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# Trends, Features and Problems of the Development of Nuclear Energy in France

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## ABSTRACT

This article analyses the trends and problems associated with the peculiarities of the development of nuclear energy in France. This country has always paid particular attention to the fuel and energy sector. Its significant potential allows it to occupy one of the top places in the world in the use of nuclear technologies in the national economy. At the same time, the relatively hostile policy of the European Union concerning nuclear energy in connection with the implementation of its course on the “green” economy creates many problems in the relations of Paris with the leadership of this integration association. Given that Germany in 2022 completely closes its nuclear power plants (NPP), and France becomes the leading country in the EU for the use of nuclear energy, the leadership of this country under the influence of political factors often has to make mutually exclusive decisions in this area. France’s position as the most significant nuclear power in the EU is complicated because it faces increasing competition in the global nuclear market. The leading positions on it are traditionally occupied by the United States, Russia, and China. Time will tell whether France will be able to cope with these threats. One thing is certain: France seeks to maintain and strengthen its position as the leading nuclear power in the EU and worldwide. France’s long-term experience in designing and building nuclear power plants and ensuring their safe operation can also be useful for Russia, as it is generally recognized that our country has been and is one of the world leaders in nuclear energy.

**Keywords:** nuclear power; energy policy; France; nuclear reactors; nuclear power plants (NPP)

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## WORLD ATOMIC ENERGY AND EUROPEAN UNION ENERGY POLICY

According to the World Nuclear Association<sup>1</sup> as of September 2020, the number of operating nuclear power plants in the world was 441 and their total installed capacity reached 391.7 GW.

53 reactors are under construction at present on the planet with total capacity 59.2 GW, of which 12 — in China, 7 — in India, 4 — in Russia. Planned construction of 106 additional nuclear reactors (total capacity 113.8 GW), including in countries that previously did not have nuclear power plants (NPP) — Egypt and Uzbekistan.

The possibility of building an NPP is being considered in Kazakhstan, Poland, Saudi Arabia. According to British Corporation forecasts BP, NPP power generation will increase by 2050, but its dynamics will depend on many factors, and therefore the scenarios for the development of nuclear power will be different.<sup>2</sup> The International Energy Agency (IEA) also anticipates an increase in NPP electricity of 28–62% by 2040 and 50–100% by 2070.<sup>3</sup>

The share of nuclear energy in global primary energy consumption was 4.3% according to BP

<sup>1</sup> Official website. URL: <https://www.atomic-energy.ru/organizations/vsemirnaya-yadernaya-assotsiatsiya-wna>.

<sup>2</sup> Energy Outlook 2020. URL: <https://www.bp.com/en/global/corporate/energy-economics/energy-outlook.html>.

<sup>3</sup> World nuclear energy prospects are linked to climate objectives. URL: <https://www.eprussia.ru/news/base/2020/3962253.htm>.

data in 2019, in electricity generation — 10.4% (4.9 and 10.2% respectively according to the EU assessment).<sup>4</sup> According to the International Atomic Energy Agency (IAEA) published in 2019, the pessimistic scenario up to 2050 assumes a 6% reduction in NPP capacity worldwide and optimistically — 80% growth, particularly from developing countries..<sup>5</sup>

The development of world nuclear energy is constrained by its security concerns. French experts point out that “due to the secrecy of governments and companies owning nuclear power plants”, in some situations it’s difficult to determine the extent and consequences of a nuclear accident. They listed nine incidents involving operational nuclear reactors, the largest of these is the Chernobyl NPP accident (Ukraine, 1986), Three Mile Island NPP (the USA, 1979 г.) and Fukushima NPP (Japan, 2011).<sup>6</sup> The problem also concerns France. Thus, in 2017 in the north-west of this country there was an explosion at the Flamanville NPP, in which several people were injured. According to public authorities, there was no threat of radioactive material being released.

It is generally recognized that the development of global nuclear energy is also affected by the challenges of reducing human pressure on the environment. It is assumed that they can be solved by a transition to the so-called “green” economy. Therefore, the President of the World Economic Forum (WEF), K. Schwab in his book, co-written by French journalist T. Malleret “Covid-19: The Great Reset”, argued that “the green economy encompasses a range of opportunities, from greener energy to ecotourism and closed-loop economies”. Further this book notes that the European “green” deal

initiated by the European Commission (EC) — “this’s a major event and the most tangible manifestation of the government’s decision not to let the COVID-19 crisis go to waste”. For this purpose, is planned to allocate 1 trillion euros to reduce greenhouse gas emissions and invest in a circular economy to make Europe the first carbon-neutral continent by 2050 and “separate economic growth from resource use”. Given the fall in energy consumption during the coronavirus pandemic, K. Schwab and T. Malleret claim that it had a positive impact on the environment. Therefore, British Corporation BP reduced the value of its assets by 17.5 billion USD, concluding that COVID-19 “will accelerate the global shift to cleaner forms of energy”.<sup>[1]</sup>

The ideas of the “green” economy are actively promoted because, according to experts of the World Economic Forum (WEF), environmental risks are constantly increasing. His latest, 16th Global Risk Report in 2021, states that “they rank first in impact and probability alongside infectious diseases”.<sup>7</sup> In this regard, there is a lively debate in the global media about the role of nuclear energy in the world economy and the question is asked: to what extent does its development contribute to the protection of the environment? The IEA report 2019 noted that over the past 50 years, nuclear energy has reduced carbon dioxide emissions by about 60 Gt, which is roughly equivalent to the world total emissions for two years. It also states that without nuclear power these emissions would be about 20% higher.<sup>8</sup>

The EU currently contributes 8% to greenhouse gas emissions, compared to 29% in China and 15% in the USA<sup>9</sup> NPP accounts for about 30% of European Union electricity generation and about the same share of

<sup>4</sup> EU energy in figures (2020). URL: <https://op.europa.eu/en/publication-detail>.

<sup>5</sup> Energy, electricity and nuclear power estimates for the period up to 2050. 2019 edition. International atomic energy agency vienna, 2019. URL: [https://www-pub.iaea.org/MTCD/Publications/PDF/19-00521\\_web.pdf](https://www-pub.iaea.org/MTCD/Publications/PDF/19-00521_web.pdf).

<sup>6</sup> Le nucléaire en France en 2021: production, avantages et risques. URL: <https://selectra.info/energie/guides/comprendre/nucleaire>.

<sup>7</sup> Global Risks Report 2021. URL: <https://www.weforum.org/>.

<sup>8</sup> Nuclear Power in a Clean Energy System. Fuel report — May 2019. URL: <https://www.iea.org/reports/nuclear-power-in-a-clean-energy-system>.

<sup>9</sup> EU energy in figures (2020). URL: <https://op.europa.eu/en/publication-detail>.



renewable energy (RE). But after the Chernobyl accident (1986), Germany decided to stop building new nuclear power plants, so the last plant in this country was put into operation in 1989. In 2002, it had passed a law prohibiting the construction of new nuclear power plants and planned to close them down completely by 2022, so there was an urgent need to increase the use of either natural gas or hard coal in Germany.

These highly controversial assessments and actions are bound to affect the energy policy of the European Union, particularly of France. Although the IEA predicts that by 2040 approximately half of the EU nuclear capacity will be decommissioned, four reactors are being installed in three EU member countries (Finland, France and Slovakia). According to the World Nuclear Association, an additional eight EU countries are planning to build [2] which inevitably creates differences between them and Germany. However, the EU Summit in December 2019 recognized the right of EU countries to determine for themselves the list of types of energy they intend to use in national economies.<sup>10</sup> Therefore, according to the European Union's strategy "Clean Planet for All", approved in 2018, the share of nuclear energy in EU domestic energy consumption will be almost unchanged by 2050 (10–16%),<sup>11</sup> although IAEA predicts that it may decrease to 3.2–5.2%. The European "green" line adopted by the EC at the end of 2019 also doesn't provide for the exclusion of nuclear energy from energy consumption by 2050.<sup>12</sup> This is consistent with global trends. Thirty countries currently have NPP, but the number of States using nuclear energy is far greater. This exists because, for

example, countries such as Denmark and Italy that do not have nuclear facilities receive about 10% of their electricity from NPP located in other countries.<sup>13</sup> However, the anti-nuclear policies of Germany, Austria and Luxembourg resulted in the European Parliament removing nuclear energy from the list of "green" technologies in March 2019. But not all politicians and social organizations in the EU agreed to this decision.

In April 2021, a group of 46 non-governmental organizations (NGO) from 18 States sent a letter to the President of the European Commission, U. von der Leyen, requesting the inclusion of nuclear energy in the list of development priorities for the production of so-called "green" investment. In addition, in early April 2021, the EU's Joint Research Centre (JRC) presented a report on problematic aspects of nuclear power development. According to the centre's experts, "nuclear energy is no more harmful to human health or the environment than any other energy production technology that is considered sustainable (solar, wind, etc.)." It can therefore claim the status of a "green" technology. But the environmental representatives of Greenpeace strongly disagreed with these conclusions.[3]

Meanwhile, the French leadership has stated that it will fight for the recognition of nuclear power as a "green" technology in accordance with EU sustainable financing rules. French Minister of Economy Bruno Le Maire emphasized the "French determination" to get the right to "green" investments for nuclear power, and therefore final decision on this issue in the EU was never taken.<sup>14</sup> Thus, Paris has made it clear that it will become a champion of nuclear energy at the pan-European level and will continue to use it. As a result, Germany is rather negative about French attempts to finance its nuclear program with EU funds,

<sup>10</sup> EU summit December 2019. URL: <https://www.consilium.europa.eu/en/meetings/euro-summit/2019/12/13/>.

<sup>11</sup> 8/11/2018 — COM (2018) 773 — A Clean Planet for all — A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy. URL: [https://ec.europa.eu/clima/policies/strategies/2050\\_en](https://ec.europa.eu/clima/policies/strategies/2050_en).

<sup>12</sup> A European Green Deal. Striving to be the first climate-neutral continent. URL: [https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal\\_en](https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en).

<sup>13</sup> Situation de l'énergie nucléaire dans le monde. URL: <https://energie-nucleaire.net/situation>.

<sup>14</sup> The EU decision on the "greenness" of nuclear and gas power is postponed. URL: <https://regnum.ru/news/polit/3245597.html>.



and the nuclear issue create a profound crisis between the two countries. However, Paris's position is understandable: at the beginning of 2021 in France, nuclear power accounted for more than 70% of electricity generation, in Germany, before the accident at the Fukushima NPP — only 25%, and now about 12%.<sup>15</sup> But this provision enables Paris to exert pressure on Germany through other energy projects.

Dr. Yunus Furuncu, energy expert of the Turkish Foundation for Political, Economic and Social Research (SETA), noted that France does not have a clear position on the project “Nord Stream — 2”: “French energy company Engie is also involved in this project. France considers the “Nord Stream — 2” as a tool it can use in its relations with Germany”. Then he noticed: “When we look at France's energy consumption, we see that it uses more nuclear energy. France, like Germany, will have to satisfy natural gas energy needs that will arise if the NPP closes. France, on the other hand, does not have a policy of closing the NPP. Stopping the “Nord Stream — 2” project will mean punishing not only Russia, but Germany as well”. [4]. Thus, Paris is trying to make the most of its unilateral dependence on nuclear power to strengthen its position in the EU. It is understandable that this dependence has been a long-term one and is due to very objective circumstances.

### HISTORY OF NUCLEAR POWER IN FRANCE

Immediately after the end of World War II in 1945, General Ch. de Gaulle established the Atomic Energy Commission (CEA) to investigate the use of atomic energy in France for both military and civilian purposes. This commissariat exists to the present time, and since 2010 has received the prefix “and on alternative forms of energy”. It is responsible for the development and implementation of all nuclear-related research and development

programmers, which include power generation, defense, medicine, radiation protection, safety, etc. As for the French civil sector, Ch. de Gaulle planned to create a fully independent national nuclear power plant, as it held the view widely known in France that economic sovereignty is priceless.

The first nuclear reactors appeared in this country in the middle of the last century around the same time as in the United States and the Soviet Union. In 1956, the first nuclear reactor with a capacity of only 2 MW, which operated until 1968, was commissioned in south-eastern France at Marcoule. Two other 40 MW experimental reactors were commissioned in 1958 and 1960 (they worked until 1980 and 1984 respectively). Until the early 1970s, eight more nuclear power plants were built, and in 1973, nuclear power accounted for about 8% of France's electricity generation.<sup>16</sup>

In response to the oil crisis of the early 1970s “France decided to switch to nuclear power on a massive scale and began an ambitious NPP program”,<sup>17</sup> to make France an independent energy power. For this, the Prime Minister of France, P. Messmer, had drawn up a plan of action for the construction of nuclear reactors, which had been approved by Parliament in March 1974. It envisaged the commissioning of 44 NPP with a total capacity of 50 000 MW by 1980. However, 40 of them, at the insistence of President G. Pompidou, were to be licensed by the leading American corporation Westinghouse, and only 4 were to be created for French projects. A total of 170 NPP were planned to be built in the country by 2000, but France had to import 100% of the uranium for further enrichment.[5]

Currently, most French nuclear reactors are licensed by the Westinghouse Corporation, but when France received it from the United States,

<sup>15</sup> The end of nuclear power in Germany. URL: <https://islam.kz/ru/news/v-mire>.

<sup>16</sup> Histoire de l'électronucléaire en France. URL: .

<sup>17</sup> Nuclear energy in France. Embassy of France in Moscow. URL: <https://ru.ambafrance.org/Atomnaya-energetika-vo-Franci>.



the NPP project was renamed in FRAMATOME (France-America-Atom). As the USA has increased the lifetime of its nuclear power plant from 40 to 60 years and plans to extend it even to 80 years, accordingly, France is now also extending their working time.[6]

The political decision on the development of nuclear energy taken by the country's authorities was based on the fact that France possessed highly skilled engineering personnel and appropriate technologies, but had no unlimited access to energy resources like the USA in the Middle East. Since the State had strict control over the design and construction of the NPP, France was able, in the opinion of the vast majority of experts, to create an efficient nuclear power plant. All reactors operating in the country are water-only, with only three operating models and only one type of reactor at each NPP.

In 1999, discussions in the French Parliament identified three main directions of French energy policy: ensure security of supply (since the country imported more than half of the energy consumed in some years); establish a system for environmental protection and reduction of greenhouse gas emissions; manage radioactive waste. The dominant view was that natural gas had no economic advantage over nuclear power, and its prices are very volatile and depend on the world energy market. It has become generally accepted that, despite the "intensive efforts", such an increase in renewable energy (RE) is not expected in the near future and such energy-saving measures are not expected to be introduced, that could completely replace nuclear energy.<sup>18</sup>

Given the high profile of the American NPP accident in Three Mile Island in 1979, in parallel with the development of nuclear power in France, an anti-nuclear movement has emerged and spread. It began to take shape in

the late 1970s, i.e. a few years after the President of V. Giscard d'Estaing declared the need to accelerate the transition to nuclear power. One of the first successes of this movement was the so-called "Plogoff case", named after a small village in Breton (Plogoff), whose inhabitants managed in 1981 to abort the project of building the NPP.

It should be noted that the debate on the future of nuclear power is still rife in French society. For example, according to the influential newspaper "Figaro", in 2018, 53% of French respondents opposed nuclear power generation.<sup>19</sup>

### CHARACTERISTICS OF THE FRENCH NUCLEAR INDUSTRY

According to the World Nuclear Association, in January 2021 France had a total of 56 nuclear reactors capable of generating 61 370 MW of total capacity and one reactor under construction. In addition, 14 reactors were dismantled. The country remains the world's "nuclear one" with approximately 70% of total electricity generated by nuclear power generation.<sup>20</sup>

Since the 1980s, no new nuclear power plants have been built in France, primarily for political reasons, so that the average life expectancy is already 30.5 years. 15 reactors have been in operation for 35 years. Proponents of the development of nuclear energy point out, as a positive example, that 97% of the electricity generated in the country, thanks to NPP and hydropower, is not related to greenhouse gas emissions. Therefore, France has one of the lowest per capita rates in the world. In addition, nuclear power plants provide, unlike RE with their so-called "ragged" rhythm of work, permanent and stable electricity production. This enables industry to technological processes

<sup>18</sup> L'énergie nucléaire en France. URL: <https://energie-nucleaire.net/situation/energie-nucleaire-france>.

<sup>19</sup> 53% des Français opposés à l'énergie nucléaire. URL: <https://www.lefigaro.fr/flash-actu/2018/10/25/.php>.

<sup>20</sup> Nuclear Power in France. URL: <https://www.world-nuclear.org/information-library.aspx>.

more efficiently and don't create energy storage tanks as required for hydrocarbons.

French experts consider that, as a result of this decision, their country now enjoys a high level of energy independence and has the lowest electricity cost in Europe. That is why in France, which is often criticized for the “peaceful atom”, the cost of kilowatt-hour of electricity (16.9 cents) is almost half that of Germany (31.47 cents). That is, if we compare prices, the cost of kilowatt electricity in the nuclear industry is much lower than that of wind, biofuels and solar panels.[7]

Nevertheless, as mentioned above, in the EU there has been a steady trend in recent years towards the phase-out of nuclear energy in favour of RE, which in turn prevents the development of full-scale scientific research in this field and the transition to the construction of new generation reactors. However, as many experts note, the price of electricity produced by nuclear power plants is artificially low, as the lifetime of reactors is continuously extended. Accordingly, the price will increase continuously to ensure future funding for dismantling and commissioning.[6] Moreover, since nuclear reactors in France are over 30 years old, the equipment for their unintended operation needs to be changed more frequently, thus increasing the cost of electricity generation. Referring to the fact that the nuclear reactors in France had been operated safely for almost two thirds of their operating life, the Ministry of Energy and Sustainable Development extended the lifetime of the NPP by 10 years by a decision dated 28 February 2016.[8] Since nuclear power in France has developed on the initiative and with the help of the State, it has so far strictly regulated and controlled the design and construction of NPP.

In addition to the Commissariat for Nuclear Power and Alternative Energy, the Agency of Safety Nuclear (ASN) holds a key position among the public actors in the nuclear industry. It's a State institution that controls all activities in the field of civil nuclear energy,

including — nuclear safety, radiation protection and informing citizens of the situation in this field, especially in emergency situations. The Agency participates in the development of the regulatory framework for the nuclear industry and advises on draft decrees, circulars, directives and resolutions of the Government. Since 2006, the agency has operated independently of the Government, although it is subordinate to the Ministry of Environment and Energy Transition.

Less well known, even in France itself, another structure is the Radioactive Waste Management Agency (ANDRA), founded in 1991.<sup>21</sup> It is a non-profit organization under the joint supervision of the three Ministries of Industry, Environment and Research. Its creation was prompted by the development of the anti-nuclear movement and public concern about the fate of radioactive waste.

Since the market economy operates on a corporate basis, the State has decided to establish large enterprises in the nuclear industry that could compete successfully in the world's nuclear market. The most important power generating company and the world's largest NPP operator in France was EDF (Électricité de France), 85% of whose shares belong to the state. It is the customer and operator of all nuclear power stations in the country and 20 NPP outside the country. Thus, EDF is both a producer and a supplier of electricity, and in the field of nuclear power is in an exceptional position.<sup>22</sup> In doing so, this not only controls French nuclear plants, but also their monopoly owner.[9] EDF is also actively offering services to other countries to decommission nuclear facilities and dispose of spent nuclear waste. To this end, this and Veolia have formed a joint venture between Graphitech for the dismantling of graphite reactors, which

<sup>21</sup> Le nucléaire en France en 2021: production, avantages et risqué. URL: <https://selectra.info/energie/guides/comprendre/nucleaire>.

<sup>22</sup> Présentation de la société ELECTRICITE DE FRANCE (E.D.F.). URL: <https://www.societe.com/societe/electricite-de-france-552081317.html>.



operates not only in France but also in other EU countries and Japan.

In recent years, the French media have witnessed an increase in critical material about EDF activities. It is justifiably accused of having incurred millions of dollars in over-expenditure on various projects that are then covered by the country's budget. After 2008, the profitability of EDF declined significantly, was unable to pay bank debts and underwent a number of significant restructurings, with massive layoffs. In addition, the company experienced technological difficulties due to the longer construction time of the NPP and increased construction costs, and the problems of radioactive waste disposal and dismantling. [10] All these difficulties inevitably lead to an increase in the cost of nuclear energy.

The second major company in the French nuclear industry, Areva, renamed Orano in 2018, is a multinational nuclear corporation. In addition to French, its shareholders include American and German companies. It was organized in 2001 by merging three French companies — Framatome, Cogema and Technicatome. They were formerly subordinate to the Atomic Energy Commissariat, and are therefore now the main shareholders of Orano. Thus, one of the world's largest vertically integrated energy holdings was created, the development strategy of which is aimed at further accumulation of all competencies and technologies of nuclear business. Orano (Areva) — is the only Western corporation that engages in all activities related to the production of nuclear energy.

The weakness of France's nuclear power industry is that, unlike Russia, it does not have uranium deposits on its territory and therefore all uranium is imported from abroad. There it is extracted from Orano (Areva) wholly or partly controlled enterprises, the main ones being Kazakhstan, Canada and Nigeria.[9] Uranium is also imported from Australia and Russia (mainly under long-term contracts) and enriched only

within the country. But this industrial company, like EDF, has serious problems: Orano (Areva) for a long time cannot finish the construction of the third power plant Olkiluoto in Finland, which started in 2005. A 10-year delay in the construction schedule and the high cost, which was three times greater than the 3.2 billion euros stipulated in the original contract [11], severely damaged the company's image. It's expected that the next generation reactor (1 600 MW) with the largest capacity in the EU will not be operational until February 2022.

Human resources are another major problem for all French nuclear power. In 2020, the sector had 220 thousand jobs in more than 2 600 companies, including small and medium-sized enterprises. These jobs are held by more skilled workers than the average for French industry. However, there is a loss of skills in the industry in many areas and a lack of quality control at all stages of design and construction involving suppliers is observed.<sup>23</sup> But, as many French experts rightly point out, there is no shortage of managers and financiers, but there is a shortage of engineers and scientists.

Thus, France's nuclear power industry, apart from its clear positive aspects, also has negative effects whose negative effects increase over time (see *table*).

Many analysts and politicians warn, that France needs to prepare for a long period of modernization of the nuclear industry, since outdated infrastructure and a decline in the skills of its personnel have led to an increasing number of violations of the operation of the NPP during inspections. However, monitoring identifies new problems related to technology violations in the manufacture of equipment. In particular, the high carbon content of steel parts supplied to nuclear plants has been found, resulting in their premature failure. In recent years, the total number of violations of NPP

<sup>23</sup> Comment l'industrie nucléaire française peut-elle rester à la pointe de l'excellence? URL: <https://www.capgemini.com>.



Table

**Advantages and disadvantages of nuclear power in France**

Advantages	Disadvantages
<ol style="list-style-type: none"> <li>1. Ensures the country's energy independence.</li> <li>2. Sufficient to satisfy the needs of the population.</li> <li>3. Does not emit greenhouse gases</li> </ol>	<ol style="list-style-type: none"> <li>1. Complexity of nuclear waste management.</li> <li>2. The growing problem of nuclear safety.</li> <li>3. Limited uranium reserves.</li> <li>4. High cost of NPP.</li> </ol>

Source: Le nucléaire en France en 2021: production, avantages et risqué. URL: <https://selectra.info/energie/guides/comprendre/nucleaire>.

rules during the inspection period has increased from 33 to 83. On one Flamanville NPP the number of violations increased from 2 to 20 during inspections.<sup>24</sup> This is largely due to the fact that all nuclear power plants in the country were built using the same type of pressure water reactor (PWR). This standardization, on the one hand, has facilitated the rapid and efficient construction of a large number of reactors. But, on the other hand, given their age, it increases the risks of operation, as technical problems detected at one NPP could potentially affect other power plants. This requires continuous and large-scale inspections of reactor safety.<sup>25</sup>

In addition, with the development of digital energy, new threats — cyberattacks — have emerged. For example, in January 2003 in the United States a “viral worm” penetrated the NPP’s corporate network in Ohio. In September 2010, about 30 thousand computer systems of industrial facilities in Iran were infected with a virus, which led to the shutdown of more than 1 300 centrifuges for uranium enrichment and the postponement of the launch date of Bushehr NPP. The Iranian authorities accused them of hacking into US intelligence networks. Cyberattacks were carried out at NPP in South Korea in 2014 and Germany in 2016.[12]

Discussions on the need to reduce nuclear energy in the energy balance of the country

resumed in 2011 under the President F. Hollande after the accident at the Fukushima NPP.<sup>26</sup> France announced a 25% reduction in the share of nuclear power (from 75 to 50%) by 2025, with an estimated 22 nuclear power plants to be shut down by that date. This goal has now been rescheduled for 2035 and the “Energy transition for green growth” bill was finally approved by the National Assembly in July 2016. Thus, France’s energy policy has to take into account the EU’s requirements.

The first reactor at the oldest French Fessenheim NPP was shut down in February 2020, and its second reactor was shut down in June 2020. But unlike Germany, France has not yet reduced the share of nuclear power plants in energy consumption and has no specific road map for their closure.[5]

France’s recent decision to resume construction of the NPP came as a complete surprise to the EU. At the end of 2020, the French Government, on its own, without informing any of its European partners, commissioned EDF to prepare a project for the commissioning of six new-generation nuclear reactors in 2021. The deadline was later extended by two years. President E. Macron considers nuclear energy as a guarantee of the country’s sovereignty and believes that France should develop it further on the basis of new technologies. There is every reason to do so. Thanks to the NPP, France is an

<sup>24</sup> France’s Atomic Crisis: Why the French Massively Shut Down Reactors. URL: <http://новости-мира.ru-an.info/>.

<sup>25</sup> The future of France’s nuclear power industry. URL: <https://www.el-info.ru/budushhee-atomnoj-energetiki-francii/>.

<sup>26</sup> Le nucléaire en France en 2021: production, avantages et risqué. URL: <https://selectra.info/energie/guides/comprendre/nucleaire>.



exporter of electricity, supplying in particular neighboring Germany and Spain. As the Russian expert D. Kosyakov rightly points out, “anti-nuclear” course of these states is based on French NPP. In addition, the supply of electricity to the EU brings France about 3 billion euros per year and is one of the main profitable exports. [10] So, the value of France’s electricity group exports in 2019 was 3 billion dollars and imports amounted to 776 million dollars.<sup>27</sup>

In general, as French analysts have noted, France has taken a significant share in international markets for nuclear supplies to foreign countries, exporting of goods and technology 5–10 times more than the French average.<sup>28</sup> At present, France is supplying its nuclear technology to China, Finland, South Africa, South Korea and the United Kingdom, with the intention of building a NPP in Vietnam.

France pays particular attention to China, since the first nuclear power plants in that country (1986 and 1987) were built using French technology. But the construction of NPP Taishan was delayed by AREVA [9], and its two new generation power units were put into operation in 2018 and 2019, i.e. later than the planned dates.

### INNOVATION IN FRENCH NUCLEAR ENERGY

After the end of the World War II, France began its own nuclear energy research and development, and therefore now possesses its own technologies for the design and construction of reactors, nuclear fuel enrichment and radioactive waste management. Such a strategy is very similar to Russia’s nuclear industry development strategy. It was this similarity that led to the signing in July

2019 of a plan for cooperation in the peaceful use of atomic energy between the State Corporation “Rosatom” and the Commissariat for Atomic Energy and Alternative Sources of Energy of France. The Parties fixed their intention to cooperate in the field of renewable energy, the construction and operation of NPP, the digitization of energy resources and other areas.

Hinders innovation in the French nuclear industry, according to experts, the absence of a national nuclear energy strategy, which should include a mandatory lifetime extension of all existing nuclear power plants to 2030. Given that the construction period of the reactor is 7–8 years, the construction sites should be operational by 2022. [13] The absence of such a strategy is due to fluctuations in the country’s energy policy as a result of diametrically opposed approaches to the future of nuclear power. It is true that nuclear energy is considered environmentally friendly in terms of greenhouse gas emissions, but also dirty in terms of nuclear waste. Proponents of its development believe that the main challenge — is to ensure a rapid transition from obsolete second-generation reactors to safer third- and even fourth-generation reactors.

Despite the complexities of the nuclear industry, France is building a third-generation EPR reactor. It’s a new European pressure reactor or “european pressurized reactor” (hence the acronym EPR). This project was developed by Orano (Areva) in the 1990s and 2000s, but the construction of these reactors in France and Finland faced technological problems. For example, the initial construction of the third EPR power unit at the Channel la Manche in Flamanville was a joint German-French project, but since Germany’s withdrawal, the reactor has not been built yet, and its cost has already exceeded 12 billion euros. In 2019, EDF corporation officially announced that construction would not be completed until late

<sup>27</sup> France | Imports and Exports | The World | Electricity | Value (USD) and Price change, years (%) | 2008–2019. URL: <https://trendeconomy.ru/data/h2/France/271600>.

<sup>28</sup> Comment l’industrie nucléaire française peut-elle rester à la pointe de l’excellence? URL: <https://www.capgemini.com/fr-fr/ressources/comment-lindustrie-nucleaire-francaise-peut-elle-rester-a-la-pointe-de-lexcellence/>.

2022.<sup>29</sup> Consequently, the cost of the reactor will increase even further — according to the Court of Accounts of France it will be 19.4 billion euros. Meanwhile, as mentioned above, the first such reactor was put into operation at the Chinese NPP Taishan at the end of 2018. At the same time, Orano (Areva) originally intended to build them outside France in order to gain the necessary experience to enable it to move immediately to the construction of units of the fourth generation. Although the initial objectives of the new generation of reactors were to achieve a high level of safety and cost-effectiveness of the NPP, their construction was not a success in Finland, and in France itself. The period from the beginning to the end of the works was estimated at 4.5 years, but was actually more than twice as long. However, the third EPR project in Europe was launched in the UK in Hinckley-Point in 2018.<sup>30</sup>

France has now decided to develop fourth-generation reactors. Research focuses on three main areas: build fast neutron reactors with sodium heat carrier; development of fast gas-cooled reactors; establishment of high-temperature gas-cooled reactors. However, the first two tracks are in competition with each other, as it is possible to compare their performance, which would allow a final choice between them.[9] And although France has gained considerable experience in the construction of fast neutron reactors called “Phoenix” (1973–2010) and “Superphoenix” (1885–1998), it was not enough. These power plants suffered a number of accidents and were therefore closed.

By comparison: fast neutron reactors commissioned in Russia are generally considered to be much safer. At Beloyarsk NPP the first such reactor works since 1981, the second — since 2016. Construction of the

third reactor is scheduled to begin in 2025. Among their unquestionable merits are the fact that they do not emit greenhouse gases into the atmosphere and “allow materials such as uranium-238 and thorium-232 to enter the fuel cycle. In this way, they can dispose of the most hazardous waste in spent nuclear fuel”. [7]

But the most promising direction in the development of nuclear power is considered to be the creation of a controlled thermonuclear reaction. The reactors to be built on this basis would be much safer from radiation. Since the problem has proved to be very costly, the major nuclear countries have joined forces to address it. France, however, has made its territory available for the realization of this idea.

To this end, a site for the construction of an international experimental nuclear reactor was identified in the south in 2005 (ITER project) — Cadarache Nuclear Research Centre. In 2007, ITER was established, and 35 countries, including Russia, began cooperation to develop this world’s largest nuclear device. It is created to prove the possibility of thermonuclear fusion as a large-scale, carbon-free source of energy based on the same principle as stellar radiation.<sup>31</sup> The practical challenge is to gain experience in the design and operation of future fusion plants.

The total cost of the project is estimated at more than 20 billion euros, which automatically places ITER at the top value of all scientific installations. Between 2020 and 2022 alone, Russia allocated some 12 billion rub.<sup>32</sup> In June 2016, the ITER Board of Directors announced that the initial completion forecasts had not been confirmed, and therefore December 2025 is the most realistic date. In November 2016, he announced that “Deuterium-tritium fusion experiments”, i.e.

<sup>29</sup> Snag-hit new French nuclear power station delayed by further 3 years. URL: <https://news.yahoo.com>.

<sup>30</sup> Le nucléaire en France en 2021: production, avantages et risqué. URL: <https://selectra.info/energie/guides/comprendre/nucleaire>.

<sup>31</sup> ITER — The Grand Project of Modernity. URL: <https://pikabu.ru/story/ityer>.

<sup>32</sup> Figure of day: how much will Russia spend on an international fusion reactor? URL: <https://news.rambler.ru/asia/42895661>.



on the creation of a basic nuclear reaction within a controlled fusion, would begin in 2035.<sup>33</sup>

Delays in the completion of the reactor are due to both organizational and technological difficulties. A number of countries have repeatedly violated their delivery schedules, resulting in the continued postponement of the reactor launch. However, in July 2020, the ITER project officially moved from the construction phase to the assembly phase of the reactor.

According to expert estimates, in an optimistic scenario, the first thermonuclear plants will be available by 2050 and humanity will receive an almost unlimited source of energy.<sup>34</sup> France, which, despite the objective difficulties of the development of the nuclear industry, has never stopped working to improve its nuclear technology, will certainly be a credit for this.

## CONCLUSION

To sum up, we can state with confidence that France's nuclear power will continue to dominate its fuel energy complex. The country has significant experience in the design, operation and safety of existing NPP, and that allows it, along with the USA, Russia, and China, to occupy one of the leading positions in the world's nuclear market. The construction on its territory of an international experimental nuclear reactor (ITER Project) to

achieve thermonuclear fusion as a large-scale, carbon-free energy source supports this thesis.

At the same time, there are many problems in the country's nuclear power industry, the main one being the technological gap with the USA and Russia, as a result, the installation of new nuclear power plants is delayed and the cost of their construction is increased, not only in the country but also abroad. In addition, the absence of a national strategy for the development of the nuclear industry prevents the French leadership from consistently defending its interests in the European Union, which advocates the gradual decommissioning of existing NPP. At the same time, Paris often makes contradictory and mutually exclusive decisions on these issues, which in general hamper the innovative development of national nuclear power.

Given these factors, it is essential for France to establish full-fledged cooperation with Russia, since the nuclear industries of the two countries share similar characteristics and have a central role for the State in their operation. Signed in July 2019, the plan of cooperation in the field of the peaceful use of atomic energy between the State Corporation "Rosatom" and the Commissariat for Atomic Energy and Alternative Sources of Energy of France gives us hope that its implementation would bring benefits to both parties. There is no doubt that the development of cooperation in this area between Russia and France will make it possible to accelerate the development and introduction of new nuclear technologies, which in turn will help to solve many of the problems of development of national economies.

<sup>33</sup> L'énergie nucléaire en France. URL: <https://energie-nucleaire.net/situation/energie-nucleaire-france>.

<sup>34</sup> When will the thermonuclear power plants be available? URL: <http://www.sib-science.info/ru/institutes/energiya-31082016>.

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