WWR-SM CONVERSION TO LEU IRT-4M OXIDE FUEL

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ABSTRACT

Previous study has shown that the best LEU fuel for conversion of the WWR-SM reactor in Ulugbek (Uzbekistan) is the IRT-3M UMo fuel. However, this fuel is not going to be available in the next couple of years. The Institute of Nuclear Physics (INP-UZ) has decided to convert the WWR-SM reactor using presently available IRT-4M oxide LEU fuel, until the IRT-3M UMo LEU fuel is available. To do that without loss of performance for the present experimental program the size of the core will increase to 20 fuel assemblies (FA) and the power of the reactor will increase to 11 MW (instead of 18 FA and 10 MW for the present core). The INP and the RERTR-ANL have cooperatively started the analysis for this conversion. This paper presents results for the neutronics analysis (burnup, power distributions and shutdown margin), the steady state thermal hydraulics analysis and the kinetics parameters for the cycle-by-cycle conversion process. Relevant comparisons are also made with the present IRT-3M HEU oxide core.

INTRODUCTION

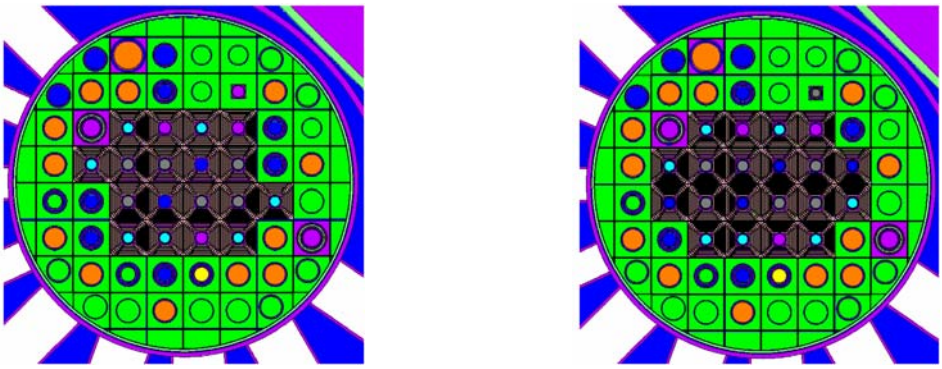
The WWR-SM [1] research reactor in Uzbekistan currently uses HEU (36% enrichment) IRT-3M fuel assemblies (6-tubes, UO_2-Al, 2.5 g U/cm^3, 309 g ^{235}U/FA) fabricated by the Novosibirsk Chemical Concentrates Plant in Russia. Previous study [2] has shown that the best LEU fuel for conversion of the WWR-SM reactor in Ulugbek (Uzbekistan) is the IRT-3M UMo dispersion fuel. However, these fuels are not going to be available in the next couple of years. The Institute of Nuclear Physics (INP-UZ) has decided to convert the WWR-SM reactor using presently available IRT-4M oxide LEU fuel, until the IRT-3M UMo LEU fuel is available. This conversion process is expected to start very soon. To do that without loss of performance for the present experimental program the size of the core will increase to 20 fuel assemblies (FA) and the power of the reactor will increase to 11 MW (instead of 18 FA and 10 MW for the present core). This conversion process will occur over a period of time with partial replacement of IRT-3M HEU fuel with IRT-4M LEU fuel until a fully loaded LEU core is obtained. This paper presents the results for the neutronics analysis (burnup, power distributions and shutdown margin), the steady state thermal hydraulics analysis and the kinetics parameters for the cycle-by-cycle conversion process. Relevant comparisons are also made with the present IRT-3M HEU oxide core.

THE WWR-SM RESEARCH REACTOR

Reactor Description

The WWR-SM reactor is located at the Institute of Nuclear Physics in Ulugbek, 30 km NE of Tashkent, Uzbekistan. The reactor first reached criticality in September 1959 and since then has been up-graded from 2 to 10 MW. Since July 1999 the reactor uses a beryllium-reflected compact core of 16 (sometimes 18) Russian-supplied 6-tube IRT-3M (HEU - 36% enrichment) fuel assemblies. Presently, the reactor operates with a configuration of 18 fuel assemblies. The control system consists of six shim rods, three safety rods and one automatic regulating rod (AR). All the control rods are 21 mm in diameter and are made of B_4C absorbers (1.7 g/cm^3) clad in 1 mm thick stainless steel. An aluminum alloy follower rod is located below each rod. The active core height is 600 mm and the core is located within a 640 mm diameter cylindrical tank

The reactor is used for radioactive isotope production, neutron activation analyses, and experiments in nuclear physics, solid-state physics, and nuclear engineering. To carry out these experiment the reactor has 9 horizontal beam tubes, a graphite thermal column, and numerous vertical irradiation channels in both core and reflector regions. Figure 1 (a) shows a horizontal cross section of the WWR-SM research reactor with 18 fuel assemblies.



(a) (b)

Figure 1 WWR-SM Horizontal Core Cross Section: (a) 18 Fuel Assemblies and (b) 20 Fuel Assemblies.

Fuel Assemblies

Figure 2 shows a horizontal cross section of both the IRT-3M (HEU) and the IRT-4M (LEU) Fuel Assemblies (FA) used in this conversion study, and Table 1 presents the parameters of those FA. The two FA are very similar and the major differences are the mass of ^{235}U/FA and the thickness of the fuel meat.

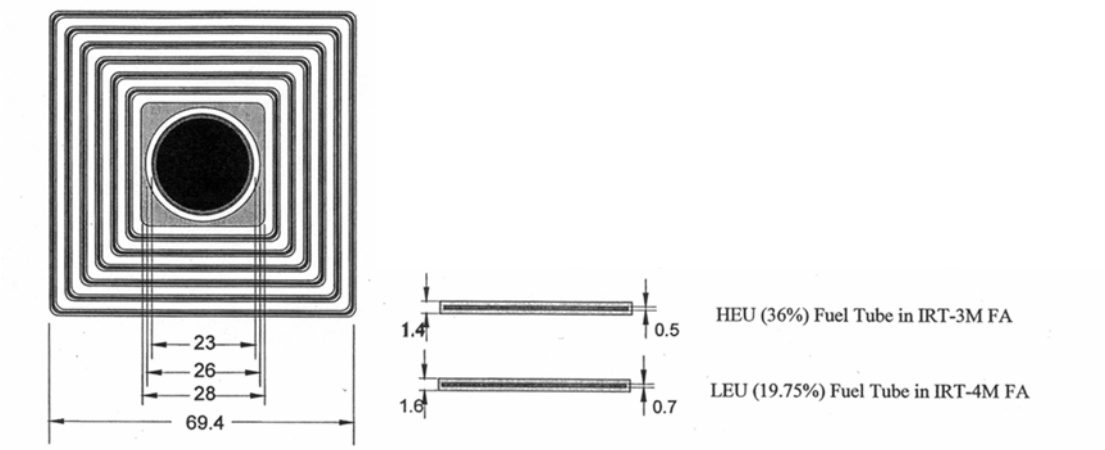


Figure 2 Cross Section of the 6-tube IRT-3M and IRT-4M Fuel Assembly

Parameter	6-Tube IRT-3M	6-Tube IRT-4M
Dispersant	UO_2-Al	UO_2-Al
Wt. % ^{235}U	36.0	19.7
$(gU/cm^3)_{meat}$	2.5	2.8
VF^D, %	28.5	31.7
$^{235}M/FA$, g	309	266
H_{meat}, cm	60	60
T_{meat}, mm	0.50	0.70
T_{clad}, mm	0.45	0.45
$T_{coolant}$, mm	2.05	1.85
Vol_{meat}, cm^3	342	481

Table 1 Fuel Assembly Parameters

METHODS AND CODES

Monte Carlo methods were used for all the neutronics analyses. The MCNP [3] code was used for all static calculations and the MCBURN [4] code was used for the burnup analyses.
Steady-state thermal-hydraulics analyses were performed using the PLTEMP [5] code.

RESULTS

As described before the following was performed for this conversion analysis: a) cycle-by-cycle burnup analysis; b) shutdown margin; c) control rods reactivity worth; d) steady-state thermal-hydraulics analysis; and e) determination of the neutronics kinetics parameters. The results of these analyses are discussed below.

Cycle-by-cycle Burnup Analysis

All the burnup analyses presented below were performed using a very detailed MCNP model in which all the experiments loaded in the core were included in the model. The end of cycle reactivity was defined as an excess reactivity between 0.5 and 1.0% with all the control rods withdrawn from the core, and a cycle length of at least about 10 days at full power is desired. Also it is a requirement that the average burnup for the discharged LEU fuel assemblies does not exceed 40%.

The analysis started with an HEU core (June/2006 core) with 18 IRT-3M fuel assemblies. This core was burned to the desired end of cycle and two IRT-3M FA were discharged. Following this, the burned fuel was shuffled and **four** fresh LEU IRT-4M fuel assemblies were loaded into the central positions in the core. This first mixed core had sixteen HEU IRT-3M and four LEU IRT-4M FA (see Figure 1b).

In all subsequent cycles similar procedure was followed but only **two** IRT-3M FA were discharged at the end of the cycle, fuel was shuffled and two fresh IRT-4M FA were loaded in the core central positions, following the normal loading pattern presently used in the reactor. Note that following normal operating experience at the reactor a time interval of 7 days exists between cycles. Also, the shuffling of the burned fuel elements must be performed in such a way that limiting conditions of operation (shutdown margin, peak clad temperature and minimum ratio for onset of nuclear boiling) are not reached.

Ten cycles were analyzed (in the last two cycles the core is fully loaded with LEU fuel) and the results of the burnup analysis are presented in Figure 3.

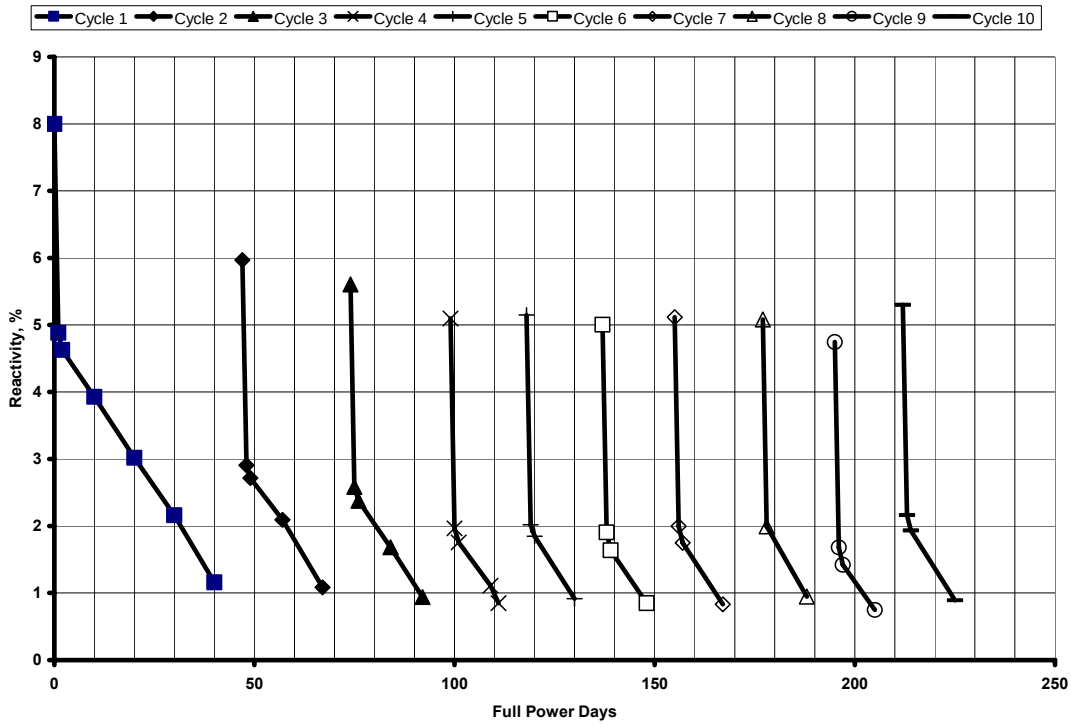


Figure 3 Cycle-by-Cycle Burnup Results

Shutdown Margin

The WWR-SM reactor criterion for the shutdown margin states that the reactor must be at least 1.0% sub-critical with all the shim rods and the automatic regulating rod fully inserted into the core. Using this condition the shutdown margin was determined for the cores analyzed and the results presented in Table 2 show that all the cores meet the shutdown margin criterion without any problem. Note that all the absorbing material of the control rods were recently replaced in the WWR-SM.

Core Configuration	Shutdown Margin (% Reactivity)
18 IRT-3M FA	-8.7
16 IRT-3M / 4 IRT-4M FA	-5.5
14 IRT-3M / 6 IRT-4M FA	-8.2
12 IRT-3M / 8 IRT-4M FA	-8.8
10 IRT-3M / 10 IRT-4M FA	-9.4
8 IRT-3M / 12 IRT-4M FA	-11.1
6 IRT-3M / 14 IRT-4M FA	-11.3
4 IRT-3M / 16 IRT-4M FA	-9.1
2 IRT-3M / 18 IRT-4M FA	-9.6
20 IRT-4M FA	-10.2

Table 2 Shutdown Margin (uncertainty less than 0.5%)

Control Rods Reactivity Worth

To have a smooth transition from the HEU core to the LEU core it is desired that the worth of the control rods do not change much as the core changes. Small changes in the worth of the control rods are also desired from the viewpoint of the possible transients caused by failures in the control rods mechanism. In Table 3 the reactivity worth of the control rods are show for the HEU core, for several mixed cores and for the final LEU core. As the results in this table show there are only small variations for the reactivity worth of each rod (or bank of rods) during the whole transition.

	18 IRT-3M	16 IRT-3M/ 4 IRT-4M	14 IRT-3M/ 6 IRT-4M	12 IRT-3M/ 8 IRT-4M	10 IRT-3M/ 10 IRT-4M	20 IRT-4M
KC-1	3.7	3.4	3.5	3.6	3.7	3.7
KC-2	4.3	4.2	4.5	4.4	4.5	4.7
KC-3	3.1	2.6	2.7	2.8	2.7	2.9
KC-4	3.3	2.9	3.0	3.1	3.0	3.2
AR	0.6	0.6	0.6	0.6	0.6	0.6
AZ-1	1.9	1.7	1.8	1.7	1.7	1.7
AZ-2	1.9	2.1	2.1	2.1	2.1	2.1
AZ-3	1.5	1.4	1.4	1.4	1.5	1.5
All AZ	5.7	5.7	5.9	5.8	5.8	5.8

Table 3 Reactivity Worth of Control/Safety Rods (%)
(Uncertainty less than 2.0%)

Steady-State Thermal Hydraulics Results

Steady-state thermal hydraulics analyses were performed using the PLTEMP code. The fuel tubes are modeled are parallel plates and the coolant flows from the top to the bottom of the fuel. Detailed power density distributions were calculated using the MCNP code; power densities are calculated for each of the flats and each of the corners of each fuel tube, and fifteen axial nodes are used.

Based on the specifications for the LEU fuel assemblies the maximum temperature in the clad surface must be 102 º C, and the WWR-SM specifies a minimum ratio to onset of nucleate boiling (ONBR) equal to 1.40. The results presented in Table 4 for the IRT-3M HEU core, for all mixed cores during the transition, and for the IRT-4M LEU core show that these conditions are met for all cases.

Core Configuration	IRT-3M Fuel Assemblies				IRT-4M Fuel Assemblies			
	ONBR	Clad Max Temp, ºC	Peak Power Density (kW/cc)	FA Location	ONBR	Clad Max Temp, ºC	Peak Power Density (kW/cc)	Location
18 IRT-3M[a]	1.56	93.7	3.05 / 3.42[b]	4-5 / 5-5	N/A			
16 IRT-3M/4 IRT-4M[c]	1.48	97.3	3.49	3-5	1.68	90.1	1.94 / 2.27	5-5 / 5-5
14 IRT-3M/6 IRT-4M	1.58	93.5	3.20	3-5	1.54	94.4	2.19 / 2.26	3-4 / 5-5
12 IRT-3M/8 IRT-4M	1.64	91.6	3.06	3-5	1.59	92.6	2.12 / 2.17	3-4 / 5-5
10 IRT-3M/10 IRT-4M	1.68	90.2	2.98	3-5	1.60	92.4	2.02 / 2.32	5-5 / 5-5
8 IRT-3M/12 IRT-4M	1.67	89.8	2.96	3-5	1.58	93.0	2.06 / 2.30	4-5 /4-4
6 IRT-3M/14 IRT-4M	1.76	88.0	2.80	3-6	1.56	94.1	2.21 / 2.40	3-5 / 5-5
4 IRT-3M/16 IRT-4M	1.83	85.7	2.64	3-6	1.59	92.5	2.02 / 2.29	4-5 / 5-5
2 IRT-3M/18 IRT-4M	1.88	84.2	2.54	3-6	1.55	94.4	2.27 / 2.38	6-6 / 5-5
20 IRT-4M	N/A				1.58	92.9	2.06 / 2.32	4-5 / 5-5

[a] Power = 10 MW
[b] A/B = Peak Power in FA with minimum ONBR / Peak Power for FA type
[c] Power = 11 MW (used for all mixed cores and for core with All IRT-4M FA)

Table 4 Steady-State Thermal Hydraulics Results

Kinetics Parameters and Reactivity Coefficients

The kinetics parameters and reactivity coefficients are important for the determination of the core response after an incident/transient. Table 5 presents the results for the HEU core, for several mixed cores and for the first LEU core. The results show that the reactivity coefficients and the kinetics parameters do not change much during the whole transition from HEU to LEU. This again is very important because it indicates that the transient response of all the cores during the transition (mixed cores) and for the LEU core will be very similar to that of the present HEU core.

	CORE CONFIGURATIONS				
	18 IRT-3M	16 IRT-3M 4 IRT-4M	14 IRT-3M 6 IRT-4M	12 IRT-3M 8 IRT-4M	20 IRT-4M
	Coolant Temperature Reactivity Coefficient (%/ºK)				
293 to 400 K	-9.3E-3	-9.5E-3	-9.5E-3	-9.4E-3	-8.6E-3
400 to 600 K	-7.5E-3	-7.6E-3	-7.5E-3	-7.4E-3	-6.9E-3
293 to 600 K	-8.1E-3	-8.2E-3	-8.2E-3	-8.1E-3	-7.5E-3
	Coolant Void Reactivity Coefficient (%/% void)				
0 to 5%	-3.0E-1	-2.8E-1	-2.8E-01	-2.8E-1	-2.9E-1
5 to 10%	-3.3E-1	-3.1E-1	-3.11E-01	-3.1E-1	-3.2E-1
0 to 10%	-3.2E-1	-3.0E-1	-2.98E-01	-3.0E-1	-3.1E-1
	Doppler Reactivity Coefficient (%/ºK)				
293 to 400 K	-2.1E-3	-2.0E-3	-2.1E-3	-2.0E-3	-2.3E-3
400 to 600 K	-1.4E-3	-1.7E-3	-1.8E-3	-1.9E-3	-2.2E-3
293 to 600 K	-1.7E-3	-1.8E-3	-1.9E-3	-1.9E-3	-2.2E-3
	Effective Delayed Neutron Fraction, β_{eff} [6]				
	7.6E-3	7.6E-3	7.7E-3	7.7E-3	7.6E-3
	Prompt Neutron Generation Time, μs				
	47	50	53	53	53

Table 5 Kinetics Parameters and Reactivity Coefficients (Uncertainty less than 3% for all parameters)

FUTURE WORK

The next step in the LEU conversion process is the accident/transient analyses. The definition of the transients/accidents to be analyzed was already completed and discussed with the local regulatory authority.

SUMMARY

The Institute of Nuclear Physics in Uzbekistan (INP-UZ) has decided to convert the WWR-SM reactor to LEU using presently available IRT-4M fuel assemblies fabricated by the Novosibirsk Chemical Concentrates Plant in Russia. To do that without loss of performance for the experimental program the core size and the reactor power need to be

increased to 20 FA and 11 MW, respectively. The conversion process requires the performance of the Safety Analysis Report (SAR). This paper presents the first part of this SAR which includes the neutronics analysis (burnup, shutdown margin, reactivity worth of the control rods, kinetics parameters, and reactivity feedback coefficients). The results presented in this paper show that there are only small changes in all neutronics parameters during the whole conversion process, i.e. from the 18 FA HEU core to the 20 FA LEU core. These results indicate that the transient response of the mixed cores and of the LEU core should be similar to that of the HEU core. However, this needs to be proven and that will be done in the very near future.

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