Conference Paper

Development of an Experimental Reactor VVER-SKD 30 MW on Supercritical Water

Novikova G. S. and Bogoslovskaya G. P.

Obninsk Institute for Nuclear Power Engineering of the National Research Nuclear University MEPhI, Studgorodok 1, Obninsk, Kaluga region, 249040, Russia

Abstract

The results of neutron-physical calculations of various variants of the location of the VVER-SKD core of 30 MW on the water of supercritical parameters are considered. The calculation is made for various fuel loads: uranium, plutonium and thorium, which in the future is considered as one of the main energy resources of the nuclear industry. Studies show that it is advisable to design a reactor with a single-pass flow of coolant and a reflector of at least 20 cm.

Keywords: supercritical water parameters, VVER-SKD, low-power reactor, experimental reactor

Corresponding Author:
Novikova G. S.
wow.day-star@yandex.ru

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1. INTRODUCTION

Specific feature of 21st century's technology based on 238U will be the use of nuclear power units ensuring fuel breeding ratio (BR) no less than unity, instead of 0.5 in modern VVER [2, 5].

The experience of industrial operation of NPP with fast breeder reactor cooled by liquid sodium, has shown the possibility of obtaining HF values in the range 1-1.2. In principle, the use of such nuclear power plants can solve the problem of reprocessing of spent nuclear fuel, provided they are effectively commercialized for the energy sector.

In the last decade, in many countries, another type of advanced nuclear power unit with a reactor cooled by water at supercritical pressure (VVER-SKD or SCWR) is being developed.

Transition to supercritical water parameters (P = 25 MPa, t = 540 °C) can provide an increase in NPP efficiency up to 44-45% instead of 33-34% with a decrease in capital and operating costs.

The VVER-SKD projects with both thermal and fast neutron spectra, implemented within the framework of large international programs, are based on long-term experience accumulated in thermal power engineering and the achievement of nuclear power technology in using water at pressures of 7-18 MPa as a coolant in 440 blocks different countries of the world.

The goal in development of VVER-SKD is to ensure the safety of the installation under normal, transient and emergency conditions. At the present stage, the solution of such a problem can not be achieved without a certain minimum of experimental work, which would form the basis for further calculations and design developments.

So, to work out problematic issues, it is proposed to develop an experimental VVER-SKD facility with a low power of about 30 MW therm [1, 4].

At one time such a strategy was chosen by A.I. Leipunsky during the development of fast breeder liquid sodium cooled reactors (BR-5/10, BOR-60, BN-350, BN-600). It has fully proved its validity and confirmed the immutable fact that when creating a new type of reactor, one can not skip over or ignore any of its stage.

2. CALCULATION CONDITIONS AND INITIAL DATA

The core of the fast-resonant VVER-SKD is designed to generate heat as a result of a controlled nuclear reaction and transfer it from the surface of the fuel elements (fuel rods) to the heat carrier during the design lifetime without exceeding the allowable fuel element damage limits.

The general requirements for the development core of the VVER-SKD are formed on many years of experience in the creation and operation cores of VVER and are as follows:

- when designing and justifying, it is necessary to comply with the requirements contained in the rules for nuclear safety of reactor plants of NP-082-07 (in case of necessary deviation from certain provisions, the argumentation and confirmation of the security provision are necessary);
- ensure the conversion rate in the range of 0.8-1 when using uranium fuel and the same value of the replacement rate (KB) when using MOX fuel;
- ensuring the achievement of the burn up of 40-60 MB day/kg U;
- ensuring the retention of fission products in the fuel cladding (fission gas release under the cladding in conditions of normal use of up to 10%);
- ensuring the health, safety and security in the design conditions, the security should be based on the basis of internal self-defense installation (negative void coefficient of reactivity, negative temperature and power coefficients of reactivity throughout the range of operating conditions);

- simplicity and technological design of the core elements (maximum use of existing technologies and experience in developing and operating VVER and BN fuel);
- mechanical stability and strength in the coolant flow, ensuring the preservation of the size and tightness of fuel rods for the entire service life;
- minimum possible (considering the rest of these requirements) absorption of neutrons by structural materials;
- absence of chemical interaction between fission products and fuel material of the casing;
- hydraulic resistance of fuel assemblies, which is provided by its "not ascent" and not to exceed the cladding temperature of the fuel element 730°C;
- radiation resistance of materials;
- the speed and efficiency of emergency protection should be sufficient to transition the active zone in a subcritical state (including accidents) and maintaining it in this state if cool down;
- acceptable size and design fuel assemblies to ensure maintainability and to use available experience of conducting transport operations in handling with fresh and spent fuel;
- the ability to control the tightness of fuel in the conditions of the reactor and reactor plant.

In the course of the work, two variants of the core were considered and worked constructively, with a single-pass and two-pass flow of the coolant.

2.1. Description and characteristics of the core with a single-pass flow scheme of the coolant

The work is an active search for cores with single circuit flow of coolant. At the moment, the calculated cores of the 19, 7 and 13 fuel assemblies placed in the reactor with a step 207 mm (Figure 1).

The main characteristics of the single-core active zone of the fast-resonant VVER-SKD are presented in Table 1.

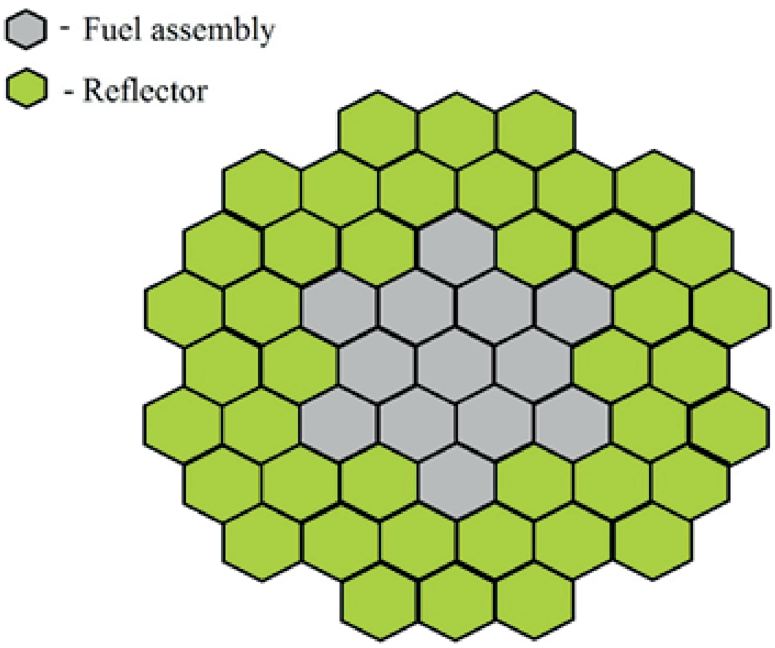

Figure 1: Radial scheme of the core of reactor VVER-SKD.

Table 1: Main characteristics of a single core of VVER-SKD.

Name characteristics	Values
The number of fuel assemblies, pcs.	19/7/13*
The size of the fuel assembly, «turnkey», mm	205
Step of fuel assembly in the core, mm	207
Average energy intensity of the core, W / cm3	35/150/80
Diameter and thickness of fuel cladding, mm	10,7x0,55
Step of the arrangement of fuel elements in a triangular lattice, mm	12
Maximum enrichment of fuel, %, not more than	20
Diameter ** of the core, m	1.04/0.64/1.04
Height ** of the core, m	1.10/0.68/0.70
Material of fuel composition	UO_2 $(U+Pu)O_2$ $(Pu+Th)O_2$ $(U+Th)O_2$
Burnout of fuel, MW day / kg U	40-70
Note * - The above values can be specified in the subsequent calculations Note ** - Without reflector	

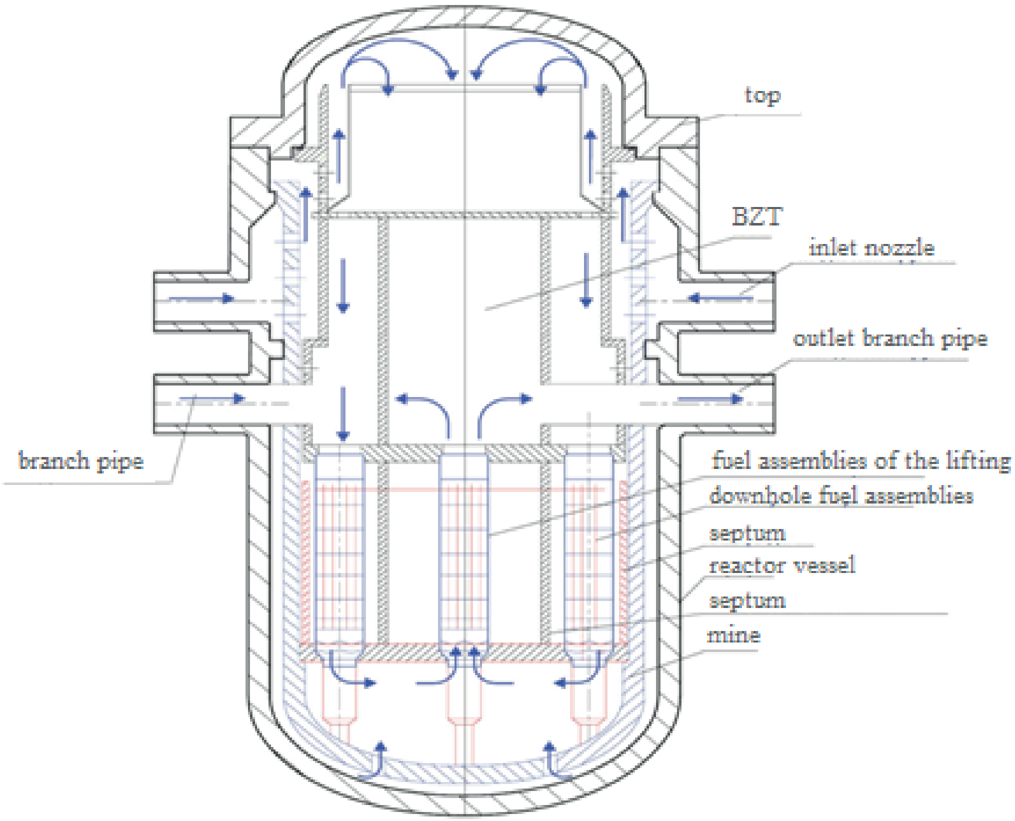

Figure 2: Cooling scheme of a two-input fast-resonance VVER-SKD.

2.2. Description and characteristics of the core with a two-pass flow scheme of the coolant

In the current flow of the heat carrier, the core is divided into two sections (approximately equal to the amount of fuel assemblies): a peripheral zone (PZ) with a descent flow of the coolant and a central zone (CZ) with a lifting motion of the coolant. Between the zones CZ and PZ there is a dividing wall (VR). The cooling scheme of the reactor is shown in Fig. 2.

The coolant flows in the descending and elevating sections are proposed to be separated at ~385 ° C. In the descending section, the heating medium will be heated at 95 ° C, in the elevating area the heating of the coolant will be 155 ° C. The main characteristics of the two-core VVER-SKD core are presented in Table 2.

Table 2: The main characteristics of the two core VVER-SKD.

Name characteristics	Values
The number of fuel assemblies, pcs.	37
The size of the fuel assembly, «turnkey», mm	205
Step of fuel assembly in the core, mm	207
Average energy intensity of the core, W / cm3	13.4
Diameter and thickness of fuel cladding, mm	10,7x0,55
Step of the arrangement of fuel elements in a triangular lattice, mm	12
Maximum enrichment of fuel, %, not more than	20
Diameter / height of the core, m	1.50/1.52
Material of fuel composition	UO_2 $(U+Pu)O_2$ $(Pu+Th)O_2$ $(U+Th)O_2$
Burnout of fuel, MW day / kg U	40-70

2.3. Fuel assembly of the fast-resonant VVER-SKD reactor

The fuel assemblies should consist of fuel rods, guide channels for moving absorbing rods in the reactor protection and control system, elements for forming a neutron spectrum using zirconium hydride, spacers and structural elements. At a stopped reactor, the fuel assembly must allow installation into the core and several permutations from one row to another during operation.

A special feature of the fuel assembly is a dense fuel grid. The distance between the fuel rods is 1.3 mm.

The analogs of the fuel assemblies in question are the bisceglia TVS-2 M of the VVER-1000 reactor; a heavy fuel assembly of the BN reactor and a heavy fuel assembly of the 5th NVNPP unit with a perforated cover [3]. Analogues of solutions for spacing of fuel rods are the honeycomb structure of the TVS-2 M spacing gratings and fuel rod fuel assemblies of BN reactors using wire spirals, which are also intensifiers of intercellular transfer and heat exchange [3].

The main characteristics of a heavy-duty fuel assembly with a hexagon head are given in Table 3.

Table 3: The main characteristics of fuel assemblies of the fast-resonant VVER-SKD reactor.

Name characteristics	Values
The size of the fuel assembly, «turnkey», mm	205
Step of fuel assembly in the core, mm	см. табл. 1, 2
Number of fuel rods in fuel assemblies, pcs.	252
Diameter and thickness of fuel cladding, mm	10,7x0,55
The diameter of the fuel pellet, mm	9,4
Step triangular lattice of the fuel rod, mm	12
The height of the fuel column, mm	
• a single core	700*)
• two-pass core	1333
Number of guide channels, pcs.	18
Central pipe, pcs.	1
The size of the guide channels and the central tube, mm	012x0,55
Thickness of sheath, mm	2,25
*) All the above data can be refined in the course of computational studies	

3. RESULTS AND ITS DISCUSSION

The calculations were performed in the software package Serpent, which is written in standard ANSI-C language and uses the method of Monte Carlo. Currently, the installation package contains the libraries in ACE format based on the evaluated neutron data libraries JEF-2.2, JEFF-3.1, ENDF/B-VI.8 and ENDF/B-VII for several temperatures. There are also several libraries of these ACE format based on various estimates publicly available via OECD / NEA Data Bank.

Table 4 provides a comparative analysis of fuel loads in a reactor with a two-way flow diagram of the coolant. It is obvious that this reactor is not promising, since it has a long fuel campaign and insufficient heating of the coolant.

4. CONCLUSION

At present, great importance is attached to the development of an experimental low-power reactor with a single-pass flow circuit for the coolant. Since a single-pass reactor has a small volume, it is necessary to install a reflector to reduce neutron leakage (it

Table 4: Specifications fuel loads for the core of the double scheme of the coolant flow.

	UO2	(U+Pu)O2	(Pu+Th)O2	(U+Th)O2
Density, g/cm3	10.97	9.3	9.45	9.64
Enrichment, %	15	17	17	10
Download of the fissile nuclei, kg	1419	1364	1386	831
Loading of raw material, kg	8043	6658	6765	7484
Burn, MW day/kg	60	75	70	69
Campaign, years	50			

is also a depleted uranium production zone). The calculations performed in the work show that the thickness of the reflector should be at least 20 cm.

In future, the following tasks must be solved to develop a 30 MW VVER-SKD reactor:

- determine the fuel profiling by the height of the core;
- calculate fuel cycles for various reactor conditions (filling with cold water, outlet to the MKU, breaking the first circuit);
- calculate the efficiency of the reactor control and protection system and the reactivity coefficients.

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