COMPARISON OF THE PARAMETERS OF THE IR-8 REACTOR WITH DIFFERENT FUEL ASSEMBLY DESIGNS WITH LEU FUEL

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ABSTRACT

The estimation of neutron-physical, heat and hydraulic parameters of the IR-8 research reactor with low enriched uranium (LEU) fuel was performed. Two fuel assembly (FA) designs were reviewed: IRT-4M with the tubular type fuel elements and IRT-MR with the rod type fuel elements. UO_2-Al dispersion 19,75% enrichment fuel is used in both cases. The results of the calculations were compared with main parameters of the reactor, using the current IRT-3M FA with 90% high enriched uranium (HEU) fuel. The results of these comparisons showed that during the LEU conversion of the reactor the cycle length, excess reactivity and peak power of the IRT-MR type FA are higher than for the IRT-3M type FA and IRT-4M type FA.

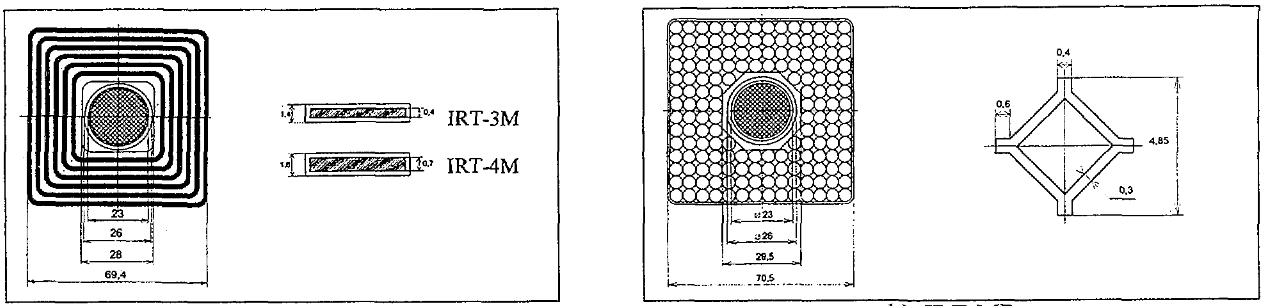
Introduction

The IRT-M type FA with tubular fuel elements are used in many research pool-type reactors (IR-8, LWR-15, IWW-7, WWR-SM). There are a several modifications of this type FA (IRT-2M, IRT-3M) which differ by number of fuel elements, fuel element sizes and fuel enrichment. It is supposed to use IRT-4M FA with tubular fuel elements on the basis of the present UO_2-Al fuel for LEU conversion of the research reactors. The thin-walled design of the tubular fuel elements has a fabricating limit of a fuel loading equal to ~36%$_{vol}$. The alternative FA design (IRT-MR) with the rod fuel elements is studied in this paper. The design of the rod fuel element allows to unify the tubular fuel element variety, to simplify a fabricating process and to increase fuel loading up to ~50%$_{vol}$. The results of design development and experimental-industrial fabricating process of rod type fuel elements with LEU were submitted in the papers [1,2].

The study of feasibility of the IRT-4M type and IRT-MR type FA usage is performed for the IR-8 reactor located in the Russian Research Center "Kurchatov Institute".

Core and fuel assembly descriptions

The IR-8 reactor core consists of 16 FA, arranged in a square 4×4 arrangement with spacing 71,5 mm. The core surrounded by a beryllium reflector has 12 beam tubes and more than 30 vertical experimental channels. The core height is 580 mm. The IRT-3M type 8-tube and 6-tube FA with UO_2-Al HEU fuel are used in the reactor. The calculations have been performed for the main operative loading of the core, consisting only of 6-tube FA. These FA have the central channel either for control rod or for sample irradiation. The IRT-4M 6-tube FA design (Fig.1a) differs from the current IRT-3M FA only by the fuel element thickness. The IRT-MR type FA design (Fig.1b) has the same shape and the overall shroud dimensions as the elementary core cell. The sizes and design of the end details are preserved. Only the outer shape and dimensions of channel for control rod are changed slightly. The basic geometrical parameters of three fuel assembly designs with the central channel are given in Table 1.



a). IRT-4M (IRT-3M) b). IRT-MR

Figure 1. Cross Sections of Fuel Assemblies and Fuel Elements

Table 1. Fuel Assembly Geometrical Parameters

Parameter	Fuel Assembly Type		
	IRT-3M	IRT-4M	IRT-MR
Number of Fuel Elements in FA	6	6	164
Area of Water Passage, cm^2	26,9	24,5	25,6
Heat Transfer Surface, m^2	1,37	1,37	1,48
Hydraulic Diameter, mm	4,1	3,7	3,5
Fuel Meat Volume, cm^3	274	479	488
Volume Fraction of Coolant	0,548	0,468	0,528
Specific Surface of Heat Transfer, 1/cm	4,62	4,62	5,0

Neutron-physical parameters

Neutron-physical calculations were based on a procedure proved by the numerous experiments. Excess reactivity and the thermal neutron fluxes were calculated using the two-group two-dimensional IRT-NOW code [3]. The neutron cross sections were computed using URAN-AM code [4].

Neutron-physical calculations have been performed for the idealized physical model of the core at the following assumptions and conditions:

- the core and reflector components are homogeneous;
- the Pb shield and experimental channels aren't taken into account;
- the reflector thickness is assumed to be ~ 30 cm;
- all control rods are removed out of the core, there are the aluminum displaceres instead of them;
- only fresh core is studied;
- the equilibrium cycle lengths are taken from calculated data given in [5].

The U_{235} loading in the LEU FA is determined to provide the same cycle length as for the HEU ITR-3M type FA [5]. U_{235} content is equal to 360 g per IRT-MR type FA. Taking into account the fabricating limit for the tubular fuel element maximum U_{235} content is equal to 309 g per IRT-4M 6-tube FA. Summary of the calculated results for two versions of the core (16 IRT-4M 6-tube FA or 16 IRT-MR rod type FA) is given in Table 2 and in Fig.2. The neutron-physical parameters for the current IRT-3M type HEU FA [5] also are given in Table 2. The relative values of FA power and the energy liberation non-uniformity coefficient in their cross section at the beginning of the cycle are shown in Fig. 2.

	1	2	3	4
A	$\frac{1.58}{6.39}$	$\frac{1.47}{6.29}$	$\frac{1.47}{6.29}$	$\frac{1.58}{6.39}$
B	$\frac{1.47}{6.29}$	$\frac{1.04}{6.03}$	$\frac{1.04}{6.03}$	$\frac{1.47}{6.29}$
C	$\frac{1.47}{6.29}$	$\frac{1.04}{6.03}$	$\frac{1.04}{6.03}$	$\frac{1.47}{6.29}$
D	$\frac{1.58}{6.39}$	$\frac{1.47}{6.29}$	$\frac{1.47}{6.29}$	$\frac{1.58}{6.39}$

a). IRT-4 M FA

	1	2	3	4
A	$\frac{1.64}{6.36}$	$\frac{1.57}{6.29}$	$\frac{1.57}{6.29}$	$\frac{1.64}{6.36}$
B	$\frac{1.57}{6.29}$	$\frac{1.04}{6.06}$	$\frac{1.04}{6.06}$	$\frac{1.57}{6.29}$
C	$\frac{1.57}{6.29}$	$\frac{1.04}{6.06}$	$\frac{1.04}{6.06}$	$\frac{1.57}{6.29}$
D	$\frac{1.64}{6.36}$	$\frac{1.57}{6.29}$	$\frac{1.57}{6.29}$	$\frac{1.64}{6.36}$

b). IRT-MR FA

Figure.2. $\frac{\text{the energy liberation non-uniformity coefficient in FA cross section}}{\text{the FA power in relative units, \%}}$

Table 2. Main Neutron-Physical Parameters of the Core

Parameter	Fuel Assembly Type		
	IRT-3M	IRT-4M	IRT-MR
Fuel Enrichment, %	90	19,75	19,75
U_{235} Loading in FA, g	265	309	360
U Density in Meat, g/cm^3	1,07	3,27	3,74
Volume Fraction UO_2, %	12	35,7	40,8
Excess Reactivity Δk/k, %	21,6	22,1	22,5
Peak Thermal Flux in active core, (n/cm^2·s)	$1{,}53\cdot10^{+14}$	$1{,}45\cdot10^{+14}$	$1{,}3\cdot10^{+14}$
Peak Thermal Flux in reflector, (n/cm^2·s)	$2{,}46\cdot10^{+14}$	$2{,}4\cdot10^{+14}$	$2{,}3\cdot10^{+14}$
Average U_{235} Discharge Burnup, %	62,9	61,6	63,0
Cycle Length, day	34	32	36

Hydraulic parameters of Fuel Assembly

The main feature of pool-type reactors operation is a low coolant pressure in the FA and a small pressure fall in the core. It causes the limitation of hydraulic FA resistance. The accuracy of this parameter estimation determines the FA heat calculation accuracy. In the case of the IR-8 reactor for the input coolant pressure P_{in}=1,9 atm, the maximum pressure fall ($\Delta P_{a.z.}$) is equal to 0,25 atm.

The hydraulic parameters of the IRT-3M and IRT-4M type FA were taken from calculated and experimental data, given in [6,7].

To define the hydraulic resistance of the IRT-MR rod type FA the experimental studies of simulated fuel assembly were made. Simulated fuel assembly consists of 25 finned square rods with d_c=4,85 mm. The rod bundle is placed into a square tube with spacing 4,92 mm. The spacer grid is located in the upper part of tube and the support grid in lower one. The hydraulic tests were made for the water flow change from 1 to 9,5 m^3/hour. The results of the measurements are presented in Fig.3.

The analyses and comparisons of the calculated and experimental data showed that the friction drag coefficient in this assembly design can be calculated as following: $\xi=0{,}47\cdot Re^{-0{,}25}$ with maximum difference ±5% (see Fig.3). The results of calculations of total pressure fall versus coolant flow are given in Fig.4 for IRT-MR rod type FA design. As it can be seen from this figure for the total hydraulic resistance of the core 0,25 atm, the coolant flow in IRT-MR FA is equal to 21,5 m^3/hour.

The hydraulic parameters of three FA types are presented in Table 3.

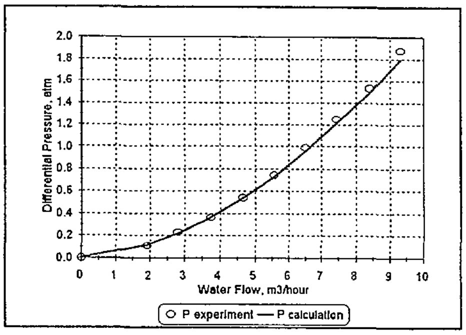


Fig.3. Pressure fall vs water flow for the simulated fuel assembly

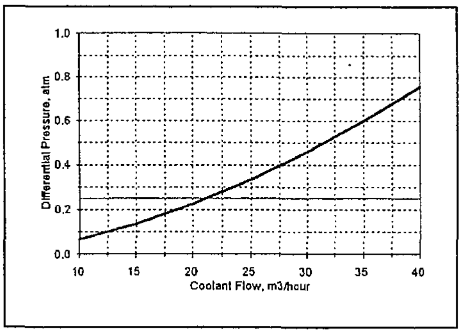


Fig.4. Pressure fall vs coolant flow for the IRT-MR rod type FA

Table 3. Hydraulic Parameters of FA

Type FA	Total resistance flow coefficient	Average coolant flow velocity, m/s	Coolant flow, m^3/hour
IRT-3M	7,32	2,6	25
IRT-4M	8,13	2,48	21,9
IRT-MR	9,23	2,33	21,5

Heat engineering parameters of Fuel Assembly

To estimate the maximum power ability of reactor the multiple heat calculations of the most heated FA, located in the cell A-1 (Fig.2) were performed. The absence of surface boiling is used as a limit factor. The key parameter is the fuel element cladding temperature, the maximum value of which should not be higher than the saturation temperature or the set allowable value ($t_{cl}^{max} \leq t_s$).

The heat calculation procedure for annular channel [9] were used for the IRT-4M FA with tubular fuel elements. The heat flux partition and temperatures were computed analytically.

The heat parameters of the IRT-MR rod type FA were computed using KANAL code [10]. The two-dimensional temperature fields in the fuel element cross section were calculated using CBA02C [11] code.

The heat calculations were performed at the following assumptions and conditions:

- for the start state of the fuel elements without taking into account of fuel burnup;
- for the nominal values of basic parameters;
- for average heat transfer characteristics in the FA cross section;
- the allowable cladding temperature is assumed to be 110°C;
- the input coolant pressure and temperature are taken from [8] (P_{in}=1,9 atm, t_{in}=45°C);
- the energy distribution at the height of the core is determined as $K_z(z)=\cos[\pi/(H+2b)\cdot(z-0.5\cdot H)]$ with K_z^{max}=1,23 [8];
- the reactor power is changed from 5 to 10 MW.

The results of the calculations are given in Fig.5. Using a condition $t_{cl}^{max} = t_s$ makes it possible to determine the maximum power of the reactor. Summary of the heat calculation results is presented in Table 4. In this table the main heat parameters [8] of the current HEU IRT-3M type FA are given.

Table 4. Heat Engineering Parameters of FA

Parameter	Fuel Assembly Type		
	IRT-3M	IRT-4M	IRT-MR
Maximum Allowable Reactor Power, MW	8*	9,8	10,4
Maximum FA Power Ability, kW	606	626	662
Specific Power, kW/l	168,4	206,3	219
Maximum Fuel Rating, kW/g^{U235}	2.29	2,025	1,84
Maximum Heat Flux, MW/m^2	695	888	902**
Maximum Fuel Meat Temperature, °C	112	114	122
Maximum Fuel Cladding Temperature, °C	110	110	110
Average Cladding Temperature, °C	110	110	103**

*) the nominal power of the reactor; **) the average value at a fuel element perimeter.

In addition the estimation of the fin efficiency in the heat transfer was studied. The heat calculations of the rod type fuel element with fins and without fins (Fig.6) showed that the fins result in:

- the reduction of the fuel element temperatures about ~14°C at the maximum power;
- the increasing of the maximum power of the reactor from 8,5 MW to 10,4 MW;
- the increasing of the non-uniformity of the heat flux and the cladding temperature at a fuel element perimeter; maximum of the heat flux is located in the square side middle (Fig.7) with $Kq=q_{max}/q_{cp}$=1,14.

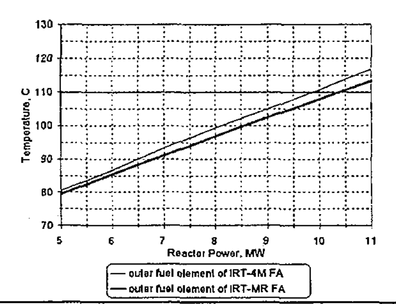
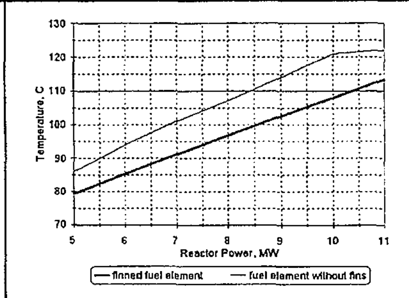
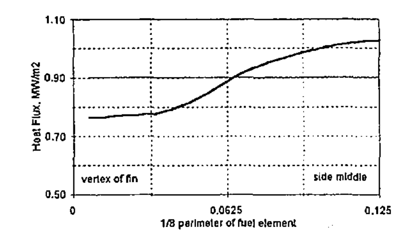
		

Figure.5. The maximum fuel element cladding temperature vs power in the cross sections at the core height $h_{a.c.}$ =290 mm.

Figure.6. The maximum fuel element cladding temperature vs power in the cross sections at the core height $h_{a.c.}$ =290 mm for two rod fuel element design.

Figure.7. The heat flux distribution on a fuel element in the cross sections at the core height $h_{a.c.}$ =290 mm for N_{FAmax}=662 kW.

Conclusions

The comparisons of the main parameters of IR-8 reactor with the three FA types – HEU IRT-3M, LEU IRT-4M and LEU IRT-MR showed that for the IRT-MR FA with the rod type fuel elements the excess reactivity, the equilibrium cycle length and peak power of the core are increased, but the thermal neutron fluxes and average flow velocity in the core are reduced.

This conclusion may be used for all reactors, utilizing the IRT-M type FA.

Acknowledgments

Authors gratefully acknowledge the collaborator of RRC "Kurchatov Institute" P.Egorenkov for his help.

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