The small modular reactors and the big ambitions

Analysis by Dr Kaschiev

In October last year, the prime minister surprisingly announced that the government was considering building small modular reactors (MMRs). On February 17 this year, it was reported that Kozloduy NPP - New Capacities and the American NuScale Power have signed a Memorandum of Understanding. The aim is to explore the possibility of building the MMPs developed by NuScale Power. Kozloduy NPP - NM claims that there are no binding clauses in the memorandum, but since it is not publicly available in the media, various comments have appeared.

NuScale Power much more clearly states the company will support Kozloduy NPP - NM in conducting research, including feasibility studies, financial evaluation of the project, various engineering evaluations, planning and licensing, with the potential goal of building a new nuclear power plant with NuScale Power MMP.

Both countries claim the technology is safe, reliable, maneuverable and ideal for Bulgaria. Some supporters of MMR suggest that by 2030 country would have 5-6 thousand MW of such capacity built. Others loudly announced that nuclear modules could be placed even in the center of Sofia?!?

This material provides information on MMP projects and especially those on NuScale Power, and provides an opportunity to assess the validity of these claims.

Large and small reactors

In the initial phase of development of nuclear energy, all reactors had low power. The idea of scaling up was quickly conceived, as it led to significant financial benefits. On the other hand, the huge electricity systems of the main countries taking part in the development, make it possible to include high-power plants. This led to the creation of reactors with a capacity of up to 1650 MW electricity (EPR). There are now at least 10 modern projects of large light reactors in the world, with several modifications, most of which are licensed and operational.

Reactors with an electrical capacity of more than 700 MW are large and those of less than 300 MW are small. From 300 to 700 MW are of average capacity, there is a class of microreactors (less than 10 MW). Most operating reactors in the world are of medium and high power. Those with low power are mainly created as prototypes of larger ones. Microreactors are intended mainly for space missions, in the past they were used by the USSR for satellites. There are ideas to potentially sue microreactors to power military bases, islands, etc.

The Chernobyl and Fukushima accidents have tightened regulatory norms and requirements and have even led to the addition of new safety systems. On the other hand, the huge size has led to problems in design, licensing and especially in construction. As a result, construction time and start-up costs increased sharply, and real prices turned out to be significantly higher than initially estimated. For example, the construction of Westinghouse's two AP-1000 reactors in the United States will take more than 8 years instead of 5 years, and the costs have already exceeded 11,000 USD / kW. The situation is similar and even worse with Areva's 5 EPR reactors under construction. in France. Sequentially, this made potential investors highly cautious.

One of the nuclear industry's ideas to restart was to circle back to designing small reactors. Thus, the reactor island can be simplified, making it more reliable, safer, easier and faster to build and ultimately cheaper and more attractive. However, the small size also leads to a number of negative consequences.

So far, only the Russian floating nuclear power plant is in operation, with two water reactors of 35 MW each. They had long been developed for icebreakers and cannot be considered a new project. Their construction lasted more than 12 years, the costs increased almost 5 times and exceeded 10,500 USD / kW of electricity. Mostly for these reasons, there are no other candidates to invest in this technology. Russia is developing 4 more projects of light water reactors for floating nuclear power plants.

Most companies have focused on developing small modular reactors. In them, as a rule, the core and all components of the primary circuit are integrated in one module. It is prepared in factory conditions and transported for installation on site. Most NPP projects have several modules. It is believed that the construction time will be less, which will reduce interest costs. It is assumed that the construction of the individual modules can be done one by one, depending on the needs and will require less initial costs. In continuous production, the cost of one module will decrease enough. However, many economists believe that even with all the favorable factors, electricity from small reactors will be more expensive than large ones.

The first large-scale project to develop the small modular reactors was launched in the 1990s in South Africa with the participation of an international team. This is a high-temperature PBMR type reactor based on the German HTR which was shut down after Chernobyl.

The enrichment is twice as high as in the light reactors, the fuel is uranium particles, coated with several shells and pressed into graphite spheres. The retarder is graphite, the heat carrier - helium, which is heated to over 700 degrees and directly feeds a gas turbine. The plans foresaw 24 modules in operation by 2030. In order to achieve good economic results, the thermal capacity has been increased from 200 to 400 MW, which, however, causes a number of technical and licensing problems. At the same time, the value of the project is growing sharply, investors and clients never emerged, and after spending 1.3 billion USD, in 2010 the project was frozen.

In 2005, 50 small reactor projects were under development and now 72 are being developed in 18 countries. 25 of them are with light and heavy water, 11 are fast neutrons with different heat carrier, 11 are high-temperature, 10 -of molten salts, etc. There are 18 projects under development in the United States, 17 in Russia, 9 in China, 8 in Japan and 7 in Canada. Even Denmark, Luxembourg and Saudi Arabia have announced that they are developing such projects.

It is not clear how many of these 72 projects are being worked on and how many will reach license and construction of a prototype stage. Only 10 are in the 4th and 5th design phases and three more designs of NPPs with small reactors are under construction or close to it:

HTR-PM, China - two modules with high temperature reactors power a steam turbine with a capacity of 210 MW of electricity. Each module has a graphite retardant and helium coolant and a thermal capacity of 250 MW. It is expected to enter operation in 2021-2022.

CAREM -25, Argentina - NPP with one integrated, light-water reactor, electric power about 30 MW.

It is expected to start construction at the end of this year ACP 100, China - integrated, single, light reactor, electric power about 30 MW.

NuScale Power

It was founded in 2007 by scientists from the University of Oregon, developing technologies for passive cooling of reactors. Since 2011, the main shareholder in it is the engineering and construction corporation Fluor. A fundamentally new project for a light water reactor with natural circulation of the heat carrier (without pumps) in the primary circuit is being developed. The driving forces are the differences in the density of the heat carrier in the core and in the steam generator, and their height. This greatly simplifies the primary circuit but imposes thermal power limitations.

The lack of pumps and pipelines in the primary circuit allows all components (core, steam generator and pressure compensator) to be integrated into one metal housing. It is mounted in an outer metal housing, which serves as a protective shell (container) and can withstand much higher internal pressure than traditional ones. A small vacuum will be maintained in the container during operation, which will limit heat loss and corrosion of the metal. Cables, pipelines of the systems for water exchange and purification of the primary circuit, steam pipelines and pipelines for return of condensate come out of it. A new type of steam generator with spiral heat exchange tubes has been developed for the project. There is not much information about its reliability, service life, whether it can be repaired, replaced, etc. Critics of the project have expressed concern that it could be damaged by vibrations in emergency processes.

As of 2010, a module with 45 MW of electric power has been developed in principle. However, low power leads to expensive output and, as with the PBMR project, power increases begin. As of 2015, a module with thermal / electric power of 160/50 MW has been developed, which in 2020 has received approval from the regulator.

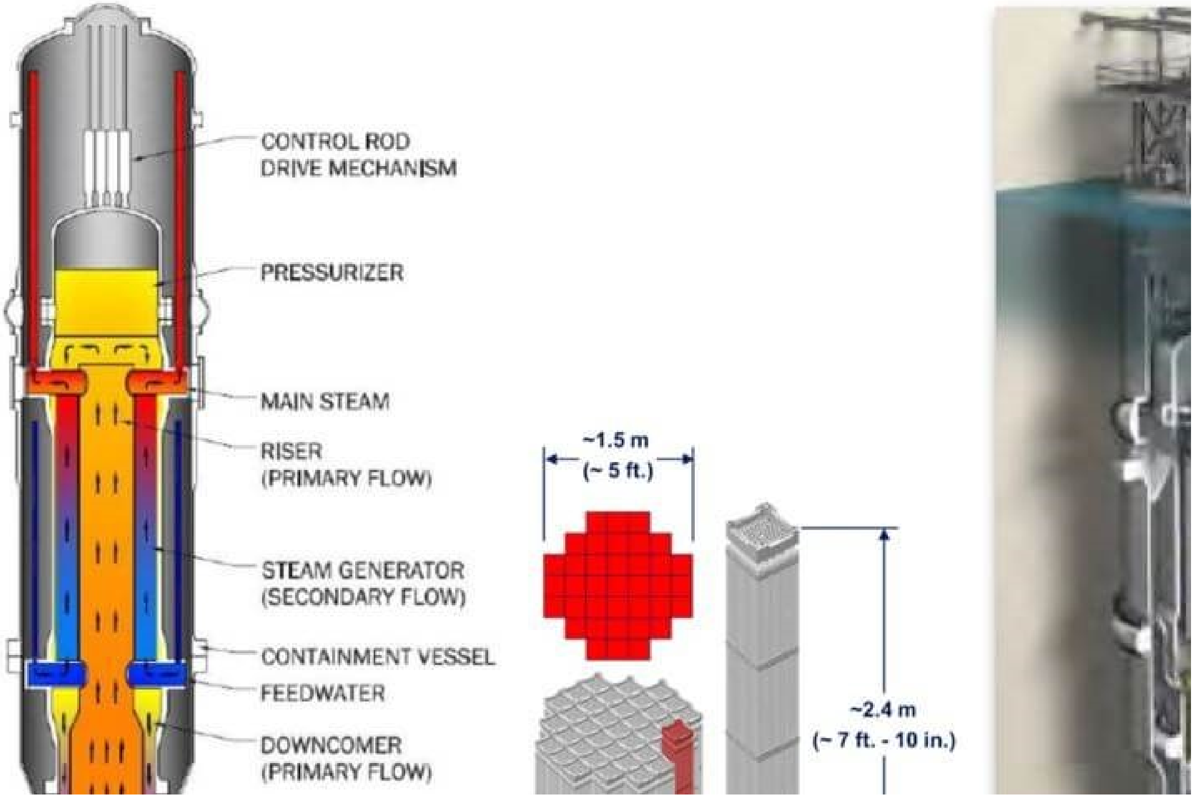
Economic results were still unsatisfactory and by 2019 a module was being developed with thermal power of 200 MW and electric power of 60 MW.

Months ago, NuScale Power announced that it was developing an even more powerful module with 250 MW of heat and 77 MW of electricity. It will be presented for licensing in 2022. The company has developments for NPPs with 4 and 6 modules, but the option with 12 modules is considered optimal. The plan is for the first NPP to have 12 modules of 77 MW and a total gross capacity of 924 MW. As you can see, for efficient operation, a nuclear power plant with MMR must have many modules and huge capacity.

NuScale Power has already invested more than $ 900 million in the development of the MMP, of which $ 317 million is from the government. Through the MDGs, the United States plans to regain its leadership in nuclear energy and to get billions of orders from around the world.

What is NuScale Power MMP

With a module of 77 MW, the hull has an inner diameter of 2.74 m and its height has been increased to 19.8 m. The containment has an outer diameter of 4.57 m and a height of 23.16 m.



The core will contain 37 standard assemblies of 17 x 17 fuel cells with a ladder height of fuel tablets of about 2 m, which will be prepared by AREVA - France. For comparison - in the core of the AR-1000 there are 157 fuel assemblies, which are twice as high. In large reactors, neutron leakage is negligible and nuclear fuel enrichment may be less. The distribution of neutron flux and energy release in the fuel in them is close to optimal and high combustion is achieved. The situation is reversed with small core size - significant neutron leakage and suboptimal distribution of energy release. Therefore, significantly less energy can be extracted per unit mass of fuel than in large reactors. This means that per unit of energy produced, such a module will generate more fuel. These significant shortcomings are common to all small reactors.

In 16 of the fuel assemblies there will be mobile neutron absorbers, each with its own electromagnetic motor mechanism. A soluble absorber (boron) in the coolant will also be used. Uranium-235 enrichment should be higher than for large reactors but will be below 4.95% (the limit for US civil reactors).

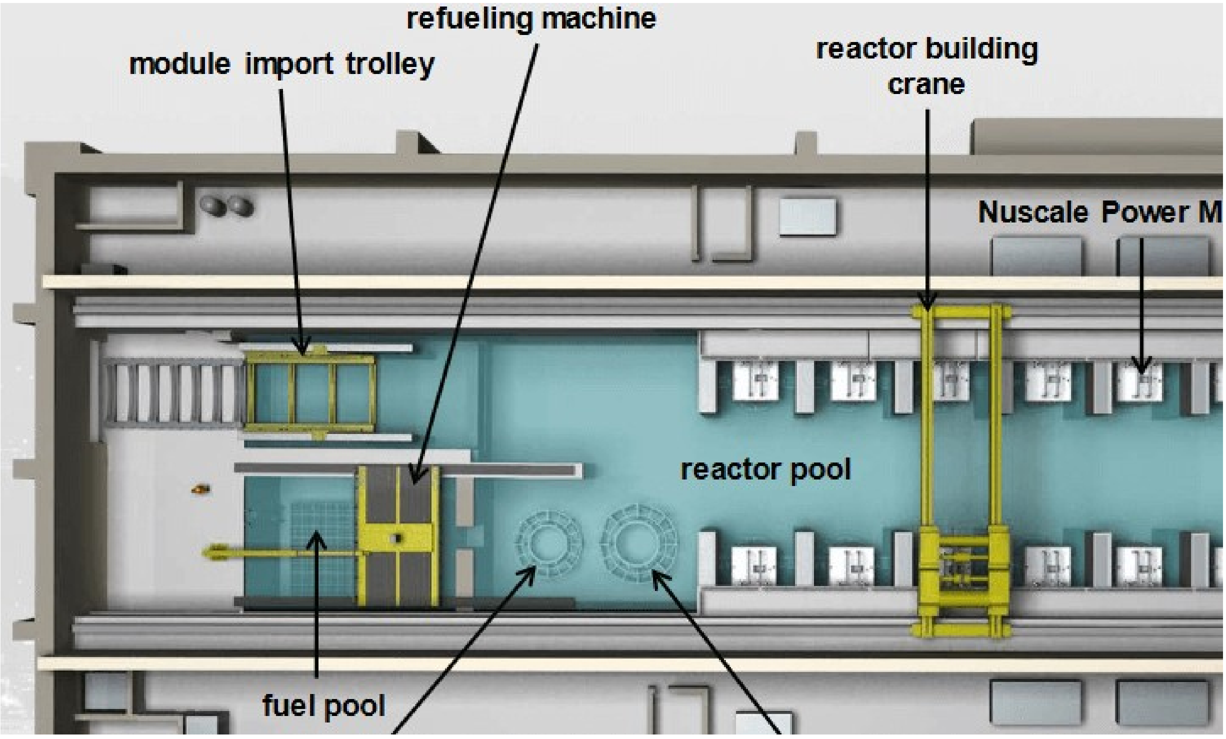
The difference in the water temperatures at the inlet / outlet of the core at 60 MW module is 56 degrees (265 - 320 o), while at large reactors it is below 35 degrees. There is no information on how much it will be with the most powerful module. The low inlet temperature in the core determines low parameters of the steam in the secondary circuit. Combined with higher heat losses, only 31% of the heat will be converted to electricity (77 MW module). Such values (and lower) are typical for small reactors, while for large water reactors they are 34-36%. This also means that per unit of electricity produced, a small reactor requires a larger amount of final heat sink than a large reactor.

From a safety point of view, NuScale's MMP has many advantages over large reactors, which cannot be discussed in detail here. Some examples: Simplifying a project eliminates a whole class of baseline events for accidents; Emergency cooling systems are passive, i.e. no pumps, energy or operator intervention are required. They consist of only two pairs of valves and heat exchangers mounted on the outside of the metal container. In them, the steam-water mixture from the steam generators is cooled by the water in the pool and returned. This can last more than 30 days, and when and if the water in the pool evaporates, cooling with air will suffice.

Nuclear power plant with NuScale Power modules

The plant project is likely to be presented to the regulator in 2023. Licensing is a major challenge, as current standards and rules have been developed for large reactors.

The module of 77 MW of electricity weighs about 700 tons and will be delivered to three segments by road, railway line, or by water from the factory. A common reactor building is envisaged, in which each module will be below ground level, in a huge pool, each of which will be in a separate section. The pool will be over 20 m deep and will contain about 50 thousand tons of water. The reactor building will be able to withstand the impact of an aircraft (no details, probably small). Each module will power a separate steam turbine, with the 12 turbines in two buildings on either side of the reactor. All modules will use several common systems and will be controlled by a common control room with 6 operators, a simulator of which has already been created.



The individual modules will be shut down for 10 days every 24 months for recharging and revision while the others run. 1/3 of the fuel will be replaced with fresh. After stopping a module, all pipelines, steam pipelines, supporting structures, cables, etc. will be disconnected and the whole will be transferred to the audit compartment. There, the upper part of the container and the inner hull will be dismantled with special tools. Such technology has not been implemented so far and its reliability and safety have yet to be proven. The spent fuel is placed in a special compartment of the pool.

The plant will also have a special building, installations for preparation, storage, and purification of boron solutions, for processing and storage of radioactive waste, for dry storage of spent fuel, laboratories, warehouses, administrative building, distribution device, cooling towers, etc. The protected area (behind the fence) will be about 140 acres, and the total much more.

If a NPP with 12 modules operates mainly in base mode, it will maintain a constant net capacity of 880 MW. During recharging of one module - about 816 MW and the need for replacement power will be small, unlike large reactors.

In the natural circulation of the coolant, changes in the heat output of the reactor are not desirable and must be made very slowly. Power increase from 20% to 100% will take more than an hour and a half. However, NuScale modules can vary their electrical power in a wide range by directing part of the steam flow directly to the capacitors. The electric power can be reduced from 100% to 20% in 10 minutes and raised back in 27 minutes (60 MW module), and the reactor will operate at rated power. NuScale Power is exploring the possibilities of using its modules to produce hydrogen, desalinated water, heating, and other purposes, combined with variable electric power mode.

Problems with the licensing of NPPs with many modules include risk analysis of the use of common systems, common staff for all modules, control from one control room, simultaneous operation of some and recharging of other modules, diagnostics, and control of metal in small free volumes, the reliability of steam generators, recharging technology and much more.

Who, where and when will build the first NPP with NuScale modules

So far only Utah Associated Municipal Power Systems (UAMPS). It is a structure of the Utah state administration that unites small energy companies on a voluntary basis, including from neighboring states. It deals with the planning, financing, construction, maintenance and operation of energy projects of general interest, as well as with the transmission and distribution of electricity. Delivers to customers about 5.5 billion kWh - about 1/7 of Bulgaria's consumption. In 2015, a project for the construction of a nuclear power plant with MMS of NuScale Power was launched. It aims for the new plant to replace obsolete coal-fired power plants and to be able to work with wind and solar parks.

The government provided a site for the first nuclear power plant with MMR and paid the cost of licensing it (about $ 63 million). It is in the National Laboratory in Idaho (INL) - one of the nuclear complexes in the United States. It is a rocky desert in the neighboring state of Idaho, which has a territory of 217 thousand km^2 and a population of 1.717 million people. INL has an area of 2310 km^2, a staff of about 4 thousand people and a budget of 1 billion dollars. At the end of 1951, for the first time in the world, electricity was received from a nuclear reactor (IBR-1), now a museum. INL has designed and built 52 nuclear reactors for various purposes, most of which have been shut down. It is now the leading center for the development of nuclear energy in the United States. INL plans to hire the first MMP in 15 years and use it as a prototype for research.

The plan envisages the construction of a NPP with 12 modules to take place within 4 years after the first concrete is poured. There will be about 1,600 jobs and 1,350 secondary jobs in construction. The plant's staff is expected to be a total of 360 people (10 times less than at Kozloduy NPP now). Against the background of an average of 0.6 people / MW of electricity at the US nuclear power plant, this is too small and leads to accusations of irresponsibility by critics of the project. About 300 additional jobs will be indirectly created in the district.

The deadlines for commissioning have been repeatedly postponed. Initially, 2019 was mentioned, then 2023.... Until recently, the first 60 MW module was planned to be operational in 2026, and the rest in 2027. The deadlines are already 2029 and 2030, which is probably due to the need to license the 77 MW modules. In order for the next modules to be loaded and installed one after the other, the pool will probably need to be emptied and the first module stopped. This shows that the idea of adding modules for those already working is not applicable. Ultimately, the initial investment for all modules will similarly be invested in large reactors and thus no significant savings in interest costs can be achieved.

BWX Technologies, Inc. was chosen to make the modules -- a company that has produced over 400 reactors for military purposes and over 300 steam generators for nuclear power plants.

Construction of other NPPs with NuScale Power MMR without federal / state subsidies is very problematic and so far there are no investors and clients for them.

Some conclusions

So far, NuScale Power's MMP NPP exists on drawings, models and simulators. An assessment of its real economic indicators, construction experience, commissioning, operation and recharging of the modules will be clear several years after the launch of the first NPP. If the project is implemented and the deadlines are not postponed, this will be possible by 2032.

Going back to the beginning - of course, there is no way to place a nuclear power plant with MMR "in the center of Sofia".

Regarding the ideas in our country, to have 5-6 thousand MW of MMR, by 2030, I can say the following - it is good to collaborate with NuScale Power (and others who are developing MMPs) and to monitor developments. However, to go to the planning and construction of a nuclear power plant with MMR in our country before the technology is proven in practice, would be an irresponsible adventure. I hope that even the current government would not go for it.

A separate issue is what will be done with the spent nuclear fuel (SNF) from the MMR, given that the authorities demonstratively do not implement their own strategy for SNF reprocessing from Kozloduy

NPP, but accumulate it on the site. Thus, they turn it into a nuclear dump and create huge technical problems and financial obligations for future generations.

Whatever new nuclear power plant is decided to be built - with a large reactor or an MMP - it could be operational by 2035. The real debate in the electricity sector must be what will replace the coal-fired power plants, for which the government failed to negotiate work capacity after the middle of 2025.