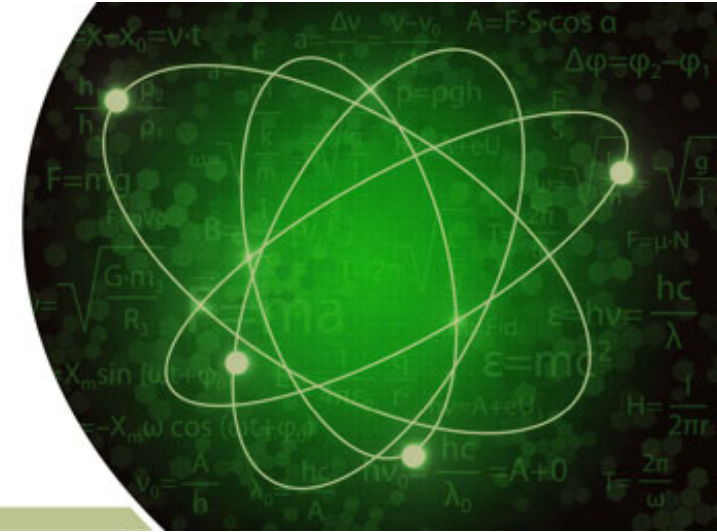




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Investigation of Region-wise Sensitivities for Nuclear Criticality Safety Validation

Bobbi Merryman

Graduate Student, University of New Mexico



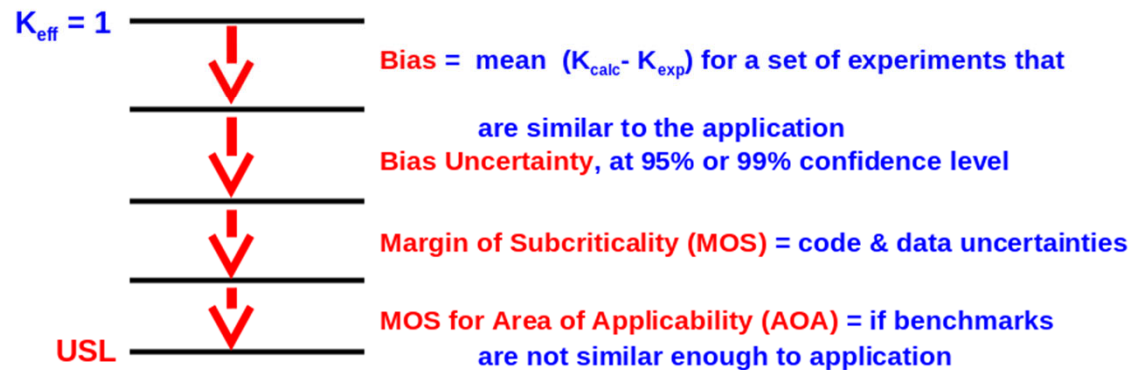
Table of Contents

- Whisper Overview
- Methodology
- Bare Fast Metal Sphere Case
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- Conclusions
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Whisper Overview

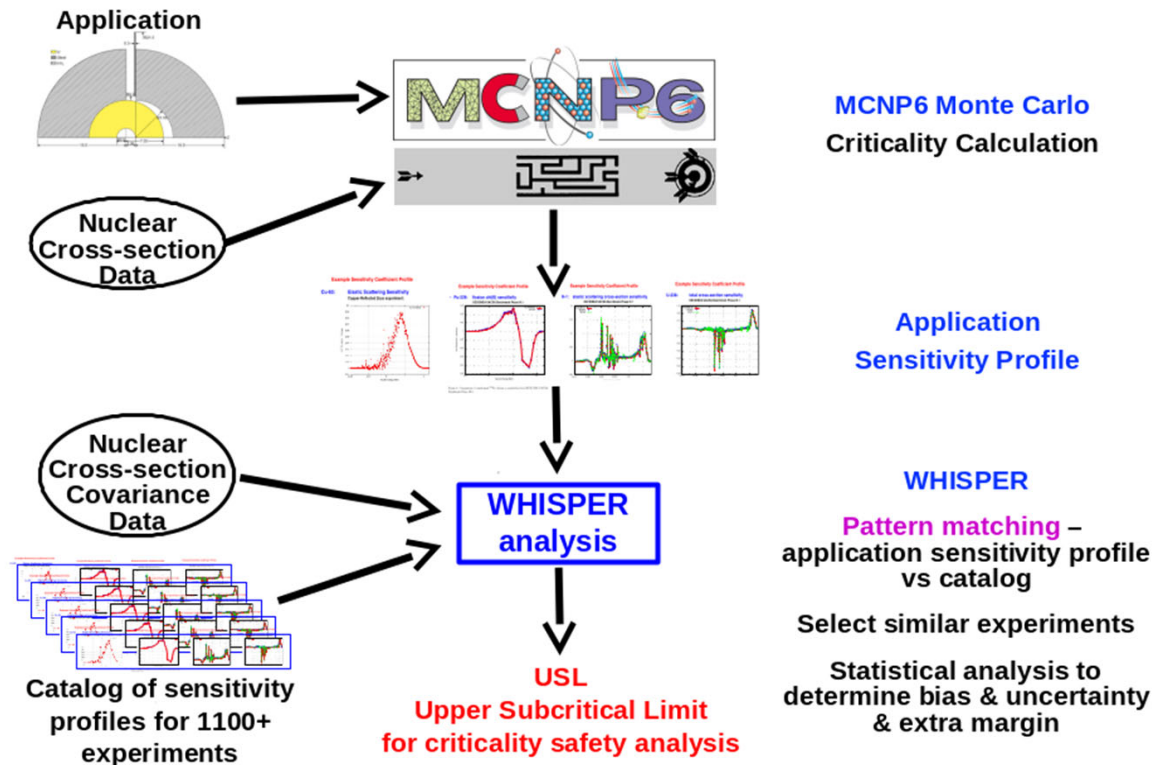
Upper Subcritical Limit (USL)

- For an application:
 - A calculated $K_{\text{eff}} < 1.0$ is NOT sufficient to ensure subcriticality
 - Must conservatively account for
 - Bias & uncertainties in the calculational method
 - Uncertainties in the physical model (eg, mass, isotopics, geometry, ...)



Must have: $K_{\text{calc}} + 2\sigma_{\text{calc}} < \text{USL}$

Whisper Overview



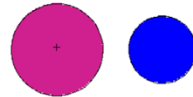
Methodology

This numerical study explores how Whisper selects benchmark populations and determines the baseline USL for various loosely coupled systems.

The following steps outline the methodology of this study:

- Models of four distinct loosely-coupled systems were constructed
- A parametric study of five separating distances between assemblies was conducted for each model
- Region-wise and overall system sensitivity profiles are developed by MCNP6.2.0
- Whisper 1.1 selected benchmark populations for the sensitivity profiles and determines a baseline USL for the sensitivity profile
- Truncated benchmark profiles and baseline USL values are compared between the two regions and the overall system for each model

Bare Fast Metal Sphere Case Description



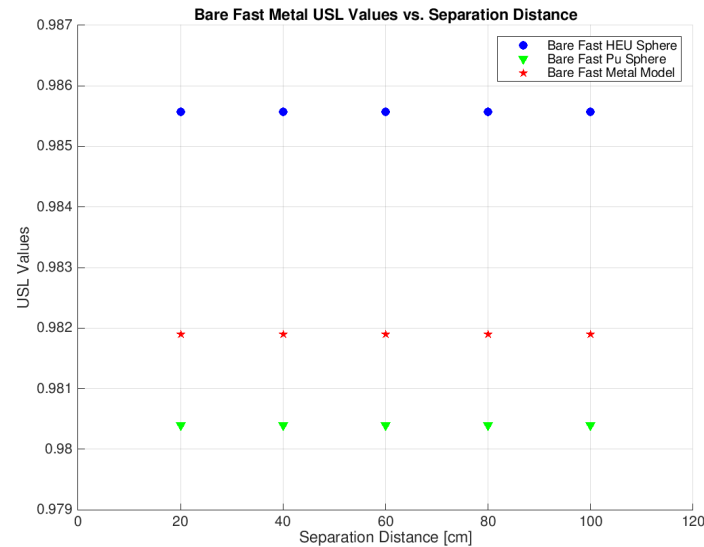
Assembly Material	Energy Spectra Description	Density [g/cc]	Assembly Radius [cm]	Calculated Regional k_{eff}
HEU	Fast	18.74	8.7407	0.9998+/-0.0001
Plutonium	Fast	15.61	6.3849	1.0001+/- 0.0001

Bare Fast Metal Sphere Case Benchmark Rankings

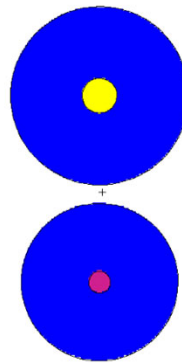
Bare Fast Metal HEU Assembly Benchmark Ranking	20	40	60	80	100
1	hmf-051-015.i	hmf-051-015.i	hmf-051-015.i	hmf-051-015.i	hmf-051-015.i
2	hmf-100-002.i	hmf-100-002.i	hmf-100-002.i	hmf-100-002.i	hmf-100-002.i
3	hmf-051-014.i	hmf-051-014.i	hmf-051-014.i	hmf-051-014.i	hmf-051-014.i
4	hmf-100-001.i	hmf-100-001.i	hmf-100-001.i	hmf-100-001.i	hmf-100-001.i
5	hmf-065-002.i	hmf-065-002.i	hmf-065-002.i	hmf-065-002.i	hmf-065-002.i
6	hmf-044-001.i	hmf-044-001.i	hmf-044-001.i	hmf-044-001.i	hmf-044-001.i
7	hmf-001-001.i	hmf-001-001.i	hmf-001-001.i	hmf-001-001.i	hmf-001-001.i
8	hmf-015-001.i	hmf-015-001.i	hmf-015-001.i	hmf-015-001.i	hmf-015-001.i
9	hmf-008-001.i	hmf-008-001.i	hmf-008-001.i	hmf-008-001.i	hmf-008-001.i
10	hmf-044-002.i	hmf-044-002.i	hmf-044-002.i	hmf-044-002.i	hmf-044-002.i

Bare Fast Metal Plutonium Assembly Benchmark Ranking	20	40	60	80	100
1	pmf-001-001.i	pmf-001-001.i	pmf-001-001.i	pmf-001-001.i	pmf-001-001.i
2	pmf-022-001.i	pmf-022-001.i	pmf-022-001.i	pmf-022-001.i	pmf-022-001.i
3	pmf-029-001.i	pmf-029-001.i	pmf-029-001.i	pmf-029-001.i	pmf-029-001.i
4	mmf-009-001.i	mmf-009-001.i	mmf-009-001.i	mmf-009-001.i	mmf-009-001.i
5	pmf-023-001.i	pmf-023-001.i	pmf-023-001.i	pmf-023-001.i	pmf-023-001.i
6	pmf-035-001.i	pmf-035-001.i	pmf-035-001.i	pmf-035-001.i	pmf-035-001.i
7	pmf-039-001.i	pmf-039-001.i	pmf-039-001.i	pmf-039-001.i	pmf-039-001.i
8	pmf-030-001.i	pmf-030-001.i	pmf-030-001.i	pmf-030-001.i	pmf-030-001.i
9	pmf-009-001.i	pmf-009-001.i	pmf-009-001.i	pmf-009-001.i	pmf-009-001.i
10	pmf-025-001.i	pmf-025-001.i	pmf-025-001.i	pmf-025-001.i	pmf-025-001.i

Bare Metal Fast System Ranked Benchmark	20	40	60	80	100
1	mmf-007-013.i	mmf-007-013.i	mmf-007-013.i	mmf-007-013.i	mmf-007-013.i
2	mmf-007-012.i	mmf-007-012.i	mmf-007-012.i	mmf-007-012.i	mmf-007-012.i
3	mmf-007-018.i	mmf-007-018.i	mmf-007-018.i	mmf-007-018.i	mmf-007-018.i
4	mmf-007-011.i	mmf-007-011.i	mmf-007-011.i	mmf-007-011.i	mmf-007-011.i
5	mmf-010-001.i	mmf-010-001.i	mmf-010-001.i	mmf-010-001.i	mmf-010-001.i
6	mmf-007-006.i	mmf-007-006.i	mmf-007-006.i	mmf-007-006.i	mmf-007-006.i
7	mmf-007-017.i	mmf-007-017.i	mmf-007-017.i	mmf-007-017.i	mmf-007-017.i
8	mmf-007-005.i	mmf-007-005.i	mmf-007-005.i	mmf-007-005.i	mmf-007-005.i
9	mmf-007-010.i	mmf-007-010.i	mmf-007-010.i	mmf-007-010.i	mmf-007-010.i
10	mmf-007-021.i	mmf-007-021.i	mmf-007-021.i	mmf-007-021.i	mmf-007-021.i



Water-Reflected Fast Metal Sphere Case Description



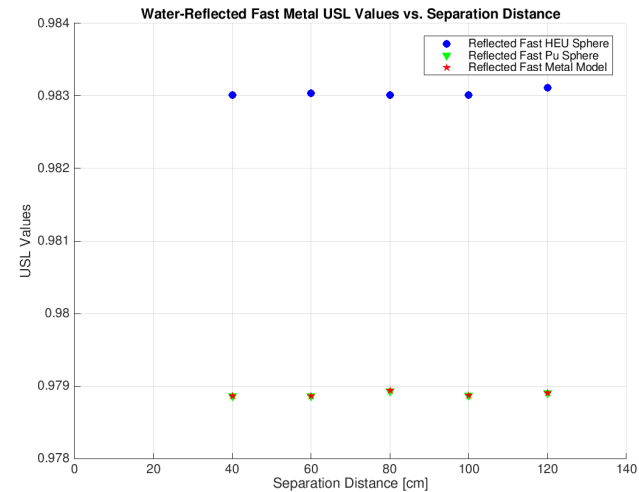
Assembly Material	Energy Spectra Description	Density [g/cc]	Reflector Thickness [cm]	Assembly Radius [cm]	Calculated Regional keff
HEU	Fast	19.74	25.400	8.7407	0.99406+/-0.00011
Plutonium	Fast	18.74	26.9180	6.3849	1.00014+/-0.00011

Water-Reflected Fast Metal Sphere Case Benchmark Rankings

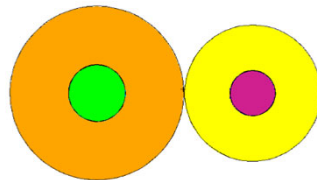
Reflected Fast Plutonium Assembly	Separation Distance [cm]				
Benchmark Ranking	40	60	80	100	120
1	pmf-011-001.i	pmf-011-001.i	pmf-011-001.i	pmf-011-001.i	pmf-011-001.i
2	pmf-044-004.i	pmf-042-001.i	pmf-042-001.i	pmf-044-004.i	pmf-044-004.i
3	pmf-042-001.i	pmf-044-004.i	pmf-044-004.i	pmf-042-001.i	pmf-042-001.i
4	pmf-027-001.i	pmf-027-001.i	pmf-042-002.i	pmf-027-001.i	pmf-027-001.i
5	pmf-042-002.i	pmf-042-002.i	pmf-027-001.i	pmf-042-002.i	pmf-042-002.i
6	pmf-031-001.i	pmf-031-001.i	pmf-031-001.i	pmf-031-001.i	pmf-031-001.i
7	pmf-044-005.i	pmf-044-005.i	pmf-044-005.i	pmf-044-005.i	pmf-044-005.i
8	pmf-042-003.i	pmf-042-003.i	pmf-042-003.i	pmf-042-003.i	pmf-042-003.i
9	pmf-042-004.i	pmf-042-004.i	pmf-042-004.i	pmf-042-004.i	pmf-042-004.i
10	pmf-036-001.i	pmf-036-001.i	pmf-036-001.i	pmf-036-001.i	pmf-036-001.i

Reflected Fast HEU Assembly	Separation Distance [cm]				
Benchmark Ranking	40	60	80	100	120
1	hmf-004-001.i	hmf-004-001.i	hmf-004-001.i	hmf-004-001.i	hmf-004-001.i
2	hmf-078-001.i	hmf-078-001.i	hmf-078-001.i	hmf-078-001.i	hmf-078-001.i
3	hmf-011-001.i	hmf-011-001.i	hmf-011-001.i	hmf-007-035.i	hmf-084-011.i
4	hmf-007-035.i	hmf-084-011.i	hmf-007-035.i	hmf-011-001.i	hmf-011-001.i
5	hmf-078-011.i	hmf-007-035.i	hmf-078-011.i	hmf-091-001.i	hmf-016-002.i
6	hmf-078-009.i	hmf-016-002.i	hmf-078-017.i	hmf-078-011.i	hmf-084-002.i
7	hmf-078-017.i	hmf-091-001.i	hmf-078-009.i	hmf-078-017.i	hmf-078-005.i
8	hmf-078-005.i	hmf-078-005.i	hmf-078-005.i	hmf-078-009.i	hmf-009-002.i
9	hmf-078-015.i	hmf-078-017.i	hmf-078-015.i	hmf-078-005.i	hmf-078-017.i
10	hmf-078-013.i	hmf-078-011.i	hmf-078-013.i	hmf-078-015.i	hmf-010-002.i

Reflected Fast Metal System	Separation Distance [cm]				
Benchmark Ranking	40	60	80	100	120
1	pmf-011-001.i	pmf-011-001.i	pmf-011-001.i	pmf-011-001.i	pmf-011-001.i
2	pmf-042-001.i	pmf-042-001.i	pmf-042-001.i	pmf-044-004.i	pmf-042-001.i
3	pmf-044-004.i	pmf-027-001.i	pmf-027-001.i	pmf-042-001.i	pmf-044-004.i
4	pmf-027-001.i	pmf-044-004.i	pmf-044-004.i	pmf-027-001.i	pmf-027-001.i
5	pmf-042-002.i	pmf-042-002.i	pmf-042-002.i	pmf-042-002.i	pmf-042-002.i
6	pmf-031-001.i	pmf-031-001.i	pmf-031-001.i	pmf-031-001.i	pmf-031-001.i
7	pmf-044-005.i	pmf-044-005.i	pmf-044-005.i	pmf-044-005.i	pmf-044-005.i
8	pmf-042-003.i	pmf-042-003.i	pmf-042-003.i	pmf-042-003.i	pmf-042-003.i
9	pmf-042-004.i	pmf-042-004.i	pmf-042-004.i	pmf-042-004.i	pmf-042-004.i
10	pmf-036-001.i	pmf-036-001.i	pmf-036-001.i	pmf-036-001.i	pmf-036-001.i



Thermal Solution Case Description



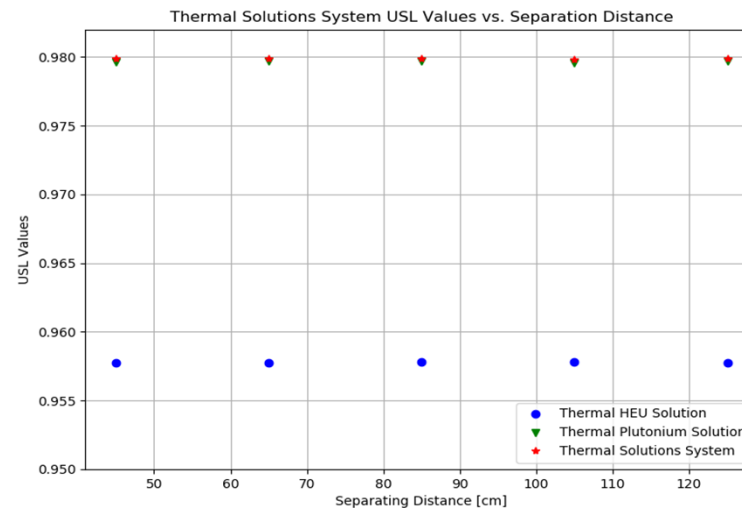
Assembly Material	Energy Spectra Description	Density [atoms/b-cm]	Aluminum Canister Thickness [cm]	Reflector Thickness [cm]	Inner Canister Radius [cm]	Calculated Regional keff
HEU Solution	Thermal	9.82964005e-2	0.1587	23.3236	11.5177	1.00578+/-0.00013
Plutonium Solution	Thermal	1.0087e-1	0.1245	30.0000	14.5151	0.99113+/-0.00015

Thermal Solution Case Benchmark Rankings

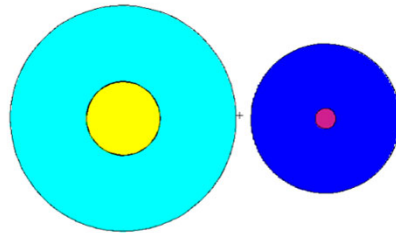
Thermal HEU Solution Assembly	Separation Distance [cm]				
Benchmark Ranking	45	65	85	105	125
1	hst-050-010.i	hst-050-010.i	hst-050-010.i	hst-050-010.i	hst-050-010.i
2	hst-050-001.i	hst-050-001.i	hst-050-001.i	hst-050-001.i	hst-050-001.i
3	hst-050-008.i	hst-050-008.i	hst-050-008.i	hst-050-008.i	hst-050-008.i
4	hst-050-002.i	hst-050-002.i	hst-050-002.i	hst-050-002.i	hst-050-002.i
5	hst-050-004.i	hst-050-004.i	hst-050-004.i	hst-050-004.i	hst-050-004.i
6	hst-050-006.i	hst-050-006.i	hst-050-006.i	hst-050-006.i	hst-050-006.i
7	hst-009-001.i	hst-009-001.i	hst-009-001.i	hst-009-001.i	hst-009-001.i
8	hst-009-002.i	hst-050-011.i	hst-009-002.i	hst-050-011.i	hst-050-011.i
9	hst-050-011.i	hst-009-002.i	hst-050-011.i	hst-009-002.i	hst-009-002.i
10	hst-050-003.i	hst-050-005.i	hst-050-009.i	hst-050-005.i	hst-050-005.i

Thermal Plutonium Solution Assembly	Separation Distance [cm]				
Benchmark Ranking	45	65	85	105	125
1	pst-001-001.i	pst-001-001.i	pst-001-001.i	pst-001-001.i	pst-001-001.i
2	pst-002-005.i	pst-011-165.i	pst-011-165.i	pst-002-005.i	pst-010-009.i
3	pst-010-009.i	pst-010-009.i	pst-010-009.i	pst-010-009.i	pst-002-005.i
4	pst-011-165.i	pst-002-005.i	pst-002-005.i	pst-010-002.i	pst-011-165.i
5	pst-010-002.i	pst-010-002.i	pst-010-002.i	pst-011-165.i	pst-010-002.i
6	pst-002-006.i	pst-002-006.i	pst-002-004.i	pst-002-006.i	pst-002-004.i
7	pst-002-007.i	pst-002-004.i	pst-002-006.i	pst-002-007.i	pst-002-006.i
8	pst-002-004.i	pst-002-007.i	pst-002-007.i	pst-002-004.i	pst-002-007.i
9	pst-002-003.i	pst-002-003.i	pst-002-003.i	pst-002-003.i	pst-002-003.i
10	pst-001-002.i	pst-001-002.i	pst-001-002.i	pst-001-002.i	pst-001-002.i

Thermal Solution System	Separation Distance [cm]				
Benchmark Ranking	45	65	85	105	125
1	pst-001-001.i	pst-001-001.i	pst-001-001.i	pst-001-001.i	pst-001-001.i
2	pst-007-010.i	pst-010-002.i	pst-010-002.i	pst-010-002.i	pst-010-002.i
3	pst-010-002.i	pst-007-010.i	pst-007-010.i	pst-007-010.i	pst-007-010.i
4	pst-002-006.i	pst-010-009.i	pst-010-009.i	pst-010-009.i	pst-010-009.i
5	pst-010-009.i	pst-002-006.i	pst-002-006.i	pst-002-006.i	pst-002-006.i
6	pst-002-005.i	pst-002-005.i	pst-002-005.i	pst-002-005.i	pst-002-005.i
7	pst-007-005.i	pst-007-005.i	pst-002-004.i	pst-002-004.i	pst-007-005.i
8	pst-007-009.i	pst-002-004.i	pst-007-005.i	pst-001-002.i	pst-002-004.i
9	pst-001-002.i	pst-001-002.i	pst-001-002.i	pst-007-005.i	pst-001-002.i
10	pst-007-007.i	pst-007-009.i	pst-007-007.i	pst-007-007.i	pst-007-009.i



Mixed Plutonium Case Description



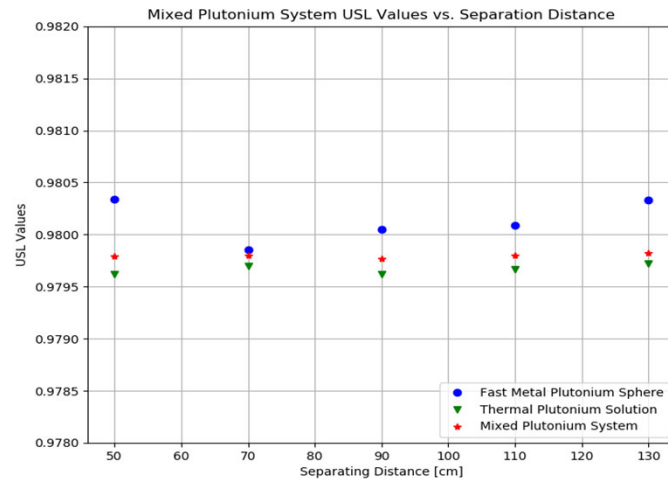
Assembly Material	Energy Spectra Description	Density	Canister Thickness [cm]	Reflector Thickness [cm]	Assembly Radius [cm]	Calculated Regional keff
Plutonium Solution	Thermal	1.0087e-1 [atoms/b-cm]	0.1245	25.4000	4.1217	1.00578+/-0.00013
Plutonium Metal	Fast	19.74 [g/cc]	N/A	30.0000	14.5151	1.00002+/-0.00010

Mixed Plutonium Case Results

Fast Metal Plutonium Assembly	Separation Distance [cm]				
Benchmark Ranking	50	70	90	110	130
1	pmf-044-004.i	pmf-042-002.i	pmf-044-004.i	pmf-044-004.i	pmf-044-004.i
2	pmf-044-005.i	pmf-042-003.i	pmf-044-005.i	pmf-044-005.i	pmf-044-005.i
3	pmf-024-001.i	pmf-044-005.i	pmf-042-002.i	pmf-042-002.i	pmf-031-001.i
4	pmf-036-001.i	pmf-027-001.i	pmf-042-001.i	pmf-031-001.i	pmf-024-001.i
5	pmf-031-001.i	pmf-044-004.i	pmf-031-001.i	pmf-042-001.i	pmf-036-001.i
6	pmf-044-003.i	pmf-042-001.i	pmf-042-003.i	pmf-042-003.i	pmf-042-001.i
7	pmf-042-004.i	pmf-042-004.i	pmf-027-001.i	pmf-027-001.i	pmf-044-003.i
8	pmf-042-001.i	pmf-011-001.i	pmf-011-001.i	pmf-042-004.i	pmf-042-002.i
9	pmf-027-001.i	pmf-042-005.i	pmf-042-004.i	pmf-036-001.i	pmf-027-001.i
10	pmf-042-004.i	pmf-031-001.i	pmf-036-001.i	pmf-011-001.i	pmf-011-001.i

Thermal Plutonium Solution Assembly	Separation Distance [cm]				
Benchmark Ranking	50	70	90	110	130
1	pst-001-001.i	pst-001-001.i	pst-001-001.i	pst-001-001.i	pst-001-001.i
2	pst-010-009.i	pst-011-165.i	pst-011-165.i	pst-011-165.i	pst-011-165.i
3	pst-011-165.i	pst-010-009.i	pst-010-009.i	pst-010-009.i	pst-010-009.i
4	pst-010-002.i	pst-002-005.i	pst-002-005.i	pst-002-005.i	pst-002-005.i
5	pst-002-005.i	pst-010-002.i	pst-010-002.i	pst-010-002.i	pst-010-002.i
6	pst-002-004.i	pst-002-004.i	pst-002-006.i	pst-002-004.i	pst-002-004.i
7	pst-002-006.i	pst-002-006.i	pst-002-004.i	pst-002-006.i	pst-002-006.i
8	pst-002-007.i	pst-002-007.i	pst-002-007.i	pst-002-003.i	pst-002-003.i
9	pst-002-003.i	pst-002-003.i	pst-002-003.i	pst-002-007.i	pst-002-007.i
10	pst-001-002.i	pst-001-002.i	pst-001-002.i	pst-011-163.i	pst-011-163.i

Mixed Plutonium System	Separation Distance [cm]				
Benchmark Ranking	50 cm	70 cm	90 cm	110 cm	130 cm
1	pst-001-001.i	pst-001-001.i	pst-001-001.i	pst-001-001.i	pst-001-001.i
2	pst-010-002.i	pst-010-002.i	pst-010-002.i	pst-010-002.i	pst-010-002.i
3	pst-010-009.i	pst-010-009.i	pst-010-009.i	pst-010-009.i	pst-010-009.i
4	pst-002-006.i	pst-002-005.i	pst-002-006.i	pst-002-005.i	pst-002-005.i
5	pst-002-005.i	pst-002-006.i	pst-002-005.i	pst-002-006.i	pst-002-004.i
6	pst-007-010.i	pst-002-004.i	pst-007-010.i	pst-002-004.i	pst-002-006.i
7	pst-002-004.i	pst-007-010.i	pst-002-004.i	pst-007-010.i	pst-007-010.i
8	pst-001-002.i	pst-001-002.i	pst-001-002.i	pst-002-003.i	pst-002-003.i
9	pst-007-005.i	pst-007-005.i	pst-002-003.i	pst-001-002.i	pst-001-002.i
10	pst-002-003.i	pst-002-003.i	pst-002-007.i	pst-002-007.i	pst-007-005.i



Conclusions

The results from the four numerical studies show that the coupled system sensitivity profile are usually dominated by a single assembly. Whisper's selected benchmark profile then reflects only the dominant assembly and the determined baseline USL is **not necessarily conservative**.

To insure that that the most conservative baseline USL is selected, it is recommended to calculate the regional baseline USL values and choose the more conservative value.

Current and Future Work

- Deriving theoretical definitions of loosely-coupled $S_{x,k}$ and c_k terms for individual regions and the overall application model for loosely-coupled systems
- Using the MCNP-calculated fission matrix to implement these derived terms for loosely-coupled system
- Determining how benchmark rankings and calculated USL values can be developed using these derived loosely-coupled sensitivity profiles and c_k values.

Acknowledgements

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Thank you for listening!
Questions?