

Need for the new materials and materials with the pre-programmed characteristics means that there will be demand for the equipment that changes properties of materials and, in the first place, for the equipment that uses radiation technologies. The current process of shifting to composite materials can be compared to the revolution in chemical production that took place in the beginning of the 1960s.

One of the promising areas of RT applications is **the market of environmental technologies** (recycling of solid household waste, medical waste, refining waste water, etc.). At the moment the demand is low, and the presence of RT in these markets is insignificant, mainly due to the high cost of RT units. Cost reduction will make possible fast expansion of RT in the corresponding market sectors.

19 Thus in cement production neutron analysis helps optimize the ratio of mixed substances before their processing and control chemical uniformity of the produced material. Fast neutron method also defines oxygen containing and correspondingly the humidity of the product without any additionally installed analyzers.

20 Geophysical nuclear logging is essential in mining industry for opening and exploitation of coal and mineral mines. Neutron analysis helps to prospect the mineral beds and monitor product quality during mining. Neutron analyzers can be calibrated for analysis of wide range of minerals.

21 Radioisotope visualization is one of the most efficient ways to monitor biochemical processes in the organism, defining the norm, the pathology and sources of the diseases.

22 Development and application of biochemical markers together with the progressive use of accurate PET diagnostics and visualization is the key point of this concept.

23 Introduction of admixture atoms into the surface of the plate or epitaxial film by bombing it with a beam of ions; modification of materials ensuring biocompatibility, wear resistance, etc.

24 From the early 2000s low energy ion beam technology has been actively spreading as a research instrument in biotechnology. Its main function is irradiation of microorganisms (or normal-sized organisms) in order to initiate gene transfer and mutation breeding.

2.3 2012-2020: NON-ENERGY RADIATION TECHNOLOGIES AND DIRECTIONS WITH THE HIGHEST POTENTIAL

It is expected that during the fourth stage two main groups of radiation technologies will be developed. The first direction is technologies already existing in the market – they will grow due to expansion of application spheres, optimization of cost parameters, geographical market expansion. The second direction is technologies yet intended for commercialization - research technologies, technologies at the R&D stage.

2.3.1. COMMERCIALIZATION OF THE NEW RADIATION TECHNOLOGIES

The first group of prospective technological solutions is connected with direct scaling of emission technologies – beam creation and control. Commercially promising R&D in the sphere of accelerator equipment is accumulated in the following directions:

Creation of linear accelerators and cyclotrons that use **superconducting radio-frequency resonators** in order to increase particle acceleration rate. Such resonators can enhance the efficiency and reduce the size of accelerator systems. The basis for using this technology is creation of cryogenic systems that are able to provide the temperature required for functioning of superconductors;

Development of new concepts in accelerator equipment, first of all – the concept of **micro accelerators** on chips. Currently in the USA several groups of researchers – including those at Cornell University (research sponsored by DARPA), at the National Accelerators Laboratory of Stanford University (SLAC), at the University of California, etc. – conduct R&D connected with miniaturization of charged particles accelerators. The researchers suggest different configurations of micro accelerators: the «laser – electron beam – photonic crystal» system, where electron acceleration comes as a result of formation of powerful electromagnetic fields in the target under short (femtosecond) laser impulses, the silicon-on-insulator (SOI) technology, etc.;

An important direction of R&D is **creation of the equipment based on laser-driven accelerator systems;**

Also actual is the direction of the **cyclotrons with strong focusing.** Several laboratories in the USA are now developing a fixed field cyclotron with strong focusing (FFAG).

Our mission is to develop revolutionary technologies and create unique accelerators for science, energy, medicine, security, ecology and industry. Technological applications of accelerators are the key to solving essential problems of humanity development.

Lawrence Berkeley National Laboratory, Department of Accelerator and Fusion Research

EQUIPMENT OF THE NEW GENERATION – SMALLER IN SIZE, CHEAPER AND MORE ENERGY EFFICIENT – IS BEING DEVELOPED. THIS EQUIPMENT WILL GENERATE EMISSION TYPES – NEUTRON, PROTON, SYNCHROTRON - THAT EARLIER HAVE BEEN USED FOR RESEARCH ONLY AND HAD NO COMMERCIAL APPLICATIONS:

Commercial prototypes of high-quality compact neutron generators for neutron and neutron-capture therapy, and for the systems of the explosives detection have already been created[25], and their wide spreading in the relevant application areas may begin as soon as in 2015-2016.

The work is also being conducted in the field of creation more compact and cheap **proton emission sources**. Researchers and engineers of the Compact Particle Acceleration Corporation (CPAC) in Livermore, California, proceed with the development of the particles accelerator that is 4 meter long, with the total cost of no more than 30 million USD. The prototype of the CPAC accelerator uses electromagnetic field for particles acceleration and has no need in bulky supplementary equipment. Also, the decrease in proton loss during the acceleration process and their localization soften the requirements for biological protection;

Synchrotron emission sources are the unique and extremely convenient research tools providing the opportunity to use wide emission spectrum (from vacuum ultraviolet to hard X-ray emission). Synchrotron radiation is used for R&D in various fields, including pharmaceutics, biotechnologies, materials science, etc. The bulkiness of synchrotrons (ring diameter up to several hundred meters) and their high cost (from 20 million USD), as well as extremely high power (from hundreds MeV and higher), make it impossible to use synchrotrons widely in medicine or in industry in the mid-term perspective. However, creation smaller-sized sources of synchrotron radiation and their wide usage in medicine or industry may become possible in the long-term perspective – after the year 2025 (for nanotechnologies, composites, usage of laser technologies for provision of charged particles acceleration).

2.3.2. DEVELOPMENT OF THE COMMERCIAL RADIATION TECHNOLOGIES: PROMISING DIRECTIONS

Development of radiation control technologies, as well as implementation of optimizing innovations (both technological and industrial), innovation transfer from the related spheres and essential potential for improvement of a number of features opens significant opportunities for scaling of a great pool of perspective trends in radiation technologies in mid-term time frame:

COMPACT NEUTRON GENERATORS ARE ALREADY BEING USED FOR LOGGING IN GEOLOGY:

Interventional radiology and cardiology[26]. According to Frost&Sullivan estimations, the European market of interventional radiology (including vascular and neurologic surgery) in 2010 reached 232.2 million USD. By 2014 it should grow close to 300 million USD.

25 The work in this direction is conducted at N.L. Dukhov VNIIA, at IPPE (Obninsk), and at Budker Institute of Nuclear Physics RAS (Novosibirsk).

26 Assessment of RT market in cardiology: Nuclear Cardiology Markets. Publication date: May 2011 (http://www.reportlinker.com/p060839-summary/Nuclear-Cardiology-Markets.html).

For the same period, the European market of interventional cardiology would grow from 284.3 million USD up to approximately 404 million USD, first of all, because of ageing of the population and increase in demand for less expensive out-patient procedures.

New generation of radiopharmaceuticals (bioradiopharmaceuticals) for therapy and diagnostics. Three diagnostic bioradiopharmaceuticals have already been introduced to the market (Zevalin, Bexxar и ProstaScint), and there are clinical tests being performed for more.

MODERN X-RAY THERAPY TECHNOLOGIES, INCLUDING:

Combining radiation with diagnostics in real-time (image-guided radiation therapy). CAT, NMR or PET scanning is in this case performed right during the X-ray therapy process. It allows controlling the position of tumor at every moment of time, and, accordingly, maintaining high precision of target radiation at each procedure;

INMR or intensity modulated radiotherapy, provided by devices of the type TomoTherapy Hi-Art or Cyberknife CyberKnife VSI (by Accuray), or RapidArc (by Varian medical systems);

Proton therapy using compact accelerators;

Ion therapy, including the carbon one. Physical features of ions inhibition in substance allow to provide great value of the ratio of a dose in the tumor zone (target) to a dose in the tissues "on the way" of an ionic beam to the target. It reaches 3 even in case of forming the distributed Bregg peak for treatment of extended neoplasms. Besides, dispersion of an ionic beam is weaker than that of a proton beam. One separate important property of ionic therapy is the speed factor: clinical research shows that fewer procedures are required in comparison with the traditional methods of treatment, and the duration of treatment is shorter (so there appears a possibility of out-patient treatment).

Neutron and neutron capture therapy. The main advantage of neutron and neutron capture therapy is the possibility of damaging tumors selectively, as well as the possibility of therapy of inoperable tumors (like brain glioblastoma)[27]. The main direction of RT equipment development for neutron capture and neutron therapy is creation of compact neutron sources, including the accelerator-type ones[28]. Besides, in the last 10 years new delivery systems (mAB, peptides, caged delivery) have been actively implemented in pharmaceutics. It makes possible creation of "targeted" pharmaceuticals on the basis of boron-10 – and, respectively, further spreading of neutron and neutron capture therapy;

IN THE MID-TERM PERSPECTIVE, RADIATION TECHNOLOGIES WILL BE ACTIVELY USED IN THE FIELD OF THE NEW MATERIALS CREATION

Among the most highly demanded types of **materials processing** there are ion implantation (polymerization; solidification; creation of complex composite materials constructed at nano-level) and **gamma-radiation** (mainly used for polymerization, including creation of composite materials[29], as well as for polymer cross-linking). Taking into account the dynamics of the composite materials market (in 2010, the global market volume made up 17.7 billion USD, the growth rate is 10.3% per year), we can expect the correspondent demand increase for radiation technologies in this sphere;

An additional stimulus for demand for radiation technologies in new materials manufacturing may become creation of **digital simulation models** of processes related to radiation technologies (namely, to ion implantation and neutron analysis), as well as formation of the relevant knowledge base[30]. Digital modeling of new materials manufacturing would allow integration of ion implantation and other highly demanded RT into industrial complexes connected with manufacturing of the new materials;

Radiation technologies implementation in **food industry, agriculture and sterilization** does not require great amount of new technological solutions.

Development in these fields is likely to move in the direction of cost reduction and technologization of units production.

PROSPECTIVE PRODUCTS FOR THESE MARKETS ARE THE FOLLOWING:

Modular scalable low-capacity unit (model solutions are customized according to the client's tasks, including change of tasks for the same client). Several companies have simultaneously entered the market with compact industrial radiators with Co-60 for batch processing,

27 Until recently, there have been major constraints for this method: absence of compact neutron accelerators (irradiation was made at research facilities) and lack of the pharmaceuticals that would have effectively provided borium-10 delivery to the tumor (in case of neutron capture therapy). In the beginning of the 1990s the USA and Western European countries resumed clinical trials of neutron capture method due to the development of boron-containing pharmaceuticals and successful results in brain glioblastoma therapy received by a Japanese neurosurgeon Hatanaka Hiroshi.

28 Currently neutron therapy with the help of accelerator-type neutron generators can be fulfilled only by 25-30 medical centers in the world. Thus, by popularity neutron therapy loses to proton therapy, facing the same problems of bulky and expensive equipment.

29 In particular, in the 1990-s – the beginning of 2000-s there were fulfilled some developments related to usage of gamma-rays for creation of composite materials on the basis of carbon fiber.

30 These works are executed, among others, by the Fraunhofer Institute.

integrated with the production lines: BREVION™ (MDS Nordion), MICROCELL™ and MINICELL™ (SteriGenics), BP1 PALLET IRRADIATOR™ (Picowave Technology). Development of the irradiation system based on a multi-purpose permanently working compact gamma emission source is being conducted by the Brazilian Center of Radiation Technologies of IPEN Institute. At the same time, IAEA recommends to transfer from usage of cobalt units to electronic accelerators, both because of the non-proliferation treaty and for the reasons of flexibility of emission control (cobalt units cannot be "switched off", it is only possible to block their radiation by a "wall");

Multipurpose units of variable capacity (for processing various food products);

Mobile modular units (for example, for irradiating fish on board ship, strawberries in the field etc.).

PROSPECTIVE RADIATION TECHNOLOGIES IN THE SAFETY SPHERE ARE THE FOLLOWING:

Firstly, distribution of technologies using terraHerz radiation for screening people and neutron analysis technology for screening luggage and bulky cargoes. Unlike traditional X-ray units, **neutron detectors provide the possibility of high-precision determination of the structure of substances**, including those hidden in luggage. Neutrons interact with the substance by destroying a small amount of the atomic nuclei (tearing off a neutron or a proton) of the inspected substance that leads to emerging of the new atomic nuclei, including the "radioactive" ones, and it is possible to determine the structure of substance by their range of gamma radiation. Neutron technologies (in combination with the traditional X-ray technologies) will essentially increase the detection rate for shell-less explosives and drugs and reduce quantity of false alarms for the security systems.

Finally, in the sphere of **ecological safety**, the most prospective fields of accelerator devices implementation are re-processing of solid household waste and medical waste, recycling, purification of wastewater from industrial factories, drinking water preparation, and purification of flow-gas (see item 4.6.)

Case study

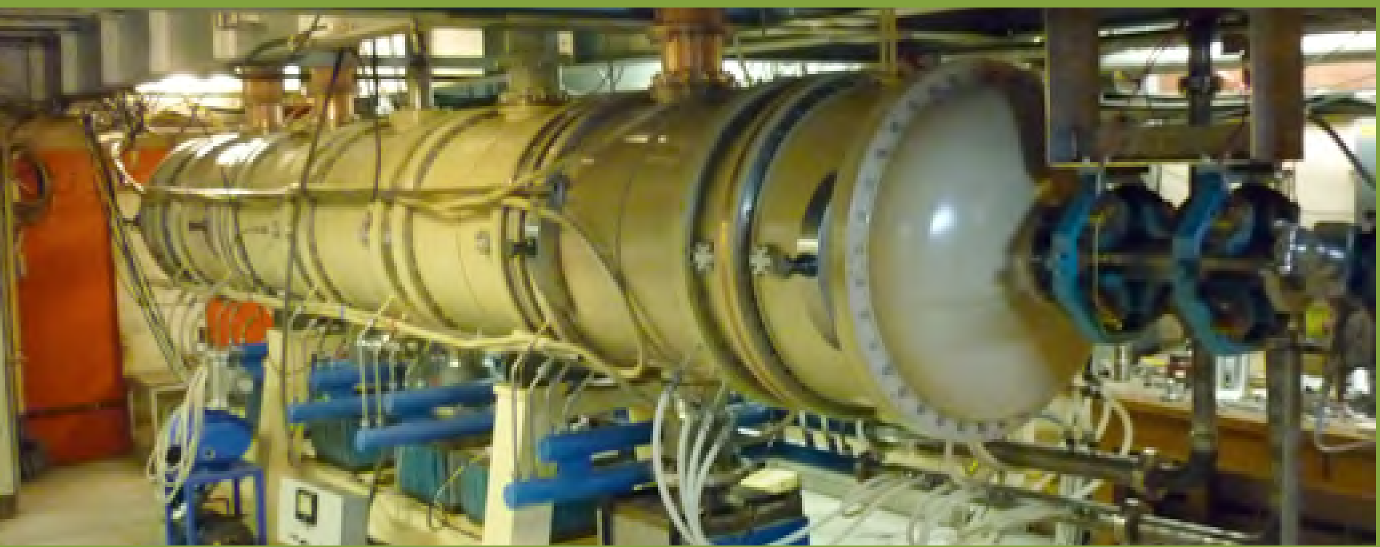
RUSSIAN COMPETENCIES – INDUSTRIAL ACCELERATORS

BUDKER INSTITUTE OF NUCLEAR PHYSICS SB RAS (NOVOSIBIRSK)

One of key owners of competencies in the field of industrial and sterilizing accelerator equipment in Russia is Budker Institute of Nuclear Physics of the Siberian Branch of the Russian Academy of Science in Novosibirsk (BINP). On the basis of the fundamental research results, in the institute there were developed various types of powerful and compact electronic accelerators that are widely used in the technological chains of different industries. Currently about 2 thousand people are engaged in production process at BINP.

Two families of industrial accelerators - ILU and ELV - are produced by the institute. They are used in various economic fields: radiation processing of polyethylene cable jackets aimed at its thermal durability increase, radiation modification of polymeric heat-shrink tubing, radiation disinsection of grain, treatment of waste water, etc. The accelerators are produced from standard systems and units; it allows to adapt them with minimal costs to the exact requirements of the technological process like energy range, power of the accelerated electron beam, length of the exhaust window etc. Constructional and scheme solutions provide continuous 24/7 work of the accelerators in the industrial production environment. The accelerators developed and produced at BINP are successfully used in many countries of the world.

In 2011, scientists and engineers of the institute have introduced a new unique impulse linear accelerator ILU-14 (up to 100 kW). Working frequency of the accelerator is 176 MHz, complete performance index is 26%. The accelerator has modular structure that allows changing within certain limits the energy of electrons and the beam capacity by choosing different module sets. This accelerator plant was created by the request of the A.I. Burnazyan Federal Medical Biophysical Center. One accelerator can sterilize 10 tons of medical waste per hour. The institute plans to supply these accelerator plants to all the largest medical centers of the country. It has been produced primarily for the national market, however, the accelerators may be supplied to the foreign markets.



Case study

COMPETENCIES OF RUSSIA

"RATEK" JSC

Joint stock company "RATEK Research and Technical Center" develops hi-tech plants aimed at detecting explosives, radioactive and fissionable materials. The principle of operation of these plants is based on neutron analysis of suspicious items.

Currently, for search of the explosives, the airport security services usually use X-ray television devices. Such detectors operate by comparing density of the surveyed substances. However, this examination requires high qualification of the personnel, and besides, the system often gives false alarm signals. The principle of operation of neutron analysis detectors is completely different.

In the new models RATEK uses targeting of a suspicious area. It means that hand luggage at first undergoes traditional X-ray screening. In case of detection of the suspicious areas in it, there is held neutron unit screening, and only the suspicious areas are irradiated, instead of the whole luggage. This method allows to reduce the quantity of nitrogen false alarms that often happen when nitrogen (for example, a usual soap bar) is located in other parts of the luggage, and to make the decision on the explosives presence in the luggage (including the liquid ones) within the 10–15 second time frame.

03

ORGANIZATIONAL DEVELOPMENT: STRATEGIES FOR THE NEW STAGE

“Nuclear medicine is one of the most definite innovative and rapidly developing sectors of global economy, and it can become a driver for the innovative development of Russian economy as well”

S.V. Kirienko, Director General, State Atomic Energy Corporation ROSATOM

3.1 EVOLUTION OF THE RESEARCH CENTERS

Organizationally, the convergence process of various technologies and knowledge areas is most accurately reflected in the evolution of research formats and content and scientific centers activities. Narrow focus (on materials, nuclear physics and so forth) is gradually losing its actuality.

THE MAIN TREND IN RESEARCH IS ENSURING INTERDISCIPLINARY WORK DUE TO LOCALIZATION OF SEVERAL RESEARCH GROUPS ENGAGED IN DIFFERENT RESEARCH DIRECTIONS AT ONE SITE

This tendency is typical, namely, for the leading non-energy radiation technologies development centers. The main research focus in RT has significantly shifted from the radiation technologies per se (beam technologies) to the nature of impact of ionizing radiation on organic and inorganic substance, as well as to combining various emission types.

3.2 STRATEGIC TECHNOLOGICAL CONSORTIUMS

Often technological changes in the industry and new research infrastructures are so large-scaled, and the competition is so fierce that **only cooperative entities like large research consortiums** can successfully solve problems. Another benefit of research alliances is practically total absence of barriers for technology transfer. The enterprises involved possess the necessary equipment park, introduce joint personnel programs and can relocate specialists promptly; they have a possibility to cope with regulatory barriers and consolidate substantial financial resources.

Companies that have competencies in radiation technologies participate in the international research consortiums in various RT application fields, mostly in medicine.

Table 2 *RT-related research consortiums*

Institution name	Specialization	Participants
International Radiotherapy Technologies and Oncology Consortium (IRTOC)	Research of new radiation technologies for the possibility of their applications in cancer therapy	28 development centers and institutions of higher education (China, India, Brazil, the USA, the UK, Czech Republic, Turkey, Taiwan, Korea)
Project consortiums NSF, NIH, FDA, NIST	Development of medical devices and systems	
ICGC (International Cancer Genome Consortium)	Creation of a full database on genetic and other features of more than 50 types of cancer.	About 40 development centers, institutes, organizations (the USA, Canada, Saudi Arabia, Finland, China, India, Germany, Italy, Japan, Spain, Mexico, the UK etc.)
MRI Consortium: Acquisition of a Single-Crystal X-ray Diffractometer for a Regional PUI Molecular Structure Facility	X-ray crystallography	Carlton college, University of Minnesota, St John University, etc. (the USA)

Source: the "Center for Strategic Research "North-West" according to data from public sources

Case study

PARTNERSHIP OF VARIAN AND SIEMENS

In October of 2011 Varian and Siemens companies declared that they plan collaboration in the sphere of diagnostic and therapeutic equipment development and cancer treatment methods. According to their management, Varian and Siemens share common corporate culture and philosophy principles, and are both oriented at medical institutions and their patients. The companies plan to start joint research and development in the future. The main priority for this partnership will be ensuring convergence of key technologies of the companies: diagnostic equipment and linear accelerators (Siemens) and "Aria" information system of treatment planning (Varian). According to companies' representatives, one of the major directions of work will be integration of therapy and visualization systems.

VARIAN-IMRIS PARTNERSHIP, AGREEMENT ON THE JOINT DEVELOPMENT OF MR-GUIDED RADIATION THERAPY SYSTEM

Varian and IMRIS companies have signed an agreement on the joint development of the innovative beam therapy systems for treatment of different types of cancer. According to the terms of the agreement, the companies will be developing a solution that should combine magnetic resonance IMRIS technologies in the field of visualization with the recently developed TrueBeam technology by Varian. The objective is to ensure possibility of using nuclear magnetic resonance (NMR) during beam therapy for tumor identification. Created in April 2010, the TrueBeam Varian system for beam therapy and radio surgery provides high speed and accuracy and allows to increase delivery speed for the doses of radiation in 1.5 times compared to older systems. Due to the use of the corporate IMRIS technology and integration of NMR with the TrueBeam system, both companies expect to increase efficiency of the beam therapy.

Specific wide-profile consortiums focusing exclusively on radiation technologies and their improvement have not been formed yet. However, the largest companies having competences in RT have started closing strategic partnership agreements for conducting joint research and development.

AT THE FOURTH STAGE OF RT DEVELOPMENT, HI-TECH INNOVATIVE CLUSTERS WOULD BECOME A DISTINCT SPECIFIC METHOD OF ENSURING SCIENTIFIC AND TECHNOLOGICAL LEADERSHIP

Key areas of RT applications develop within the cluster logics; the companies connected with innovations in radiation technologies are often located in similar clusters. Besides, a range of clusters has formed around large research centers for RT.

3.3 INTEGRATION AND CO-OPERATION: MERGERS, ACQUISITIONS, PARTNERSHIPS

3.3.1. THE ROLE OF STRATEGIC INVESTORS

Already at the previous stage of RT development, the strategic players showed themselves as integrators and consolidators of technological solutions[1]. Besides, activity of the venture funds investing in development of specific products with the subsequent sale of the products to their strategic investors increased substantially. The new round of development, connected, first of all, with technological breakthroughs in the field of miniaturization of solutions and convergence with the related areas of ICT and biotechnologies, makes the positions of today's leaders unstable, due to the possibility for the strategic players from other industries to enter this formerly «closed» market.

1 For example, Elekta AB company (turnover of 1.4 billion USD) in the 2000-s used an aggressive strategy of mergers and acquisitions in the markets of equipment for «serving» software and brachytherapy.

In the current situation of a new radiation technologies development stage in progress, the role of strategic players determining the main business models of behavior has become extremely important; the community of the professional financial investors ready to place stakes on technological developments, has been created. Among successful investments into RT, it is necessary to mention the investment of Riverside Partners to IZI Medical Products in 2010, with the subsequent sale of the Landauer company in 2011; financing of the MBO Core Oncology by Compass Capital fund in 2007 with the subsequent sale of the part of the Theragenics company's business in 2012; Summit Partners investment to IMPAC Medical Systems in 1996 with the subsequent sale of the Elekta AB company in 2005.

Nuclear medicine is one of the most definite innovative and rapidly developing sectors of global economy, and it can become a driver for the innovative development of Russian economy as well

S.V. Kirienko, Director General, State Atomic Energy Corporation ROSATOM

In relation with the information above, formation of the following trends important for further RT development should be expected:

STRATEGIC INVESTORS INCREASING THE VOLUME OF FINANCING FOR NEW SOLUTIONS

It also concerns the solutions commercialized by small companies that evolved from research centers. The latter are the main source of fundamental knowledge about the nature of radiation and its impact on substance;

Increase of demand for the developments based on radiation technologies from the key players of related industries. Here RTs either open new technological possibilities, or supplement their settled business models, or open new possibilities for radical transformation of the existing markets;

Venture capital shows increased interest to the developments in the sphere of radiation technologies that are either the only possible technological solution, or the only possible alternative for resolving a number of tasks.

3.3.2. THE ROLE OF COMPANIES POSSESSING KEY COMPETENCIES

In order to provide technological development of RT at the expense of convergence, the next step will demand cooperation and/or integration of the companies possessing RT competencies with the players of the new type possessing competencies in breakthrough areas:

The companies from life science sphere, first of all – biotechnological companies that possess technologies and competencies related to bio-engineering and a number of more general processes related to the properties of organic matter. Most actual is interaction with biotechnological companies in the context of developing new radiopharmaceuticals based on biotechnological delivery systems (monoclonal antibodies, peptides, etc.);

The information technology companies that can provide visualization and systems management. Despite the fact that many large companies producing equipment have their own large IT divisions (that offer to the market their own platforms of visualization and management), breakthrough IT solutions transfer in RT implementation occurs due to co-operation with the companies specializing in software and software-hardware complexes for medicine. For further development of software and IT for radiation technologies, the following requirements are obligatory:

— The possibility to integrate products and services between major platforms, possessing cross-platform systems of tags, formats, tools;
— 3D and 4D visualization and data presentation systems, automatic data processing;
— High interactivity, attention to end user requirements and not to the production process requirements;
— Access via Internet, flexible system of installation and support of radiation units and technologies;
— Possibility of remote access, data output to the end user devices;
— Usage of cloud systems, virtual working space;
— Complex user support system oriented at efficiency of business processes (ICT service providers practically become business partners);

Engineering companies. The tasks of integration are acquiring competences and testing the new technologies, such as customized engineering, technological chains embedding, design of customized materials, simulation modeling of RT processes. Besides, engineering companies have a possibility to transfer technologies and competencies from various spheres of science and practice. For example, basic competencies in production of composite materials with high reflective capacity used in forming micro- and nanotubes have allowed launching a series of R&D related to miniaturization of charged particles accelerators. R&D of Cornell University are carried out in strong collaboration with SonicMEMS Laboratory, the university division engaged in problems of micro electromechanical systems (including materials and micro power sources).

Case study

ATLANPOLE BIOTHERAPIES

Atlanpole Biotherapies is a cluster specializing on immune-biotherapy, radiopharmaceuticals, regenerative medicine and innovative technologies in biotherapy. The cluster is based in Nantes (France). It includes 70 companies, 3 universities, 49 research laboratories, 2 medical centers, the Institute of cancer diseases, Audencia Nantes School of Management, 5 research institutes carrying out fundamental research in the field of transplantology, oncology, cardiology, etc.

International partners of the Atlanpole Biotherapies cluster are:

— SCIENCE PARK RAF Spa: Milan, Italy
— Parc Scientific Of Barcelona: Barcelona, Spain
— Leiden Bio Science Park - Life Meetsscience: Leiden, The Netherlands
— Centre For Advanced Studies - Cardiff University : Cardiff, Wales, UK
— BIOWIN: Gosselies, Wallonia, Belgium
— MEDCOAST Scandinavia: Goteborg, Sweden
— Business Region Goteborg: Goteborg, Sweden
— Technologiepark Heidelberg GMBH: Heidelberg, Germany

MERGERS AND ACQUISITIONS TYPICAL FOR THE STAGE OF MARKET CONSOLIDATION, WILL BECOME THE MOST IMPORTANT FORM OF ENSURING SCIENTIFIC AND TECHNOLOGICAL LEADERSHIP AT THE FOURTH STAGE OF RT DEVELOPMENT

The market of RT is mature and consolidated; at the stage of active consolidation, there appear new hi-tech industries which would later become the sources of the innovative growth: biotechnologies, ICT, new materials.

LARGE PLAYERS OF RT MARKETS ACTIVELY ACQUIRE SMALL AND MEDIUM-SIZED INNOVATIVE COMPANIES:

Siemens has been working for a long time both in the field of biotechnologies and biopharmaceuticals (the agreement of 2004 and the joint venture with SEQUENOM Inc.; the agreement with IDL Biotech AB in 2007), and in the field of IT for biotechnologies (purchase of Elan Software Systems SA in 2009);

Philips invests into biopharmaceutical companies (creation of a joint venture with RXi Pharmaceuticals Corporation in 2010; agreement with Biocartis in 2010);

General Electric also buys innovative companies (agreement, license and technological cooperation with Geron Corporation in 2009; agreement on joint R&D and technological cooperation projects with Dyax and Refine Technology, purchase of Xcellerex in 2012).

Most obvious acquisition of the new competencies occurs in biotechnology. This process is connected with the change of the technological bases, namely, transfer to biotechnologies, genomics, molecular medicine (caused, among other things, by the expiration of patents). The researchers talk about the next peak of mergers and acquisitions, which is the first one since 2006.

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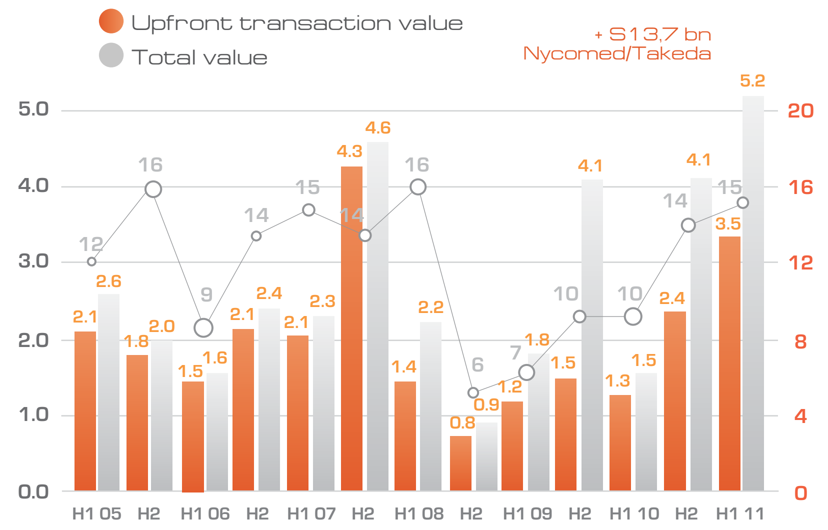
Figure 5 Dynamics of mergers and acquisitions (pharmaceuticals and biotechnologies)



Source: HBM Partners, Biotech/Pharma M&A report 2011

3.4 GOVERNMENT PROGRAMS OF RADIATION TECHNOLOGIES SUPPORT

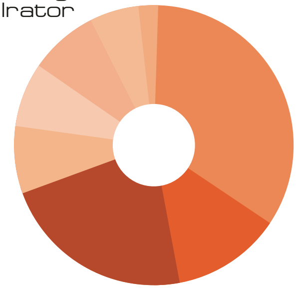
Increased attention to non-energy applications of the radiation technologies is represented, first of all, by the new generation of government programs and initiatives connected with RT development.

For example, in the USA, the Committee on Science of the Department of Energy (DOE) supports R&D projects in the field of accelerator equipment in order to most effectively use unique competencies and pilot units of various laboratories and universities. Seven largest laboratories and twenty universities are involved in these projects. The programs, first of all, support research aimed at achievement and maintenance of the world leadership in the field of radiation technologies and special accelerating equipment.

Before June 1, 2012, the Committee on Science of DOE should have accepted the 10-year strategic research plan in the field of accelerating technologies. This plan also presumes expansion of accelerator applications in various fields of energy industry, medicine, manufacturing, etc.

It is based on the results received during creation of the report "Accelerators for American Future". The key task of the report was identification of the main directions for development of accelerating equipment and defining the main research objectives in this area.

Figure 6 *Structure of state financing of R&D in accelerator equipment in the USA (million USD)*



Source: U.S. Department of Energy (2011)

In Russia in 2011 a Roadmap of nuclear medicine development was approved. It was developed by the Presidential Commission for Modernization and Technological Development of Russia's Economy. One of the main features of the Roadmap is development of the new radiation technologies for diagnostics and therapy. Within the frames of the Roadmap realization, since 2013 the annual volume of government investment into this sector will increase more than in 3 times, and its total volume will surpass 100 billion RUB.

Case study

STATE ATOMIC ENERGY CORPORATION ROSATOM IS A STRATEGIC INVESTOR TO NON-ENERGY RADIATION TECHNOLOGIES

In Russia, the State Atomic Energy Corporation ROSATOM has created a long-term program «Radiation technologies». The main objective of the program's implementation is achievement of the global technological leadership by the national nuclear industry, assistance for increasing gross profit and capitalization of the State Atomic Energy Corporation ROSATOM organizations, gaining stable market position by expanding the company's presence in the internal and external markets in the following areas: nuclear medicine, isotope products, agriculture, ecology, processing of solid household waste, water preparation, screening systems and change of materials' properties.

Major tasks of the Program are:

Consolidation, support and development of various directions of science, technology, industry, competitive services and assistance to the development of different types of business activities within State Atomic Energy Corporation ROSATOM profile activities;

Initiation of the projects on creating joint hi-tech production facilities in the form of the private-state partnership and on rendering services within the Program's activity directions; participating in development of the new types of products and services, their tuning before industrial production;

Assistance to increase of the production volumes by State Atomic Energy Corporation ROSATOM member organizations; it concerns increasing volume manufacturing of the products in demand and providing more services within radiation technologies field; increasing exports, bringing relevant markets to saturation;

Participation in creating educational clusters in partnership with the leading scientific, educational and academic institutions on the issues of interdisciplinary education;

Participation in preparing infrastructure for creation of intellectual property products: technoparks, production clusters, engineering companies, research centers, etc.

Case study

PARIS SACLAY DEVELOPMENT

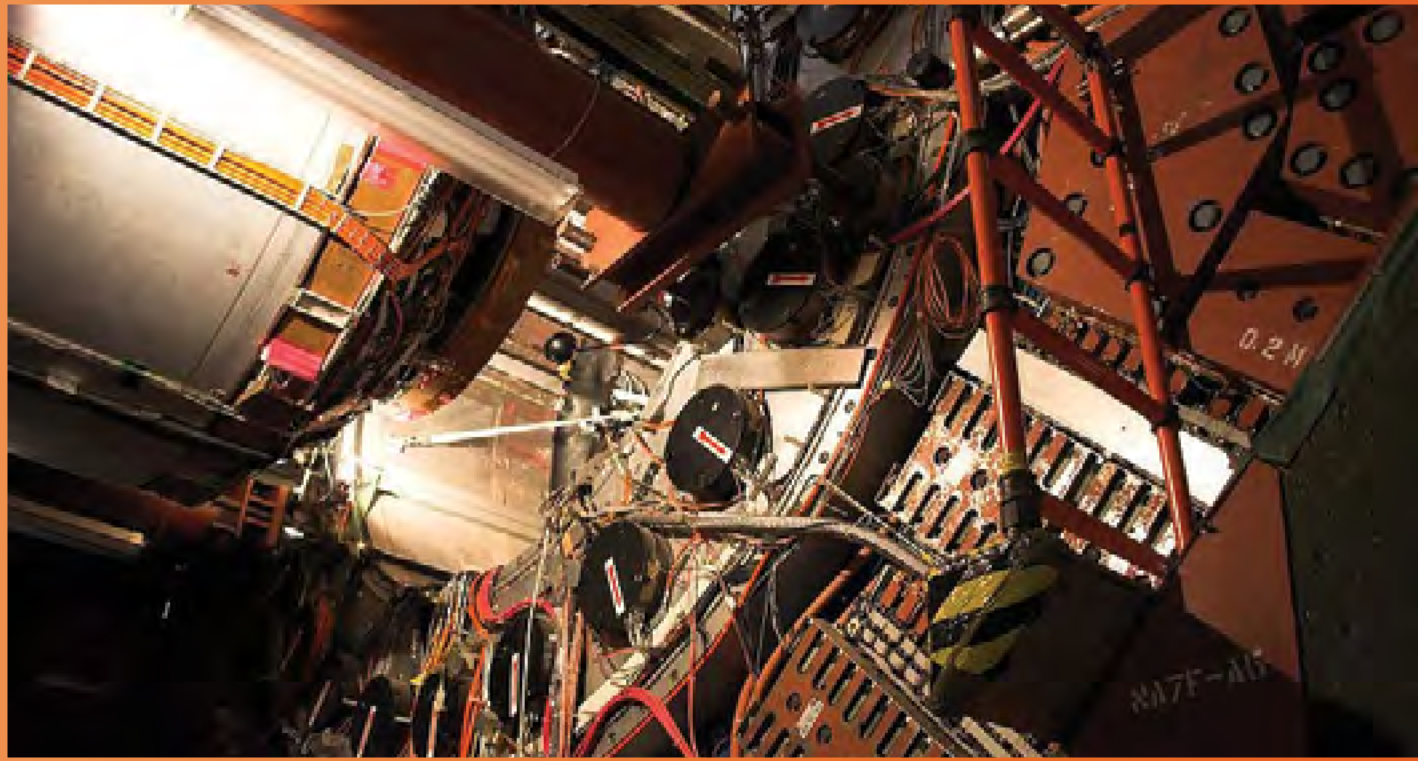
In 2008, 23 research organizations (2 universities, 6 research institutes and 10 engineering Grandes Ecoles known as the "Ivy League", 2 education- and R&D-related clusters, and others) have decided to create a joint campus in Saclay, France. Upon Saclay project completion significant scientific, educational, research resources would be concentrated there: about 30 thousand students and at least 20 thousand engineers and researchers. The accent on interdisciplinarity and consolidation should allow Saclay to become one of the largest centers (up to 1% of world scientific publications volume) in the profile topics.

The main directions of research at Saclay should be the following ones:

— New technologies in energy industry;
— Nanotechnology;
— Nuclear technology (simulation, nuclear physics, materials science, analytic chemistry, radioactive waste/spent nuclear fuel management, etc.);
— Fundamental research in nuclear physics;
— Medical technologies;
— Climate and environment.

Case study

RESEARCH PROGRAM OF SLAC NATIONAL ACCELERATOR LABORATORY



The SLAC research program is connected mainly with the fundamental questions of all possible matter properties (its structure, methods of influencing substance at macro- and micro-levels). Specifics of the fundamental research at SLAC has led to the formation at a single site of the unique research tools complex based on accelerator equipment. The main directions of research at SLAC are:

— Physics of accelerators;
— Astrophysics and cosmology;
— Physics of elementary particles;
— Materials science and nanotechnology;
— Structural biology;
— Molecular research of environment;
— Molecular and atomic transformations.

04

THE FORECAST FOR THE DEVELOPMENT OF THE RADIATION TECHNOLOGIES MARKET

«The tendency today is that the market of alternative nuclear applications is much larger than the nuclear energy market, and is developing faster»

Pyotr Schedrovitsky, Advisor of Director General of State Atomic Energy Corporation ROSATOM

The global RT market in its current state has been formed by the processes of consolidation, mergers and acquisitions in the 1990s and the 2000s.

TOTAL VOLUME OF THE RT APPLICATIONS MARKETS AT THE CURRENT STAGE IS AROUND 200 BILLION USD, HALF OF THIS VOLUME BELONGS TO THE NUCLEAR MEDICINE MARKET

According to the estimations of the majority of experts, in the nearest decades the potential volume of these markets can make up to 400-500 billion USD due to large-scale development of the South American and Asian countries' economies. The demand of global community for high-quality medical services, food safety, environmental safety, transportation services safety, high quality of hi-tech industrial products can be satisfied by expansion of the radiation technologies markets.

4.1 GEOGRAPHICAL REORGANIZATION OF THE RADIATION TECHNOLOGIES MARKETS

Geographical transformation of the radiation technologies applications markets will become a noticeable feature at the fourth stage of the RT development:

In OECD countries (USA, Canada, EU, Japan, Korea), progressive consumption growth in the expensive segments related to the radiation technologies is taking place. The most expensive solutions are proton therapy (unit cost within 125-150 million USD), bioradiopharmaceuticals (the average cost of one dose the mAB-drug Zevalin for Non-Hodgkin-Lymphome treatment is around 30 thousand USD), combined PET-CAT units (cost of one procedure is 3.5-4.5 thousand USD), up-to-date screening systems. All of them are demanded by the developed countries. Out of 37 active proton therapy centers, 11 are located in the USA, 9 in Japan and 4 in Germany; only 7 centers have been created in the developing countries (3 experimental ones in Russia, 2 in China, 1 in the South African Republic, 1 in Poland).

The markets of the radiation technologies applications are growing in the developing countries, first of all, in BRIC countries. Progressive increase of medical expenses (growth in medical services in China was almost 9 times for the last 15 years, from 20 USD to 180 USD per capita[1]), intensive industrial growth, growth of food products consumption in the developing countries create solvent demand for the relevant applications of radiation technologies. Only the market potential for linear accelerators for cancer therapy in China is about 1000 items of equipment (that is, no less than 6 billion USD, including cost of interior equipment)[2], in Russia – about 200 items (about 1.2 billion USD)[3].

THE GROWTH OF RT APPLICATIONS MARKETS IN BRIC COUNTRIES IS ADDITIONALLY STIMULATED BY CREATING THE REGULATORY BASE FOR A NUMBER OF RADIATION TECHNOLOGIES APPLICATIONS:

Medicine — in China, equipment for nuclear medicine is included into the corresponding regulation and certification systems; in India, the whole set of regulatory measures related to nuclear medicine was introduced in 2001 by the National Commission on Nuclear Energy Regulation[4])

Food processing — in China, in 2001 at the national level there were approved and introduced 17 standards related to irradiation of food products, and a unified system of irradiated products marking[5]; in India, similar standards were adopted in 1994; Brazil first approved radiation food processing in 1973, while in 2001, the existing regulatory basis was significantly expanded[6]).

1 An additional stimulus for nuclear medicine development is intensive urbanization of the developing countries; according to Kalorama's data, the health care market in the cities is on average thrice as large as the rural market.

2 According to the data of Elekta ("Radiation Oncology Market in China")

3 According to the data of the Ministry of Public Health and Social Development of Russian Federation.

4 AERB safety code on nuclear medicine facilities AERB/SC/MED-4, The Safety Code for Medical Diagnostic X-ray Equipment and Installations AERB /SC/MED-2 and other.

5 It is used not by all Chinese manufacturers – see correspondent examples in the book of PJ Cullen, Brijesh K. Tiwari, Vasilis Valdramidis, "Novel Thermal And Non-Thermal Technologies For Fluid Foods", 2011.

6 Ioannis S. Arvanitoyannis, "Irradiation of Food Commodities: Techniques, Applications, Detection, Legislation, Safety and Consumer Opinion", 2010.

IT SHOULD BE TAKEN INTO CONSIDERATION THAT ONLY THE DEVELOPED COUNTRIES CAN AFFORD BUYING EXTREMELY EXPENSIVE EQUIPMENT, WHILE THE DEVELOPING COUNTRIES HAVE TO CONSIDER MUCH CHEAPER SOLUTIONS[7]

High potential of the radiation technologies applications markets in the developing countries is indirectly confirmed by introducing long-term national policies in the relevant spheres, as well as by a set of protectionist measures taken by the governments of the BRIC countries:

In 2009, at the peak of the world economic crisis, in China there was launched a system of subsidies for the national manufacturers of medical equipment with the motto "Buy products made in China"[8]. Simultaneously, a large-scale program of resource base renewal of the national health care system was launched (reconstruction of 3,700 medical centers, 11,000 clinics, and construction of 2,400 new medical centers);

In 2010, the Ministry of Trade of Korea initiated an anti-dumping investigation against foreign suppliers of the screening (X-ray) complexes; the results of investigation proved that European manufacturers of the mentioned equipment intentionally decreased their prices that led to considerable financial losses of Chinese manufacturers. Based on the investigation, anti-dumping fees were introduced for Smiths Heimann Gmbh screening complexes – 33.5%, for other imported European complexes – 71.8%;

In 2011, in Russia there was formed a United Technological platform "Radiation technologies", coordinated by the Nuclear Cluster of Skolkovo.

The pool of players in the global market of the radiation technologies will remain practically the same at the fourth stage of RT development. Usually emerging of the new companies and/or change of an integrator for the key product in the market takes place in case of pivotal changes in technical principles of this product's manufacturing (different product generations have different owners of basis competencies). The markets of all types of radiation technologies equipment are highly consolidated.

7 The case study example for China: in 2009, the Ministry of Health Care of China increased control over purchases of medical equipment with the cost exceeding 710 thousand USD (namely, X-ray units entered the list) for medical institutions in rural areas.

8 China Market Research Group (CMR), 2009.

THE CONSEQUENCES OF GEOGRAPHICAL TRANSFORMATION OF THE RT APPLICATIONS MARKETS AND PROGRESSIVE FAST GROWTH OF BRIC COUNTRIES' ECONOMIES FOR THE CORPORATE STRUCTURE OF THE MARKET WILL BE THE FOLLOWING:

Emerging of the new generation of national manufacturers (China[9], India[10], Brazil, Russia). Their key function will be meeting the demand for relevant equipment, including the equipment produced under license or simply copied, by supplying already existing equipment types to the existing infrastructure and systems (medical centers etc.) or built-in simultaneously with renewal of these infrastructures (for instance, the health care modernization program in China).

Adjustment of market strategies of the "old school" leading companies because of the emerging new national players in the growing markets: large corporations will stand at the traditional crossroads of ensuring their presence in the markets of the developing countries:

— Localization of equipment manufacturing in the consumer countries;

— Acquisitions of the competitive national manufacturers.

9 BMEI, Shinva, HaiMing, Weida Group, TUB, Chengdu Twin Peak Accelerator Technology (medicine), Nuctech (security), SINAP, FERES (irradiation) etc.

10 SAMEER (medicine), BARC, NNCAT (radiation) etc.

4.2 NUCLEAR MEDICINE MARKET

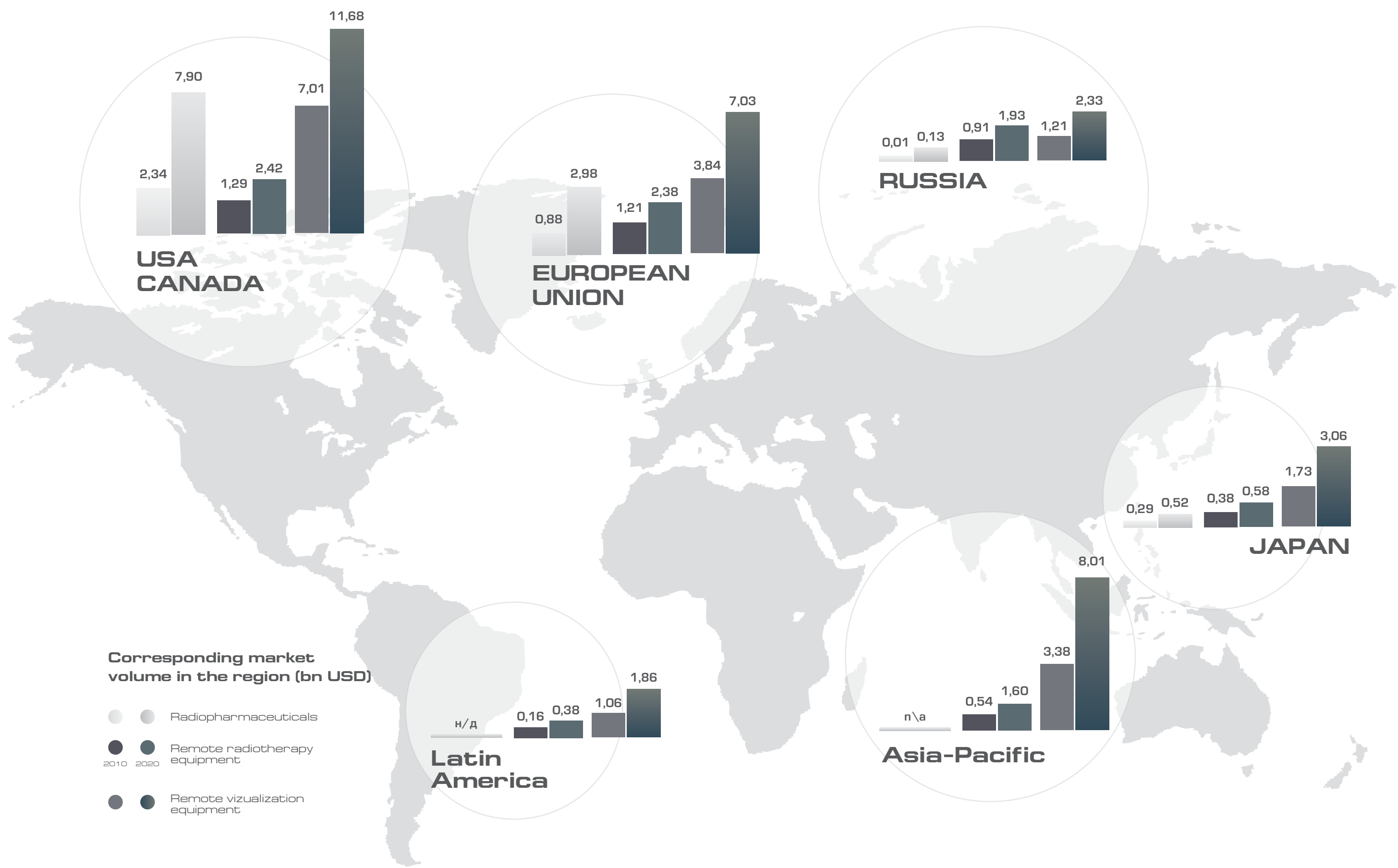
This market has historically been a "locomotive" for applications of the radiation technologies, and currently it demonstrates high growth rates as well. High saturation of the market in North America, Japan and Western Europe is the model for spreading nuclear medicine and rapid market growth in China, South-East Asia, South America and Eastern Europe.

RADIATION TECHNOLOGIES ARE RELATIVELY WIDESPREAD IN THE MARKET OF MEDICAL PRODUCTS AND HEALTH CARE MARKET

The global market of nuclear (radiological) medicine consists of several principal segments: equipment (for diagnostics and therapy), medical services and somewhat like a separate "submarket" of radiopharmaceuticals. Total nuclear medicine market volume is currently around 100 billion USD, with a 70% share of the medical services segment.

Forecast for nuclear medicine market growth is rather optimistic: according to different estimates, the total market volume may reach from 500 billion USD to almost 1,000 billion USD by 2025; correspondingly, volumes of the equipment market and radiopharmaceuticals market by 2020 are estimated at 60-80 billion USD.

Figure 7 *Diagnostic and therapeutic equipment, and radiopharmaceuticals markets (forecast, billion USD)*



4.3 THE MARKET OF FOOD IRRADIATION

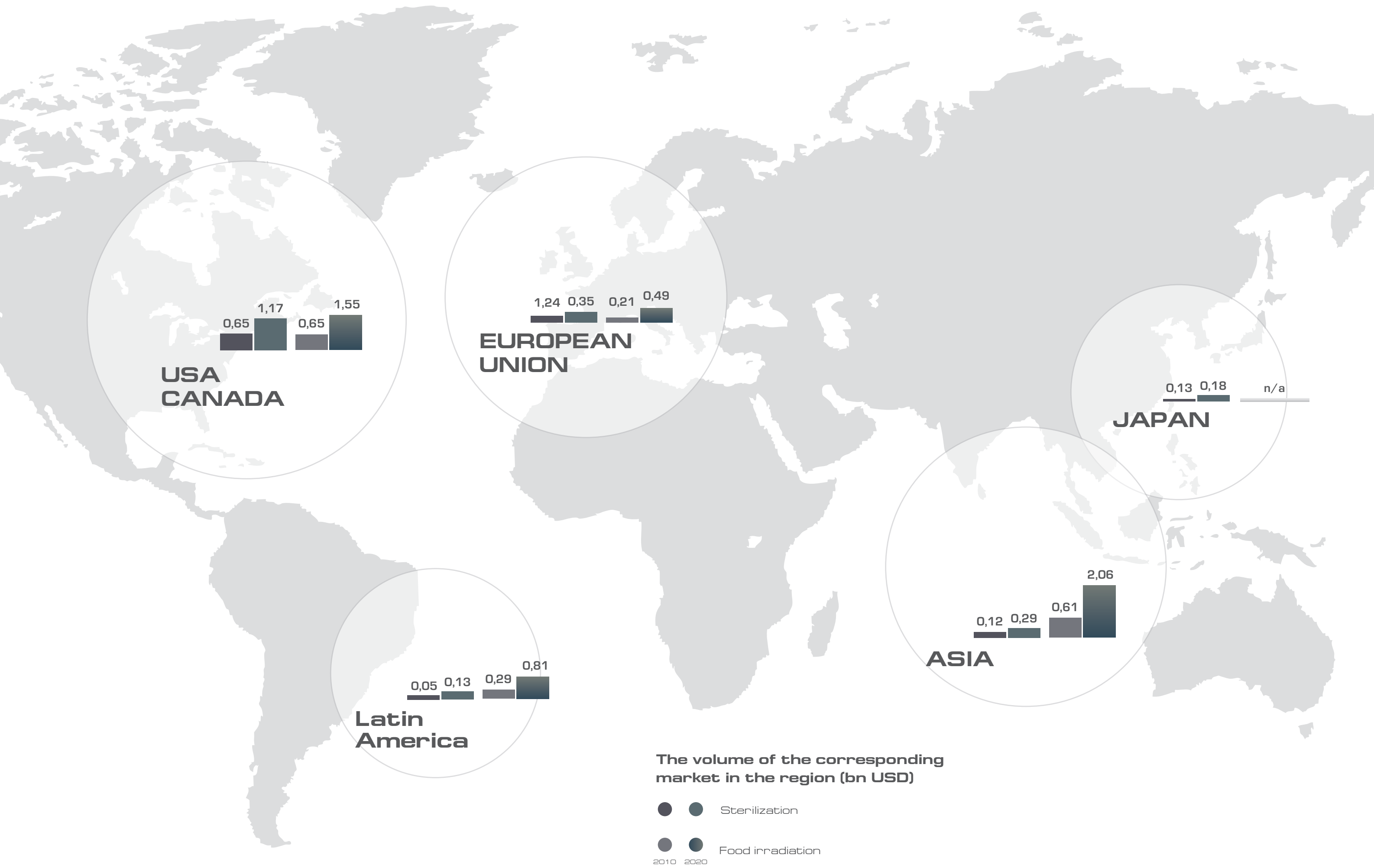
Currently radiation treatment of food commodities is used in more than 40 countries of the world. Total count of food irradiation units is about 220 (it was 218 in 2009). Major share of this market belongs to the USA (40 units). Use of irradiation in the EU countries is constrained by strict regulations of food commodities control. The amount of units for irradiation in Europe is fairly small: 2 items in Belgium, 5 items in France, 5 items in Germany.

HOWEVER, FOOD IRRADIATION IS WIDELY USED IN CHINA: THERE WERE 78 IRRADIATION UNITS IN THIS COUNTRY IN 2009. DEVELOPING ASIAN COUNTRIES, FIRST OF ALL INDIA, SHOW ACTIVE INTEREST IN THIS TECHNOLOGY

The information concerning the volume of the market of food commodities irradiation and sterilization differs. According to the report issued in 2008 by Global Industry Analysts, Inc., the volume of the world market of services in the sphere of irradiation treatment of food should exceed 2.3 billion USD by 2012[11]. According to Bain, the world market of food irradiation services has the following perspectives: market volume of food irradiation at 1.6 billion USD in 2009, long-term forecast (after the year 2030) at 22.5 billion USD. The growth forecast is at 10% per year, with stable dynamics. Consolidation of the market is relatively low, with many technological solutions and players present.

11 http://www.prweb.com/releases/food_irradiation/gamma_radiation/prweb1530744.htm, and http://www.strategyr.com/Food_Irradiation_Trends_Market_Report.asp

Figure 8 *Sterilization and food irradiation market (forecast, billion USD)*



Source: the Center for Strategic Research "North-West" on the basis of BCC Research, GIA, Frost&Sullivan, «Status of food irradiation in the world» (Tamikazu Kumea, Masakazu Furutab, Setsuko Todorikic, Naoki Uenoyamad, Yasuhiko Kobayashi; Radiation Physics and Chemistry, Volume 78, Issue 3, March 2009, Pages 222–226), FIPA.

4.4 THE MARKET OF NON-DESTRUCTIVE EXAMINATION AND SECURITY EQUIPMENT

Non-destructive examination (NDE) is applied in various industries, such as automobile and aircraft manufacturing, maintenance of transport and energy infrastructure and others.

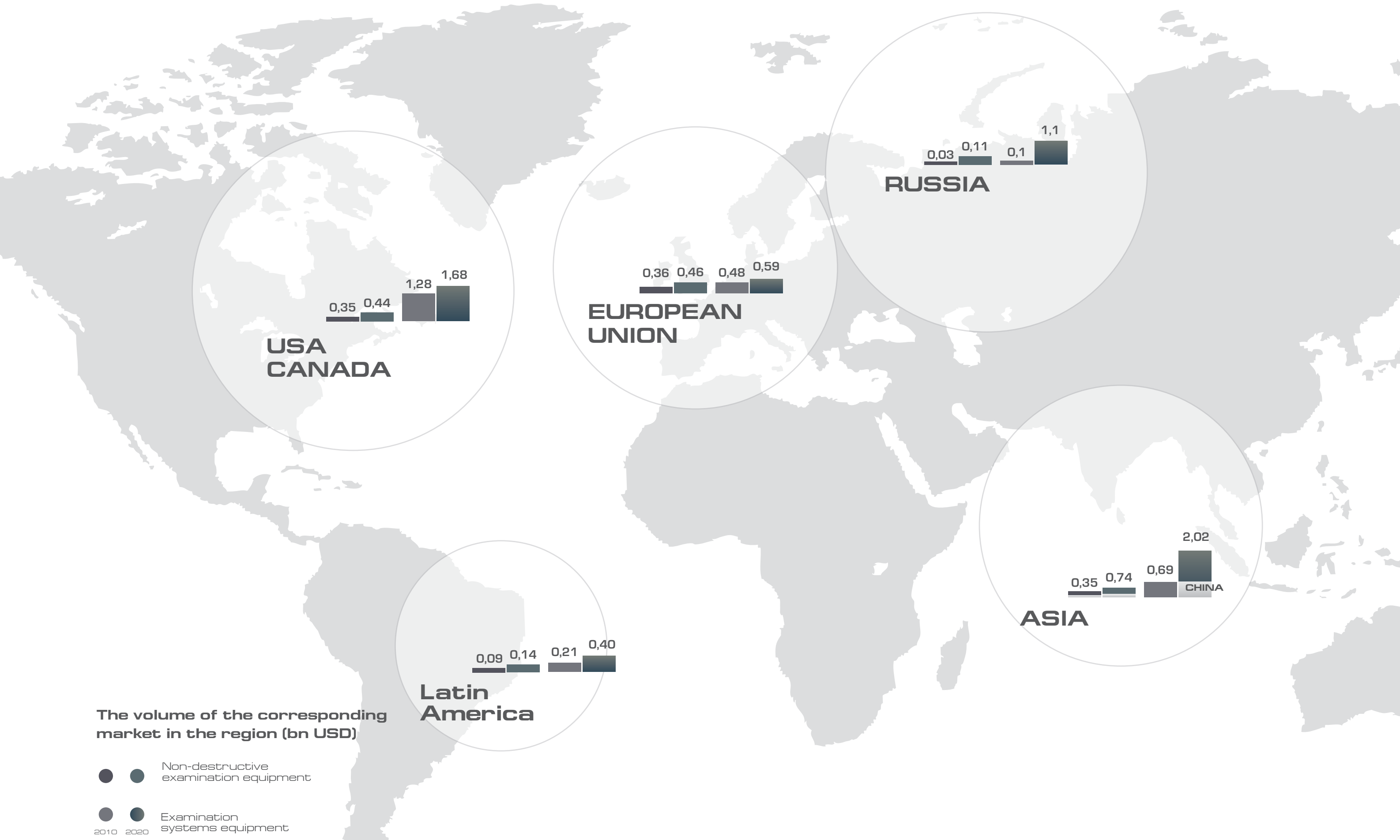
CURRENTLY, ACCORDING TO FROST&SULLIVAN ESTIMATIONS, THE VOLUME OF THE EQUIPMENT MARKET FOR NON-DESTRUCTIVE EXAMINATION IS 1.5 BILLION USD

Some more 2 billion USD fall upon the corresponding services; growth rate of the equipment market is about 5-7% annually. The share of the radiation technologies of non-destructive examination is comparatively small in the total volume of the market - about 4% or only 60 million USD. Radiation technologies of non-destructive examination include X-ray-graphical method, radiographic and X-ray methods.

World market of the security systems consists of four main segments: video monitoring, screening systems, biometrics and CBRN (chemical, biological, radiological, nuclear). It is rather difficult to estimate total volume of the world security market: quantitative expert evaluations differ significantly. In accordance with certain estimations, the world security market makes up from 100 to 150 billion USD. Of these, 5 billion USD report for screening devices, and 10 billion USD – for biometric systems and video surveillance. Estimated market growth rates also differ – from 5% to 10% per year.

In security industry, radiation technologies are applied in screening systems. In money terms, 70% of the screening systems market falls upon the systems that use X-ray emission. In natural equivalent non-radiation metal detector units are the leading type of the equipment.

Figure 9 *Non-destructive examination and security market (forecast, billion USD)*



Source: the Center for Strategic Research "North-West" on the basis of GIA, Frost&Sullivan, BCC Research, data of SC« Rosatom », Weapons & Contraband Detection, BCC Research

QUALITY CONTROL GROWS IN IMPORTANCE, THUS CREATING ADDITIONAL DEMAND FOR NEW SYSTEMS OF NON-DESTRUCTIVE EXAMINATION IN VARIOUS INDUSTRIES

Among these industries are automobile manufacturing, space industry, security industry, metallurgy, oil and gas industry etc. Radiation technologies, first of all X-ray examination, are essential for the corresponding equipment complexes.

Main customers of the screening systems represent transport infrastructure objects, government and customs. Political risks in the sphere of screening systems market are especially high, due to high responsiveness of government institutions to security problems. Thus, a successful Chinese company Nuctech has extremely limited possibilities in the non-Asian markets.

4.5 MATERIALS MODIFICATION MARKETS

Markets of materials modification with the help of radiation technologies are highly fragmented – first of all, due to the specific character of end-use industries of this equipment. Main sectors of RT applications for various materials modification are the following:

Production of microelectronics and, in the wider sense, processing of semiconductors. Radiation technologies are widespread in microelectronics, exactly microelectronics accounts for the main part of industrial RT applications. Out of 19 thousand of industrial accelerators installed as for 2008, 10 thousand were used for ion implantation. Total volume of the market of the equipment for production of electronics is estimated at 45-50 billion USD. Taking into consideration total growth of microelectronics market (up to 550 billion USD by the year 2020), as well as regular renovation of the equipment used for its production, there can be expected substantial growth in demand for installations of ion implantation in the corresponding market.

Processing of polymers. Main limitations for growth of the market share in polymers radiation processing are high prices of the equipment and presence of long-settled chemical technologies in the industry. Therefore, radiation processing of polymers is applied in the areas where usage of traditional chemical methods results in worse product quality. Global market of the equipment for polymers radiation processing made up 137 million USD in 2009, while the products manufactured with the help of this equipment could be estimated in money terms at 30-50 billion USD. Taking into account possible cost reduction of industrial accelerators, and growth of the new materials market, increase of demand for polymers radiation processing units can be expected. The operations that can be fulfilled with the help of RT are polymerization (in different phases of monomers and prepregs); cross-linking (for cable jackets, parts of radial auto tyres, etc); hardening (including hardening aimed at adding combined features to the hydrophobic-hydrophilic-type surfaces). According to expert estimations, market volume for the relevant equipment may reach as much as 300 million USD by 2020.

High-precision technologies of changing the materials' physical properties (electron-beam technologies of welding, cutting, drilling, polishing). These technologies are applied in many fields: energy, space industry, automotive production, oil-and-gas industry, construction, medical equipment production, etc. It can be said for sure that growth of usage of these technologies mostly depends on total dynamics of the global economy growth. In the sphere of technologies of changing the materials' physical properties, there exist several radiation technologies; among them the leading position is held by electron-beam welding. According to Bain's estimations, market volume of the radiation equipment for changing the materials' physical properties (the biggest share of which belongs to electron-beam welding technologies) is about 165 million USD, and the growth rate is about 4-5% a year.

4.6 MARKETS OF NEW RADIATION TECHNOLOGIES COMMERCIALIZED AT THE FOURTH STAGE OF THE RT DEVELOPMENT

The key essentially new market for the radiation technologies that should be commercialized at the fourth stage is the market of environmental safety technologies. Cost reduction of radiation technology units will make them highly competitive, thus giving the possibility for wide expansion of RT to various market segments, including:

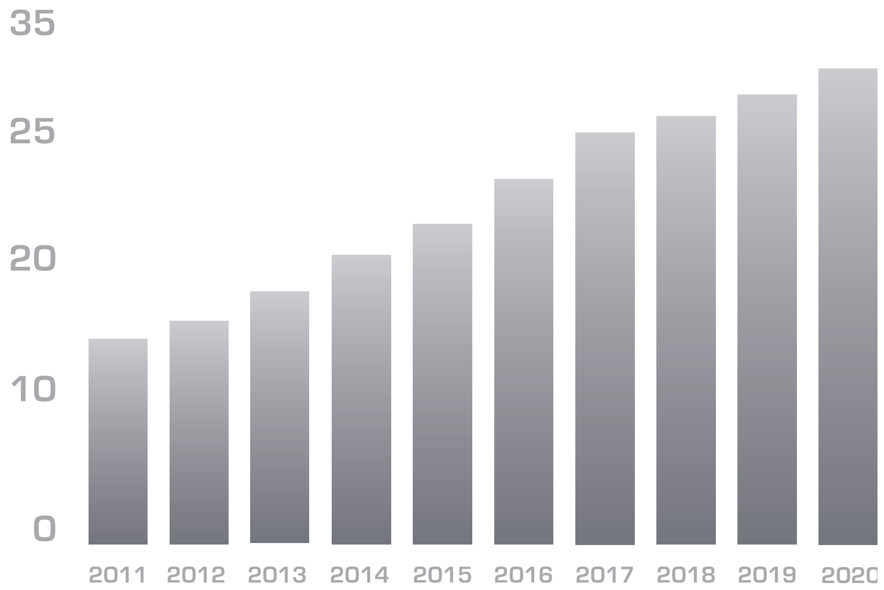
The market of processing solid household waste and medical waste and recycling. Total global market volume counts for as much as 6,900 million USD according to Bain's estimations, and the market growth rate is estimated at 6% per year. Potential of the market growth could be as high as 23 billion USD by 2025. According to expert evaluations, there globally exist about 5,000 waste incineration plants and about 800 plants producing energy from the incinerated waste. In 2007, based on Bain's estimations, the leading waste processing technologies were burning on grates (1,800 million USD) and burning in furnaces with fluidized bed (around 600 million USD). Advanced technologies of pyrolysis and gasification accounted for 153 million USD only. The main reason for poor demand for the innovative technologies is the extremely high cost of such plants (including those with the RT units)[12]. Therefore, cost reduction of accelerator technologies could create great potential for their applications in processing of solid household waste. Currently, in the world there is no waste processing plants using exactly radiation technologies for solid household waste processing. There are some pilot facilities in Japan that use pyrolysis technologies for reprocessing used automobile tyres. There is also a number of plants under construction that announce implementation of the new technologies, however they should be put into action only by 2013-2015.

Flue-gas purification market. The market volume of the technologies for flue-gas purification from sulfur dioxide constituted about 17 billion USD in 2011 (according to GBI Research data). Currently radiation technologies are very poorly represented in this market: only one pilot radiation flue-gas purification plant in the world functions in the launch

12 The cost of one solid household waste reprocessing plant with the capacity of 250-300 thousand ton per year and using standard technology, according to expert estimations, can make up from 100 up to 300 million EUR. The cost of the pilot Plasco plant (plasmothermal gasification) with the capacity of 220 ton per day (around 80 thousand ton per year) is 90 mln. Canadian dollars; the cost of the pilot Geoplasma plant with the capacity of 300-400 ton per day (around 110 thousand ton per year) is 520 mln. USD.

mode at the Pomorzany power plant in Poland. This plant has been designed by the Polish specialists, while the accelerators have been provided by the Japanese government; the cost of the unit made up as much as 25 million USD. Considering high purification quality (decrease of sulphur-containing substances emissions by 95%), and conditioned that the cost of the equipment could be decreased, it would be possible to expect active radiation technologies expansion into this market.

Figure 10 *Flue-gas purification market (forecast, billion USD)*



Source: McIlvaine Company

Water treatment market (drinking water treatment, waste water processing). Most of the urbanized countries possess the system of municipal and industrial processing of waste water, although in a number of developing and post-socialist countries, there still exists a wide-spread practice of pouring wastewaters out into the natural water basins without any purification. According to different estimations, global market volume for water treatment makes up from 57 billion USD up to 203 billion USD (Bain's and BCC Research estimations). The market potential, based on Bain's evaluation, could reach as much as 388 billion USD, while the market growth rate is estimated at 5% per year. Currently, the share of the radiation technologies in this market is feasibly small – there is only one plant for waste water treatment after paint production functioning in the Korean Republic. It uses the radiation unit with the Russian ELV-12 accelerator. Its construction cost was about 4 million USD, and operational costs make up around 1 million USD per year.[13]

13 It should be taken into consideration that a modern waste water purification plant simultaneously uses mechanical, chemical and biological purification methods. According to expert evaluations, the waste water purification market is closely connected to the markets of water desalination and water treatment (drinking water processing), due to the fact that the background production for these processes is the standard one. The market players are integrated structures, plants dealing with "turnkey" purification. In order to successfully function in the market, a company must have access to all types of purification technologies. The large part of the new market players has evolved from membrane manufacturers. In other words, in case of cost decrease, radiation technologies could be included into the "standard kit" for waste water processing.

NEW RADIATION TECHNOLOGIES AT THE FOURTH STAGE OF DEVELOPMENT WILL BE APPLIED IN THE EXISTING MARKETS

In particular, RT will be applied in nuclear medicine market (neutron and neutron capture therapy, compact accelerators for proton therapy, bioradiopharmaceuticals, ion therapy, complex diagnostic systems), security market (neutron activation analysis and complex systems), etc.

05

POSITIONS OF RUSSIA

"Partnership with Russia is extremely important for us, and it concerns not only the energy industry. I personally attach great value to Russia's potential and willingness to assist developing countries in cancer treatment. You possess unique experience in radiotherapy and nuclear treatment methods"

Yukiya Amano, Director General of the International Atomic Energy Agency (IAEA)

5.1 MAIN OBJECTIVES OF RT DEVELOPMENT IN RUSSIA

Main objective of the radiation technologies development in Russia in the mid-term perspective is to provide large-scale investment into non-energy sectors of radiation technologies applications. The severe economic decrease in the 1990s made Russia in fact skip the stage of commercialization of the technological backlog in RT sector. The lack of financial resources for the corresponding activity directions was burdened by the fact that nuclear industry, closely connected with the issues of defense capacity and non-proliferation of nuclear technologies, was "out-of-bounds" and restricted.

THE OBJECTIVE OF COMMERCIALIZATION OF THE NUMEROUS RESEARCH RESULTS WOULD BE IN PARTICULAR SOLVED WITHIN THE FRAMEWORK OF A UNIFIED TECHNOLOGICAL PLATFORM "RADIATION TECHNOLOGIES" CREATED IN THE BEGINNING OF 2011 (SEE 5.2.)

The second important objective of RT development in Russia is accumulation of the missing competences in RT-related spheres that are necessary for dynamic development.

Table 3 Main competencies in RT and their allocation in the Russian Federation

Competencies	R&D	Engineering	Production
Production and turnover of isotope products	NRC "Kurchatov Institute" SSC RF RIAR Karpov SSC RF SRPCI SPbSU RPA V.G. Khlopin Radium Institute	NRC "Kurchatov Institute" SSC RF RIAR Cyclotron Co., Ltd RPA V.G. Khlopin Radium Institute	«Diamed» Ltd. FMBPC NRC "Kurchatov Institute" Leningrad NPP FSUE PA «Mayak» SSC RF RIAR RPA V.G. Khlopin Radium Institute Karpov SSC RF SRPCI Cyclotron Co., Ltd "Atommed" center
Production and turnover of radiopharmaceuticals	GC «Medradiopreparat» FMBA JSC «Oksi-med» SINP MSU (Moscow) SSC RF Alikhanov ITEP RPA V.G. Khlopin Radium Institute» Karpov SSC RF SRPCI FSUE «SSC RF – PEI» (Obninsk) The Institute of Problems of Chemical Physics of RAS FSBI MRRC MoHSD (Obninsk) TPU (Tomsk)	GC «Medradiopreparat» FMBA FSUE "Federal center of nuclear medicine projects design and development" of FMBA FSI RRC RST (SPb) SINP MSU (Moscow) SSC RF Alikhanov ITEP Karpov SSC RF SRPCI FSUE «SSC RF – PEI» (Obninsk) FSBI MRRC MoHSD (Obninsk) "Atommed" center	GC «Medradiopreparat» FMBA FSUE "Federal center of nuclear medicine projects design and development" of FMBA NRC "Kurchatov Institute" FSI RRC RST (SPb) SINP MSU (Moscow) RPA V.G. Khlopin Radium Institute Karpov SSC RF SRPCI FSUE «SSC RF – PEI» (Obninsk) RFNC – vniitf "Atommed" center "RONIK — nuclear and medical technologies" TPU (Tomsk)
Technologies for scanning and analysis (non-destructive examination, security)	NRC "Kurchatov Institute" RPA V.G. Khlopin Radium Institute NRNU MEPhI The P.N. Lebedev Physical Institute of Russian Academy of Sciences (FIAS) Institute of Solid State Physics, RAS JINR (Dubna) ISPMS SB RAS Institute NDT TPU (Tomsk) SSC RF TRINITI SPb SIT (TI) SSC RF IHEP FSUE D.V. Efremov NIIEF (Spb) INR RAS OJSC S&TC "RATEC" SPC "Doza" Ltd JSC "NRI "Electron"	Institute of Solid State Physics, RAS JINR (Dubna) ISPMS SB RAS Institute NDT TPU (Tomsk) SPb SIT (TI) SSC RF IHEP Institute on Laser and Information Technologies of RAS OJSC S&TC "RATEC" SPC "Doza" Ltd JSC "NRI "Electron" FSUE D.V. Efremov NIIEF (Spb)	JINR (Dubna) Institute on Laser and Information Technologies of RAS JSC S&TC "RATEC" JSC «Lumex-protection» FSUE D.V. Efremov NIIEF (Spb)
Equipment for medical diagnostics	NRC "Kurchatov Institute" FSI RRC RST (SPb) FSUE D.V. Efremov NIIEF (Spb) SRI of Cardiology SD RAMS Dukhov VNIIA FSBI MRRC MoHSD (Obninsk) Institute NDT TPU (Tomsk) SSC RF IHEP "Atommed" center JSC "NRI "Electron"	FSI RRC RST (SPb) FSUE D.V. Efremov NIIEF (Spb) JSC «NIITFA» FSUE «SSC RF – PEI» (Obninsk) Cyclotron Co., Ltd Dukhov VNIIA Institute NDT TPU (Tomsk) "Atommed" center "RONIK — nuclear and medical technologies" JSC "NRI "Electron"	FSUE D.V. Efremov NIIEF (Spb) JSC «NIITFA» FSUE «SSC RF – PEI» (Obninsk) Cyclotron Co., Ltd Dukhov VNIIA "Atommed" center "RONIK — nuclear and medical technologies" JSC "NRI "Electron"

Table 3 *Main competencies in RT and their allocation in the Russian Federation*

Competencies	R&D	Engineering	Production
Medical accelerators	SRINP TPU (Tomsk) NRC "Kurchatov Institute" FSUE D.V. Efremov NIIEF (Spb) JINR (Dubna) SSC RF TRINITI JSC "NRI "Electron"	SRINP TPU (Tomsk) FSUE D.V. Efremov NIIEF (Spb) JINR (Dubna)	FSUE D.V. Efremov NIIEF (Spb) JINR (Dubna)
Industrial accelerators (equipment for irradiation, spraying, sterilization, etc.)	INP SB RAS JSC «NIITFA» FSUE D.V. Efremov NIIEF (Spb) NRNU MEPhI Saint-Petersburg Electrotechnical University "LETI" (ETU) The P.N. Lebedev Physical Institute of Russian Academy of Sciences (FIAS) Institute of High Current Electronics SB RAS ISPMS SB RAS SRI NP SPbSPU RIARAE-RAAS SSC RF TRINITI SPb SIT (TI) INR RAS Institute of Strength Physics and Materials Science of the SB of RAS (Tomsk) The Institute on Laser and Information Technologies of RAS	INP SB RAS Institute of High Current Electronics SB RAS ISPMS SB RAS SRI NP SPbSPU All-Russia Agricultural Radiology and Agro-Ecology Scientific Research Institute SSC RF TRINITI Institute of Strength Physics and Materials Science of the SB of RAS (Tomsk) The Institute on Laser and Information Technologies of RAS "RONIK – nuclear and medical technologies" FSUE D.V. Efremov NIIEF (Spb)	INP SB RAS Institute of High Current Electronics SB RAS Institute of Strength Physics and Materials Science of the SB of RAS (Tomsk) The Institute on Laser and Information Technologies of RAS JSC "Svetlana-Semiconductors" JSC "SRI Giricond" JSC "Diakont" "RONIK – nuclear and medical technologies" FSUE D.V. Efremov NIIEF (Spb) "Korad-Service"
Research and extra-large accelerators	SRINP TPU (Tomsk) NRNU MEPhI ISPMS SB RAS SSC RF IHEP B.P.KONSTANTINOV PNPI JINR (Dubna)	SRINP TPU (Tomsk) SSC RF IHEP INP SB RAS B.P.KONSTANTINOV PNPI JINR (Dubna)	ISPMS SB RAS B.P.KONSTANTINOV PNPI FSUE D.V. Efremov NIIEF (Spb) JINR (Dubna)
Research reactors	SSC RF RIAR NRNU MEPhI MIPT SRI NP SPbSPU STC "Syntez" SSC RF TRINITI B.P.KONSTANTINOV PNPI	SSC RF RIAR SSC RF TRINITI B.P.KONSTANTINOV PNPI	SSC RF RIAR SSC RF TRINITI B.P.KONSTANTINOV PNPI

Source: CSR NW according to the data provided by the companies

SUCH IMPORTANT DIRECTIONS AS INDUSTRIAL ICT AND LIFE SCIENCE ARE UNDERDEVELOPED IN RUSSIA

This fact restricts creation of breakthrough innovations and essentially new world-class "blockbuster products".

Providing cross-disciplinary and scientific and technical cooperation between specialists and companies from different industries will be ensured via long-term strategic partnerships, in part - within the framework of cluster policy.

Case study

STRATEGIC ACTIVITY OF FSUE "EFREMOV SCIENTIFIC RESEARCH INSTITUTE OF ELECTROPHYSICAL APPARATUS" (NIIEFA)

In Russia, one of the largest competence centers for all types of accelerators (linear accelerators, cyclotrons, extra-large accelerators) is Federal State Unitary Enterprise "D.V. Efremov NIIEFA". The main short-term objective of NIIEFA is production scaling. Thus, in 2014 NIIEFA will become a base for mass production of cyclotrons and SPECT systems. This project is being implemented within the framework of the state program of organization of mass cyclotron technics production. The program aims at the creation of small-scale Russian accelerators production for equipping centers of positron emission tomography (PET-centers) both in Russia and abroad. State Atomic Corporation "Rosatom" plans to use such cyclotrons for equipping medical centers in different regions of the country. In 2012, activity on equipment modernization of the existing production facilities started: among that, purchasing of equipment, creating of equipment stock and introducing a test bench for component testing.

The prototype model of a SPECT system developed by NIIEFA has already passed clinical trials in one of the hospitals in Moscow. Taking into consideration all the observations made during the trials, the SPECT system will be improved and put into mass production. According to the NIIEFA's management, total production volume starting in 2014 will make up to 10 cyclotrons and up to 20 SPECT systems annually. Cyclotron production is aimed primarily at the national market, international sales might be possible as well.

5.2 RADIATION TECHNOLOGIES

THE UNIFIED RUSSIAN TECHNOLOGICAL PLATFORM

Technological platform "Radiation technologies" is a new initiative in the sphere of private-state partnerships. It was approved by the Government Commission on High Technology and Innovation on April 1, 2011 (within a list of technological platforms). Coordinator of the technological platform is the Nuclear Technology Cluster of the «Skolkovo» Foundation (see 5.3.).

ACTIVITY OF THE TECHNOLOGICAL PLATFORM "RADIATION TECHNOLOGIES" IS AIMED AT JOINING THE EFFORTS OF GOVERNMENT, BUSINESS AND SCIENCE IN THE FOLLOWING DIRECTIONS:

- Development, popularization and support of safe commercial usage of the radiation technologies;
- Development of the legitimate and stable platform for communications with key customers, oriented at meeting interests of all the participants and therefore developing radiation technologies industry in general;
- Regular coordination of the long-term vision of technology development between the industry players;
- Coordinated utilization of the limited state and corporate resources for research and development;
- International cooperation and integration of the Russian players into the global community.

MAIN OBJECTIVES WITHIN THE FRAMEWORK OF THE TECHNOLOGICAL PLATFORM "RADIATION TECHNOLOGIES" ARE:

- Performing long-term scientific and technological forecast on the basis of foresight methods. It should determine major scientific and technological priorities of the radiation technologies development;

- Preparing and conducting expert discussion of a strategic research and development program, and coordinating utilization of state and corporate resources for its implementation;
- Describing functional requirements for end products and systems from the customers' side;
- Performing technological audit of the Russian players in the sphere of radiation technologies with subsequent technological chains mapping;
- Promoting Russian developments, products and services in radiation technologies in the international markets, entering international associations, developing territory-based innovative clusters;
- Developing and negotiating on technical regulations and standards;
- Developing training and professional development programs for scientific, engineering and technical staff.

The technological platform includes more than 70 organizations, in particular R&D institutions, institutions of higher education, manufacturing and engineering enterprises, companies partially owned by state, small and medium businesses (residents of the "Skolkovo" Foundation).

Target organizational structure of the technological platform consists of the Coordinator, the Industrial Council, the Council of Customers and the Association of Professionals.

THE COORDINATOR OF THE TECHNOLOGICAL PLATFORM, THE NUCLEAR TECHNOLOGY CLUSTER OF THE "SKOLKOVO" FOUNDATION, FULFILLS THE FOLLOWING FUNCTIONS:

- Coordination of activities of the managing and executing departments of the technological platform;
- Representation of the participants' interests at development institutions, at public authorities of the Russian Federation at all levels;
- Establishing contacts and interaction with Russian and foreign players, customers, regulators, international technological platforms, associations in the radiation technologies industry;
- Coordination of scientific and technological foresight, development of strategic R&D program, technological audit and mapping of technological chains, formation of the functional requirements to end products and systems on behalf of the customers;
- Coordination of technological regulations and requirements including the international ones, assistance in training and professional education for scientific, engineering and technical staff;
- Stimulation of financing into priority project in the sphere of the radiation technologies both from state and private sources.

The Industrial Council of the technological platform will be formed from the representatives of all levels of authorities in Russia, from the representatives of the partially state-owned companies and the representatives of the private businesses. The purpose of the activity of the Industrial Council is to develop recommendations for technology development and assist in decision-making that will contribute to the development of the radiation technologies industry in general.

The Council of the Customers will be created in form of the working groups in six priority directions of radiation technologies applications: Medicine, Security, Food and Water (disinfection, sterilization of agricultural and food commodities, waste water treatment), Heavy Industry (radiation chemistry, changing properties of materials), Energy Industry (oil cracking, flue-gases purification, biomass irradiation and other), Big Science (equipment for research units). The working groups are formed from the representatives of the expert community, corporate customers, consumers, regulatory bodies.

FOR 2012, THE FOLLOWING ACTIVITIES ARE PLANNED FOR THE WORKING GROUPS:

- Defining functional requirements from the customers of technologies and equipment to end products and systems;
- Defining the possibilities of Russian developers and producers (both current and prospective);
- Describing 3-5 top-priority technological chains where products based on radiation technologies (devices, equipment, technologies) could be embedded;
- Evaluating possibilities of developers and producers, as well as prospects of the running projects by their possible embedding into existing technological chains;
- Analyzing R&D projects and forming a grounded list of suggestions for the strategic program of research within the technological platform «Radiation technologies»;

- Developing requirements to PR and GR (providing recommendations for the development of technological regulations and legal acts);
- Defining the key technological challenges/problems for the technological platform up to the year 2015 (creating the technological roadmap).

THE ASSOCIATION OF PROFESSIONALS IN RADIATION TECHNOLOGIES IS FORMED FROM THE DEVELOPERS OF RADIATION EQUIPMENT AND TECHNOLOGIES, SPECIALISTS OF THE RADIATION TECHNOLOGIES SECTOR WHO APPLY RT IN PRACTICE IN INDUSTRY, MEDICINE, AGRICULTURE AND OTHER AREAS

Main objectives of the Association are consolidation of the experts' experience and competencies within the framework of the technological platform "Radiation technologies", representation of the participants' interests in business and legal fields, creation of communication forums for the experts, formation of market trends for expansion of the radiation technologies applications and defining long-term development directions for equipment manufacturers.

WITHIN THE FRAMEWORK OF THE ASSOCIATION THE FOLLOWING SUPPORT WILL BE PROVIDED TO THE PARTICIPANTS:

Establishing contacts and communicating with main customers and regulators (coordinating technical and functional requirements to end products and systems, defining and negotiating on technical regulations and standards);

Representing interests of the participants in government authorities at all levels, in the development institutions, etc. (attracting investment, developing and implementing strategic research program of the technological platform);

Popularizing the radiation technologies sector (developing certain processes, showing advantages of the radiation technologies applications);

Providing international integration (promoting Russian R&D to the international markets, joining international associations - International Irradiation Association, American Society of Mechanical Engineers etc.).

IN SEPTEMBER 2012 THE INTERNATIONAL CONFERENCE ON RADIATION TECHNOLOGIES DEVELOPMENT AND THEIR APPLICATIONS IN VARIOUS SECTORS OF THE WORLD ECONOMY WILL BE HELD IN RUSSIA, WITH PARTICIPATION OF THE ASSOCIATION OF THE PROFESSIONALS, INNOVATIVE ENTREPRENEURS AND REPRESENTATIVES OF THE TECHNOLOGICAL COMPANIES

Besides that, within the framework of the Technological platform "Radiation technologies" the following activities are scheduled for 2012:

To publish a report containing basic top scientific and technical priorities for the radiation technologies development;

To form a strategic research and development program;

To perform technological audit of the Russian players in the radiation technologies sector and perform technological chains mapping.

5.3 “SKOLKOVO” NUCLEAR TECHNOLOGY CLUSTER

The Nuclear Technology Cluster of the “Skolkovo” foundation was founded in 2010, while first experts of the Cluster started their work in 2011. The main objective for its creation was the need for nuclear technologies transfer from the military and energy sectors into the civil sector and for development of the promising directions of nuclear developments applications: nuclear science technologies, radiation technologies, technologies for creation of new properties of materials, mechanical engineering, instrument engineering, new microelectronics, etc.

THE NUCLEAR TECHNOLOGY CLUSTER PROVIDES INNOVATIVE DEVELOPMENT OF NUCLEAR TECHNOLOGIES FOR ENSURING GLOBAL TECHNOLOGICAL LEADERSHIP AND HIGH LEVEL OF NATIONAL DEFENSE CAPACITY

One of the results of the Cluster activity should become technology and product diversification. It is assumed that nuclear industry groundwork can be used in the markets that are new for the industry players – in nuclear medicine, security, creation of the new materials and others.

There are five clusters in the “Skolkovo” Foundation, according to five directions of the innovative technologies development. These technologies, including the Nuclear Technology Cluster, have been announced as priority directions by our country leaders. Participants of the Nuclear Technology Cluster support innovations in nuclear energy industry and in related directions. Currently more than 50 innovation companies have entered the Cluster. One of the top priority aims of the “Skolkovo” Foundation is commercialization of the developments of the innovation center residents.

MAIN ACTIVITY OF THE RESIDENT COMPANIES AT THE NUCLEAR CLUSTER IS DEVELOPMENT IN THE SPHERE OF THE RADIATION TECHNOLOGIES AND NEW MATERIALS

On the basis of the analysis of perspective technology development in nuclear industry, comparison to the global level and estimation of the human resources potential, strategic technological directions were defined for the Nuclear Technology Cluster (in general, concerning radiation technologies development and equipment for their applications).

ANALYSIS OF THE WORLD TRENDS IN TECHNOLOGICAL DEVELOPMENT AND COMMERCIAL PERSPECTIVES FOR RT IN VARIOUS MARKETS ALLOWED DEFINING A LIST OF PRIORITIES FOR THE CLUSTER ACTIVITY. THESE DIRECTIONS DETERMINE THE PRIORITY ORDER FOR ACCEPTING PROJECTS AND COMPANIES TO SKOLKOVO:

01. Medical isotopes and radiopharmaceuticals

02. Radiation therapy and magnetic therapy

03. Laser technologies for diagnostics and therapy, cosmetology and biotechnologies

04. Diagnostic systems using radiation and magnetic fields

05. Disinfection of food.

06. Sterilization of medical products

07. Sputter coating, implantation

08. Industrial sputter coating

09. Purification and modification of surfaces

10. Electron-beam epitaxy

11. Radiation technologies in production of filters

12. Means of control for materials structure and compounds quality

13. Screening security systems

14. Radiation methods of waste processing, including radioactive waste processing

15. Radiation methods of cleaning territories, purification of exhaust gases and waste water

16. Electron-emitting, radiation-chemical technologies and electromagnetic field technologies

17. Logging

18. Radioactive exploration of the Earth's crust

19. Robotic exploration and maintenance of the radiation units

20. Neutron generators

21. Microscopes and telescopes

22. Microwave electronics

23. Detectors, sensors and dosimeters

24. Radiation methods of material cutting and welding

25. Metal overlaying and hardening

26. Semiconductor doping methods

27. Radiation anneal

28. Systems of calibration, checking and certification of detectors

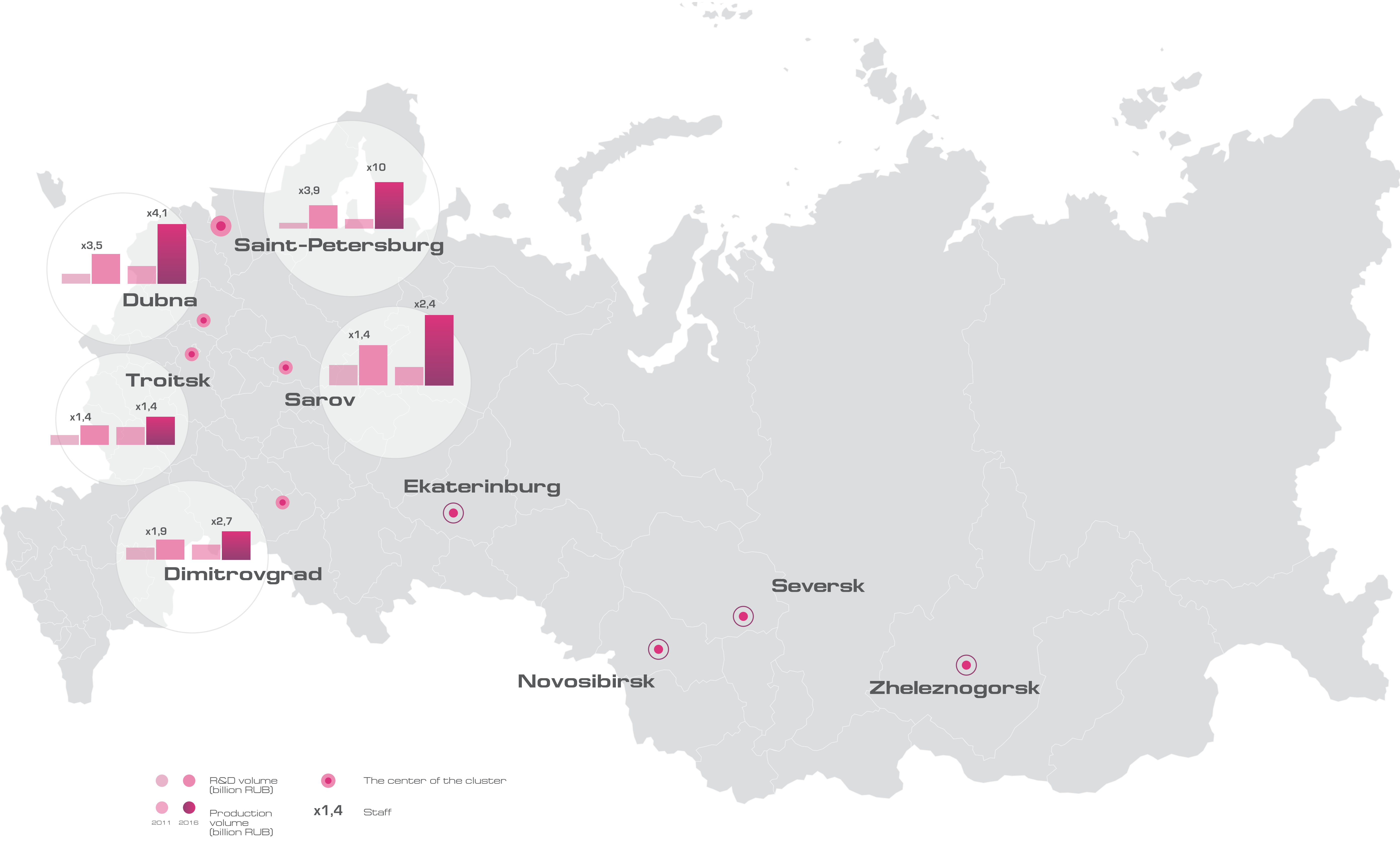
5.4 NON-ENERGY RADIATION TECHNOLOGIES CLUSTERS IN THE REGIONS OF RUSSIA

Currently Russia experiences active formation of territory-based innovation clusters. Among them, nuclear clusters can be pointed out, first of all related to non-energy radiation technologies development. The mentioned clusters have different specialization and are oriented at different application markets. Special attention in these clusters is paid to the nuclear medicine market, security market and the market of industrial application of laser-beam technologies.

All the clusters are based on their own development infrastructure.

IN THEIR ACTIVITY, ALL CLUSTERS VIEW AS PRIORITY ACHIEVING HIGH EFFICIENCY OF THE NEWLY CREATED TECHNOLOGY TRANSFER CENTERS, COMMERCIALIZING PROMISING DEVELOPMENTS AND INVESTING THEIR OWN FINANCIAL RESOURCES INTO PROSPECTIVE INTERDISCIPLINARY DIRECTIONS, INCLUDING NEW MATERIALS SCIENCE, BIOTECHNOLOGIES AND BIOPHARMACEUTICS

Figure 12 *Main radiation technology clusters in Russia*



Together, Russian competence centers are able to adequately develop a limited number of directions in radiation technologies. To keep up with the global developments, we need to define our priorities in this area within a year in order to concentrate there our limited resources

D.Kovalevich, RIA Novosti (www.ria.ru), Moscow, June 9, 2012

Nuclear Technology Cluster of the "Skolkovo" Foundation started its activity in May 2011. Within a year, we have created a world-class expert council, have brought in over 100 project applications and have approved 15 grants starting from 100 thousand USD up to 5 million USD.

Speaking about the Cluster, I mean the whole entity of our partners: startup companies, entrepreneurs, technological corporations, venture investors, universities, research centers, experts in science and business. The Cluster is an informal network which we help to grow by jointly working out technological priorities, supporting new teams' development and creating opportunities for applied realization of research results.

I sincerely hope that this report reflecting our team's view at the perspectives of radiation technologies development will become a basis for new partnerships and joint projects.

Denis Kovalevich,
Director of the Nuclear Technology Cluster of the "Skolkovo" Foundation