International Conference on Spent Fuel Management
15 – 19 June 2015 in Vienna, Austria

Multiple Recycle of Remix Fuel Based on Reprocessed Uranium And Plutonium Mixture in Thermal Reactors

Yu.S. Fedorov[1], O.V. Kryukov[2], A.V. Khaperskaya[2]

IAEA-CN-226-106

1 – Khlopin Radium Institute, St-Petersburg, Russia
2– State Corporation ROSATOM, Moscow, Russia

E-mail: fys@khlopin.ru

INTRODUCTION

- The problem of spent fuel accumulation may be solved by utilization of regenerated uranium and plutonium in thermal reactors.
- The well-known way of U and Pu reuse in thermal reactors is their separate recycling as MOX fuel for Pu (oxide mixture of regenerated Pu with depleted natural U) and UOX fuel from regenerated U after its re-enrichment.
- The alternative approach has been developed which is based on the fuel fabrication using a mixture of regenerated U and Pu for reuse in the same thermal reactors which generate the SNF.

Recycle of regenerated uranium and plutonium fuel in thermal reactors

Composition of different types of nuclear fuel for thermal reactors:

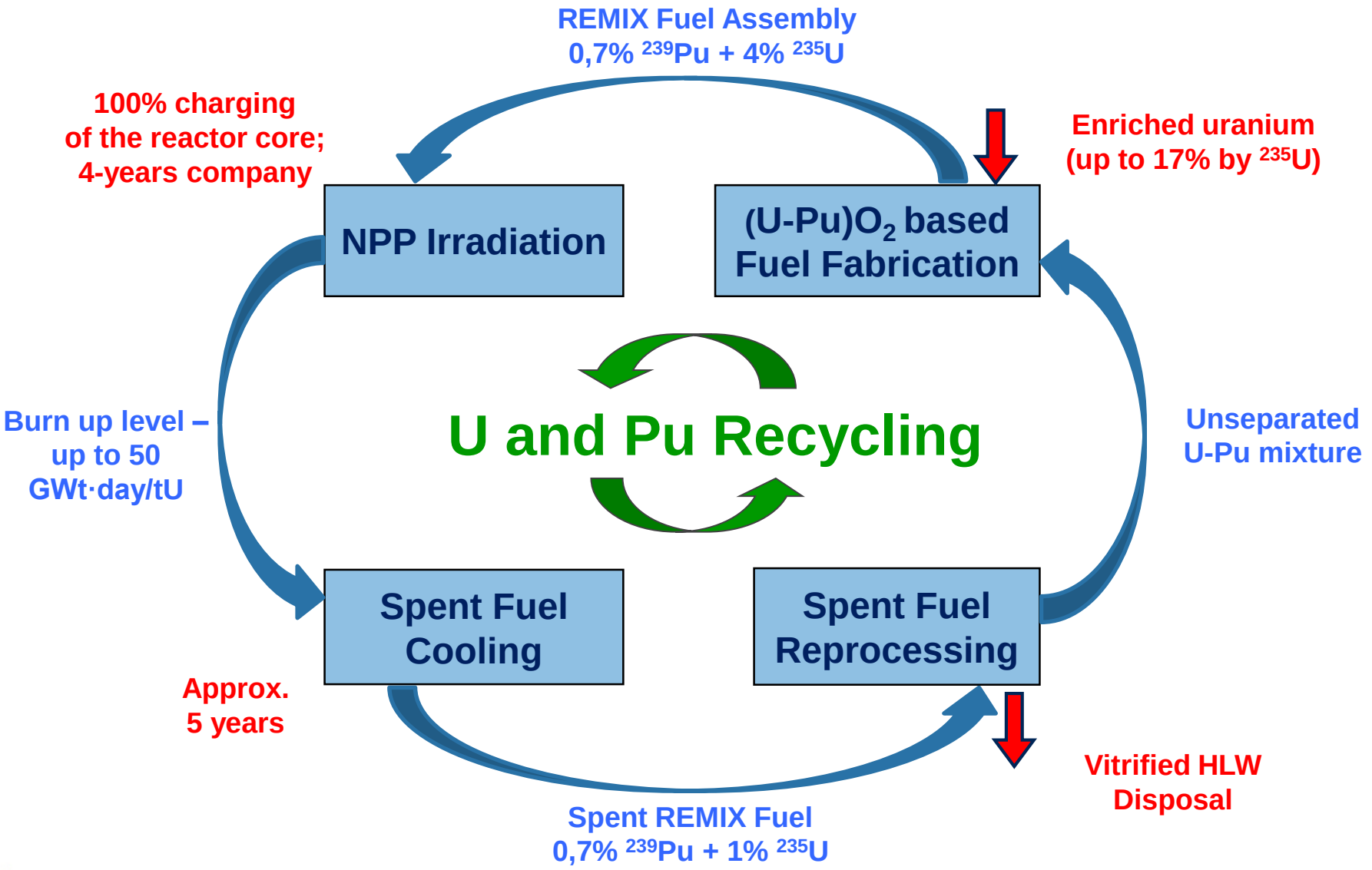
1. Uranium oxide (3.5 – 4.5 % ^{235}U + ^{238}U) – single cycle, processed
2. MOX (5 -7 % ^{239}Pu + ^{238}U) – single cycle, recycling with restrictions
3. REMIX (1% ^{239}Pu + 3% ^{235}U + ^{238}U) – multiple cycle, processed

REMIX - REgenerated MIXture of U, Pu oxides

REMIX is prepared directly from the mixture of uranium and plutonium recovered in the course of SNF reprocessing and corrected with natural enriched uranium with ^{235}U content about 16-17%.

REMIX fuel allows multiple recycling of all the amount of uranium and plutonium recovered from SNF at 100% charging the core of VVER-1000 reactor with this fuel.

Closing of the PWR Fuel Cycle



Recycling of unseparated uranium and plutonium

TABLE 1 – U and Pu content (%) in regenerated REMIX fuel of VVER-1000
(Initial content U-235 is 4.4%, burn-up 50 GW·days/t, 5 year storage)

Nuclides	REMIX fuel composition before recycling		
	1st	3rd	5th
^{235}U	4.2	4.3	4.5
^{236}U	0.47	0.97	1.2
$^{239+241}Pu$	0.62	0.90	0.91
$^{238+240+242}Pu$	0.34	0.63	0.74
ΣPu	1.00	1.5	1.7
$^{239+241}Pu+^{235}U$	**4.8**	**5.2**	**5.3**

These data indicate that even at 5 recycles the composition of key nuclides of uranium and plutonium changes insignificantly.

TABLE 3. Neutron-physical characteristics of stationary loading of reactor core with natural uranium and REMIX fuel for burn-up (GWt·days/t). Reactor work period between reload 297 effective days

Neutron-physical characteristics	Uranium fuel	Regenerated REMIX fuel		
		1 var.	2 var.	3 var.
Initial Pu content in fuel, % mass	**0.0**	**1.0**	**2.0**	**3.0**
Average fuel enrichment in ^{235}U, % mass	**4.33**	**4.14**	**3.81**	**3.45**
Economy of natural U,%	0.0	20.0	27.4	35.4
Economy of SWU, %	0.0	-2.2	8.8	19.3
Power reactivity coefficient, nominal power value, fuel campaign beginning (end), (1/MW) $\cdot 10^{-5}$	- 0.50 (- 0.71)	-0.56 (-0.73)	-0.59 (-0.74)	-0.58 (-0.74)
Effective retarded neutron yield, nominal power value, fuel campaign beginning (end), %	0.63 (0.56)	0.58 (0.55)	0.55 (0.53)	0.52 (0.52)

Increase in Pu content in REMIX fuel results in economy of SWU and in decrease of natural U consumption, while the reactivity coefficient remains almost the same as compared to uranium fuel.

The use of the stored SNF

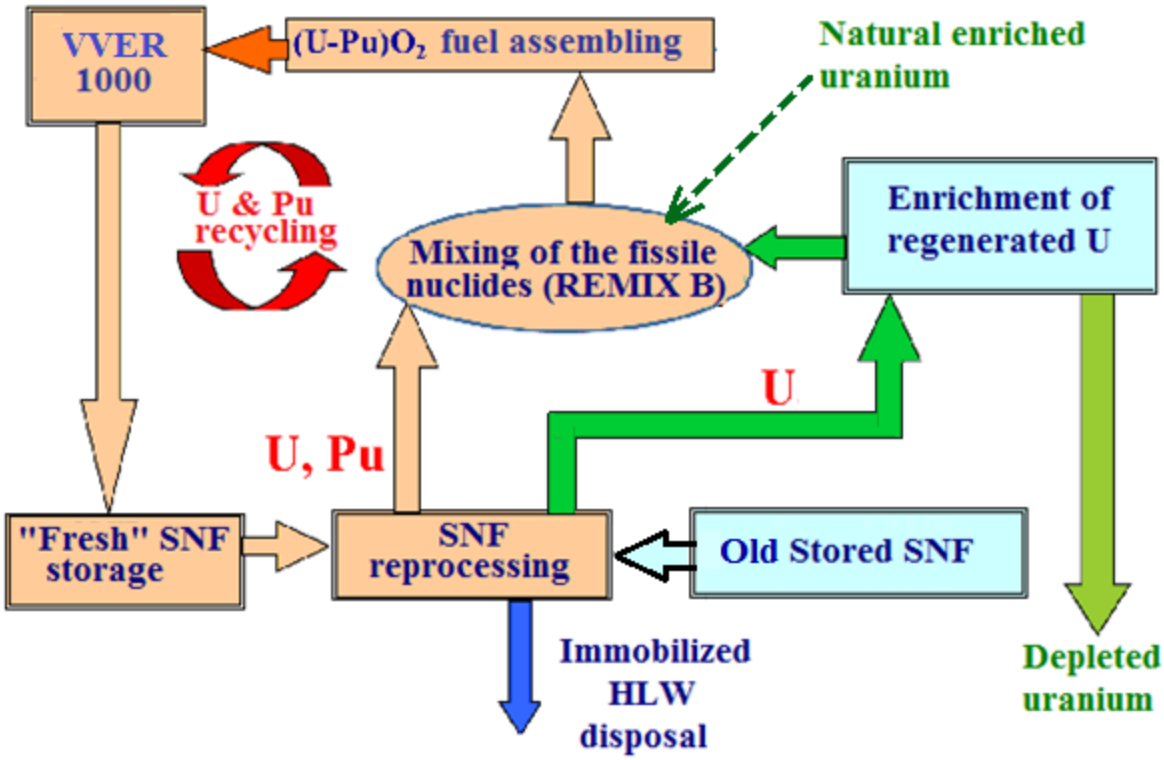


Fig. 4 – The sketch of involving the stored SNF into the closed fuel cycle of thermal reactors based on REMIX fuel

Feasibility study

Feasibility study on the comparison the REMIX fuel in a Closed Fuel Cycle of thermal reactors with Open Fuel Cycle of high burn-up spent fuel with direct disposal after long term storage has been performed.

KRI has prepared the basic data for a feasibility study and JSC Atomproekt (former VNIPIET) has performed it.

The following parameters were used :

1. **The actual infrastructure of nuclear fuel production in Russia , including facilities under construction;**
2. **NFC for NPP VVER-1000 loaded REMIX fuel made of fissile uranium and plutonium nuclides regenerated by VVER-1000 spent fuel reprocessing with addition of fresh enriched natural uranium;**
3. **Fresh UO_2-fuel containing 6.1% ^{235}U should be involved into open NFC at 70 GW*d/t burn-up;**
4. **The same power should be generated in closed NFC by 250 tons of REMIX fuel with burnup of 50 GW*d/t and by 170 tons of fresh UO_2-fuel of the second type in open NFC.**

Diagram of a Closed Fuel Cycle with REMIX fuel

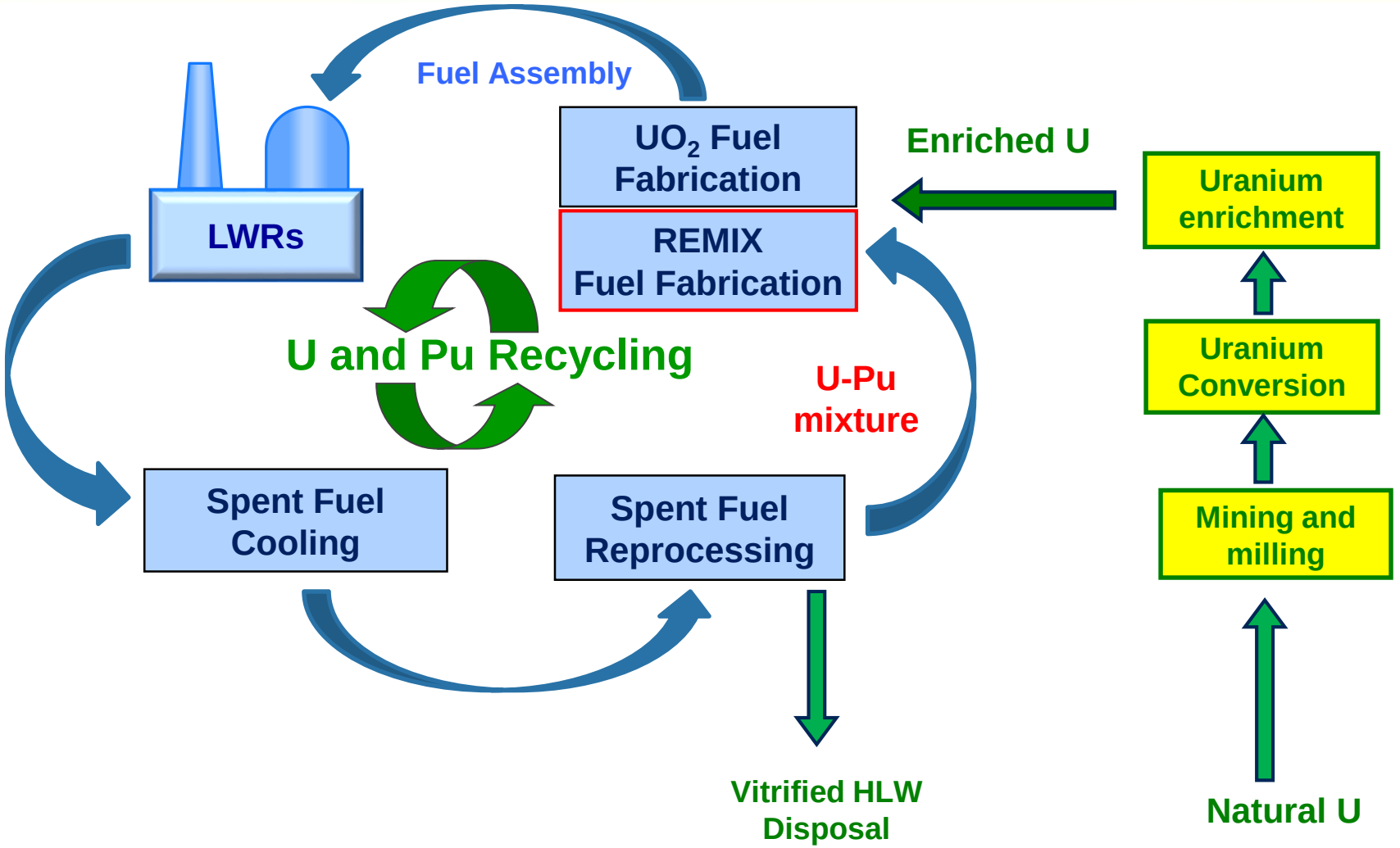
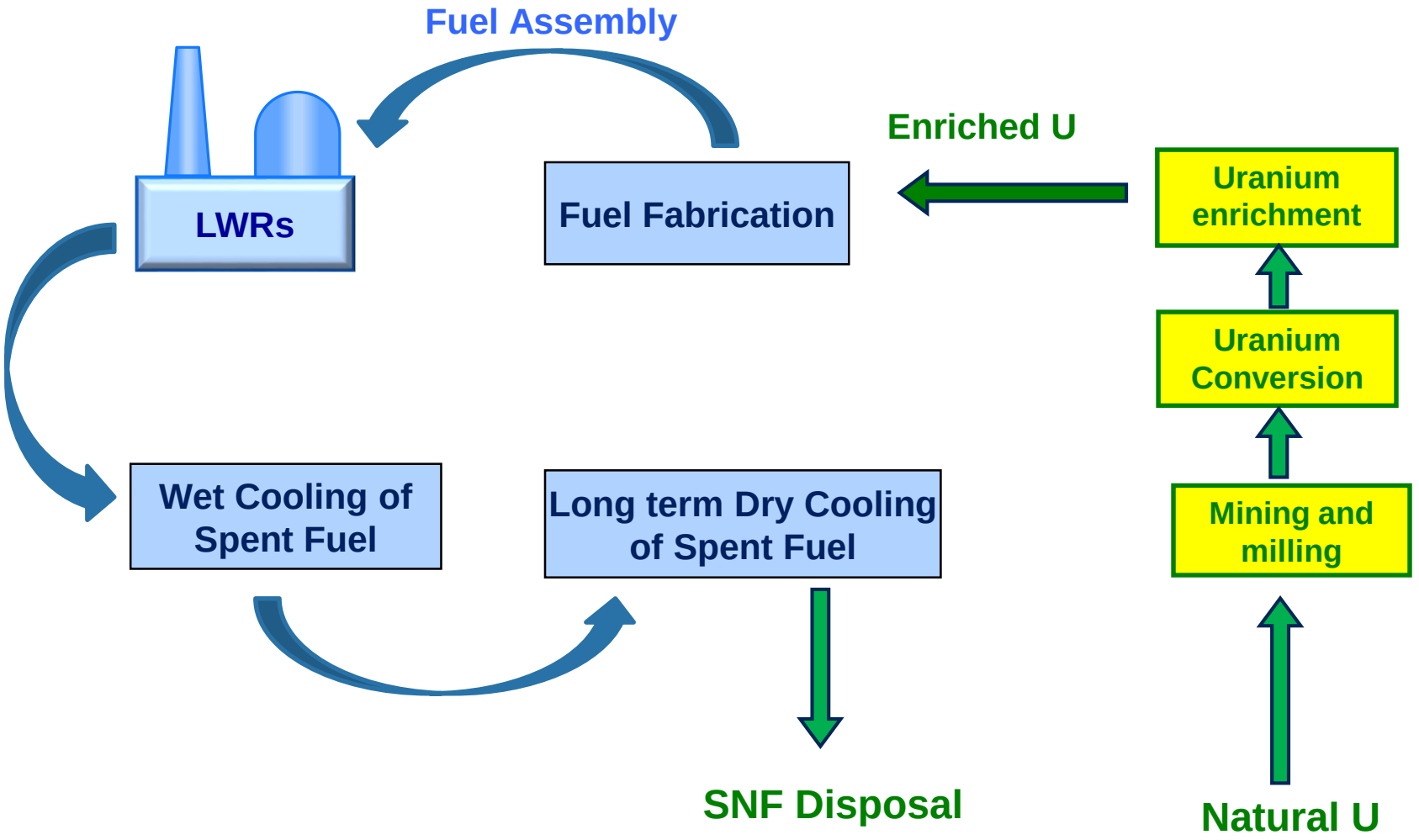


Diagram of Open Fuel Cycle with high burnup nuclear fuel



THE RESULTS OF THE FEASIBILITY STUDY

POCATOM

The relative costs of NFC organization (%)

Item	U and Pu Recycling (REMIX)	SNF direct disposal
CAPEX	26	100
OPEX	95	100
Total costs for the NFC	89	100

1) The preferred calculation result is the using the REMIX fuel in the closed NFC.
2) The cost of 1 kWh of electrical power with the use of the REMIX technology is lower by 11% as compared to an open fuel cycle.

Start of the work on a REMIX fuel

The state Corporation "Rosatom“ made the decision on starting the program for modeling and experimental verification of REMIX fuel use for VVER-1000 reactor as Strategic investment project in 2014.

The purpose of the program is:

- **Calculation and confirmation of nuclear safety of the design of the fuel assemblies with a REMIX fuel for loading in VVER-1000**
- **the fabrication of three experimental fuel assemblies containing multiple fuel rods with the REMIX fuel**
- **Bench testing of three combined experimental fuel assemblies containing fuel rods with REMIX-fuel**
- **Download of assemblies with REMIX fuel in the reactor VVER-1000 #3 of Balakovo NPP in the summer of 2016**

CONCLUSIONS

Using of REMIX fuel in the NFC of thermal reactors makes possible:

- **multiple recycling of Pu and U total amount regenerated from SNF,**
- **reduction of the accumulated SNF amount,**
- **decrease in the amount of consumed natural uranium**

The program on REMIX fuel testing in the VVER-1000 has started in 2014