

Cu covariance study including impacts on past (and future) experiments

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CSEWG 2024

Overview

- Why do we care about Cu nuclear data?
- Current state of Cu63 and Cu65 covariances
- Impact on specific critical experiments

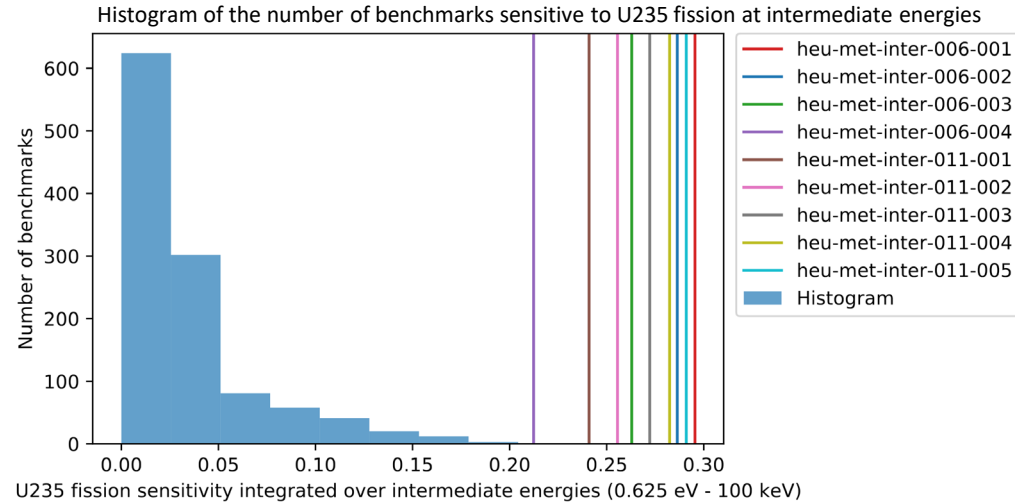
DISCLAIMER: this is from the point of view of a user of processed covariance data

NOTE: the scope of this study has been focused to date (only certain nuclides/reactions, covariances within single nuclide/reaction only, no angular distributions)

NOTE2: unless otherwise specified, correlations (not covariances) are plotted

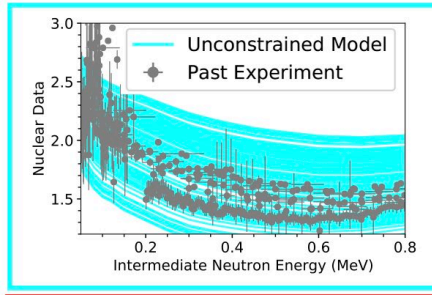
Why do we care about Cu nuclear data?

- Copper does have some uses in the nuclear industry (corrosion barrier for waste), but it is also useful for intermediate energy criticality experiments
 - Cu is a useful reflector for intermediate energy experiments
 - Therefore useful to help validate actinide materials at intermediate energies (which is a high priority mission need)
 - Zeus series of experiments use a lot of Cu but are among the most sensitive intermediate energy experiments
- Some critical experiment design metrics utilize covariance data

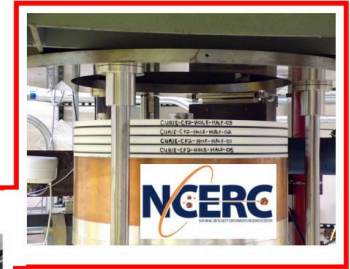


PARADIGM tackles issues in actinide intermediate energy nuclear data (ND) by transforming the ND pipeline

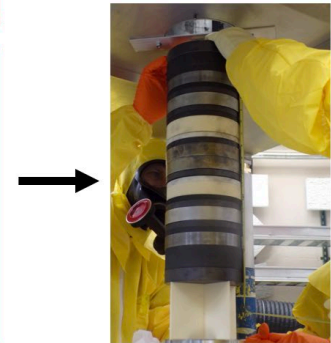
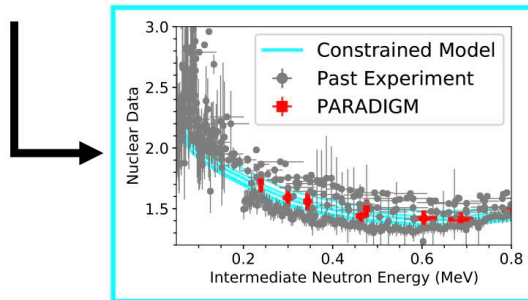
- Couples capabilities provided by new LANSCE MARK-IV neutron target with NCERC integral experiments and nuclear theory
- Utilizes machine learning for experiment design
- Focused on ^{239}Pu from 1-600 keV
- Will include two integral experiment configurations (1-30 keV and 30-600 keV)
 - When simulations shown here were run, the team was deciding between 6 configurations



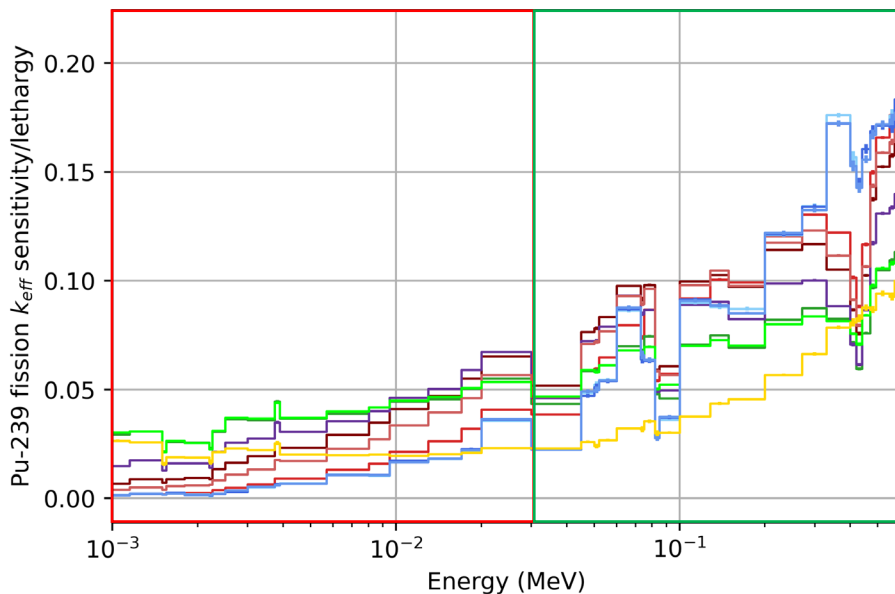
New theory and joint LANSCE & NCERC experiments lead to ...



... more precise nuclear data for applications.



252 group, Pu239 fission keff sensitivity



- 01_HF_5_18_10_40_252g.i
- 02_HF_5_18_16_90_252g.i
- 03_HF_4_22_14_80_80_252g.i
- 04_HF_3_5_12_120_252g.i
- 05_HF_16_12_13_70_252g.i
- 06_HF_0_25_15_80_80_252g.i
- pu-met-fast-047-001_252g.i
- pu-met-fast-047-002_252g.i
- pu-met-fast-047-003_252g.i
- pu-met-mixed-003-002_252g.i

Integrated 1-30 keV

| Name | Sens |
|-----------------------------|-----------|
| 06_HF_0_25_15_80_80_252g.i | 1.298E-01 |
| 03_HF_4_22_14_80_80_252g.i | 1.291E-01 |
| 04_HF_3_5_12_120_252g.i | 1.208E-01 |
| 02_HF_5_18_16_90_252g.i | 1.014E-01 |
| 05_HF_16_12_13_70_252g.i | 8.075E-02 |
| pu-met-mixed-003-002_252g.i | 6.899E-02 |
| 01_HF_5_18_10_40_252g.i | 5.082E-02 |
| pu-met-fast-047-002_252g.i | 4.047E-02 |
| pu-met-fast-047-003_252g.i | 4.018E-02 |
| pu-met-fast-047-001_252g.i | 3.980E-02 |

Integrated 30-600 keV

| Name | Sens |
|-----------------------------|-----------|
| 05_HF_16_12_13_70_252g.i | 2.850E-01 |
| 02_HF_5_18_16_90_252g.i | 2.849E-01 |
| pu-met-fast-047-001_252g.i | 2.811E-01 |
| 01_HF_5_18_10_40_252g.i | 2.806E-01 |
| pu-met-fast-047-002_252g.i | 2.798E-01 |
| pu-met-fast-047-003_252g.i | 2.795E-01 |
| 04_HF_3_5_12_120_252g.i | 2.491E-01 |
| 06_HF_0_25_15_80_80_252g.i | 2.116E-01 |
| 03_HF_4_22_14_80_80_252g.i | 2.106E-01 |
| pu-met-mixed-003-002_252g.i | 1.443E-01 |

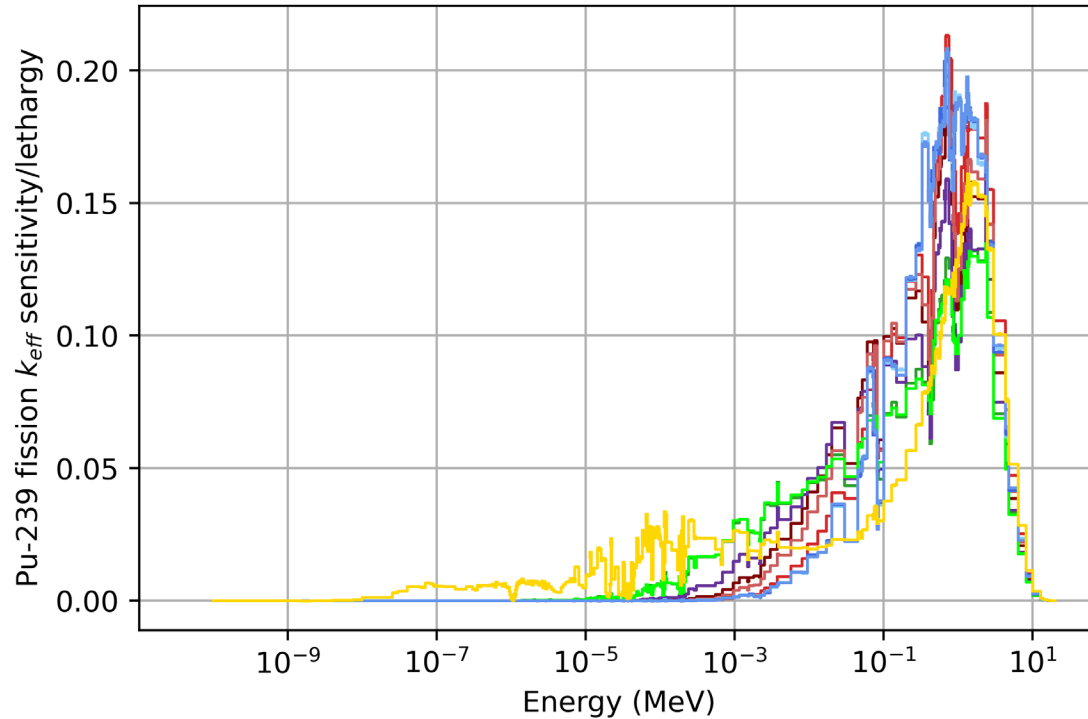
PARADIGM candidate files

- Reds:** Alumina + boron
- Greens:** Alumina + graphite
- Purple:** Alumina
- Blues:** Jupiter
- Gold:** PMM003-002

Sensitivities using MCNP



252 group, Pu239 fission keff sensitivity



- 01_HF_5_18_10_40_252g.i
- 02_HF_5_18_16_90_252g.i
- 03_HF_4_22_14_80_80_252g.i
- 04_HF_3_5_12_120_252g.i
- 05_HF_16_12_13_70_252g.i
- 06_HF_0_25_15_80_80_252g.i
- pu-met-fast-047-001_252g.i
- pu-met-fast-047-002_252g.i
- pu-met-fast-047-003_252g.i
- pu-met-mixed-003-002_252g.i

PARADIGM candidate files

Reds: Alumina + boron

Greens: Alumina + graphite

Purple: Alumina

Blues: Jupiter

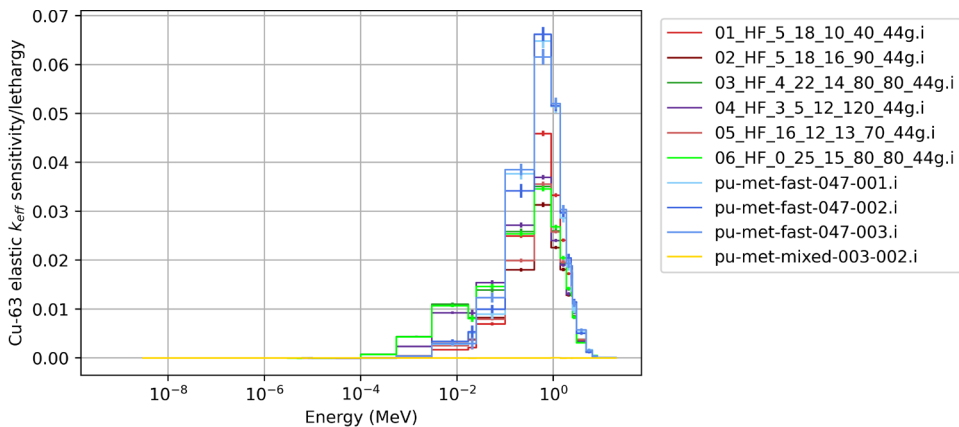
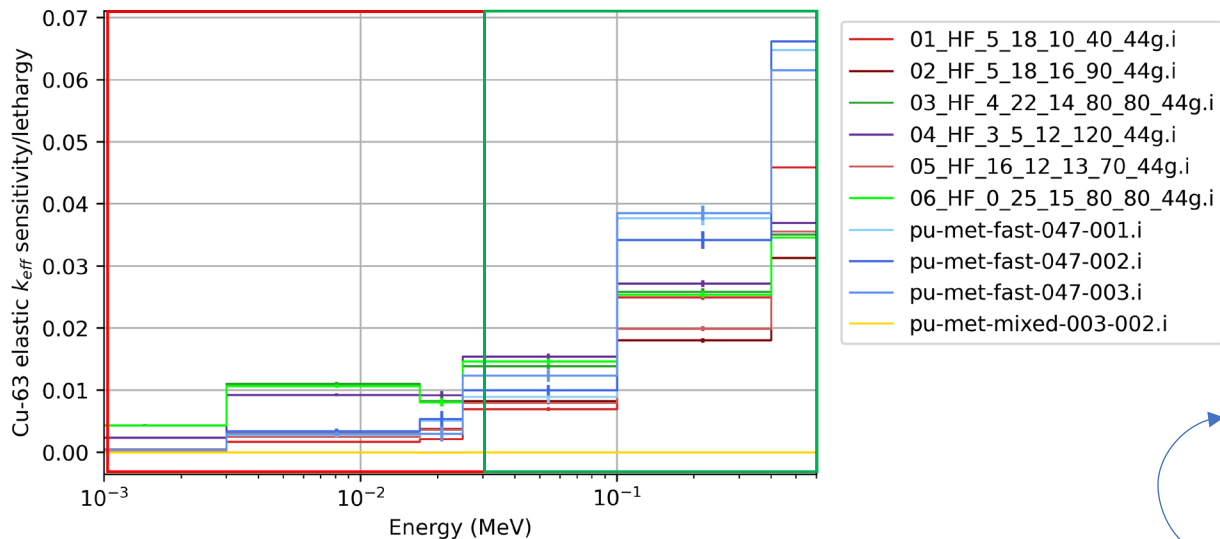
Gold: PMM003-002

Sensitivities using MCNP

11/4/2024



44 group, Cu63 elastic keff sensitivity

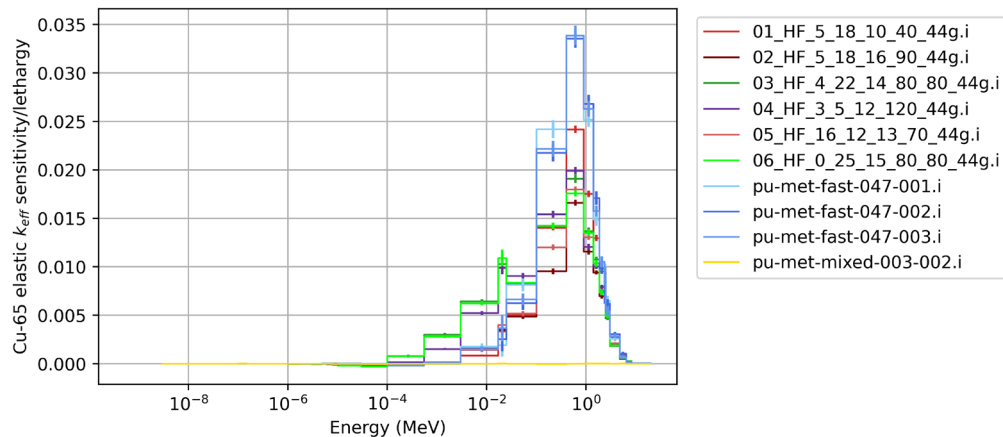
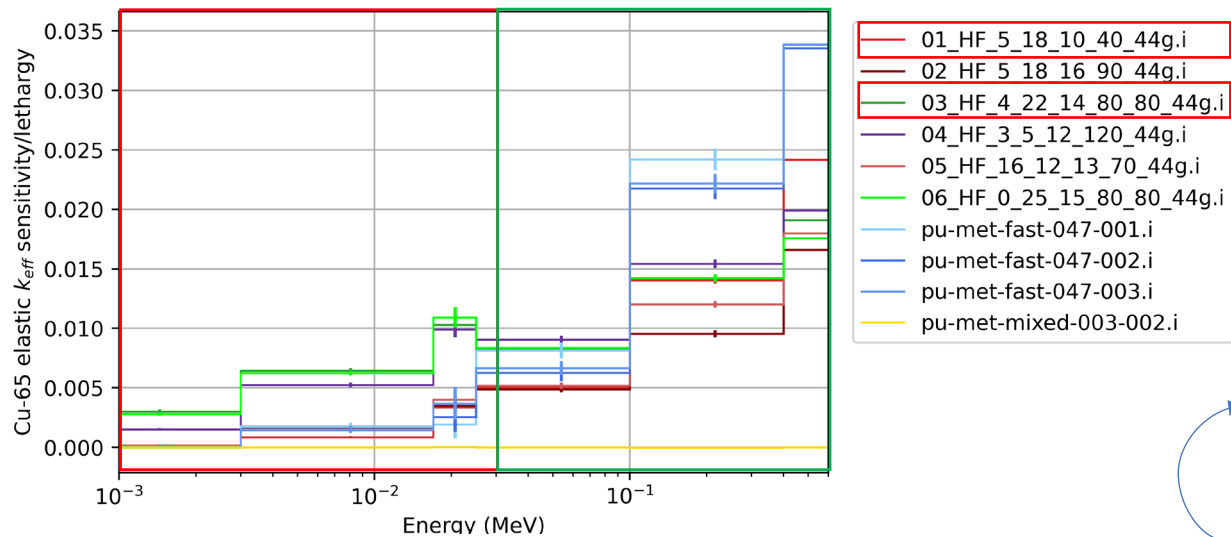


PARADIGM candidate files

- Reds: Alumina + boron
- Greens: Alumina + graphite
- Purple: Alumina
- Blues: Jupiter
- Gold: PMM003-002

Sensitivities using MCNP

44 group, Cu65 elastic keff sensitivity



PARADIGM candidate files

Reds: Alumina + boron

Greens: Alumina + graphite

Purple: Alumina

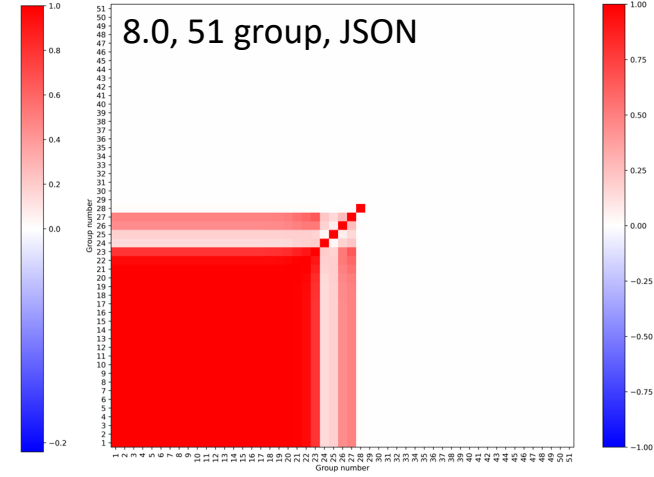
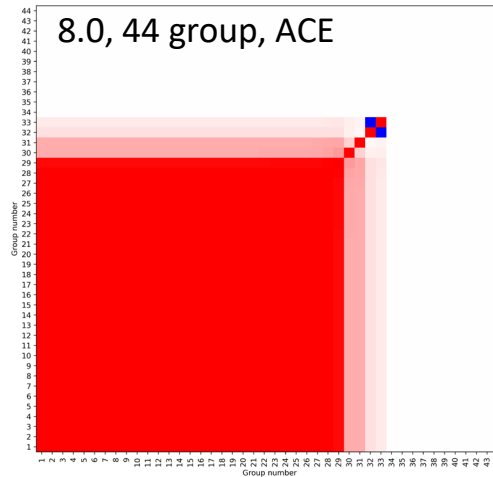
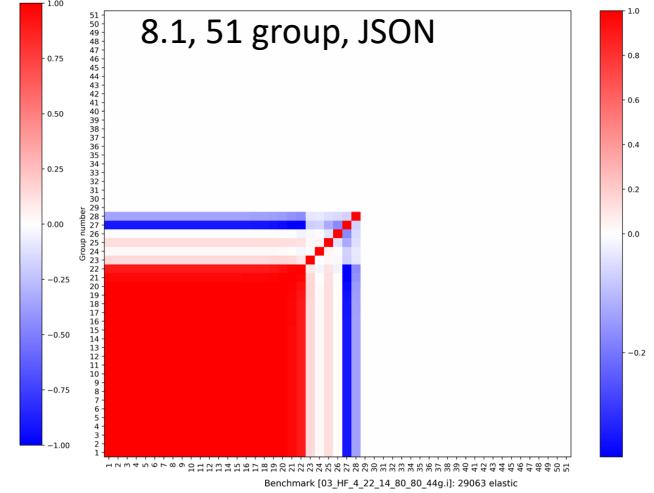
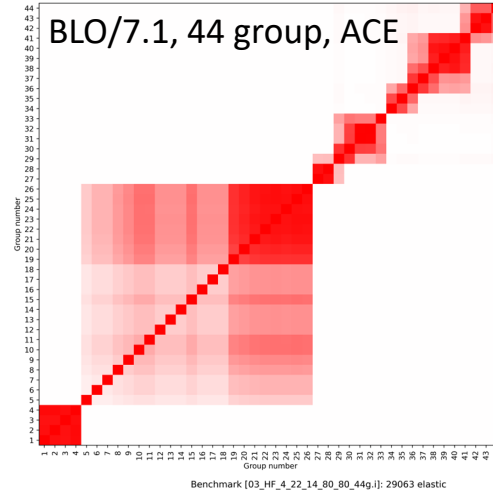
Blues: Jupiter

Gold: PMM003-002

Sensitivities using MCNP

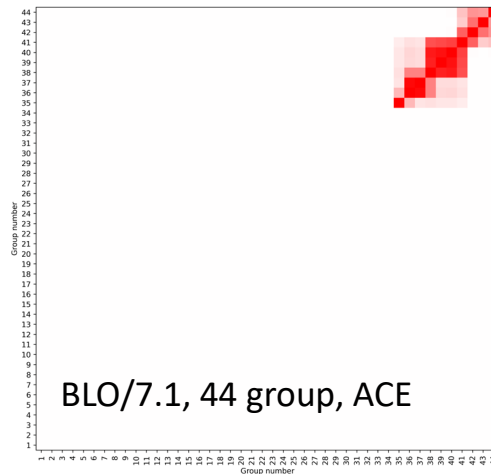
Cu63 elastic

- ENDF8.0+8.1 are missing high energy covariances.
 - No data above ~400-500 keV
 - This will be common among other reactions too
- Note that for many actinide intermediate energy experiments, Cu63 elastic peaks at 700 keV or so (and matters all the way up to 5 MeV or so)



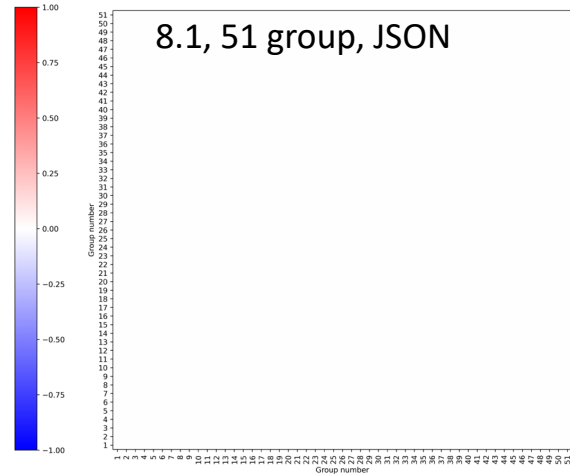
Cu63 inelastic

- ENDF8.0+8.1 covariances do not exist



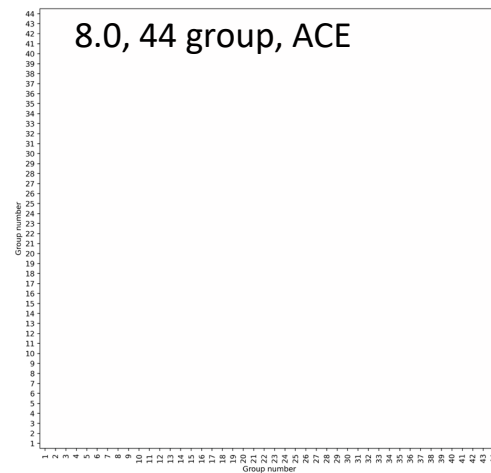
BLO/7.1, 44 group, ACE

Benchmark [03_HF_4_22_14_80_80_44g.l]: 29063 inelastic

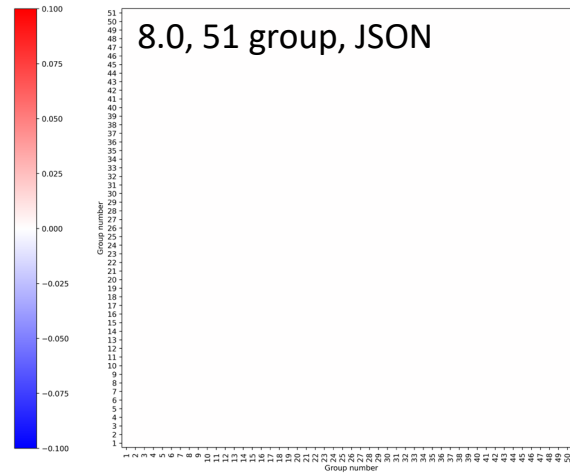


8.1, 51 group, JSON

Benchmark [03_HF_4_22_14_80_80_44g.l]: 29063 inelastic



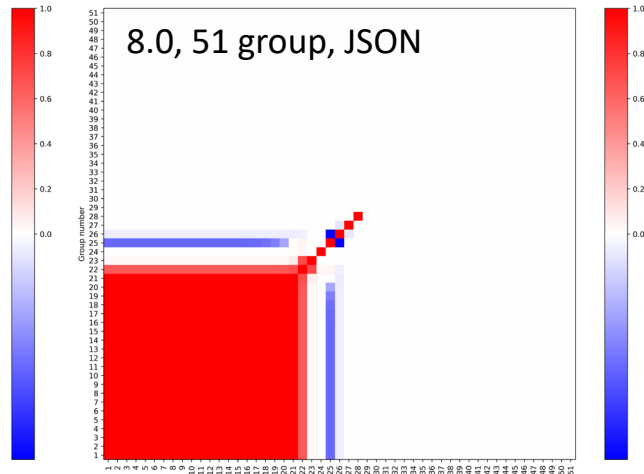
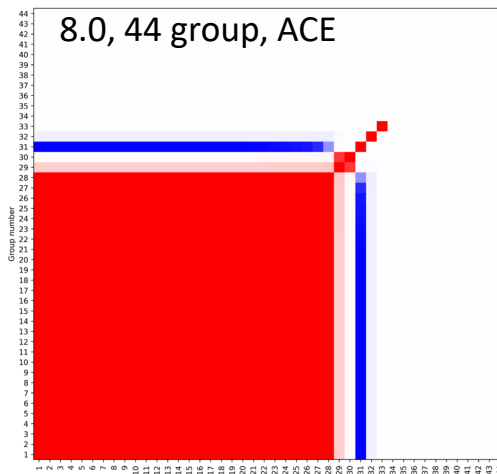
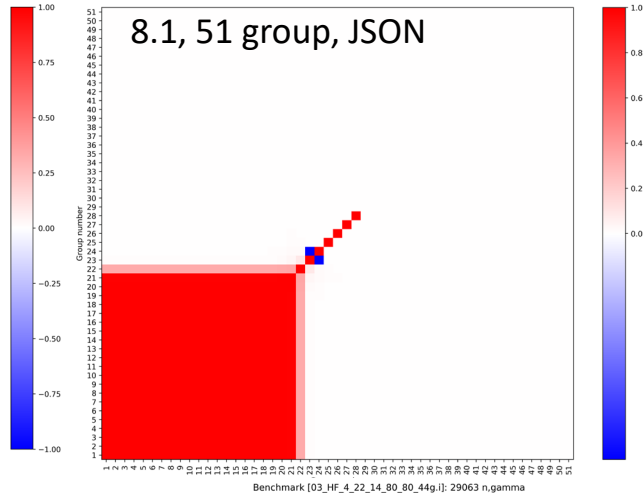
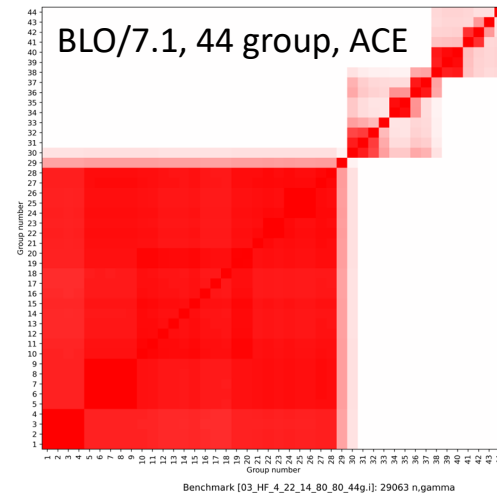
8.0, 44 group, ACE



8.0, 51 group, JSON

Cu63 (n,gamma)

- ENDF8.0+8.1 are missing covariances above ~400-500 keV
 - For actinide intermediate energy experiments, Cu63 (n,gamma) matters until 2-3 MeV
- Issues in ENDF8.0+8.1 are not obvious from correlation plot

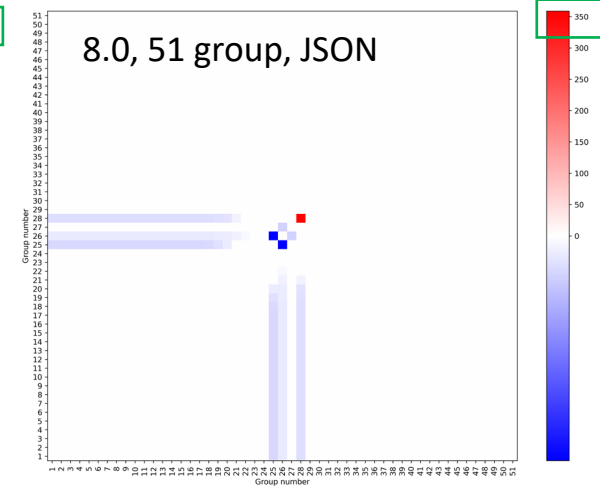
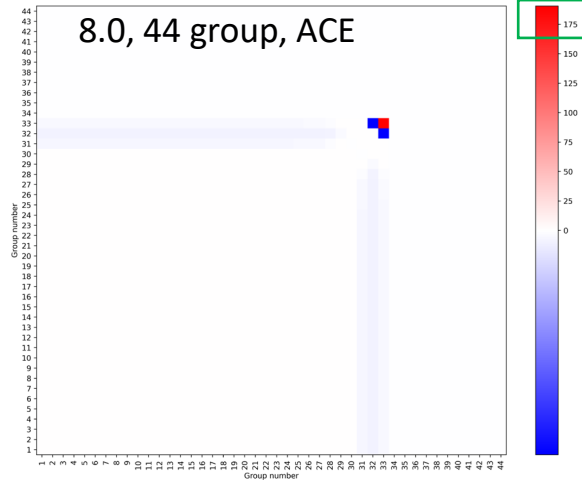
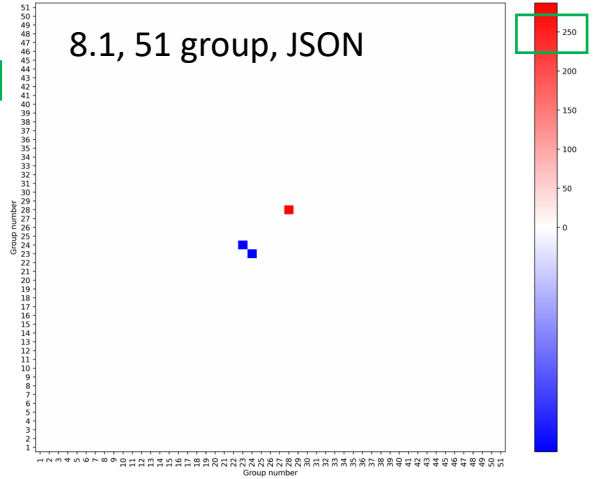
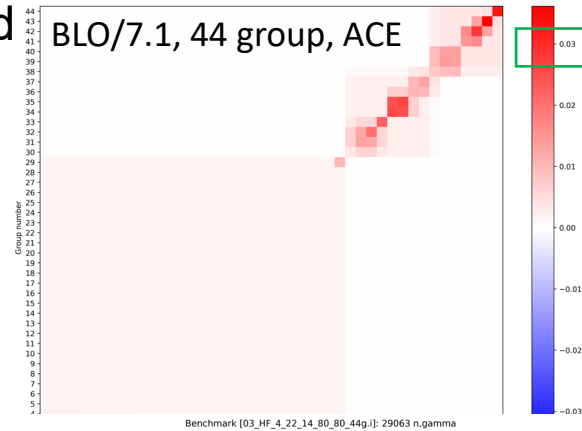


Cu63 (n,gamma) covariances

Benchmark [03_HF_4_22_14_80_80_44g.i]: 29063 n,gamma

Benchmark [03_HF_4_22_14_80_80_44g.i]: 29063 n,gamma

- Plotting covariances (instead of correlations) shows issue in ENDF8.0+8.1
 - Not color bar values
- Having a single energy bin with huge covariance will result in a very large impact on k_{eff} uncertainty (for any system with non-zero sensitivity)

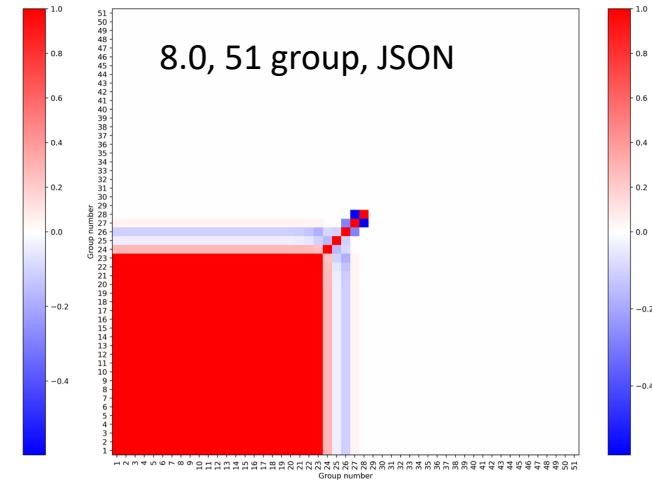
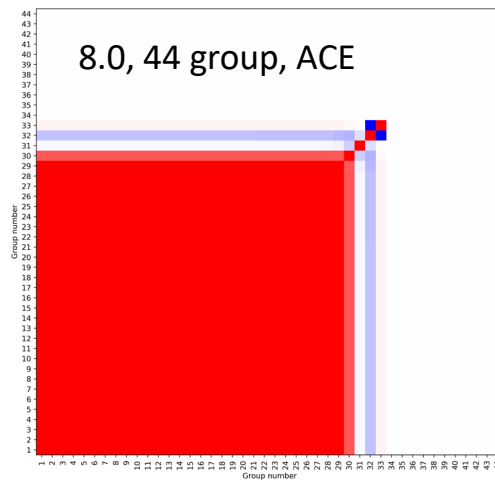
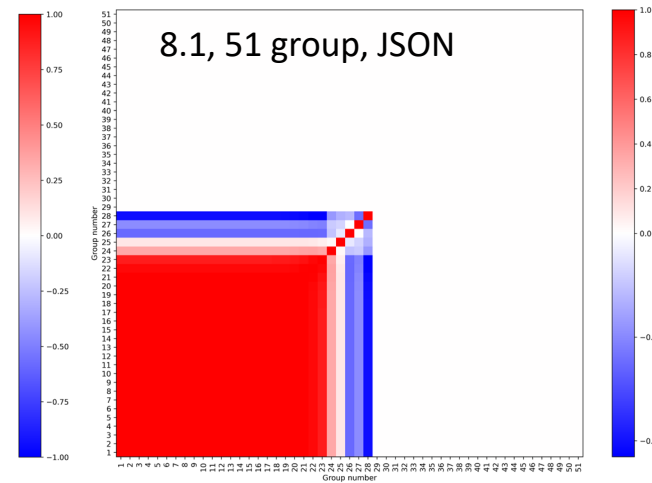
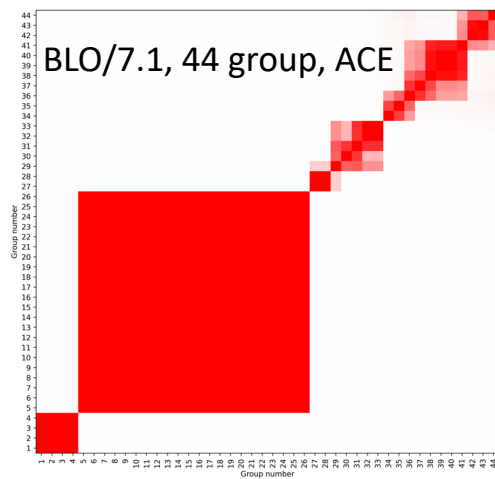


Cu65 elastic

Benchmark [HF_4_22_14_80_80_44g.I]: 29065 elastic

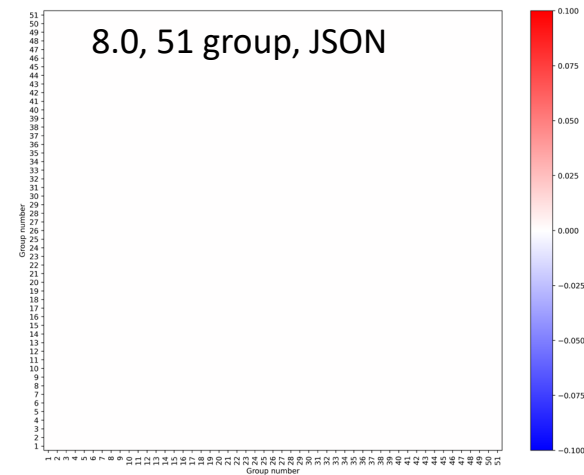
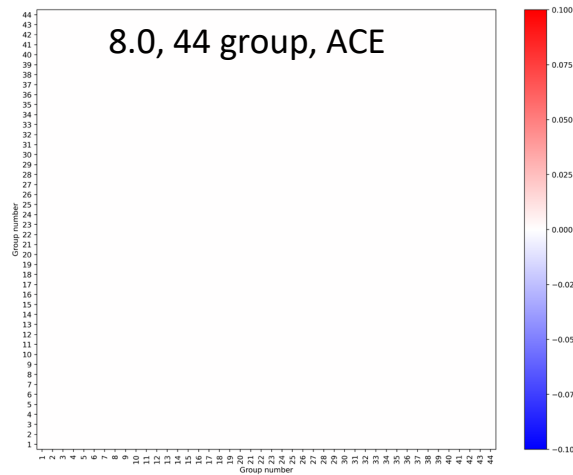
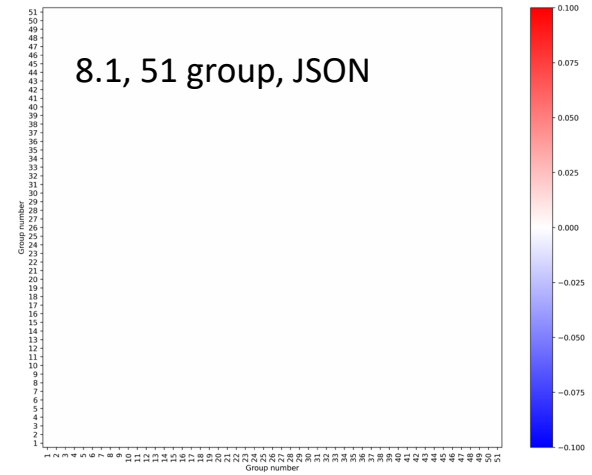
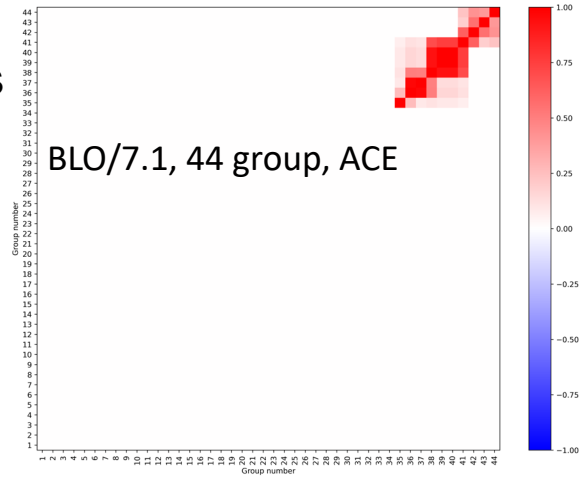
Application [03_HF_4_22_14_80_80_44g.I]: 29065 elastic

- ENDF8.0+8.1 is missing some high energy covariances



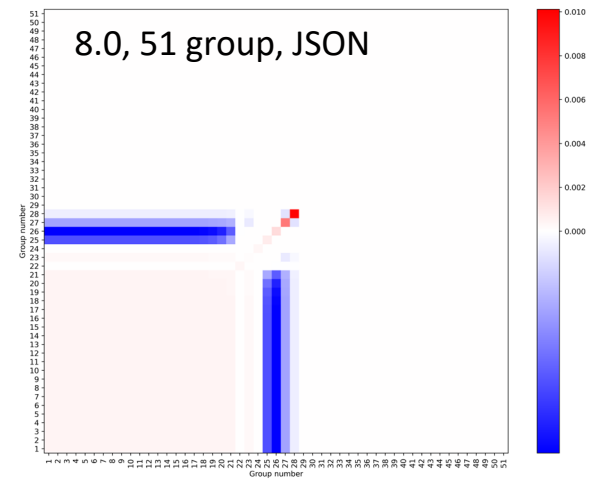
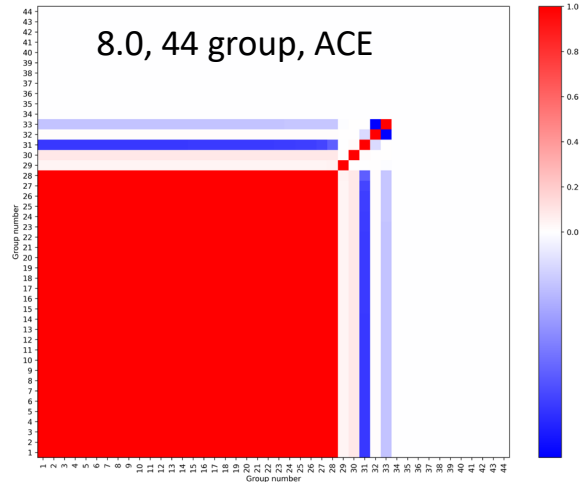
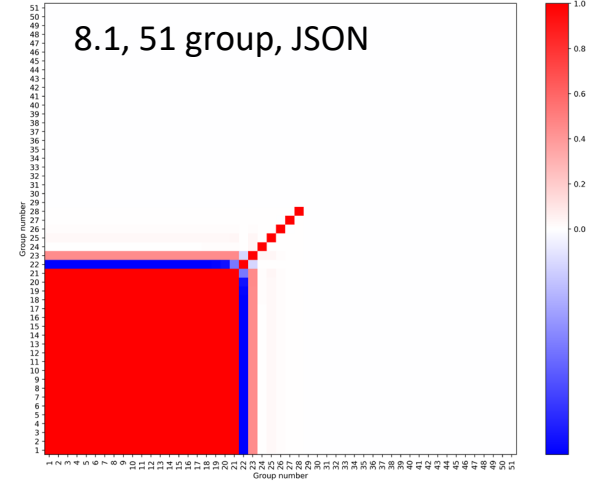
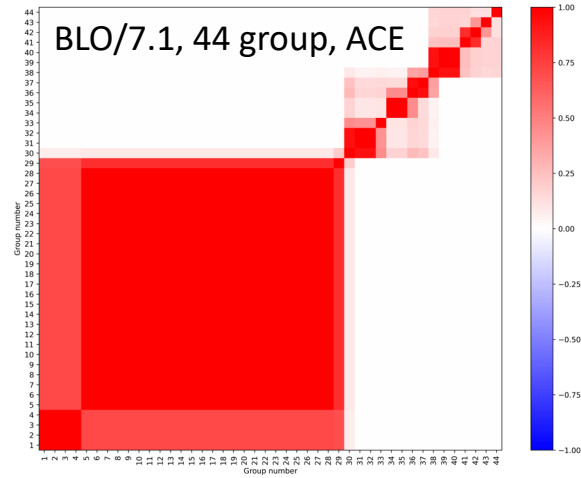
Cu65 inelastic

- ENDF8.0+8.1 covariances do not exist



Cu65 (n,gamma)

- ENDF8.0+8.1 is missing some high energy covariances

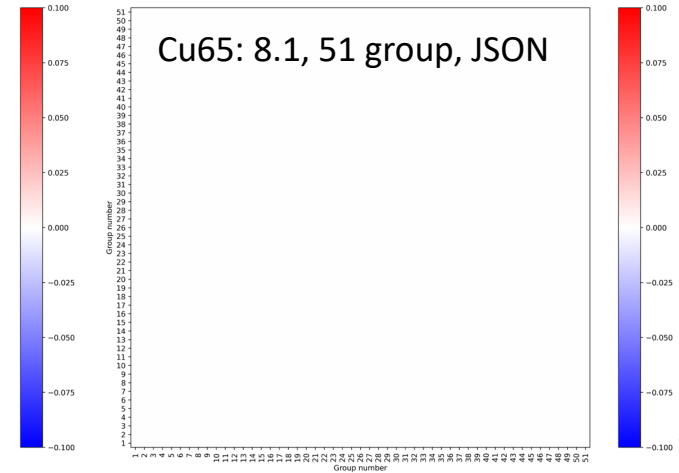
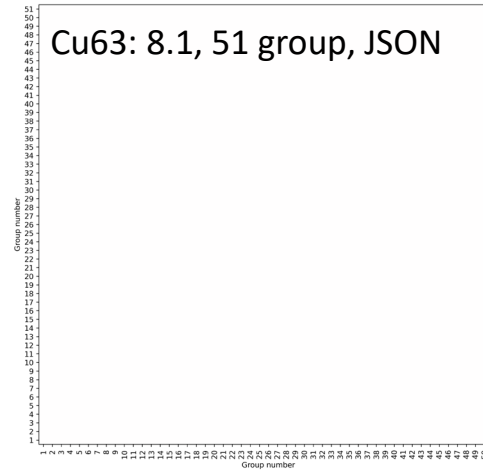
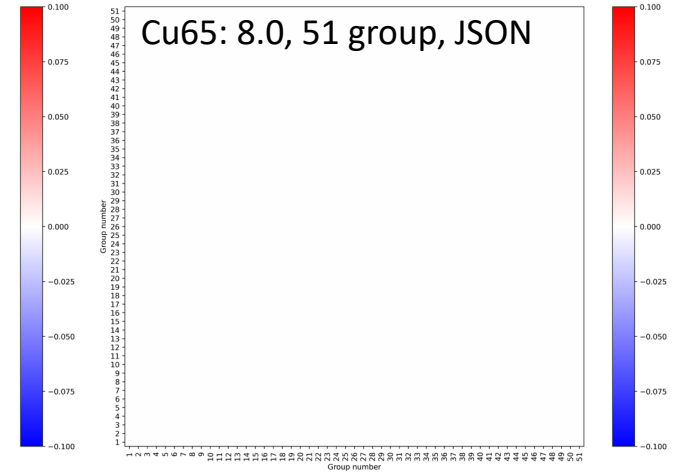
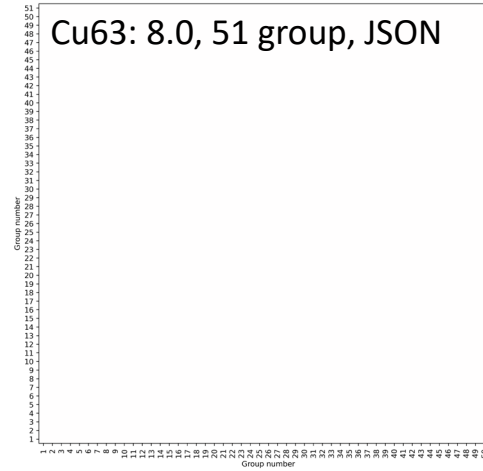


(n,p) reactions

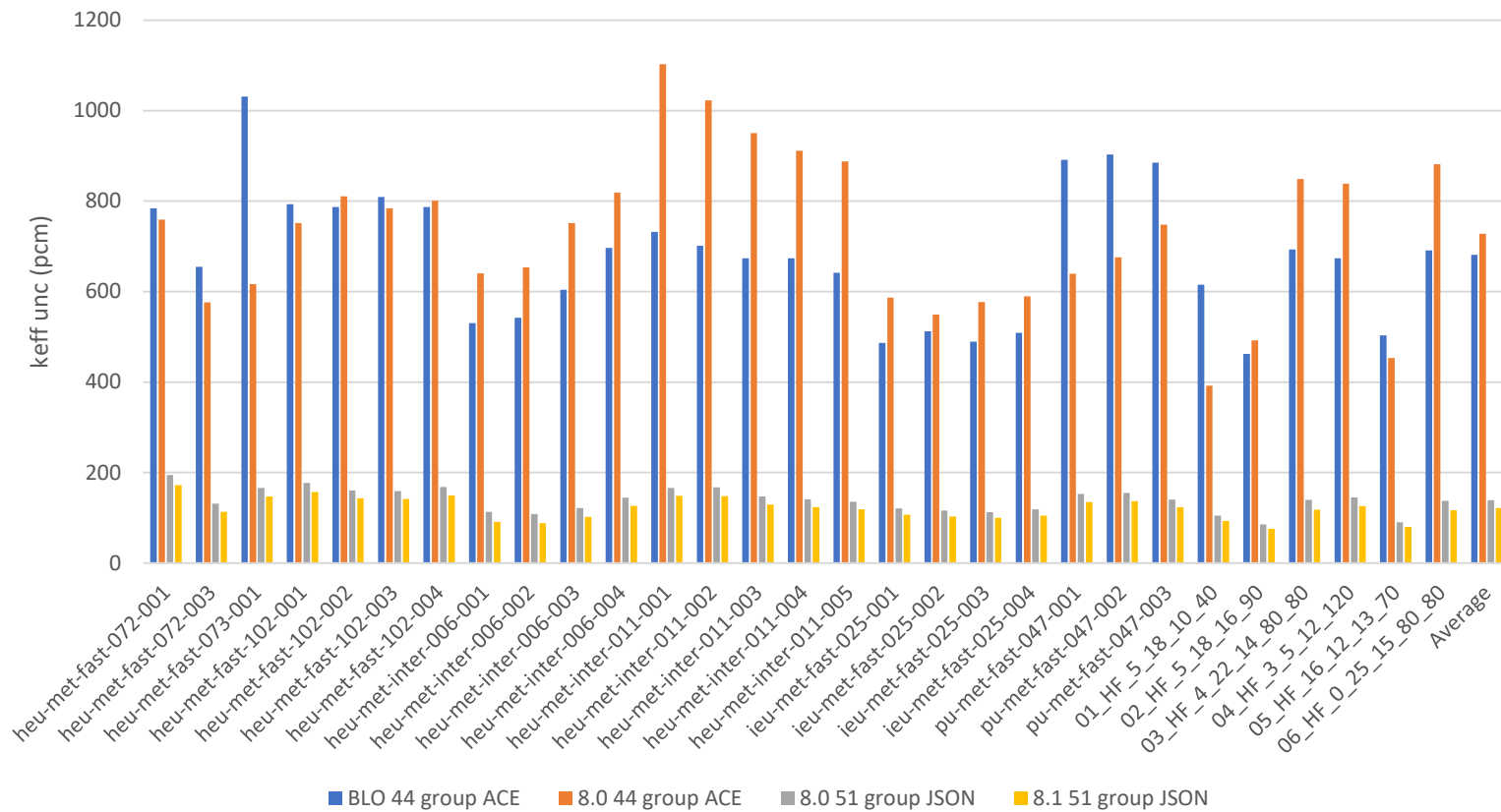
- Covariances do not exist for Cu63 and Cu65 (n,p) in ENDF 8.0 nor 8.1

Benchmark [03_HF_4_22_14_80_44g.I]: 29063 n,p

Benchmark [03_HF_4_22_14_80_44g.I]: 29065 n,p



Cu63 elastic



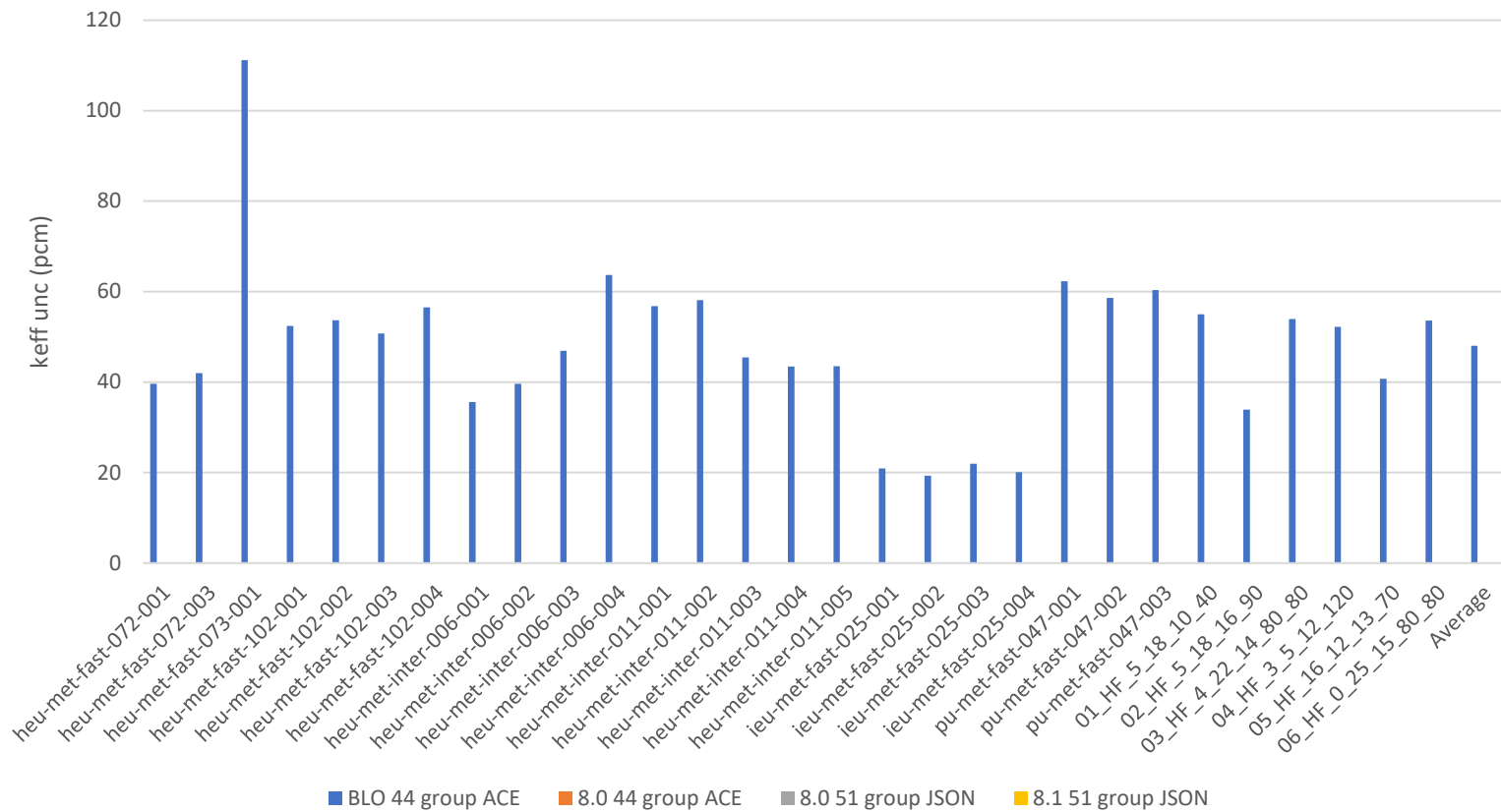
Cu63 elastic

- k_{eff} unc (in pcm) shown to the right
- 8.0 JSON and 8.1 are smaller than BLO
 - Since they are missing high energy covariances
- Not clear why 8.0 ACE is so different compared to 8.0 JSON?

| Benchmark | BLO 44 group ACE | 8.0 44 group ACE | 8.0 51 group JSON | 8.1 51 group JSON |
|-----------------------|---------------------|---------------------|----------------------|----------------------|
| heu-met-fast-072-001 | 784 | 760 | 195 | 172 |
| heu-met-fast-072-003 | 655 | 576 | 131 | 113 |
| heu-met-fast-073-001 | 1031 | 617 | 166 | 147 |
| heu-met-fast-102-001 | 793 | 752 | 177 | 157 |
| heu-met-fast-102-002 | 787 | 811 | 161 | 143 |
| heu-met-fast-102-003 | 810 | 785 | 159 | 142 |
| heu-met-fast-102-004 | 787 | 801 | 168 | 150 |
| heu-met-inter-006-001 | 530 | 641 | 113 | 91 |
| heu-met-inter-006-002 | 542 | 654 | 109 | 88 |
| heu-met-inter-006-003 | 604 | 751 | 122 | 102 |
| heu-met-inter-006-004 | 697 | 819 | 144 | 126 |
| heu-met-inter-011-001 | 732 | 1103 | 166 | 149 |
| heu-met-inter-011-002 | 702 | 1023 | 168 | 148 |
| heu-met-inter-011-003 | 674 | 951 | 147 | 129 |
| heu-met-inter-011-004 | 674 | 912 | 141 | 124 |
| heu-met-inter-011-005 | 641 | 888 | 135 | 119 |
| ieu-met-fast-025-001 | 486 | 587 | 121 | 107 |
| ieu-met-fast-025-002 | 512 | 549 | 116 | 103 |
| ieu-met-fast-025-003 | 490 | 577 | 113 | 100 |
| ieu-met-fast-025-004 | 509 | 589 | 119 | 105 |
| pu-met-fast-047-001 | 892 | 640 | 153 | 135 |
| pu-met-fast-047-002 | 903 | 676 | 155 | 137 |
| pu-met-fast-047-003 | 885 | 748 | 140 | 124 |
| 01_HF_5_18_10_40 | 615 | 392 | 105 | 93 |
| 02_HF_5_18_16_90 | 462 | 492 | 85 | 76 |
| 03_HF_4_22_14_80_80 | 693 | 849 | 140 | 118 |
| 04_HF_3_5_12_120 | 674 | 838 | 146 | 126 |
| 05_HF_16_12_13_70 | 504 | 454 | 90 | 80 |
| 06_HF_0_25_15_80_80 | 691 | 882 | 138 | 116 |
| Average | 681 | 728 | 139 | 121 |



Cu63 inelastic



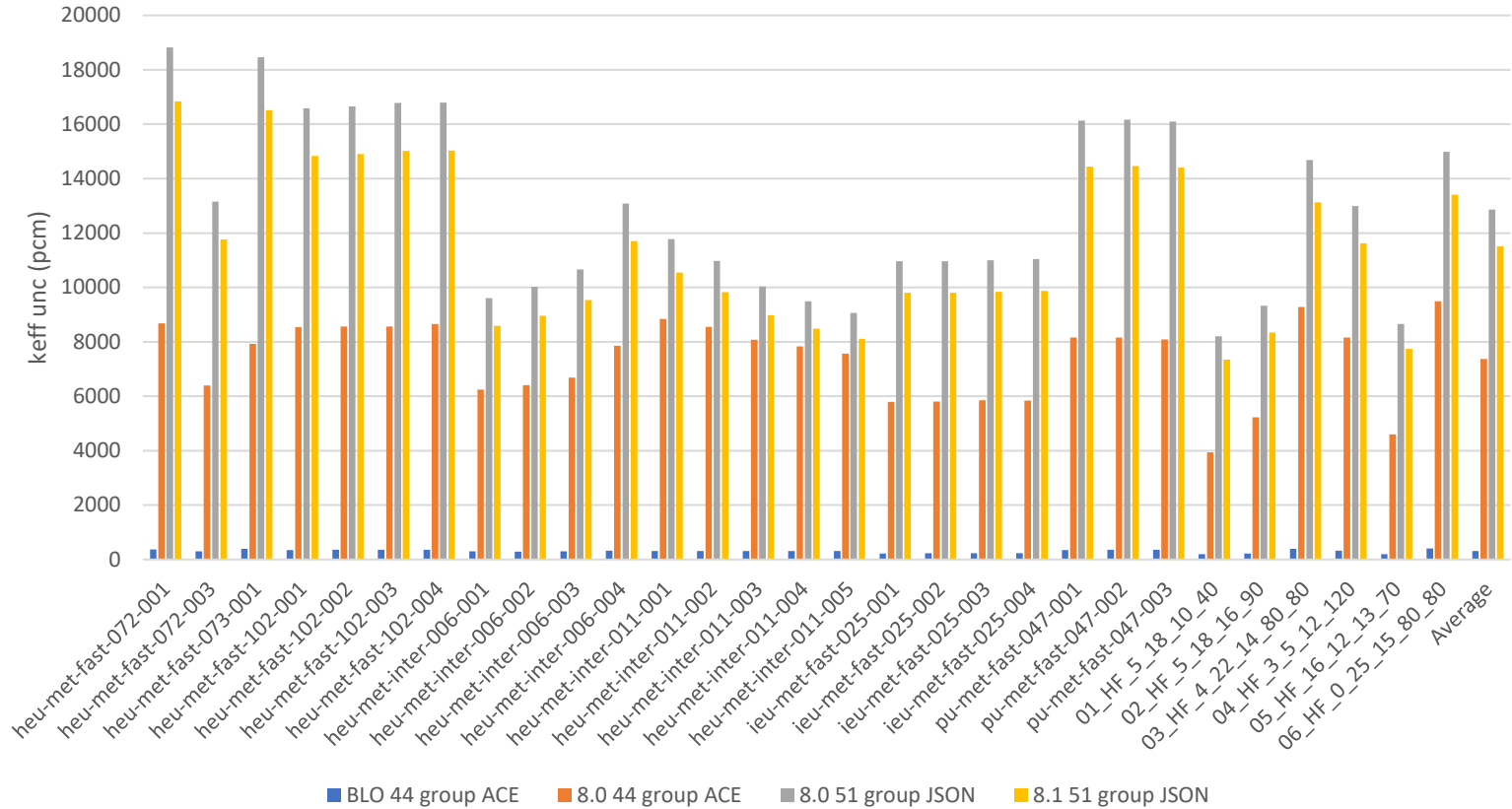
Cu63 inelastic

- k_{eff} unc (in pcm) shown to the right
- Due to covariances not existing, everything other than BLO shows 0 uncertainty...

| Benchmark | BLO 44 group ACE | 8.0 44 group ACE | 8.0 51 group JSON | 8.1 51 group JSON |
|-----------------------|---------------------|---------------------|----------------------|----------------------|
| heu-met-fast-072-001 | 40 | 0 | 0 | 0 |
| heu-met-fast-072-003 | 42 | 0 | 0 | 0 |
| heu-met-fast-073-001 | 111 | 0 | 0 | 0 |
| heu-met-fast-102-001 | 52 | 0 | 0 | 0 |
| heu-met-fast-102-002 | 54 | 0 | 0 | 0 |
| heu-met-fast-102-003 | 51 | 0 | 0 | 0 |
| heu-met-fast-102-004 | 57 | 0 | 0 | 0 |
| heu-met-inter-006-001 | 36 | 0 | 0 | 0 |
| heu-met-inter-006-002 | 40 | 0 | 0 | 0 |
| heu-met-inter-006-003 | 47 | 0 | 0 | 0 |
| heu-met-inter-006-004 | 64 | 0 | 0 | 0 |
| heu-met-inter-011-001 | 57 | 0 | 0 | 0 |
| heu-met-inter-011-002 | 58 | 0 | 0 | 0 |
| heu-met-inter-011-003 | 45 | 0 | 0 | 0 |
| heu-met-inter-011-004 | 43 | 0 | 0 | 0 |
| heu-met-inter-011-005 | 44 | 0 | 0 | 0 |
| ieu-met-fast-025-001 | 21 | 0 | 0 | 0 |
| ieu-met-fast-025-002 | 19 | 0 | 0 | 0 |
| ieu-met-fast-025-003 | 22 | 0 | 0 | 0 |
| ieu-met-fast-025-004 | 20 | 0 | 0 | 0 |
| pu-met-fast-047-001 | 62 | 0 | 0 | 0 |
| pu-met-fast-047-002 | 59 | 0 | 0 | 0 |
| pu-met-fast-047-003 | 60 | 0 | 0 | 0 |
| 01_HF_5_18_10_40 | 55 | 0 | 0 | 0 |
| 02_HF_5_18_16_90 | 34 | 0 | 0 | 0 |
| 03_HF_4_22_14_80_80 | 54 | 0 | 0 | 0 |
| 04_HF_3_5_12_120 | 52 | 0 | 0 | 0 |
| 05_HF_16_12_13_70 | 41 | 0 | 0 | 0 |
| 06_HF_0_25_15_80_80 | 54 | 0 | 0 | 0 |
| Average | 48 | 0 | 0 | 0 |

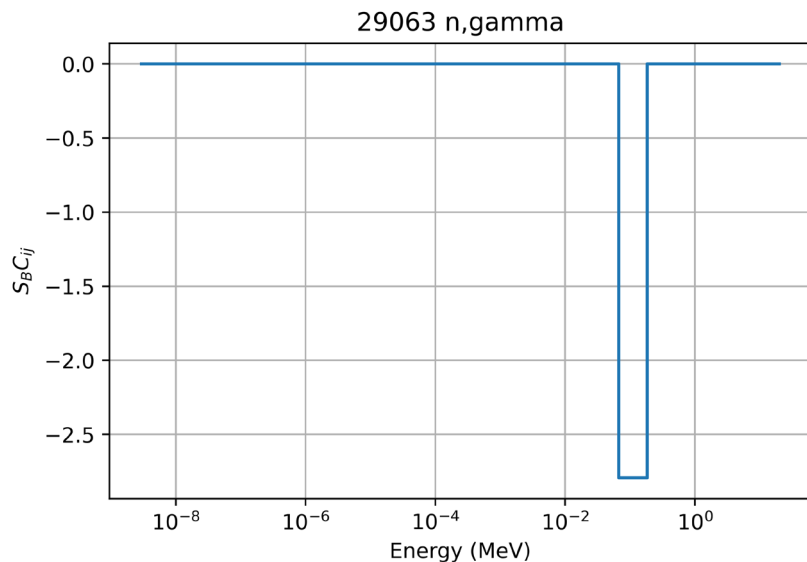


Cu63 (n,gamma)



Cu63 (n,gamma)

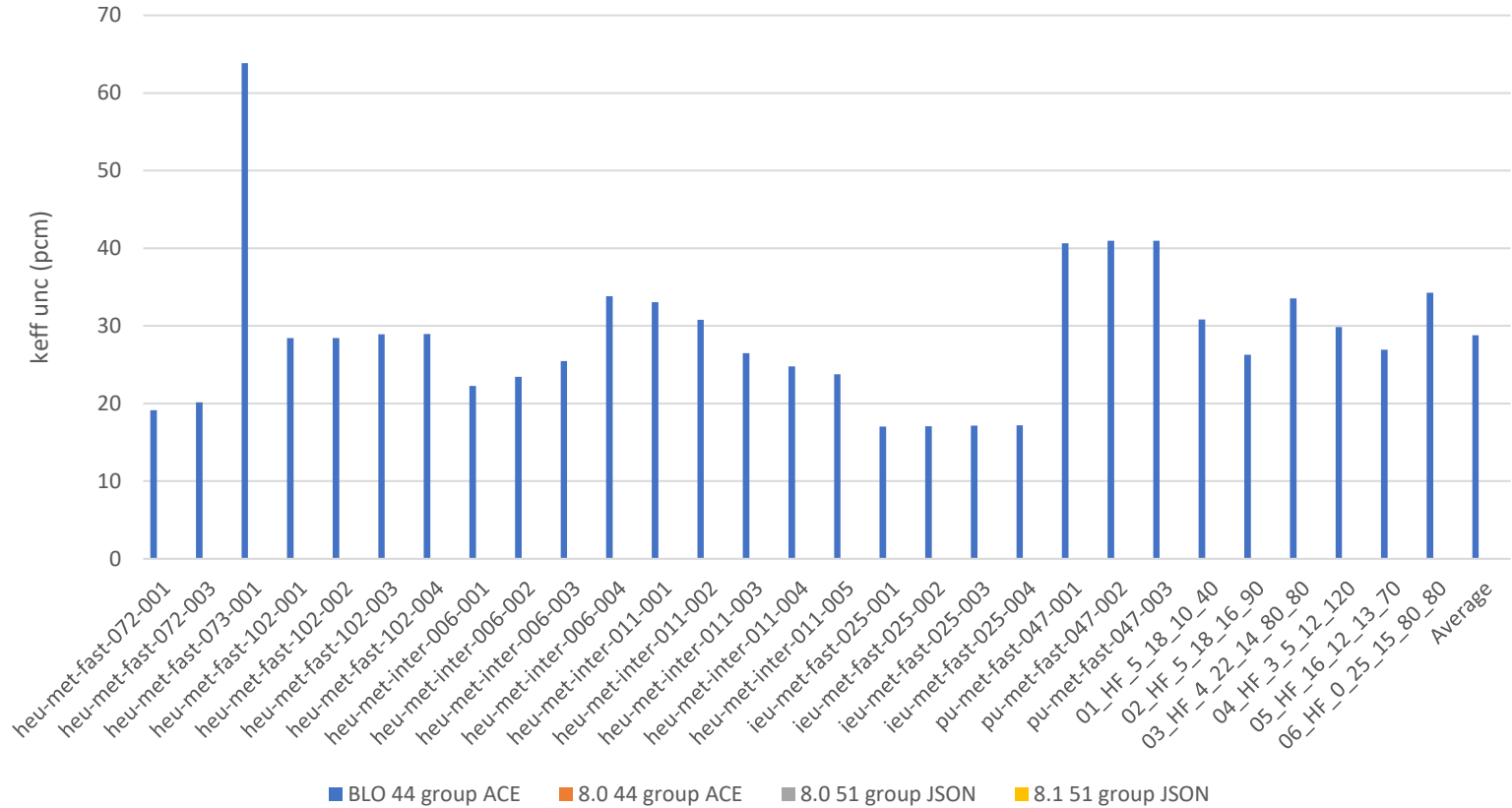
- k_{eff} unc (in pcm) shown to the right
- 8.0 and 8.1 are VERY large!
 - 100% of uncertainty from a single large value in the covariance



| Benchmark | BLO 44 group ACE | 8.0 44 group ACE | 8.0 51 group JSON | 8.1 51 group JSON |
|-----------------------|---------------------|---------------------|----------------------|----------------------|
| heu-met-fast-072-001 | 367 | 8679 | 18823 | 16841 |
| heu-met-fast-072-003 | 297 | 6391 | 13150 | 11766 |
| heu-met-fast-073-001 | 389 | 7924 | 18462 | 16518 |
| heu-met-fast-102-001 | 352 | 8543 | 16585 | 14839 |
| heu-met-fast-102-002 | 353 | 8559 | 16654 | 14901 |
| heu-met-fast-102-003 | 355 | 8567 | 16782 | 15015 |
| heu-met-fast-102-004 | 356 | 8661 | 16797 | 15028 |
| heu-met-inter-006-001 | 295 | 6241 | 9602 | 8591 |
| heu-met-inter-006-002 | 293 | 6406 | 10019 | 8964 |
| heu-met-inter-006-003 | 297 | 6691 | 10662 | 9540 |
| heu-met-inter-006-004 | 320 | 7853 | 13082 | 11704 |
| heu-met-inter-011-001 | 316 | 8847 | 11780 | 10540 |
| heu-met-inter-011-002 | 313 | 8551 | 10979 | 9824 |
| heu-met-inter-011-003 | 311 | 8083 | 10039 | 8983 |
| heu-met-inter-011-004 | 308 | 7837 | 9486 | 8488 |
| heu-met-inter-011-005 | 307 | 7564 | 9064 | 8111 |
| ieu-met-fast-025-001 | 225 | 5795 | 10958 | 9805 |
| ieu-met-fast-025-002 | 226 | 5801 | 10960 | 9807 |
| ieu-met-fast-025-003 | 226 | 5852 | 10999 | 9841 |
| ieu-met-fast-025-004 | 226 | 5845 | 11038 | 9876 |
| pu-met-fast-047-001 | 352 | 8155 | 16135 | 14436 |
| pu-met-fast-047-002 | 353 | 8154 | 16164 | 14462 |
| pu-met-fast-047-003 | 353 | 8083 | 16100 | 14404 |
| 01_HF_5_18_10_40 | 193 | 3940 | 8206 | 7343 |
| 02_HF_5_18_16_90 | 218 | 5229 | 9326 | 8344 |
| 03_HF_4_22_14_80_80 | 392 | 9285 | 14682 | 13135 |
| 04_HF_3_5_12_120 | 327 | 8158 | 12990 | 11622 |
| 05_HF_16_12_13_70 | 201 | 4599 | 8657 | 7745 |
| 06_HF_0_25_15_80_80 | 401 | 9486 | 14987 | 13408 |
| Average | 308 | 7372 | 12868 | 11513 |



Cu63 (n,p)



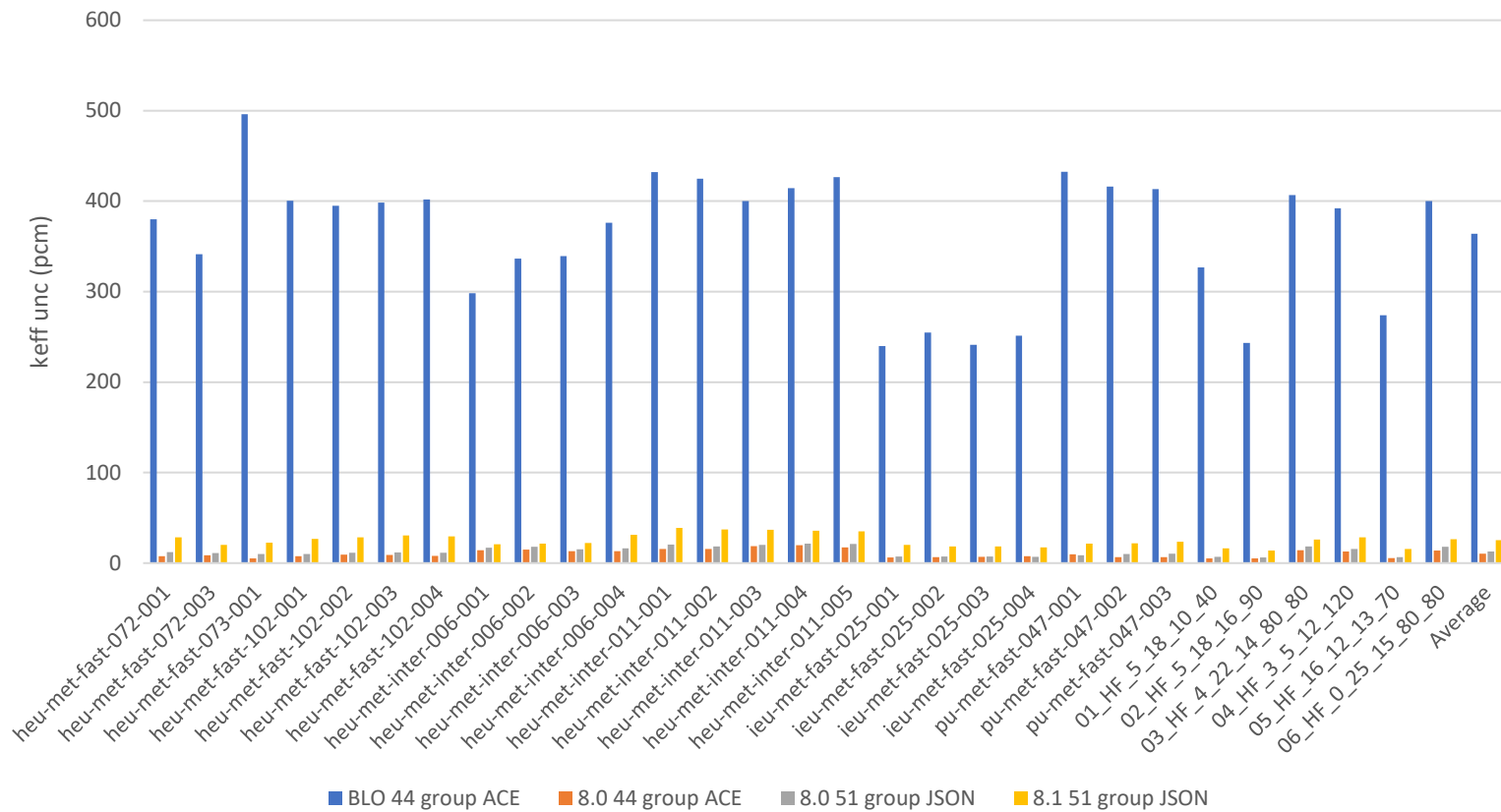
Cu63 (n,p)

- k_{eff} unc (in pcm) shown to the right
- Similar to Cu63 inelastic

| Benchmark | BLO 44 group ACE | 8.0 44 group ACE | 8.0 51 group JSON | 8.1 51 group JSON |
|-----------------------|---------------------|---------------------|----------------------|-------------------|
| heu-met-fast-072-001 | 19 | 0 | 0 | 0 |
| heu-met-fast-072-003 | 20 | 0 | 0 | 0 |
| heu-met-fast-073-001 | 64 | 0 | 0 | 0 |
| heu-met-fast-102-001 | 28 | 0 | 0 | 0 |
| heu-met-fast-102-002 | 28 | 0 | 0 | 0 |
| heu-met-fast-102-003 | 29 | 0 | 0 | 0 |
| heu-met-fast-102-004 | 29 | 0 | 0 | 0 |
| heu-met-inter-006-001 | 22 | 0 | 0 | 0 |
| heu-met-inter-006-002 | 23 | 0 | 0 | 0 |
| heu-met-inter-006-003 | 25 | 0 | 0 | 0 |
| heu-met-inter-006-004 | 34 | 0 | 0 | 0 |
| heu-met-inter-011-001 | 33 | 0 | 0 | 0 |
| heu-met-inter-011-002 | 31 | 0 | 0 | 0 |
| heu-met-inter-011-003 | 26 | 0 | 0 | 0 |
| heu-met-inter-011-004 | 25 | 0 | 0 | 0 |
| heu-met-inter-011-005 | 24 | 0 | 0 | 0 |
| ieu-met-fast-025-001 | 17 | 0 | 0 | 0 |
| ieu-met-fast-025-002 | 17 | 0 | 0 | 0 |
| ieu-met-fast-025-003 | 17 | 0 | 0 | 0 |
| ieu-met-fast-025-004 | 17 | 0 | 0 | 0 |
| pu-met-fast-047-001 | 41 | 0 | 0 | 0 |
| pu-met-fast-047-002 | 41 | 0 | 0 | 0 |
| pu-met-fast-047-003 | 41 | 0 | 0 | 0 |
| 01_HF_5_18_10_40 | 31 | 0 | 0 | 0 |
| 02_HF_5_18_16_90 | 26 | 0 | 0 | 0 |
| 03_HF_4_22_14_80_80 | 34 | 0 | 0 | 0 |
| 04_HF_3_5_12_120 | 30 | 0 | 0 | 0 |
| 05_HF_16_12_13_70 | 27 | 0 | 0 | 0 |
| 06_HF_0_25_15_80_80 | 34 | 0 | 0 | 0 |
| Average | 29 | 0 | 0 | 0 |



Cu65 elastic



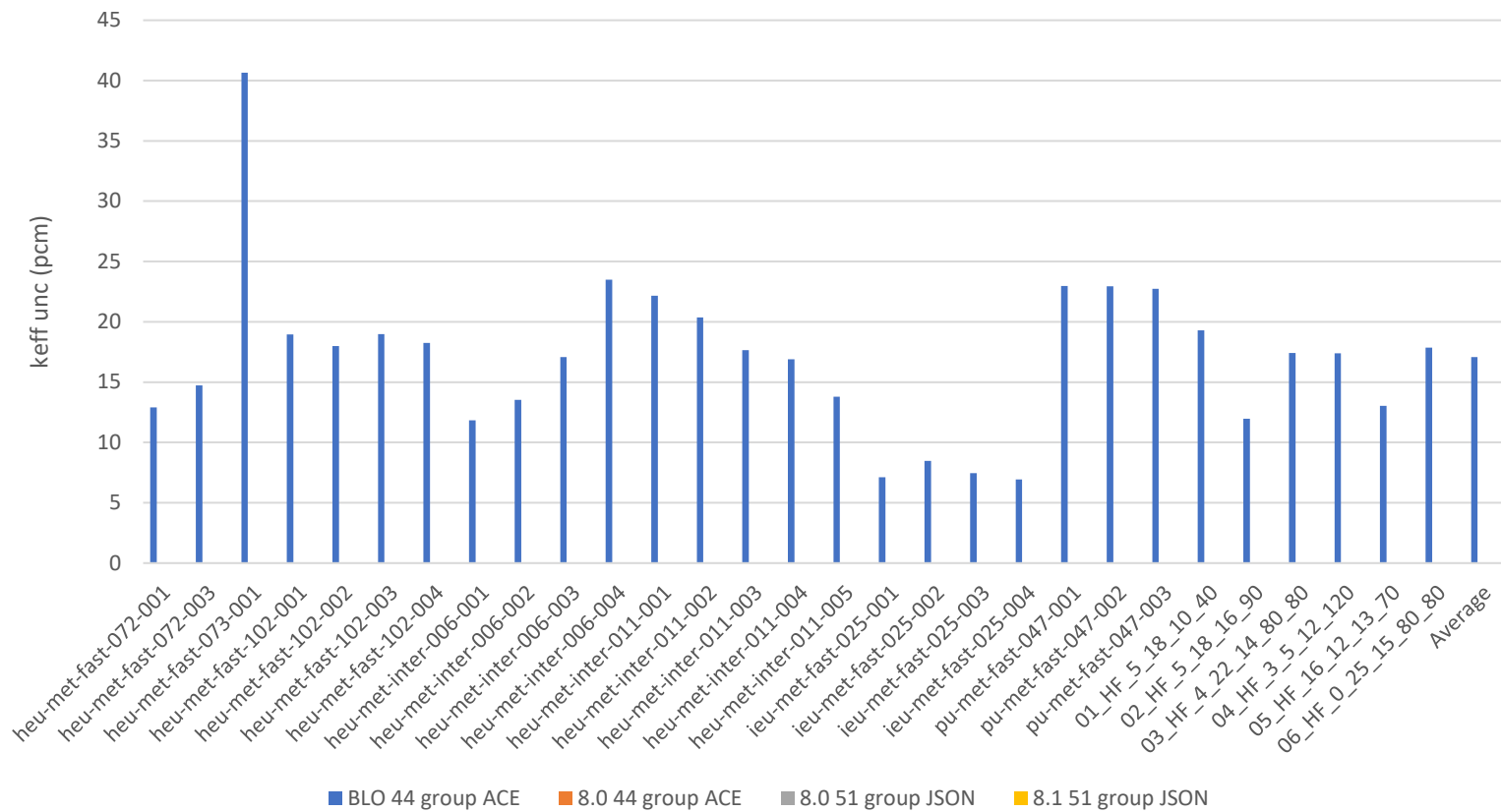
Cu65 elastic

- k_{eff} unc (in pcm) shown to the right
- 8.0 JSON and 8.1 are much smaller than BLO
 - Because they are missing high energy covariances

| Benchmark | BLO 44 group ACE | 8.0 44 group ACE | 8.0 51 group JSON | 8.1b4 51 group JSON |
|-----------------------|---------------------|---------------------|----------------------|------------------------|
| heu-met-fast-072-001 | 380 | 8 | 12 | 29 |
| heu-met-fast-072-003 | 341 | 9 | 11 | 20 |
| heu-met-fast-073-001 | 496 | 5 | 10 | 23 |
| heu-met-fast-102-001 | 401 | 8 | 10 | 27 |
| heu-met-fast-102-002 | 395 | 9 | 11 | 28 |
| heu-met-fast-102-003 | 398 | 9 | 12 | 31 |
| heu-met-fast-102-004 | 402 | 8 | 11 | 30 |
| heu-met-inter-006-001 | 298 | 14 | 17 | 21 |
| heu-met-inter-006-002 | 336 | 15 | 18 | 21 |
| heu-met-inter-006-003 | 339 | 13 | 15 | 22 |
| heu-met-inter-006-004 | 376 | 13 | 16 | 31 |
| heu-met-inter-011-001 | 432 | 16 | 20 | 39 |
| heu-met-inter-011-002 | 425 | 15 | 19 | 37 |
| heu-met-inter-011-003 | 400 | 19 | 20 | 37 |
| heu-met-inter-011-004 | 414 | 20 | 21 | 36 |
| heu-met-inter-011-005 | 427 | 17 | 21 | 35 |
| ieu-met-fast-025-001 | 240 | 6 | 7 | 20 |
| ieu-met-fast-025-002 | 255 | 6 | 7 | 18 |
| ieu-met-fast-025-003 | 241 | 7 | 7 | 18 |
| ieu-met-fast-025-004 | 251 | 8 | 7 | 17 |
| pu-met-fast-047-001 | 432 | 10 | 9 | 22 |
| pu-met-fast-047-002 | 416 | 7 | 10 | 22 |
| pu-met-fast-047-003 | 413 | 7 | 10 | 24 |
| 01_HF_5_18_10_40 | 327 | 5 | 7 | 16 |
| 02_HF_5_18_16_90 | 243 | 5 | 6 | 14 |
| 03_HF_4_22_14_80_80 | 407 | 14 | 18 | 26 |
| 04_HF_3_5_12_120 | 392 | 13 | 16 | 29 |
| 05_HF_16_12_13_70 | 274 | 6 | 7 | 16 |
| 06_HF_0_25_15_80_80 | 400 | 14 | 18 | 27 |
| Average | 364 | 11 | 13 | 25 |



Cu65 inelastic



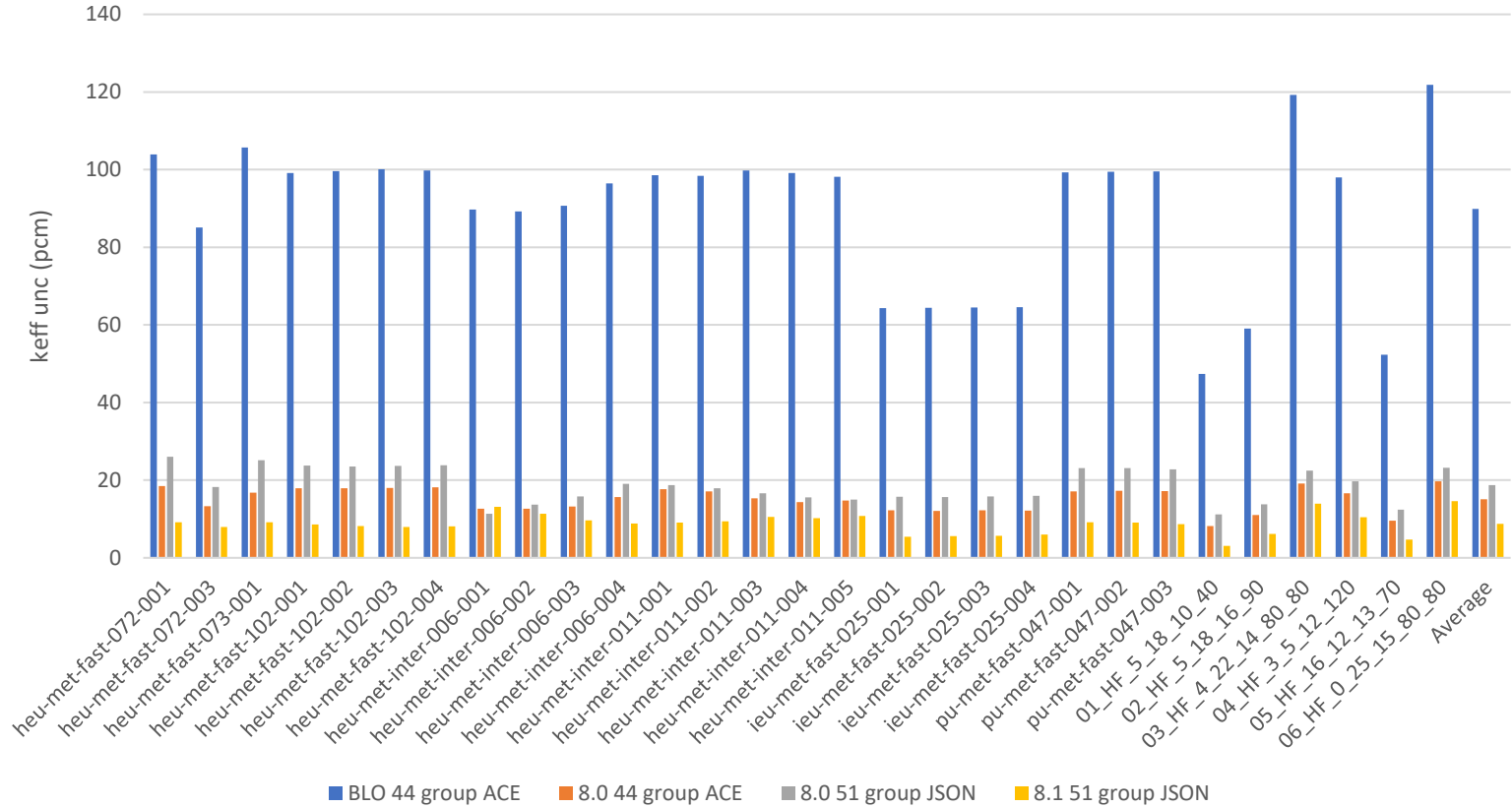
Cu65 inelastic

- k_{eff} unc (in pcm) shown to the right
- All 0 other than BLO

| Benchmark | BLO 44 group ACE | 8.0 44 group ACE | 8.51 group JSON | 8.1b4 51 group JSON |
|-----------------------|------------------|------------------|-----------------|---------------------|
| heu-met-fast-072-001 | 13 | 0 | 0 | 0 |
| heu-met-fast-072-003 | 15 | 0 | 0 | 0 |
| heu-met-fast-073-001 | 41 | 0 | 0 | 0 |
| heu-met-fast-102-001 | 19 | 0 | 0 | 0 |
| heu-met-fast-102-002 | 18 | 0 | 0 | 0 |
| heu-met-fast-102-003 | 19 | 0 | 0 | 0 |
| heu-met-fast-102-004 | 18 | 0 | 0 | 0 |
| heu-met-inter-006-001 | 12 | 0 | 0 | 0 |
| heu-met-inter-006-002 | 14 | 0 | 0 | 0 |
| heu-met-inter-006-003 | 17 | 0 | 0 | 0 |
| heu-met-inter-006-004 | 24 | 0 | 0 | 0 |
| heu-met-inter-011-001 | 22 | 0 | 0 | 0 |
| heu-met-inter-011-002 | 20 | 0 | 0 | 0 |
| heu-met-inter-011-003 | 18 | 0 | 0 | 0 |
| heu-met-inter-011-004 | 17 | 0 | 0 | 0 |
| heu-met-inter-011-005 | 14 | 0 | 0 | 0 |
| ieu-met-fast-025-001 | 7 | 0 | 0 | 0 |
| ieu-met-fast-025-002 | 8 | 0 | 0 | 0 |
| ieu-met-fast-025-003 | 7 | 0 | 0 | 0 |
| ieu-met-fast-025-004 | 7 | 0 | 0 | 0 |
| pu-met-fast-047-001 | 23 | 0 | 0 | 0 |
| pu-met-fast-047-002 | 23 | 0 | 0 | 0 |
| pu-met-fast-047-003 | 23 | 0 | 0 | 0 |
| 01_HF_5_18_10_40 | 19 | 0 | 0 | 0 |
| 02_HF_5_18_16_90 | 12 | 0 | 0 | 0 |
| 03_HF_4_22_14_80_80 | 17 | 0 | 0 | 0 |
| 04_HF_3_5_12_120 | 17 | 0 | 0 | 0 |
| 05_HF_16_12_13_70 | 13 | 0 | 0 | 0 |
| 06_HF_0_25_15_80_80 | 18 | 0 | 0 | 0 |
| Average | 17 | 0 | 0 | 0 |



Cu65 (n,gamma)



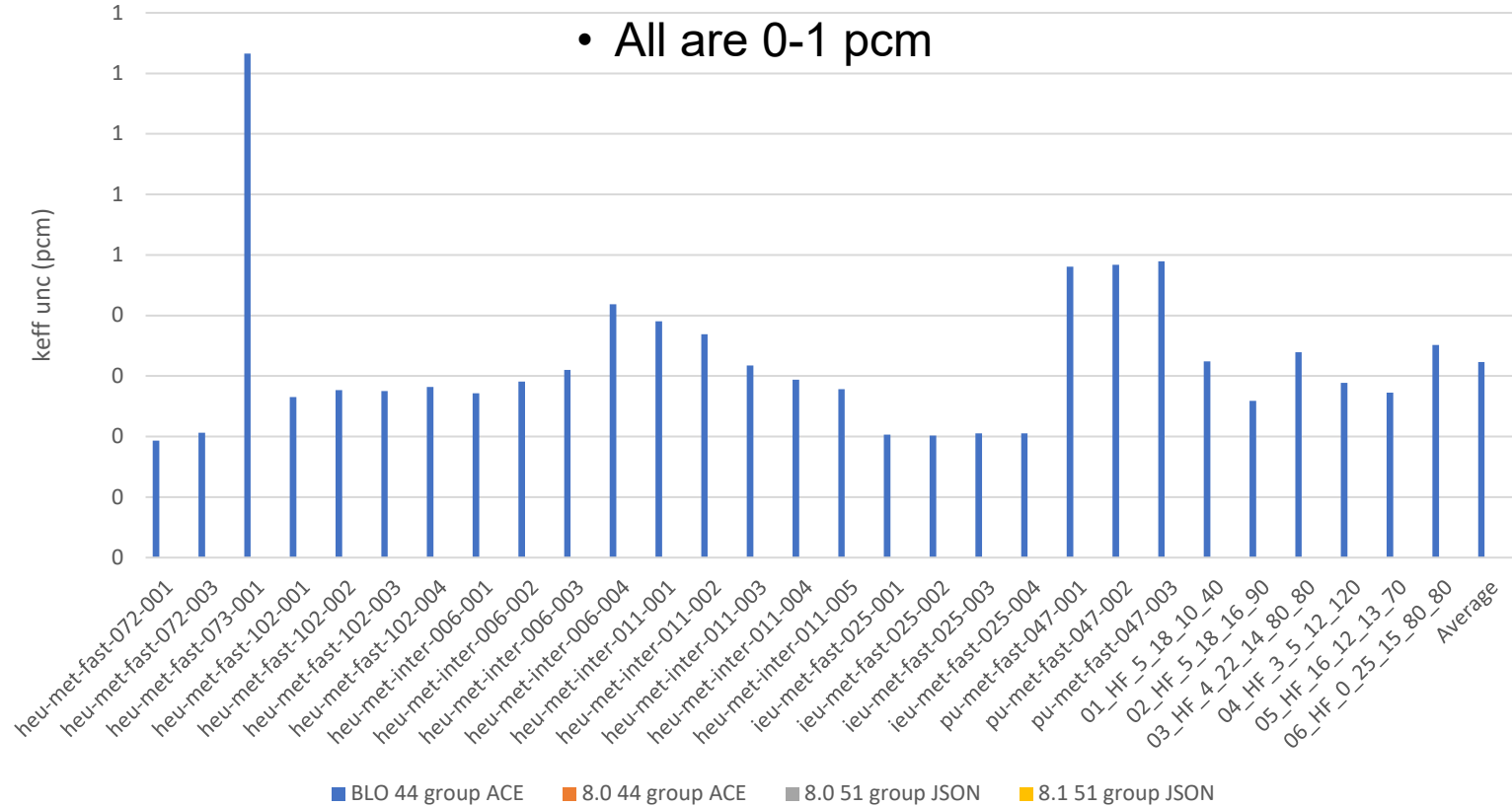
Cu65 (n,gamma)

- k_{eff} unc (in pcm) shown to the right
- 8.0 JSON and 8.1 are smaller than BLO
 - Because they are missing high energy covariances

| Benchmark | BLO 44 group ACE | 8.0 44 group ACE | 8.0 51 group JSON | 8.1b4 51 group JSON |
|-----------------------|---------------------|---------------------|----------------------|------------------------|
| heu-met-fast-072-001 | 104 | 19 | 26 | 9 |
| heu-met-fast-072-003 | 85 | 13 | 18 | 8 |
| heu-met-fast-073-001 | 106 | 17 | 25 | 9 |
| heu-met-fast-102-001 | 99 | 18 | 24 | 9 |
| heu-met-fast-102-002 | 100 | 18 | 24 | 8 |
| heu-met-fast-102-003 | 100 | 18 | 24 | 8 |
| heu-met-fast-102-004 | 100 | 18 | 24 | 8 |
| heu-met-inter-006-001 | 90 | 13 | 11 | 13 |
| heu-met-inter-006-002 | 89 | 13 | 14 | 11 |
| heu-met-inter-006-003 | 91 | 13 | 16 | 10 |
| heu-met-inter-006-004 | 96 | 16 | 19 | 9 |
| heu-met-inter-011-001 | 99 | 18 | 19 | 9 |
| heu-met-inter-011-002 | 98 | 17 | 18 | 9 |
| heu-met-inter-011-003 | 100 | 15 | 17 | 11 |
| heu-met-inter-011-004 | 99 | 14 | 16 | 10 |
| heu-met-inter-011-005 | 98 | 15 | 15 | 11 |
| ieu-met-fast-025-001 | 64 | 12 | 16 | 5 |
| ieu-met-fast-025-002 | 64 | 12 | 16 | 6 |
| ieu-met-fast-025-003 | 65 | 12 | 16 | 6 |
| ieu-met-fast-025-004 | 65 | 12 | 16 | 6 |
| pu-met-fast-047-001 | 99 | 17 | 23 | 9 |
| pu-met-fast-047-002 | 99 | 17 | 23 | 9 |
| pu-met-fast-047-003 | 100 | 17 | 23 | 9 |
| 01_HF_5_18_10_40 | 47 | 8 | 11 | 3 |
| 02_HF_5_18_16_90 | 59 | 11 | 14 | 6 |
| 03_HF_4_22_14_80_80 | 119 | 19 | 22 | 14 |
| 04_HF_3_5_12_120 | 98 | 17 | 20 | 10 |
| 05_HF_16_12_13_70 | 52 | 10 | 12 | 5 |
| 06_HF_0_25_15_80_80 | 122 | 20 | 23 | 15 |
| Average | 90 | 15 | 19 | 9 |



Cu65 (n,p)



Conclusions

- Cu nuclear data is important (and important for actinide intermediate energy nuclear data)
- There seem to be major issues (at least with the processed data I was using) for some reactions:
 - Missing fast covariances in ENDF8.0+8.1
 - Cu63 (n,gamma) also has a separate issue
- Cu covariances could definitely use an update for ENDF9.0

Other nuclide/reactions I have seen major issues with in ENDF8.0

- Ni60 inelastic
- Ni60 (n,p)
- Ca40 elastic
- Ca40 (n,gamma)
- U235 (n,gamma)

DISCLAIMER: these have not been investigated in detail. Issues could be in covariances or in processing

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