PROSPECTS OF THE USE OF FAST NEUTRON REACTORS

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Abstract

The aim of this article is to consider fast-neutron reactors as a source of energy which is able to replace non-renewable natural resources that are the basis of the energetics and economic stability in Russia at the moment. The advantages of this type of reactors in comparison to the modern widely used thermal reactors are shown. The main problems of construction and functioning of fast-neutron reactors are mentioned.

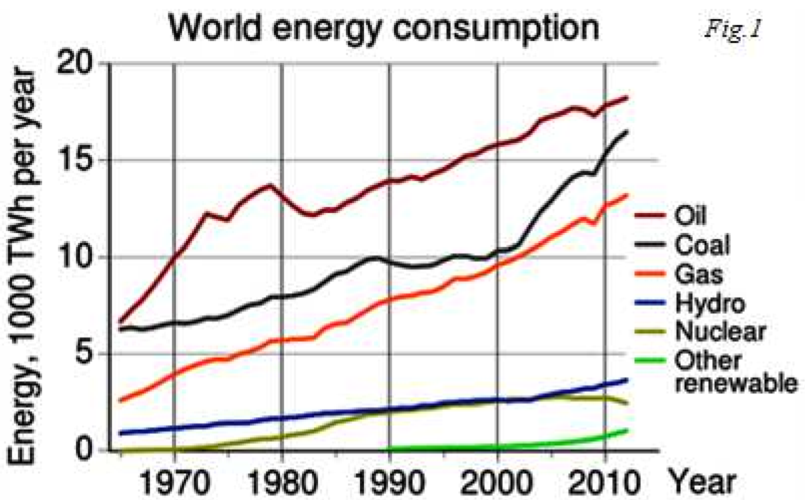
Key words: fast neutron reactors, thermal neutron reactors, chain-reaction, non-renewable resources, uranium

Research field: energy production, nuclear power plants

Related science: nuclear engineering

Introduction

Nowadays, energy is one of the most valuable goods, so many countries use it actively. One of these countries is Russian Federation. The revenues from foreign economic activity of Russia in 2013 is about 38% of the income of the total Federal budget, [5] and fuel and energy goods is the greatest part of Russianexport [4]. Obviously, Russia strongly depends on export of oil and gas resources, which are non-renewable. Besides, some part of these resources is spent on maintenance of the state needs. In the interview to the "Russian news service" the Minister of natural resources and ecology Yuri Trutnev said that the proved oil reserves of Russia would suffice for approximately 25 years, gas reserves - for 70 years. Nowadays there are two solutions of the problem: either Russia covers a lack of resources with import, or actively develops nuclear energy. At the moment nuclear energy does not exceed 20% of the total amount of the energy, produced in the country.



The graph of the ratio of energy sources to the world consumption (Fig. 1) shows that the energy from burning oil, gas and coal exceeds consumption of nuclear energy by times. It is evident that the consumption remains increasing.

All these facts and assumptions make Russia depend on the countries which export resources. So, the only solution is creation of its own energy base which is able to cover the needs of the whole country. At the moment the only real alternative is nuclear energy. However, taking into account the amount of energy generation, current methods of processing of nuclear fuel have some strong disadvantages, such as spent nuclear fuel, radioactive waste, the disposal of which is still not developed, and the necessity of processing large amount of natural uranium to extract the necessary isotope uranium-235. The perfect solution in this situation is the construction of fast reactors, which will be discussed further.

Why fast neutron reactors?

It is known, due to collision of U-235 and neutron, U-235 releases some energy and emits on average 2.5 neutrons. Each of these neutrons causes the breakdown of another 2.5 nuclei launching the so-called chain reaction. The number of emitted decaying nuclei neutron must exceed the number of neutrons, leaving uranium conglomerate to keep the reaction stable. In this case, the reaction proceeds with the release of energy. The following graph presents the cross-section of interaction between nuclei U-235 and a neutron (Fig.2 2[6]).

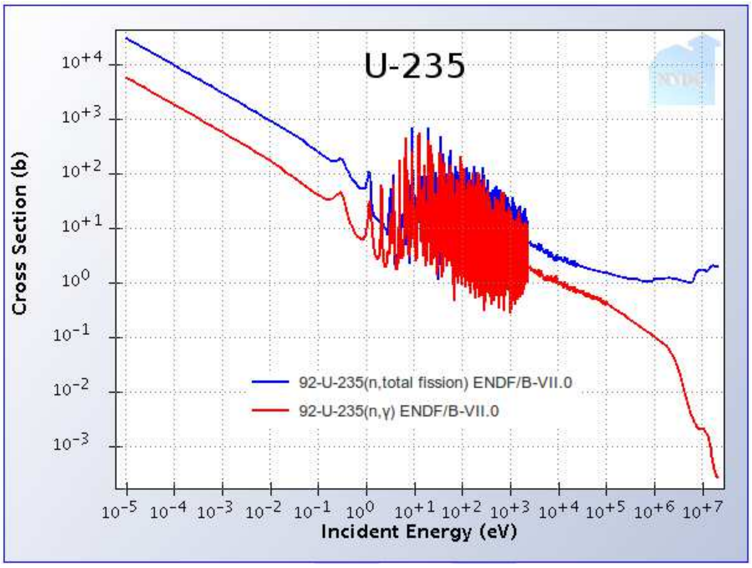


Fig.2

It is seen that the probability of interaction between nuclei U-235 and a neutron involved in the chain reaction grows with decreasing energy of neutrons. Actually, most of the neutrons released in the fission of uranium-235 nuclei have energy of about 1-2 MeV while the required energy of neutron for thermal reactor is less than 0.03 MeV.Therefore, water or graphite is used in thermal nuclear reactors to decrease the speed of neutrons to the same order as the speed of the thermal vibrations of atoms in the crystal lattice. As already mentioned, there is only 0.7% of the isotope nuclei U-235 in natural uranium, so, it is necessary to process tons of ore to obtain a few pounds of a suitable isotope. There are two possible options of fission of the atom nuclei U-235:

$$ {}^{235}_{92}U + {}^{1}_{0}n \begin{cases} \nearrow {}^{144}_{56}Ba + {}^{89}_{36}Kr + 3{}^{1}_{0}n \\ \searrow {}^{140}_{54}Xe + {}^{94}_{38}Sr + 2{}^{1}_{0}n \end{cases} $$

Spent nuclear fuel, opposed to fresh, has a significant radioactivity due to a large number of fission products and tends to self-heating in air to high temperatures, so after removal from the reactor core it is put in the cooling pool or at the periphery of the active zone of the reactor for 2-5 years. After reduction of the residual energy release of fuel it is sent to the storage, disposal or recycling. Fig. 3 presents the cross-section of interaction between nuclei U-238 and a neutron (Fig.3[6]):

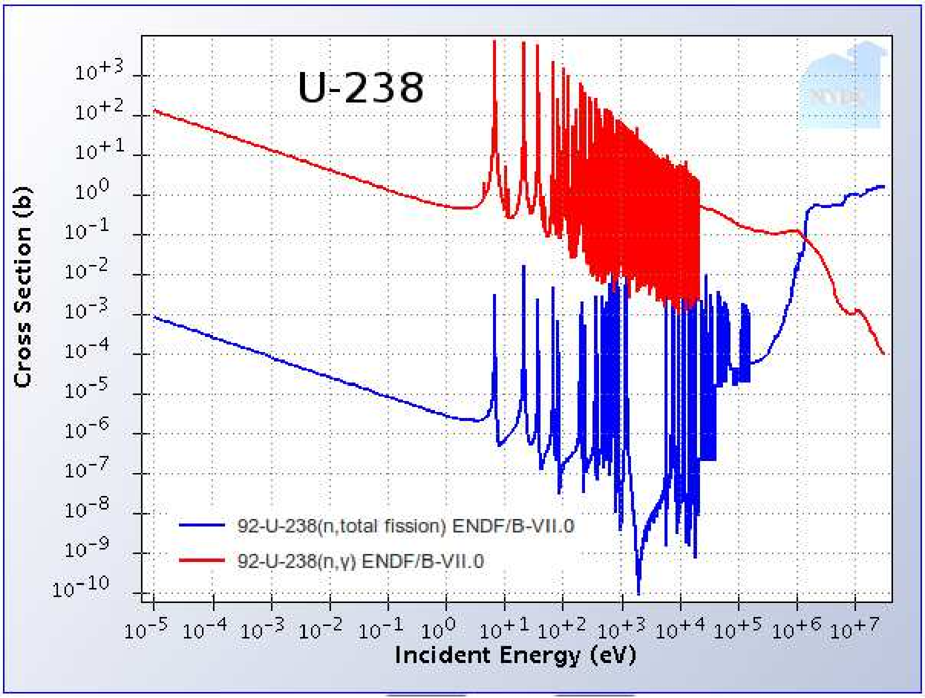


Fig.3

It is obvious, for large energies (>10^5 eV) the probability of interaction between neutrons and nuclei of uranium-238 increases when energy rises. However, the neutrons released in the reaction have on average entire energy of 1.25 MeV, which is not enough to start a self-sustaining reaction in uranium-238.

Let us consider the range of energy, at which the neutron can be captured by uranium-238 with the formation of uranium-239, which decays into plutonium-239 through beta-decays: This isotope has the same trend, so fast reactors can split and destroy this actinide as fuel rather than let them accumulate as in thermal reactors. The following reaction illustrates this process:

$$^{238}_{92}\mathrm{U} + {}^{1}_{0}\mathrm{n} \xrightarrow{\gamma} {}^{239}_{92}\mathrm{U} \xrightarrow[23,5\ \mathrm{min}]{\beta^-} {}^{239}_{93}\mathrm{Np} \xrightarrow[2,3565\ \mathrm{d}]{\beta^-} {}^{239}_{94}\mathrm{Pu}$$

Another source of fuel is natural thorium:

$$^{1}_{0}\mathrm{n} + {}^{232}_{90}\mathrm{Th} \rightarrow {}^{233}_{90}\mathrm{Th} \xrightarrow[22,3\ min]{\beta^-\ 1,243\ MeV} {}^{233}_{91}\mathrm{Pa} \xrightarrow[26,967\ d]{\beta^-\ 0,5701\ MeV} {}^{233}_{92}\mathrm{U}.$$

In the spontaneous fission of thorium uranium-233 is produced, which fission is very similar to uranium-235 fission. It is also released from the spent fuel in a chemical way.

As the cross-section of fission of fast neutrons is less than heat, the critical mass of substances in the reactor core should be higher (up to 20 % in fast reactors via 2-4% in thermal reactors). However, new fuel is produced in cassettes with thorium or natural uranium located around this core, so such big amount of substance is necessary only at the first step of operation.

In general, it is obvious that the design and construction of fast reactors is very expensive, but still remains cost-effective, as each neutron capture in the core of such a reactor leads to 1.5 times more neutrons of fission than in the core of reactor on thermal neutrons (Fig.4 [6]).

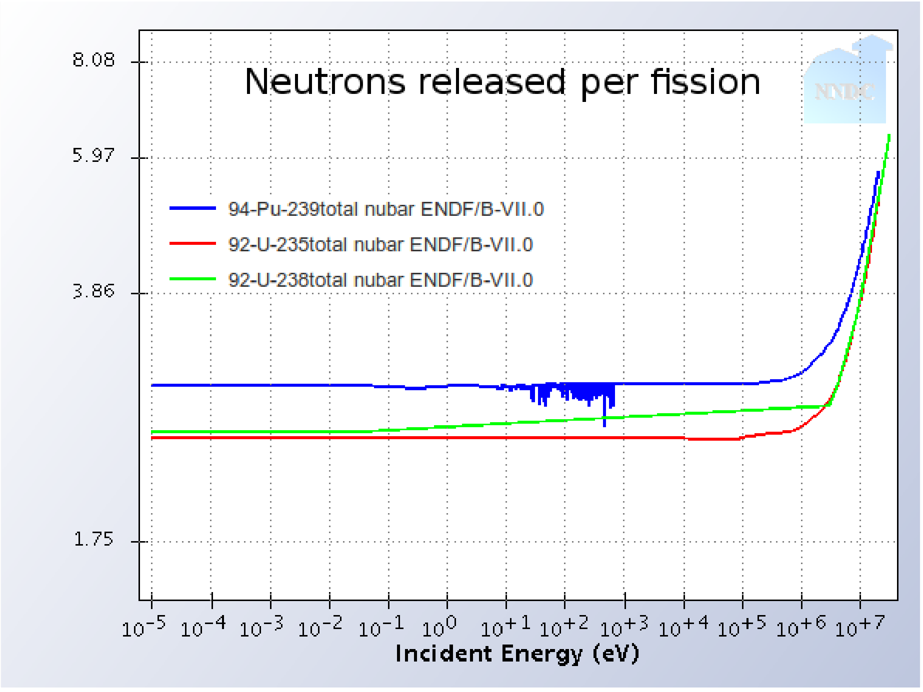


Fig.4

Therefore, for the processing of nuclear fuel in the fast neutron reactor far more neutrons can be used. It allows gaining a lot more fuel than it was originally produced (from uranium-238 and thorium).[1]

Selection of coolant

As cooling fast reactor with water or graphite is unacceptable, the question of selection of the new coolant appears. There are several options:

• Gases. Cooling with helium was considered, but due to its low heat capacity this gas is not suitable for cooling high-power reactors

• Mercury. For mercury testing the coolant reactor BR-2 with thermal power of 100 kW was built, but later the coolant was considered to be economically unprofitable.

• Molten salt. Reactors with this coolant work on different versions of fluorides of fissile materials (uranium, thorium, plutonium). In 1959 this training reactor was built in the Oak Ridge National Laboratory

• Liquid metal (lead-bismuth or lead) coolant. Some projects with this kind of coolant are currently being developed in Russia (Lead-bismuth fast reactor, Fast reactor with lead coolant, Angstrem - the project of a mobile ATPP, series of reactors for nuclear submarines)

• With sodium coolant. It is the most popular coolant for fast reactors around the world. Nowadays, the only operating fast neutron reactor is the bn-600 fast neutron sodium-cooled reactor. It was put into operation in April 1980 at the 3rd unit of Beloyarsk NPP in Sverdlovsk region near the town of Zarechny. Its electric capacity is 600 MW.

According to the Director of Rosatom, Sergey Kirienko, the construction of the reactor BREST-300 in Seversk, Tomsk region, is being prepared. This reactor will be used for the gradual development of all operating modes of fast neutron reactors with liquid metal coolant, after which the technology can be replicated in industrial scale.

Conclusion

The fast neutron reactors have clear benefits. Fuel for these reactors is sufficient for tens of thousands of years. The amount of spent nuclear fuel is incredibly small. In addition, the spent fuel of fast reactor reduces the radiotoxicity of the mined uranium much faster than a thermal reactors' one (150-200 years via 220 thousand years of Pressurized water reactors). Another advantage of fast nuclear reactors is processing U-238 instead of U-235 as there is only 0.7% of the U-235 in natural uranium. So it is necessary to process tons of ore to obtain a few pounds of a suitable isotope. Besides, related technical problems seem to be solvable, taking into account the future perspectives and the size of the problem in other branches being able to produce enough energy (for example, fusion).

From the economical point of view the cost of construction of such reactors is much higher than the cost of thermal reactors. However, it seems to be much more profitable and reasonable in the future. Thus, the extension of the existing data base of fast reactors, the accumulation of working experience, as well as the development of technology seem to be the most perspective course development of the Russian energy sector.

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