# Fusion Neutron Induced Transmutation of Spent Fuel Actinides*

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# Outline

- Status of Fusion Energy Development
- Fusion Neutron Transmutation
- Issue and Analyses
- Conclusions

# Fusion Energy Development

- International Thermonuclear Engineering Reactor (ITER) is Progressing Toward Construction
- USDOE is Developing Strategy to Build Fusion DEMO Plants in 2040

# Fusion Transmutation of Waste

- Fusion Neutrons May Help Fission Power to Destroy Spent Fuel Actinides
- Benefits of Transmutation

  -Reducing HLW Volumes by factor of 10-100

  -Reducing Long-term Risks with Disposed Wastes
- Risks Associated with Transmutation

  -Plutonium Proliferation

  -Safety: Handling of Radioactivity, Particularly Higher (Am and Cm) Actinides Generated During Transmutation

# Issue

How Far Can Transmutation Go?

Considering

(1) Reduction of Performance,

(2) Handling of Am and Cm Isotopes, and

(3) Final Disposal of Remaining Actinide Waste – Waste Quantity Reduction Factor.

# Neutronics Calculations (Blanket Model)

## Motivation: High Nuclear Performance, Low SNF Inventory (High Destruction Rate, Relative to Inventory)

- One-dimensional Blanket Model
  - First Wall: 5 mm, Ferritic Steel Structure
  - Blanket-1: 30 cm, 2%FS+50%Be+48%MS
  - Blanket-2: 30 cm, 2%FS+50%C+48%MS
  - Reflector: 40 cm, Graphite
- Molten Salt: Flibe (2 g/cc)
  - Actinide Concentration 14.8 mg/cc (0.74 w/o)

# Neutronics Calculations
# (Code, Library, and performance Control)

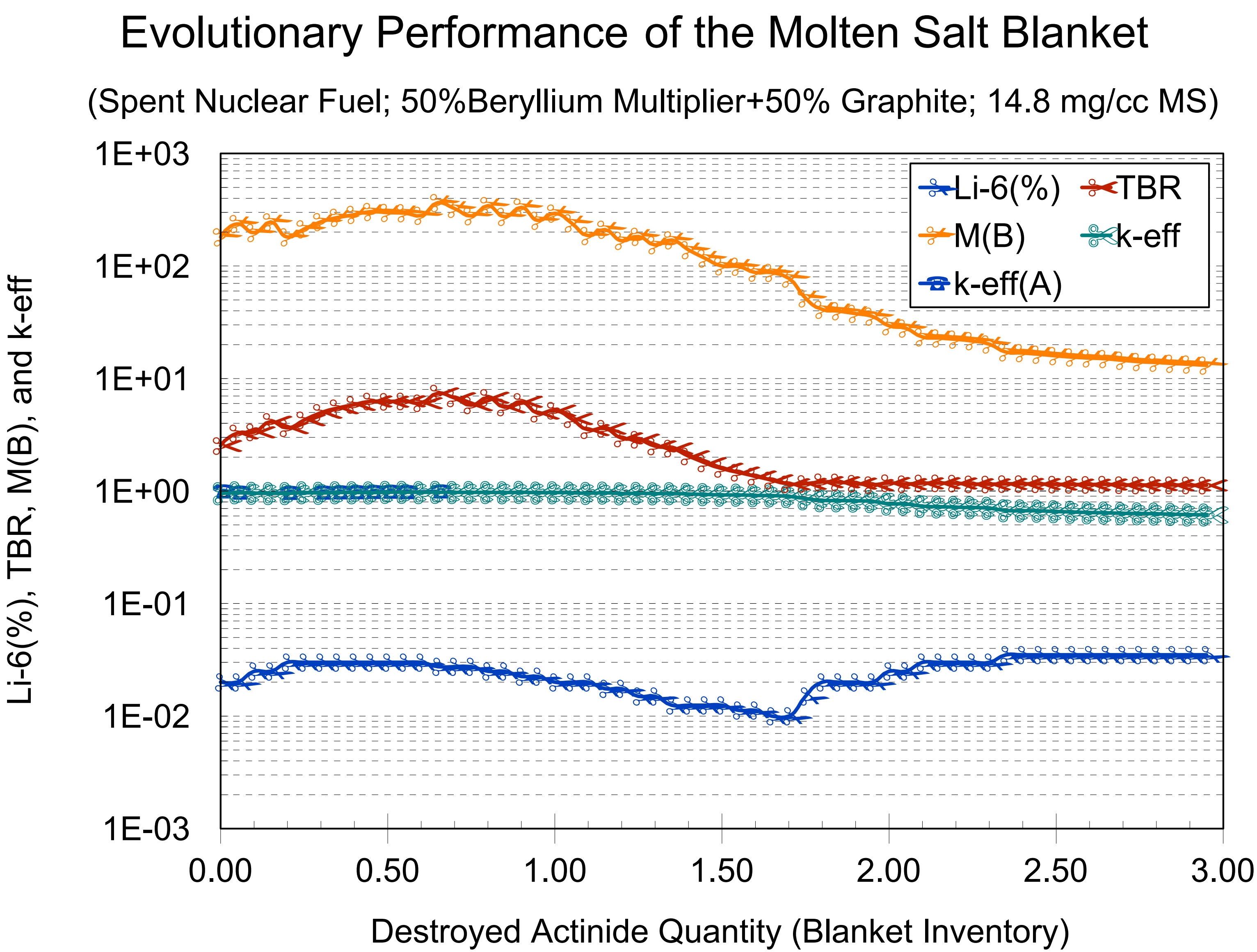
- MCNP4B Monte Carlo Code
- ENDF/B-VI Nuclear Data Library
- Varying Li-6 Enrichment to Control

  Criticality (K-eff < 1)

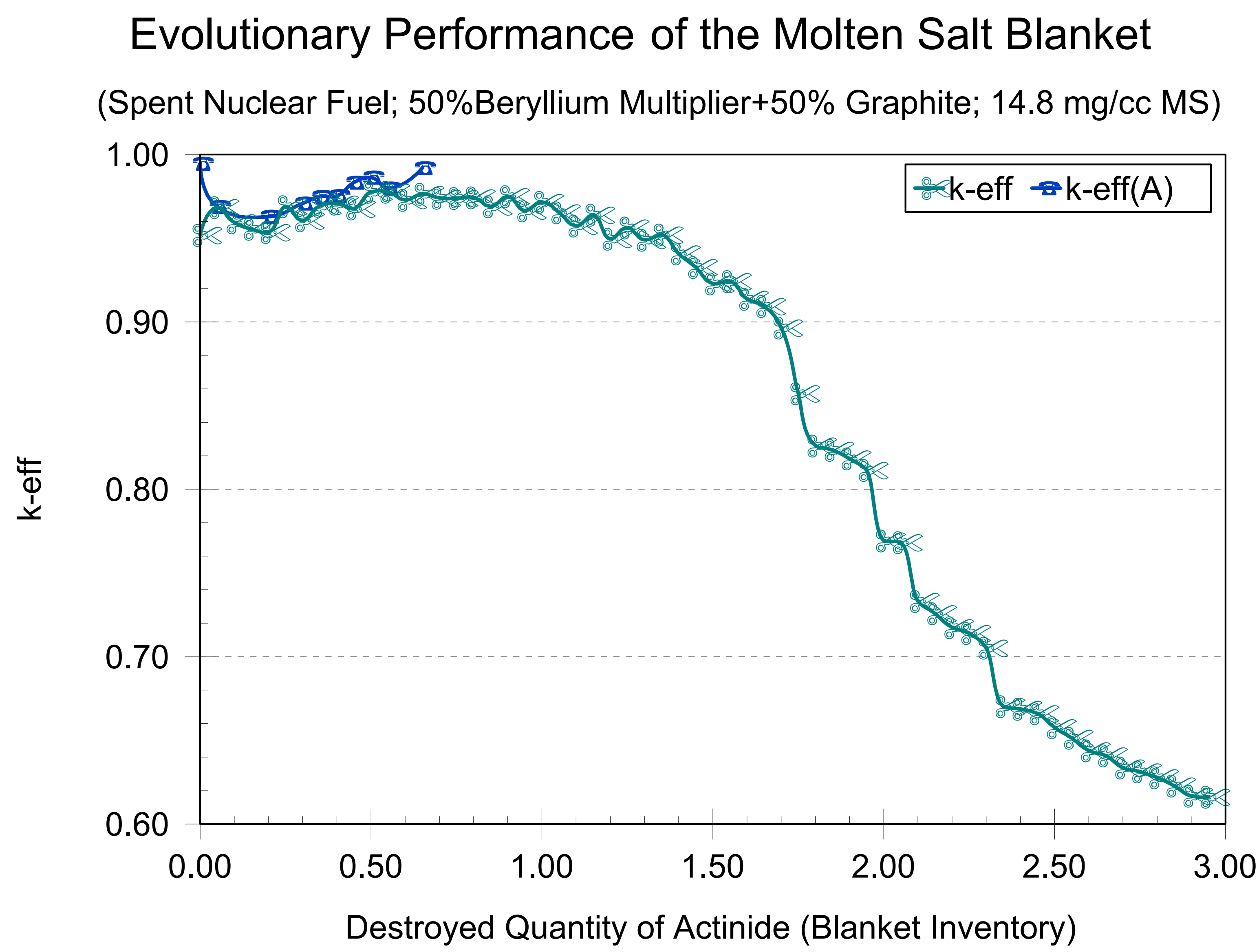
  Tritium Breeding (TBR > 1.1)
- Fission Products Removed and Spent Fuel Actinides Replenished During Transmutation Burn-up Calculations

# Waste (Quantity) Reduction Factor

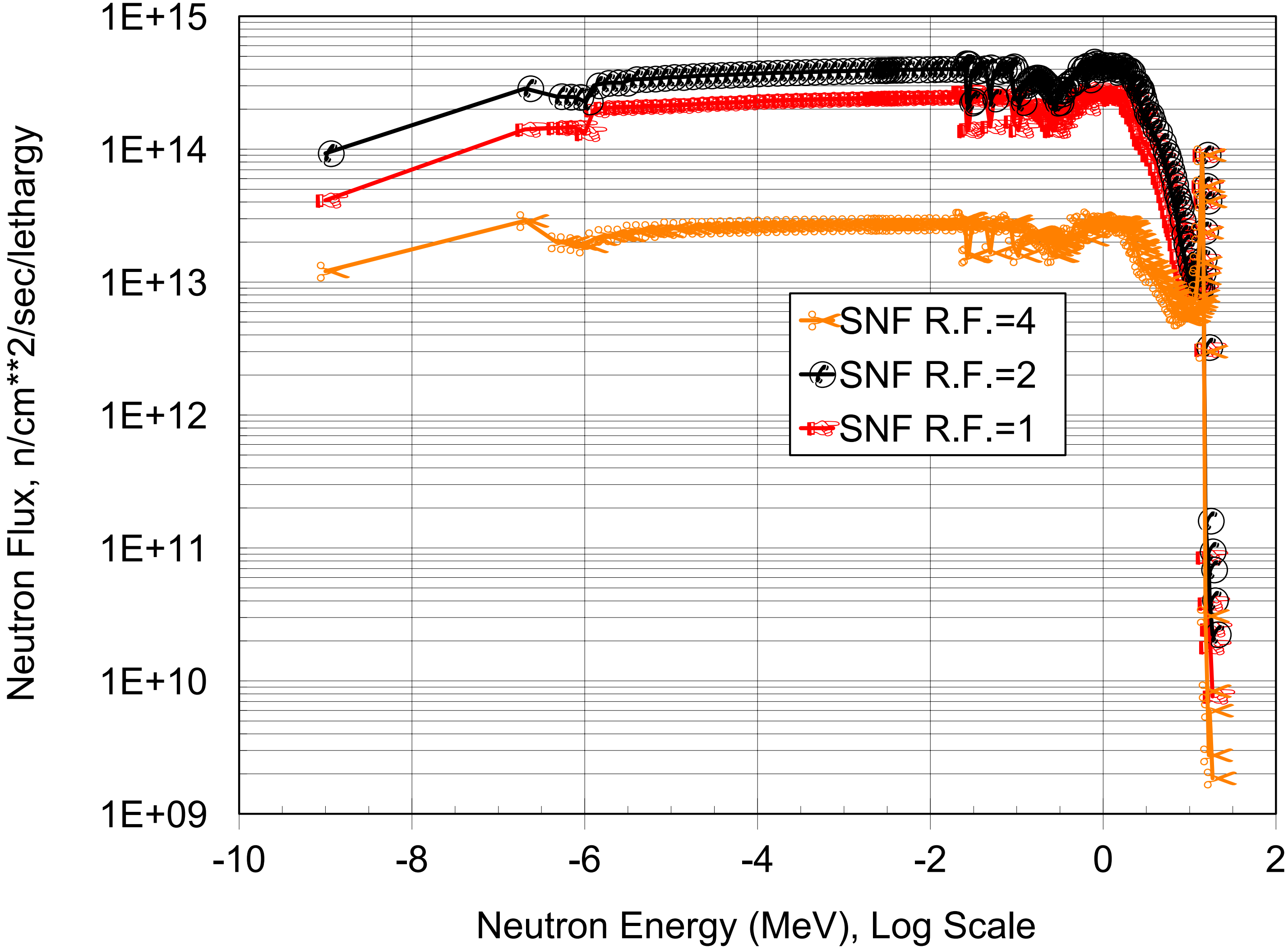
- Defined as Ratio of Initial Waste Quantity and Final Waste Disposal Quantity
- Waste Reduction Factor = 1 + Waste Destroyed in the Waste Transmuter (In Units of Waste Inventory in the Reactor)/Waste Inventory in the Reactor

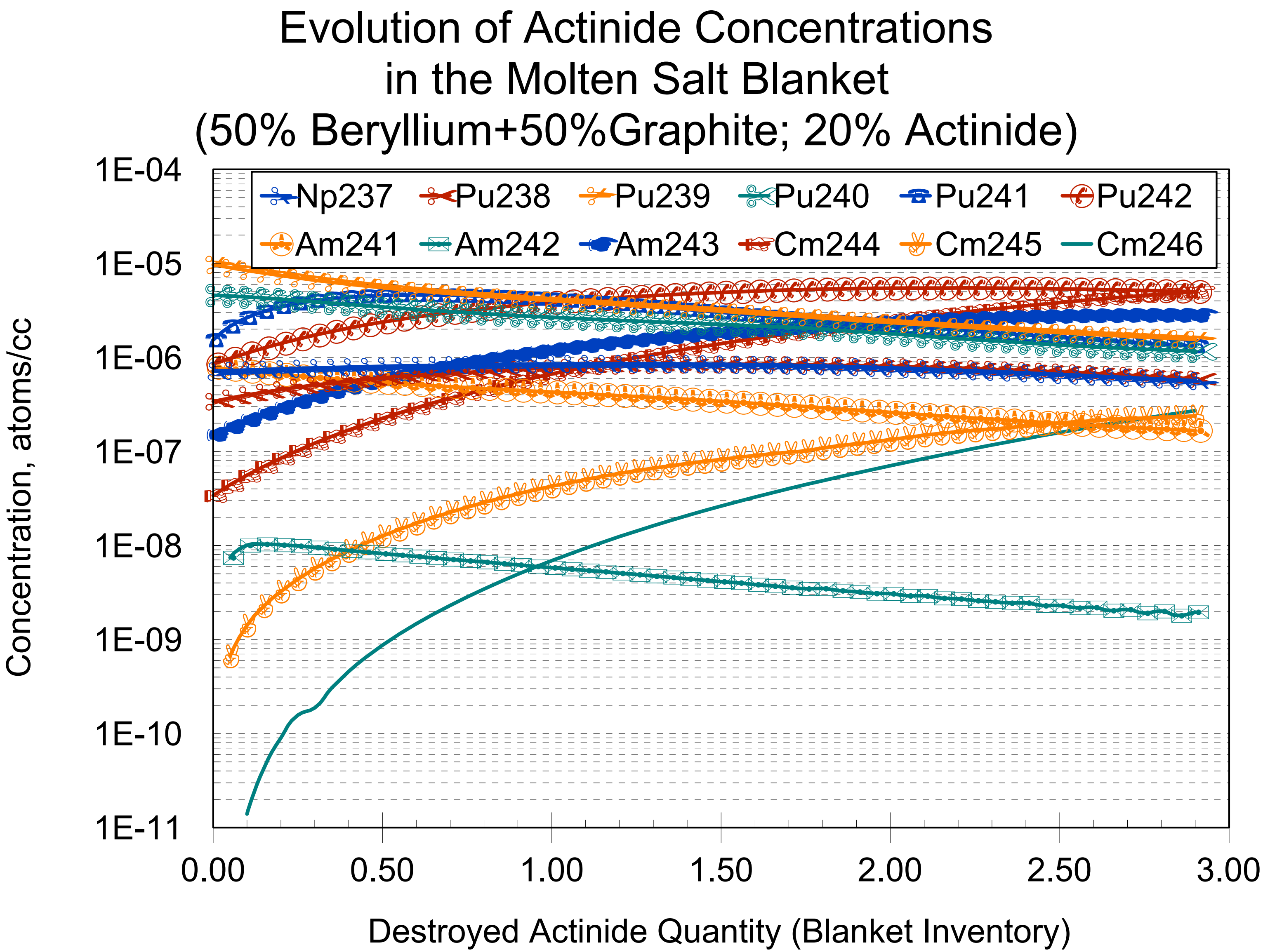


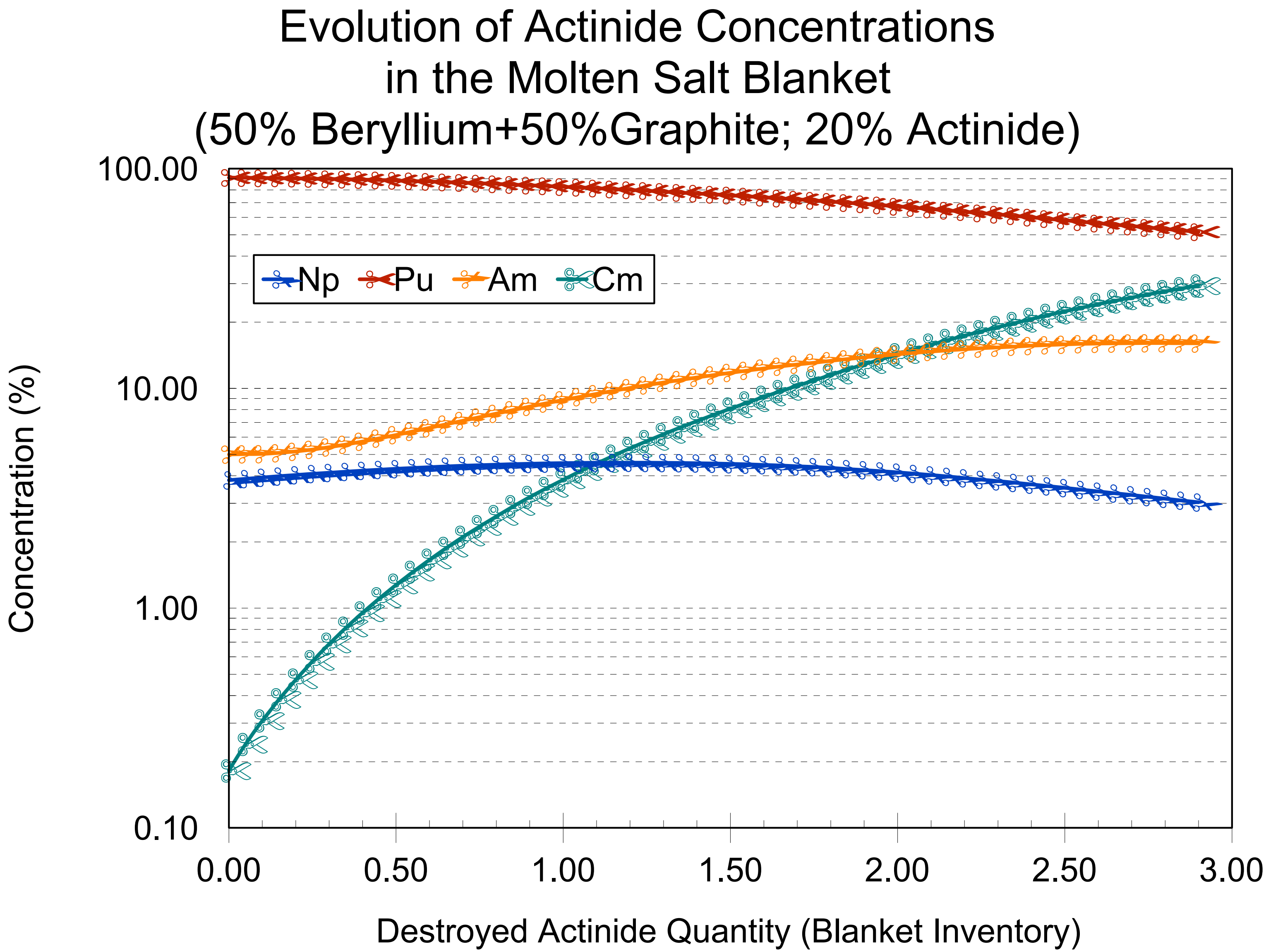
Evolutionary Performance of the Molten Salt Blanket
(Spent Nuclear Fuel; 50%Beryllium Multiplier+50% Graphite; 14.8 mg/cc MS)
Li-6(%), TBR, M(B), and k-eff
1E+03
1E+02
1E+01
1E+00
1E-01
1E-02
1E-03
0.00
0.50
1.00
1.50
2.00
2.50
3.00
Destroyed Actinide Quantity (Blanket Inventory)
Li-6(%)
TBR
M(B)
k-eff
k-eff(A)


Evolutionary Performance of the Molten Salt Blanket
(Spent Nuclear Fuel; 50%Beryllium Multiplier+50% Graphite; 14.8 mg/cc MS)
k-eff
k-eff(A)
1.00
0.90
0.80
0.70
0.60
k-eff
0.00
0.50
1.00
1.50
2.00
2.50
3.00
Destroyed Quantity of Actinide (Blanket Inventory)

# Neutron Fluxes at 1 MW/m**2




Evolution of Actinide Concentrations
in the Molten Salt Blanket
(50% Beryllium+50%Graphite; 20% Actinide)
Np237
Pu238
Pu239
Pu240
Pu241
Pu242
Am241
Am242
Am243
Cm244
Cm245
Cm246
Concentration, atoms/cc
1E-04
1E-05
1E-06
1E-07
1E-08
1E-09
1E-10
1E-11
0.00
0.50
1.00
1.50
2.00
2.50
3.00
Destroyed Actinide Quantity (Blanket Inventory)



Evolution of Actinide Concentrations
in the Molten Salt Blanket
(50% Beryllium+50%Graphite; 20% Actinide)
Np
Pu
Am
Cm
100.00
10.00
1.00
0.10
Concentration (%)
0.00
0.50
1.00
1.50
2.00
2.50
3.00
Destroyed Actinide Quantity (Blanket Inventory)

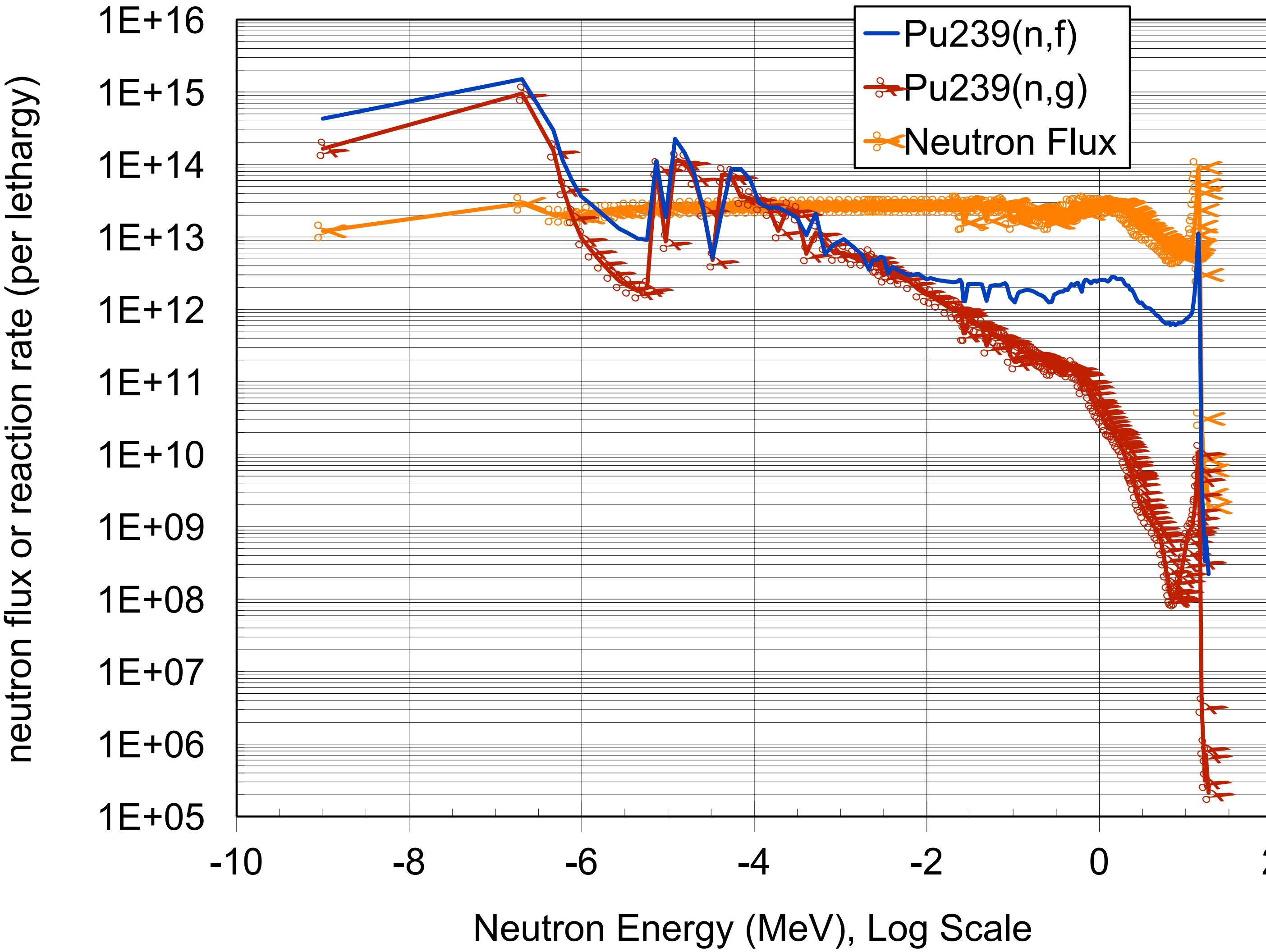
# Nuclear Performance of FTWs at Several SNF Inventory Reduction Factors

| Performance Parameter | Initial Operation | SNF Inventory Reduction Factor: 2 | SNF Inventory Reduction Factor: 4 |
|---|---|---|---|
| Li-6 in Lithium (%) | 0.02 | 0.02 | 0.035 |
| k-eff<br>(Accident) | 0.9519<br>(0.9946) | 0.9713<br>(0.986) | 0.6162 |
| M-Blanket<br>(Fission/Neutron)<br>(Capture/Neutron)<br>(Capture/Fission) | 181<br>(12.7)<br>(18.2)<br>(1.43) | 294<br>(20.7)<br>(26.7)<br>(1.29) | 13.1<br>(0.928)<br>(1.63)<br>(1.76) |
| TBR | 2.53 | 5.2 | 1.13 |

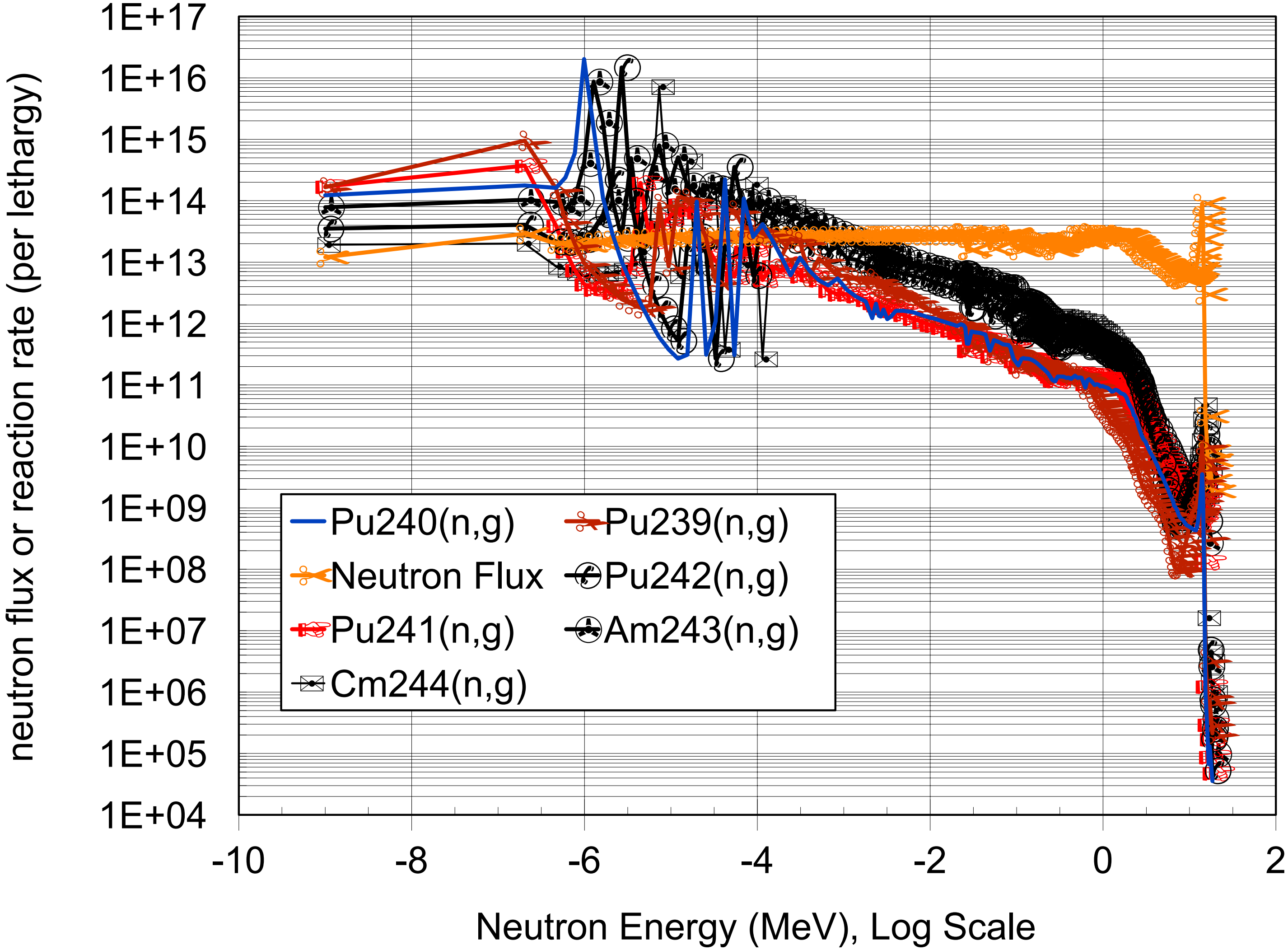
# Fractions (%) of Actinides in Disposed Waste After Transmutation at Several SNF Inventory Reduction Factors

| Element | SNF Inventory Reduction Factor: 1 (No Transmutation) | SNF Inventory Reduction Factor: 2 | SNF Inventory Reduction Factor: 4 |
|---|---|---|---|
| Np | 3.82 | 4.6 | 3.03 |
| Pu<br>(Fissile) | 91.0<br>(66.0) | 82.7<br>(53.0) | 51.6<br>(29.8) |
| Am<br>(Am242m) | 5.0<br>(0.0) | 8.9<br>(0.38) | 16.0<br>(0.065) |
| Cm<br>(Cm245) | 0.18<br>(0.0) | 3.8<br>(4.3) | 29.4<br>(4.4) |

# Neutron Reaction Rates at 1 MW/m**2



# Neutron Reaction Rates at 1 MW/m**2



# Technical Results

- Nuclear Performance in the Sub-critical Assembly Drops Significantly After Substantial Am and Cm Isotopes Accumulated.
- Less Than One Fission per Source Neutron is Expected when Am and Cm Isotopes are Accumulated to > 50% of Total Actinides.
- Major Actinide Destruction Process Occurs in Plutonium Isotopes via Fission Reactions in Pu239 and Pu241.

# Conclusions

- High Nuclear Performance in FTW is Not Expected for Soft Spectrum Blankets in Scenarios Leading to Significant Reduction of SNF Inventory
- Further Analysis Should be Conducted for Harder Spectrum Blankets.
- Nuclear Data may Play an Important Role in Making Assessment.