Fuel Cycle Concept with Advanced METMET and Composite Fuel in LWRs

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Generation II Light Water Reactors (LWRs) are the dominant world commercial nuclear power plant. Currently, 90% of the installed reactors worldwide operate on a once-through nuclear fuel cycle, utilizing uranium dioxide fuel. To optimize the fuel cycle MOX fuel has been considered for thermal reactors, although some limitations exist, that make MOX fuel be used only in one fuel cycle. The most relevant are: the degradation of Pu isotopic vector, the insufficient uranium density, high operating fuel temperature and the low serviceability under transients.
We suggest replacing the container design fuel rod, for which possibilities are practically exhausted, by dispersion type fuel elements. Structurally, advanced METMET dispersion type fuel consists of uniformly distributed higher density fuel granules of U-Mo, U-Nb-Zr or U_3Si alloys that are metallurgically bonded between themselves and to fuel cladding with specially developed Zr-based matrix alloys. A fuel meat retains controllable porosity in the range of 16- 38% to accommodate fuel swelling [1-2].

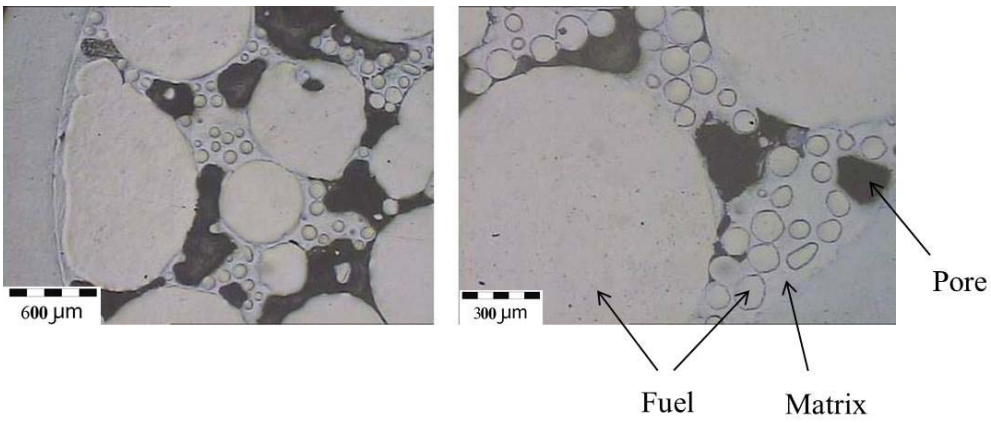

Fig. 1. Microstructure of modified composite fuel with higher uranium content. Conditions: 72% volume fraction of fuel under the cladding, technological parameters: t = 900°C and τ =60 s, fuel column length: 800 mm.

The primary advantages of advanced METMET fuel for application in thermal reactors are high uranium content (25-50% higher in comparison with the standard UO_2 pelletized fuel rod), low temperature of fuel (<500 ºC, cold fuel), the extension of burn-up (100 MW*d/kgU) and serviceability under transient conditions.
Due to high uranium content and hence intermediate neutron spectrum the main economically significant characteristics for PWR's can be improved:
1. Larger quantities of generated plutonium (~2.5-3 times higher).
2. Increasing of fissionable plutonium isotopes up to 75-78% in spent fuel (harder neutron spectrum).
3. Increasing the breeding ratio up to 0.7-0.8 (by reducing the hydrogen-to-heavy metal ratio).
4. The prolongation of the campaign will be more than 30% in effective days (up to 500 additional effective days).
5. Increasing the time between refueling, in other words, increasing the Unit Capacity Factor (UCF). In this case instead of a year or a year and a half fuel cycle at two year cycle becomes feasible.

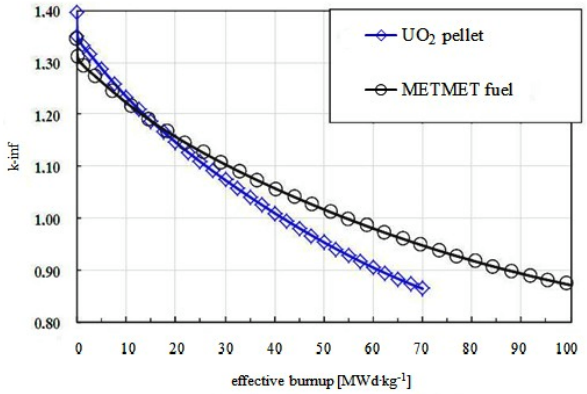

Fig. 2. K-inf versus effective burn-up for UO_2 and advanced METMET fuel

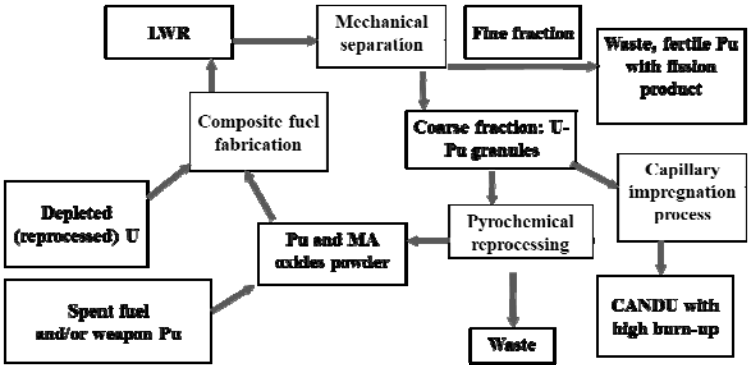

Fig. 3. LWR fuel cycle with composite fuel and multiply recycling of Pu

On the basis of METMET fuel, composite U(Th)-PuO_2 fuel (an analogue of MOX) can be fabricated where depleted uranium alloy and dioxide plutonium powder have initially separate arrangement [1-2]. The fuel element development approach consists of individual operations used to fabricate a fuel element with uranium as the main component and to fill it with plutonium dioxide powder, which minimizes dust producing operations on the fuel element fabrication. According to new fuel element design, a framework fuel element having a porous uranium alloy meat (U-Mo or U-Zr alloys) is filled with standard PuO_2 powder of less than 70 micron fraction prepared by pyrochemical or other methods. In this way a high uranium content fuel meat metallurgically bonded to cladding forms a heat conducting framework, pores of which contain PuO_2 powder. Instead/or in combination with Pu dioxide powder, other MA oxides can be used based on Am and Np. This approach can be also implemented with the use of Th granules in place of depleted uranium alloy granules. In this case the conversion ratio is increased.

Due to this as compared to MOX fuel the new one features higher thermal conductivity, higher uranium content, hence, high conversion ratio, does not interact with fuel cladding and fabrication technology is more environmentally clean. Composite fuel is intended for use in thermal and fast reactors as it features higher characteristics in comparison to MOX or metallic (U-Pu-Zr) fuel.

Mechanism of composite fuel operation: first PuO_2 burns up in metmet fuel form while Pu generates in the metmet fuel that first serves as a breeding blanket and then begins to burn up. Consequently, the components of the composite fuel have different Pu isotope compositions at the cycle end. The plutonium dioxide powder will basically accumulate non-fissionable isotopes while the METMET fuel – fissionable species.

In composite fuel U alloy and PuO_2 powder have initially separate arrangement in a fuel composition, so we can separate fissile Pu from fertile one. Mechanically evoked from cladding granules of generated U-Pu alloy can be used repeatedly in PWR and CANDU reactors using capillary impregnation method as they have high content of generated Pu. Hence in comparison to MOX we can multiply use of generated Pu in spent fuel and instead of partial recycling implement full recycling which drastically reduces the fuel waste.

Thus, using novel concept based on high density dispersion and composite fuel the closed U-Pu cycle in thermal reactors can be implemented – as the fuel available to these reactors may be increased by ~48% (18% in case of MOX). The remained Pu fissile isotopes can be used from the accumulated thermal reactor spent fuels.

References

[1] A. Savchenko, A. Vatulin, K. Lipkina, G. Kulakov, et all, Journal of Progress in Nuclear Energy in press,1-7 (2013), http://dx.doi.org/10.1016/j.pnucene.2013.10.007.

[2] A. Savchenko, et all, Journal of Progress in Nuclear Energy **138-144**, 57 (2012).