RERTR 2014 — 35th International Meeting on
Reduced Enrichment for Research and Test Reactors

October 12-16, 2014
IAEA Vienna International Center
Vienna, Austria

Successful Operation of WWR-SM Research Reactor after Conversion to LEU Fuel

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ABSTRACT

WWR-SM research reactor, operating at 10 MW, was converted to LEU fuel in 2009.

Active core of WWR-SM research reactor of the Institute of Nuclear Physics of Academy of Science of Republic of Uzbekistan (INP AS RU) currently contains 24 IRT-4M type fuel assemblies made in Novosibirsk chemical plant, Russian Federation.

WWR-SM research reactor is a pool type reactor intended for production of neutron fluxes in the range of 10^{12}-$3x10^{14}$ neutron/cm^2 with energy of 0.1-9 MeV and operates at 10 MW. Reactor has 40 vertical and 10 horizontal channels for irradiation of samples. For realization of State scientific–technical programs, branch-wise tasks in the field of fundamental and applied scientific studies, solving scientific-technical tasks, 29 vertical and 9 horizontal channels are used and assigned to scientific departments of the INP AS RU. Other channels are reserved and used for control over technical conditions of reactor and carry out orders of side organizations.

Important studies in fundamental and applied fields of nuclear physics, radiation physics of solid state, radiation material science, radiochemistry, activation analyses, information technologies and scientific devices construction are done using WWR-SM research reactor. These studies allow to solve actual for the Republic problems of geology, mining, metallurgic and jewelry industry, medicine, ecology, agriculture, criminalistics, and also to develop technologies of producing new radioisotopes, modify constructional materials, mineral raw materials and other different products.

Main tasks, solved at reactor are to provide and to service scientific departments with neutron fluxes and to perform physical and nuclear-analytical studies, and also to introduce scientific and technological developments of the institute to get different radioisotopes (I-125, I-131, P-32, P-33, S-35, Tc-99m generator, Sm-153, Ir-192, Au-198), to modify materials and crystals.

Full technological cycle of reactor operation using 19.7% enriched by U-235 IRT-4M type fuel was developed and realized at WWR-SM research reactor. Estimates of radiation levels in technological rooms and surrounding territory while using IR-4M type fuel have been made. Potential of technical possibilities of WWR-SM research reactor of INP AS RU is kept to perform scientific research and to carry out industrial orders using the flux of $1.5x10^{14}$ ncm^{-2}s^{-1} in the active core of reactor while using IR-4M LEU fuel.

INTRODUCTION

WWR-SM research reactor refers to the pool type nuclear reactors, designed to produce the neutron flux intensity in the range $10^{12} \div 3x10^{14}$n/cm^2 with energy 0.1 ÷ 9 MeV and operates at a power of 10 MW. Reactor has 40 vertical and 10 horizontal channels. 29 vertical and 9 horizontal channels are assigned to the scientific personnel to meet state scientific and technical programs, to create industrial jobs in the field of basic and applied research, and to solve scientific and technical problems. The other channels are reserved and used to control the technical state of the reactor and to execute the orders of outside organizations.

With the help of the WWR-SM important research is conducted in basic and applied fields of nuclear physics, radiation physics, solid state physics, radiation-radiochemistry, activation analysis. These studies allow to solve actual to the Republic problems of geology, mining, metallurgy and jewelry industry, medicine, ecology, agriculture, forensic science, as well as to develop new technology for production of radioisotopes, to modify construction materials, minerals and various products.

Main tasks solved at the reactor are providing and servicing scientific units with neutron fluxes and the performance of physical and nuclear analytical studies, as well as the introduction of scientific and technological developments of the Institute for receiving different isotopes (Iodine - 125, Iodine - 131, P - 32, P - 33, S - 35, Technetium generator - 99m, Samarium - 153, Iridium – 192, Gold - 198), modification of minerals and crystals.

ACHIEVED RESULTS

Currently using the WWR-SM 12 scientific projects, of which 4 projects for fundamental research, 6 projects on the state scientific and technical programs, 1 on innovative development and 1 project for young scientists in applied research are carried out at the Institute.

Thermal-hydraulic and neutronic calculations for the core with LEU fuel were performed [1, 2]. Since 2009, based on these calculations, the WWR-SM research reactor converted to low-enriched fuel, mastered and implemented a full technological cycle of operation of the reactor with 19.7% enriched by ^{235}U fuel based on IRT-4M fuel assemblies. The estimation of the expected radiation environment in the rooms and surrounding territories while using IRT-4M fuel assemblies (FA) was made.

Mixed cores with 6-tube and 8-tube IR-4M LEU fuel assemblies were studied [3].

Changes of mechanical, electric and thermal properties of reactor materials depending on neutron fluence were studied as well [4-6].

Stored potential of technical capabilities of the WWR-SM reactor of INP AS RU for research and implementation of industrial orders due to the neutron flux density reached ~$1.5x10^{14}$n/cm^{2}s in the active core of reactor during its operation with low-enriched IRT-4M FA.

In 2013, the reactor operated 3648.75 hours at nominal power while the energy release was 38454.1 MW•hour, and the effective utilization of the reactor was 60.81%. Taking into account reactor power increasing modes to an optimal power, 1092 block-containers were irradiated with the general irradiation time of 91770.34 hours.

Research was conducted on distribution of thermal power for the configuration of the reactor core of 18 IRT-3M FA and 20 and 24 IRT-4MFA in order to conserve nuclear fuel. It was determined that the maximum allocation of thermal power accounts for the central (by height) region of the fuel elements (FE), and the most heat-stressful place is the center of the outer FE. The rest of FE have approximately the same thermal load. It is appropriate to note that during fuel leakage control should pay special attention to the tightness of the external FE.

Important practical, as well as economic (due to the constant rise in prices for nuclear fuel) value is in the knowledge of the burn-up of nuclear fuel in FA and optimization of reloading operations in active core, depending on the degree of burn-up of nuclear fuel in FA. Analysis of ^{235}U burn-up in FA were undertaken using IRT-2D and Rebus codes. The analysis performed of the reloading operations when 24 pieces of 6-tube IRT-4M low-enriched nuclear fuel were loaded in the active core of reactor. It is concluded, that in order to save nuclear fuel, the most convenient active core is the reactor core with 24 fuel assemblies, and the maximum burnup of ^{235}U isotope is 60%. The use of in-core 24 fuel assemblies in the active core and bringing burn-up of ^{235}Uisotope to 60% gave a 10% savings in nuclear fuel in annual perspective.

Fuel assemblies with different burnups were studied [7].

The flux of fast and thermal neutrons for the active core with 20 FA.

Excess reactivity: 1.22%, non-uniformity.

Table 1. Fast neutron flux in the active core with 20 fuel assemblies.

3.33E+11	1.66E+12	4.55E+12	3.98E+12	2.38E+12	2.99E+12	1.88E+12	4.91E+11
1.44E+12	6.42E+12	1.33E+13	1.65E+13	1.42E+13	1.35E+13	7.94E+12	2.52E+12
5.58E+12	1.84E+13	2.94E+13	3.42E+13	3.52E+13	2.76E+13	1.56E+13	6.17E+12
1.06E+13	2.61E+13	3.71E+13	4.28E+13	4.25E+13	3.59E+13	2.49E+13	9.71E+12
1.08E+13	2.63E+13	3.60E+13	4.16E+13	4.19E+13	3.62E+13	2.51E+13	1.00E+13
5.72E+12	1.71E+13	2.67E+13	3.13E+13	3.20E+13	2.83E+13	1.72E+13	5.51E+12
2.15E+12	8.10E+12	1.25E+13	1.41E+13	1.55E+13	1.39E+13	8.64E+12	2.23E+12
4.78E+11	1.86E+12	3.08E+12	3.93E+12	3.78E+12	3.25E+12	2.00E+12	5.04E+11

Table 2. Thermal neutron flux in the active core with 20 fuel assemblies.

2.87E+12	7.36E+12	9.49E+12	1.06E+13	9.08E+12	7.00E+12	6.00E+12	3.11E+12
7.45E+12	1.34E+13	1.59E+13	1.81E+13	1.42E+13	9.59E+12	1.22E+13	8.28E+12
1.25E+13	1.75E+13	1.14E+13	1.19E+13	1.16E+13	1.01E+13	1.57E+13	1.26E+13
1.43E+13	1.07E+13	1.00E+13	1.05E+13	1.10E+13	9.95E+12	9.11E+12	1.34E+13
1.41E+13	9.62E+12	1.00E+13	1.08E+13	1.02E+13	9.74E+12	1.03E+13	1.37E+13
1.26E+13	1.71E+13	1.11E+13	1.11E+13	1.12E+13	1.09E+13	1.74E+13	1.26E+13
8.47E+12	1.43E+13	1.44E+13	1.30E+13	1.67E+13	1.75E+13	1.55E+13	8.84E+12
3.22E+12	6.49E+12	5.29E+12	8.87E+11	6.85E+12	9.88E+12	7.94E+12	3.54E+12

Excess reactivity: 6.25%, non-uniformity.

Table 3. Fast neutron flux in the current active core with 24 fuel assemblies.

5.32E+11	1.67E+12	4.17E+12	3.52E+12	2.13E+12	2.91E+12	2.10E+12	5.95E+11
2.58E+12	8.27E+12	1.24E+13	1.42E+13	1.23E+13	1.28E+13	9.49E+12	3.31E+12
7.50E+12	2.33E+13	2.70E+13	2.93E+13	3.00E+13	2.46E+13	1.76E+13	7.42E+12
1.01E+13	2.41E+13	3.27E+13	3.73E+13	3.68E+13	3.08E+13	2.12E+13	8.73E+12
9.88E+12	2.36E+13	3.20E+13	3.66E+13	3.62E+13	3.10E+13	2.23E+13	9.18E+12
7.24E+12	2.13E+13	2.54E+13	2.74E+13	2.75E+13	2.52E+13	2.08E+13	6.99E+12
3.24E+12	1.10E+13	1.26E+13	1.26E+13	1.36E+13	1.32E+13	1.10E+13	3.20E+12
6.55E+11	2.32E+12	3.13E+12	3.57E+12	3.37E+12	3.15E+12	2.33E+12	6.52E+11

Table 4. Thermal neutron flux in the current active core with 24 fuel assemblies.

2.80E+12	6.34E+12	8.22E+12	9.22E+12	7.92E+12	6.26E+12	5.62E+12	3.02E+12
6.31E+12	9.68E+12	1.34E+13	1.56E+13	1.22E+13	7.88E+12	9.52E+12	7.19E+12
9.07E+12	7.99E+12	8.76E+12	1.03E+13	9.82E+12	7.20E+12	6.68E+12	9.79E+12
1.24E+13	8.47E+12	7.97E+12	9.55E+12	9.42E+12	7.49E+12	7.54E+12	1.16E+13
1.22E+13	8.30E+12	7.82E+12	9.36E+12	9.28E+12	7.57E+12	7.81E+12	1.14E+13
9.02E+12	7.83E+12	8.33E+12	9.58E+12	9.75E+12	8.45E+12	7.71E+12	8.71E+12
7.33E+12	1.23E+13	1.31E+13	1.16E+13	1.47E+13	1.56E+13	1.29E+13	7.36E+12
3.31E+12	6.65E+12	5.24E+12	8.10E+11	6.18E+12	9.19E+12	7.68E+12	3.47E+12

The transition to the new core configuration with 24 FA is advantageous for the following reasons. When 24 FA are loaded into the core, reactivity margin increases by about 4%, which allows to load 2 shielded channels (one shielded channel consumes about 1.5-2% reactivity) to resume irradiation of topaz. Reactor operation time also increases without fuel shuffling [8]. The average load on the FA is reduced from 500 kW to 417 kW, which allows to bring burn-up to 55%. This gives a 10% savings in nuclear fuel.

Conclusion

Based on performed calculations of active core (thermal hydraulic and neutronic for mixed cores) Institute of Nuclear Physics started to use along with 6-tube LEU IRT-4M also 8-tube IRT-4M fuel assemblies in WWR-SM research reactor. And the reactor was increased to 24 FA.

The experimental measurement and the neutron flux in the reactor core, as well as their theoretical calculations were performed. Comparison of experimentally measured (using threshold monitors) and calculated (using IRT-2D code) flux density of fast and thermal neutrons in the WWR-SM reactor core showed their agreement to within 5%. A map of the neutron flux in the core was prepared, which has practical implications for the use of radiation technologies.

The effects of radiation on the physical and mechanical, electrical and thermal properties of structural materials and reactor fuel materials were investigated. The results of these studies can be used to create new structural materials and to improve the parameters of research reactors. The results of the study are published in leading international journals and abstracts of international conferences.

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