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Concept of a Gas Cooled Fast Reactor

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Currently in a number of the countries the development of reactor designs for the following generation is being carried out.

Among reactors of a new generation the direction of high-temperature gas cooled reactors (both thermal, and fast – GFR), in particular, is recognized.

The purpose of the given work is research the opportunities of HTGRs with a hard neutron spectrum to increase the duration of reactor campaign due efficient neutrons usage at preservation of specific core power density, characteristic for HTGRs with a thermal neutron spectrum. The given purpose can be achieved at use fuel blocks with dense packing of coated particles in the fuel block volume.

To solve the presented problem the variant of so-called “return” fuel assembly is proposed where the coated fuel particles in fuel block matrix material occupy all volume of the block except for standard channels under the coolant. In this case the volume fractions of materials in prismatic type assembly will take approximately 19/31/50 %% accordingly for the coolant, fuel kernels and matrix including the coatings. As results of unit-cell calculations show the small rate of reactivity falling presumes to compensate the reactivity margin by control rods without burnable poison using. The core campaign is comparable with service life of power plant and can consists of 40 years.

KEYWORDS: gas cooled fast reactor, hard neutron spectrum, coated particles, matrix material, return fuel block design

1. Introduction

Currently in a number of the countries the development of reactor designs for the following generation is being carried out.

Though in immediate prospect (10 years and more) as it is marked, for example in [1], the plants of a new generation will not be ready to commercial use, the future of nuclear power and maintenance of its steady development and viability [2] considering in connection with creation of such systems.

Among reactors of a new generation the direction of high-temperature gas cooled reactors (both thermal, and fast – GFR), is recognized.

The combination of advantages of a hard neutron spectrum with achievements in the field of high-temperature reactors on thermal neutrons effectively allows to solve the problems of safety improving, reduction of environmental effect by an effective utilization of nuclear fuel and natural resources, burning of plutonium of different quality and minor actinides, maintenance of non-proliferation of nuclear materials. The high parameters of the coolant open the ample opportunities of use high-potential heat in different processes.

The purpose of the given work is research the opportunities of HTGRs with a hard neutron spectrum to increase the duration of reactor campaign due efficient neutrons usage at

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preservation of specific core power density, characteristic for HTGRs with a thermal neutron spectrum. The given purpose can be achieved at use fuel blocks with dense packing of coated particles in the fuel block volume.

2. Concept background

The idea to use the fuel on the basis of coated particles, placed in a matrix material, was realized in high-temperature helium reactors on thermal neutrons. At the analysis of applicability of this concept to reactors on fast neutrons it is necessary to take into account, that the volume fraction of heavy metal in an active core should be not lower 30÷40 %, and concentration of easy nuclides (C, N, O) – should be lower, than in HTGRs. At use of coated particles technology in fast reactor the volume fraction of fuel in an active core with pebble-bed design does not exceed ~15 %. Even at absence of a multilayered coatings of fuel particles the share of fuel does not exceed 30 %. Thus, the direct carrying of the decisions accepted for HTGRs with thermal neutron spectrum and pebble-bed core, is unacceptable for conditions of helium high-temperature reactor on fast neutrons.

More perspective variant of the developed technologies usage is application of HTGR concept with the active cone on the base of prismatic fuel blocks. As a prototype the fuel block of reactor designs Fort Sent Vrain and GT-MHR is selected. To increase the volume fraction of fuel in fuel block the variant of "return" configuration is offered. The geometry and the sizes of standard fuel block of GT-MHR design are kept, however coated particles in matrix material occupy all volume of the block except for standard channels under the coolant (Figure 1).

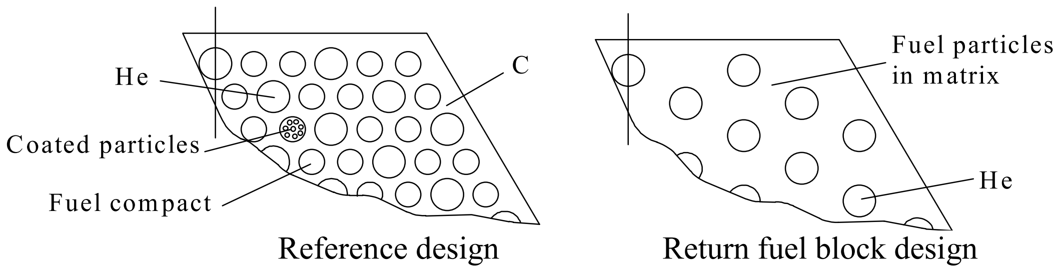

Fig.1 Reference and return configurations of fuel block

The parameters of coated particles accepted for research are given in table 1.

Table 1 Parameters of coated particles

UO_2 kernel of 1500 μm diameter		
Thickness of layers, μm	Type	Density, g/cm^3
90	BPyC	1,0
40	IPyC	1,7
40	SiC	3,2

At such configuration the volume fractions of materials in prismatic type assembly will take approximately 19/31/50 %% accordingly for the coolant, fuel kernels and matrix including the coverings.

As fuel the low-enriched uranium was used where the content of ^{235}U does not exceed 20%. The share of fuel material volume occupied by coated particles is accepted equal of 0.7, i.e. close to extreme theoretically possible for dense packing.

Potentially as a material of matrix in which the coated particles set the different high-temperature materials having acceptable neutronics properties, such as well known silicon carbide, different ceramics can be used. As the candidates metals (V, Ti, Cr) can be considered also.

The choice of core characteristics significantly depends on objects in view. For preservation of an opportunity of active core cooling down through the reactor vessel without excess of limiting fuel temperature the configuration of an active core is kept same, as in GT-MHR. Accepted low core specific power density (~6,5 MW/m^3 at thermal reactor power of 600 MW), on the one hand, alongside with increased due hard neutron spectrum conversion results to low reactivity decrease per unit of fuel burnup and to maintenance of core campaign (without refuellings), comparable with reactor plant service life. On the other hand, the big specific load of heavy metal (as a whole more than 200 t per core), results in high initial expenses and deterioration of fuel cycle economics.

Thus, the offered concept can be considered as variant of reliable long-term storage of nuclear materials in reactor conditions (so-called the concept of the postponed processing) with an opportunity of the future processing the irradiated fuel for allocation and recycle of nuclear and other materials.

3. Calculation method

To analysis of core with different type of matrix material the calculations of unit-cells were carried with using code WIMS-D4 [3] and nuclear libraries UKNDL, FOND2. Calculations were conducted in 23-group approximation. The material of matrix and coated particles consisting of kernels in ceramic coverings were homogenized and further calculation was carried out without taking into account double heterogeneity of fuel which effect in systems with a hard spectrum is insignificant.

4. Results

Comparison of characteristics of different options with different materials of matrix at dense packing of coated particles was made (Table 2). Initial enrichment of fuel for different compositions was selected from condition of maintenance identical initial reactivity margin.

Table 2 Characteristics of variants with different material of matrix

The characteristic	The material of matrix				
	SiC	ZrC	ZrN	BeO	Al_2O_3
Density of matrix, g/sm^3	3,2	6,4	7,3	3,0	3,7
The relation of concentration of easy nucleus (O, C, N) to uranium (a)	7	6	7	8	8
Rate of multiplication coefficient decrease per fuel burnup, rel. unit	1	1,44	1,74	1,19	1,08
Campaign of core, rel. unit (b)	1	0,69	0,57	0,83	0,90

[a] the relation of concentration of easy nucleus to uranium for GT-MHR consists of ~480

[b] campaign of an active core for variant with SiC consists of about 40 years

The results given in Figure 2, show, that from neutronics point of view practically all given high-temperature materials can be used as material of matrix. A little bit worse characteristics show connections of zirconium owing due not optimal neutron balance because of absorption on Zr. Restriction at a choice can becomes faster reasons of technological character, and also matrix resistance in GFR conditions. Small rate of reactivity falling presumes to compensate the reactivity margin by control rods without burnable poison using. The core campaign is comparable with service life of power plant.

Thus, the variant of return fuel block design with increased diameter of fuel kernels is perspective for the further development.

To develop this concept it is necessary to solve a number of basic problems among which as key are the following.

- Development of new kinds of fuel with the high specific content of heavy nucleus, capable to provide the fission products retention at neutron fluence $\geq 5 \cdot 10^{21}$ cm^{-2} (E > 0,18 MeV) and temperatures ~ 1600-1800 °C.
- The analysis of properties and choice of high-temperature in-core materials compatible to a fuel composition.
- Choice of active core performance satisfying both requirements of a fuel cycle, and to conditions of maintenance of passive safety at reactor cooling down at accidents at acceptable economic parameters.

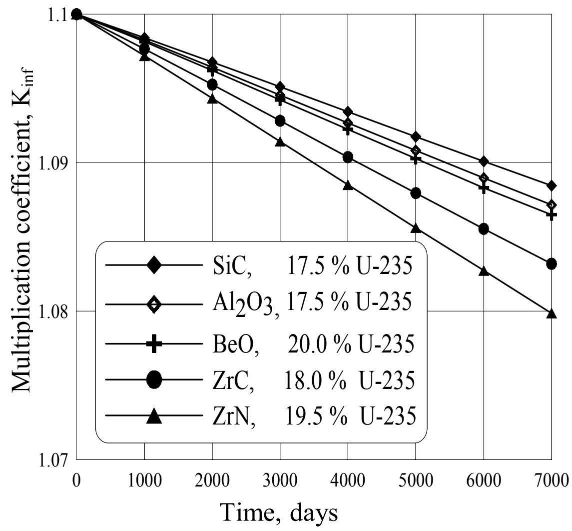

Fig.2 Dependence of multiplication factor versus irradiation time for different matrix materials

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