

Modern Reactors: Future Reactors

Baryakhtar Victor Grigorievich, Bykovskiy Yaroslav Timurovich

Department: Physics-Mathematics, Faculty of Physics-Mathematics, National Pedagogical M.P. Dragomanov University, 01601 Kiev, 9 Pirogova Str., Kiev, Ukraine, E-mail: www.fmi.npu.edu.ua

***Abstract:** At present, a significant amount of effort is devoted to designing and creating the fast-fission reactors. These reactors allow to substantially reduce the amount of radioactive waste. Another advantage is related to the fact that uranium-238 can be used as a fuel instead of uranium-235 which is a rare isotope of uranium. In this case, the amount of a fuel for NPPs increases by hundreds of times. In the fast-fission reactors, thorium, in addition to uranium, can be used. The supplies of thorium exceed that of uranium by tens of times. It is expected that such reactors will be available on the market in 10-15 years.*

***Keywords:** energy production, nuclear energy, nuclear power plants, physically safe*

1 Introduction

Let us note, that Ukraine possesses a large amount of natural uranium, occupying the sixth place in the world in this respect. Moreover, Ukraine has the rich experience of the exploitation of the NPPs and the unique experience of the liquidation of consequences of the Chernobyl NPP accident. It has the capability to train the highly skilled personnel to work at the NPPs, from technicians to operators.

The nuclear power engineering of the fourth generation is intended to eliminate or significantly alleviate three basic threats:

- proliferation of the technology of the weapon-grade isotope's production and fabrication of the nuclear weapons on their basis
- radioactive contamination of the environment resulting from accidents on a large scale
- radioactive contamination of the environment as a result of the unreliable storage or dispersion of radioactive waste in the case of a terror attack.

The examples of these threats are well-known. In particular, Ukraine went through the terrible Chernobyl disaster, consequences of which have not completely been

eliminated up until now. At the same time, **Ukraine has transferred all of its nuclear warheads, rockets and other nuclear weapons to Russia and is the first and the only country in the world that willingly gave up the possession of its nuclear arsenal** [33]. Such nuclear policy is not very common. As long as nuclear weapons will remain the most significant tool of geopolitics and an important deterrent in confrontation, many non-nuclear states will seek to possess the nuclear weapon.

The international programs such as Generation IV and INPRO were created for development of the nuclear technologies of the fourth generation. The main developers and participants of these programs are the leading nuclear states. Due to the openness of the programs, any interested state can participate in them. Ukraine is a participant of the program INPRO and, in addition, participates in the realization of some projects in the framework of the program Generation IV.

The basic distinction between the nuclear power engineering of the next generation and the current one is that the former has multiple levels. Within the next generation, the construction of complexes including reactors with various targeted functions is expected. As the most promising, we mention three types of reactors of the fourth generation. Their list and the schematic representation are given in Fig. 1 (a-c). The reactors can be categorized into the following types according to their main purposes:

- the power reactors which primary goal is to generate electricity
- the reactors-mutators aimed at the deep burning of the weapon-grade isotopes and long-lived radioactive isotopes
- the reactors for the production of an environmentally pure (carbon-free) fuel such as hydrogen via hydrolysis of water and for the production of a synthetic hydrocarbon fuel from coal.

A reactor of some type can be constructed and endowed with such fuel cycle that it will be able to combine different functions (for example, to produce electric energy and to burn undesirable isotopes). The experience shows that a specification of such high-tech equipment as reactors allows to simplify the technological decisions as to their usage. The liquid sodium, helium, and alloys of lead can be used as coolants.

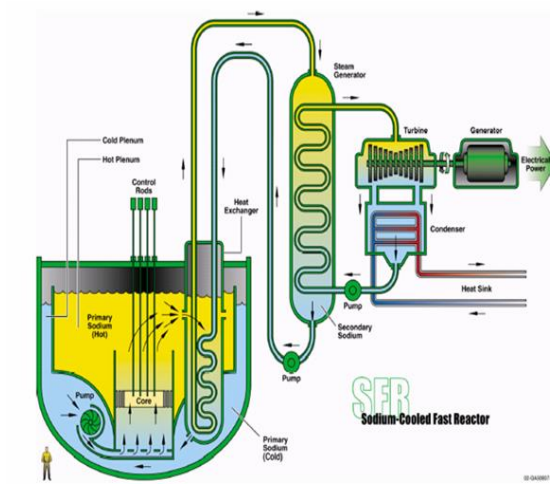


Figure 1(a)

Sodium-cooled fast-fission reactor, SFR

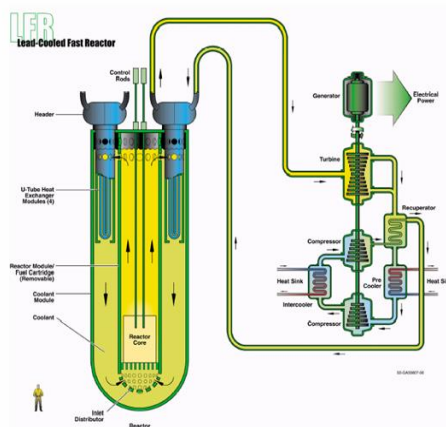


Figure 1(b)

Lead-cooled fast-fission reactor, LFR

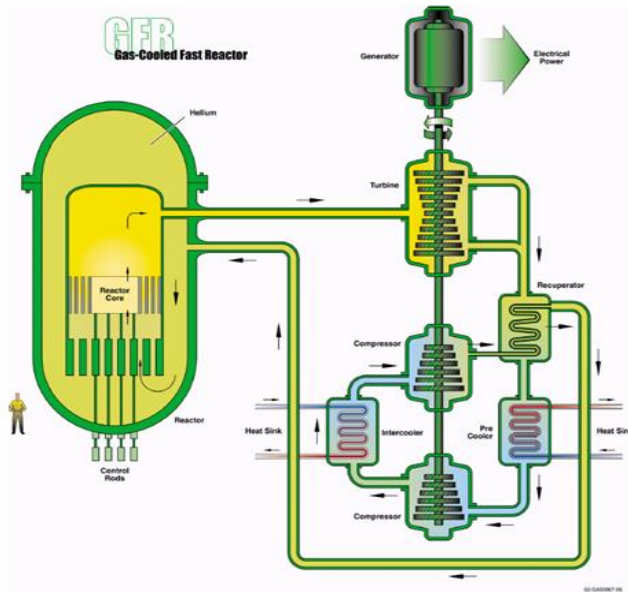


Figure 1(c)

Gas (helium)-cooled fast-fission reactor, GFR

Now, we will give a brief characteristic to each type of reactors mentioned above.

A helium-cooled fast-fission reactor (GFR-type). A specific feature of this reactor is high temperature (up to 1000 C) and high pressure (7 MPa) of helium that is used as a heat carrier. The temperature of helium at the output is approximately equal to 800°C. This reactor is sufficient for the electric energy production, generation of hydrogen by means of the hydrolysis of water and for the deep burning of weapon-grade and radiotoxic isotopes. As a basic structural material of the active zone, it is assumed to use materials based of silicon carbide. The problematic issue is the radiation resistance of structural core materials of the active zone at the radiation doses as high as 70-90 dpa (displacement per atom \equiv dpa).

A sodium-cooled fast-fission reactor (SFR) with closed fuel cycle. The temperature of sodium at the output is about 800°C. The reactor is aimed for production of the electric energy and burning of weapon-grade and radiotoxic isotopes. As structural materials of the active zone, it is assumed to use special steels that are produced and tested at the present time. The stability of structural materials under corrosion and irradiation (up to doses of 200 dpa) can state a problem.

A fast-fission reactors are reckoned on the attainment of a deep burning and, hence, on the very efficient use of uranium-238. With the development of this technology, the supply of uranium and thorium (if adding thorium to the cycle) on Earth will be sufficient for 5 thousand years and more. To design such reactors, it will require improving of the existing nuclear technologies (the evolutionary component) as well as developing and implementing of the cardinally new technologies (the revolutionary component), especially at the stage of development of the fuel cycle and structural materials.

A molten salt reactors (MSRs) are very promising in all respects. This revolutionary nuclear technology was developed more than four decades ago in the form of a research molten salt breeder reactor that was built in Oak Ridge. The main difficulty in usage lies in the production and testing of the necessary structural materials and in careful control over the chemical composition of a fuel mixture. The advantage is that it does not require a reactor case, its structural elements can be easily changed, a fuel cycle can be varied, and it has low radiation loads on the structural materials. The large-scale studies and engineering development are still needed. The main difficulties lie in the design and testing of the necessary structural materials and in the development of means for the careful control over the chemical composition of a fuel mixture.

2 Future Reactor

All researchers dealt with new units for the nuclear power engineering thought about the idea of a reactor that will be safe by the physics of its processes. One of the first proposals was to combine an accelerator with a nuclear reactor. In such system, the reactor would be in a subcritical state. The accelerator irradiates the reactor substance and transforms protons in neutrons, by increasing the neutron field in such way. While the accelerator operates, the coefficient of multiplication of neutrons $k > 1$, like a standard reactor. The transition to the operation mode with $k = 1$ can be realized at the expense of rods-absorbers. In other words, the accelerator together with a system of rods-absorbers make this system to be completely analogous to an ordinary nuclear reactor. The advantage of the system over the ordinary nuclear reactor consists in the possibility to instantaneously (for a very short time) stop the chain nuclear reaction. It is related to the fact that the shutdown time for an accelerator is very small. Unfortunately, it gradually became clear that this system does not solve completely the problem of creation of a physically safe reactor. The reason is related to the accumulation of a huge amount of radionuclides for the operation period, like the ordinary reactor. Their decay occurs even if the chain nuclear reaction is stopped. The energy of decay of radionuclides is so high that can cause the melting of the reactor. Just such scenario was realized in the accident at the Fukushima NPP. The chain reaction was terminated, but the system of cooling was destroyed. As a result, the reactor was heated to a temperature of about 2000°C.

The above reasoning indicates that the physically safe reactor must combine a small volume, where the reaction is running, with properties of a fast-fission reactor, so that a small amount of radioactive elements is produced. Just such type of a reactor was proposed by L.P. Feoktistov [1, 2]. The Feoktistov reactor has the following structure. Uranium-238 is charged into a cylindrical pipe. With the help of uranium-235, a nuclear reaction of multiplication of the same type as in a fast-fission reactor is “ignited.” At the expense of the burning of uranium-235, plutonium-239 is created from uranium-238 and becomes a fuel for the subsequent process. Thus, the relevant wave of combustion with the permanent burning of uranium-238, the production of plutonium, and its burning is propagated. All this occurs in a small volume. The amount of produced radioactive elements is small.

The detailed study of processes running in a Feoktistov reactor was performed at the National Scientific Center “Khar’kov Physico-Technical Institute” under the guidance of Academician A.I. Akhiezer. It was shown that the operation of Feoktistov’s nuclear reactor is stable. Placed under Earth’s surface, it becomes a physically safe reactor, since the produced “small” amount of radionuclides cannot contaminate the environment. The physicists (Academician N.F. Shul’ga, Professor S.P. Fomin, and others) in Khar’kov have shown that the material of the pipe in Feoktistov’s reactor undergoes the action of a very high radiation load. Namely, the number of displacements of atoms due to the irradiation attains the value of 200. At the present time, the materials used in the nuclear power engineering can endure only 100 dpa in 1 cm³. For this reason, the realization of Feoktistov’s reactor depends on the fabrication of new radiation-resistant material. We note that this difficulty is present also for the fast-fission reactors.

We note that an analogous idea was advanced by Edward Teller [3] in 10 years after L.P. Feoktistov. In Teller’s project, thorium-232 was used instead of uranium-238. The calculations performed by physicists in Khar’kov showed that Teller’s reactor is not workable. But if the fuel will consist of 50% of thorium -232 and 50% of uranium-238, then the reactor will operate. We note that E. Teller well understood the importance of physically safe reactors of the Feoktistov--Teller type. In the 1990s, more than 100 silo launching rocket units were present in Ukraine. When they should be destroyed, E. Teller sent his disciples into the Khar’kov Physico-Technical Institute, who had to explain the significance of physically safe reactors to the physicists in Khar’kov and the necessity of their placement underground. In Teller’s opinion, the underground mines of launching rocket units would be an ideal version for the location of reactors of this type.

In 2001, Professor Hiroshi Sekimoto at the Tokyo Institute of Technology [4] advanced independently Feoktistov’s idea and started to intensively work in this field. Sekimoto’s works on the physically safe reactors with running wave induced the studies in many countries of the world, including the USA, where the TerraPower company was established. In 2006, this company claimed that the reactor with running wave will be produced in 2020. The company is strongly supported by Bill Gates. In the opinion of Bill Gates, such reactors can solve the problem of the struggle against CO₂ and can preserve Earth’s climate.

3 References

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