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Types, Problems and Conversion Potential of Reactors Produced in Russia

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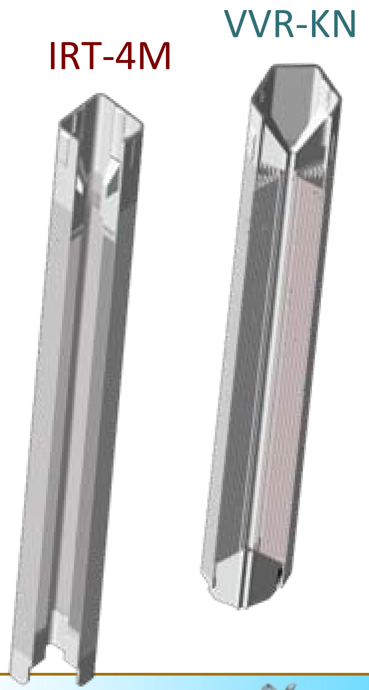
Activities purpose:

Prevention of nuclear weapon proliferation and suppression of nuclear terrorism by minimization and possible complete elimination HEU from the peaceful use of nuclear energy.

Russian-US Cooperation is aimed at:

1. **Development of new types of LEU fuel.**
2. **Conversion of the reactors in third countries.**
3. **Feasibility studies on the possible conversion of the specific reactors in Russia and USA.**

Practical Steps of Non-Proliferation Efforts:

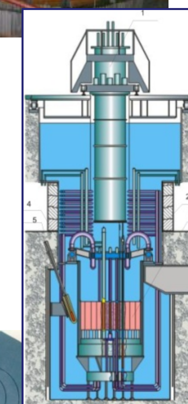


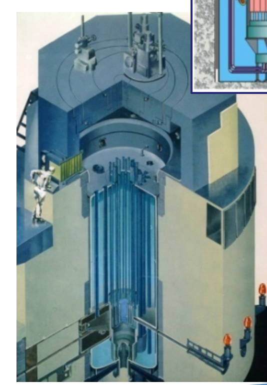
1.LEU fuel is developed for the conversion of research reactors (RR) built by the Russian design in third countries (21 RR in 14 countries): IRT-4M, VVR-M2 and VVR-KN (UO_2+Al).

2.The design justification for the conversion of RR to LEU fuel is worked out. The safety of RR converted to LEU fuel is proved.

3.The number of Russian-designed RR in third coun is converted to LEU Fuel
(IRT-1 (Libya), DRR (Vietnam), BRR (Hungary),
WWR-CM Tashkent (Uzbekistan),
IRT-Sofia (Bulgaria), and others).

Russian RR and Russian-designed RR Abroad





- **Training Russian RR: IRT-T and IRT-MIFI;**
- **High flux Russian RR: WWR-M, WWR-TS, IVV-2M, IRV.M2;**
- **Unique and record-setting Russian RR: SM-3, MIR.M1, IBR-2M, PIK;**
- **Dedicated Russian RR: IGR, IWG 1;**
- **Foreign RR: IRT-Sofia (Bulgaria), IRT-1 (Libya), MARIA (Poland), WWR-CM Tashkent (Uzbekistan), WWR-K Alma-Ata (Kazakhstan), BRR (WWR-C) (Hungary), DRR (IVV-9) (Vietnam) and others.**

Considerable part of Russian RR is water-water pool-type (tank, VVR-type) with steady power level except unique, record-setting and dedicated reactors (vessel, pressurized, steady-power and pulsed reactors)

RR in Russia and Abroad

Russian RR

Reactor	Location	Start-up, year	Thermal power, MW	Maximum thermal neutron flux density in core, $sm^2 \cdot s^{-1}$
WWR-M	Gatchina	1959	18	$4 \cdot 10^{14}$
IR-50*4	Moscow	1961	0,05	10^{12}
SM-3*1	Dimitrovgrad	1961 (1992 - reconstruction)	100	$5 \cdot 10^{15}$
WWR-TS	Obninsk	1964	15	$1{,}3 \cdot 10^{14}$
IVV-2M	Zarechny	1966	15	$5 \cdot 10^{14}$
MIR.M1*1	Dimitrovgrad	1967 (1975 - reconstruction)	100	$5 \cdot 10^{14}$
IRT-T	Tomsk	1967	6	$1{,}1 \cdot 10^{14}$
IRT-MIFI	Moscow (MEPhI)	1967	2,5	$5 \cdot 10^{13}$
IRV-M2*3	Lytkarino	-	4	$8 \cdot 10^{13}$
Pulsed IBR-2M*1	Dubna	1984 (2011 - reconstruction)	2 (average) $1{,}5 \cdot 10^{3}$ (pulse)	$1 \cdot 10^{16}$ (pulse) $1{,}2 \cdot 10^{17}$ (fast neutrons in the pulse)
PIK*2	Gatchina	2011	100	$5 \cdot 10^{15}$

*1 – after reconstruction; *2 – under construction/continuation of construction;
*3 – balancing and commissioning; *4 – temporary shutdown

Foreign RR of Russian Design

Reactor	Location	Start-up, year	Thermal power, MW	Maximum thermal neutron flux density in core, $sm^2 \cdot s^{-1}$
WWR-CM Tashkent	Tashkent, Uzbekistan	1959	10	$1{,}0 \cdot 10^{14}$
Pulsed IGR	Semipalatinsk, Kazakhstan	1961	-	$1{,}0 \cdot 10^{18}$ (pulse)
IRT-2000	Sofia, Bulgaria	1961	2	$3{,}2\text{-}3 \cdot 10^{13}$
WWR-K	Alma-Ata, Kazakhstan	1967	10	10^{14}
IR-100	Sevastopol, Ukraine	1967	0,2	$4{,}8 \cdot 10^{12}$
IWG 1	Semipalatinsk, Kazakhstan	1975	до 720	$5 \cdot 10^{15}$ (in the loop channel)
IRT-1	Tajura, Libya	1983	10	$2{,}2 \cdot 10^{14}$
DRR (IVV-9)	Dalat, Vietnam	1984	0,5	$2{,}1 \cdot 10^{13}$
BRR*1 (WWR-C)	Budapest, Hungary	1959 (1990 - reconstruction)	10	$2{,}3 \cdot 10^{14}$
ETRR-1	Inshas, Egypt	1961 (2003 - reconstruction)	2	$1{,}5 \cdot 10^{13}$

*1 – after reconstruction; *2 – under construction/continuation of construction;
*3 – balancing and commissioning; *4 – temporary shutdown

Principles of Conversion to LEU Fuel for Present Russian RR:

- **Preservation (improvement) of consumer characteristics (neutron flux density, core quality, experimental potential);**
    - **Preservation of safety (determination of negative factors and their impact on safety / compensation for the negative effects);**
- **Non-degradation of performance characteristics;**
    - **Achieving economic feasibility**

MIR.M1 and IRT-MIFI Main Characteristics

Characteristics	Figures	
	MIR.M1	IRT-MIFI
Reactor type	channel-tube, loop-type reactor	water-water, pool reactor
Main tasks	tests of experimental fuel elements/FA and engineering materials in various mediums	staff training, scientific and research work
Thermal power, MW	100	2.5
Maximum thermal neutron flux density, $\bullet 10^{14}$ $sm^{-2} \bullet s^{-1}$	5.0	0.48
Coolant	water	water
Reflector / moderator	beryllium / beryllium	beryllium / water
Water temperature at the core inlet/outlet, ^{o} C	30 ÷70 / up to 98	45 / -
Duty cycle duration, effective days	up to 40	-
Experimental potential and performance characteristics	experimental loop channels: water/water-steam/gas; maximum diameter: 120; inlet/outlet temperature^{o} C: 300/600; pressure, MPa: 6.5÷20	neutron flux density at the HEC outlet, $\bullet 10^{10}$ $sm^{-2} \bullet s^{-1}$: thermal 0.085÷610 epithermal 0.097÷275 fast 0.034÷185

MIR.M1 Conversion to LEU Fuel (6-tube MR FA, fuel thickness 0.94 mm)

"RR core quality" (target consumer characteristic) is determined through the function:

$$k = \frac{2\tilde{\Phi}}{\tilde{N}(1 + \tilde{Ц} \cdot \tilde{G})},$$

where $\tilde{\Phi}$ - ratio of annual fluence on the experimental channel casing for the LEU-core to the same characteristic for the HEU-core,
similarly: $\tilde{N}$ - ratio of annual FA requirement for LEU-core to the same characteristic for the HEU-core, $\tilde{G}$ - ratio of U mass in FA with LEU fuel to the same characteristic with HEU fuel, $\tilde{Ц}$ = 0,208 – relative U cost (counted by values of separate work unit (SWU) needful for the enrichment up to 20 % and 90 %)

MIR.M1 Main Characteristics МИР.М1 with LEU Fuel (6-tube FA MR, fuel thickness 0.94 mm)

Characteristics	HEU	LEU			
	UO_2	UO_2		U-9% Mo	
“RR core quality” (***k***)	1	1	**0.91**	1	**1.32**
U meat density, g/sm^3	1.027	2.9	2.75	2.9	3.56
Fuel volume fraction in the meat, relative unit*	0.112	0.317	0.300	0.178	0.219
Maximum permissible volume fraction of fuel, relative unit	-	0.394	0.434	0.394	0.220
Limiting accumulation of fission products in discharged FA, g/sm^3	0.752**	0.420	0.374	0.420	0.626
^{235}U loading in fresh FA, g	356	460	437	460	565
^{235}U burnup, relative unit	0.814	0.736	0.690	0.736	0.892
Annual FA requirement	99	85	95	84	57
Lifetime, days	125.9	147.3	131.0	147.3	219.3
Annual U consumption, kg	**39.1**	**197.5**	**210.7**	**197.5**	**162.9**

* - technologically maximum permissible value - 0,300

** - reliable operability of FA is confirmed by the years of operating experience

MIR.M1 Main Characteristics with LEU Fuel (6-tube MR FA, fuel thickness 0.94 mm)

To preserve target consumer characteristic for MIR.M1 (***k* = *1***) with present LEU fuel **substantially greater volume fraction of fuel with UO_2 is required** (which isn't ensured by today's technology of fuel fabrication at acceptable burn-up levels).
In implementing process requirements (volume fraction of fuel in fuel material is 0.3) – neutron flux density reduced by **5-7 % in the loop channels.**

U-Mo dispersion fuel (in process of development) ensure the best values. However, annual U consumption for LEU fuel by 4-5 times more.

IRT-MIFI Main Characteristics with LEU Fuel

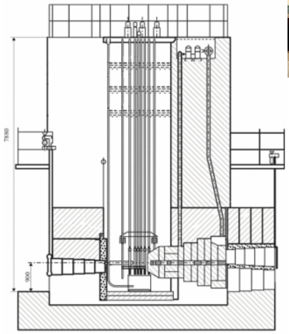
FA	IRT-3M (HEU)	IRT-4M	IRT-3M (U-9%Mo)	IRT-U (U-9%Mo)*
^{235}U enrichment, %	**90.0**	19.7	19.7	19.7
Number of FA in core loading	15	**19**	16	16
Reactivity charge, β_{eff}	8.8	8.8	9.7	9,5
Total effectiveness of control rods, β_{eff}	35	29	29	28
Average burn-up, %	30.3	27.1	28.4	27,1
Average annual FA consumption, pcs./4000 MW hour	1.1÷1.3	1.1÷1.3	1.1÷1.3	1.1÷1,3
Subcriticality for “cocked” safety rods, β_{eff}	13	10	8	8
Permissible power, MW	4.5	4.5	4.2	-
Fast neutron flux density (E > 0,8 MeV) in the design cell, relative unit	**1**	0.95	0.93	0.96
Thermal neutron flux density (E < 0,63 eV) in the design cell, relative unit	**1**	0.91	0.85	0.83

* - FA with rod-type fuel elements

IRT-MIFI Conversion to LEU Fuel

- Use of fuel UO_2-Al (IRT-4M) can’t save the same number of FA in the core loading. It results in significant decrease in neutron flux density in the core, reflector and at the experimental channel outlet;

- Conversion to LEU dispersion fuel U-9% Mo-Al (IRT-3M or IRT-U) doesn’t result in unacceptable change of safety settings, but results in significant deterioration in IRT-MIFI consumer characteristics.



LEU Fuel Requirements

- high U-235 density (U-Mo dispersion fuel with U meat density >3,5 g/sm^3) and U-Mo monolithic fuel);
- software reliability with large values of burn-up;
- commensurable operation cost for FA with HEU and LEU fuel (including fuel processing).

Today there is no LEU fuel meeting the Russian customer requirements.

New fuel materials (U-Mo, dispersion and monolithic fuel) should be brought to a complete state.

The Russian RR Conversion Potential

Declaration:

“…To further improve security of nuclear facilities worldwide, including by minimizing the use of HEU for civilian purposes and the consolidation and conversion of nuclear materials…”

D. Medvedev, B. Obama

The Russian RR Conversion Potential

It's necessary:

- to maintain qualitative indexes of the Russian research base;
- to carry out direct investment in conversion (modernization / reconstruction);
- to take into account long RR operation life (the majority of RR work since mid-60's of XX century);
- to take into account the existing strategy of RR use and development;
- to take into account importance and contract responsibility prohibiting long-term breaks in RR operation;
- to ensure reliability of FA with large values of burn-up;
- to develop new types of LEU;
- to compare operation costs for FA with HEU and LEU fuel (including fuel processing costs).

Conclusion

System approach to conversion of the Russian RR to LEU fuel requires:

- to provide the advantage of conversion with non-deterioration in consumer settings.
- To identify negative factors and assess their impact on safety.
- To determine the economic feasibility.

The existing commercially produced LEU and fuel materials don't meet the Russian customer requirements:

- It's necessary to develop new fuel materials (on the basis of LEU) meeting the needs of existing and prospective RR.

LEU fuel can be used when designing new RR :

- There is a possibility to offset negative factors during the development of new facilities.

Thank You for your attention!