Material Attractiveness of Advanced Nuclear Fuels

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To meet the needs of future reactors to have design that are safer, more economical, produce less waste, and are proliferation resistant, new nuclear fuels are being developed. Two of these radically different fuel designs are TRISO based fuels and Lightbridge's fuel. TRISO fuel consists of small (~500 µm diameter) UCO kernels surrounded by layers of SiC and graphite. Thousands of these particles are then added to a graphite matrix and formed into spheres or cylindrical pellets. Lightbridge's fuel consists of metallic UZr in a cruciform geometry that has a helical twist. Both of these fuels use HALEU, with ^{235}U enrichments as high as 19.75%.

MCNP6.2 radiation transport burnup simulations were performed of fuel pins (non-proprietary Lightbridge PWR design) and pebbles (based on X-energy's TRISO fuel design) to quantify the plutonium content at the end of the fuel's life. These plutonium compositions were assessed using the material attractiveness methodology proposed by Bathke et al. and compared to weapons grade plutonium, reactor grade plutonium, and plutonium from used MOX fuel. These values, shown in the table below, indicate that for a technologically advanced state (FOM_1) the plutonium has medium attractiveness and for a non-technologically advanced state (FOM_2) the plutonium has low attractiveness. While both the Lightbridge and TRISO produced plutonium have noticeably smaller values, the logarithmic nature of the Bathke et al. methodology cases these plutonium compositions to have the same attractiveness categories as reactor grade plutonium.

Pu composition	M (kg)	h (W/kg)	S (n/s/kg)	D (rad/h)*	FOM_1	FOM_2
Weapons - grade Pu	16.30	2.18	$6.20x10^4$	~0	2.55	1.75
MOX - used	221.9	6.28	$3.75x10^5$	~0	2.24	0.90
Reactor - grade Pu	21.21	16.40	$4.07x10^5$	~0	1.98	0.86
Lightbridge - used	22.87	81.68	$8.44x10^5$	~0	1.35	0.48
TRISO	25.41	35.63	$7.26x10^5$	~0	1.63	0.53

*Dose rate determined to be ~0 for all plutonium compositions based on previous work.

Due to the limitations of the Bathke et al. methodology, other factors should be considered. The ^{235}U enrichment of the used TRISO fuel is 3.1% with that of Lightbridge being 1.7%. The mass of plutonium produced by each of these fuels per GWD is 133 g for TRISO and 85 g for Lightbridge. This is much less than the 254 g for traditional PWR used fuel. The cladding on the metallic Lightbridge fuel is zirconium, which is expected to have similar difficulties in reprocessing to that of traditional PWR UO_2 fuel. However, the TRISO fuel has shells of SiC and carbon in a graphite matrix, mating the fuel more difficult to reprocess.

While TRISO and Lightbridge fuel are significantly different, they both produces less plutonium per GWD than tractional PWR fuel and the plutonium that is produced has noticeably lower attractiveness values. It is felt by the authors that both TRISO and Lightbridge used fuels have equivalent resistance to weaponization.