
# Material Attractiveness of Advanced Nuclear Fuels

**2023 ANS Winter Meeting (ANTPC 2023), November 12 – 15, 2023**

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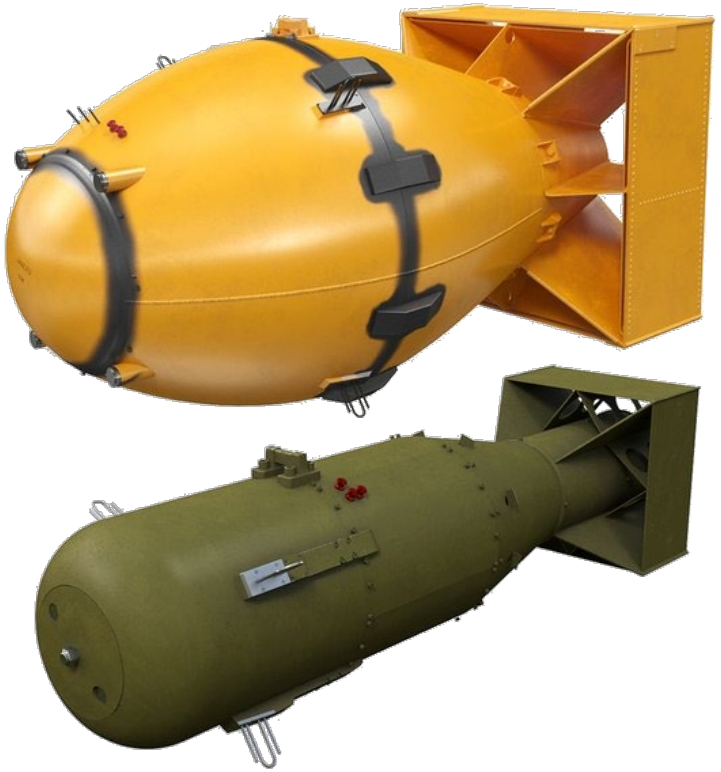
# Not All Uranium and Plutonium are the Same



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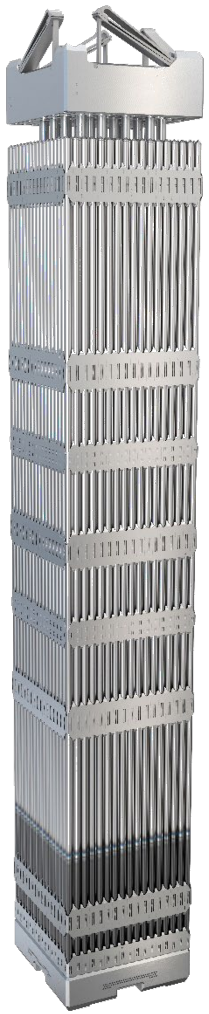


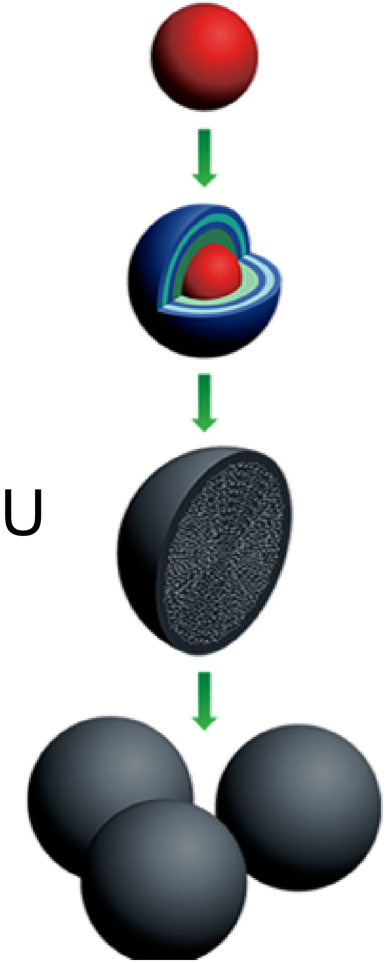
# Goals* of Advanced Nuclear Fuels

- Example design criteria
  - Safety
    - E.g. accident tolerant fuel
  - Economics
    - E.g. less frequent refueling outages
  - Waste Management
    - E.g. thorium based fuels
  - Proliferation
    - Safeguardability
    - Proliferation resistance
    - Etc.

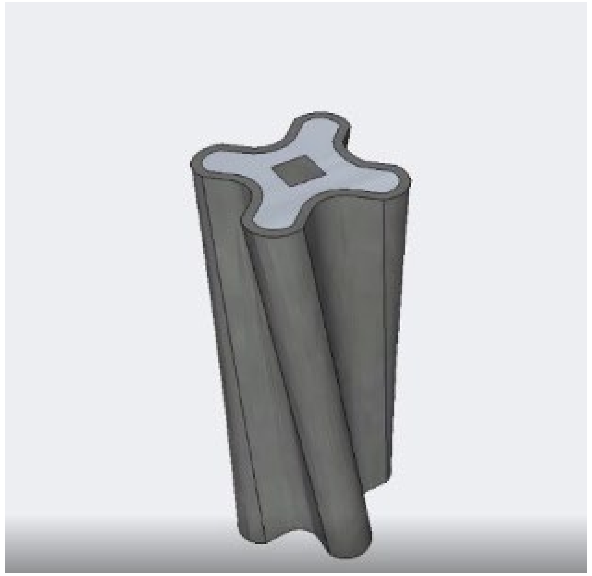
*Based on Generation IV International Form goals

# Two Advanced Fuels

- TRISO fuel
  - UCO kernel
  - SiC cladding
  - Small size
    - 0.4 mm diameter
  - Imbedded in graphite matrix for moderation
  - Compatible with HALEU



- Lightbridge fuel*
  - UZr metallic fuel
  - Cruciform geometry
  - Compatible with existing PWRs
  - Compatible with HALEU



*T. Britt, B. Goddard, and M. Shah "Innovative Fuel Design to Improve Proliferation Resistance," *Journal of Nuclear Materials Management*, **47(3)**, 5-8 (2019)

# Radiation Transport Simulations

- MCNP 6.2 burnup simulations
  - X-energy single pebble
    - 19.75% enriched
    - Burnup 161,000 MWd/MTU
  - Lightbridge single fuel pin
    - 19.75% enriched
    - Burnup 199,960 MWd/MTU

| Pu composition | $^{238}$Pu | $^{239}$Pu | $^{240}$Pu | $^{241}$Pu | $^{242}$Pu |
|---|---|---|---|---|---|
| Weapons - grade Pu* | 0.00% | 93.60% | 5.90% | 0.40% | 0.10% |
| MOX - used* | 0.51% | 51.03% | 28.58% | 15.80% | 4.09% |
| Reactor - grade Pu | 2.40% | 53.60% | 23.60% | 14.30% | 6.10% |
| Lightbridge | 14.20% | 35.50% | 19.70% | 14.60% | 16.00% |
| TRISO | 5.89% | 32.80% | 22.06% | 18.99% | 20.25% |

*B. Goddard and A. Totemeier, "Improved Disposition of Surplus Weapons-Grade Plutonium Using a Metallic Pu-Zr Fuel Design," *Nuclear Technology*, **209(5)**, 696-706 (2023)

# Material Attractiveness (Bathke et al.*)

- Critical mass (*M*), heat generation (*h*), spontaneous fission (*S*), and radiation dose (*D*) determine a materials attractiveness
- $FOM_2 = 1 - \log_{10}\left(\frac{M}{800} + \frac{Mh}{4500} + \frac{MS}{6.8(10)^6} + \frac{M}{50}\left[\frac{D}{500}\right]^{\frac{1}{\log_{10} 2}}\right)$
- $FOM_1 = 1 - \log_{10}\left(\frac{M}{800} + \frac{Mh}{4500} + \frac{M}{50}\left[\frac{D}{500}\right]^{\frac{1}{\log_{10} 2}}\right)$

| FOM | Weapons Utility | Attractiveness |
|---|---|---|
| > 2 | Preferred | High |
| 1-2 | Attractive | Medium |
| 0-1 | Unattractive | Low |
| < 0 | Unattractive | Very Low |

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*C. Bathke et al.,"The Attractiveness of Materials in Advanced Nuclear Fuel Cycles for Various Proliferation and Theft Scenarios," *Nuclear Technology*, **179(1)**, 5-30 (2017)

# Material Attractiveness

| FOM | Attractiveness |
|---|---|
| > 2 | High |
| 1-2 | Medium |
| 0-1 | Low |
| < 0 | Very Low |

| Pu composition | M (kg) | h (W/kg) | S (n/s/kg) | D (rad/h) | $FOM_1$ | $FOM_2$ |
|---|---|---|---|---|---|---|
| Weapons - grade Pu | 16.27 | 2.18 | $6.20 \times 10^4$ | ~0 | 2.55 | 1.75 |
| MOX - used | 21.91 | 6.28 | $3.75 \times 10^5$ | ~0 | 2.24 | 0.90 |
| Reactor - grade Pu | 21.21 | 16.40 | $4.07 \times 10^5$ | ~0 | 1.98 | 0.86 |
| Lightbridge | 22.87 | 81.68 | $8.44 \times 10^5$ | ~0 | 1.35 | 0.48 |
| TRISO | 25.41 | 35.63 | $7.26 \times 10^5$ | ~0 | 1.63 | 0.53 |

# Bathke et al. Methodology Criticism

- Lightbridge, TRISO, and reactor grade Pu all have the same **category** of material attractiveness
  - Logarithmic nature of the Bathke et al. methodology hides the fact that both Lightbridge and TRISO produce about twice as much heat and spontaneous fission neutrons
- Other factors should be considered
  - TRISO fuel has shells of SiC and carbon in a graphite matrix, making the fuel more difficult to reprocess
  - The mass of plutonium produced by each of these fuels per GWD

| Pu composition | Pu (g/GWd) |
|---|---|
| Reactor - grade Pu | 254 |
| Lightbridge | 85 |
| TRISO | 133 |

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# Take Away Message

- TRISO and Lightbridge fuel are significantly different from each other
  - They both have lower attractiveness values than traditional PWR fuel
  - They both produces less plutonium per GWd than traditional PWR fuel
- It is felt by the authors that both TRISO and Lightbridge used fuels have equivalent resistance to weaponization

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