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ENRICHMENT REDUCTION POSSIBILITY FOR MEPHI RESEARCH REACTOR

V.Alferov, E.Kryuchkov, and M.Shchurovskaya
Atomic Research Center
National Research Nuclear University MEPhI,
31 Kashirskoe Shosse, 115409 Moscow, Russia

ABSTRACT

The IRT MEPhI pool type research reactor (2,5MW) currently uses IRT-3M HEU (90%) fuel assemblies (FA). The University plans to perform the technical feasibility studies of conversion of IRT MEPhI reactor from HEU to LEU fuel. In the framework of the feasibility studies we propose to pay more attention to the problems of models validation as for operating HEU fuel core as for future LEU fuel core and the problems of collaboration of different research reactors. Validated operating HEU fuel core model is an obligatory condition for feasibility studies of reactor conversion from HEU to LEU fuel. The University has a broad range of experience in research reactor calculation support development and implementation, neutronic codes validation by comparison to plant data and measurements. For the validation of HEU fuel core model developed at MEPhI an extensive comparison with measured values was performed. Using this model three different types of LEU FA will be analyzed: IRT-3M tube-type FA with U9Mo-Al fuel, IRT-4M FA with UO_2-Al fuel, and pin-type FA with U9Mo-Al fuel. Several preliminary investigations showed that due to specific IRT MEPhI operation mode (fuel cycle has practically arbitrary length, FA is discharged only at maximum burn up, the number of FA's in the core can vary) the requirements to new fuel would be less stringent than for the reactors performed the irradiation services.

1. Introduction

The IRT MEPhI pool type research reactor (2,5MW) currently uses IRT-3M HEU (90%) fuel assemblies. The reactor first reached criticality in May 1967. IRT MEPhI began to operate with 4(3) tube IRT-2M FA's in 1975. The reactor is used for testing of the wide range neutron flux control channels for NPP reactors, ionization chambers and new types of radiation protective cables, neutron capture therapy investigations, neutron activation analyses, experiments in nuclear physics and personnel training. The reactor has 10 horizontal beam tubes, a graphite thermal column, and vertical irradiation channels in the reflector.

A problem of conversion of research reactors from HEU to LEU fuel was discussed and investigated for many years. Recent years several types of new LEU fuel were developed, now are tested and some of them are used at operating research reactors. There are some experimental results. Now the conversion studies except of their main goal have new sense – these studies stimulate neutronic model development and especially validation for research reactors (and for operating HEU fuel cores too). From our point of view, conversion studies can also be useful for the development of different research reactors collaboration. The University plans to perform the technical feasibility studies of conversion of IRT MEPhI reactor from HEU to LEU fuel.

2. Feasibility Studies for LEU Conversion

The criteria for LEU conversion of a specific reactor are:
- safety parameters;
- experiment performance (the ability of the reactor to perform its scientific mission);
- annual FA consumption (annual operating costs).

Some IRT MEPhI specific requirements are discussed further.

Safety parameters

Requirements to nuclear safety parameters (shutdown margins, margin to onset of nucleate boiling) are the same for IRT MEPhI as for all research reactors. The requirements to radiation safety parameters are more stringent due to the reactor location at University.

Due to low power of the reactor and not large working time per year the calendar time when FA is used in the core is near to 10 years. That is LEU FA should support hermeticity during larger period than usually for the research reactors with larger power. The term “FA service lifetime” should take into account calendar time.

Experiment performance

IRT MEPhI does not perform significant irradiation services. That is the neutron fluxes in vertical channels near the core are not the key parameters.

The tasks concerned with testing of wide range neutron flux control channels, with testing of ionization chambers and with personal training do not require the work on nominal power level for a long time and do not significantly depend on neutron flux level and neutron spectrum.

The tasks concerned with neutron capture therapy investigations could be affected by neutron flux level and neutron spectrum near the core (studies should be performed).

Annual FA consumption

Due to specific IRT MEPhI operation mode reactor fuel cycle has practically arbitrary length. The core is reloaded in two cases: excess reactivity is not enough or calculated average burn up of one of the FA's has reached maximum value 55%. If excess reactivity is not enough and maximum average burn up of all FA's is less than 55% the number of FA's in the core can be enlarged or some of these FA’s can be discharged (but later they will return to the core). In such case fuel cycle length and burn up of discharged FA’s are not the key parameters to compare the different types of fuel.

An attempt to preserve a fuel cycle length and FA’s number in the core results in the reduction of discharged FA’s burn up and increase of FA consumption. That leads to the fact that LEU fuel types with U-235 content equal to the HEU fuel one are not suitable for conversion. IRT MEPhI case is free of the mentioned above requirement. When FA is discharged only at maximum burn up (the same as for HEU fuel) the FA consumption is defined mainly by mass of burned U-235.

For LEU fuel with U-235 content equal to the HEU fuel the FA’s number for the initial loading should be lager, but FA consumption during further reactor operation will be equal to the HEU fuel case. That is, as for FA consumption, the requirements to LEU fuel for IRT MEPhI would be less stringent than for the reactors performed the irradiation services.

Specific procedure for FA consumption definition is necessary for IRT MEPhI. Due to the absence of equilibrium fuel cycle in practice, the problem of annual FA consumption definition can not be reduced to the analysis of such equilibrium cycle or any other short period. Fuel consumption for IRT MEPhI can be defined as a number of loaded fresh FA’s for rather long period of time (several generations of FA’s in the core, i.e. W~70000 MW·hours).

For example during the period 1991-2009 integral energy generation was 65000 MW·hours and 21 fresh FA's were loaded in the core. Calculated data for fuel types comparison should be defined by analogous manner (by modeling of reactor operation for the period with W~70000MW·hours).

3. Validation of HEU fuel core model

Validated operating HEU fuel core model is an obligatory condition for feasibility studies of reactor conversion from HEU to LEU fuel. LEU fuel core can be investigated only when a good agreement between measured and calculated values for operating HEU core is obtained. The University has a broad range of experience in research reactor calculation support development and implementation, neutronic codes validation by comparison to plant data and measurements. For IRT MEPhI research reactor TIGRIS code was developed and used for core follow calculations since 1995 [1]. The model based on TIGRIS code is suggested to use in feasibility studies. To illustrate background experience some results of HEU core model validation are presented further.

Models and codes

The TIGRIS code is a three-dimensional nodal simulator. The code is used in the support of the IRT MEPhI reactor in reload planning, cycle analyses and licensing calculations. TIGRIS code is intended for 3-dimensional (in rectangular geometry) diffusion steady state neutronic calculation based on nodal or finite difference algorithm. The processes of fuel burn up, reactor xenon poisoning and beryllium poisoning by He-3 and Li-6 are calculated. 4 (6) group assembly homogenized cross sections were prepared with the GETERA lattice code [2]. GETERA code uses the collision probability method.

For model validation the extensive comparison with measured values was performed. The reactor multi-cycle operation history since the moment when IRT MEPhI began operation with IRT-2M fresh fuel (1975) till the current time was simulated in detail with the actual control rod positions. Reactivity for experimental critical control rod (CR) positions at startup without Xe poisoning and for Xe equilibrium state were calculated for 120 cycles. Excess reactivity and reactivity worth of control rods for 25 cycles was compared with measured values. Calculated fuel burn up distributions (including axial shapes) were compared with the results of special experiments.

The results of calculation of experimental critical states at reactor startup since 1995 are shown in Figure 1 (β_{eff}=0,0077).

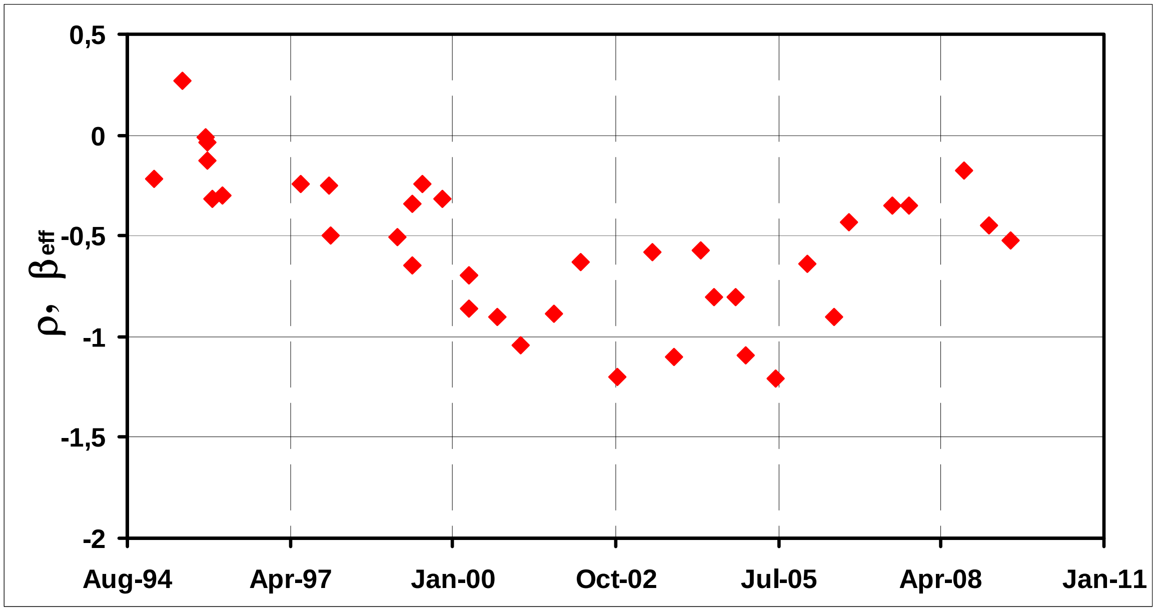

Figure 1 Calculated reactivity for experimental critical control rod positions at startup

Control rods worth

Integral reactivity characteristics (control rods worth, excess reactivity) are measured using calibration procedure. Regulating rod worth is measured by asymptotic period method, shim rods worth is measured by compensation with regulating rod, scram rods worth is measured by rod "drop" method. The calculated results are obtained by the analogous manner - by modeling of experimental calibration procedure. An example of the results of such modeling is presented in Figure 2. The calculated reactivity for different experimental critical control rods positions in the course of shim rods calibration is presented. It is important that calculated reactivity difference between different measured critical CR's positions for the same core is less than $0{,}4\beta_{eff}$. This value was defined by numerous calibration procedures modeling. For a diffusion code it is the minimum difference which can be reached if control rod position is measured with accuracy ±5mm from the bottom of control rod channel. Using the results of calibration procedure modeling the curves of shim and regulating rods integral reactivity (S-curves) are obtained as for experiment (an example of such curves is presented in Figure 3). Calculated scram rod worth is a difference between the reactivity of two calculations: scram rod is fully withdrawn and fully inserted (other CR's at critical position). The results of measured and calculated reactivity worth of CR's for IRT MEPhI are shown in Table 1. The described procedure of calculated CR worth determination allows to take into account the CR's interference as in experiment.

Table 1 IRT MEPhI reactivity worth of CR's: Measured Vs Calculated (AZ-1,2,3- scram rods, KC-1,2,3-shim rods, AR-regulator)

Date	(Calculated- Measured)/ Measured, %						
	AZ-1	AZ-2	AZ-3	AR	KC-1	KC-2	KC-3
07.07.97	0	-10	-4	5	6	3	3
05.01.98	-5	-5	-3	4	-1	-2	-4
18.05.99	0	-8	-1	3	3	-1	0
23.11.99	7	-6	5	5	-4	-1	-2
10.05.00	-3	-6	-3	6	8	10	7
15.03.01	-2	-7	-3	4	-6	-10	-9
15.03.02	-3	-8	-8	1	-2	-7	-6
02.06.03	-4	-6	-4	13	7	6	4
24.03.04	-5	-6	-4	11	7	8	6
16.01.06	-5	-6	0	15	5	5	3
02.10.07	-1	-1	-5	10	0	2	2
02.03.09	-	-	-	6	-2	-1	-4

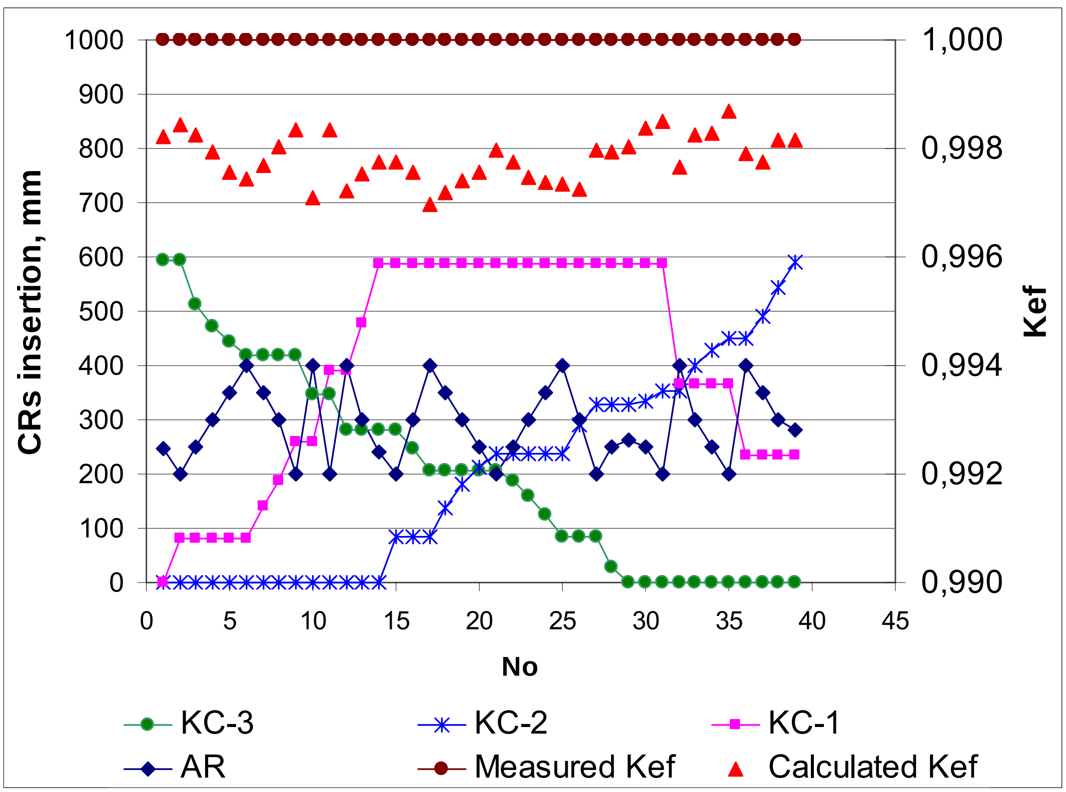

Figure 2 An example of calculation of set of measurements with different CR's positions (CR's calibration modeling, KC-1,2,3-shim control rods, AR-regulator)

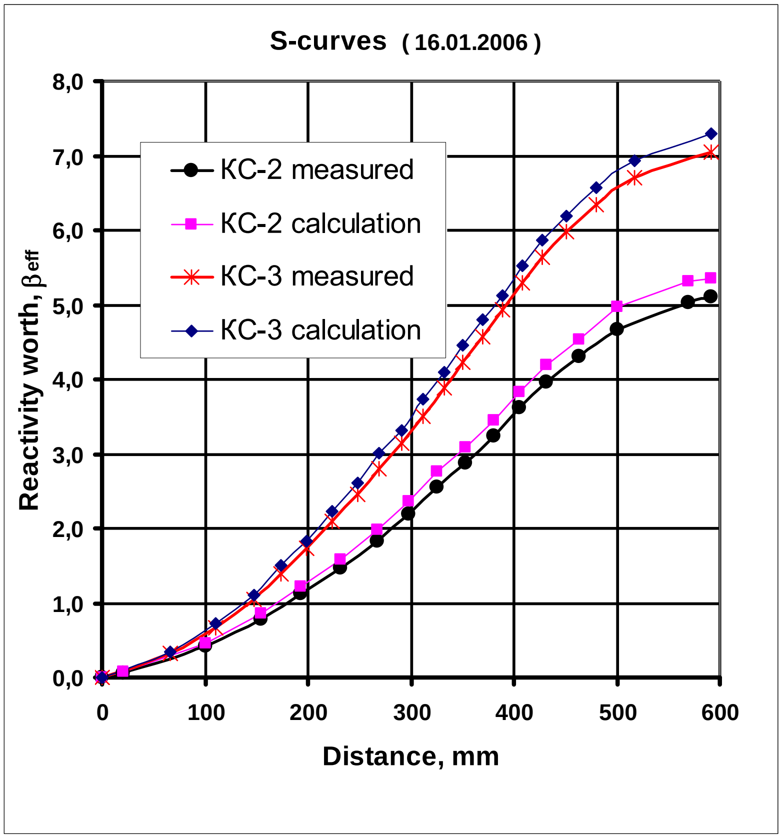

Figure 3 Reactivity worth of shim rods

Excess reactivity

The experimental value of excess reactivity is measured using control rods S-curves in accordance with critical CR's position. The excess reactivity can be calculated by two ways as a result of calculation with all CR's withdrawn and using calculated S-curves in accordance with calculated critical CR's position. A comparison of the measured and calculated results is presented in Table 2. Excess reactivity calculated using S-curves shows better agreement with measured values. When the excess reactivity is large and many CR's are inserted two calculation methods have a large difference (up to $0,8\beta_{eff}$). It is necessary to take into account for adequate comparison of measured and calculated values. Often it is unacceptable to compare the result of calculation with all CR's withdrawn with measured excess reactivity. Also if we are going to compare calculated and measured shutdown margin it is better to define the calculated value as a difference between the calculated excess reactivity and the calculated integral worth of shim and regulating rods (not as a result of calculation with all shim and regulating rods inserted).

Table 2 IRT MEPhI excess reactivity

Date	Excess reactivity, β_{eff}		
	Measured	Calculation (S-curves)	Calculation (all rods withdrawn)
07.07.97	5,2	5,1	5,3
18.05.99	7,8	7,4	6,6
23.11.99	5,9	5,6	5,5
10.05.00	6,8	6,7	6,3
23.10.00	6,3	5,6	5,6
09.10.01	6,1	5,0	4,9
15.03.02	9,3	8,0	7,1
28.10.02	7,4	6,3	6,0
02.06.03	6,7	6,3	6,3
14.10.03	6,5	5,8	5,8
24.03.04	8,5	8,6	7,9
16.01.06	8,8	8,8	8,0
28.09.06	7,4	7,5	6,9
10.02.07	7,9	7,8	7,5
04.02.09	6,1	6,0	5,7

Results of HEU fuel core model validation

So, neutronic model based on TIGRIS code ensures acceptable accuracy for operational problems of IRT MEPhI reactor with HEU fuel core. It means that the part of calculation model describing control rods and reflector (including beryllium poisoning) is well adapted to a specific reactor and that there is a good experience in experiment and calculation results comparison. It is especially important for a diffusion code for which reflector description is a main problem. The part of calculation model mentioned above will be the same for LEU fuel core and it makes planning LEU fuel investigations more adequate to reality.

4. Preliminary studies on LEU fuel core model validation

For model validation it is very useful to carry out the comparison with the experiments for LEU fuel FA's. The results of critical experiments with LEU fuel IRT-4M were presented at meeting RERTR-2006 [3]. The IRT-4M 8-tube and 6-tube fuel assemblies were loaded to the Tajoura critical facility in January 2006. We use some presented at meeting RERTR-2006 results for initial validation of TIGRIS code. Reflector description of the Tajoura critical facility was got from [4]. 6-group cross section library was prepared for IRT-4M FA's and the reflector. Horizontal beam tubes were taken into account as homogeneous regions (water-aluminum-emptiness with relative volume fractions).

The results of calculation of experimental critical states with different CR's insertion for the 16 FA's core are presented in Table 3. MCNP results from Table 3 are the results presented at [3].

Table 3 Results of critical state calculation (Tajoura critical facility)

Measured Rods Insertions at Critical State, mm					
AZ-1/AZ-2	0	0	0	0	0
KC-1	443	71	625	650	650
KC-2	443	650	0	650	650
KC-3/KC-6	650	650	650	650	650
KC-5/KC-6	650	650	650	650	650
KC-7	443	650	650	71	590
KC-8	443	650	650	650	0
RR	589	650	650	650	650
Calculated Reactivity, $					
TIGRIS	0,16	0,28	0,28	0,21	0,20
MCNP	-0,30	-0,22	-0,28	-0,22	-0,21

In TIGRIS calculation experimental rods insertions were reduced by 30 mm to take into account the real position of CR and active part of FA. Without displacement the first 70 mm of KC-1 has no worth (in measurement). The assumption that real CR position is higher than measured value arises from analysis of calculated and measured form of KC-1 S-curve (S-curve in relative units). KC-1 S-curve was defined from calculations with several KC-1 positions, the other rods positions: KC-2=300 mm, KC-3,4,5,6,7,8,RR=600 mm, AZ-1,2=0 mm (Figures 4,5). After displacement by 30 mm the calculated curve has approximately the same form as measured.

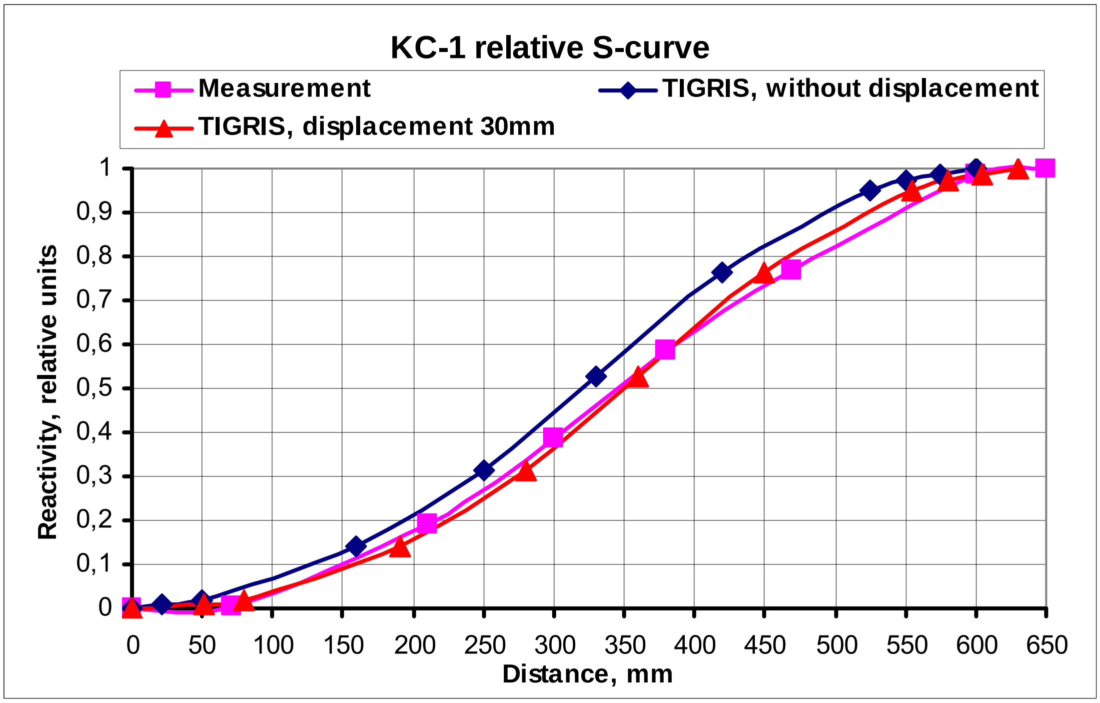

Figure 4 Reactivity worth of KC-1 (relative units)

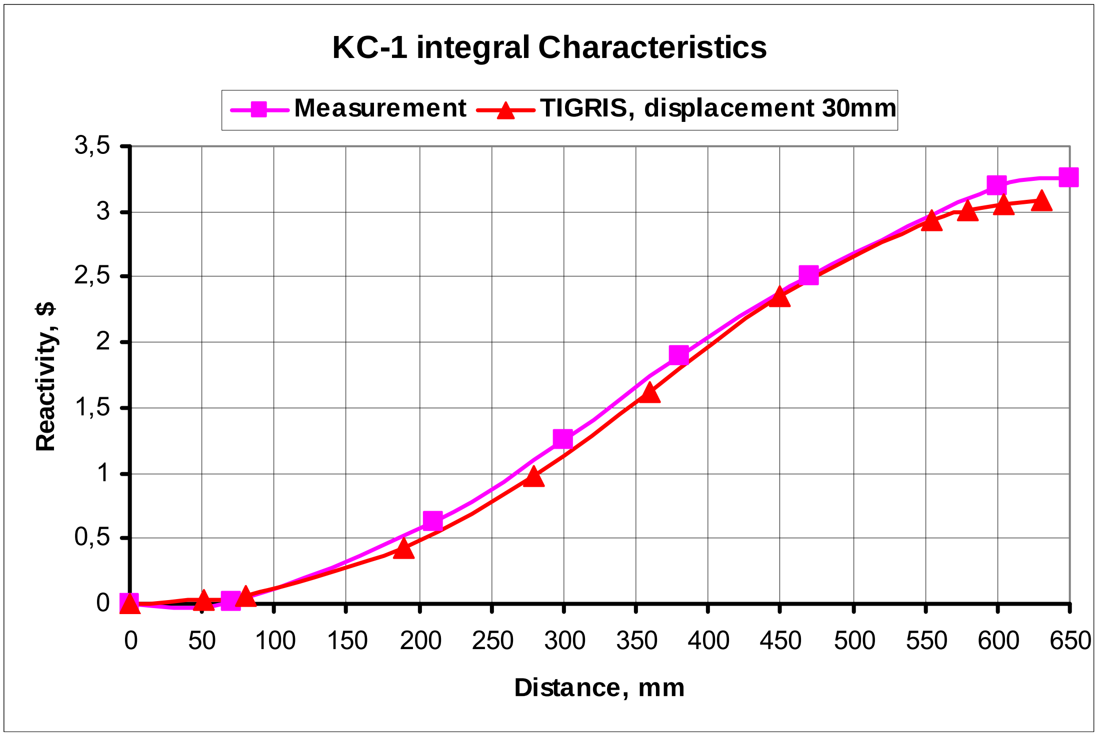

Figure 5 Reactivity worth of KC-1

The results of calculations with different sets of rods fully inserted or fully withdrawn for the 16 FA's core are presented in Table 4. MCNP and CITATION results from Table 4 are the results presented at [3].

Table 4 Results of reactivity calculation with different sets of rods fully inserted or fully withdrawn

	Reactivity, $		
	MCNP	CITATION	TIGRIS
All Rods Out	20,07	21,08	19,98
All Shim and Regulating Rods Inserted	-3,23	-5,05	-2,56
All Rods Inserted	-10,77	-11,08	-9,12

Good agreement of some TIGRIS results with experiment and Monte Carlo model results was obtained for Tajoura Critical Facility with LEU. For a diffusion code such good agreement in absolute values (one critical state and calculation with all rods out) is not very significant and can change after reflector model or other initial data changing, but the agreement with experiment and Monte Carlo model for a set of states with different insertions of different rods and for CR worth is a really good result.

5. Conclusions

The preliminary analysis of main requirements which LEU fuel should meet to be suitable for conversion shows that on the one hand, some safety requirements may be more stringent than for other research reactors, on the other hand, some experiment performance requirements and FA consumption requirements may be less stringent. When fuel cycle length and FA's number in the core are not required to be preserved and FA is discharged only at maximum burn up (the same as for HEU fuel), LEU fuel with U-235 content equal to the HEU fuel can ensure FA consumption during reactor operation equal to the HEU fuel case. In such case, if future studies will demonstrate that experiment performance is not significantly diminished by the conversion, LEU fuel with U-235 content equal to the HEU fuel may be more suitable than LEU fuel type with larger U-235 content if it would support hermeticity during larger period.
HEU fuel core model validation demonstrates that neutronic model based on TIGRIS code ensures acceptable accuracy for operational problems of IRT MEPhI reactor. Some results for LEU fuel core model validation are obtained. Feasibility studies for LEU conversion can be started for IRT MEPhI.

6. References

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