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International Economic Cooperation Between Rosatom and Foreign Companies in the Field of Nuclear Technology

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This research was aimed at identifying and studying international economic cooperation between the Russian state corporation Rosatom and other countries. In addition, the thesis has an analysis of various types of nuclear technologies that exist in the world.

The study of both the international and the Russian nuclear technology market was conducted by collecting information from authoritative sources. Based on the collected data, an analysis of the materials was carried out.

Throughout the study, the consequences of various nuclear disasters were identified that were eliminated or the elimination work is still taking place through the international cooperation of various countries with appropriate skills and knowledge. Moreover, the importance of cooperation between countries in the field of nuclear technologies was revealed, as well as, what impedes the development of these technologies in other countries.

The study revealed that the lack of proper knowledge of nuclear technologies and fear of them prevents some countries from developing this business area. After the tragedy in Fukushima, a few countries abandoned the use of nuclear technology. However, a complete rejection of these technologies is difficult for them, as there is a lack of special knowledge and skills for decommissioning. In addition, this work provides statistics on the age of nuclear reactors in the world, and according to it, more than half of the working reactors will soon require a regular shutdown. One of the areas of business in the market of nuclear technologies and services will receive a fast pace of development of services for the decommissioning of radiation facilities and services for the management of radiation waste and spent nuclear fuel.

During the writing of the thesis it was revealed that one of the reasons that impede the development of international cooperation between the countries in the nuclear technology market is the insufficient legislative framework for regulating and managing the process of approving nuclear power plant projects.

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List of Symbols

IAEA – International Atomic Energy Agency

INES – International Nuclear Event Scale

NPT – Non-Proliferation Treaty – Treaty on the Non-Proliferation of Nuclear Weapons

RW – Radioactive Waste

NPP – Nuclear Power Plant

FE – Fuel Element

SNFS – Spent Nuclear Fuel Storage

SNF – Spent Nuclear Fuel

MW – Megawatt

RBMK – High-Power Channel-Type Reactor

FNPP – Floating Nuclear Power Plant

VVER – Water-Water Energetic Reactor

Definitions list

All definitions are taken from the official IAEA glossary. (Nuclear Security Series Glossary, 2015; ГЛОССАРИЙ МАГАТЭ ПО ВОПРОСАМ БЕЗОПАСНОСТИ/IAEA GLOSSARY ON SAFETY, 2007)

Control rods — a movable reactor assembly that acts on reactivity and is used to control a nuclear reactor. Regulating rods are made of neutron absorber material.

Emergency core cooling system - a system that ensures the removal of residual heat from the core after the failure of the standard cooling system (for example, in an accident with loss of coolant).

Fuel element - the main structural element of the active zone of a heterogeneous reactor, in the form of which fuel is loaded into it. The fuel rods consist of a fuel core, cladding and end parts.

Radiation syndrome - a common disease with specific symptoms that develops as a result of radiation damage. Depending on the total radiation dose and the time of exposure to ionizing radiation, acute and chronic forms of radiation syndrome are distinguished.

Radioactive waste - by-products of liquid, solid and gaseous products, formed at all stages of the nuclear fuel cycle and not of value for further use (subject to different methods of processing, storage or disposal depending on their activity and half-life of radionuclides).

Radioactive waste repository - a facility designed for the disposal of solid or solidified radioactive waste.

RBMK - channel high power reactor. Thermal single-circuit power reactor with boiling coolant in the channels and direct supply of saturated steam to the turbine. The "light" water acts as a coolant, and graphite is a moderator.

Spent fuel - nuclear fuel extracted from the reactor after irradiation and not subject to further use in this reactor. Spent fuel after discharge from the reactor is temporarily located in the storage pool.

Spent nuclear fuel storage facility - installation or specially prepared site for the safe storage or disposal of radioactive waste, on which control is provided.

1 Introduction

This chapter is aimed at creating an understanding of the thesis. It includes background of the study, research questions and challenges and research methodology.

1.1 Background of the Study

Since the 1950s, the peaceful uses of nuclear fission energy, especially in electricity, have been on an ever-increasing scale, both quantitatively and qualitatively, and geographically. Many nuclear experts agree on the critical importance of factors such as reliability and safety.

In nuclear energy, reliability is determined by the number of accidents and emergency situations. The International Atomic Energy Agency (IAEA) has developed a special scale that was called International Nuclear Event Scale (INES). INES is divided into seven levels: the maximum seventh level means a serious threat to the life and health of the population, as well as for the entire ecosystem due to the strong release of radioactive materials. (Yudin, 2017)

In the entire history of mankind, only eight incidents were registered, exceeding the mark of two on this scale. Since the 2000s, only one such incident has been recorded - the accident at the Fokushima 1 nuclear power plant that happened in 2011. Such a small number of incidents at the beginning of the 21st century indicates the high reliability and safety of nuclear power plants, as well as increased control over emergency situations. (Yudin, 2017)

The widespread use of nuclear energy involves the establishment of cooperation on a multilateral and bilateral basis. Such collaboration is primarily aimed at the non-proliferation of nuclear weapons and the exclusion of the use of peaceful nuclear installations, facilities and materials for military purposes (non-proliferation); safe use of nuclear energy; compensation for damage caused by the use of atomic energy; scientific researches; regulations of trade and exchange of nuclear materials and technologies, construction of nuclear power plants, reactors and installations; storage and processing of spent nuclear fuel (SNF) and radioactive waste (RW). (Yudin, 2017)

Many experts recognize the weakening influence of international organizations, and especially the United Nations, over the past 10 years. Nowadays international relations are changing dynamically (for example, recent events between the United States and Iran) due to alterations in

world politics and economics, globalization processes, the emergence of new centers of influence and new problem regions. (Yudin, 2017)

The aim of this study is to verify all cooperation in the field of nuclear technology between states and to consider potential prospects for expanding areas of activity between a Russian corporation and foreign companies.

1.2 Research Question, Challenges and Research Problem

The main objective of this thesis is to study and consider existing and upcoming international economic cooperation between the Russian state corporation Rosatom and other countries.

In addition, the study will examine various types of nuclear technologies that exist in the world and historical examples of cooperation between countries during nuclear disasters, and what consequences they have in the development of nuclear technologies nowadays.

Furthermore, some recommendations will be given to Rosatom on expanding its influence in the global market not only in the construction of new nuclear power plants, but as well as in other areas.

The research challenge is that there are not very many studies on this topic, and therefore the study itself will take place mainly by collecting secondary information from authoritative sources and official websites of nuclear organizations in different countries. Another task is to obtain relevant and reliable information.

1.3 Data Collection

One of the challenges of this study was the lack of research and materials in various fields. Information was collected by using the official websites of the State Atomic Energy Corporation of Rosatom and its enterprises, as well as by studying the documents of international organizations in nuclear energy. During the study, attention was also paid to trusted news publications.

The advantage of collecting information from such sources is that the primary information has already been collected by experts and analyzed from a professional point of view, which gives confidence in the reliability of the materials used.

1.4 Reason for Choosing the Topic of Thesis

This topic was chosen, since now there are many misconceptions, rumors and false information on the Internet and other media. All this adds to a misconception about the use of peaceful atomic energy in society. In this work, it has already been mentioned that prejudices about the dangers of nuclear power, based on unfounded facts and data taken from nowhere, impede the development of nuclear power in some countries.

The nuclear industry is developing rapidly in recent years. Every year, the requirements for the safety of nuclear facilities are becoming more stringent. Leaders from different countries have already been formed in the nuclear services market; Rosatom is also included in these lists and occupies the first lines in many areas. However, the state corporation does not stop there and is expanding its presence both in Russia and abroad.

2 International Economic Cooperation

International cooperation is an integral consequence of the globalization of the global economy. Countries are fighting for presence on world markets in various sectors of the economy. Nuclear technologies, the leaders of which are now undergoing various changes, are no exception.

2.1 Definition

International economic cooperation is the economic relations between states or international companies, the result of which is economic growth and competitiveness of products (Feldstein, 1988). The main types of international cooperation are foreign trade, the system of international commodity-money relations, as well as scientific and technical cooperation. The grounds for such cooperation are the mutual interest of a political, economic and scientific-technical nature, the presence of common problems and the establishment of relations between states. (Fateyev, Hakhverdyan, Khlobystov, Melnyk, & Klisinski, 2017)

Special organizations were created to regulate international economic relations in the field of nuclear technology. **International Atomic Energy Agency** (IAEA) was created on December 3, 1955, in connection with the decision of the UN General Assembly. Currently, 168 states are members of the IAEA. The IAEA is an intergovernmental forum in the development and application of peaceful atom. (About us, n.d.)

International Commission on Radiation Protection (ICRP) was created in 1950. It created an international system of radiation protection and legislation, and also monitors their implementation. (Governance, n.d.)

The World Nuclear Association (WNA) was established in 2001. It includes leading companies in the nuclear industry. The activities of this organization are aimed at promoting nuclear energy and supporting companies in the industry. (Our Association, n.d.)

World Association of Nuclear Operators (WANO) was established on May 15, 1989. It brings together all the operators of the world's nuclear power plants and facilitates the exchange of experience in operating nuclear power plants to achieve a high level of safety and reliability. This organization is not commercial and not a supervisory authority. (About us, n.d.)

2.2 Importance of Economic Cooperation between Countries in Nuclear Industry

Since end of the twentieth century the problems of cooperation in the field of nuclear energy have become the subject of heated international discussions. The main question to be discussed at the deliberation is how to increase reliability in nuclear energy. Reliability in this area is understood as the ability of technology to run smoothly over a long period of time.

Two areas that cause the longest discussions are nuclear power plants and nuclear weapons. Both areas of development of nuclear technologies have shown what their improper and non-peaceful use can lead to. Disasters such as the accident at the Chernobyl NPP (1986) and the Fukushima-Daiichi NPP (2011), as well as the atomic bombings of Hiroshima and Nagasaki (1945), greatly influenced the perception of atomic energy and everything related to this. (Fukushima Nuclear Accident, n.d.; Chernobyl Nuclear Accident, n.d.; Bombings of Hiroshima and Nagasaki - 1945, 2014)

Despite the sad consequences of each of these disasters, they also showed what improvements should be made in atomic technology. For example, after the bombing of Hiroshima and Nagasaki, people learned what acute radiation syndrome is and how to deal with it. Accidents at nuclear power plants showed specialists and scientists what needs to be modernized in the construction of nuclear power plants in order to avoid such outcomes of events. The most important criterion for events is the number of accidents and contingencies at nuclear facilities. The IAEA has developed an international nuclear event scale to measure such incidents. The highest hazard class of an accident is 7, and the lowest is 1. (International Nuclear and Radiological Event Scale, n.d.)

Public opinion is one of the barriers in international cooperation on the use of peaceful atomic energy. Due to the disasters in Chernobyl and Fokushima, many countries began to abandon the use of nuclear power plants. Germany based on the incidents in Chernobyl and Fukushima refused to use nuclear energy. Now there are 9 power units of eight nuclear power plants in the country. By 2022, Germany plans to completely abandon nuclear power. (Nuclear Power in Germany, 2019)

The development of the nuclear industry in some countries (Philippines, Thailand, Indonesia) is inhibited due to the negative attitude of the population towards atomic energy. This is provided that the Asia-Pacific market is developing at the fastest pace in the world. Another risk factor is the threat of a terrorist act. According to 2016 data, reports of a terrorist threat at nuclear power plants in Ukraine and Belgium were recorded, which served as a reason for tightening access

control at nuclear power plants. One of the points of criticism in discussions on the development of nuclear energy is the lack of control over the operation of nuclear power plants (Panteley, 2017). Only with international cooperation high results can be obtained in studying the use of the energy of a peaceful atom.

2.3 International Cooperation in Nuclear Industry

Nuclear technology began to develop rapidly after World War II. Even then, scientists began to understand the importance of international cooperation in this area. If people did not share their discoveries with each other, the world would not have gone so far in the development and possibilities of using a peaceful atom.

- **Collaboration in the aftermath of the Fukushima accident in 2011**

Japan will remember the middle of March forever. It was the time when one of the largest earthquakes in the history of this wonderful country happened. In addition to 20,000 thousand Japanese citizens (more than 2,500 people were missing as the return wave carried them into the ocean for hundreds of kilometers), the tsunami caused by the collision of two tectonic plates also covered the Fukushima Daiichi nuclear power plant. (Fukushima employees, 2017)

March 11, 2011. First, an earthquake of magnitude nine occurred, as a result of which the reactor emergency shutdown mode was activated. However, there was damage to the power lines, which caused the nuclear power plant to be de-energized. In order to continue the safe shutdown mode, emergency power supply to the entire station is started. The collision of tectonic plates caused a tsunami wave. The government declared a state of emergency on the entire North Pacific coast. The evacuation of station personnel and residents of cities near the plant began. In total, only 50 people remain to continue shutting down the nuclear power plant.

A tsunami forms and floods the nuclear power plant. Since emergency generators were located right off the coast, they were the first to go out of service due to flooding. This led to a shutdown of the emergency power supply station. Two employees in the basement died. Monitoring the readings of the state sensors of the reactors became impossible. Reactor cooling systems failed. Employees need to cool the reactors, but it could only be done with the help of mobile electricity generators. However, the roads in the territory of nuclear power plant were damaged, which made it impossible to deliver generators.

Engineers were trying to find out the current state of the first power unit. Using improvised means of generating electricity (car batteries, mobile generators), they tried to turn on the devices and see the status of the systems and take readings. Since there was no light, the employees looked at the readings on the sensors with the help of flashlights and recorded data directly on the panel devices. The level of radiation began to rise. Employees were shielded with the help of special uniforms (suits and respirators). Meanwhile, the pressure in the reactor was still rising.

The complete lack of communication with the head of the power plant. Unable to take readings. The Prime Minister announced a nuclear accident. There was a proposal to reduce pressure by opening valves and releasing steam through it. However, in complete darkness, employees were unable to do this. The level of radiation was growing inexorably.

March 12, 2011. Evacuation of the population continued. Employees were able to find the valves, but they cannot be opened due to a lack of electricity, as the mechanism that puts them into operation did not work due to a lack of electricity. Using brute force, employees were able to open the valves and reduce the pressure in the reactor.

Five hours later, the first power unit exploded. Employees understood that not only the first reactor is damaged. Explosion hazard arose in the second and third ones.

March 13, 2011. At the third power unit the cooling system failed. Fuel elements were located above the water level. Pressure was released in its containment; at the same time a mixture of sea water and boric acid was pumped into it in order to cool the reactor.

March 14, 2011. The third reactor exploded. Experts say the reason is the same as in the first one. Ambulances began to pick up the victims. Injection of water and hydrochloric acid continued into the first and third reactors. The cooling system of the second reactor failed. It also started the injection of the cooling mixture. Employees began to discharge steam from the reactor, but the valve failed. The pressure inside the reactor rose, its cooling became impossible.

March 15. 2011. Despite the valve being repaired, the second unit also exploded. At the same time, a fire occurs in the spent nuclear fuel storage (SNFS) facility. The fire in the SNFS was eliminated.

March 16, 2011. Employees noticed a flame at the corner of the fourth power unit, but there was no fire. A puff of white smoke was seen above the third power unit, but, fortunately, a second

explosion did not occur. During the investigation, the court pleaded guilty to the Fokushima-Daiichi nuclear power plant. (Fukushima workers and tragedy victims, 2017)

After the examination, the NPP staff set one of the important tasks - to prevent the radioactive elements from entering the groundwater, which would lead to ocean pollution. Japanese scientists had to come up with a technology that helps to this day to avoid the leakage of radiation into groundwater. Along the perimeter of the NPP, deepenings were made into the earth of the NPP's territory one meter long; pipes were inserted into them, through which freezing gas is supplied. Due to this, the ground under the station is frozen, and groundwater is forced to bypass the perimeter of the nuclear power plant to enter the Pacific Ocean, while remaining clean. (Fukushima workers and tragedy victims, 2017)

Attention to this tragedy was riveted by the whole world. Almost immediately after the accident, the governments of France and the United States offered their help in eliminating the consequences of the disaster. It was planned that the Japanese government, together with the US Department of Energy and the French National Research Agency, will seek and select specialists and organizations that are knowledgeable in this area. Under the agreement, the United States will assist Japan with technologies for the storage and disposal of waste; France will work on the creation of remote-control technologies that will be able to perform tasks subject to increased radiation. (Goebel, 2011)

At the beginning of 2019, it became known that the Russian state corporation Rosatom won two tenders for a project to eliminate the consequences of the accident at the Fokushima nuclear power plant. Rosatom offered assistance in the aftermath of the emergency, as well as help in the decommissioning of nuclear power plants, which were considered unsafe by the Japanese government. In 2015, Japan developed a new strategy to maintain the country's energy balance by launching only sixteen out of forty-five power units that operated before the Fukushima-Daiichi nuclear disaster. (Росатом выиграл два тендера по проекту ликвидации последствий аварии на АЭС "Фукусима"/Rosatom has won two tenders for the project to eliminate the consequences of the accident at the Fukushima nuclear power plant, 2019)

- **Cooperation in the aftermath of the Chernobyl accident**

In order to understand why the accident at the Chernobyl nuclear power plant happened, the plan for the construction of the fourth reactor should be considered. The main component of a nuclear reactor is fuel elements. In them a chain reaction occurs. In a RBMK type reactor, their role is played by zirconium tubes 3.5 meters long and 10 mm in diameter. Uranium dioxide tablets

are placed in them. The fuel rods are placed in the moderator; this type of reactor uses graphite as a moderator. The operation of the reactor is monitored by a control and protection system (CPS). The CPS provides start-up, shutdown of the reactor, and regulates its power. It includes rods that contain a substance that strongly absorbs neurons, such as Cadmium or Boron. The full introduction of these rods into the core of the reactors will lead to a complete shutdown of the reactor. And by extracting them from the core, reactor power is regulated. (RBMK Reactors, 2019)

April 25, 1986. A turbocharger test of the fourth reactor was scheduled for this day. At one o'clock in the morning, a decrease in reactor power began. Three hours after the start of the test, the reactor power was reduced to 1600 MW. After 10 hours, a decrease in the power required for the reactor's own needs followed; disconnected the second generator. At two o'clock in the afternoon, it was expected that the reactor capacity would be only 30%, but at the request of the dispatcher of the Kiev Energy District, the reactor was operating at rated power (50%) until 23:00. After eleven o'clock in the evening, the power was again reduced to 1600 MW. At 23:10, the ban on power reduction was lifted. (Хронология аварии на ЧАЭС/Chronology of the Chernobyl accident, n.d.; CHERNOBYL: CHRONOLOGY OF A DISASTER, 2011)

At 00:00, a night shift of workers entered on duty. Twenty minutes later, the reactor power was reduced to the planned 700 MW. In just eight minutes, the power dropped to 500 MW. Due to the complexity of the steering, the xenon core was poisoned, which served to reduce the thermal power of the reactor to 30 MW. In order to increase the power of the reactor, employees of the control center removed the control rods. Only 18 rems remained in the core, instead of the minimum allowable 30 rem. (CHERNOBYL: CHRONOLOGY OF A DISASTER, 2011)

After half an hour, employees were able to increase capacity to 200 MW. However, to prevent automatic shutdown of the reactor, workers blocked the safety system. A sharp decrease in the reactivity of the RBMK occurred. Testing of the turbogenerator has begun; the tubular valves were cut off, followed by a strong uncontrolled increase in reactor power. The channels for the control rods were damaged, so they could only go 2-2.5 meters, instead of a full thrust of 7 meters. In a few seconds, the steam and reactor power increased and exceeded more than 100 times than the required value. (CHERNOBYL: CHRONOLOGY OF A DISASTER, 2011; Chronology of the Chernobyl accident, n.d.)

The fuel overheated, the surrounding zirconium shell exploded, and as a result, the fuel was leaked. An exothermic reaction began. At 1:23:47, the first explosion occurred; three seconds later, a second followed. Water vapor was the first to precipitate, then hydrogen was released.

The reactor and parts of the construction were destroyed. According to expert estimates, 8 out of 140 tons of fuel leaked from the reactor. The fire was eliminated and taken under control only an hour and a half after the explosion. (Chronology of the Chernobyl accident, n.d.)

Firefighters, who arrived first at the epicenter of the explosion to extinguish the fire, received severe burns. The skin was burned even under clothes; they started vomiting. Firefighters were evacuated to the 6th radiological hospital in Moscow by ambulance aircraft. After a couple of weeks, they all died of radiation syndrome. (The liquidators of the Chernobyl accident, ЧЕРНОБЫЛЬ: Как умирали после взрыва/Chernobyl: How they died after the explosion, 2019)

After the disaster report was sent to the International Atomic Energy Agency on August 20, 1986, it was found that an extraordinary sequence of events, negligence, mismanagement and safety breaches led to disaster. (Хронология аварии на ЧАЭС/Chronology of the Chernobyl accident, n.d.)

After this disaster, the countries of Europe and North America did not build a single power plant for sixteen years, and all projects were frozen. Insurance premiums were significantly increased, and the profitability of nuclear power decreased. (The Database on Nuclear Power Reactors, n.d.)

Since 2016, Belgium has been helping the Chernobyl Nuclear Power Plant manage radioactive waste. (Бельгия продолжает содействовать работе с РАО на Чернобыльской АЭС/Belgium continues to facilitate work with radioactive waste at the Chernobyl nuclear power plant, 2019)

After the Chernobyl disaster, Cuba helped thousands of Soviet children treat and rehabilitate on Liberty Island. The complex was located in Tarara, where there were several youth and children's camps. The humanitarian program "Children of Chernobyl" was in force from 1990 to 2011; according to the Cuban government, 26 thousand people received help and treatment (86% of them were children). (Как Куба лечила тысячи детей Чернобыля/How Cuba treated thousands of Chernobyl children, 2019)

- **Cooperation among countries in the field of disposal and management of radioactive waste**

Storage and surveillance of radioactive waste is a complex and expensive process. Companies that have claimed responsibility for the provision of these services, undertakes to control these wastes throughout the entire storage period. Not all countries have the geographical, human, financial and scientific resources to provide such a service. In fact, this is the most important

problem in the field of disposal and storage of RW. At the international level, there is a discussion of ways to solve this dilemma, in which the leadership of the nuclear industry of the Russia takes an active position.

In total, there are three main documents on the storage and disposal of radioactive waste:

1) Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management

The Convention was signed on September 5, 1997, entered into force on June 18, 2001. The objectives of this convention are to achieve a high level of safety in the management of spent nuclear fuel and radioactive waste, prevention and elimination of consequences of accidents at radiation facilities. The transfer of radioactive waste and spent nuclear fuel can only be carried out if all the conditions of the comment are met. (Nuclear safety conventions, 1997)

2) Treaty on the Non-Proliferation of Nuclear Weapons

This agreement was adopted on June 12, 1968, entered into force on April 22, 1970. According to this agreement, the parties undertake to cooperate in the development of technologies for the use of peaceful atom, in accordance with 4th article. (Treaty on the Non-Proliferation of Nuclear Weapons, 1968)

3) Bamako convention

The Convention was adopted on January 30, 1991. According to its provisions, the import of hazardous waste, including radioactive, is prohibited in the territory of African member countries. (Bamako Convention, n.d.)

In international practice, it is accepted that radioactive waste is returned to the country that produced nuclear fuel. According to some data, in the territory of the Russian Federation there are radioactive waste from countries such as Bulgaria, Hungary, the Czech Republic, Finland, Germany, and Ukraine. Moreover, there is an opinion that RW of Iran is also buried in the territory of the Russian Federation. (Международные инициативы по созданию международных могильников и хранилищ радиоактивных отходов в России/International initiatives to create international repositories and storage facilities for radioactive waste in Russia, n.d.)

Now, there is no legislation in the world for the disposal of radioactive waste. On the contrary, according to the laws of Saudi Arabia, the death penalty is applicable for the import of radioactive

waste into the country. The United States believes that if all the radioactive waste that was exported from the USA as nuclear fuel returns to the country, then its territory will turn into a repository for most of the world's SNF. (International initiatives to create international repositories and storage facilities for radioactive waste in Russia, n.d.)

The exception for today is the Russian Federation, in connection with the legislation of which RW can be imported for temporary technical storage; but an exact time frame for such storage is not defined. This type of storage involves additional costs, but at the same time increases the risk of an accident or terrorist attack. Moreover, there is a possibility that the walls of the fuel assembly as a result of storage may undergo corrosion, which may affect the possibility of RW returning to its homeland. Therefore, in order to be safe, they will have to stay in Russia for forever. (International initiatives to create international repositories and storage facilities for radioactive waste in Russia, n.d.)

Last year, the news that Germany sent its RW to the Russian Federation caused a strong response among residents of Europe and Russia. Eco-activists carried out actions to protect the environment of Russia. These transportations were carried out based on an agreement between Urenco Deutschland and the Russian company Tenex. (Поезд с ядерными отходами отправился из ФРГ в Россию/A train with nuclear waste left Germany for Russia, 2019)

3 Nuclear Technology

It is well known that atomic energy is used to produce electricity. At nuclear power plants, the heat released in the reactor core is turns into steam that rotates a turbogenerator that produces electrical energy. Nuclear power plants of icebreakers generate electricity for the operation of engines that rotate propellers. However, the use of the huge energy that is hidden in the atom does not end there. This chapter will discuss the various uses of this energy in different areas of human activity.

3.1 Definition

The modern nuclear industry is a product of the development of the phenomenon of radioactivity, adapted to industrial needs through such sciences as nuclear physics and radiochemistry.

Nuclear technology - a set of engineering solutions that allow the use of nuclear reactions or ionizing radiation. The most famous areas of application of nuclear technology are nuclear weapons, nuclear energy, and nuclear medicine. (Fundamentals, n.d.)

The main quality of nuclear technology is catholicity. All over the world, high-tech devices and unique objects are used, beautiful and ancient artifacts are admired, nature is protected, recovery from fatal diseases occurs, controlling of ultra-modern earth and space technology, learning of the secrets of our planet and far corners of the Universe. However, often people do not even know that all these possibilities appeared due to the unlimited power of a peaceful atom, which scientists have relatively recently been able to successfully direct to serve people. (Fundamentals, n.d.)

3.2 Types of Nuclear Technology

Atom is not only electricity resource, but also the solution to many pressing problems. Deep knowledge, respectful and serious attitude to the power of the atom makes it a human assistant in the prevention, diagnosis and treatment of various diseases, obtaining materials with new

properties, studying chemical and biological processes, exploring our home planet, improving agricultural activities.

- **Power generation**

Perhaps one of the most famous ways to use the energy of a peaceful atom is to generate electricity. This happens with the help of special facilities - nuclear power plants.

A modern nuclear power plant is an enterprise which main purpose is the production of electricity using the energy released during the fission chain reaction. In other words, a nuclear power plant can be regarded as a commercial organization that produces and sells "nuclear" electricity.

The picture, that is presented in Appendix 2, shows the process of operation of the nuclear power plant. NPP is a complex of buildings in which technological equipment is located. The main building is the place, where the reactor hall is located. It includes the reactor itself, a nuclear fuel holding pool, a reloading machine (for carrying out fuel refueling), all of this is monitored by operators from a block control panel. The nuclear island and the turbine island are buildings that are adjacent to each other; but in general, this complex is called a nuclear power unit. (How does the NPP work, n.d.)

Nuclear power plant can perform its work only due to strong nuclear fission reaction. Uranium-235 or Plutonium is used as fuel. Nuclear fission fragments that produce tremendous kinetic energy, that help to generate the electricity, are the key product of any nuclear power plant. (Power Generation, n.d.; How does the NPP work, n.d.)

In 1954, the world's first nuclear power plant was built. The principle of operation of nuclear power plants is the fission of an atom using a neutron. A tremendous amount of energy is released as a result of this process. The heat generated in the reactor warms the water, as a result of which steam will form, which causes the turbines to spin and generate electricity. (Power Generation, n.d.)

- **Nuclear fleet**

Due to the nuclear reactor located on the nuclear icebreaker, there is the possibility of year-round navigation along the Northern Sea Route, as well as the posting of large-tonnage vessels. Such a vessel has unlimited navigation. Its service life is 40 years before retirement. (The Nuclear Icebreaker Fleet, n.d)

Such vessels are only at the disposal of the Russian Federation in a division of Rosatomflot. By the virtue of the Northern Sea Route, an alternative has appeared to the traditional routes of transport links between the countries of the Pacific and Atlantic basins. This may save time; for example, the route from the port of Murmansk to Japan is about 14 000 kilometers, and through the Suez Canal (Southern Sea Route) - 23 thousand kilometers. On the first route, transportation of various goods will take about eighteen days, on the second, about forty; saving time in more than half a month. (Performance Of State Atomic Energy Corporation Rosatom In 2018, 2019)

- **The use of nuclear technology in medicine**

The easiest and most well-known use of nuclear energy in medicine is x-ray research (radiography). Regardless, whether it's a dentist's appointment, where a snapshot of a diseased tooth is taken and a 3D model of all jaws, then a trip to a traumatologist with a broken limb. X-rays allows doctors and scientists to see the internal state of the patient's organs, including the stomach and duodenum, gall bladder, colon, chest, spine, breast, lungs. (Many Uses of Nuclear Technology, 2017)

Radiation therapy. It is also called the Gold Standard for Cancer Treatment; it destroys cancer cells through directed ionizing radiation (beam). Over 80% of cancer patients go through this procedure. CyberKnife is the latest system that delivers radiation that is harmful to malignant cells with high accuracy without touching healthy cells. Using this technology, it became possible to fight even with metastases in the brain. Radioactive medical isotopes such as Molybdenum-99, Iodine-125, Ruthenium-106 are actively used to treat cancer. Radiopharmaceuticals are specially prepared medications with radioactive isotopes inside. They allow using positron emission computed tomography to reveal at the cellular level the very first signs of cancer. (Rosatom Group - Nuclear Medicine, n.d.)

Positron emission tomography and computed tomography are by far the most accurate method for examining the state of the thyroid gland, heart, kidneys, lungs, stomach, and blood circulation. It helps to detect the smallest bone fractures, signs of Parkinson's and Alzheimer's disease. (Many Uses of Nuclear Technology, 2017)

Ionizing radiation. With it, dressings and sutures, medicines, biological tissues, disposable medical syringes and blood service systems - tubes, droppers, filters, needles, clamps made of various polymeric materials and metal are sterilized. (Many Uses of Nuclear Technology, 2017; Rosatom Group - Nuclear Medicine, n.d.)

Nuclear medicine has saved many lives and continues to do so. Without it, the fight against deadly diseases in the modern world no longer seems.

- **Water purification using nuclear technology**

People living, for example, in Russia, in the USA, in Europe, in Canada, take clean water for granted. However, this is far from being such. It's worth looking at African and some Asian countries where dirty water, which contains microorganisms dangerous to health, is one of the main causes of death. There are not many ways to purify water in the world, and the most popular of them is chlorination, which leaves toxic substances in the water that are also harmful to humans.

In the mid-twentieth century, scientists found that it is possible to remove all harmful bacteria and viruses from water with the help of gamma radiation, while preserving all the beneficial properties in it for humans. (Nuclear Technology and Applications - Water, n.d.)

- **Destruction of dangerous viruses**

According to the World Health Organization, about 200 million cases of malaria infection are diagnosed each year in the world. Its carriers are mosquitoes, which are also responsible for the spread of Zika virus, West Nile fever and Lyme disease. The risk group consists of almost half of the planet: Africa, the Middle East, South America, Southeast Asia. (Many Uses of Nuclear Technology, 2017)

In order to reduce the spread of these deadly viruses, scientists have developed a unique rational sexual sterilization. For it, males are specially bred or caught and exposed to radiation. After this procedure they are released into the wild in their natural habitat; they cannot bear offspring, and after mating with them, the females lay unfertilized eggs. Thus, the number of insects that carry dangerous viruses is reduced. (Many Uses of Nuclear Technology, 2017)

- **Food preservation**

Food shortages are one of the most acute problems of the twenty-first century. From a lack of food, people get sick and die. This problem is not only in production, but also in long-term storage technologies. In developing countries, products simply rot in warehouses; but even in developed countries, the quality of the product that goes on the table for people in doubt. After all, chemical extension spoils the quality of the product, as well as its properties.

An example of how this technology works is shown in Appendix 3. Back in the twentieth century, scientists proposed to disinfect food products using radiation; such experiments were carried out. After irradiation, all products were tested, and it was found that they did not lose their beneficial properties, and harmful bacteria and microorganisms were destroyed. It was called cold pasteurization. This method helps extend the shelf life of even perishable products. Scientists also found that if radiation is exposed to agricultural products, then productivity increases, because plants no longer need to spend energy on pest control. This pasteurization method is allowed in 69 countries, the leaders of which are the USA and China. (Many Uses of Nuclear Technology, 2017)

- **Check for hazardous explosives and weapons, pavement scan**

Explosive detection systems based on miniature particle accelerators - neural generators - make it possible to distinguish between hazardous and explosive substances from a distance of half a meter. Such technologies were used at the 2018 World Cup and at the 2014 Sochi Olympics. They will also be used at the Tokyo Olympics 2020. Screening systems are used at airports, train stations and bus stations. They are absolutely safe, since the property of x-rays is used, which gives ultra-low radiation. This technology has been approved by the World Health Organization, confirming that it is safe for humans and animals. (Security Systems, n.d.)

There is also a contactless scanning system that allows to shine through the contents of cars and trucks. The unique Berkut roadway monitoring system, in the course of its movement, checks the quality and composition of the roadway. (Security Systems, n.d.)

X-rays can test the quality of production of complex and huge equipment, for example, a pipeline. Such an inspection helps to identify microcracks, welding errors, non-metallic and slag inclusions, and much more. The same control is used in the construction of bridges, buildings and pipelines. (Security Systems, n.d.)

- **Authentication of works of art and archaeological finds**

Using special equipment, the composition and structure of various substances are analyzed. Thus, it is possible even to find out the age of a work of art. For example, when acquiring an expensive nineteenth-century painting, a radiological examination can be ordered. The method is based on the study of carbon isotopes. (Many Uses of Nuclear Technology, 2017)

- **Nuclear weapon**

Powerful atomic energy is used not only for peaceful purposes, unfortunately. Almost immediately after the discovery of atomic energy, the most terrible kind of weapon in the world was created - nuclear weapon.

The consequences of detonation of a nuclear weapon differ from a conventional explosion not only in scale. An electromagnetic pulse, penetrating radiation, as well as radioactive contamination of the territory are added to the standard set of a flash of light and a shock wave. (Weapons of Mass Destruction - Nuclear, n.d.)

When a nuclear bomb explodes, a flash of light appears, which lasts from a split second to several tens of seconds, it depends on the power of the charge. Everything that is close to this outbreak (within a radius of several kilometers) is ignited, melted, charred, people inevitably die; and those who see this flash of light will always be blinded, as the retina burns out completely. People who are in the epicenter of the explosion and next to it simply disappear, since the ground under this nuclear explosion is heated up to several thousand degrees. Only a heap of coal will be detached from a person, which is sprayed by a shock wave. If there was a building nearby (or what was left of it), then there will only be a shadow from the person on the wall or staircase burnt from radiation. (Weapons of Mass Destruction - Nuclear, n.d.)

Simultaneously with the visible, light radiation from the point of the explosion is the invisible - penetrating radiation. In fact, this is a powerful stream of ionizing radiation, namely: fission fragments, neutrons, electrons, gamma rays. The burst lasts from several seconds to several tens of seconds, but all these particles are absorbed by the air and do not spread very far: even with a strong explosion, danger to people arises only within a radius of two to three kilometers from the epicenter (the danger zone of a light flash and a shock wave is greater). However, special devices were invented - neutron bombs, which expand the area of radiation damage. A little later, after three simultaneous “flashes” of light, ionizing and radio-frequency radiation, a shock wave arrives. This is a wall of dense air, rushing from the center with supersonic speed, more than 350 meters per second. True, agility is quickly lost, and at several kilometers the wave becomes sound. It only describes the method of action of a nuclear bomb from an explosion on the ground. But explosions of such weapons can occur both above the ground and in the atmosphere. The consequences of such explosions can be even more insignificant than ground ones. (Weapons of Mass Destruction - Nuclear, n.d.)

Because of such destructive action of this kind of weapons, Treaty on the Non-Proliferation of Nuclear Weapons was created and signed by almost all independent states. (Treaty on the Non-Proliferation of Nuclear Weapons, 1968)

The future of humanity is inextricably linked to the use of huge energy hidden in the atom. In the modern world, it is almost impossible to imagine the world without the use of nuclear technology; so much they entered the life of mankind. People cannot do without these technologies, either in space or on Earth. Their saving and healing powers are indispensable at present.

According to the International Atomic Energy Agency, the cost of energy received at nuclear power plants has almost covered the cost of creating all nuclear technologies. Details on the benefits of nuclear power will be discussed in the next section.

3.3 Benefits of Using Nuclear Energy and Technology

The global level of carbon dioxide emissions is 32 billion tons per year. Scientists suggest that by 2030 the amount of carbon dioxide emitted will exceed the mark of 34 billion tons. (Benefits of Nuclear Energy, n.d.)

Now the whole world is talking about global warming and rapid climate change. In connection with these phenomena, scientists are looking for alternative sources of electricity and improve existing ones. One of the promising and rapidly developing alternatives is nuclear energy.

Nuclear power has a huge number of advantages over traditional and other alternative methods of generating electricity.

- **Stability and reliability**

Nuclear power is a stable source of basic generation 24/7. Other alternative forms are dependent on external factors, such as waves, the sun, wind, which cannot be constant. There is no such problem with nuclear power. As soon as fission processes (uranium or plutonium) begin in the reactor, energy will continue to be produced. At certain intervals, specialists can simply add uranium to a nuclear installation, which ensures that the fission reaction does not stop. A nuclear power plant can produce electricity without interruption for a year, or even more, depending on the type of reactor. The safety systems of Russian's NPPs can be seen in Appendix 4. (Benefits of Nuclear Energy, n.d.)

- **Less raw material and space required**

Nuclear fission is a very powerful release of energy. A small amount of 28 grams of Uranium-235 can produce an equivalent amount of energy, which will produce one hundred metric tons of coal. Coal and oil reserves are rapidly depleted. While the reserves of uranium and plutonium are still enough for many years. (Comby, 1996)

A nuclear power plant occupies much less space than wind and solar. That allows to build NPP near industrial centers and large cities. (Benefits of Nuclear Energy, n.d.)

- **Renewable resource**

The fissile material (Uranium-235) does not burn completely, which allows it to be used again after regeneration. The prospect of switching to a closed fuel cycle is considered, which means an almost complete absence of waste. (Benefits of Nuclear Energy, n.d.)

- **Reducing the greenhouse effect**

The active development of nuclear energy can reduce emissions of greenhouse gases - carbon dioxide and methane. Nuclear energy is a pure form of energy because it does not emit any greenhouse gases. (Comby, 1996; Benefits of Nuclear Energy, n.d.)

- **Economic development**

A nuclear power plant is the place where only highly qualified employees work, as the specific nature of the activity obliges to do so.

The construction of nuclear power plants ensures economic growth, as new jobs appear. One job during the construction of nuclear power plants creates more than ten jobs in related industries and specialties (Benefits of Nuclear Energy, n.d.). Because of the development of nuclear energy, scientific research is increasing and contributing to development in the export of high-tech products. In addition, such projects have high returns for the local community in the form of taxes and solvent demand for goods and services. (Атомная отрасль России/Nuclear Industry of Russia, n.d.)

People expand their energy needs much faster than their production increases. And not all methods are safe for the environment. Also, there is an acute shortage of traditional resources. Due to the development of atomic technologies, it has become possible to reduce greenhouse gas emissions during electricity production, which is the sin of traditional methods of generating

electricity. Many countries are beginning to consider the possibility of developing nuclear technology in their homeland. Finally, myths about the terrible and destructive power of a peaceful atom, some of them will be disassembled a bit later, begin to collapse and people pay attention to such energy.

3.4 Myths about Nuclear Energy and Technology

People who are not versed in nuclear energy tend to believe in the myths that opponents of such an alternative source of energy spread. This, as was already written earlier, greatly impedes the development of nuclear technologies in many countries. However, after all, without using the capabilities of a peaceful atom, it is no longer possible to imagine modern life. Radiation therapy, which saves the cancer patients with waiters, airport security racks help prevent terrorist attacks, an X-ray examination, which every person has done at least once in his life. Nuclear technology around us, although not all people know all of this. Next, the most popular and common myths about nuclear technology and their refutation will be provided.

Myth 1. Accidents cannot be avoided at nuclear power plants.

All three of the most famous accidents at nuclear power plants – Three Mile Island, Chernobyl, Fukushima – were the cause of not only insufficient technological components, but also the organizational structure. In the United States, after the incident on Three Mile Island in 1979, a serious restructuring of the security systems took place, which led to the fact that over the entire period the country did not have a single accident at more than one hundred operating reactors. (Debunking 9 myths about nuclear energy, 2019; Атомная энергетика: мифы и реальность/Nuclear Power: Myths and Reality, 2011)

The Chernobyl accident in 1986 was the cause of a hastily made reactor, an outdated type, as well as arrogant engineers who ignored the critical state of the reactor at the time of the test and thought that nothing bad would happen. Through this catastrophe, the World Association of Nuclear Power Operators was created. (Nuclear Power: Myths and Reality, 2011)

In the case of Fukushima in 2011, then the catastrophe was caused by a natural disaster, as well as features of the managerial structure. Already after the accident, it was recognized that problems at the station were ignored until the incident. The management of the Tokyo Electricity Company for many years was silent about the violation of safety measures at nuclear power

plants. In addition, Japan did not have an independent oversight body. (Nuclear Power: Myths and Reality, 2011)

After each accident at the NPP, certain conclusions are made about the imperfection of the operation of some NPPs, which are then eliminated.

Myth 2. Atomic energy is an expensive pleasure.

The operation of the power plant itself is relatively cheap. The problem is that this station still needs to be built. The construction of a nuclear power plant is a project of billions of dollars, and delays in the project increase the cost of building a station very significantly; there were cases that each additional day increased the project cost to one million dollars. (Debunking 9 myths about nuclear energy, 2019)

According to energy experts, the construction of a new nuclear power plant can be carried out only subject to federal loan guarantees of tens of billions of dollars. Another caveat is that nuclear power could not succeed anywhere without the direct support of the state. All organizations in this area, so far, are owned by states. But if it is calculated that the power of such stations is huge, then it's payback will not take long. (Debunking 9 myths about nuclear energy, 2019)

Myth 3. The weak side of nuclear energy – radioactive waste

The problem with RW is solvable, countries only need to acquire special technologies and territories for their storage. As the practice of various incidents shows, the main reason is a person and his neglect of his duties. (Nuclear Power: Myths and Reality, 2011)

Myth 4. Solar and wind energy will become a replacement for nuclear reactors

In the coming decades, and even a century, this is impossible. The share of generation of such energy in the world is about 3% of all generated electricity. These two types of energy require vast areas for windmills and solar panels, which in many places cannot be built. A nuclear power plant occupies a relatively small area and generates a huge amount of energy. (Debunking 9 myths about nuclear energy, 2019)

In order to objectively assess the harm and benefits of various alternative energy sources, a full analysis is necessary. Any energy production is expensive, just some more, some less. Belief in such myths impedes the development of nuclear energy, that is why scientists and experts in this

field are doing everything possible to ensure that people have a correct idea of nuclear energy, and not the nonsense that opponents of this type of alternative energy spread.

4 Nuclear Technology in the World

Earlier in the thesis, the most common types of nuclear technology were considered. Now, a study will be conducted on the various technologies that owned or developed by Rosatom, its competitors and ongoing and upcoming economic cooperation with other countries.

4.1 Nuclear Technology in Russia

The development of the Russian nuclear industry began during the Second World War. It was Russia (then the USSR) that became the first country to build and launch a nuclear power plant. Now, Rosatom takes a leading position at the world level in different directions in the nuclear industry. Despite skepticism from international companies to the ambitions of the Russian corporation at the time of its founding in 2007, Rosatom became an organization to be reckoned with and respected.

4.1.1 Briefly About State Atomic Energy Corporation Rosatom

The State Atomic Energy Corporation Rosatom is a Russian state holding company that unites more than 335 enterprises in various fields of nuclear energy applications: civil nuclear companies, a nuclear weapons complex, research organizations and the only nuclear icebreaker fleet. (About us, n.d.; Performance Of State Atomic Energy Corporation Rosatom In 2018, 2019)

The corporation is one of the leaders in the nuclear industry market, ranks second in the world in uranium reserves, fourth in the world in nuclear energy production, controls 36% of the world uranium enrichment services market, and also has a 17% share in the nuclear fuel market. (About us, n.d.)

Rosatom takes first place in foreign orders for the construction of nuclear power units, its portfolio includes 36 power units. The total portfolio of foreign orders for the full cycle of operation of nuclear power plants is estimated at 202.4 billion dollars. (Performance Of State Atomic Energy Corporation Rosatom In 2018, 2019)

The state corporation has extensive markets for its presence: the natural uranium market, the uranium conversion and enrichment services market, the nuclear fuel market, the power engineering market, the electricity and capacity market, the construction and service market of nuclear power plants, the market for RW and SNF management, and decommissioning of nuclear facilities, composite materials market, wind energy market, nuclear medicine market. (Performance Of State Atomic Energy Corporation Rosatom In 2018, 2019)

4.1.2 Nuclear products, technologies and services of Rosatom

The State Atomic Energy Corporation Rosatom provides an extensive list of products and services.

- Products and services in the field of nuclear energy

Undoubtedly, the largest range of services and products of Rosatom provides precisely in the field of nuclear energy. Rosatom is one of the few companies in the world that has competencies in all segments of the nuclear fuel cycle. (About us, n.d.)

The successful development of the nuclear industry is carried out through sustainable raw material supply. Since Russia has its own uranium production, this gives customers a guarantee of reliable supplies, a long-term prospect in providing raw materials for nuclear generation and the competitive cost of production. More details about the uranium fuel cycle can be seen in Appendix 5. The company has unique competencies that allow it to carry out the whole range of work from exploration to the extraction and processing of natural uranium. (Добыча рана/Mining, n.d.)

Rosatom also has uranium mining assets abroad. All of them are united in the holding Uranium One. Holding is a supporter of clean energy, therefore, production is carried out using underground leaching technology, which is more environmentally friendly than traditional methods of extraction of raw materials. (Uranium One: About Us, n.d.)

Rosatom's fuel company TVEL enriches uranium through the most efficient technology of today - gas centrifuge. Enriched uranium enters the domestic and foreign market under the TENEX trademark. Deliveries have been made to foreign-design nuclear power plants in Europe, America, Asia and Africa for over 45 years. TVEL JSC is a monopoly supplier of fuel to Russian nuclear power plants, all ship and research reactors. (Обогащение урана/Uranium enrichment, n.d.)

The Atomenergomash group of companies represents the engineering division of the state corporation Rosatom. Atomenergomash is a competent supplier of reactor island equipment for VVER nuclear power plants, the only manufacturer in the world of industrial fast neuron reactors, as well as reactor plants for atomic icebreakers. This company is involved in the construction of all new Russian-designed nuclear power plants in Russia, Turkey, Finland, Belarus, Bangladesh and other countries. (Ядерное и энергетическое машиностроение/Nuclear and Power Engineering, n.d.)

JSC Atomenergoproekt carries out a full range of design and survey work on the construction and modernization of nuclear power plants. When performing the project, modern design technologies are used, including mathematical modeling based on one of the most powerful supercomputers in Russia, using the technology of "Virtual NPP". Almost 80% of the company's portfolio of orders is foreign projects. (Проектирование, инжиниринг и строительство АЭС/Design, engineering and construction of nuclear power plants, n.d.)

In Russia, there are 36 power units at 10 nuclear power plants. All of them generate more than 19% of all electricity produced. All nuclear power plants are affiliates of Rosenergoatom Concern JSC. As a result of the operation of the nuclear power plant, 210 million tons of carbon dioxide are prevented from emitting annually, which is a significant contribution to the fight against global warming. The priority for the operation of Russian nuclear power plants is safety. Over the past 20 years, they have not registered a single serious violation of safety, which is classified above the first level according to the INES scale. (Генерация электроэнергии/Power generation, n.d.)

The world's first floating nuclear power plant, Academician Lomonosov, is a new class of energy sources based on Russian nuclear shipbuilding technologies. Now, "Academician Lomonosov" is located in the port of Pevek in the Chukotka Autonomous Region. The purpose of this station is to provide electricity to remote industrial enterprises, port cities, gas and oil platforms located on the high seas. The FNPP was developed with a large margin of safety, which will allow it to endure various natural disasters, including tsunamis. (Power generation, n.d.)

- Products and services in applied and fundamental science

The nuclear industry is one of the youngest areas of human activity. In the innovation management unit of the State Atomic Energy Corporation Rosatom, research is being conducted in such areas as nuclear physics, plasma physics, laser physics, quantum optics, radiochemistry, acoustics, metal science and many others. Research and development costs are around 1 million euros per

day. Rosatom is collaborating with the IAEA in three international innovative research projects at once, including a project of creation of closed-cycle nuclear reactor that will minimize RW. (Прикладная и фундаментальная наука/Applied and fundamental science, n.d.)

- Nuclear icebreaker fleet

Russia has the world's only nuclear icebreaker fleet. Through to his appearance, the development of the Far North began. The nuclear icebreaker fleet has already been discussed earlier in the third chapter. The fleet is owned by the enterprise of the State Atomic Energy Corporation Rosatom Rosatomflot, its main activities are icebreaking support for vessels, conducting high-latitude scientific expeditions, providing emergency rescue operations. Rosatomflot also provides sightseeing cruises to the North Pole. Much attention is paid to the icebreaker fleet with the goal of returning the Russian Navy to the Arctic. Without the participation of the icebreaker fleet, it is impossible to restore strategically important bases. The confident development and modernization of the nuclear icebreaker fleet allows to hope for the strong leadership of the Russian Federation in the Arctic. (Атомный ледокольный флот/Nuclear-powered icebreaker fleet, n.d.)

- Nuclear medicine

JSC Rusatom Healthcare is responsible for the development of nuclear medicine (medical diagnostics and radiation therapy). One of the most common types of nuclear testing is PET diagnostics, a graphical representation of the activity of which can be seen in Appendix 6. Currently, work is underway to create a network of nuclear medicine centers in the country, one of which will appear in Irkutsk in the coming years. (Nuclear medicine, n.d.)

Without nuclear medicine, it is impossible to imagine the detection and treatment of cancer. The treatment of this deadly disease occurs due to radioactive radiation, which focuses in the areas of affected tissues and organs. It damages the DNA of tumor cells, which leads to their destruction. There are three best known methods for treating cancer through nuclear medicine. First, proton therapy. Tumor atoms are confined by protons, heavy particles. They can be very precisely set direction and place of stop. The destruction of tissue occurs exactly at the stop place, which allows to save areas of tissues and organs that are not susceptible to cancer. The second way is a cyber knife. It generates about 200 rays that converge at one point. Alone, these rays are very weak and do not damage the parts of the body through which they pass, but at the epicenter the dose will be destructive. And the third method is brachytherapy. Capsules of the size of rice grains are placed in the patient's body for several months, after which they are removed. Tumors are

very sensitive to radiotherapy, they are destroyed under such a low dose of radiation, but the healthy tissues around the casing remain intact.

- New businesses

Jointly with the development of business lines traditional for Rosatom, the state corporation is also exploring and developing new business lines and entering new markets.

A subsidiary of JSC TVEL, LLC RUSAT, is a pool of competences of Rosatom scientific and industrial enterprises for the development of additive production in Russia. This organization coordinates projects to produce 3D printers, additive powders, components, software, as well as 3D printing services. Additive technologies have several advantages, since they allow scientists to create products of the most complex forms, and due to three-dimensional printing, the mass of products and the prototype production time are significantly reduced. Products printed on 3D printers are used from the areas of nuclear and space technology to medicine. (Аддитивное производство/Additive Manufacturing, n.d.)

The fuel company TVEL also created an industry integrator in the field of energy storage systems. This is about lithium-ion batteries, which can reduce equipment maintenance costs, and have unique properties and advantages compared to systems using other types of batteries. Energy storage systems are already used in passenger transport, they are equipped with in-plant and municipal facilities, emergency and uninterrupted power supply systems. (Накопители энергии/Energy Storage Systems, n.d.)

Furthermore, TVEL is engaged in decommissioning of nuclear and radiation hazardous facilities. The company has qualified personnel, infrastructure and material and technical base, which are necessary for the performance of these complex tasks. Currently, work is underway to decommission the facilities of the "nuclear heritage". (Вывод из эксплуатации/Removal from service, n.d.)

TVEL also includes metallurgical production, which specializes in the production of products from zirconium, calcium, hafnium, titanium, niobium for high-tech industries. Chepetsk Mechanical Plant is a world leader in the production of zirconium. Zirconium is widely used in the nuclear industry, for example, for the manufacture of shells of a fuel element. Hafnium is an indispensable element in the nuclear industry, used in heat-resistant alloys for aerospace technology and powerful magnets. Niobium is a superconducting material, products from it and its alloys are used in

medical tomography, magnetic systems for the study of thermonuclear reactors and accelerator technology, and in high-speed transport. (Металлургия/Metallurgy, n.d.)

The state corporation Rosatom is creating a new company that will be responsible for the development of quantum technologies. Quantum Technologies Joint Venture LLC will be created, with a registered capital of 300 million rubles (approximately 4.62 billion US dollars). With the help of quantum technologies, ultra-reliable information transfer systems can be created. In the near future, quantum technologies are expected to become the basis computers that will have a record speed of calculations, as well as ultra-precise sensors. Moreover, Rosatom is involved in the creation of a Russian quantum computer, the project of which is planned to be completed before 2024.**Invalid source specified.**

Quantum computers are a new class of computer technology that can solve problems that are not available for the most powerful "classic" supercomputers. Through them, scientists will be able to simulate complex molecules to develop new drugs and materials, complex logistics tasks, work with big data and perform many other tasks. (Rosatom will create a new company in the field of quantum technologies, 2020)

Rosatom holds one of the leading positions in the nuclear technology market. The corporation has a huge range of services in various fields, which helps to maintain competitive advantages. The state corporation is not afraid to enter new markets and is trying to expand its presence.

4.2 Competitors of Rosatom

One of the distinguishing features of Rosatom State Corporation is its vertical state integration. After Rosatom was established in 2007, by 2010 it had already taken its place in most segments of the nuclear energy industry. The Russian nuclear giant combined a whole network of infrastructure, construction and engineering companies. Not afraid to use the most breakthrough technologies, Rosatom today can offer the world the most reliable nuclear projects. (Под тенью санкций: как Россия захватывает рынок мировой атомной энергетики/Under the shadow of sanctions: how Russia captures the global nuclear energy market, 2019; Органы управления/Management, n.d.)

The business strategy of a Russian company was originally developed with the goal of achieving the goals of the country itself. Tasks for the civil sector will be implemented no matter what, even

if they are financially disadvantageous. Foreign competitors do not do this, apart from China. (Under the shadow of sanctions: how Russia captures the global nuclear energy market, 2019)

Rosatom's former rivals are currently experiencing hard times: the French company Orano (the former Areva), the company for the construction of nuclear reactors, was recently on the verge of bankruptcy, but could get out of this situation only due to state injections of financial resources. (Yudin, 2017)

Since 2017, the American company Westinghouse went through bankruptcy with the decision of its main creditor Toshiba. But the nuclear exporters of the PRC and South Korea are taking the place of these two companies. Let consider in detail the closest competitors of Rosatom. (Nuclear exports: who steps on the heels of Rosatom, 2017)

- **Chinese Atomic Export Companies**

In 2017 the talk was about the onset of Chinese nuclear exports to the world market. Researchers have gained certain advantages from Chinese exporters: it is assumed that Chinese reactors will be cheaper, the massive construction of a nuclear power plant in China will serve as a source of highly qualified personnel, through to its vast financial resources, Chinese companies can offer better financing conditions. (Атомный экспорт: кто наступает на пятки Росатому /Nuclear exports: who steps on the heels of Rosatom, 2017)

However, experts also say that Chinese companies have many problems that will take years to resolve. The main task of the exporter is to prioritize in favor of solvent customers. This quality is in doubt with Chinese customers. In July 2014, Argentina announced a default on its bonds, its currency is now continuing to fall, as well as industrial production. Romania does not manage to attract investors to the construction of two units at the Cernavoda NPP. (Nuclear exports: who steps on the heels of Rosatom, 2017)

Pakistan does not participate in the Treaty on the Non-Proliferation of Nuclear Weapons at all, and this prevents the receipt of commercial nuclear technologies from the members of the Nuclear Suppliers Group. In this regard, Pakistan is considered a non-reference country of nuclear exports. (Non-Proliferation Treaty, n.d.)

To start exporting nuclear reactors, Chinese companies have yet to prove their quality, as well as their ability to build blocks on time and on budget. As well as to guarantee that the reactors will be able to run smoothly without downtime due to malfunctions. In addition to all this, Chinese

companies also must prove the quality of their components, as a couple of times it was discovered inappropriate storage of important large components. (Nuclear exports: who steps on the heels of Rosatom, 2017)

There are still questions to regulatory and supervisory companies. Several companies are engaged in regulation of the nuclear industry at once, and their powers overlap. Due to overwork, these organizations are not able to make decisions on time. This leads to a low regulatory system, which has been repeatedly noted in the reports of international organizations. It is also noted that the institutions of the central government of China are fragmented and weak, and state-owned corporations have a great influence. For each reactor model, there is a big fight, because they are projects of huge organizational financial investments. This industry should be well regulated, therefore, according to the Convention on Nuclear Safety, an independent expert body must be present in countries producing nuclear technology. It is worth noting that Chinese organizations are actively involved in various IAEA regulatory activities. (Nuclear exports: who steps on the heels of Rosatom, 2017)

- **South Korean Atomic Exporters**

South Korean nuclear power companies are rapidly entering global markets. In 2009, the South Korean consortium won a tender for the construction of a four-unit nuclear power plant in the United Arab Emirates; the project is estimated at $20 billion. The contract includes not only the implementation of nuclear power plants, but also the supply of highly qualified specialists, since the UAE is a novice in nuclear energy. This was the first major entry into the global nuclear energy market. In 2015, South Korea and Saudi Arabia signed a contract for the construction of two $2 billion SMART compact reactors. Saudi Electricity also signed an agreement to supply cooling equipment with KEPCO and LG Electronics. In 2016, KHNP signed an agreement with Kenya on the construction of nuclear power plants. This is only part of the signed contracts and agreements. (Nuclear exports: who steps on the heels of Rosatom, 2017)

For Rosatom, this is a serious competitor, not in the near future, but already at the moment. Now, customers from different countries are choosing a supplier based on political relations, the economic cost of the reactor, the ability to adhere to time frames and quality. (Nuclear exports: who steps on the heels of Rosatom, 2017)

Here were listed the two main competing countries for Rosatom, which very rapidly occupy their niches in the global nuclear technology market. Rosatom also does not lag behind them and explores new business markets, as well as improves and expands its main focus - nuclear energy.

4.3 Probable, Upcoming and Existing Cooperation

At the end of 2018, the Rosatom foreign orders portfolio amounted to 36 power units in 12 countries of the world, which makes the corporation the world leader in the number of power units being built abroad. Even such impressive indicators do not stop Rosatom from continuing to negotiate and search potential partners and customers. (Performance Of State Atomic Energy Corporation Rosatom In 2018, 2019)

International cooperation involves establishing relationships with foreign partners, competitors and potential customers in the person of the public in other countries and governments. The State Atomic Energy Corporation Rosatom takes an active part in international conferences and forums and conducts joint activities with reputable international organizations in the field of the use of nuclear energy.

- **Floating Nuclear Power Plants**

The construction of the world's first floating nuclear power plant «Academician Lomonosov» aroused great interest among different countries that are not economically profitable to build full-fledged nuclear power plants, or if there is not enough space on land for this. Even though projects of such stations were already up to now, it was Rosatom that was able to build it first. (ПАТЭС доплывут до Китая/FNPP will sail to China, 2014)

Since the beginning of the construction of the Academician Lomonosov, interest from China and South America in the project has grown every year. The construction of the FNPP is cheaper, according to various estimates, the building of the FNPP “Academician Lomonosov” came out at 30 billion rubles (this is about 500 million US dollars). According to Rosenergoatom, the cost of such stations will decrease by about 30% with the serial production start. Compared with the classic nuclear power plants, which cost several billion US dollars, then the FNPP is more profitable. (Алексей Лихачёв: «Российские атомщики могут считать 2018 год успешным»/Alexei Likhachev: “Russian nuclear scientists can consider 2018 a successful year”, 2019)

This type of nuclear power plant will be in place in the countries of Africa, as well as in the countries of the Middle East. Since in the world there is already insufficient fresh water, and as it is known, in African countries this problem is even more common. FNPP can serve not only as electricity generation, but also as a mobile desalination plant. A floating nuclear power plant can desalinate about 40-240 tons of water, and its cost will be much lower than when using other energy

sources. The construction of the FNPP will serve the creation of new jobs, as well as the re-qualification of workers. (Alexei Likhachev: “Russian nuclear scientists can consider 2018 a successful year”, 2019)

Floating nuclear power plants will also be relevant in remote regions, where the construction of conventional energy sources is very difficult, if not impossible. This also includes various island states where territories cannot allow the construction of a sufficient number of power plants of various types. For example, in East Timor, tsunamis and earthquakes are not uncommon, the economy of this region after the 90s of the last century was re-qualified for oil and gas production, but due to the lack of tourism infrastructure in this country, there is practically no one. According to 2016 data, there is no renewable energy in East Timor. (Восточный Тимор/East Timor, n.d.)

- **Terrestrial Nuclear Power Plants**

Russia now occupies about 70% of the world market for the construction of nuclear power plants abroad. One of the competitive advantages of Rosatom is that reference units of power units go for export, that is, customers can clearly see how their order will look and work by visiting, for example, the Leningrad or Novovoronezh NPPs. (Alexei Likhachev: “Russian nuclear scientists can consider 2018 a successful year”, 2019)

Every year, more and more countries want to join the ranks of those which use nuclear energy. Rosatom is confident that the demand for nuclear power plants will grow. Nonetheless, cooperation in the field of nuclear energy consists not only in the design, implementation and maintenance of nuclear power plants, but also in solving the back-end problem. The back end is the final stage of the life cycle of a nuclear power plant, that is, its decommissioning, as well as the disposal of spent nuclear fuel. Despite the growing interest in many countries in nuclear power plants, there are still those countries that want to remove the use of such energy from their territory. (Alexei Likhachev: “Russian nuclear scientists can consider 2018 a successful year”, 2019)

A vivid example is Germany, which, as mentioned earlier, plans to decommission all power units by 2022. Since 2019, Germany has been importing spent nuclear fuel from its nuclear power plants into Russia for storage and disposal. It is possible that Rosatom will also take part in the decommissioning of power units in Germany. (Nuclear Power in Germany, 2019)

The Gulf countries are also interested in building not only floating nuclear power plants, but also traditional ones, that is, land-based ones. Almost every country in this region is currently negotiating for cooperation. Farthest in the negotiations, Rosatom advanced with Saudi Arabia. The

state corporation has already passed prequalification, and in 2020-2021 the results of the tender for the construction of Belene NPP (powerful two-unit nuclear power plant) are expected; at about the same time, the start of construction is expected. **Invalid source specified.**

This year, Rosatom State Corporation plans to apply for a license for the construction of the Hungarian Paks-2 NPP. Design documents for this nuclear power plant have already been submitted in October last year and their licensing is expected in June 2020. (Rosatom opens the nuclear cycle, 2020)

Currently, the final work is underway on the construction of the first nuclear power plant in Belarus, the Belarusian NPP. It is located 18 km from the town of Ostrovets. It is being built according to the standard project of the 3+ generation NPPs, which fully complies with the post-Fukushima safety and production criteria. At the first power unit, pre-commissioning and testing are already underway; the second power unit is completing construction work. In 2020, it is planned to begin full-scale commissioning. (Projects, n.d.; Start of the reactor plant equipment hot run at the Power Unit No.1 of Belarus NPP, 2019)

Rosatom and China Nuclear Corporation (CNNC) have a long partnership. The Tianwan NPP is an example of the largest Russian Chinese economic cooperation. All the first four nuclear power units were built by Russia. And in June 2018, a contract was signed for the construction of the seventh and eighth generation 3+ power units. (Projects, n.d.)

Uzbekistan and Russia have more than half a century of nuclear cooperation. Since 2017, negotiations have been ongoing on the construction of a nuclear power plant in Uzbekistan. In 2018, Rosatom and Uzatom signed an agreement on the construction of a modern nuclear power plant with VVER-1200 reactors of generation 3+. In October 2018, a solemn start to the construction of a nuclear power plant took place. In addition to the contract for the construction of nuclear power plants, a memorandum of cooperation in the education and training of personnel in the nuclear industry was also signed. The construction of the nuclear power plant is scheduled to begin in 2022 with a loan from the Russian government. (Президент РФ В. Путин и Президент Узбекистана Ш. Мирзиеев дали старт проекту строительства первой АЭС в Узбекистане/President of the Russian Federation V. Putin and President of Uzbekistan Sh. Mirziyoyev launched a project to build the first NPP, 2018; Росатом планирует договориться с Узбекистаном о строительстве АЭС в I квартале 2020 года/Rosatom plans to agree with Uzbekistan on the construction of a nuclear power plant in the first quarter of 2020, 2020)

- **Sea transportation along the Northern Sea Route**

Rosatom plans to enter a new shipping market for it. According to plans, the State Corporation wants to become one of the fifteen world leaders in transportation. Using the Northern Sea Route, it is possible to reduce the amount of time spent transporting cargo by 10-40% from the largest Asian ports to the main European harbors. If the corporation succeeds in achieving its goals, then by the number of shipments it will catch up with the world leader - the Danish company Maersk. Despite the reduction of the transportation period, it is not a fact that the price will also become lower than along the Southern Sea Route. This is because payment will be required to accompany icebreakers on the entire route. Rosatom is serious about the implementation of this project and plans to launch the first shipments this year.**Invalid source specified.**

Financing for this project is 6.97 billion dollars: 5.76 billion dollars will be invested in the construction of modern ships for transportation, the rest will go to modernize the port infrastructure. Financing will come from Rosatom's own funds, bank loans and reinvestment of cash flows. (Rosatom is going to spend $7 billion on world leadership in shipping, 2019)

Analysts believe that alone Rosatom will not reach the level that he plans, because there is no shortage in this business. Russian Corporation needs to enlist the support of already experienced companies such as Maersk. Rosatom considers its advantage an atomic icebreaker fleet.**Invalid source specified.**

- **Collaboration for research and scientific purposes**

Rosatom has already been cooperating with the African continent for almost 20 years since the signing of the nuclear technology agreement with Namibia and Angola, and then with Ghana, Kenya, Uganda, Morocco and Algeria. Also, Rosatom has an agreement with Tanzania on the extraction of uranium.

Russia has been cooperating with Nigeria since 2009 after the signing of an agreement on the design of nuclear power plants and the creation of a multi-purpose research reactor. In 2016, an agreement was signed with Ethiopia on the use of nuclear technology in medicine, industry and agriculture. In 2017, Rosatom signed an agreement with Zambia on the construction of a center for nuclear science and technology. In the same year, an agreement was signed on the use of a wide range of technologies, including the training by Russia of specialists for servicing nuclear power plants. (Росатом представил в Замбии проект сооружения Центра ядерной науки и технологий/Rosatom presents in Zambia the project for the construction of the Center for Nuclear Science and Technology, 2018)

In 2019, several agreements were signed in Rwanda, according to which a center for nuclear science and technology in the field of radiobiology will appear in the country. The creation of these centers will mark the beginning of the construction of atomic infrastructure in an African country, as well as give impetus to the development of nuclear science, which will make it possible to produce highly qualified nuclear physicists. (Росатом в Африке/Rosatom in Africa, 2019)

The planned construction of the Center for Nuclear Research and Technology in Bolivia, an agreement with which was signed in 2016. This project will be unique for the nuclear industry, since the area chosen by the Bolivian side in the city of El Alto is the highest (4100 meters above sea level) of all the sites on which nuclear structures were built. The Bolivian authorities are awaiting the completion of the construction of the Center for Nuclear Research and Technology in 2023. (Росатом и Агентство по атомной энергии Боливии подписали контракты по проекту сооружения в стране Центра ядерных исследований и технологий/Rosatom and the Bolivian Atomic Energy Agency have signed contracts for a project to build a Nuclear Research Center, n.d.; Власти Боливии ожидают завершения реализации проекта Росатома в 2023 году/Bolivian authorities expect the completion of the Rosatom project in 2023, 2020)

Unfortunately, so far nuclear reactors are being built only in Egypt - the four-unit Al-Dabaa nuclear power plant. The building of four power units will take about a decade. Construction is being funded by Egypt and a Russian state export loan (Projects, n.d.; Rosatom in Africa, 2019). More and more African states conclude that the development of their countries without nuclear energy is almost impossible.

- **Cooperation in SNF and RW management**

The State Atomic Energy Corporation Rosatom offers its foreign customers the management of spent nuclear fuel and radiation waste. (Что входит в Интегрированное предложение?/What is included in the Integrated Offer?, n.d.)

The global market for the decommissioning of nuclear facilities, as well as the management of radioactive waste and spent nuclear fuel, is new and developing. TVEL JSC estimates this market at 100 billion euros by the year 2030. Therefore, it is not surprising why Rosatom is so actively establishing cooperation in this area. (Топливная компания росатома «твэл» будет

сотрудничать с испанскими компаниями в области вывода ядерных объектов из эксплуатации/Rosatom fuel company fuel will cooperate with Spanish companies in the field of decommissioning of nuclear facilities, 2020)

On February 26, 2020, TVEL JSC signed a memorandum with Spanish companies ENUSA, ENSA and IDOM on decommissioning of nuclear facilities, as well as dismantling of nuclear and radiation hazardous facilities. The cooperation plans include the decommissioning and dismantling of research reactors, land cleaning and rehabilitation of territories, including uranium mines. (Топливная компания Росатома «ТВЭЛ» и испанские компании будут сотрудничать в области вывода из эксплуатации ядерных объектов/TVEL Fuel Company of Rosatom and Spanish companies will cooperate in the decommissioning of nuclear facilities, 2020)

Rosatom already has extensive experience in international projects for the removal of nuclear and radiation hazardous facilities. So, in 2019, the consortium of the German Uniper Anlagenservice and NUKEM Technologies (part of the Rosatom circuit) won a contract for dismantling four reactor vessels in Sweden (Oskarshamn NPP And Barsebek NPP), work should begin this year. In addition, NUKEM, as part of an international consortium, has a contract for the withdrawal of the German Biblis nuclear power plant. A near-surface repository of spent nuclear fuel is also under construction in Bulgaria. **Invalid source specified.**

Due to the entering to the new markets, Rosatom will continue to develop its main direction - the construction of NPPs and will also strengthen its position as a manager of the entire life cycle of nuclear power plants. (Rosatom will save Europe from nuclear facilities, 2020)

As can be understood from the foregoing in this chapter, Rosatom is taking great steps to increase its presence in various markets and is very successful in this. The company is not afraid to try its hand in new areas of business, even if they are not related to its main activity - nuclear energy.

5 Analysis and Findings

The purpose of this research is to study the international nuclear technology market, the consequences of inadequate monitoring of radiation hazardous facilities, to analyse existing agreements and upcoming agreements of various countries with Rosatom. This chapter will provide information on the state of the global nuclear technology market, ratings of countries and companies. And, the difficulties encountered by the author of the thesis will be listed.

5.1 Current State of Business in Nuclear Technology Market

According to 2019, there are 192 operating nuclear power plants in thirty-one countries; 442 power units are exploiting at these stations. The Top 5 countries for nuclear power generation include: USA, France, Japan, Russia, South Korea. (ТОП-5 стран – мировых лидеров по производству атомной энергии/TOP 5 countries - world leaders in nuclear energy production, 2019; The Database on Nuclear Power Reactors, n.d.)

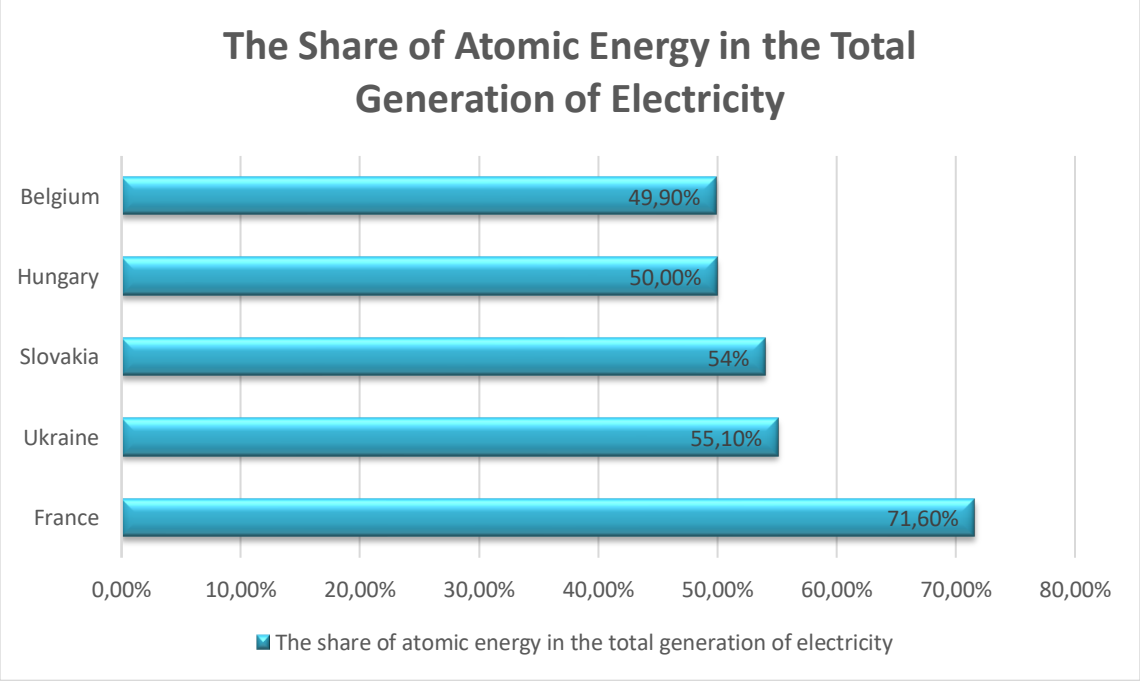

Figure 1. The Share of Atomic Energy in the Total Generation of Electricity (2020). Adapted from The Database on Nuclear Power Reactors provided by IAEA.

In 2018, according to the IAEA, the share of nuclear energy in global electricity consumption was 11%. If compare the five leaders in electricity generation and the five countries that are most dependent on nuclear electricity (shown in the Figure 1), it can be seen that only France is on these two lists. According to the IAEA, 13 states depend on nuclear energy for more than one-fourth. (The Database on Nuclear Power Reactors, n.d.)

Pursuant to the calculations of the state corporation Rosatom, in 2018 11 thousand tons of heavy metal in the form of fuel for reactors was distributed on the world market. The ratio between the reactors and the need for uranium fuel can be seen in Appendix 7. Experts believe that with the expansion of the nuclear reactor fleet in the world, by 2030 the market for nuclear fuel consumption services will increase to 12 thousand tons. The companies that stand out in this market are Westinghouse, Framatome, GNF and Rosatom State Corporation. Their shares are provided in Figure 2. (Performance Of State Atomic Energy Corporation Rosatom In 2018, 2019)

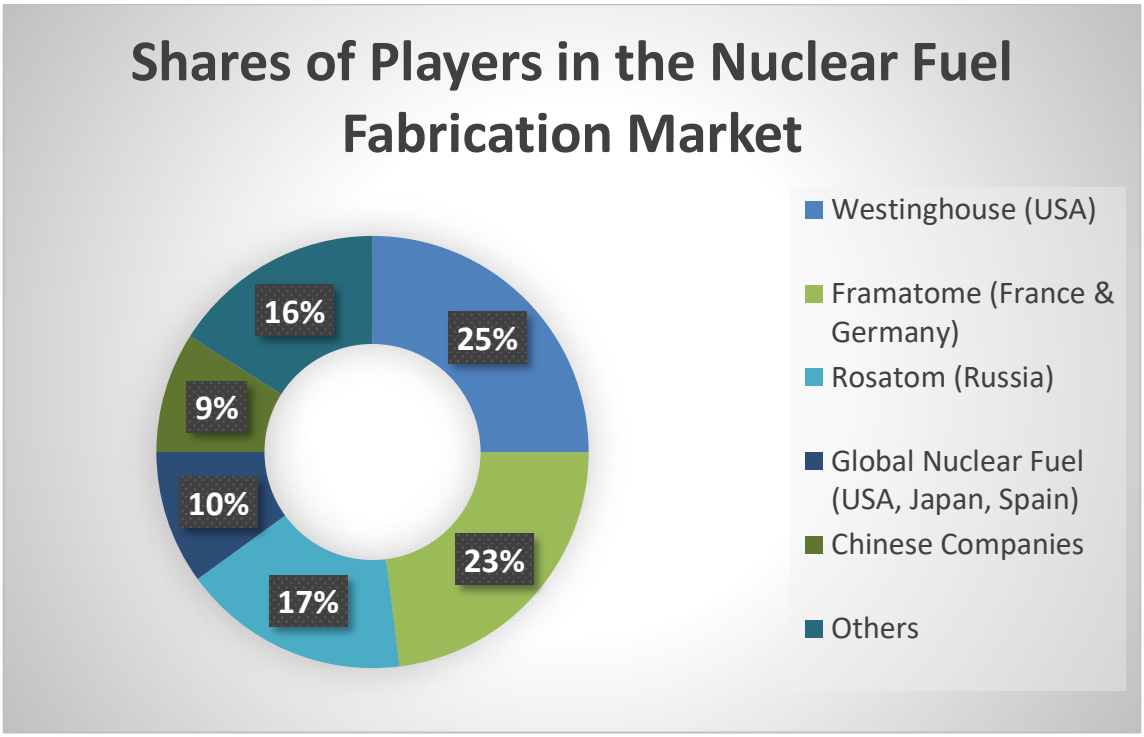

Figure 2. Shares of Players in the Nuclear Fuel Fabrication Market (2018). Adapted from report "Performance Of State Atomic Energy Corporation Rosatom In 2018", provided by State Atomic Energy Corporation Rosatom.

In 2018, natural uranium production decreased by 9% compared to 2017, the volume amounted to about 53 thousand tons. Deliveries from secondary sources are estimated at 20 thousand tons. The largest producers of uranium continued the strategy of reducing uranium production, making

a bias on the optimization of production. Some extractive assets were mothballed (MacArthur River mine in Canada, Langer Heinrich mine in Namibia). The shares of the largest players in the market of natural uranium can be seen in Figure 3. (Performance Of State Atomic Energy Corporation Rosatom In 2018, 2019)

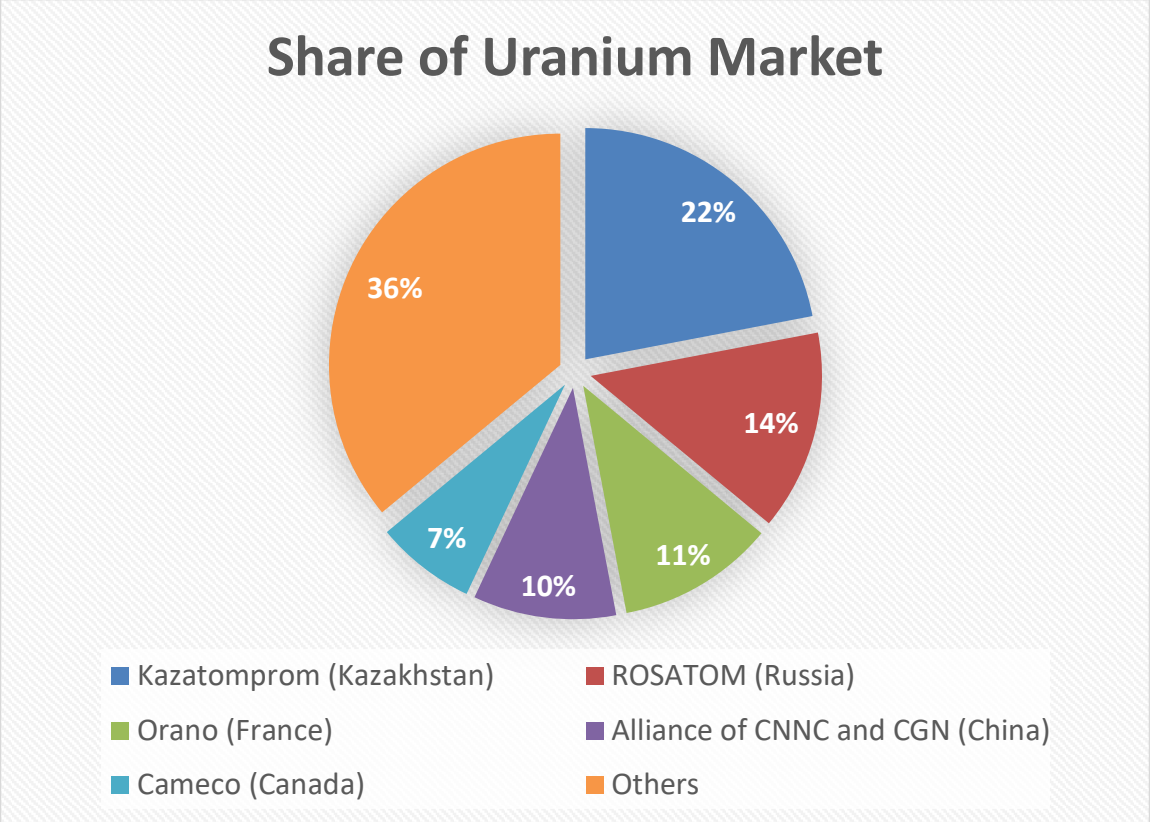

Figure 3. Share of Uranium Market (2018). Adapted from report "Performance Of State Atomic Energy Corporation Rosatom In 2018", provided by State Atomic Energy Corporation Rosatom.

One of the problems of the world market of nuclear power plants is the obsolescence of reactors. Figure 4 shows the age of all reactors in July 2019. From it can be seen that more than 50% of the reactors were built over 30 years ago. The average projected lifetime of a nuclear reactor is 50-70 years. For a long time, at the end of the last century and the beginning of this century, there was practically no construction of nuclear power plants and nuclear reactors, so the question of the decommissioning of many nuclear reactors will soon arise, but only a few companies have the necessary knowledge and experience. As previously written, experts predict a large market growth in the removal of radioactive objects. (The World Nuclear Industry Status Report, 2019)

For example, in the USA, reactors were originally built from 40 years of operation, but companies may request to extend the licensing for operation for another 20 years. However, the aging of

world reactors now exceeds those that are now given for construction. According to the IAEA, 80 reactors operating in the world are over 41 years old. And this suggests that in the next decade, most of them will have to be decommissioned. However, now, only 52 power units are under construction in the world, which is unlikely to offset the energy productivity that 80 old reactors provide. (The World Nuclear Industry Status Report, 2019; World Nuclear Performance Report, 2019)

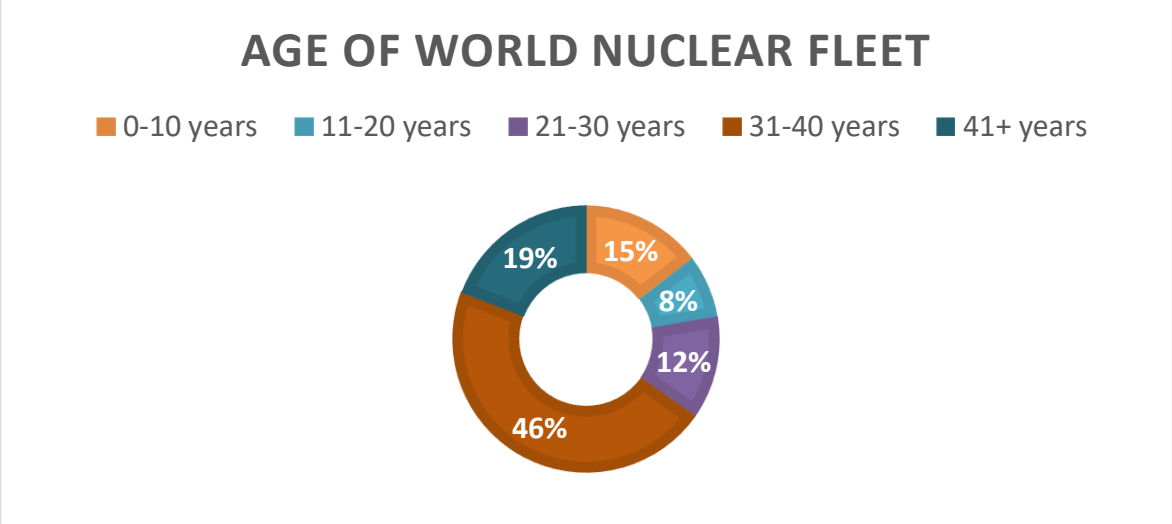

Figure 4. Age of World Nuclear Fleet for 417 Reactors (2019). Adapted from The World Nuclear Industry Status Report 2019.

Now on the world market for nuclear technology there are new requirements for competitiveness. A very low share of leaders in the nuclear industry of developed countries is observed. Even though former leaders are still present on the market, the role of many companies from this list is declining. Japanese companies (Toshiba, Mitsubishi, Hitachi) refuse new projects in Turkey and the UK. Some sources report that the UAE, South Africa and Saudi Arabia abandoned Japanese nuclear power plant projects because these companies simply lacked experience in building nuclear reactors. The American Westinghouse and the French Framatome are currently undergoing restructuring and a low number of orders. After the tragedy in Fukushima, the Japanese abandoned the active development of the nuclear industry. In the USA, nuclear energy is becoming less competitive due to the abundance of cheap gas. (Конкуренция на мировом рынке ядерных энергетических технологий/Competition in the global nuclear energy technology market, 2019)

Developing countries, at the beginning of the development of nuclear energy, need financial support, which, unfortunately, not all nuclear builders can assume. Another advantage of the Russian

state corporation Rosatom is the possibility of providing a state loan. The same service is offered by Chinese companies. (Competition in the global nuclear energy technology market, 2019)

In general, the nuclear technology market is currently undergoing certain changes. Leaders of the past are replaced by other companies that provide technology more advanced and safer. The place of the state corporation Rosatom still remains in the ranking of the leaders of the global nuclear services market, and every year its indicators are improving in many ways.

5.2 Limitation

Thesis was aimed at studying nuclear technology, as well as analysis of existing and upcoming cooperation between Russia and other countries in this area. All information that is provided in the thesis is relevant at the time of writing the study. The data were taken from various reliable sources, both Russian and foreign.

These are the challenges that the researcher encountered: not all countries have information available on the state of the nuclear technology market; Asian countries do not have enough information on the topic of the study, at least in English; little open-source research has been done to analyze the global nuclear technology market.

6 Recommendation to Improve Business Collaboration

Atomic technology can rightfully be considered as one of the highest achievements of engineering thought and the development of science. The growing of a global partnership will be able to reduce the prevailing tensions of political relations between world powers. Nuclear technologies still need to be improved, and all the potential that now exists is not the limit of its development.

It is no secret that the demand of the Earth's population for electricity is growing every year. Nuclear power plants are one of the most promising sources of electricity. Earlier, in research work, the advantage of nuclear power plants was already discussed. Many developed countries do not have enough territories to build other alternative energy sources (wind or solar), since they require a large amount of land. One of the advantages of nuclear power plants is that they do not occupy vast territories and can be built in the outskirts of megacities. (Climate Change and Nuclear Power, 2016)

To improve international cooperation, a major role is played by participation in various international innovative projects in the field of nuclear technology, participation in international forums on nuclear energy. These are such events where agreements are concluded, new clients and partners are found. (Международное сотрудничество/The international cooperation, n.d.)

Restoring international relations in the nuclear industry between Russia and the United States, which stopped in the 1980s, is one of the challenges. The number of disagreements on various issues gives no doubt about the complexity of this process. The unification of these powers is necessary to solve global problems, including climate change and the prevention of a nuclear catastrophe. Now, there is no monopoly on nuclear weapons, the technology of its manufacture has existed for more than 70 years, and the means for its implementation are in simple access. All this increases the possibility of nuclear terrorism. (Пути к партнерству. Возможные проекты сотрудничества России и США в ядерной сфере/Partnership paths. Possible nuclear cooperation projects between Russia and the USA, 2017)

A report prepared by the Russian Center for Energy and Security and the US Nuclear Threat Initiative proposed project options that could resume relations between Russia and the United States of America. Projects were provided in various areas of the nuclear industry: the development of new reactors, the development of new solutions for radioactive waste management, the development of the nuclear fuel non-proliferation, the enhancement of the safety of power plants, as

well as the fight against illegal proliferation of nuclear materials. (Partnership paths. Possible nuclear cooperation projects between Russia and the USA, 2017)

The practical implementation of these projects will give rise to the restoration of trusting relations between the USA and Russia, because without it, normalization of bilateral relations is impossible.

The World Nuclear Association believes that future projects and orders for the construction of nuclear power plants should be only generations 3+ and 4. The latter type includes fast neutron reactors that can short-circuit the nuclear fuel cycle, solving the problem of providing nuclear fuel for a long time. To date, only Rosatom has the physical embodiment of such reactors; they are installed at the Novovoronezh (VVER-1200) and Beloyarskaya (FN-800) nuclear power plants. The IAEA can personally see and observe systems of post-Fukushima safety requirements. (Атомная «Гармония» поможет Парижскому соглашению по климату/Atomic "Harmony" will help the Paris climate agreement, 2018)

There is a chance that Rosatom’s technologies will become the basis for the World Nuclear Association. This will allow the production of such reactors to become conveyor, which, in turn, reduce their cost.

To develop cooperation in the nuclear industry, it is also necessary to have general regulation and standards for the construction of nuclear power plants. Now, the settlement of the issue with different states with different requirements spends a lot of time, which delays the construction of new power units. (The World Nuclear Industry Status Report, 2019)

A large contribution to the development of international economic relations is made by large organizations regulating nuclear energy. They are: IAEA, Euratom and the Commonwealth of Independent States. (Роль международных организаций – МАГАТЭ, Евратом и СНГ – в области использования мирного атома/The role of international organizations - IAEA, Euratom and the CIS - in the field of peaceful atom use, 2015)

To facilitate cooperation between countries, it is necessary to create and implement uniform standards in the field of application of industrial radiation technologies and ensuring radiation safety. Negotiations are already underway between the countries on the creation of a single platform for cooperation in the field of decommissioning of nuclear and radiation hazardous facilities, the handling of nuclear materials and radioactive substances (RW) and spent nuclear fuel (SNF) and the rehabilitation of territories. (The role of international organizations - IAEA, Euratom and the CIS - in the field of peaceful atom use, 2015)

Also, the energy industry needs to address the issue of technology assessment. That is, to pay attention not only to the costs during the construction of power plants, but also to consider the costs of the entire life cycle of nuclear power plants, including environmental impact.

7 Conclusion

Nuclear technology has become one of the notable objects of worldwide discussion in recent years. The nuclear technology market is undergoing changes, industry leaders are changing, newcomers are taking their place. Rosatom, despite its short existence compared to other companies (13 years, not considering the nuclear legacy of the USSR), was able to achieve great success, for example, becoming a leader in the construction of foreign nuclear power plants, having the largest portfolio of foreign orders.

Business cooperation between countries is accompanied by economic development. This study analyzed various nuclear technologies, as well as existing and upcoming cooperation between countries in the second, third and fourth chapters. The second chapter emphasized the importance of economic cooperation between countries in the field of nuclear technology.

Data for the study was collected from authoritative and verified sources, which allows to rely on the relevance of the information collected in the thesis. The seventh chapter made some recommendations for improving and expanding economic cooperation between countries.

International economic cooperation is necessary for the modern world. Now every country is trying to show its superiority in one area or another, hoping for economic growth. However, world society will not be able to fully receive the benefit that goes from using the energy of a peaceful atom without uniting countries in improving and developing nuclear technologies. This is precisely the area that has enormous potential and hopes for it in various spheres of life, be it energy, medicine or environmental protection.

The combination of efforts and knowledge will open great benefits in the use of nuclear energy, as well as possibly eliminate or smooth global conflicts between countries.

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Президент РФ В. Путин и Президент Узбекистана Ш. Мирзиеев дали старт проекту строительства первой АЭС в Узбекистане/President of the Russian Federation V. Putin and President of Uzbekistan Sh. Mirziyoyev launched a project to build the first NPP. (2018, 10 19). Retrieved 02 26, 2020, from State Atomic Energy Corporation Rosatom: https://www.rosatom.ru/journalist/news/prezident-rf-v-putin-i-prezident-uzbekistana-sh-mirzieev-dali-start-proektu-stroitelstva-pervoy-aes-/

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Росатом планирует договориться с Узбекистаном о строительстве АЭС в I квартале 2020 года/Rosatom plans to agree with Uzbekistan on the construction of a nuclear power plant in the first quarter of 2020. (2020, 01 22). Retrieved 02 26, 2020, from Atomic Energy 2.0: https://www.atomic-energy.ru/news/2020/01/22/100811

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Росатом хочет стать мировым лидером морских перевозок/Rosatom wants to become the world leader in shipping. (2019, 11 20). Retrieved 02 26, 2020, from Vedomosti: https://www.vedomosti.ru/business/articles/2019/11/20/816799-rosatom-liderom

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Топливная компания росатома «твэл» будет сотрудничать с испанскими компаниями в области вывода ядерных объектов из эксплуатации/Rosatom fuel company fuel will cooperate with Spanish companies in the field of decommissioning of nuclear facilities. (2020, 02 26). Retrieved 02 26, 2020, from Energy Experts: http://www.energy-experts.ru/news26976.html

Топливная компания Росатома «ТВЭЛ» и испанские компании будут сотрудничать в области вывода из эксплуатации ядерных объектов/TVEL Fuel Company of Rosatom and Spanish companies will cooperate in the decommissioning of nuclear facilities. (2020, 02 26). Retrieved 02 26, 2020, from State Atomic Energy Corporation Rosatom: https://www.rosatom.ru/journalist/news/toplivnaya-kompaniya-rosatoma-tvel-i-ispanskie-kompanii-budut-sotrudnichat-v-oblasti-vyvoda-iz-ekspl/

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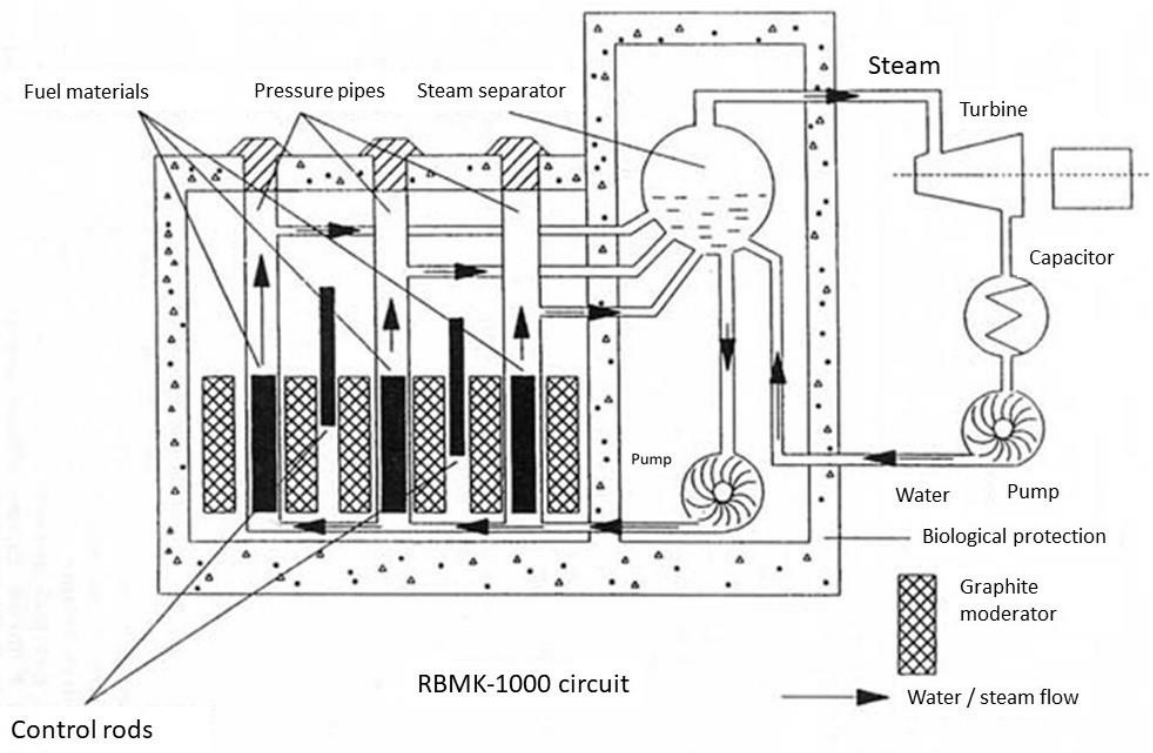
Ядерное и энергетическое машиностроение/Nuclear and Power Engineering. (n.d.). Retrieved 02 22, 2020, from State Atomic Energy Corporation Rosatom: https://rosatom.ru/production/engineering/

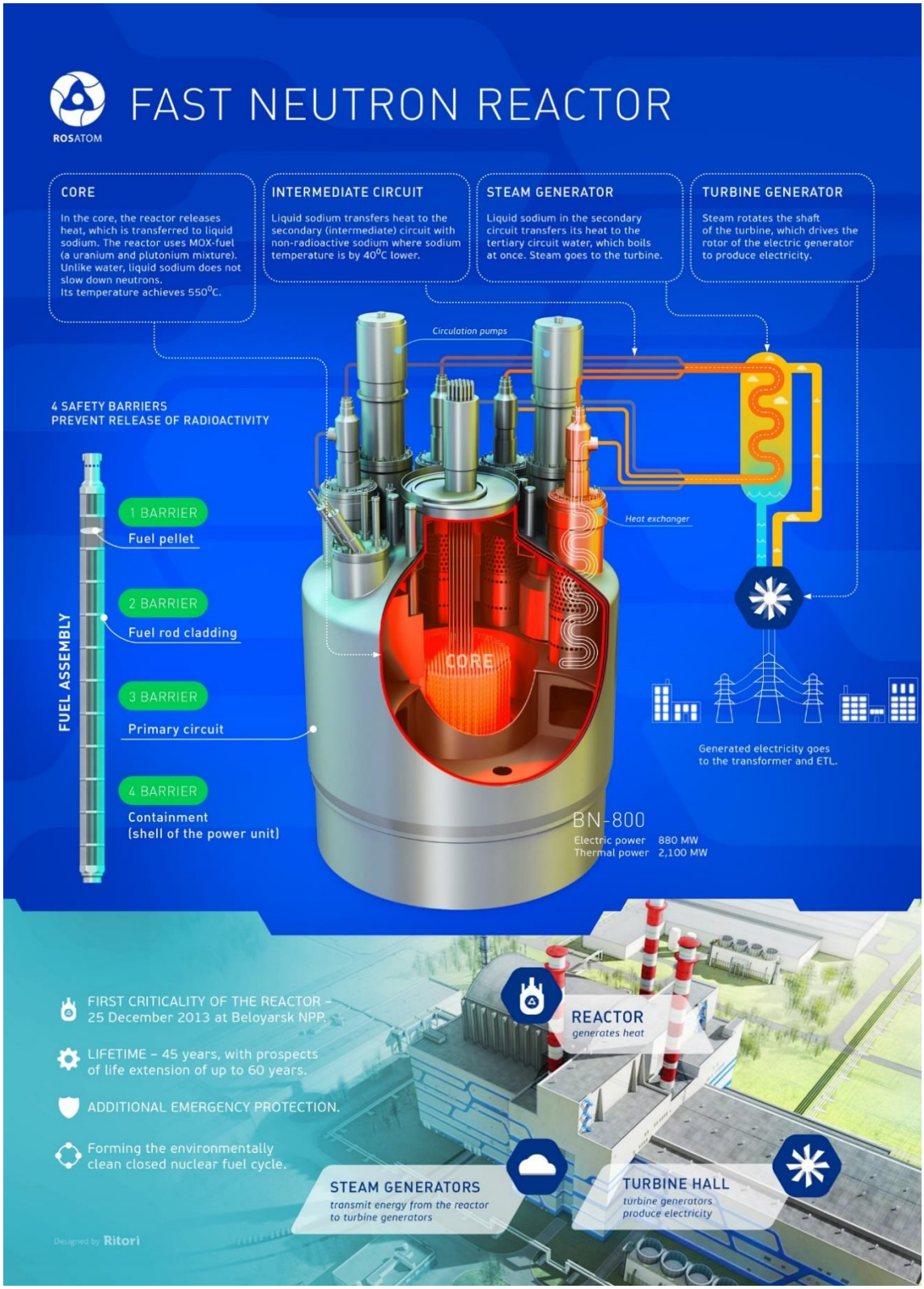
Appendix 1

The design of the RBMK type reactor, which was installed at the time of the explosion at the Chernobyl nuclear power plant. (Nuclear Energy Agency, 1995). Date of access: 15.02.2020



Appendix 2

The process of operating of NPP. Picture is taken from the Rosatom webpage. (Power Generation, n.d.). Date of access: 11.02.2020.

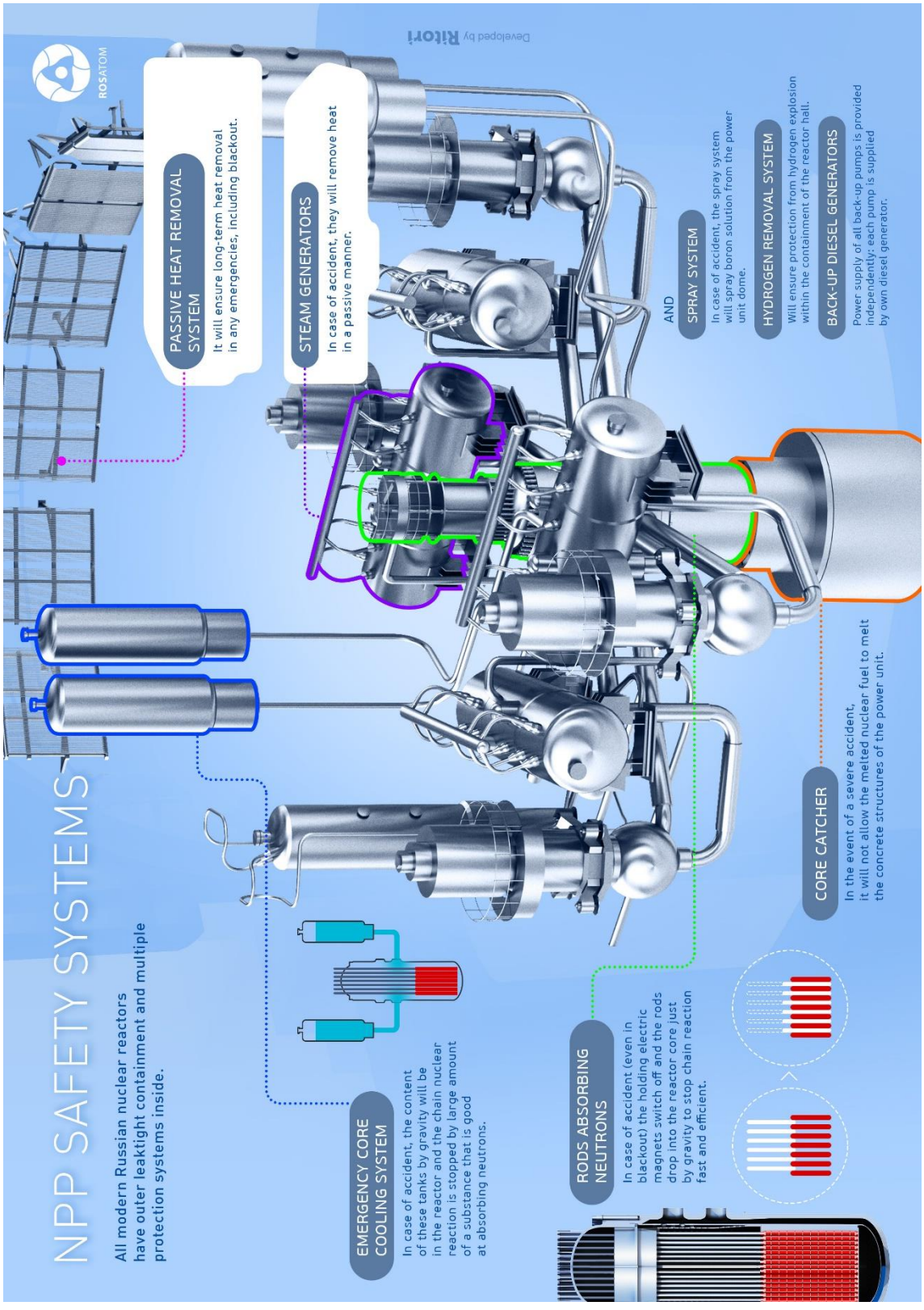


Appendix 3

Application of Nuclear Technologies. Picture is taken from Rosatom webpage. (New business areas, n.d.). Date of access: 17.02.2020.

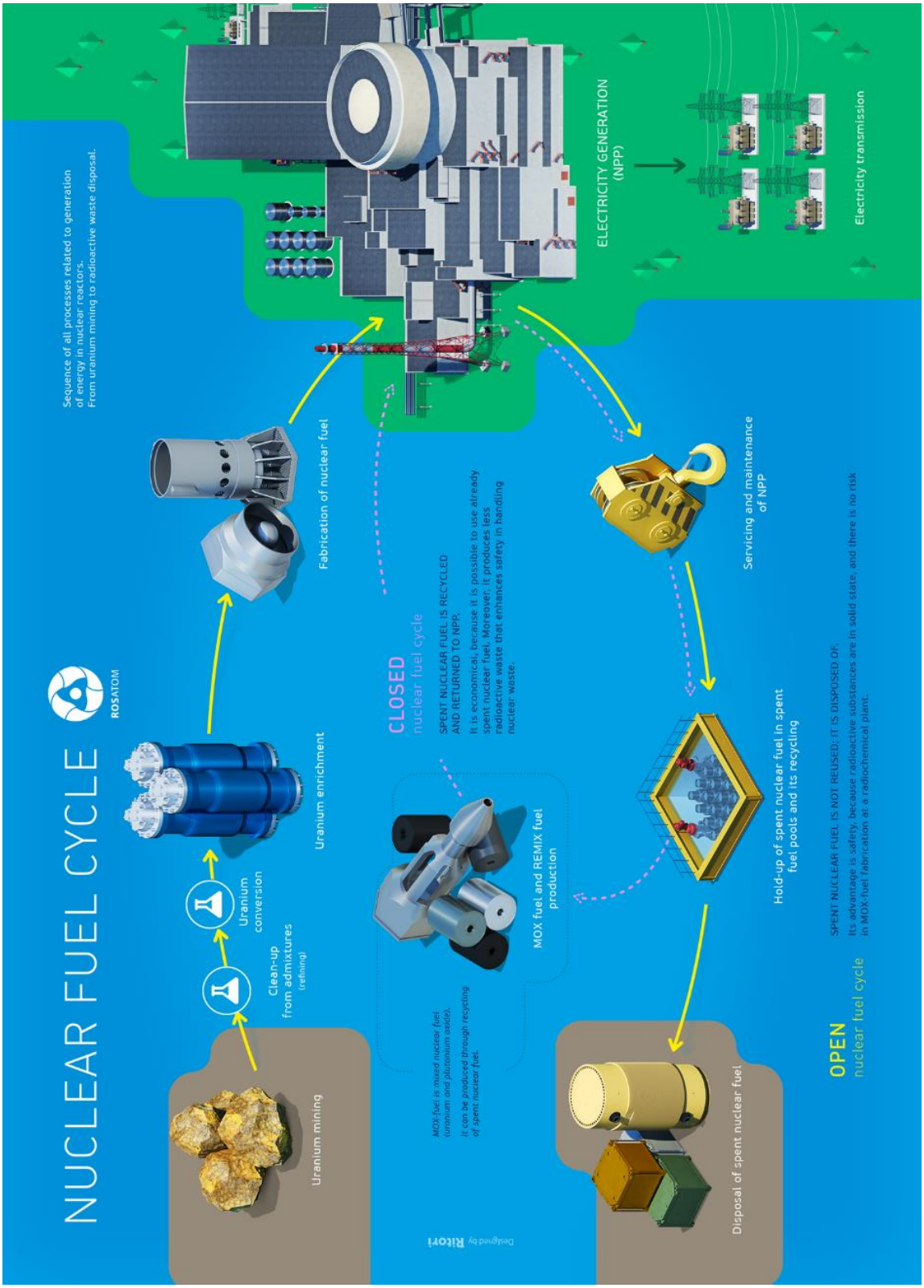
Appendix 4

NPP's Safety systems. Picture is taken from Rosatom official Webpage. (Benefits of Nuclear Energy, n.d.). Date of access: 11.02.2020.



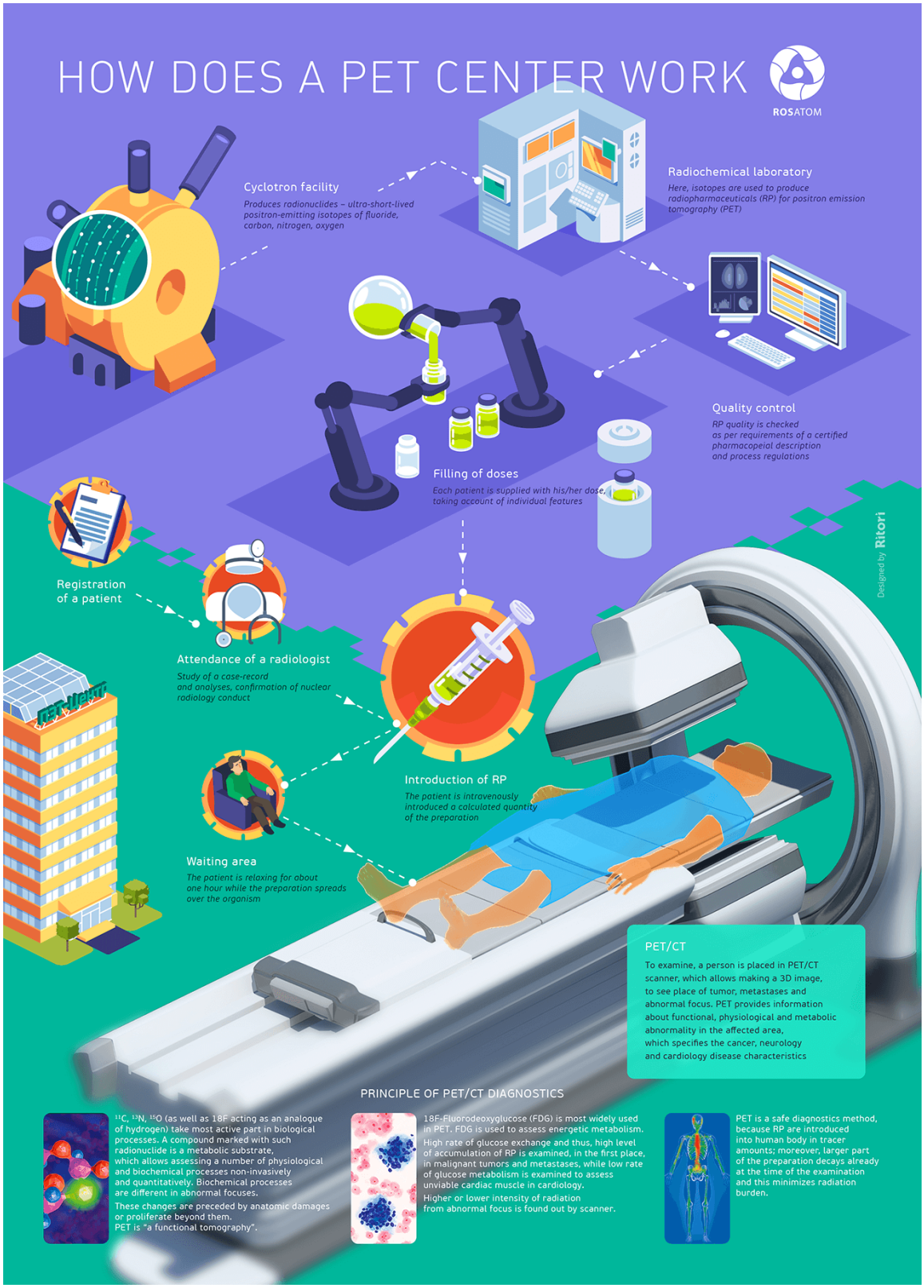
Appendix 5

Scheme of the uranium fuel cycle. Taken from the official page of Rosatom State Corporation. (Nuclear fiel cycle, n.d.). Date of access: 22.02.2020.



Appendix 6

Graphic image of the work of the PET center. Taken from the official website of the state corporation Rosatom. (Nuclear medicine, n.d.) Date of access: 22.10.2020.



Appendix 7

World Nuclear Power Reactors & Uranium Requirements. Taken from World Nuclear Association web page. (World Nuclear Power Reactors & Uranium Requirements, 2020)

COUNTRY (Click name for Country Profile)	NUCLEAR ELECTRICITY GENERATION 2018		REACTORS OPERABLE February 2020		REACTORS UNDER CONSTRUCTION February 2020		REACTORS PLANNED February 2020		REACTORS PROPOSED February 2020		URANIUM REQUIRED 2020
	TWh	% e	No.	MWe net	No.	MWe gross	No.	MWe gross	No.	MWe gross	tonnes U
Argentina	6.5	4.7	3	1702	1	27	1	1150	2	1350	198
Armenia	1.9	25.6	1	376	0	0	0	0	1	1060	77
Bangladesh	0	0	0	0	2	2400	0	0	2	2400	0
Belarus	0	0	0	0	2	2388	0	0	2	2400	701
Belgium	27.3	39.0	7	5943	0	0	0	0	0	0	999
Brazil †	14.8	2.7	2	1896	1	1405	0	0	4	4000	325
Bulgaria	15.4	34.7	2	1926	0	0	1	1000	1	1000	331
Canada	94.5	14.9	19	13,553	0	0	0	0	2	1500	1538
China	277.1	4.2	47	45,688	12	12,244	42	48,660	170	199,610	9834
Czech Republic	28.3	34.5	6	3932	0	0	2	2400	2	2400	665
Egypt	0	0	0	0	0	0	4	4800	0	0	0
Finland	21.9	32.5	4	2764	1	1720	1	1250	0	0	765
France	395.9	71.7	57	62,250	1	1750	0	0	0	0	8936
Germany	71.9	11.7	6	8052	0	0	0	0	0	0	1264
Hungary	14.9	50.6	4	1889	0	0	2	2400	0	0	352
India	35.4	3.1	22	6219	7	5400	14	10,500	28	32,000	967
Iran	6.3	2.1	1	915	1	1057	1	1057	5	2760	157
Japan	49.3	6.2	33	31,679	2	2756	1	1385	8	11,562	2000
Jordan	0	0	0	0	0	0	0	0	1	1000	0
Kazakhstan	0	0	0	0	0	0	0	0	2	600	0
Korea RO (South)	127.1	23.7	24	23,231	4	5600	0	0	2	2800	4903
Lithuania	0	0	0	0	0	0	0	0	2	2700	0
Mexico	13.2	5.3	2	1600	0	0	0	0	3	3000	251
Netherlands	3.3	3.1	1	485	0	0	0	0	0	0	83
Pakistan	9.3	6.8	5	1355	2	2322	1	1170	0	0	196
Poland	0	0	0	0	0	0	0	0	6	6000	0
Romania	10.5	17.2	2	1310	0	0	2	1440	1	720	185
Russia †	191.3	17.9	38	29,203	4	4903	24	25,810	22	21,000	4834
Saudi Arabia	0	0	0	0	0	0	0	0	16	17,000	0
Slovakia	13.8	55.0	4	1816	2	942	0	0	1	1200	515

Slovenia	5.5	35.9	1	696	0	0	0	0	1	1000	141
South Africa	10.6	4.7	2	1830	0	0	0	0	8	9600	283
Spain	53.4	20.4	7	7121	0	0	0	0	0	0	1290
Sweden	65.9	40.3	7	7569	0	0	0	0	0	0	962
Switzer-land	24.5	37.7	4	2960	0	0	0	0	0	0	390
Thailand	0	0	0	0	0	0	0	0	2	2000	0
Turkey	0	0	0	0	1	1200	3	3600	8	9500	0
Ukraine ‡	79.5	53.0	15	13,107	0	0	2	1900	2	2,400	1893
UAE	0	0	0	0	4	5600	0	0	0	0	966
United King-dom	59.1	17.7	15	8883	1	1720	3	5060	6	7820	1820
USA †	808.0	19.3	96	97,896	4	5000	3	2550	18	8000	19,746
Uzbeki-stan	0	0	0	0	0	0	2	2400	2	2400	0
WORLD*	**2563**	c **10.3***	**441**	**391,565**	**54**	**61,034**	**109**	**118,532**	**330**	**360,782**	**68,240**
	TWh	**% e**	**No.**	**MWe**	**No.**	**MWe**	**No.**	**MWe**	**No.**	**MWe**	**tonnes U**
	NUCLEAR ELECTRICITY GENERATION		OPERABLE		UNDER CON-STRUCTION		PLANNED		PROPOSED		URA-NIUM RE-QUIRED