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Principles of the organization of space-planning solutions for nuclear medicine facilities

Balakina A.E. [1], **Lempl Yu.I.** [1 *]

[1] National Research Moscow State University of Civil Engineering, Russia

Abstract: It is nearly impossible to imagine modern medicine without the use of nuclear technologies, the introduction of which has led to the emergence of new methods of prevention, diagnosis and treatment of various diseases, as well as reduced mortality rates among patients and improved the quality of life of patients with diseases in the field of oncology, cardiology, neurology and others. The purpose of this article is to systematize the principles of the organization of architectural space-planning solutions based on the studied experience of the constructed nuclear medicine facilities. The methodology of this research constitutes an analysis of statistical data and academic papers, in which the authors examine the core process equipment used at nuclear medicine facilities, the main architectural typological zones of nuclear medicine facilities, and highlight the requirements to the premises in which the source of ionizing radiation is located. In addition to the analysis of academic papers, the methodology of this research includes the analysis of practical experience in the architectural design and construction of nuclear medicine facilities, as a result of which the authors analyzed space-planning and architectural solutions used in the design and construction of nuclear medicine facilities. As part of this article, the authors present, in particular, an analysis of the experience of personal design of a number of Russian nuclear medicine facilities. Furthermore, special attention in the article is paid to the principles of architectural and planning solutions for children's medical institutions (in particular, with oncological specialization). The result of the research is to build up a sketch model of the space-planning solution of the nuclear medicine facility as a multi-purpose facility, to determine the principles that affect the formation of space-planning solutions. The research is aimed at forming a space-planning solution for a multi-purpose nuclear medicine facility, taking into account the possibility of increasing its capacity during operation.

Keywords: space-planning solutions of a multi-purpose nuclear medicine facility (NMF), environment of the NMF, architectural principles of the NMF, medical institution, adaptive space, radiation therapy rooms, radiopharmaceuticals production facilities, positron emission computed tomography (PET centers) research rooms, clean rooms

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*Corresponding author E-mail: jurij.lempl@gmail.com

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1. INTRODUCTION

Despite the urgency of the problem, when studying the literature on this issue, it should be noted that there is a negligible quantity of scientific studies on the topic of architectural and construction development of the base of the public health system in the form of a certain set of building typologies. One of the few theses in this area was defended in 2015. The author of the paper Gayduk A.R. [1] investigated the architecture of pediatric cancer centers. One of the main issues of the research was the study and proposals for the formation of the environment of such institutions.

In the modern period the problems of architecture of therapeutic complexes, their placement in the structure of cities are reflected in the articles [2, 3, 4]. The factors influencing the formation of space-planning solutions in the reconstruction of healthcare facilities have been considered in the articles [5, 6, 7]; the types of reconstruction and further development of the typology of medical treatment facilities have also been determined.

Theoretical basis of research in the field of architectural composition and planning of health-related complexes was carried out by other scientists. Among them are Christie J., Nagasawa Y. [8], Chefurka T. [9], Balakina A.E., Tesler N.D. [10, 11,12,13] and others.

Medical sciences and technologies develop exponentially. They require a special approach in the area of design, construction and operation. Nuclear medicine is one of such recent directions. Some safety issues of nuclear and radiation medicine facilities are covered in the papers of Tikhonov A.A., Turlak V.A., Sokolov E.E., Tsyba A.F., Kamalov I.I., Malykha G.G., Telichenko V.I., Dorogan I.A., etc. However, they refer mainly to the technical aspect of the construction and operation of facilities. Theoretical architectural and construction studies in this area fall behind. Although they are extremely important for this new typological direction of public health facilities, which require the creation of new regulations, rules and guidelines.

Nuclear medicine is actively developing in Russia and abroad. It is justified primarily by the fact that this field of medicine helps to make an accurate diagnosis at early stages of many diseases, in therapy this field is applied in oncology, cardiology, neurology for the diagnosis and treatment of a number of dangerous diseases. A number of works are devoted to the study of the design of nuclear medicine facilities and their features [14, 15, 16]. In paper [17], the main technological equipment used in nuclear medicine facilities (NMF) is studied, and requirements to the main premises where the radiation source is located are proposed. In papers [18, 19] the definition of the NMF has been given, the main architectural typological zones in nuclear medicine facilities have been investigated. Papers [23, 24] describe the basic principles of space organization for medical rooms, including rooms with the placement of ionizing radiation sources. Analyzing the space-planning solutions of NMF, it may be concluded that each particular medical center was built for its local tasks with reference to a specific location. For nuclear medicine facilities, as of today there is no systematization of the typology of space-planning solutions, determination of the basic principles of their construction and extension.

Approximately 400,000 children and adolescents aged from birth to 19 years old are diagnosed with cancer each year worldwide [27, 28]. In high-income countries, where, as a rule, comprehensive services are available, more than 80% of children make a complete recovery from cancer. In low- and middle-income countries, recovery is estimated to occur in only less than 30% of cases [29, 30, 31]. Since it is virtually impossible to prevent cancer in children, the most effective way to improve the indicators of clinical outcome is timely and correct diagnosis followed by effective treatment based on individually tailored maintenance therapy. Correct diagnosis is critical in prescribing the relevant course of treatment for a particular type and stage of cancer. The standard therapy includes chemotherapy, surgical interference and/or radiation therapy. Nuclear medicine techniques are used to diagnose and treat pediatric oncology. In our country, the leading centers, such as the Research Institute of Pediatric Oncology and Hematology (Russian Cancer Research Center) named after N.N. Blokhin (located on Kashirskoye Highway in Moscow), the children's building in the territory of the Republican Oncology Center (32 Pirogova St., Ulan-Ude, Buryatia), the National Medical Research Center of Pediatric Hematology, Oncology and Immunology named after Dmitry Rogachev (Samora Machel St., Moscow), the children's unit of FSBI «N.N. Petrov National Medical Research Center of Oncology» of the Ministry of Health of Russia, etc. were constructed. This article is also

devoted to the generalization and study of the principles of organization of pediatric oncology inpatient facilities.

2. METHODS AND MATERIALS

The materials and methods of this research represent the analysis of academic papers on the research topic [1, 8, 10], the generalization of practical experience of architectural design and construction of NMF in Russia and abroad [18, 14, 32], the study of statistics and scholarly works for NMF design, the analysis of the author's personal experience in the design of medical institutions, including the Republican Oncology Center in Ulan-Ude, the Endocrinology Research Center in Moscow, the Research Institute of Pediatric Oncology and Hematology (Russian Cancer Research Center) named after N.N. Blokhin in Moscow and other facilities. The methodology of this research also represents the analysis of practical experience in the application of architectural and artistic solutions, the assessment of the prospective development of architectural and artistic design of NMF, the analysis of architectural principles used in NMF, the analysis and systematization of regulatory, technical and scientific literature on the area of research, on-site investigation of NMF. The above-listed three facilities, as well as the Proton Radiation Therapy Center of the Medical Institute named after Berezin Sergey (MIBS) in Saint Petersburg, the Institute of Nuclear Medicine in Khimki, the Nuclear Medicine Center in Dimitrovgrad, the Cardiology Center on Rublyovskoye Highway in Moscow and many other medical facilities were taken as a basis for the study. The papers of domestic and foreign scientists in the area of architectural and space-planning solutions [20, 25, 26] are the theoretical basis of the research. The experience of implemented projects in Russia and abroad, the author's own experience in the design organization engaged in the development of projects for the construction and reconstruction of healthcare facilities are the practical basis of the research.

Fig. 1 shows the methodological scheme of the research according to which the principles of organization of space-planning solutions of NMF are determined based on the analysis of theoretical sources, scientific articles, domestic and foreign experience in NMF design, statistical data and personal experience of the article authors.

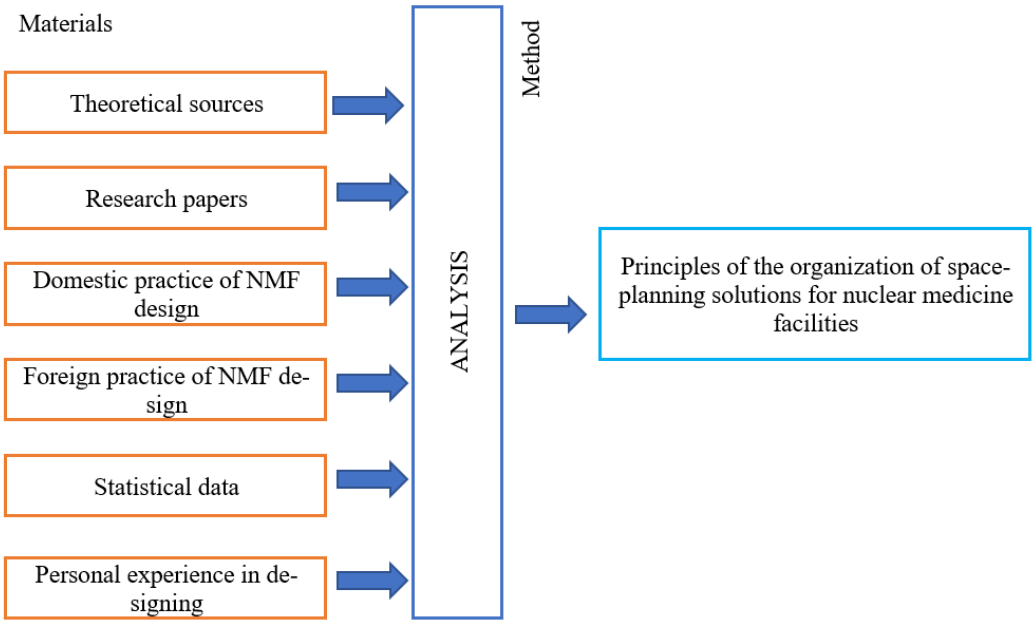

Fig. 1. Methodological scheme of the research.

3. RESULTS AND DISCUSSION

Let us consider the principles of architectural design of the space-planning solutions of NMF. The content and description of the typological zones of NMF are presented in papers [3, 4] and on the scheme (Fig. 2).

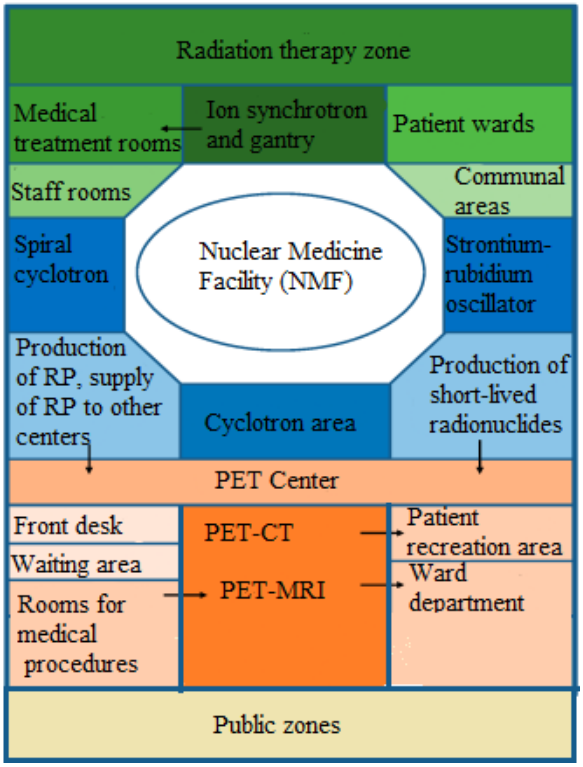

Fig. 2. NMF zoning scheme.

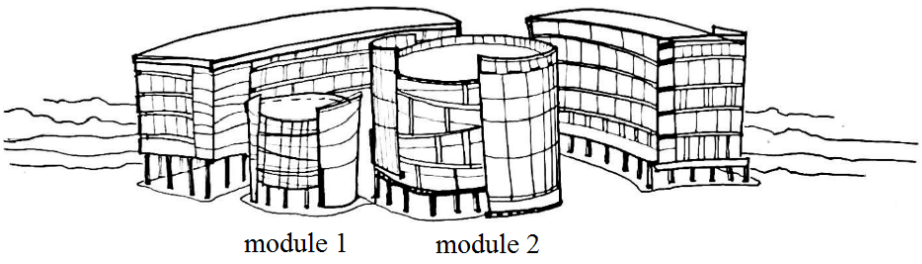

Fig. 3. Scheme of the space-planning solution of NMF.

As can be seen from Fig. 1, the main block of the NMF can include three groups of rooms: rooms with accelerators and radiation therapy treatment rooms; rooms with cyclotrons and a radiopharmaceuticals (RP) manufacturing area; PET center rooms with their own infrastructure.

All these groups of rooms constitute a certain **core of the NMF**, the dimensionality of which determines the subsequent capacity of the whole center. In most cases, the attachment to this core represents ward buildings of different orientation, where the methods of diagnostics and/or treatment of NMF are applied in some or other way.

Fig. 3 shows the scheme of the architectural and planning solution of NMF with two ward buildings. The core of this facility is two modules circular in plan consisting of four and five floors. The typological zones of the NMF core are generally located on the ground and first floors. This is due to the presence of radiation sources in these zones that require radiation protection measures. Such

measures are wall structures up to 1,000 mm thick made of heavy-weight concrete with lead protection added. In addition, the radiation source equipment itself is heavy equipment and, as a rule, it is not installed on the floors above the first floor. This is described in detail in papers [18, 19, 23].

In Fig. 2, module one is the proton center. There are a beam accelerator and brachytherapy rooms on the ground floor of this center. The first floor houses the radiation therapy treatment rooms. Doctors' offices and an administration office are located on the second and third floors. The proton center located in the first module can receive patients by referral, as an outpatient center, as well as serve the inpatient facilities located in close proximity to the core.

There are a cyclotron and a laboratory for production of radiopharmaceuticals (RP) in module two on the ground floor, the first floor houses a PET center with three PET units. There are doctors' offices on the second floor, an administration office is located on the third floor. The main function of this module is diagnosis and treatment using the PET center, as well as the production of radiopharmaceuticals (RP). This module can also work for acceptance of visitors by referral as an outpatient unit, as well as perform procedures for patients of the inpatient units situated in the immediate vicinity.

The scheme of Fig. 4 shows a combined plan of the first floor of module one and module two of the NMF core. The first module houses radiation therapy treatment rooms, there is a PET center in the second module. There are an entrance group for outpatients, registration office, queue management system, cloakroom, waiting and recreation area in the center between the modules.

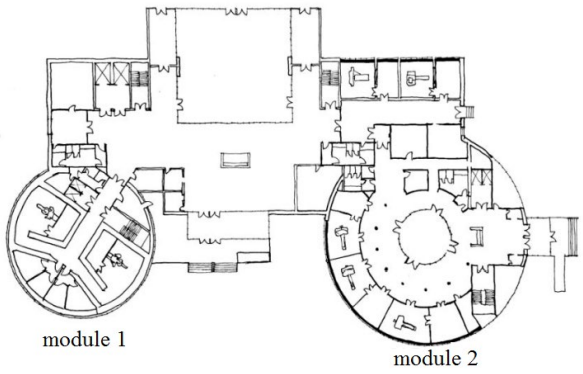

Fig. 4. Fragment of the first floor plan.

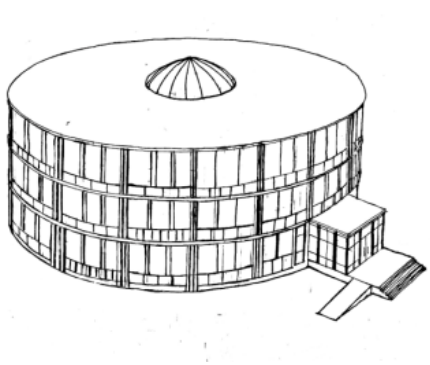

Fig. 5. Fragment of the facade of module 2 of NMF.

Fig. 5 shows a fragmentary version of the facade solution of module 2, which represents a strict structure combining a steel support structure and decorative glass elements.

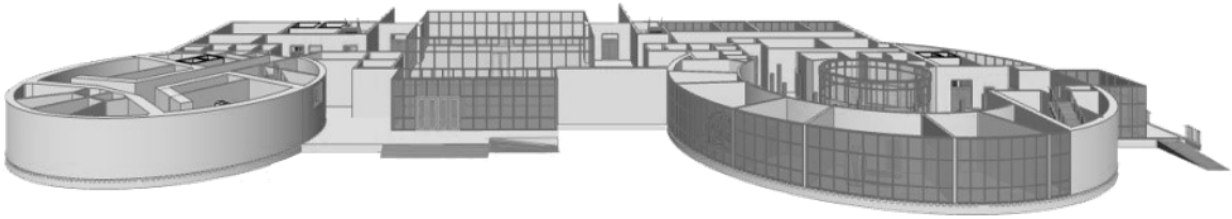

Fig. 6. NMF cross-section at the first floor level.

A cross-section of the NMF at the ground floor level is presented in Fig. 6.

Fig. 7 shows the layout of the NMF at the first floor level. As can be seen from the plan,

medical admission units are placed at this level in the clinical buildings. Ward departments are located on the next floors. These buildings are wide and double-corridor. The wards are placed along the facades and have natural lighting. The rooms that do not require natural lighting, such as medical treatment rooms, drug storage rooms and others are placed in the central part of the clinical buildings. Doctors' offices are located in modules one and two. The central passage houses a recreation area and a winter garden.

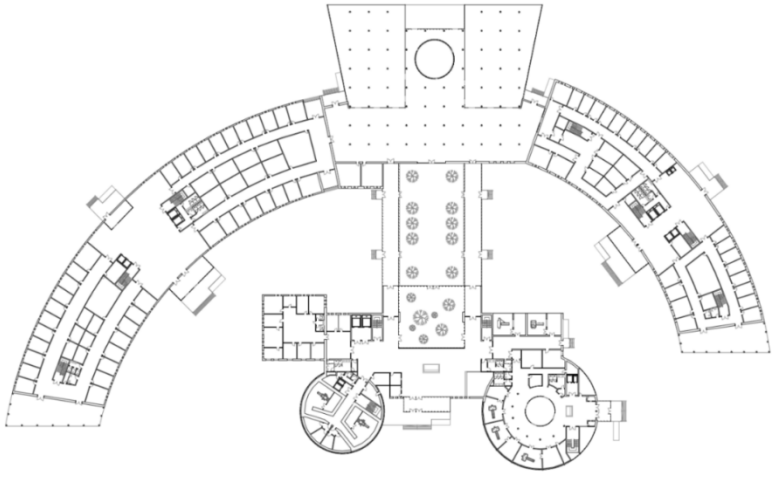

Fig. 7. Space-planning solution of the NMF. First floor plan.

Fig. 8 also shows the clinical oncology buildings for children and adults, which are united by a common passage with the NMF modules owing to a wide gallery, within which a winter garden space is arranged. The use of biophilic design has a positive effect on the mood and psychological state of patients. For this reason, it is recommended for public areas to arrange space using the principles of proximity to nature.

Let us consider separately the architectural principles for the pediatric oncology building.

The pediatric oncology building is a 6-storey building with an area of approximately 14,000.00 sq. m., which is adjacent to other modules of NMF. One of the main principles for pediatric oncology buildings is **to create a space that embodies hope, lifts the spirits and perception of environment of little patients**. The architectural task is to arrange a space that will be **as flexible as possible** to meet today's and tomorrow's needs. **The integration of the building into the general complex of the NMF optimizes the quality of patient care** and promotes the use of innovative technologies for cancer treatment. **The integration of the pediatric clinical building into the natural landscape** is also important. Creation of a beautiful landscaped promenade design, arrangement of a special playground, promenade paths and even bicycle lanes for recovering patients. Creation of a facility that with its spirit and technology can offer children a comfortable and convenient stay, where they could not only receive high-quality treatment, but also study, play, walk, and admire the landscape.

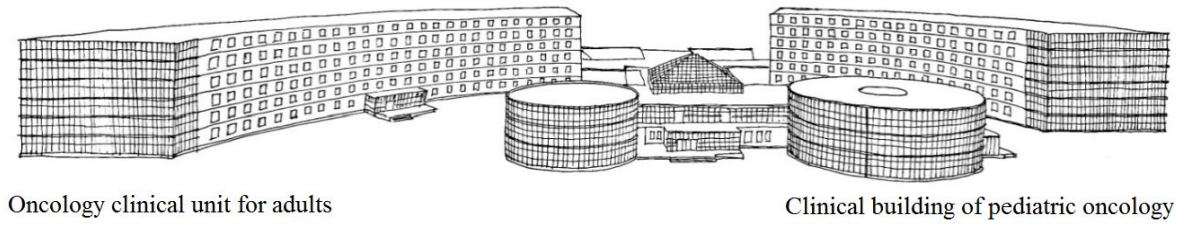

Fig. 8. Scheme of the architectural and planning solution of NMF. The pediatric building is to the right.

The proposed building is connected with the NMF core at the first floor level. A medical admission unit with heavy diagnostic equipment is organized on the first floor. It is envisaged to place here the rooms with magnetic resonance imaging (MRI) scanner, computerized tomograph (CT) and others.

There are ward departments of radiation therapy unit, surgery unit and intensive care unit on the 2nd – 4th floors. The ward departments offer comfortable single and double rooms with maternal beds. Special furniture is provided for a long stay of a mother together with her child. There are activity rooms inside each ward department. A glazed recessed balcony with overhead light is organized at the end of the building on each floor. This is a play area for children, which is illuminated by natural light. Children who are not allowed to walk outside also spend time here (Fig. 9).

Recreation areas are organized throughout the ward floors on the northern and southern end walls of the building. Daylight, glare, and heat emission are controlled by the ratio of viewing glass to a solid wall. Stained-glass structures surround a ward with glass boxes that provide good insolation and comfortable perception, visually enlarging the space. Panoramic windows at the ends of the building make it possible to admire the landscape design and take walks without going outside. The metal frames “focus” the views and correlate with the materiality of the facade extending elements. Schemes of the facades are shown in Fig. 9.

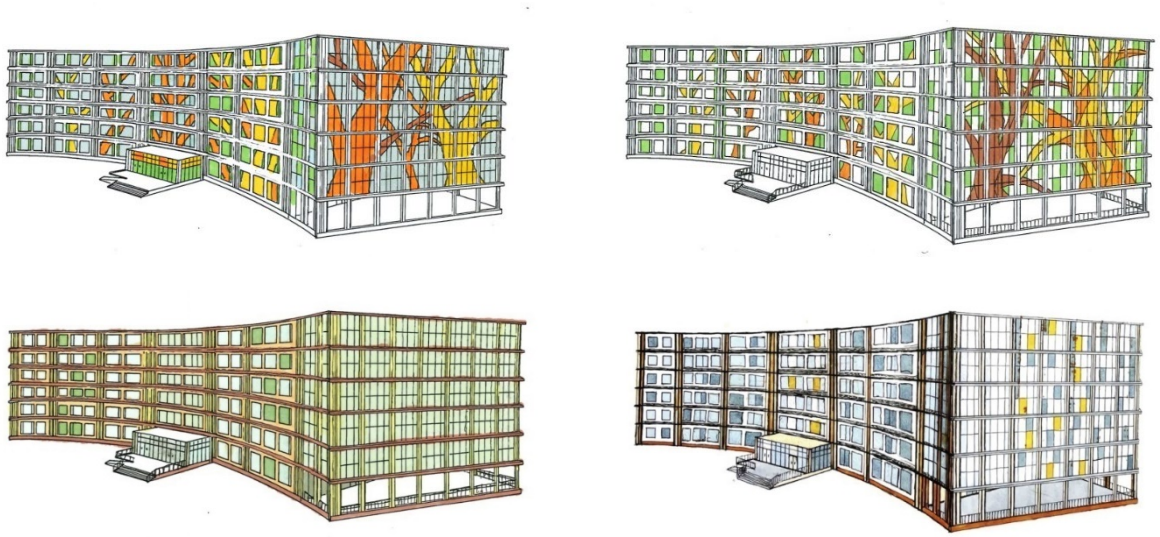

Fig. 9. Schemes of the facade of the pediatric oncology clinical building.

The fifth floor houses a surgery block and resuscitation department, the sixth floor is a mechanical floor. The options of space arrangement in the pediatric building are presented below. Comfortable single and double mother and child wards are located on the floors of the ward departments (Fig. 10).

Fig. 10. Boxed ward of mother and child.

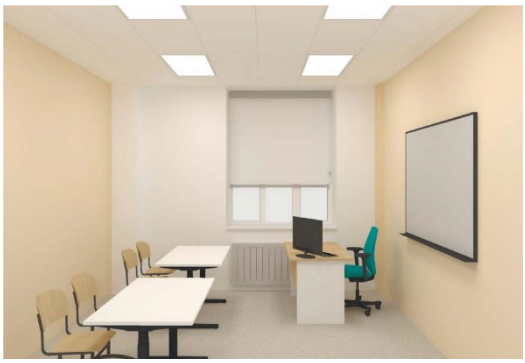

Fig. 11. Child training room.

There are also two classrooms and one playroom on each floor (Fig. 11, 12). Glazed recessed balconies with overhead light and a winter garden are planned at the ends of the building. The areas of winter gardens are simultaneously a meeting place for patients and visitors. Fig. 13 shows the design proposals for corridors and a canteen in the pediatric building.

Fig. 12. Playroom.

Fig. 13. Rooms of the pediatric building.

The building is architecturally divided into several spaces reflecting the internal program: patient support and treatment, training and education, play areas, promenade and recreation. Biophilic design elements are often used in the interiors (Fig. 14).

Fig. 14. Lobby interiors with the use of biophilic design.

The territory of the children's center also includes a promenade area with small forms, a bicycle lane, landscape design, and a cascade of fountains. There is a specialized playground in the territory, which is also adapted for recreation of children with disabilities. All this allows to provide a good rest and accommodation for little patients. The promenade area in the territory of the children's center becomes an architectural accent of the project – the public space of the complex. There is a landscaped sidewalk along the pedestrian paths, which has social corners that enhance the pedestrian impressions. Landscape design complements the lobby and entrance to the building. A passage in the third floor level maintains a formal and visual connection with the NMF core.

The main principles of architecture of such building are as follows: creation of a balanced, flexible architectural solution and general composition; organization of a pediatric oncology building taking into account up-to-date medical requirements; creation of glazed verandas with arranged winter garden in the building; organization of interaction between a patient and nature; organization of oriel facades in the places where wards are located; organization of stained-glass end facades for promenade; organization of wards with comfortable home conditions; organization of playrooms and classrooms; and biophilic design.

Moreover, the following principles should be taken into account in the building: organization of the entrance and navigation system; organization of patients' outdoors exit to the promenade area and children's playground; organization of landscape design and bicycle lanes; organization of fountains in the rest areas for children, ensuring all requirements for people with limited mobility (PLM).

The layout of the adult ward building is organized similarly to the children's ward building (Fig. 6). Single or double wards with enhanced comfort, spacious halls and corridors, interiors with the use of wildlife components (flora, fauna, water) are located here.

Fig. 15 shows an option of the space-planning solution of the NMF with two core modules and placement of several ward buildings around the core. Such placement of ward buildings makes it possible to use high-tech equipment of the NMF core more efficiently. This is justified by the fact that all medical areas in which the NMF is in demand are close to the core and form a single multi-purpose medical cluster (MMC NMF) with it.

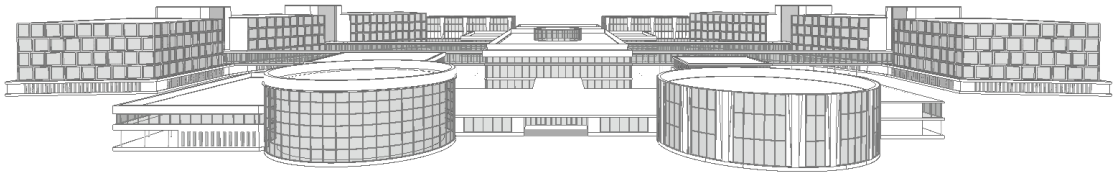

Fig. 15. Architectural solutions of MMC NMF.

Fig. 16 shows the model and scheme of the facade of MMC NMF.

As the figure shows, such planning solution of the NMF allows to ramp up the ward buildings and increase the capacity of the facility, at the same time each ward building can be organized according to different medical areas, which use nuclear medicine in treatment and diagnostics [7].

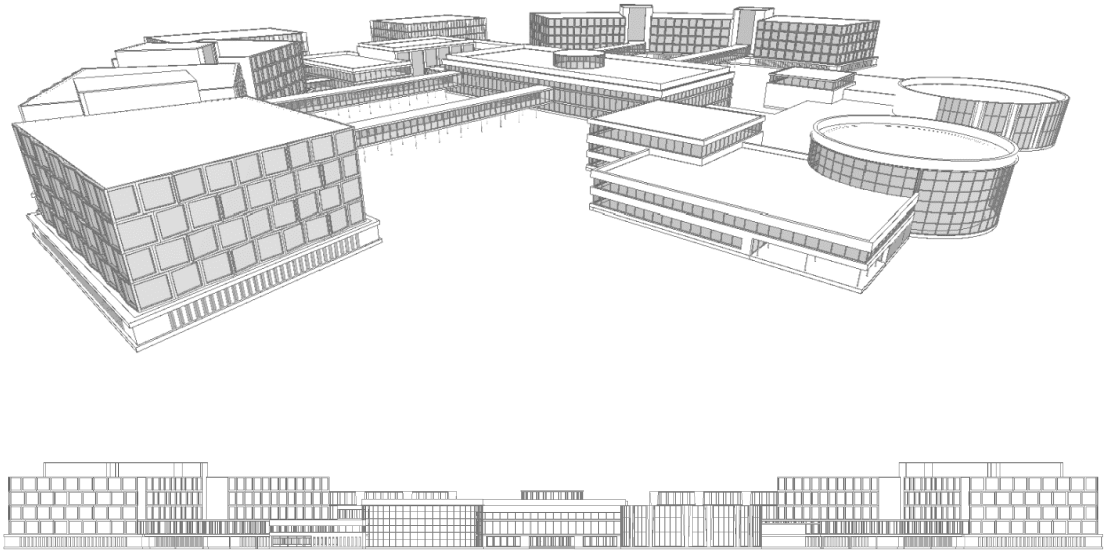

Fig. 16. Model and facade of MMC NMF.

An important role is also given to the organization of the NMF environment. In the proposed option, it is the arrangement of a winter garden on a part of the roof, park and garden landscaping, organization of an interesting and healthy playground in the immediate vicinity to the pediatric building.

Activities for people with limited mobility (PLM) are a special place in the space arrangement. These are specialized wards, comfortable rest areas, and barrier-free access to all areas of the NMF.

4. CONCLUSIONS

Let us emphasize the main principles of space-planning solutions of NMF:

1. Organization of autonomous centralized modules related to the use of radiation sources, namely radiation and radionuclide therapy, production of radiopharmaceuticals (RP). This principle is determined by the increased demand for the use of nuclear medicine in various areas. These areas include oncology, neurology, endocrinology, and cardiology. Placement of NMF modules surrounded by the centers of various areas will enable to consider NMF within a medical cluster, increase significantly the efficiency of their application and improve the quality of medical services.
2. The considered nuclear medicine modules can be designed as outpatient buildings and accept patients who are not in inpatient units. The use of this principle will make it possible for outpatients from different regions of the Russian Federation to undergo examination in the NMF in a rapid and qualitative manner and receive an appointment in one of the medical centers of the cluster.

3. Organization of a unified system of registration office and waiting area for outpatients. This principle implies the use of the most modern information systems that allow to avoid queues, receive any medical service within the registration office using on-line communication systems.

4. Organization of comfortable and attractive environment in waiting areas with the use of wildlife components (flora, water, natural light). It is not a secret that nature gives strength to people. Arrangement of green areas, mini-fountains in waiting areas, use of biophilic design lifts the spirits, creates an atmosphere of comfort and prosperity.

5. Organization of bedroom blocks for different medical areas in close proximity to the central modules of NMF. This principle is combined with the principle of creating medical clusters in existing and promising areas of medicine that use NMF.

6. Possibility to expand the capacity of the center through constructing new bedroom blocks (clinics). Expansion of the cluster in non-new areas.

7. Arrangement of special activities for people with limited mobility (PLM). This principle is given special attention in the article, because the patients of the NMA include immunocompromised people and people with dexterity impairment. Therefore, the list of activities for PLM in the NMF is not limited to the standard ones, but provides for the arrangement of special promenade areas, places for recreation and games namely for such patients.

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INFORMATION ABOUT AUTHORS

Balakina A.E., e-mail: balakinaae@mail.ru, ORCID ID: https://orcid.org/0000-00A01-8105-290X, National Research University Moscow State University of Civil Engineering" (NIU MGSU), Head of Architecture Department, Moscow State University of Civil Engineering, Professor, Candidate Architect, Member of the Union of Architects of Russia, Honorary Worker of Higher Professional Education, Honorary Architect of Russia, Honorary Builder of Russia

Lempl Yu.I., e-mail: jurij.lempl@gmail.com, ORCID ID: https://orcid.org/0000-0003-3526-5693, National Research Moscow State University of Civil Engineering, Postgraduate Student