TRANSFER OF INNOVATION TECHNOLOGIES AS A FACTOR OF THE WORLD NUCLEAR POWER INDUSTRY DEVELOPMENT

Mihail Nikolaevich Dudin*, Evgenia Evgenevna Frolova**, Julia Alexandrovna Artemieva, Natalia Vladimirovna Ivanovskaya, Elena Vitalievna Sitkareva*,

Abstract: *This article is devoted to studying the experience of the technological transfer in the nuclear power industry through the example of three countries: France, China and South Korea. The main goal of this article is to find the key regularities that provided these countries with the technological breakthrough in the area of reclaiming the potential of the "peaceful atom." The following basic conclusions have been made within researching the theme of the article: ● The nuclear power industry can be considered as an objective alternative of the traditional (hydrocarbon) power industry if technologies of exploiting nuclear power stations constantly develop and can be characterized by safety and stability of exploitation, ● Technological transfer is a key factor of the nuclear power industry development. The use of the technological transfer allows the recipient countries to quickly develop the infrastructure of the nuclear power industry and form their own scientific engineering potential, and the delivering countries get direct economic advantages, ● The experience of South Korea, China and France showed that the most optimal approach to the nuclear power industry development on the basis of technological transfer is based on subsequent use of two strategies. Initially the transfer strategy is used. Within it the recipient country uses foreign scientific engineering and technological achievements, and along with it creates its own production and scientific engineering infrastructure, and ● The accumulation strategy allows the countries that used to be recipients to develop their own nuclear technologies on the basis of the accumulated experience and to clone them abroad (in those countries that have not created their own nuclear power industry by now).*

Keywords: *atom, atomic power, nuclear power station, technological transfer, transfer strategy, accumulation strategy, nuclear power, China, France, South Korea.*

* Russian Presidential Academy of National Economy and Public Administration (RANEPA), 82, Vernadsky prosp., Moscow, 119571, Russian Federation.

** Far Eastern Federal University, 8, Suhanov Str., Vladivostok, 690950, Russian Federation

*** People's Friendship University of Russia (RUDN University) 6, Miklouho-Maclay Str., Moscow, 117198, Russian Federation

1. INTRODUCTION

The world nuclear power industry is one of the youngest technologies. Its history is slightly over 60 years. Measuring the power industry of our civilization, it can be considered as "a historical moment." However, even in this historical interval it is possible to observe essential changes, in particular [1, 2]:

- The countries that were the first to use atomic power for peaceful purposes leave this segment of the world power market (these countries may include Italy and Germany),
- The countries that only over the latest 15-25 years have started to actively use the nuclear power to meet the relevant needs of the economy and social sector show the priority development rates in this area.

The brightest examples are China and Korea. These countries managed to create their own nuclear power industry on the basis of the long-term and universal programs related to the transfer of foreign technologies and so called localization [3, 4]. In this case it is necessary to interpret localization as production of equipment and supply of services (on designing, constructing, etc.) at national enterprises of the country implementing the project on constructing the nuclear power station, as well as training local personnel and designer supervision [5].

There is also less known but thereby more interesting experience of France in this area. Thus, for example, at the initial stages of its formation and developing the AREVA French Company (the world giant, supplier of technologies for the whole life cycle of nuclear power stations) also used the advantages of the foreign technologies transfer [6].

What is in common in these three countries (China, South Korean, and France)? When programs related to nuclear technologies transfer started, the governments of these countries had an urgent task to increase their own energy security (all three countries were essentially at the height of national economic and energy crises). The accelerated development of the electrical energy industry was required. Along with this (subject to non-availability of the sufficient amount of internal hydrocarbon resources), expanding the park of power stations working on the traditional fuel could not solve the problems every country had at that time. All three countries chose to development the nuclear power industry as the one that complies with the criteria of stable development and national energy independence [7, 8].

The decision on the national power policy in the above countries was taken at the end of the 60s of the previous century when light-water nuclear power stations proved their competitiveness as civil power technologies both in the USSR and the USA. In order to save financial resources and time, three countries under consideration (South Korea, China, and France) chose the way of the technologies transfer because from the very beginning there was a task to construct a large park of nuclear power stations. Consequently, in order to achieve full technological independence in the future, they acknowledged that it was necessary to develop their own industries of nuclear technologies. These are all available essential prerequisites for the transfer and localization in the area of nuclear power technologies. That is why it will be correct to consider French, Chinese and South Korean experience of using technological transfer in the nuclear power industry.

Methodology. In this article the aggregate of scientific methods was used. In particular, methods of economic and statistical analysis were applied. The analysis allowed to reveal the peculiarities of the nuclear power industry development in the countries considered in the article (France and South Korea). Besides, methods of content analysis were used. They allowed to generalize the regularities and peculiarities of the formation and developing of the nuclear power industries in all three countries under consideration, as well as to define the role of technological transfer in this development. The obtained data allowed to conclude that the technological transfer provided the breakthrough in the area of using atomic power in all three countries. Each of three countries under consideration used its approach to organize the technological transfer. However, herewith, the most essential results can be obtained only when initially the strategy of technologies transfer from more developed countries to the recipient countries is used, and in the future the recipient countries start accumulating their own scientific engineering and technological base to develop nuclear power industry.

Results. The French experience of the peaceful atom is interesting by the critical role played in it by the transfer of technologies of the USA. The French power policy of the recent sixty years is characterized by stiff centralized approach and a great role of the government in its formation and implementation. During the times of the Charles de Gaulle government (1959-1969) nuclear technologies (civil and military) became a synonym of the independence of France. Historically the development of the French nuclear industry can be divided into four stages [9]:

1. Development of its own technologies related to developing nuclear power stations (1952–1969),

2. Transfer to the American license of light-water nuclear power stations (1969–1974),
3. Adaptation of the American technology and development of its own project on the technology basis (1974–1981), and
4. Development of its own projects of nuclear power stations and their serial construction in France and abroad (since 1981 – up to now).

At the present time all French operating nuclear power stations have three standard capacities (power): 900 MW, 1,300 MW, and 1,450 MW. This is one of the highest degrees of the technological standardization that exist in the world.

Proceeding to the research of the South Korean experience, it is necessary to note that in the post-war years, being extensively supported by the USA, the South Korean economy experienced explosive growth. Since the end of the 1950s Korea worked at the recipe of the "Korean economic miracle": tough planning (based on 5 years' plans), state support for industrialization, involvement of foreign investments and technologies. The rapidly increasing economy suffered great power hunger that was satisfied by the imported hydrocarbons and timber (Table 1).

Table 1.
Consumption of Primary Power in South Korea (thous. tons of oil equivalent) [10]

Year	*Total*	*Nuclear power*	*Coal*	*Petrol*	*Natural compressed gas*	*Water power*	*Other*
1968	15,820	-	5,407	5,507	-	232	4,674
1978	38,087	581	9,893	24,123	-	452	3,038
1990	93,192	13,222	24,385	50,175	3,023	1,590	797
1999	181,363	25,766	38,155	97,270	16,849	1,517	1,806

The latter energy resource was used so brutally that by the end of the 1950s Korean forests had merely disappeared. The history of the formation and developing of the nuclear power industry in South Korea can be divided into four stages [10]:

Full dependence, attempts to individually develop heavy-water technologies of nuclear power stations (late 1960s – mid-1970s),

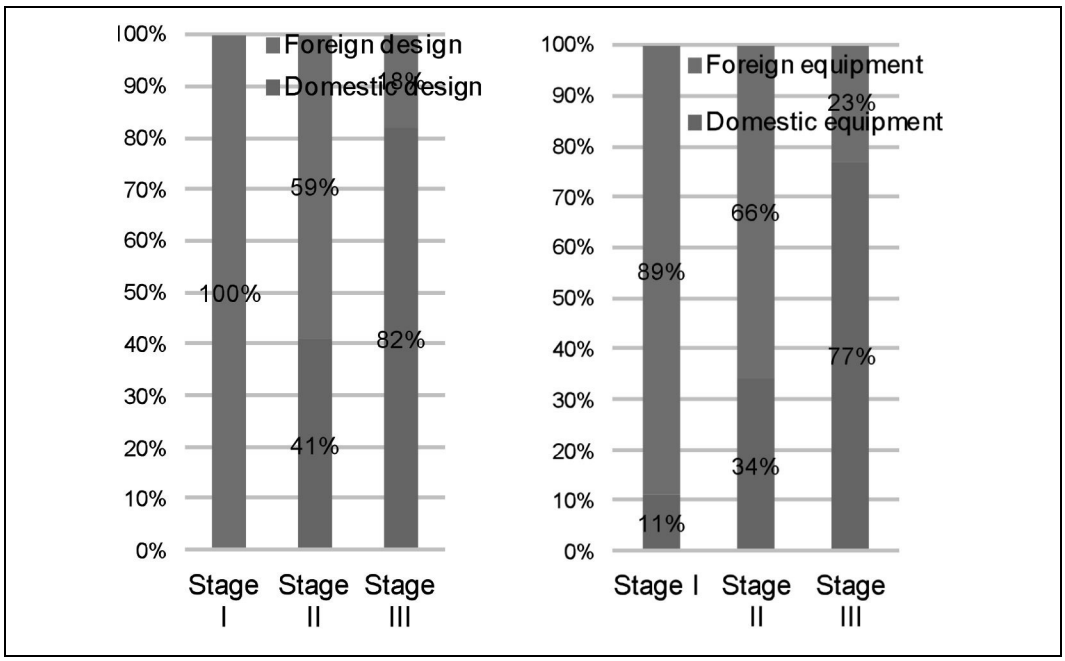
Construction of commercial light-water nuclear power stations under the dominating role of foreign suppliers (mid-1970s – early 1980s);

Development of self-sufficiency, expanding of works on the transfer and localization of foreign technologies (mid-1980s – late 1990s), and

Beginning of the export program, gradual withdrawal from the dependence on foreign licensors (since 2000 up to now).

As a result, by the beginning of the 2000s South Korea had achieved technological self-sufficiency in the nuclear power industry (Fig. 1).

Figure 1: Stages of Transfer and Localization of Foreign Technologies in the Nuclear Power of South Korea [10].



Having achieved self-sufficiency, in 30 years after the launch of the first Korean nuclear power station and in 20 years after the beginning of the nuclear power technologies transfer, South Korea started exporting such technologies itself. In December, 2009 after the long preparation South Korea and the United Arabic Emirates concluded an agreement about strategic partnership that stipulated their cooperation in the area of nuclear power.

In December 27, 2009 the consortium guided by the KEPCO Company (Korea Electric Power Corporation) won the tender for constructing a nuclear power station in the Arabic Emirates with the South Korean project APR-1400. Korean nuclear experts are also responsible for exploiting the nuclear power station. The consortium consists of

- KHNP company (construction, contraction, and exploitation),
- KEPCO company (design),
- Hyundai/Samsung company (construction),
- Korea Plant Service and Engineering company (repair and maintenance) and Korea Nuclear Fuel company (fabrication of nuclear fuel),
- Doosan Heavy Industries company (supply of the turbine equipment), and
- WESTINGHOUSE company that maintains definite positions in the Korean industry, and that is why it got orders in the area of the control and management systems.

After considering the Korean experience, let's turn to China. The Chinese experience of the transfer and localization of foreign technologies in the area of nuclear power industry is interesting due to its scale and diversification strategy. China strives to get access to all existing nuclear technologies. It became the basis of its scientific engineering and industrial policy. The history of the transfer of foreign technologies to China can be conditionally divided into three stages [11]:

1. Transfer of military technologies, above all, Soviet ones (mid-1950s – mid-1960s)
2. Era of the peaceful atom with the concentrated localization of all foreign technologies of nuclear power stations (early 1970s up to now), and
3. Cloning and export access (early 1990s up to now).

At the present time Pakistan implemented two Chinese export projects of nuclear power stations with the capacity of 300 MW put into operation in 2000 and in 2011. Works related to two blocks with the capacity of 1,000 MW are being performed. The announced plans of the Chinese companies include projects of nuclear power stations in Argentina, Romania, South African Republic, etc.

Foreign companies make an attempt to defend themselves from "Chinese cloning" by limiting the territory of using technologies. That is why agreements on using its intellectual property are concluded only on the territory of the PRC. However, along with this, it is possible to state that the Chinese experience of implementing projects in the area of nuclear power is the most successful one. Chinese nuclear experts actively promote projects under their own brands and trademarks in the whole world financially supported by the PCR and relatively low prices. Under such powerful

internal market and export ambitions, China can implement the most large-scale serial construction of nuclear power stations and increase the competitiveness of its technologies even more.

Discussion. Considering the experience of France, South Korea and China within forming the national nuclear power industry, it is necessary to pay more attention to the key stages of development that were mentioned in the previous part of this article. Thus, if one considers the French experience, it is primarily necessary to mention that it is in the 1950s when France developed its own projects of nuclear power stations with gas-graphite reactors. By the end of 1960s it became obvious that French projects of reactors could not compete with light-water reactors that had been already used in the USSR and the USA. Further use of uncompetitive reactors would have caused unjustified expenditures, technological isolation, and full loss of export markets of nuclear technologies.

Under these conditions in 1969 France took the revolutionary decision to restructure the national nuclear industry and transfer to light-water reactors according to the American license [12].

The decision about reconsidering the technical policy of the French nuclear power industry was taken on the basis of economic estimation: the use of American license happened to be cheaper than using industrial nuclear power stations based on national gas-graphite reactors with the capacity of 1,000 MW. The FRAMATOME (Franco-Américaine de Constructions Atomiques) company became the license holder. One of its shareholders was the American WESTINGHOUSE licensee company. During the period from 1974 to 1981 when developing the French standard of the reactor construction, the emphasis was made on the adaptation of the project of the American WESTINGHOUSE company. In the mid-1980s France developed the national model of the N4 reactor with the capacity of 1,450 MW. It was a signal about the independence of the French nuclear power industry [12, 13].

Thus, considering the experience of the French nuclear power industry, it is possible to conclude that initially this country made an attempt to use the strategy of accumulating its own scientific engineering potential to master opportunities and advantages of exploiting power resources obtained on the basis of using nuclear technologies for peaceful purposes. However, the implementation of the accumulation strategy would not have been successful if France had passed to the transfer strategy in the development of the nuclear power industry, i.e. it had started using foreign (basically American)

scientific engineering and technological achievements in the area of the "peaceful atom" reclamation. The experience accumulated during implementing the transfer strategy enabled France to create its own scientific engineering and technological solutions that would provide this country with joining pool leaders on exploiting nuclear power for peaceful purposes.

The South Korean experience of developing the national nuclear power industry includes four key stages that have specific peculiarities that are considered in details below. Within the **first stage**, based on the agreement with the American WESTINGHOUSE company as a general contractor, in the South Korea three blocks of the nuclear power station were constructed. Due to insufficient experience in the nuclear area, the national KEPCO (Korea Electric Power Corporation) electric company entirely relied on foreign suppliers and transferred to them all responsibility for implementing the project from designing and constructing, and putting new nuclear power stations into operation. The activity of South Korean industrial enterprises was limited by the construction of general civil facilities [14].

At the **second stage** having launched the first nuclear power station under full support of American vendors, in the mid-1980s South Korea started an ambitious program on achieving self-sufficiency in the nuclear power industry. Based on the contacts with foreign general contractors (American WESTINGHOUSE, French EDF and FRAMATOME, Canadian AECL), six blocks of nuclear power stations were constructed. The project on constructing nuclear power stations was managed by KEPCO under support of foreign architect engineers (American BECTEL, etc.). KEPCO purchased additional (non-nuclear) equipment. Korean suppliers performed construction works and supplied equipment of the general industrial class.

At the **third stage,** like before, KEPCO concluded separate contracts for large systems. However, it undertook full responsibility for the projects related to constructing nuclear power stations and provided South Korean with basic contracts. Foreign suppliers acted as subcontractors and consultants. During this period the provision about technologies transfer was firstly included in the supply contract.

In the mid-1980s the Korean government carried out the institutionalization of the national nuclear power industry, and allotted tasks and responsibility between Korean member organizations. The transfer of technologies and implementation of the project of the nuclear power station itself were done simultaneously. The transfer covered the transfer of technical information, software products, licenses for patents use,

theoretical (auditorium) preparation, onsite training, consultations and joint research and development of Korean and foreign organizations.

The transferred documents were typical and included instructions and materials related to licensing the project of the nuclear power station in the supervision body, documents on providing the quality, regulations and specifications, design documentation, calculations, regulations, figures, engineering specifications and procedures. Installation, verification, and validation were the basic tasks when transferring software, including initial programming codes. In the process of technologies transfer, consultations were available. The transfer of technologies related to designing the nuclear steam generation plant (this is the most principle element of any generating nuclear station) was organized by close cooperation of Korean specialists with the Swedish and Swizz ABB-CE company. Korean specialists carried out technical expertise, construction of models and researches and developments together with ABB-CE.

The design group of KAERI (Korea Atomic Energy Research Institute) was delegated to the American office of ABB-CE in Windsor, Connecticut, where they together with engineers of ABB-CE developed the project of the nuclear steam generation plant starting with early stages. Two years later the center of designing nuclear steam generation plants was transferred from Windsor to the Korean office of KAERI in Taejon. During this period about 4,700 technical documents and 110 computer programs were transferred, 300 persons were trained in theory, and 200 persons were trained on site. In the area of technologies transfer, when designing stations for the KOPEC (Korea Power Engineering Co., Inc.), the work was organized according to the similar logic. At the third stage KOPEC obtained about 13 million pages of technical documents and 300 computer programs, 650 persons were trained, 550 of them attended theoretical (auditorium) training, and 100 were trained on site. KOPEC tried to strengthen self-sufficiency by gradual improvement of the project related to developing nuclear power stations [15].

Special attention was paid to the **standardization** of nuclear power stations. The project of the Yonggwang nuclear power station became referential. On its basis the package of the standardized technical documentation was developed for further serial construction of the nuclear power station and obtaining economic benefit due to typical works. In legal terms Korean enterprises used a comprehensive approach: license agreements were concluded for a part of technologies, and some production technologies were transferred by creating joint ventures (for example, with

the French Framatome company for producing large-sized tanks and vessels of nuclear steam generating plants). License agreements were concluded for 10 years, and then they were prolonged. The agreements were plurilateral. For example, licensors of the American WESTINGHOUSE were Korean KEPCO, KAERI, DOOSAN and other companies [15].

At the **fourth stage** projects are implemented by Korean enterprises individually under considerably smaller volume of consultations made by foreign vendors. By now South Korea has launched several projects on the development of nuclear reactors of new generation. It enables the country to actively develop external economic and internal power industry relations by supplying equipment and technological developments to the states and countries that are interested in developing the nuclear power industry on their territories.

It is obvious that the South Korean experience of developing the nuclear power industry considerably differs from the French one. South Korea was initially focused on the transfer strategy and use of exterior scientific engineering and technological achievements in the area of reclaiming the potential of the nuclear power to meet the relevant needs of the national economy and social sector. Herewith, starting from the second stage, South Korea started striving for creating its own solutions for the development of the national nuclear industry. It enables this country not only to create the infrastructure on producing key parts, aggregates, and components for nuclear power stations but also to formulate the expanded national scientific engineering base in the area of peaceful atom technologies. It ensures the success of South Korea on external markets and allows to actively promote the technologies to reclaim nuclear power that have already been developed on the external markets. The earned profits from promoting nuclear technologies are invested in researching and creating new highly technological solutions in this area.

Initially the Chinese nuclear sector developed in the military direction under active support of the Soviet Union. Particularly, **within the first stage** in October 15, 1957 the agreement on transferring the technology on creating the nuclear weapon to China was signed between the USSR and the CPR. The formation of the large-scale and defense industries firstly became the basic goal and driver of the development during the second Chinese five-year plan (1958—1962) [3]. Not only technical but also organizational areas were copied. For example, "The Second Ministry of Machine Building" was copied from the Soviet Ministry of the Medium Machine Building (that was responsible for the nuclear power industry) [16, 17].

The development of the peaceful atom started in February, 1970 (**at the second stage**) when the government of the CPR affirmed the Plan on creating nuclear power industry. The development of the nuclear area rested upon the economy achievement. Practical works on constructing the first nuclear power station in the CPR started only in the late 1970s when the CPR declared the "Reforms and Transparency Policy" on establishing socialism with the Chinese specificity, including the attraction of foreign investors. China did not save resources for developing its own competences in the area of developing the production base for nuclear power stations (it set a task on 100% national engineering and production for the whole production chain). Having the most capacious internal market on constructing nuclear power stations (today forecasting up to 2030 is above 100 new blocks), from the very beginning China has shaped the course for the transfer of all leading technologies of its time [17].

Foreign countries faced a harsh choice: the entrance ticket to the Chinese market was the technologies transfer. The formats were similar to the Korean experience: license agreements and/or establishment of joint ventures (with a majority share of the Chinese partner that is usually a Chinese enterprise). Herewith, at the same time China performed works on three-four various technologies of nuclear power stations (Soviet/Russian, French, American – light-water, Canadian of the CANDU type).

The exclusively universal character of the transfer was a peculiar feature. Technologies were transferred on a comprehensive basis and covered stages related to designing, producing, constructing, and exploiting. Simultaneously Chinese specialists participated in training programs, herewith in the formalized and non-formalized type. The latter occurred according to the following procedure. 10-15 Chinese specialists gathered around one foreign specialist (for example, a welder on the site) and wrote everything in details in their notebooks.

This is how China prepared for the status of the largest world "breeding ground of nuclear power stations". Today the production capacities of China can produce above 10 sets of equipment for nuclear power stations per year (to compare, figures on foreign capacities are about 2, maximum 5 sets) [18].

At **the third stage** Chinese nuclear experts achieved independence on construction technologies and exploitation of nuclear power stations of so called second generation (today the leading companies offer customers nuclear power stations of the third and 3+ generations) and entered the external market with them. China managed to collect the most leading

technological foreign achievements in the form of projects nuclear power stations (Russian, American, French, and Canadian) [19, 20, 21-22].

The Chinese experience related to the nuclear power industry development can be considered in terms of the conversion of military technological solutions in the civil production. Herewith, China like South Korea initially used the transfer strategy to create the platform where the modern national nuclear power industry of the country developed. Later on China used the integration of the transfer and accumulation strategies to form both production and at the same time scientific engineering potential in the area of reclaiming opportunities of the nuclear power industry. At the present time China like South Korea actively develops external economic relations and promotes its own technological solutions on exploiting nuclear technologies for peaceful purposes.

2. CONCLUSIONS

The considered experience of France, South Korea and China shows that the accelerated development of the nuclear power industry of these countries would not have been possible without the full scale international cooperation on the transfer of foreign technologies and the production localization. Their success was based on the following components:

Availability of a long-term national plan on achieving self-sufficiency in the area of nuclear technologies on the basis of localization and transfer of foreign technologies that cover all areas of the industry. The plan must contain the description of the works volumes, areas of technologies transfer and priorities, and take into account the possibilities of labor and financial resources, workforce productivity and accessible material and technical basis. The projects standardization aims at decreasing unit costs when constructing series,

Concluding contracts on constructing nuclear power stations with vendors subject to technologies transfer; works on designing and constructing of nuclear power stations must be performed after or simultaneously with training and transfer of technical documents and software. Close cooperation on technologies transfer can be implemented in the format of license agreements and establishing of joint ventures.

Obviously, the use of the international technological transfer allowed all three countries under consideration to solve the problem of providing the national economy and social sector with power. Moreover, active cooperation of the countries under consideration with vendors, as well as

intensive study of foreign technological experience with simultaneous work on creating their own scientific engineering solutions allows France, South Korea, and China to enter the pool of leaders of the nuclear power industry, and to develop external economic relations, including through the promotion of their own technologies in other countries and states.

This article made an overview and considered the key moments of forming the nuclear power industry in three countries (South Korea, France and China). This work did not reflect economic characteristics of the technological transfer in the nuclear power industry. This issue will be revealed in further researches on this topic.

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