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Title: Bias and Uncertainty Under-Prediction in MCNP6.1 Lattice Physics Calculations with Depletion

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Bias and Uncertainty Under-Prediction in MCNP6.1 Lattice Physics Calculations with Depletion

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NNSA Nuclear Criticality Safety Program

Outline

- Motivation & Previous Work
- Calculations and Issues
- Results

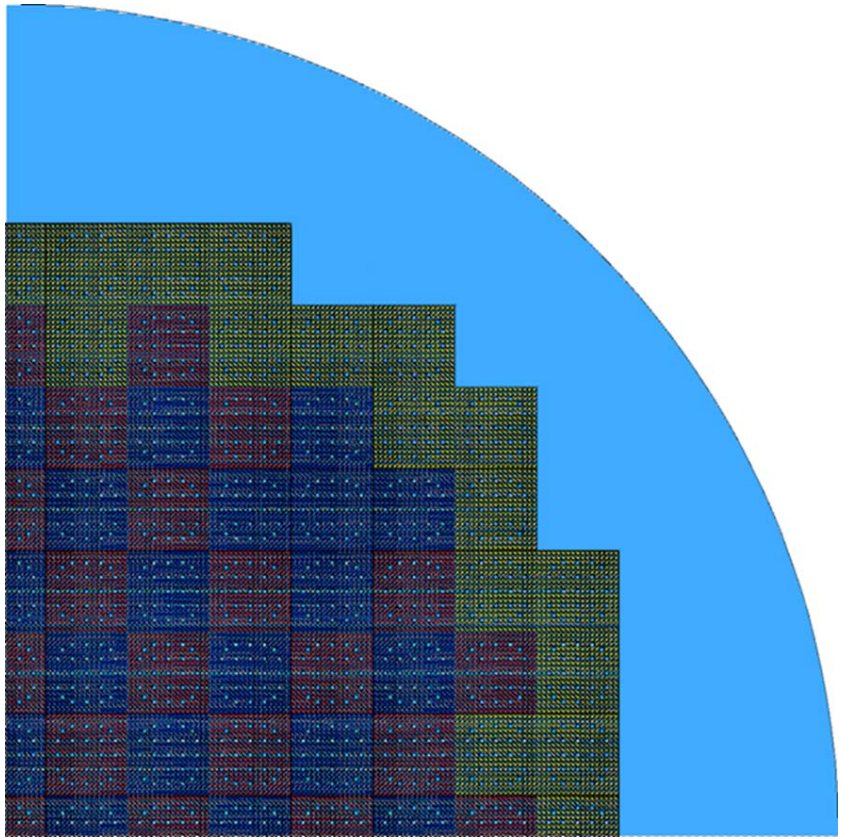
Motivation

- **Monte Carlo criticality calculations have well-known issues.**
  - **Bias in Results: Arises from renormalization with a small batch size.**
  - **Under-prediction of Uncertainties: Criticality calculations do not account for positive correlation between cycles.**

- **Previous work has focused on static calculations, no assessment on how depletion calculations are affected.**

Previous Work, Static Case

- **2-D PWR, fresh fuel**



F.B. Brown, "A Review of Monte Carlo Criticality Calculations – Convergence, Bias, Statistics," *Proc. M&C 2009* Saratoga Springs, NY May 3-7 (2009).

Bias Along Diagonal

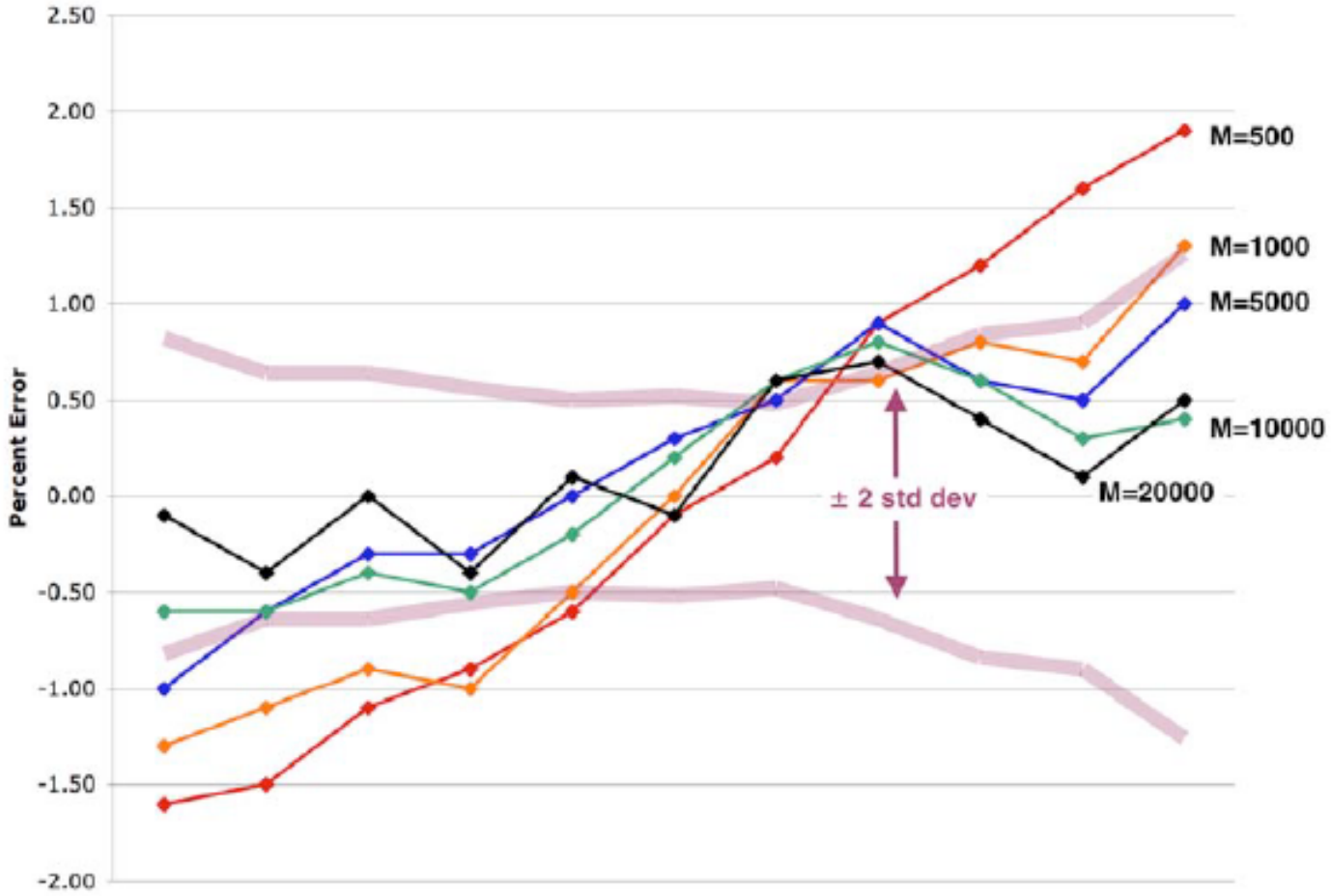


Figure 4. **Percent error in fission rates along diagonal, for 2D quarter-core PWR problem (M = neutrons/cycle)**

Uncertainty Under-Prediction

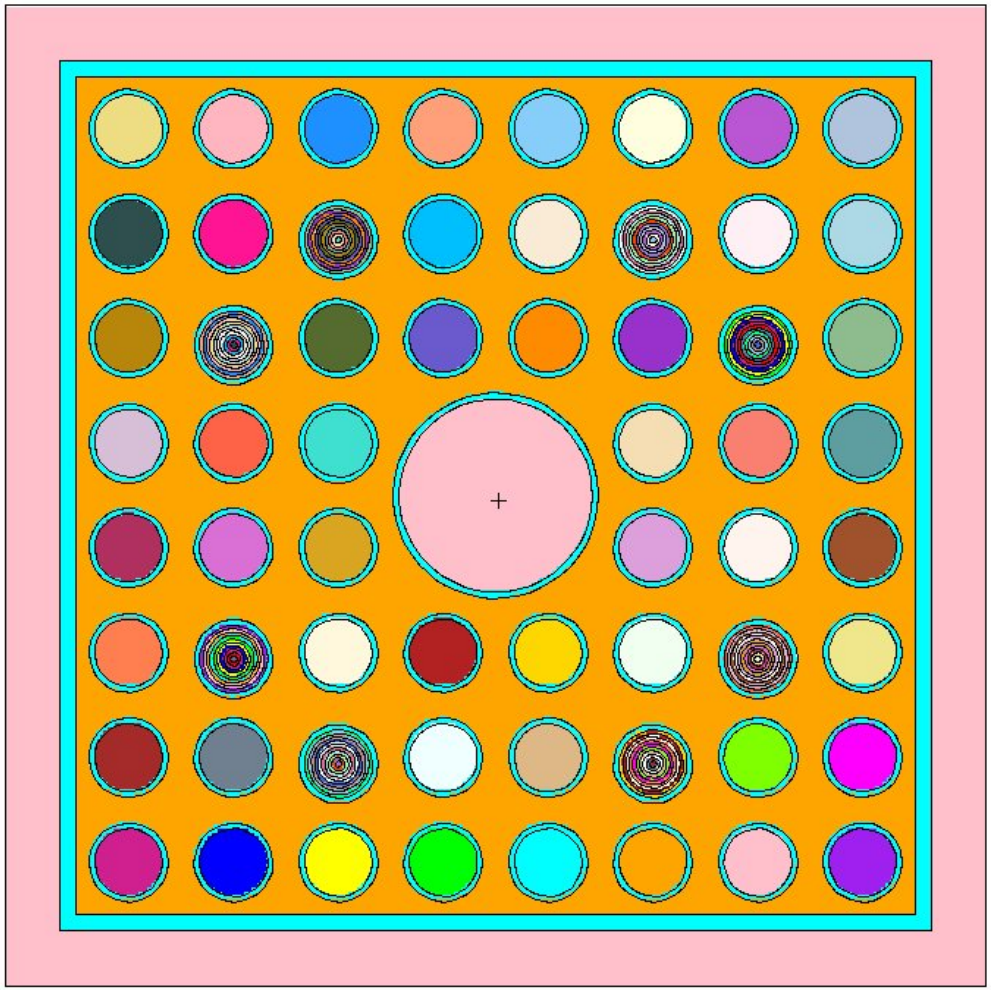
Table 2. True relative errors in quarter-assembly fission rates for MCNP calculation for PWR-2D problem, as multiples of MCNP-calculated relative errors, $\sigma_{TRUE} / \sigma_{MCNP}$

3.4	3.1	2.7	2.7	2.6	2.3	2.7						
3.3	3.7	3.6	3.7	3.7	2.7	2.9						
3.8	3.8	3.9	4.0	3.6	3.3	3.0	2.9	2.5	2.5	2.2		
3.8	3.9	4.2	3.3	3.5	3.4	3.2	3.6	3.0	3.0	2.8		
3.9	3.6	3.5	3.3	3.4	3.4	4.0	3.9	3.5	3.2	3.1	2.5	1.7
4.1	3.8	3.5	3.2	2.9	2.6	2.9	3.2	3.1	2.8	2.7	1.9	1.7
3.4	3.4	3.2	3.5	2.6	2.4	2.6	3.0	2.9	2.9	2.8	2.3	2.1
4.2	3.5	3.4	3.1	2.7	2.3	2.0	2.4	2.5	2.5	2.1	2.3	2.3
3.9	3.6	3.1	2.9	2.3	1.9	1.9	2.3	2.4	2.9	2.7	2.7	2.2	2.8	2.3
3.7	3.3	3.6	2.4	2.2	2.2	2.5	1.8	2.2	2.6	2.7	2.9	2.5	2.4	2.5
3.0	3.1	3.0	2.2	2.2	2.1	2.4	2.5	2.4	2.6	2.7	2.6	2.7	3.0	2.6
2.9	3.7	3.3	2.6	2.5	2.8	3.0	2.9	3.5	3.2	3.3	3.1	3.1	3.2	3.3
3.2	3.1	2.9	3.1	3.2	3.3	3.5	3.5	3.6	3.9	3.7	3.9	3.5	3.4	2.9
3.4	3.0	3.1	3.6	3.4	3.5	3.9	3.7	4.0	4.3	4.0	4.3	3.8	4.2	3.5
3.5	3.2	2.8	3.5	3.8	3.9	3.9	3.9	4.1	4.1	4.6	4.4	4.7	4.5	3.8

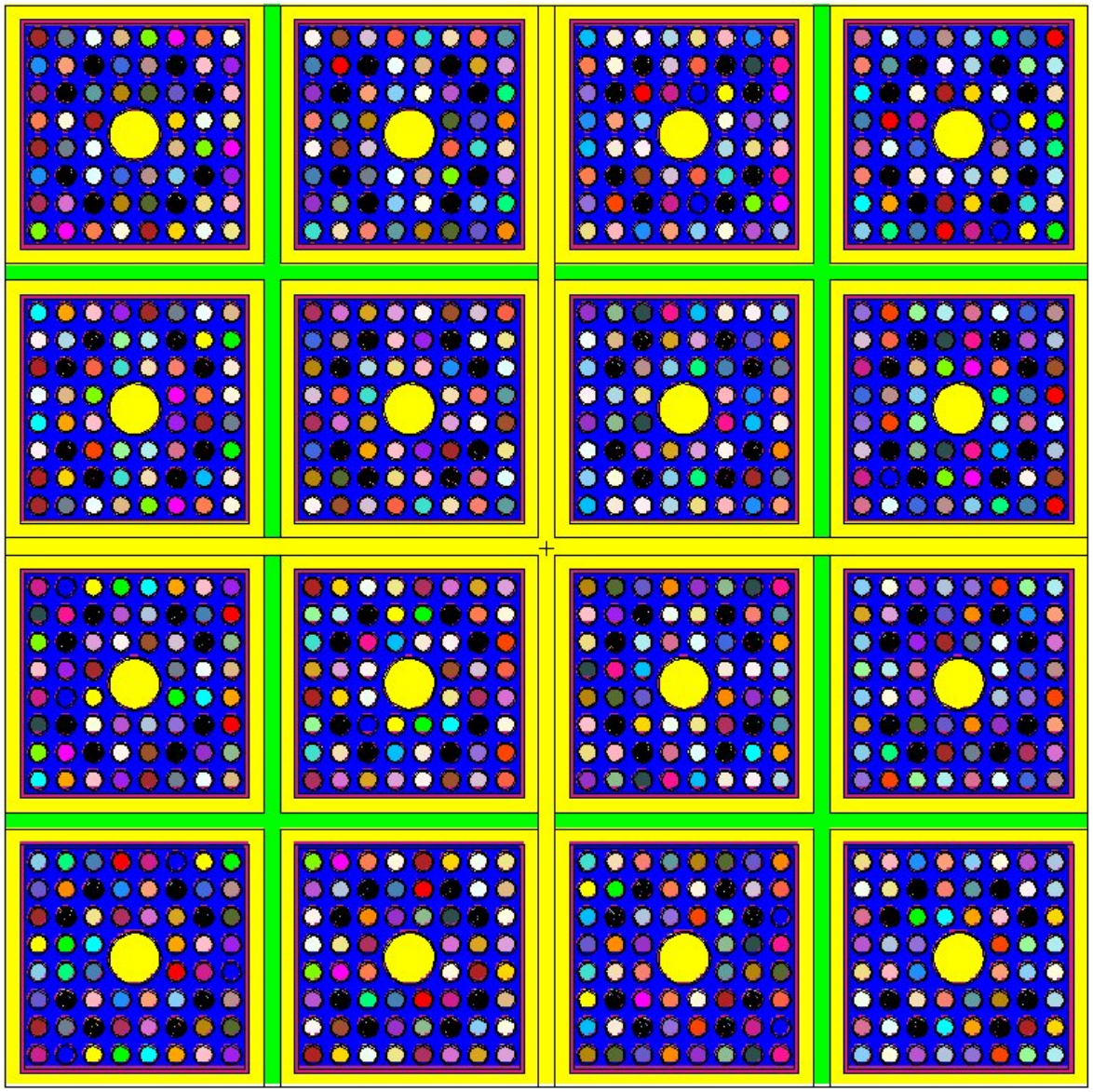
Average factor = 3.1

Reference Input Case

- **OECD/NEA Burnup Credit Benchmark Phase IIIB**
  - **Reflected 2D BWR-like assembly**



Full Geometry



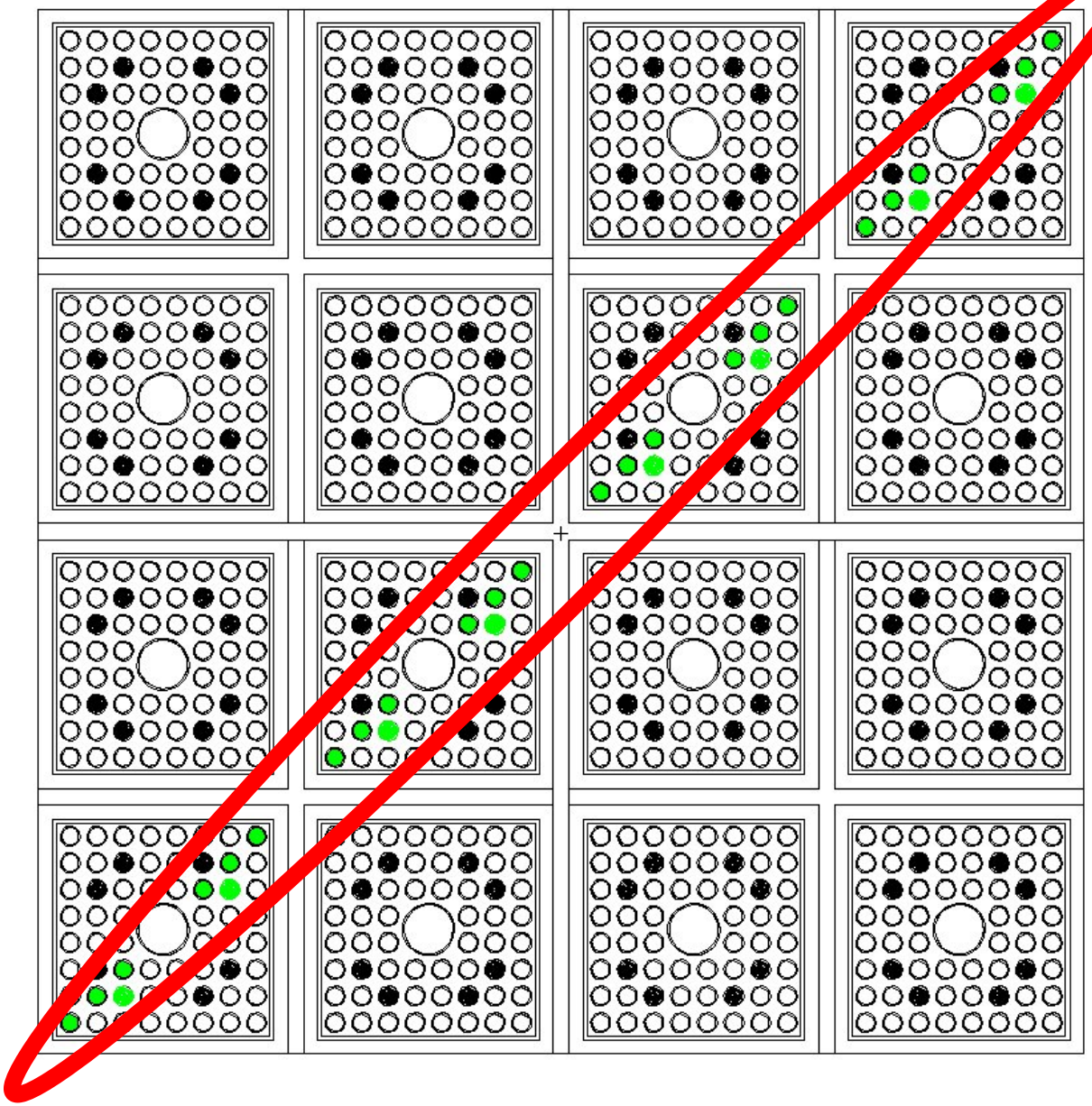
- **Geometry**
  - **Four assemblies were grouped together into a quad assembly**
    - 1 cm B4C control blade between them
  - **Four quad assemblies were grouped together**
    - 1 cm water between them
- **Burnup zones**
  - **Each fuel pin was had its own material number**
  - **Each gadolinium pin had 10 material numbers**
    - Same radius for each region
- **Power of 192 kW**
- **Burnup Steps**
  - **1 burnup step of 1 day**
    - Account for the Xe-135
  - **12 burnup steps of 90 days**
  - **1 decay step of 5 year**

Tallies

- **Reaction rate tallies:**
  - **Fission of U-235**
  - **Fission of Pu-239**
  - **Capture of U-238**
  - **Capture of Pu-239**
  - **Capture of Xe-135**
  - **Capture of Gd-157**

- **Tallies were placed along the diagonal of the geometry.**

Tally Locations



Cases

- **Reference Case**
  - 10,000 particles per cycle
  - 100 cycles
  - 10 cycles skipped
  - Shannon entropy and source converged within 10 cycles
  - 25 Independent Cases
  - Computing Time: about 140 hours/case with 16 cores

- **Bias Case**
  - 100 particles per cycle
  - 10,000 cycles
  - 10 cycles skipped
  - 23 Independent Cases
  - Computing Time: about 240 hours/case with 16 cores

Memory Issue & Resolution

- **Input case exceeded the 32 GB memory limit of moonlight node**
  - **Surface coefficient array used vast majority of memory when using LIKE BUT TRCL**

- **To decrease the amount of memory needed**
  - **The lines in the source code:**
    - `mxj = mxj + 9 * ncl_like(m1c)`
    - `nsc = nsc + 32 * ncl_like(m1c)`
  - **Were changed to:**
    - `mxj = mxj + 1 * ncl_like(m1c)`
    - `nsc = nsc + 4 * ncl_like(m1c)`

- **Overly conservative. About a factor of 3 times less memory for current problem.**

Memory Usage

Number of Quad Assemblies	Memory Usage(GB) Using 16 Cores	Memory Usage(GB) Using 1 Core
1	3.9	1.4
2	6.4	2.4
3	8.9	3.5
4	11.3	4.5
6	16.3	6.6
9	23.8	9.8

Tally Biases

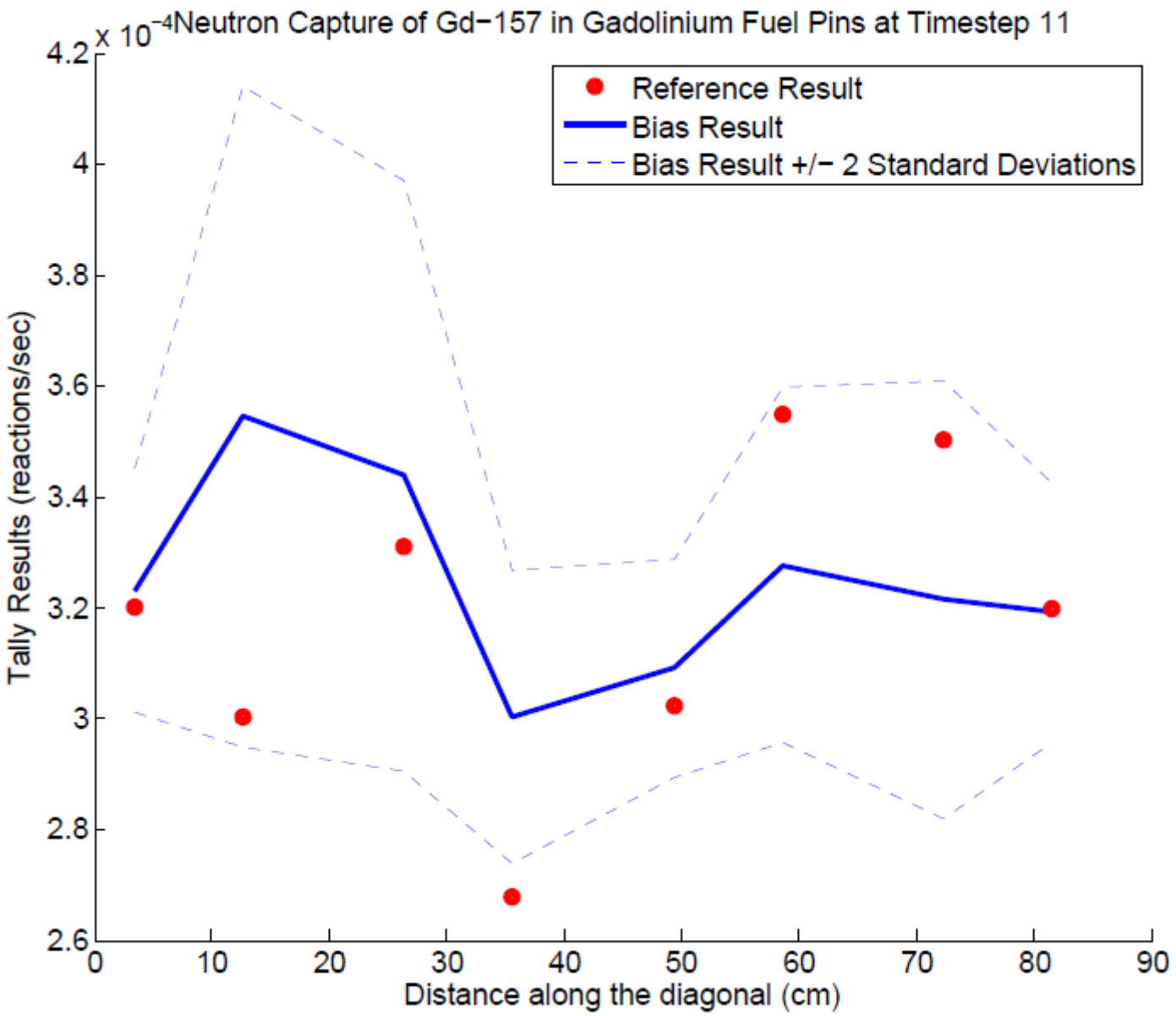
- **Biased results arise when not running a sufficient amount of particles per cycle.**

- **Compare results for**
  - **Batch size of 10,000 for 100 cycles (reference case)**
  - **Batch size of 100 for 10,000 cycles (biased case)**

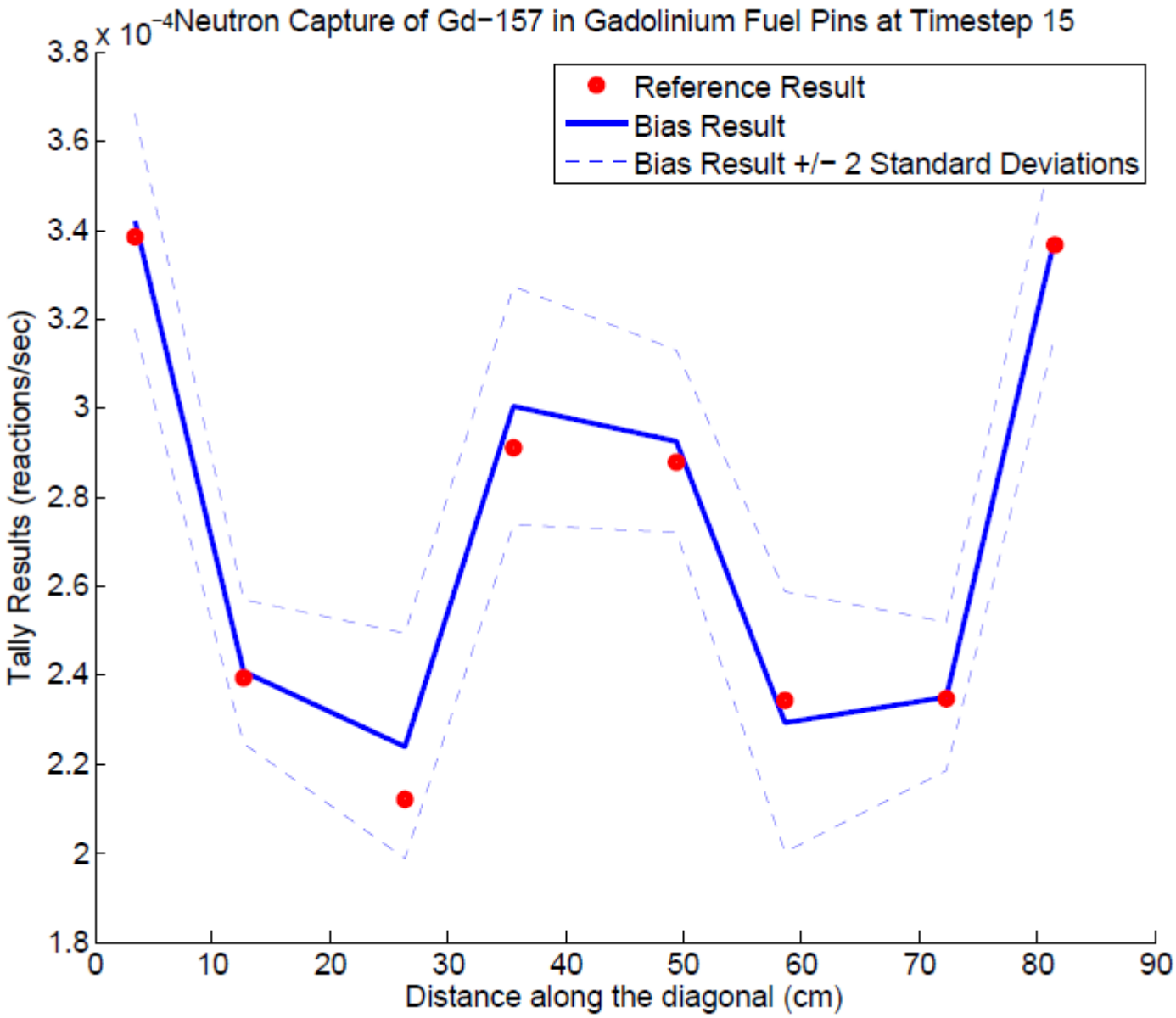
  - **Note: Total number of neutrons each time step is the same (on average) for both cases.**

- **How do the results compare?**

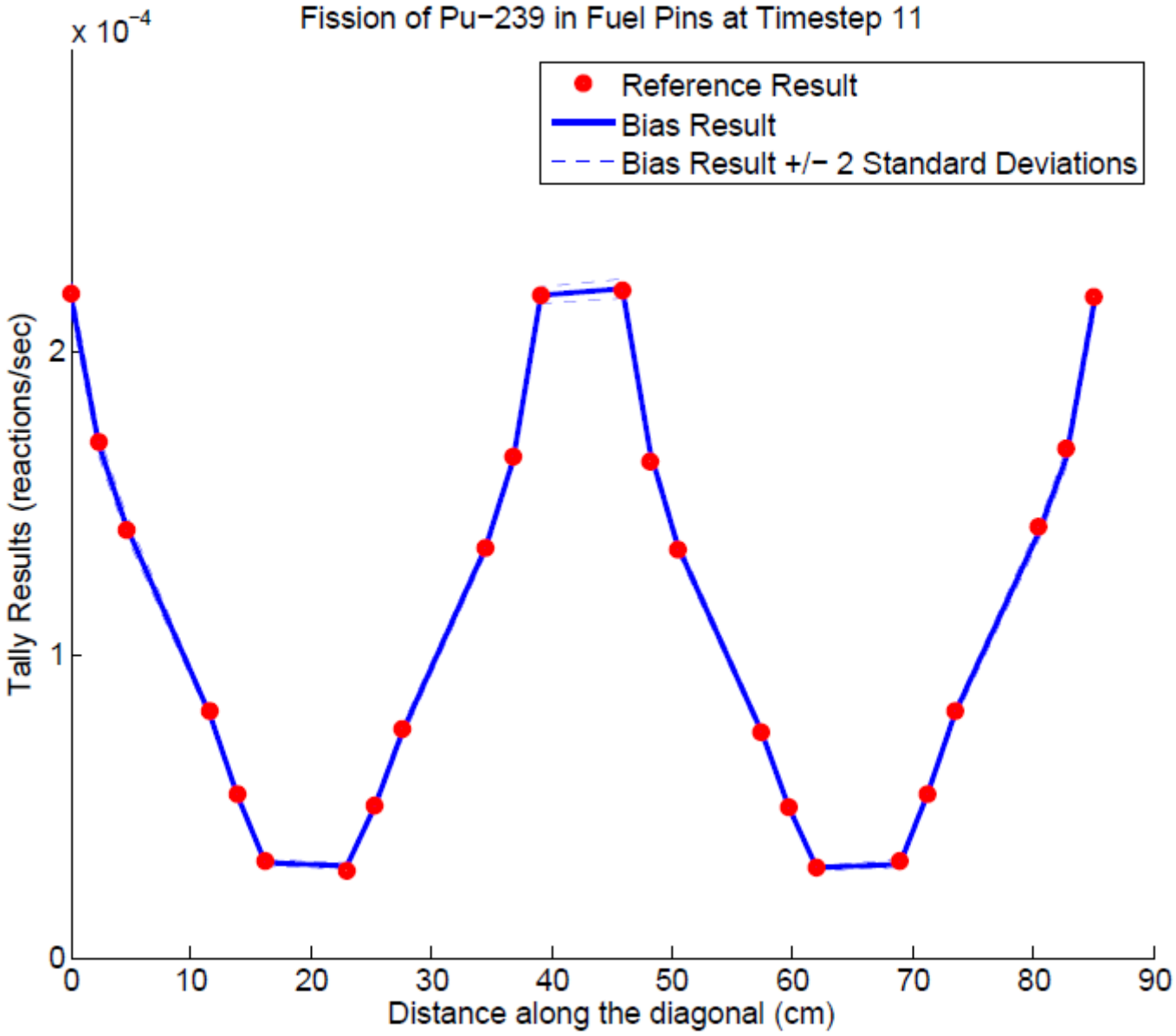
Tally Bias Results



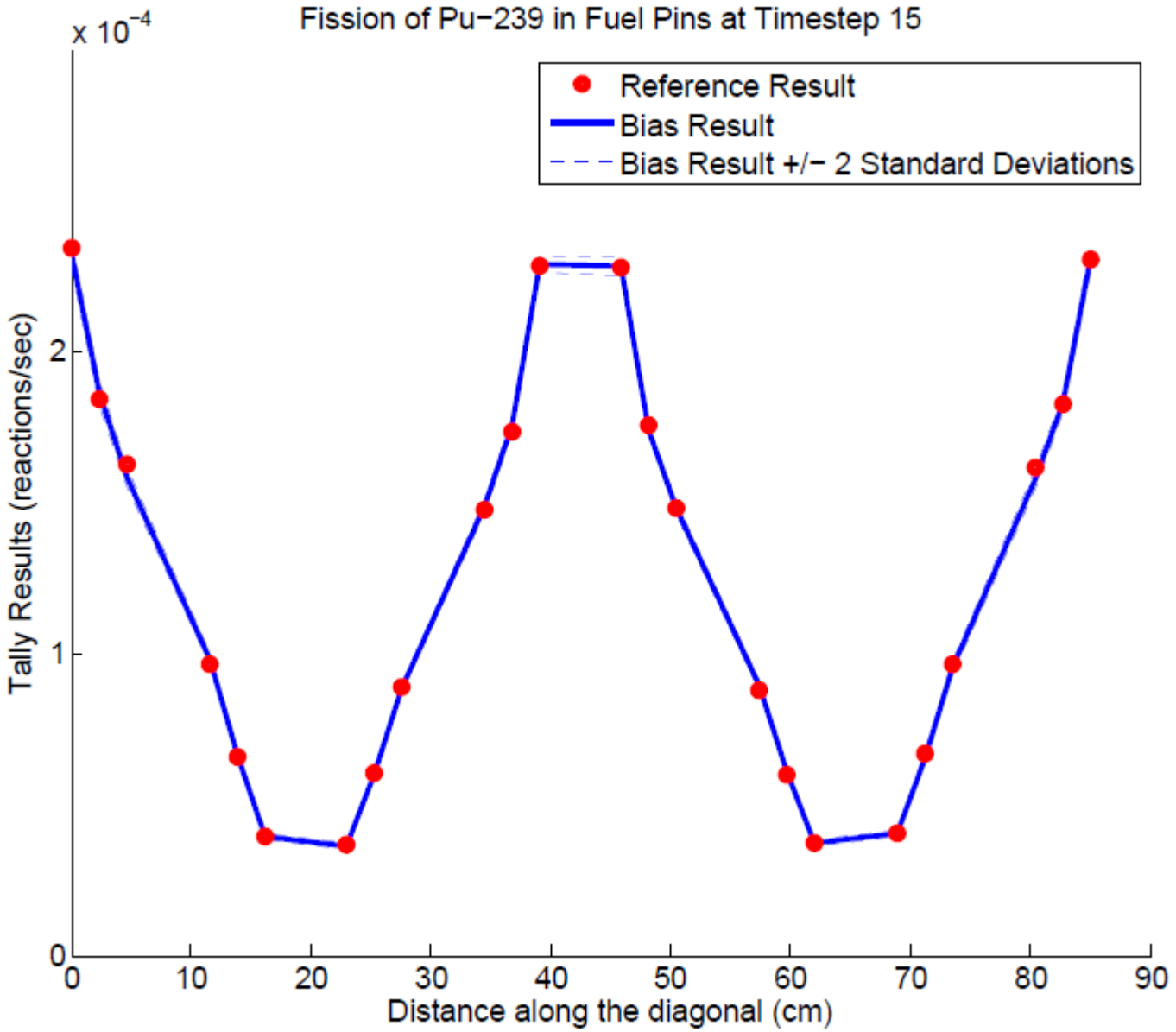
Tally Bias Results



Tally Bias Results



Tally Bias Results



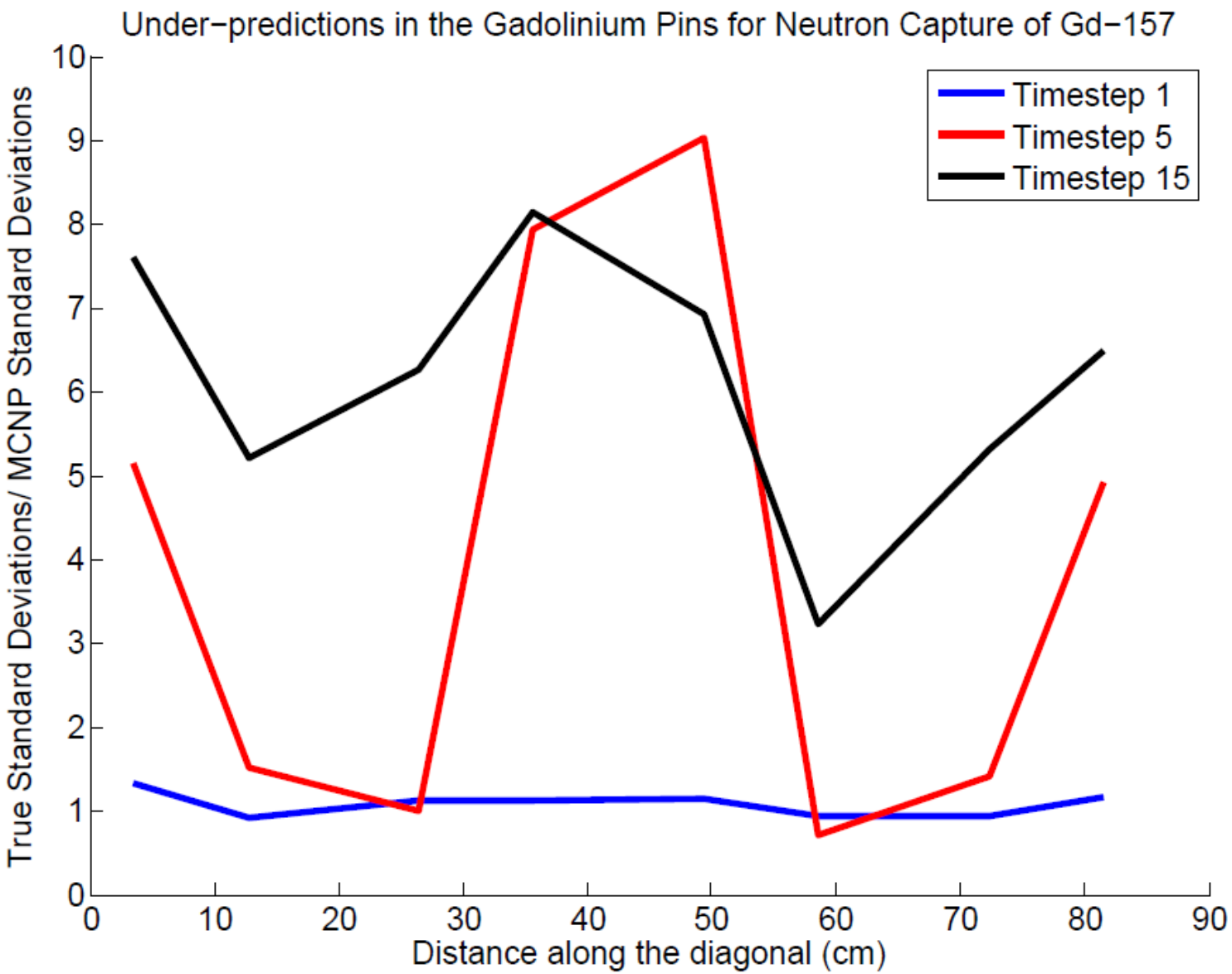
Tally Bias Results

- **Gd-157 neutron capture biased tally had the greatest deviation from the reference case.**
  - **Suggestive, but inconclusive.**
  - **The results were still within 2 true standard deviations of the mean for most tallies.**
- **Other tally results did not show much of an effect.**
- **Bias did not have much of an effect on this problem.**
  - **A larger or less symmetric problem could show more bias effects.**

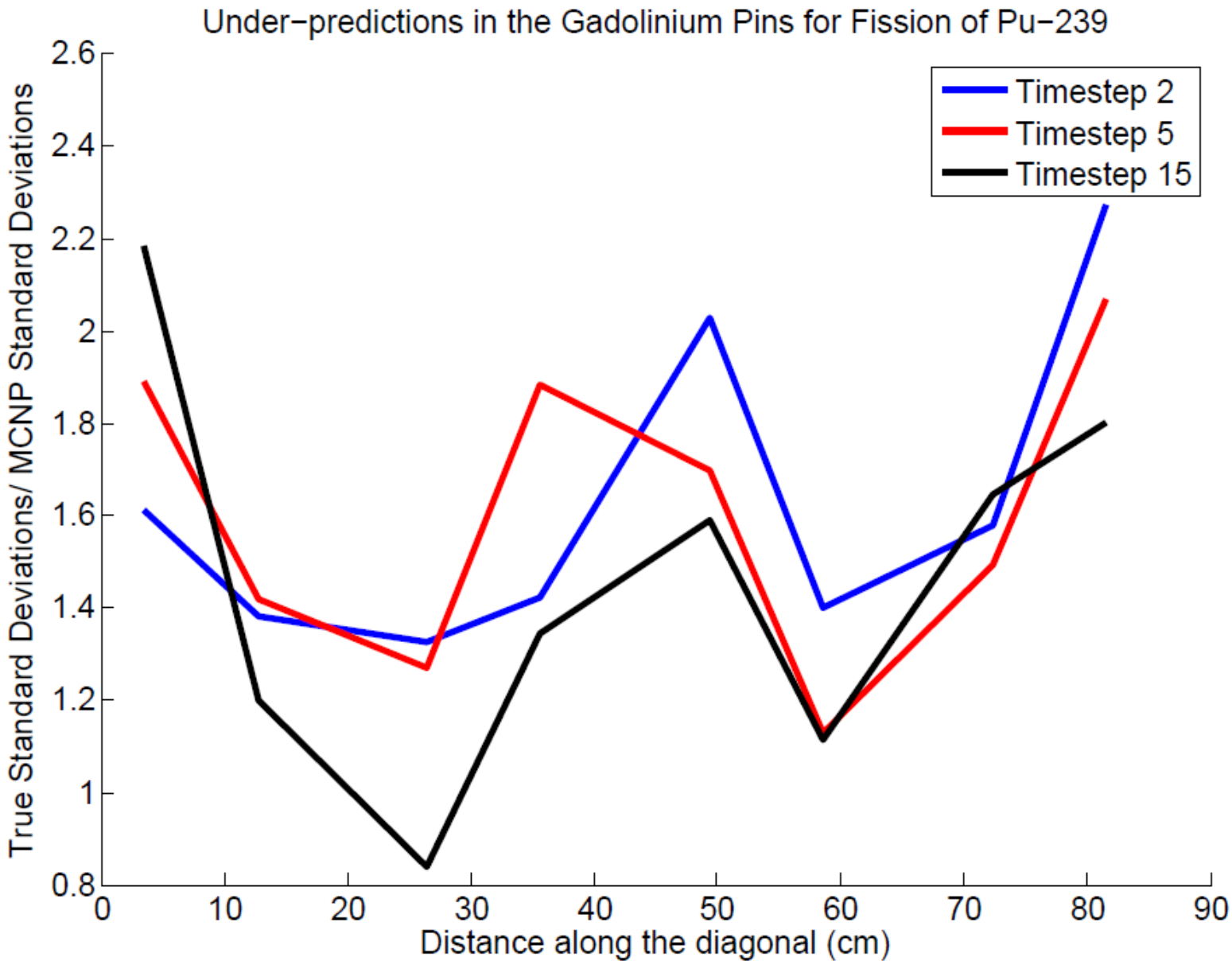
Uncertainty Under-prediction

- **MCNP assumes the cycles are independent to calculate uncertainties.**
  - **This results in an under-prediction of the uncertainties.**
- **Function of location, timestep, and tally type.**
  - **Uncertainty under-prediction is shown as:**
    - True Uncertainty / MCNP Reported Uncertainty
  - **Note: True uncertainty determined empirically from independent runs with 25 different random number seeds**
- **The results come from the 10,000 particles / cycle reference case.**

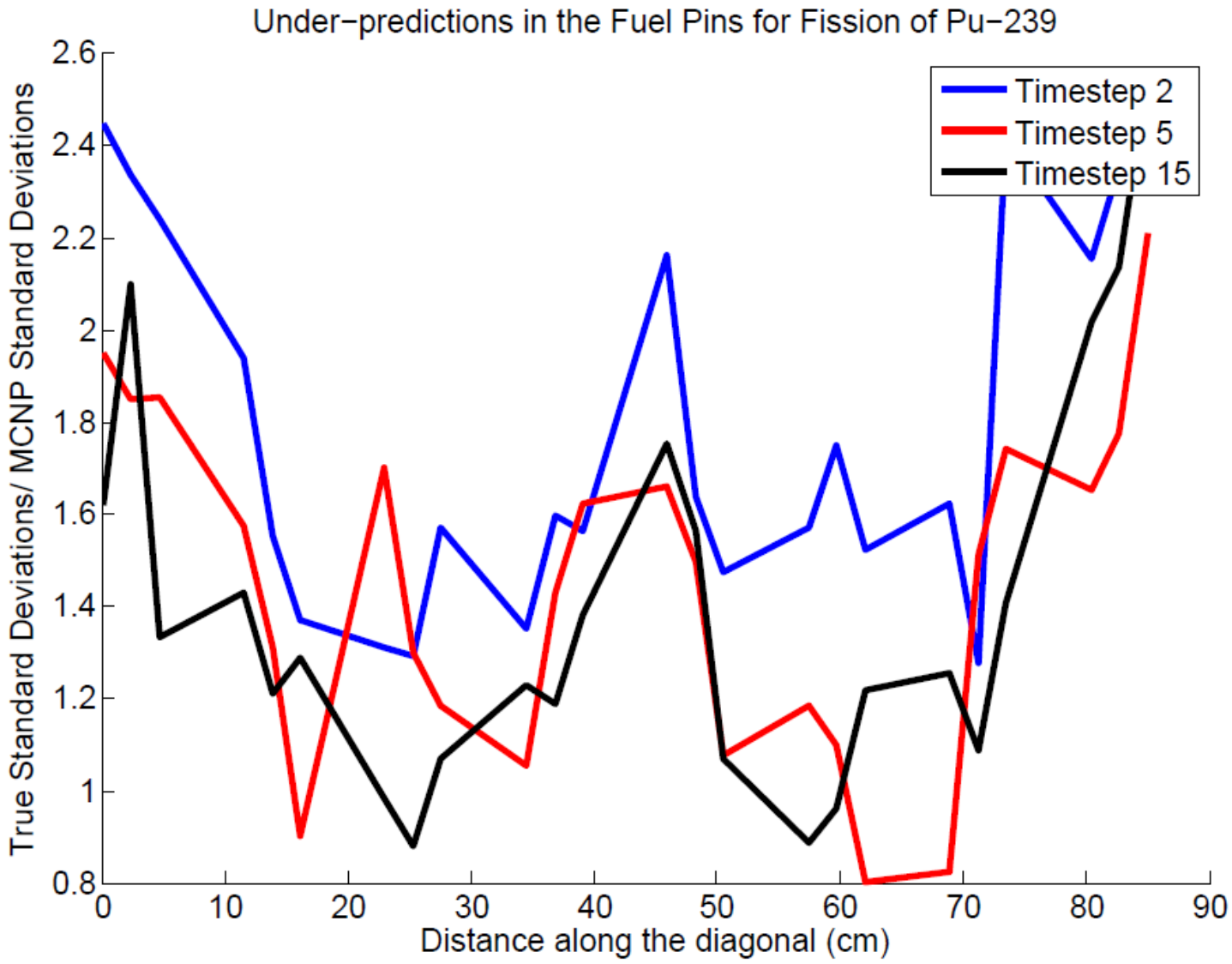
Gd-157 Capture Along Diagonal



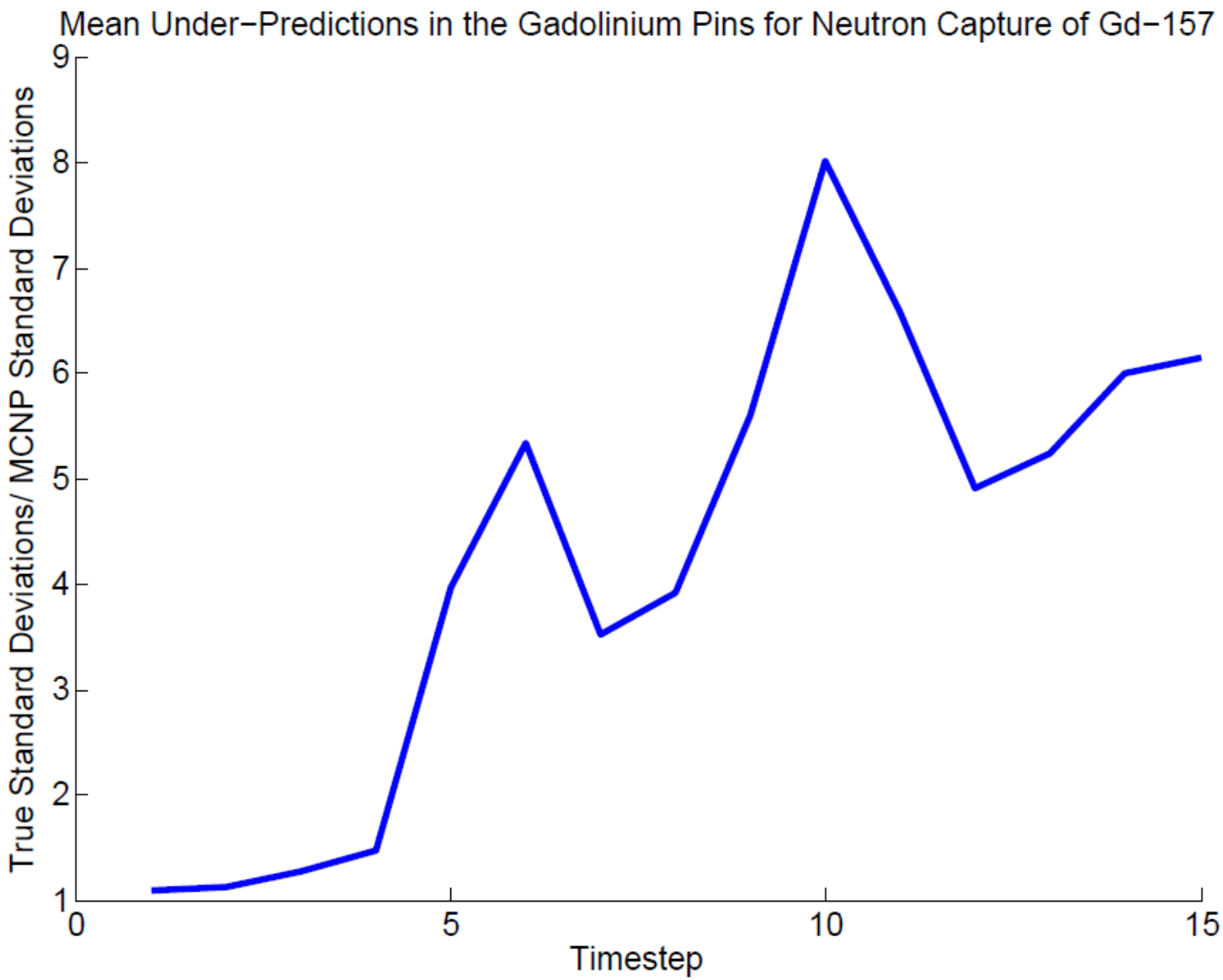
Pu-239 Fission Along Diagonal (Gd Pins)



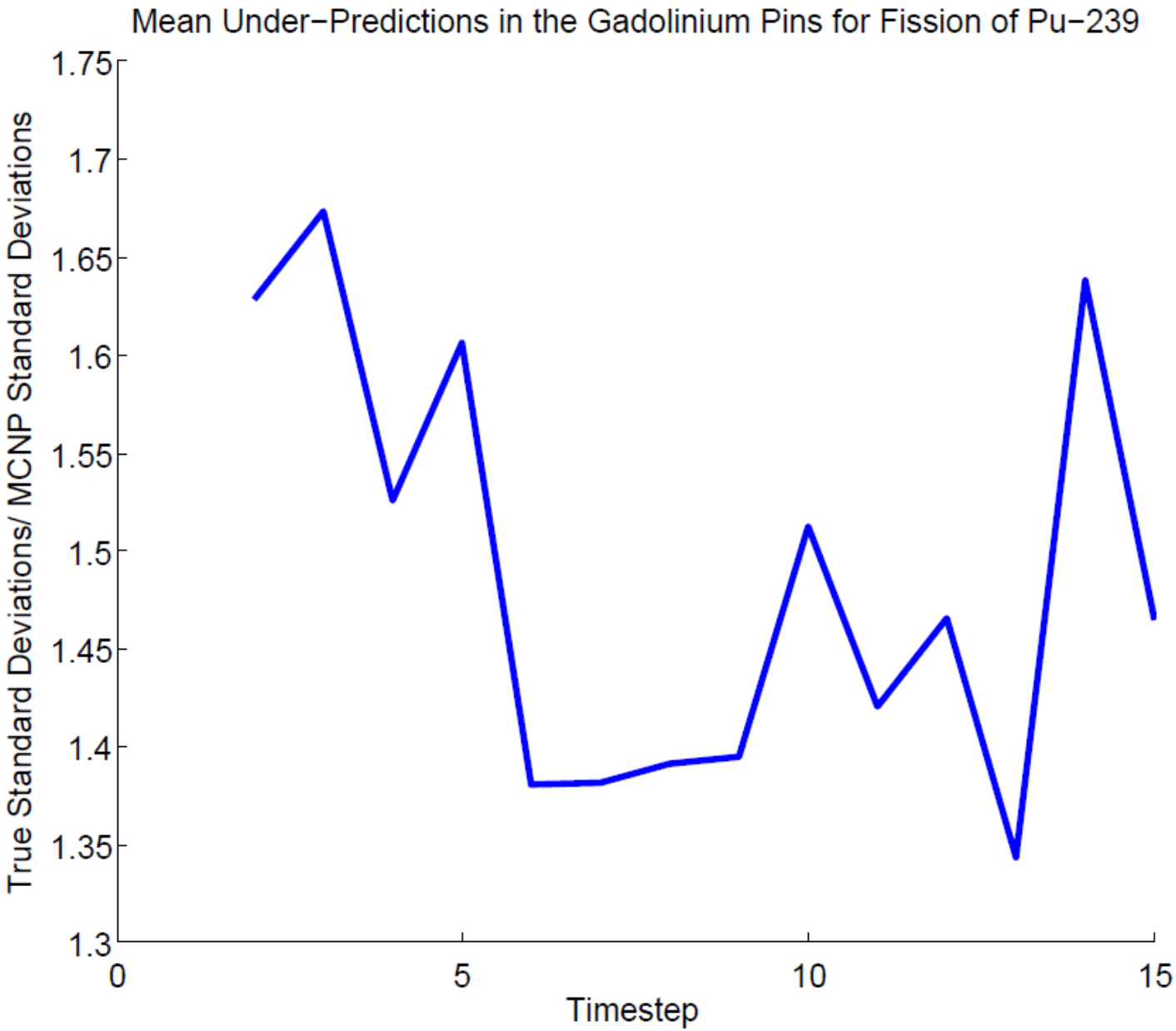
Pu-239 Fission Along Diagonal (Fuel Pins)



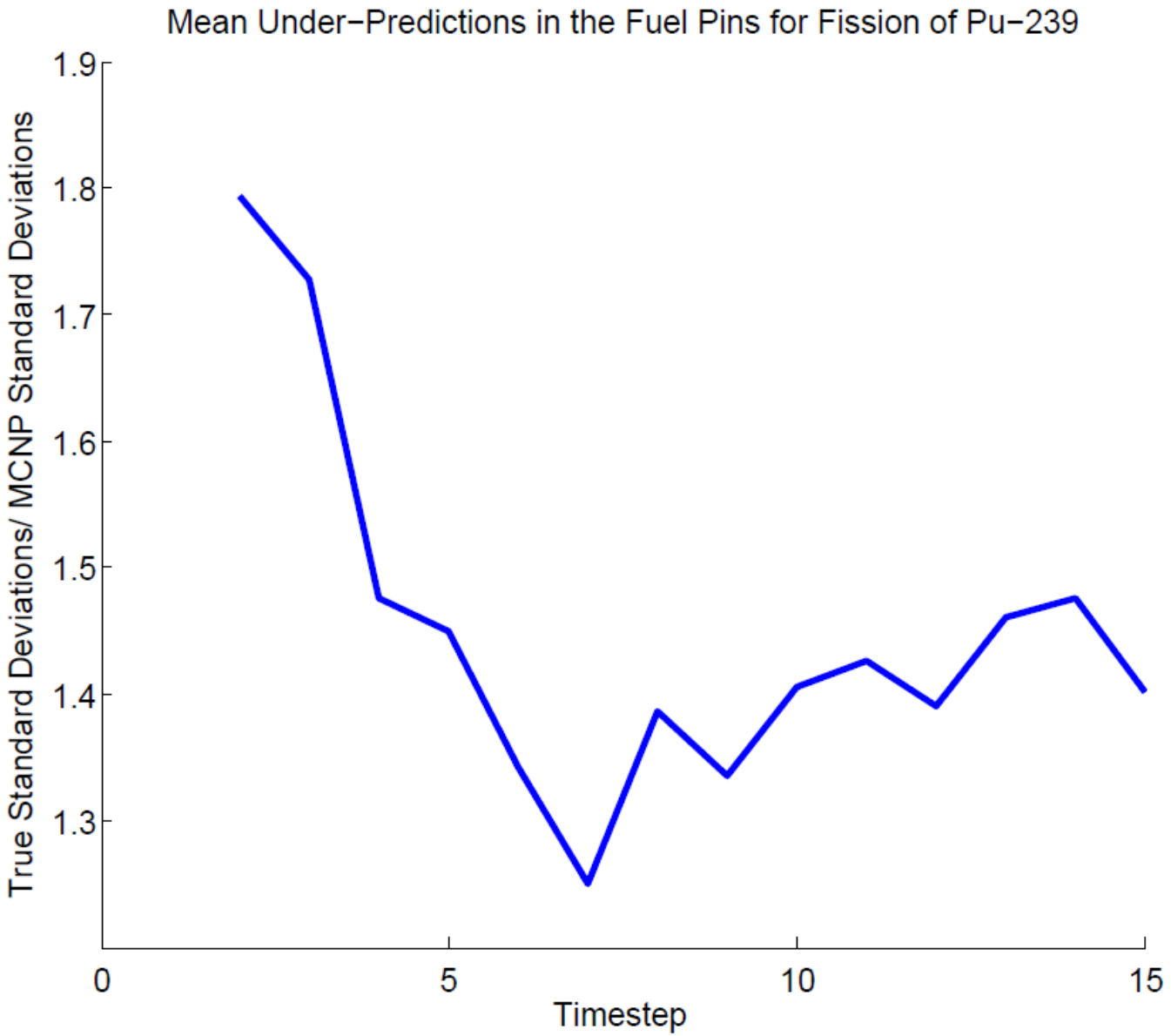
Gd-157 Capture with Time



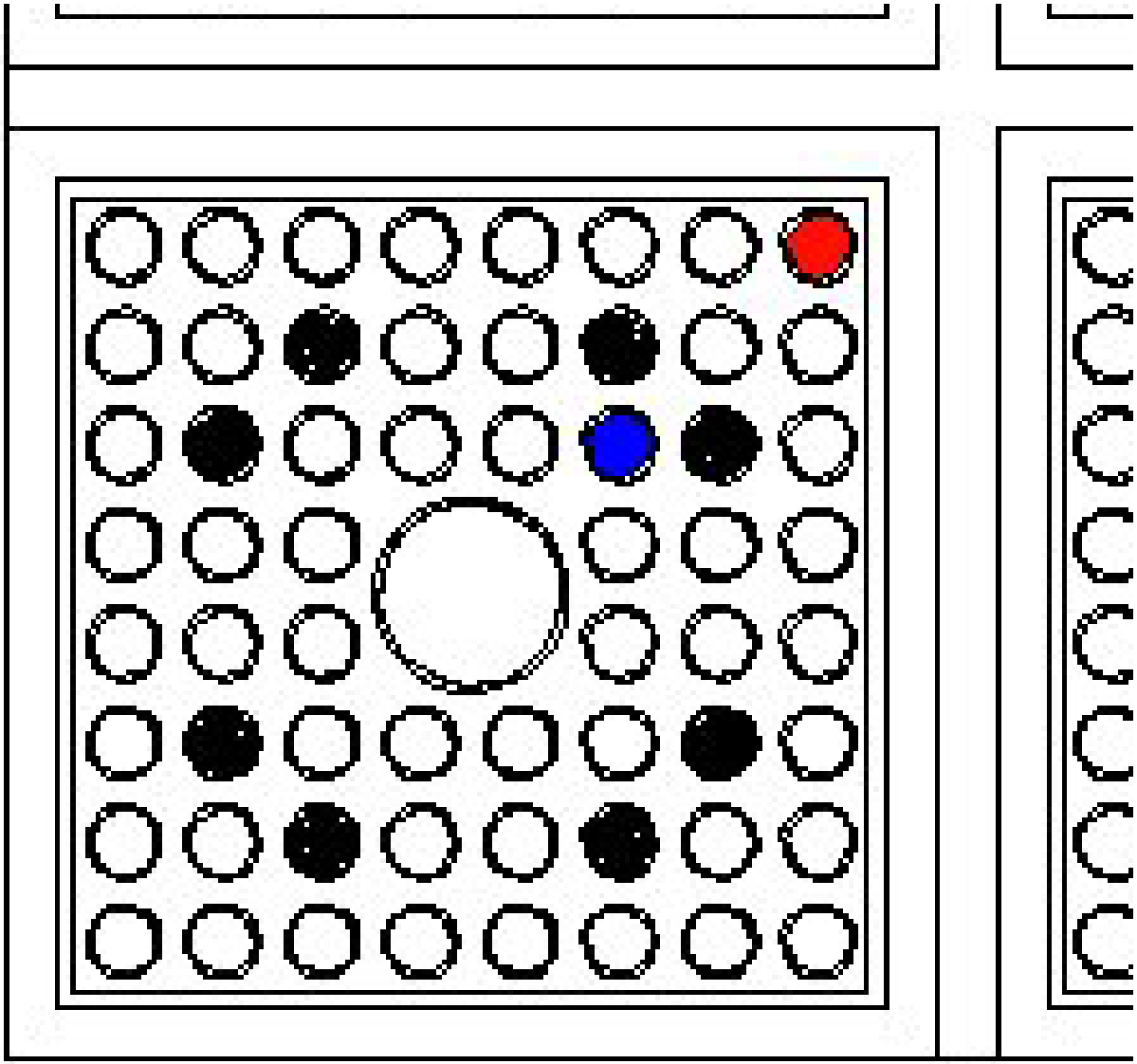
Pu-239 Fission (Gd Pins) with Time



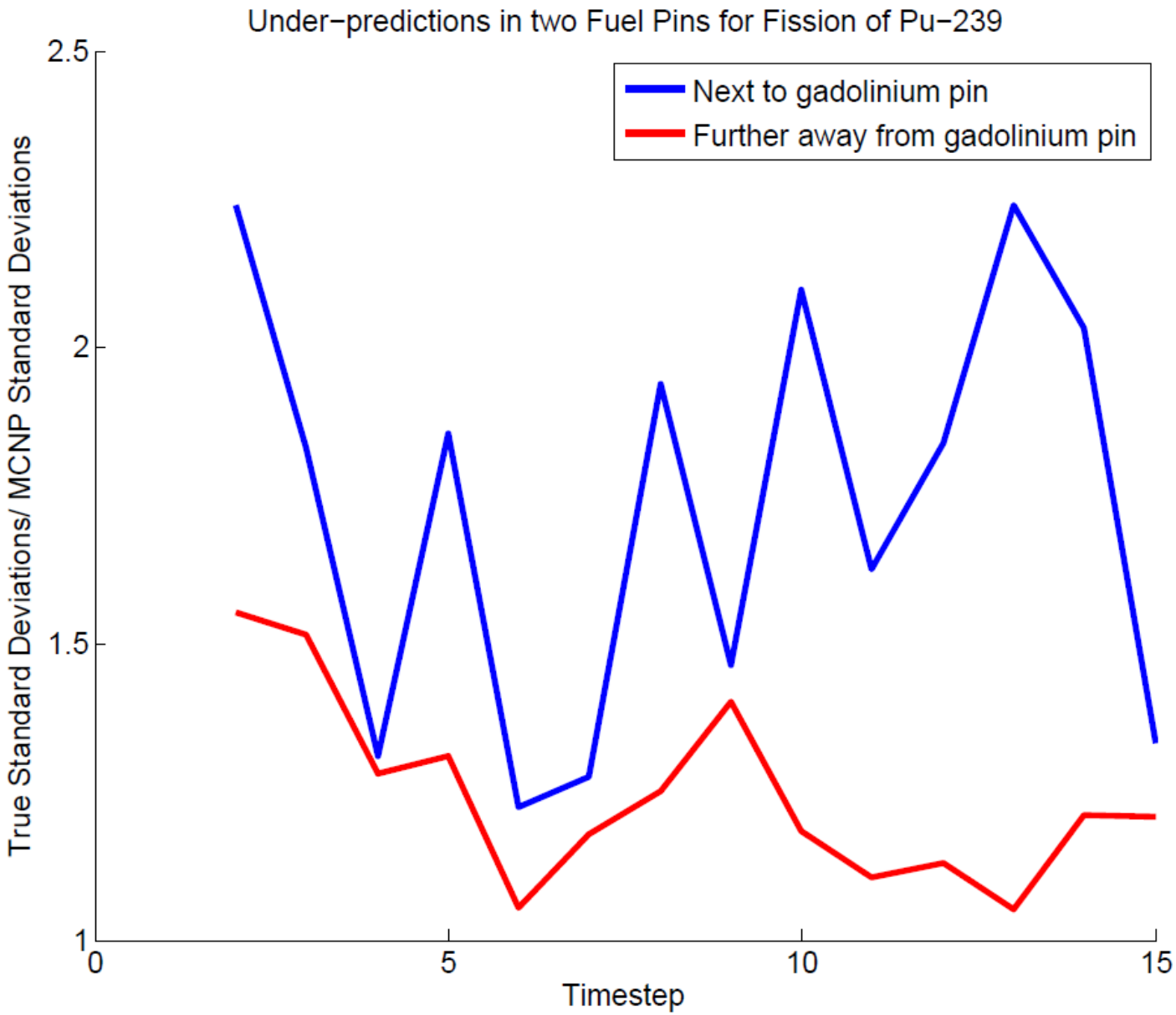
Pu-239 Fission (Fuel Pins) with Time



Uncertainty Under-prediction Results



Pu-239 Fission (2 pins) with Time



Uncertainty Under-Prediction Results

- **The uncertainty under-prediction of the Gd-157 capture tally increases with time.**
  - **It is under-predicted by a factor of about 8 for some tally locations.**

- **Under-prediction does not change much with time for the other tallies for this case.**

- **Tallies had greater under-prediction when they are located close to the gadolinium pins.**

Summary & Future Work

- **Conclusion**
  - **Bias did not have much of an effect on the results of this problem.**
  - **Results suggest that under-prediction of local tally uncertainties is greater near localized strong absorbers**
    - Especially for reactions involving those absorbers
- **Future Work**
  - **To try to see a greater effect from bias try with:**
    - Non symmetric problem
    - Larger problem

Questions?