Impact of Assembly-Specific Conditions on BWR BUC

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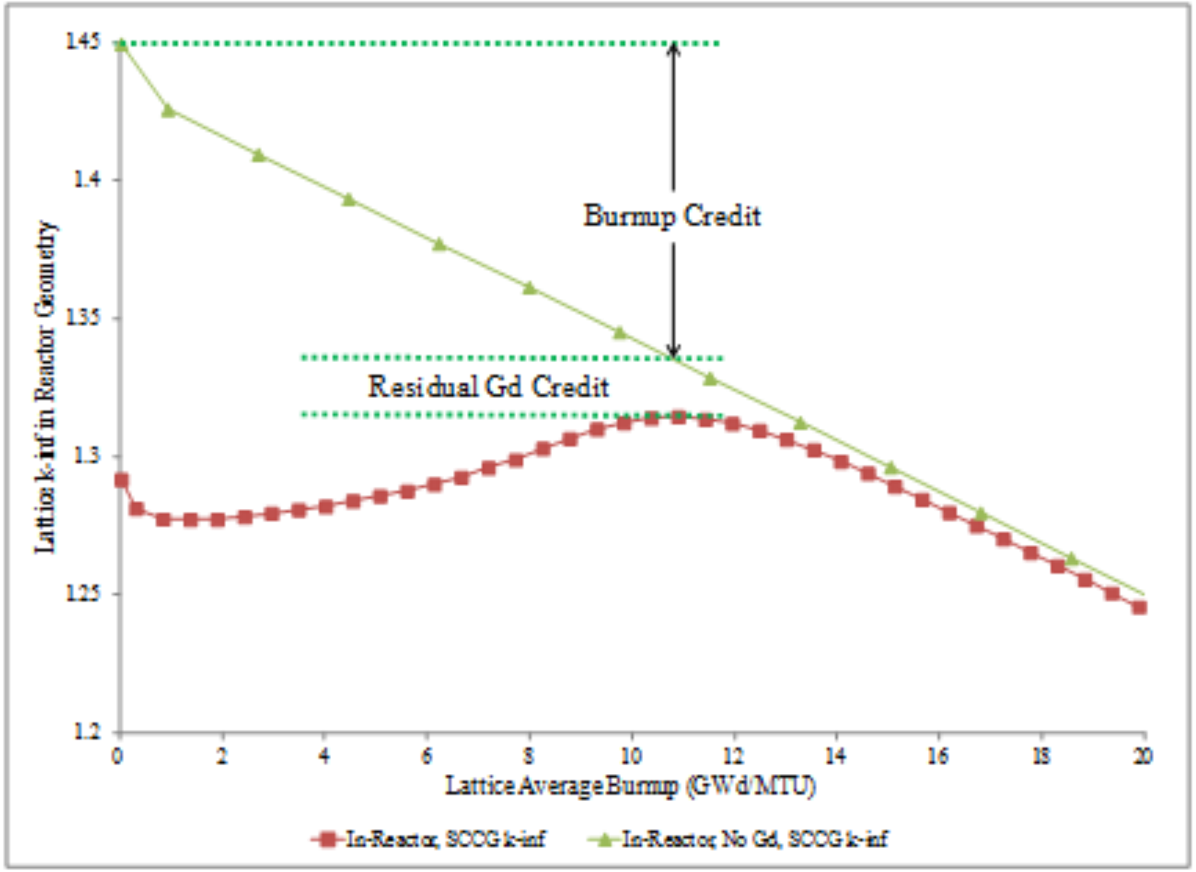
SCALE User's Forum

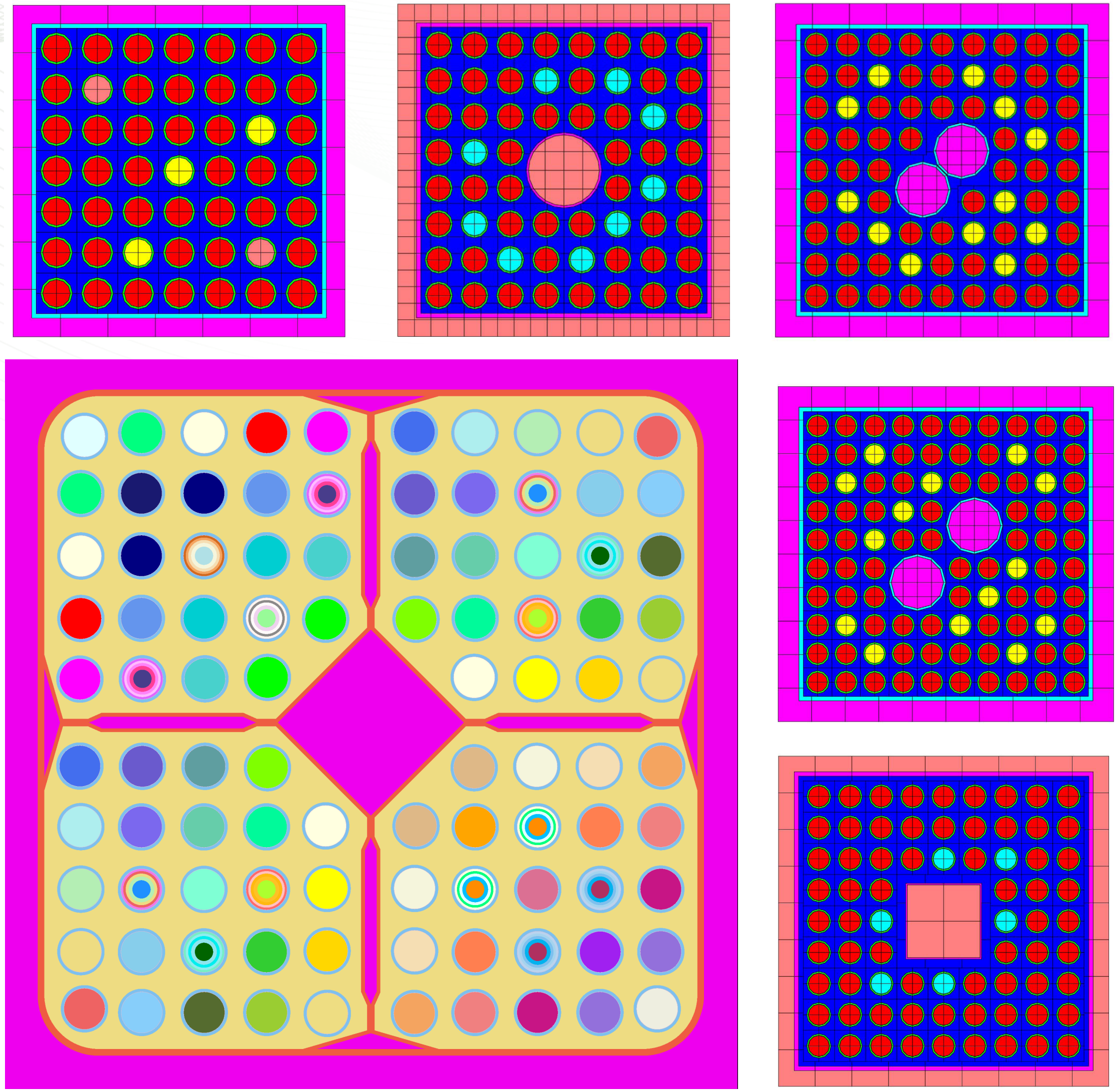
What is Burnup Credit and Why is it Needed?

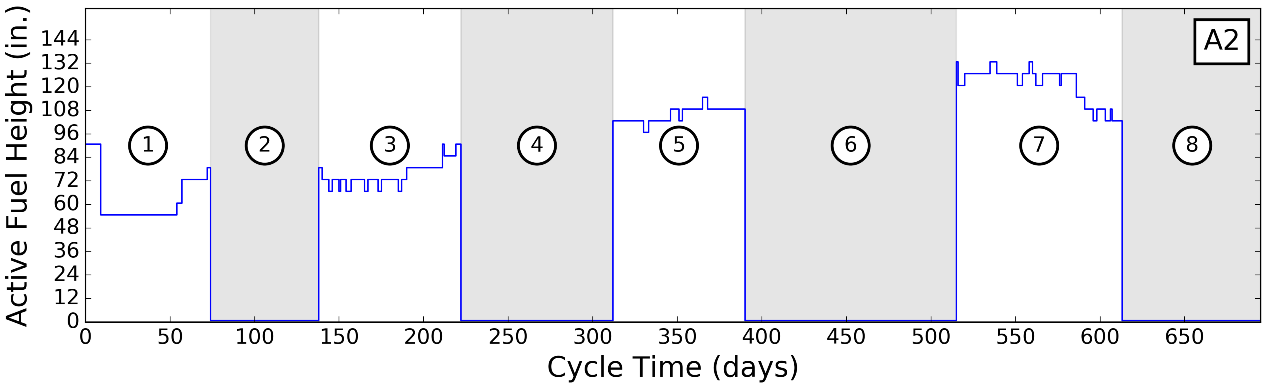
- Burnup credit – taking credit for the ***depletion*** of fuel and/or burnable absorbers after irradiation
- Burnable poison credit – taking credit for existence of burnable poisons in the fuel (fresh or depleted)
- Current assumption for storage and transportation of BWR fuel: fresh fuel without burnable absorber
  - Works for older fuel (lower enrichment), but not for modern BWR fuel
- Spent fuel pools are crowded and fuel needs to be moved to dry cask storage

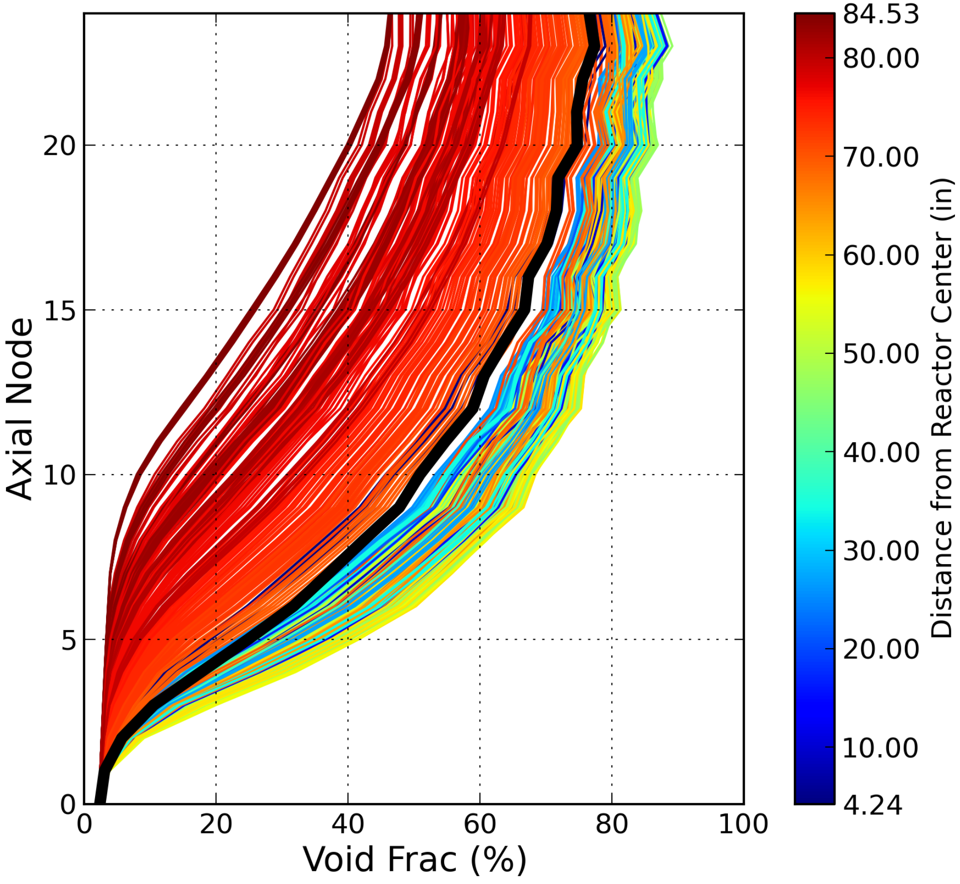


NUREG/CR-7194

BWRs are Complex…







Previous Work

- Numerous publications for PWR burnup credit
- **NUREG/CR-7157**: Computational Benchmark for BWR Burnup Credit
- **NUREG/CR-7158:** Review and Prioritization of Technical Issues Related to Burnup Credit for BWR Fuel
- **NUREG/CR-7194**: Peak Reactivity Burnup Credit for BWRs
- Extended Burnup Credit
    1. Axial void profiles
    2. Control blade use
    3. Axial burnup profiles

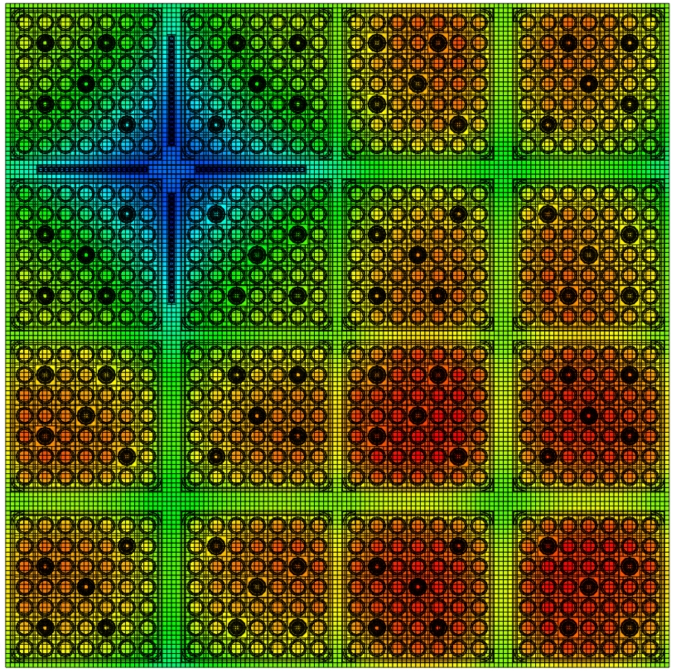
    NUREG/CR-7224

    4. Reactor operating conditions
    5. **Correlated/assembly-specific conditions**

    NUREG/CR in Process

Background

- Previous studies modify one parameter at a time to isolate the impact of that particular parameter
  - Limiting conditions are assumed for the parameters that are held constant
  - Not realistic, but allows determination of the most important parameters to cask reactivity and is likely limiting
- Previous studies indicate that the burnup profile, coolant density profile, and control blade history have the largest impacts on cask reactivity
- NUREG/CR-7158 identified that the correlation of various parameters should be studied for BWR burnup credit
  - Unlike current PWRs, BWRs contain control blades that are used during operation, leading to significant changes in operating parameters when the control blade is inserted

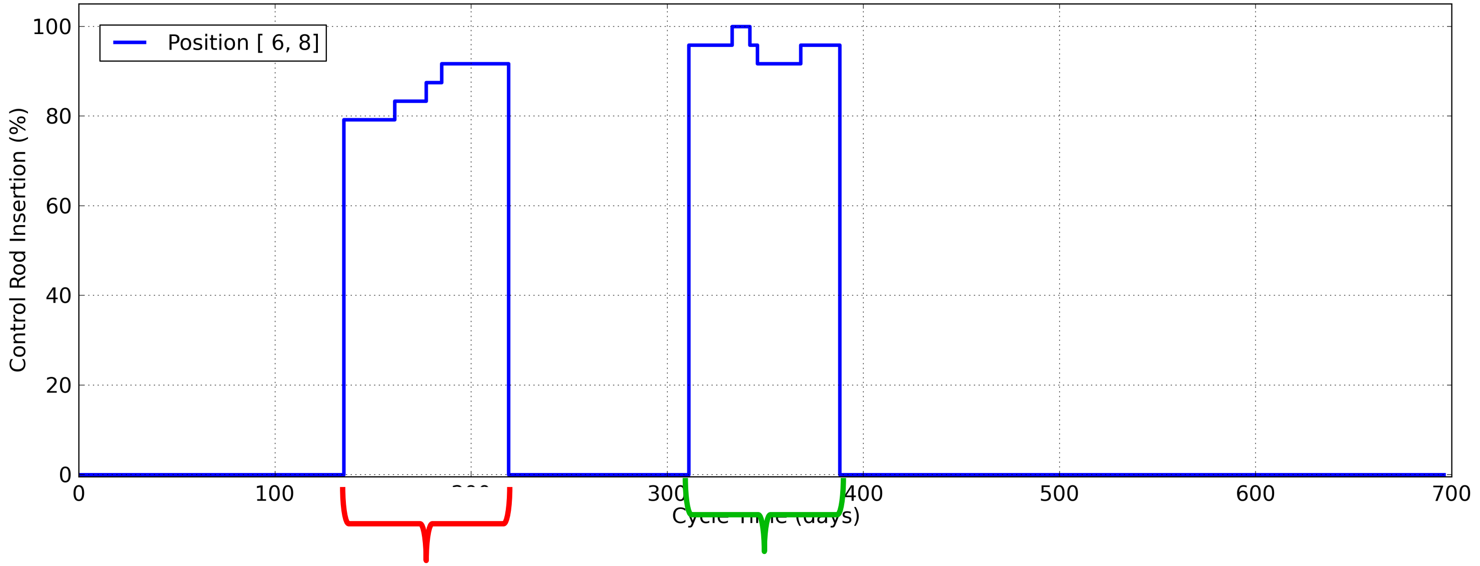


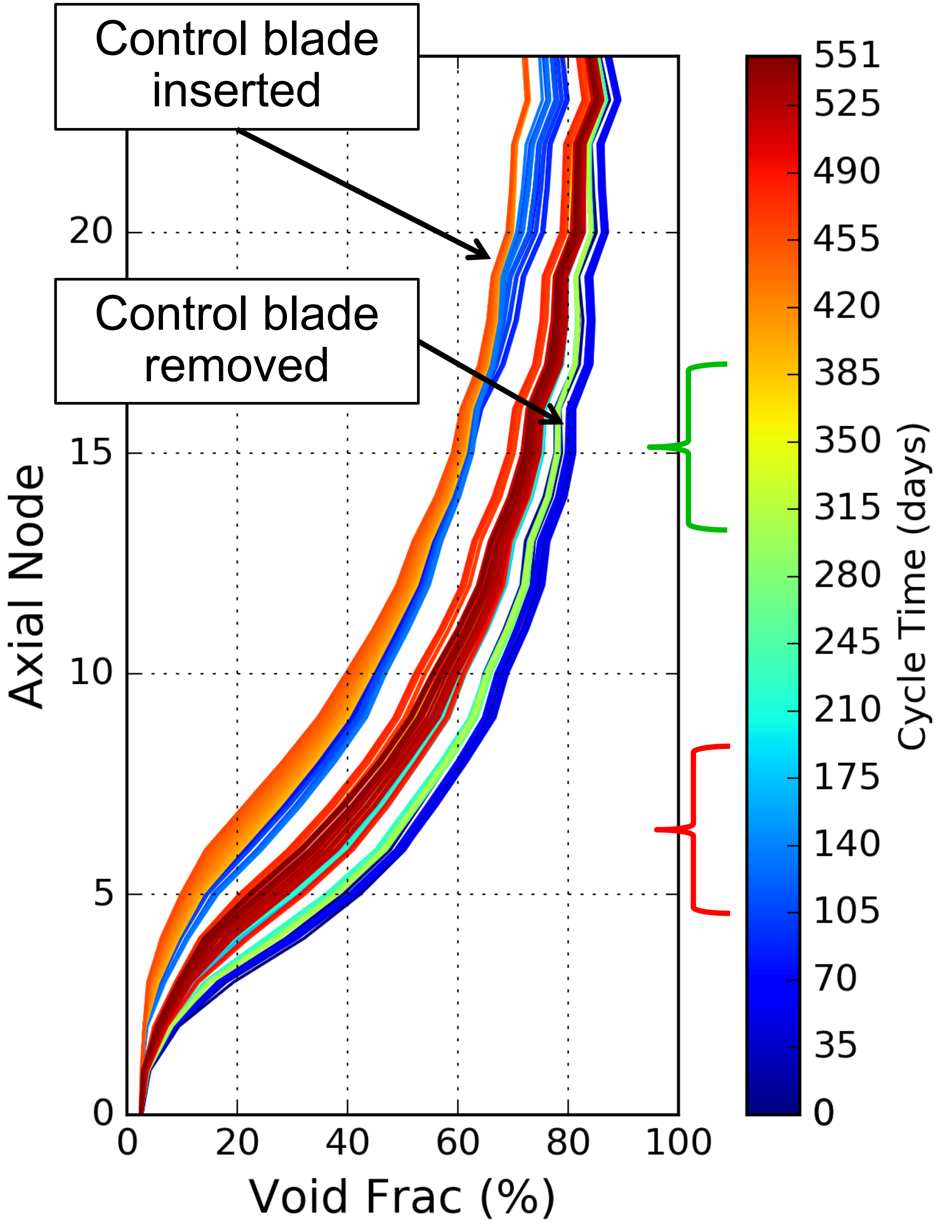
Correlated Parameters in BWRs

- Nearly all operating conditions are correlated with one another in some way
  - As gadolinium is depleted, the power for the assembly increases, leading to higher coolant void fraction
  - As bottom fuel (typically higher enriched) is depleted, the assembly power shifts toward the top of the fuel assembly
  - If the control blade is inserted, the power in the lower part of the assembly will decrease, coolant boiling will decrease, leading to increased power in the top of the assembly
- <u>The most significant parameter with which others are correlated is control blade insertion</u>
  - Results in a step change of various conditions
  - While control blade insertion ***increases*** cask reactivity, the changes to other conditions as a result of control blade insertion should ***decrease*** cask reactivity
- How do you get data that is correlated?
  - We know things are correlated, but there isn't a great way to tell, for example, how much void decreases with control blade insertion
  - Use conditions observed by a single fuel assembly in the core follow data

Example: Control Blade and Coolant Density Correlation

- Before the control blade is inserted, the void fraction is high due to high assembly power
- When the control blade is inserted, the assembly power and void fraction decreases instantaneously
- After the control blade is removed, the void fraction instantaneously jumps to a high value (low coolant density) as a result of increase in assembly power




Control blade inserted

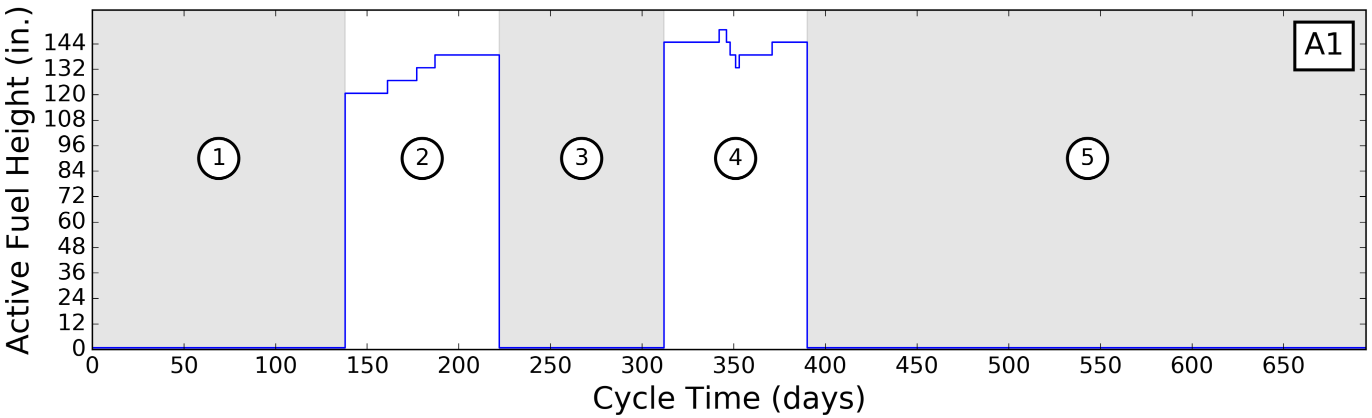
Control blade removed

Assembly-Specific Conditions Study

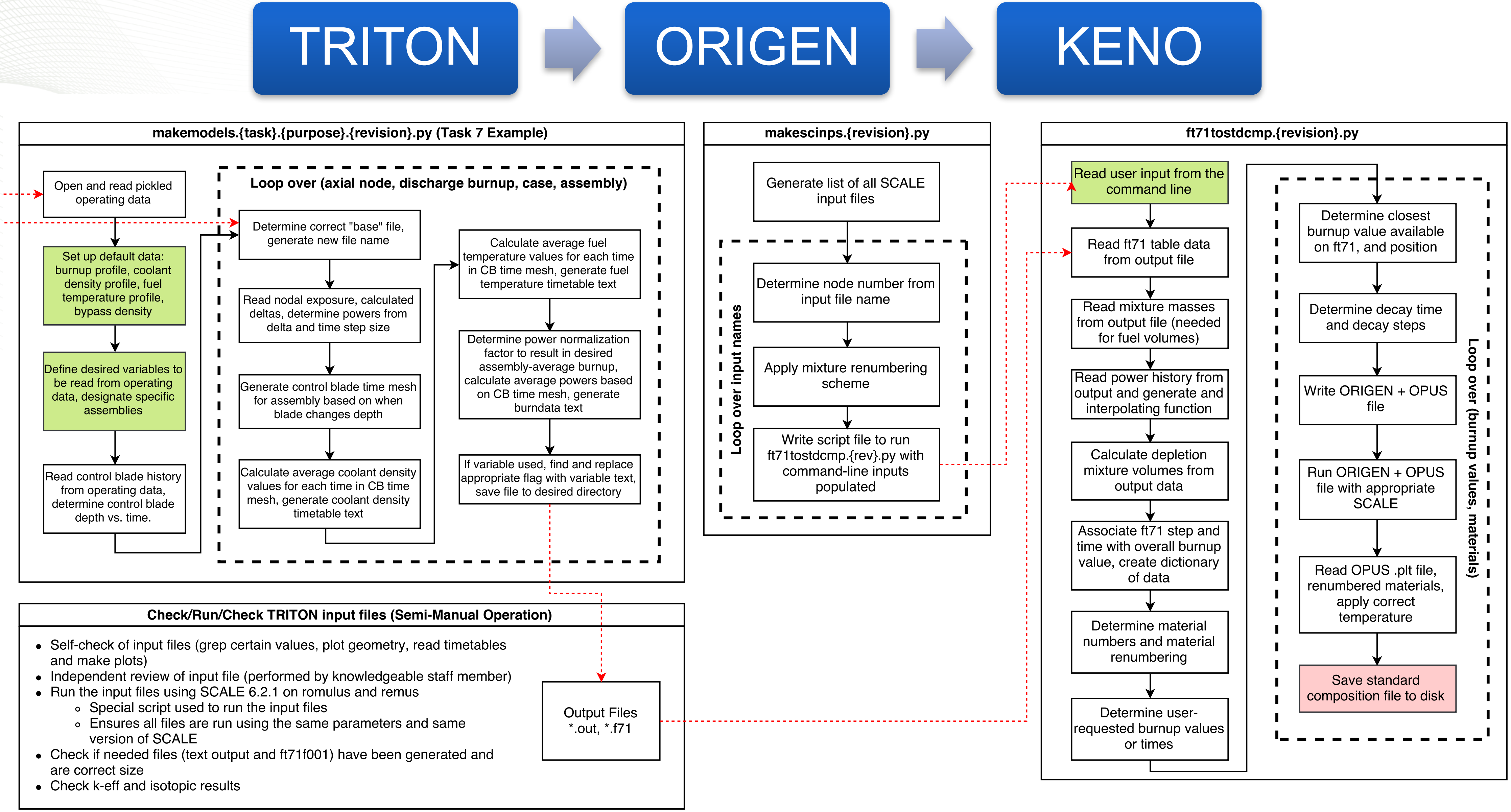
- Goals
  - Determine the level of conservatism built into using uncorrelated, but limiting assumptions for the coolant density, burnup profile, and control blade history
  - Confirm that reactivity impacts of conditions analyzed individually are similar to the reactivity impacts when conditions are correlated
- Methodology
  - Determine the conditions to model: (1) control blade insertion, (2) axial coolant density profile, (3) axial burnup profile (and power history), and (4) the axial fuel temperature
  - Determine baseline cask reactivity assuming limiting conditions for the four parameters of interest
  - Choose a number of assemblies from the operating data that may provide useful insight regarding the impact of assembly-specific conditions
  - Using the time-dependent operating data for those assemblies, substitute assembly-specific conditions for the base conditions to determine the impact on cask reactivity

Assembly-Specific Conditions Study, Cont.

- Models the same as previous studies: GE14 fuel assembly, GBC-68 fuel cask model
- SCALE/TRITON used for all depletion calculations, KENO-V.a used for all cask criticality calculations
- Two assembly-average discharge burnup values tested: 25 and 50 GWd/MTHM
  - Cycle time and power adjusted to yield same discharge burnup values for every case
  - Actual assembly burnups vary between 20 and 50 GWd/MTHM, depending on how many cycles the assembly has been present in the core
- Operating conditions are averaged over time for every interval in which the control blade position is constant
  - Assumption is that when the control blade position is constant, the operating conditions are fairly constant as well
  - The change in control blade position may result in a large enough change in another condition that warrants a separate depletion step and update of conditions



BWR Burnup Credit With SCALE; It's Complicated…



TRITON → ORIGEN → KENO

makemodels.{task}.{purpose}.{revision}.py (Task 7 Example)

Open and read pickled operating data

Set up default data: burnup profile, coolant density profile, fuel temperature profile, bypass density

Define desired variables to be read from operating data, designate specific assemblies

Read control blade history from operating data, determine control blade depth vs. time.

Loop over (axial node, discharge burnup, case, assembly)

Determine correct "base" file, generate new file name

Read nodal exposure, calculated deltas, determine powers from delta and time step size

Generate control blade time mesh for assembly based on when blade changes depth

Calculate average coolant density values for each time in CB time mesh, generate coolant density timetable text

Calculate average fuel temperature values for each time in CB time mesh, generate fuel temperature timetable text

Determine power normalization factor to result in desired assembly-average burnup, calculate average powers based on CB time mesh, generate burndata text

If variable used, find and replace appropriate flag with variable text, save file to desired directory

makescinps.{revision}.py

Generate list of all SCALE input files

Loop over input names

Determine node number from input file name

Apply mixture renumbering scheme

Write script file to run ft71tostdcmp.{rev}.py with command-line inputs populated

ft71tostdcmp.{revision}.py

Read user input from the command line

Read ft71 table data from output file

Read mixture masses from output file (needed for fuel volumes)

Read power history from output and generate and interpolating function

Calculate depletion mixture volumes from output data

Associate ft71 step and time with overall burnup value, create dictionary of data

Determine material numbers and material renumbering

Determine user-requested burnup values or times

Loop over (burnup values, materials)

Determine closest burnup value available on ft71, and position

Determine decay time and decay steps

Write ORIGEN + OPUS file

Run ORIGEN + OPUS file with appropriate SCALE

Read OPUS .plt file, renumbered materials, apply correct temperature

Save standard composition file to disk

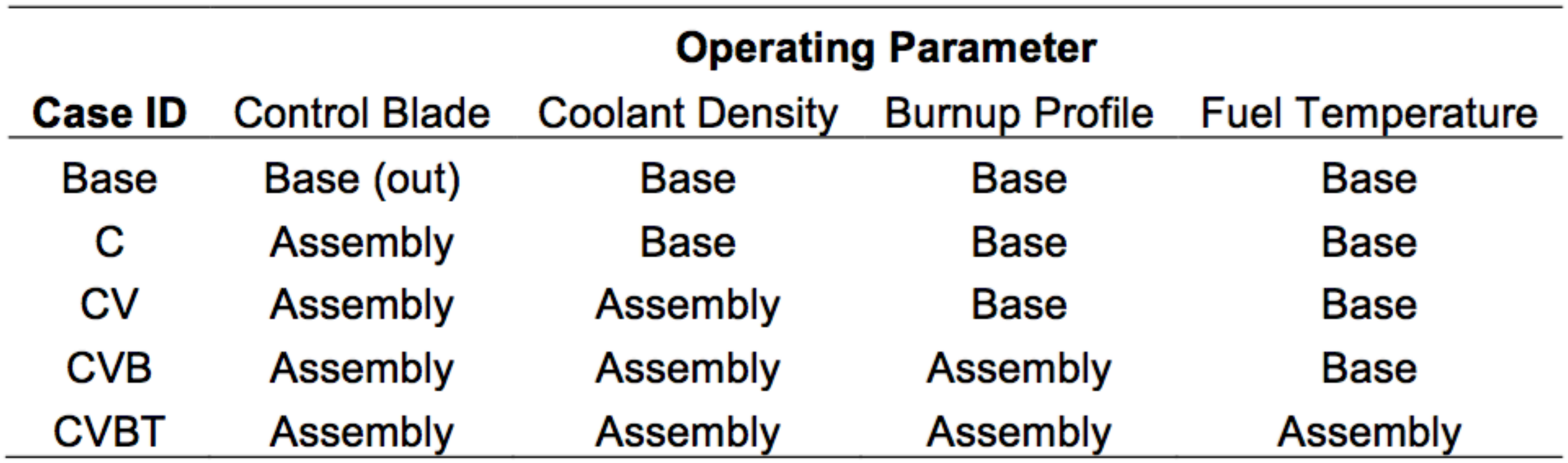
Check/Run/Check TRITON input files (Semi-Manual Operation)

- Self-check of input files (grep certain values, plot geometry, read timetables and make plots)
- Independent review of input file (performed by knowledgeable staff member)
- Run the input files using SCALE 6.2.1 on romulus and remus
  - Special script used to run the input files
  - Ensures all files are run using the same parameters and same version of SCALE
- Check if needed files (text output and ft71f001) have been generated and are correct size
- Check k-eff and isotopic results

Output Files
*.out, *.f71

Assembly-Specific Conditions Study, Cont.

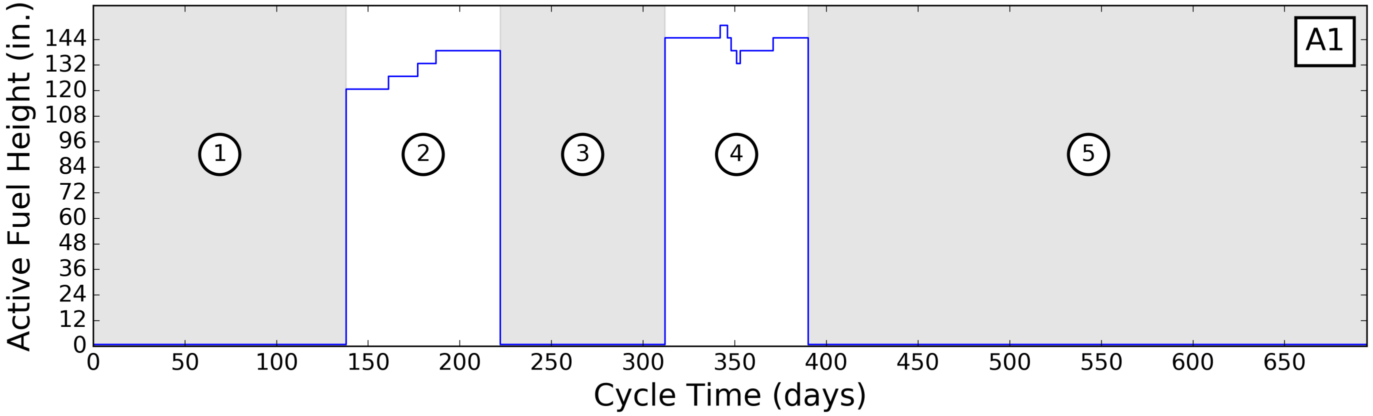
- Five separate calculations for each assembly
  - Base: base conditions for all parameters of interest
  - **C**: assembly-specific control blade history, base conditions for others
  - **CV**: assembly-specific control blade history and coolant density (void fraction), base conditions for others
  - **CVB**: assembly-specific control blade history, coolant density, and burnup profile, base conditions for fuel temperature
  - **CVBT**: assembly-specific control blade history, coolant density, and burnup profile, and fuel temperature

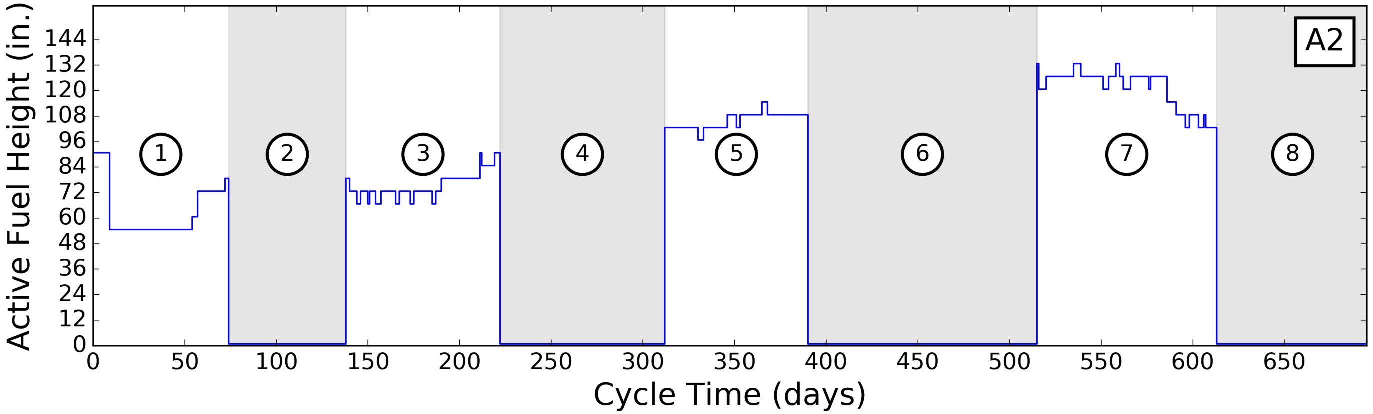


	Operating Parameter			
Case ID	Control Blade	Coolant Density	Burnup Profile	Fuel Temperature
Base	Base (out)	Base	Base	Base
C	Assembly	Base	Base	Base
CV	Assembly	Assembly	Base	Base
CVB	Assembly	Assembly	Assembly	Base
CVBT	Assembly	Assembly	Assembly	Assembly

Chosen Fuel Assemblies

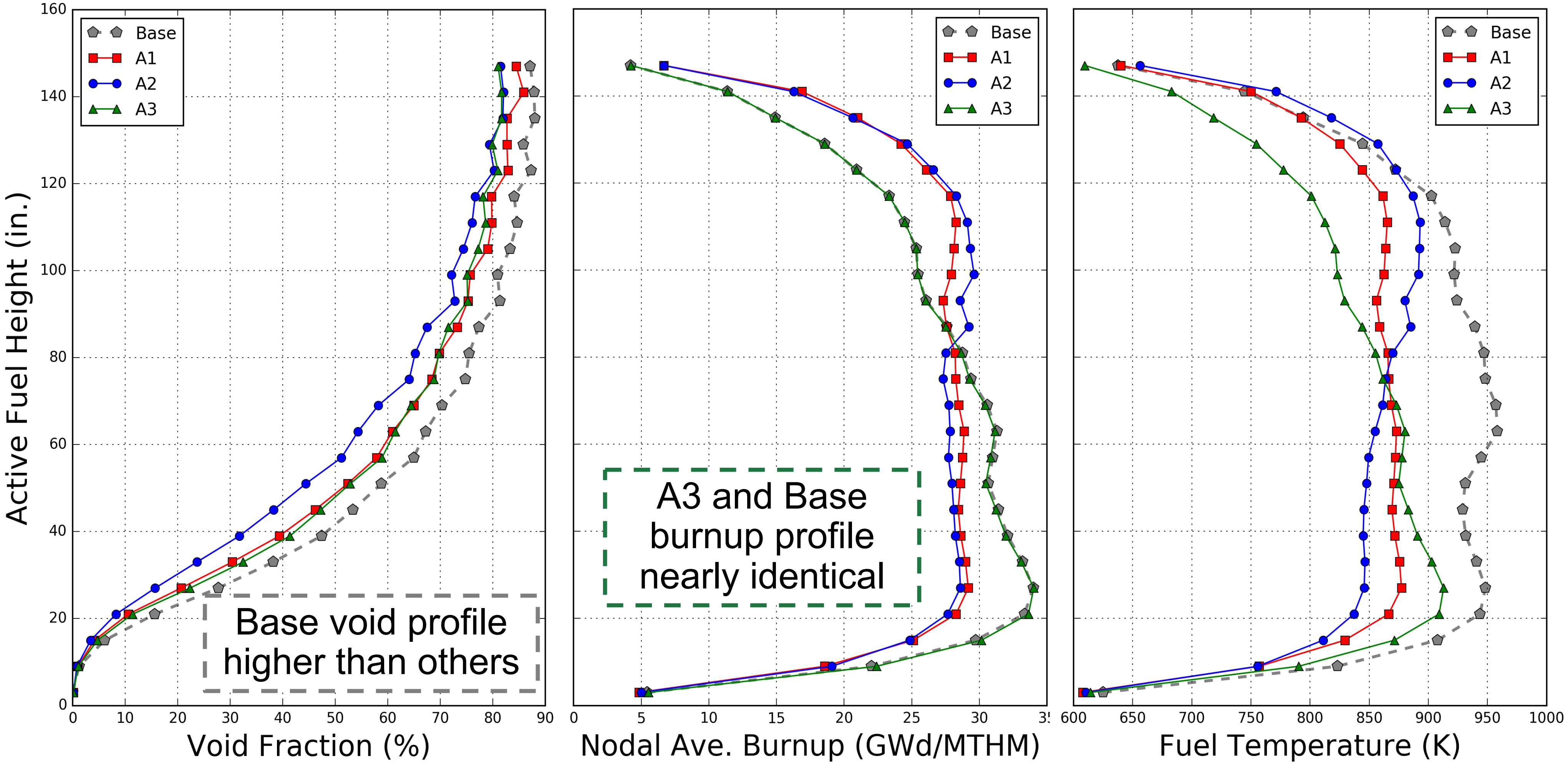
- **Assembly 1 (A1)** chosen because it was the most limiting control blade history in NUREG/CR-7224
- **Assembly 2 (A2)** chosen because it had the most irradiation time where the control blade was inserted
- **Assembly 3 (A3)** chosen as a control; A3 contains no control blade insertion, but it resulted in one of the most limiting burnup profiles identified in NUREG/CR-7224





Base Conditions vs. Assembly-Specific Conditions

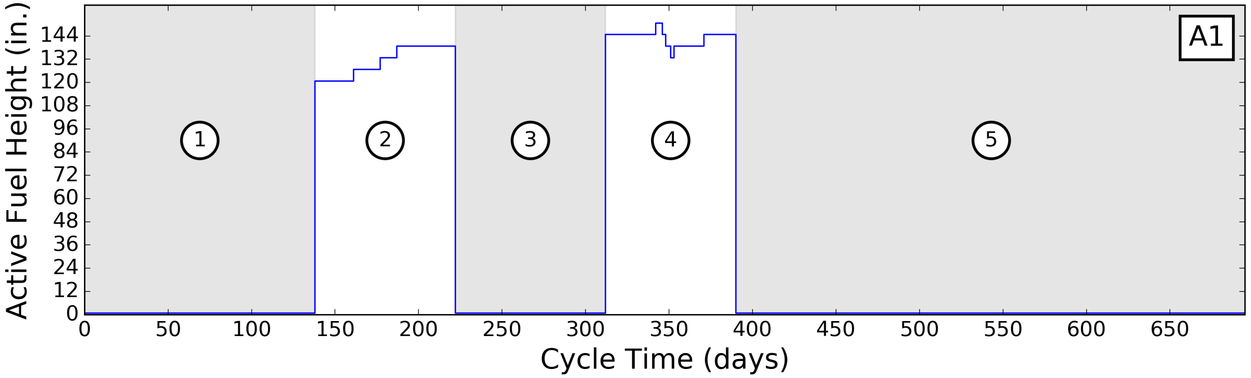
Cycle-Averaged Base and Assembly-Specific Conditions

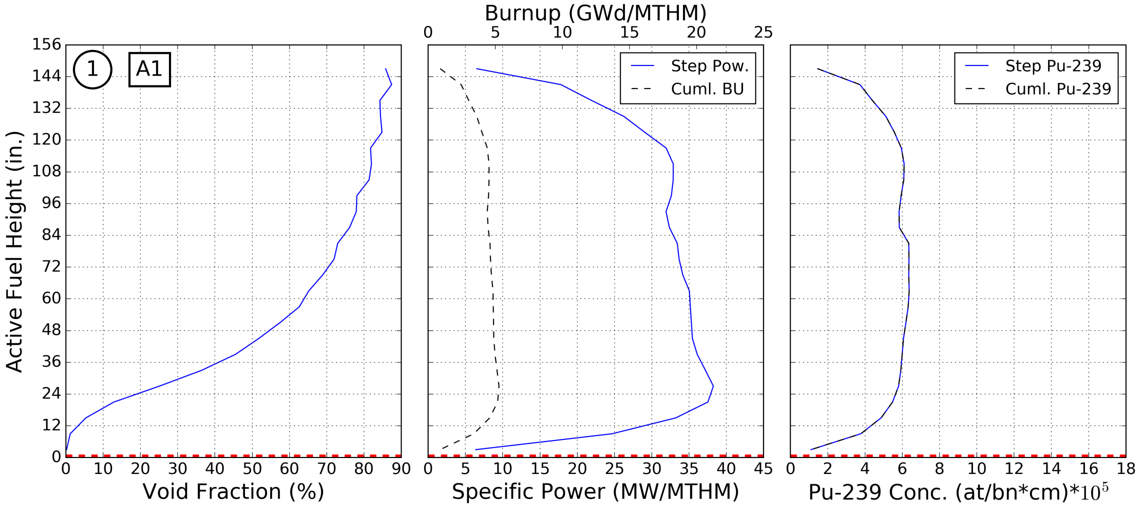


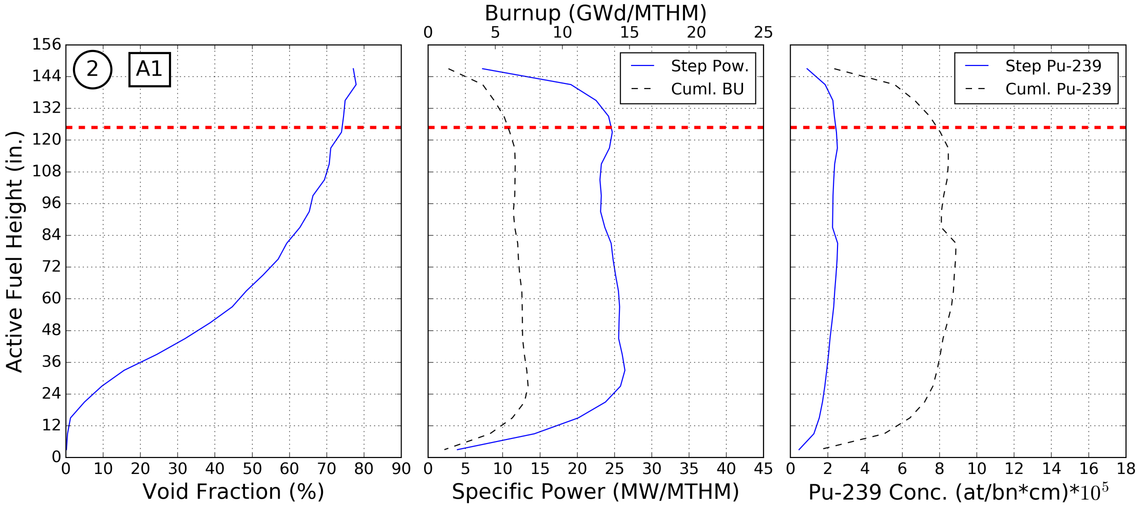
Base void profile higher than others

A3 and Base burnup profile nearly identical

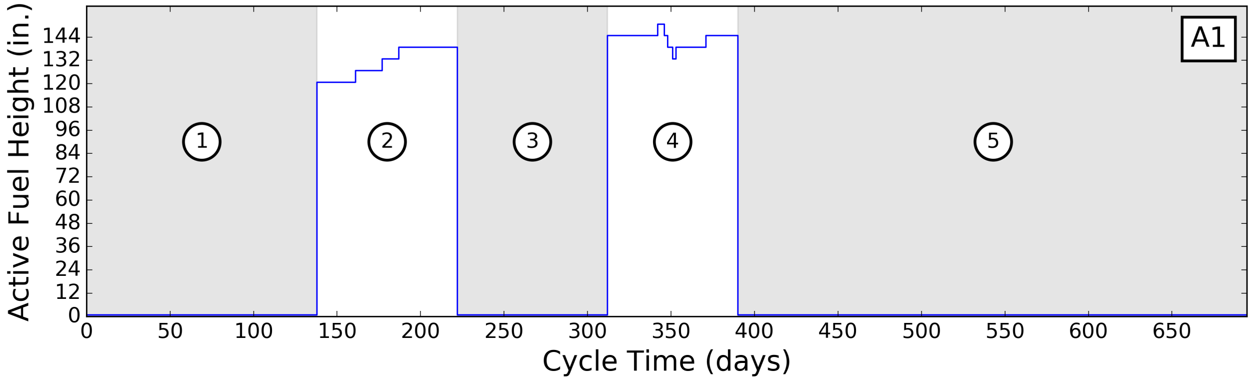
Assembly-Specific Results

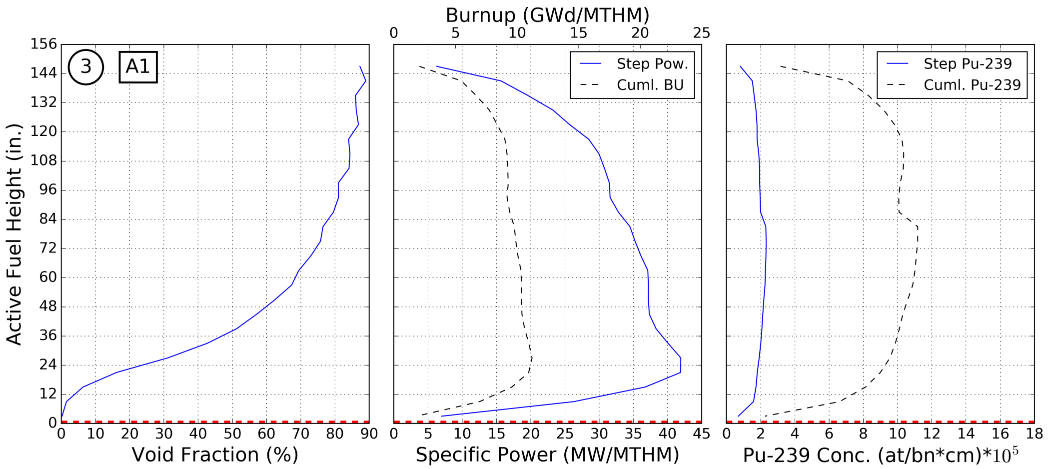


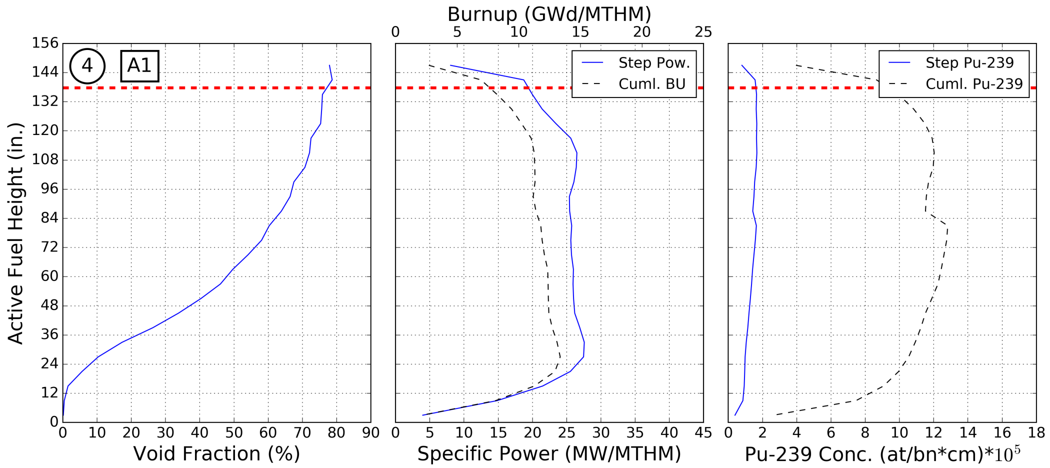


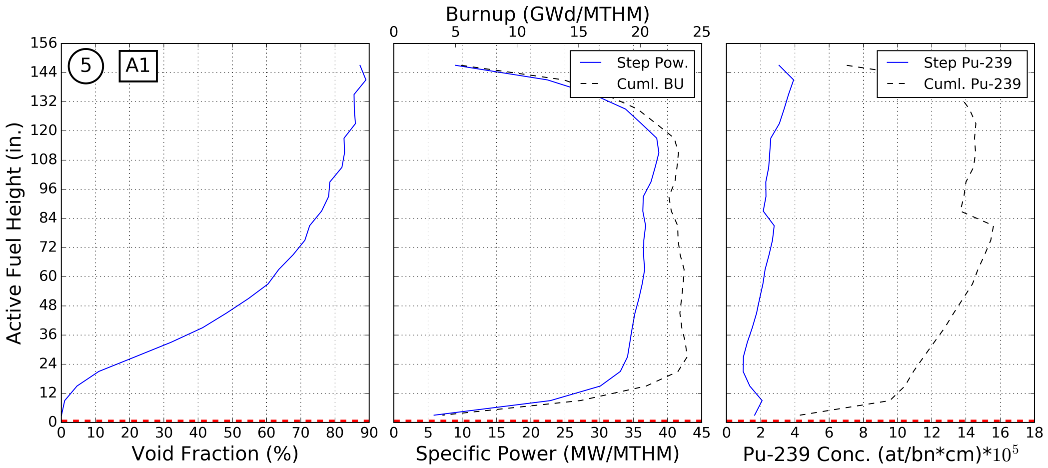


Assembly-Specific Results

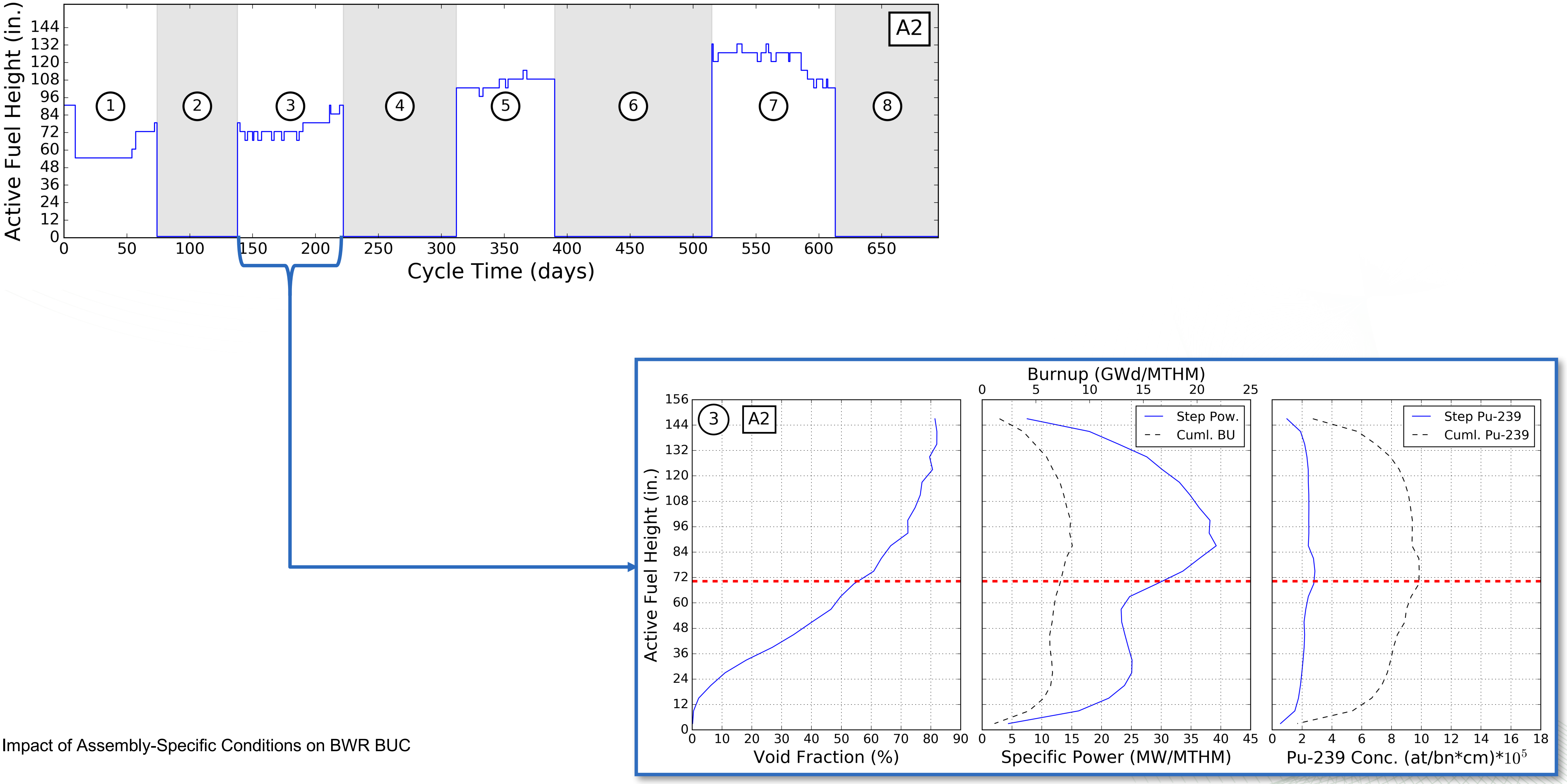




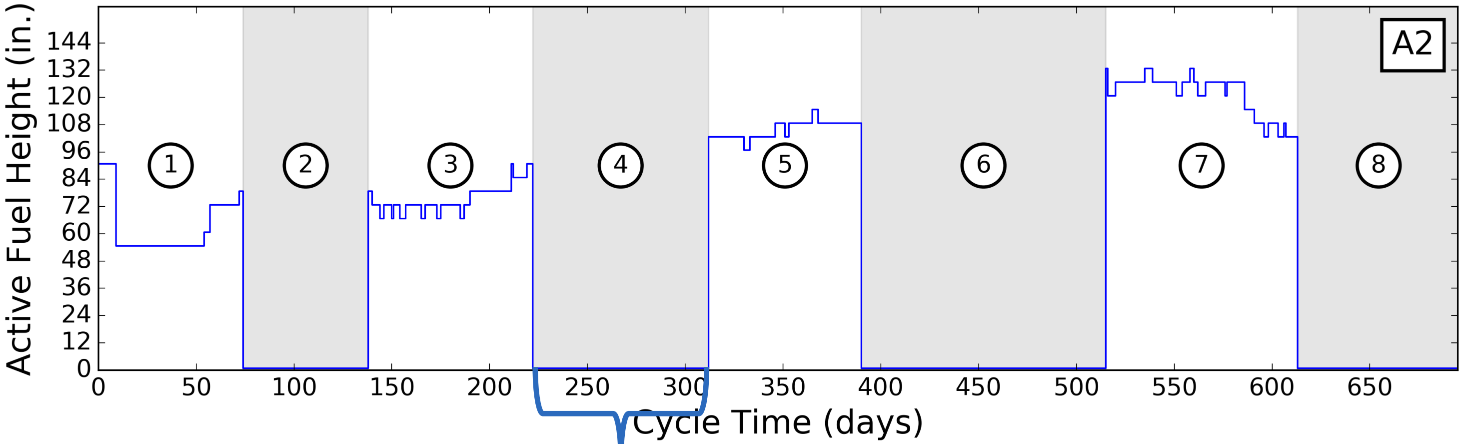




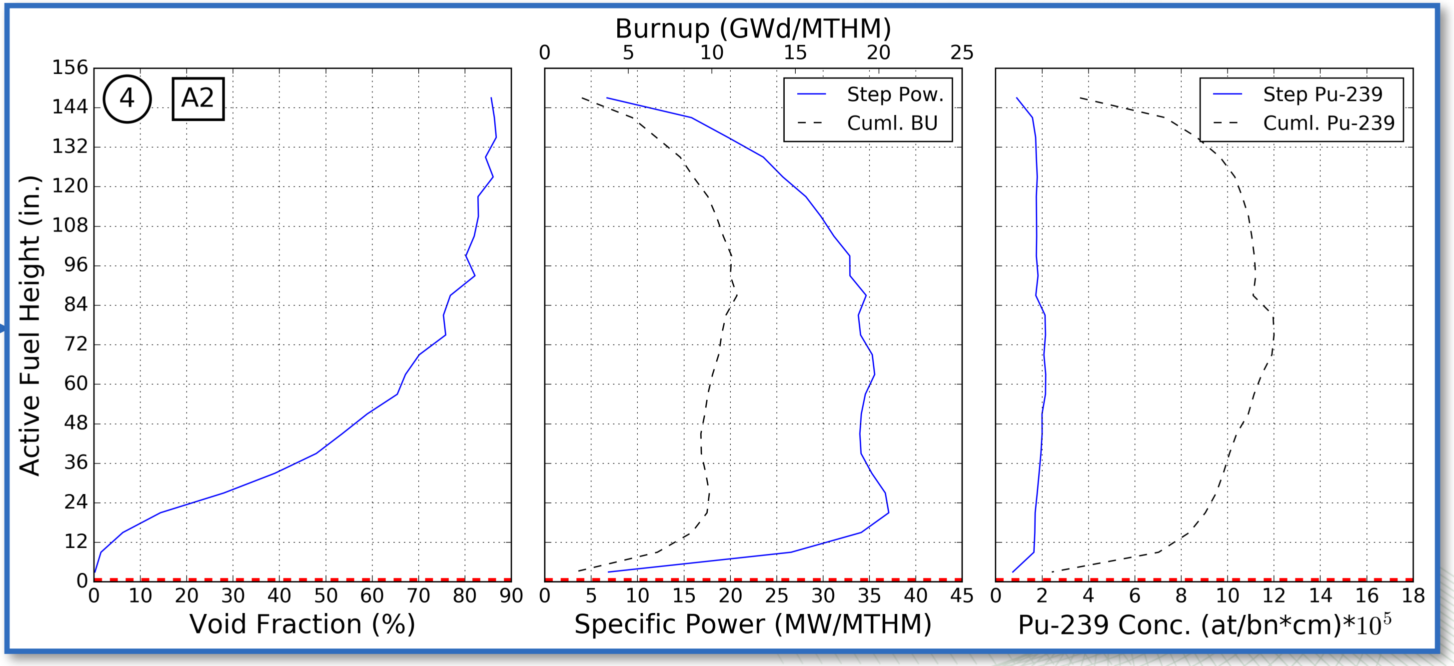
Assembly-Specific Results (A2)



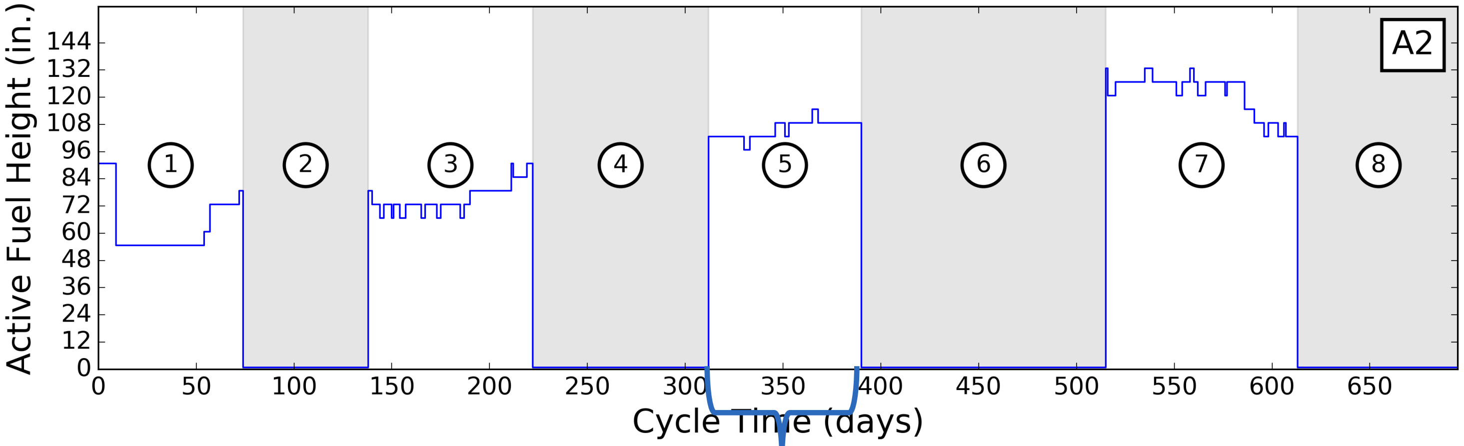
Assembly-Specific Results (A2)



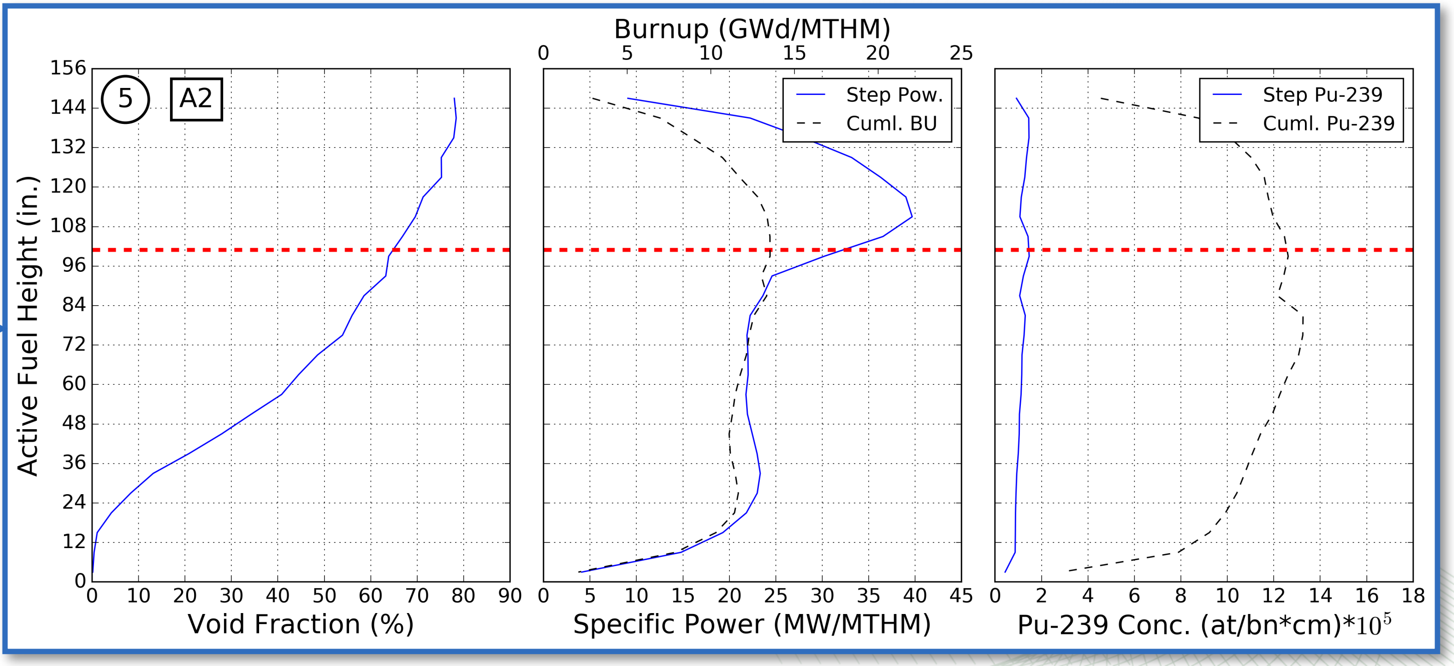
<u>If the control blade is OUT, power distribution follows a fairly typical shape</u>



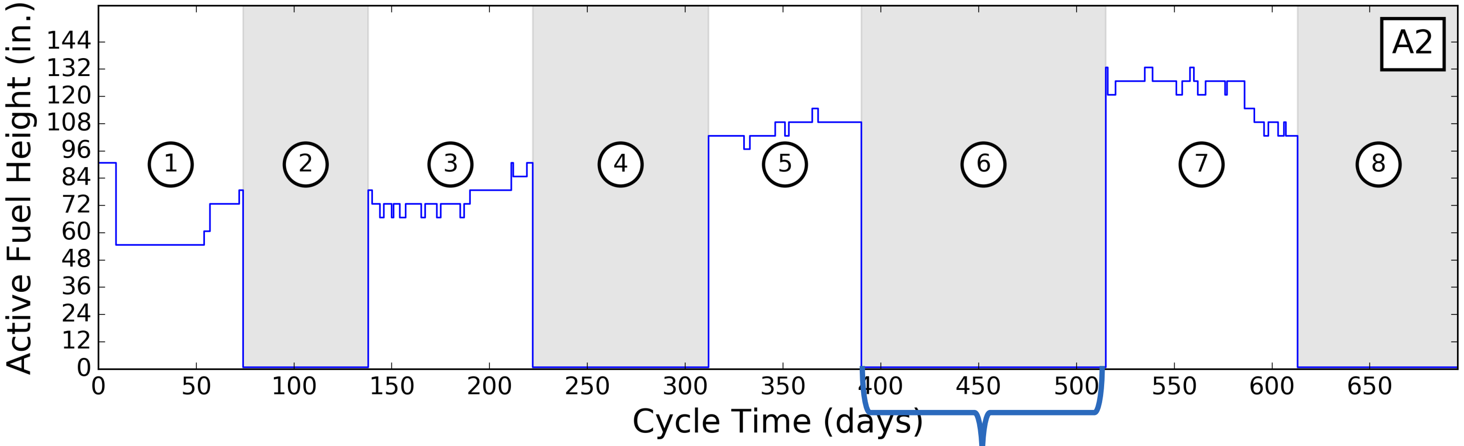
Assembly-Specific Results (A2)

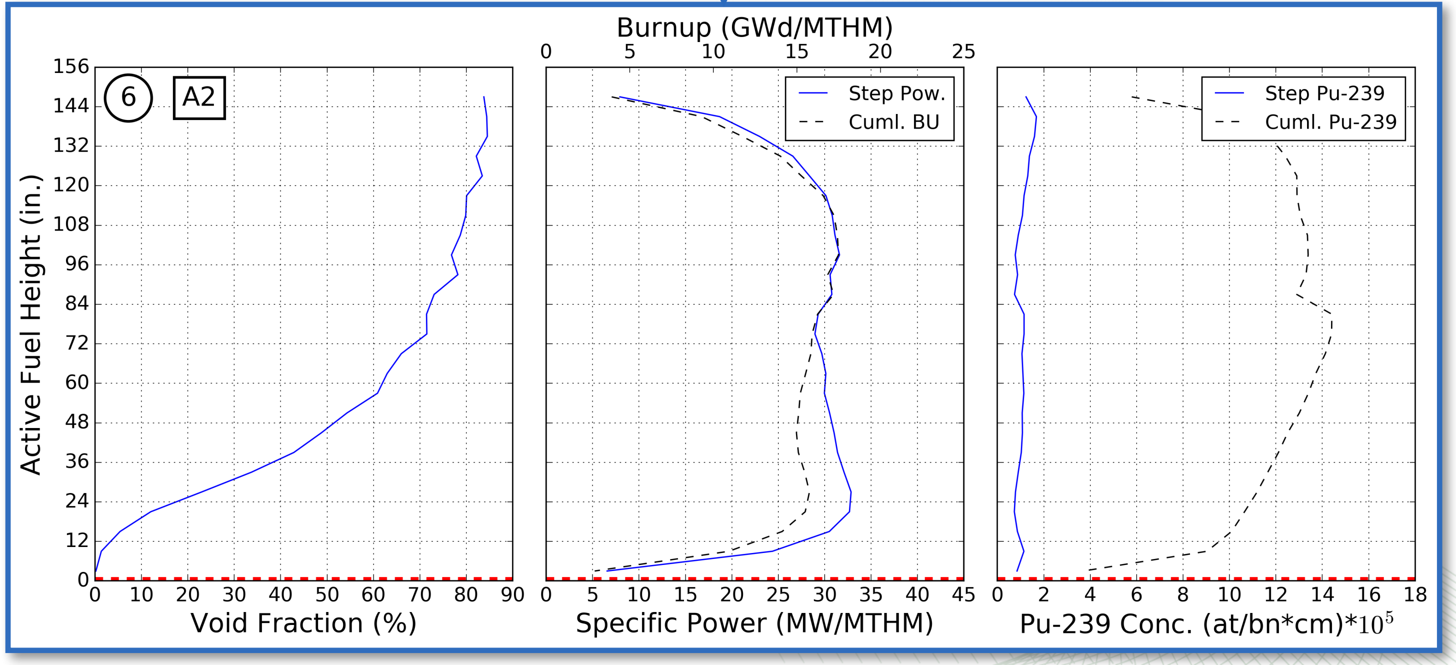


<u>If the control blade is IN, power distribution become very top-peaked and coolant void fraction decreases</u>

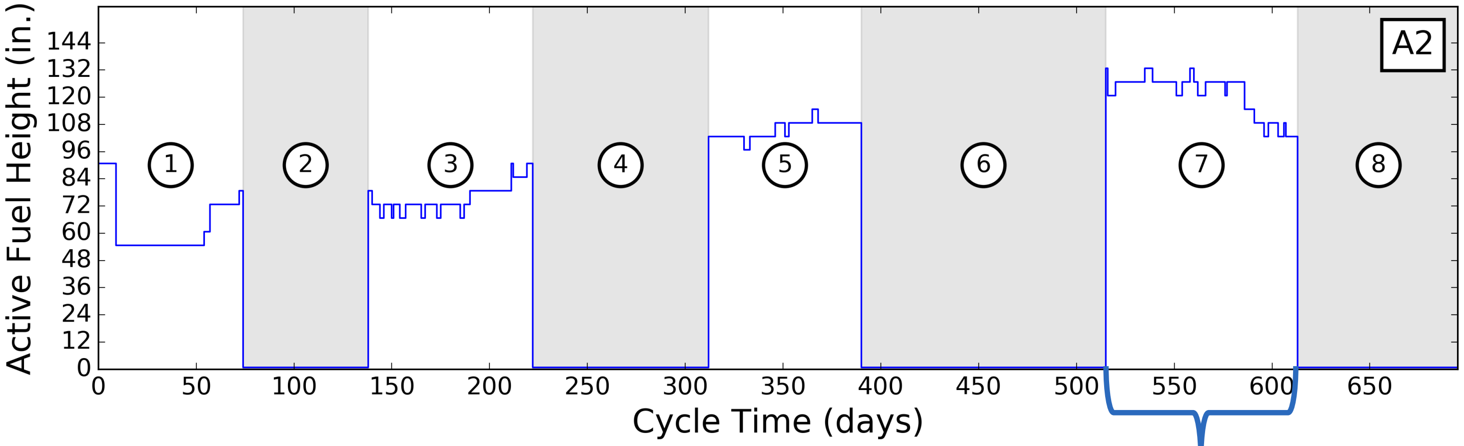


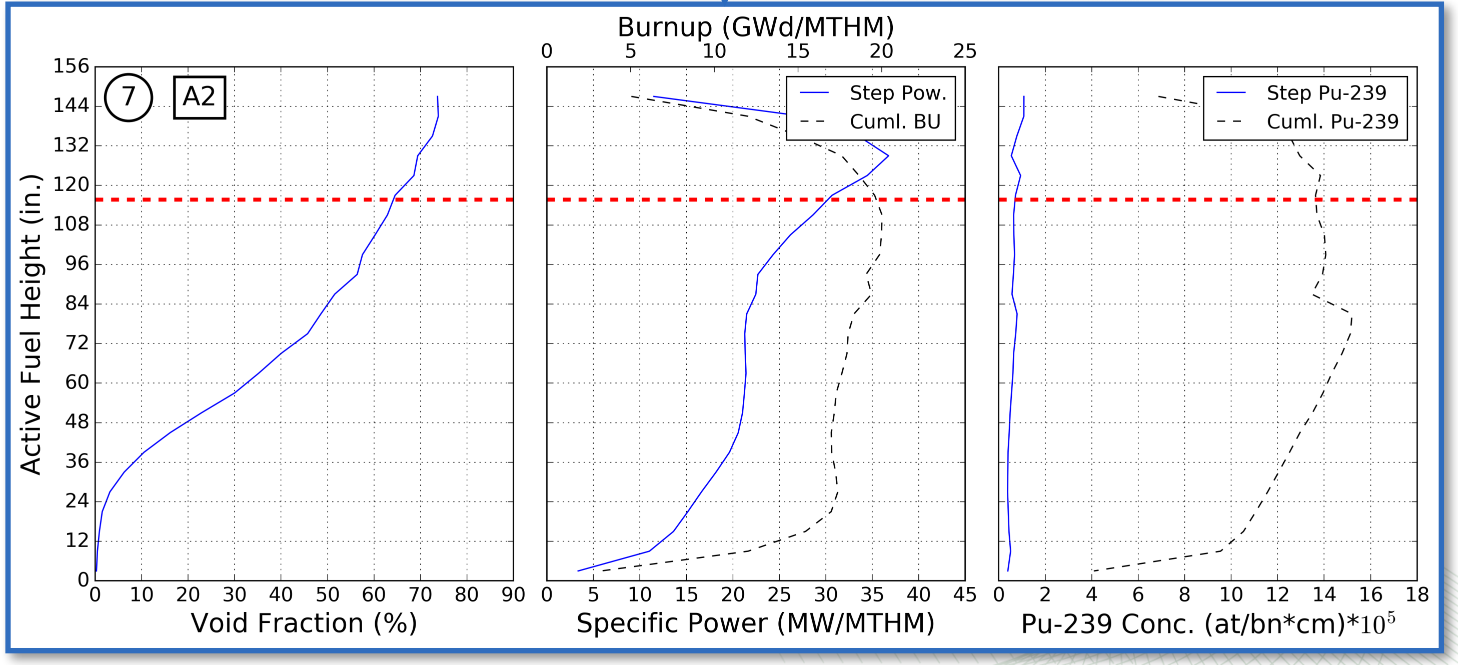
Assembly-Specific Results (A2)





Assembly-Specific Results (A2)





Actinide Only (AO) Results

25 GWd/MTHM

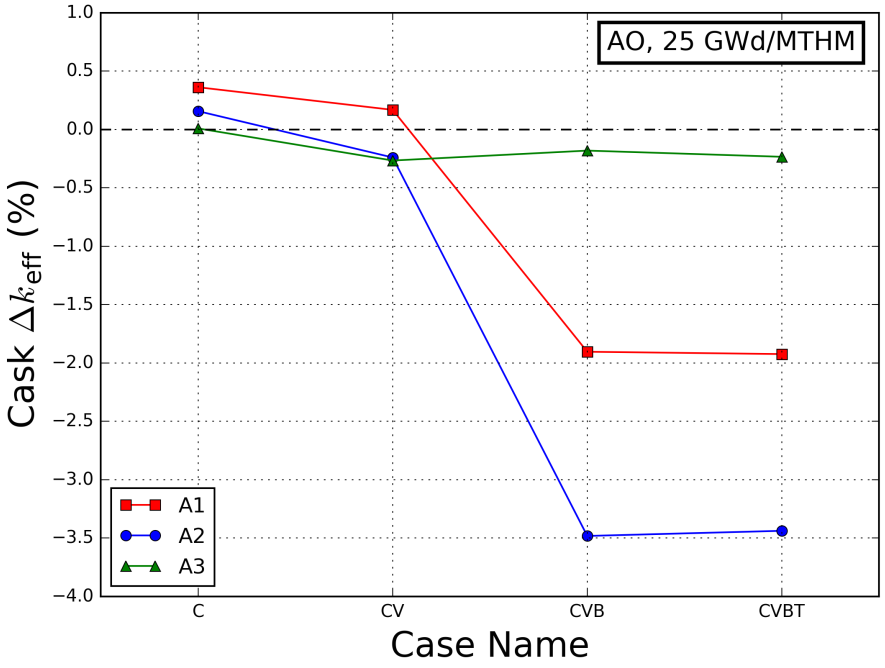
Case ID	A1 k_{eff}[a]	A2 k_{eff}[a]	A3 k_{eff}[a]	A1 Δk_{eff}[b]	A2 Δk_{eff}[b]	A3 Δk_{eff}[b]
Base	0.89955	0.89955	0.89955	0.00%	0.00%	0.00%
C	0.90316	0.90111	0.89963	0.36%	0.16%	0.01%
CV	0.90122	0.89714	0.89688	0.17%	-0.24%	-0.27%
CVB	0.88050	0.86472	0.89773	-1.91%	-3.48%	-0.18%
CVBT	0.88030	0.86516	0.89720	-1.93%	-3.44%	-0.24%

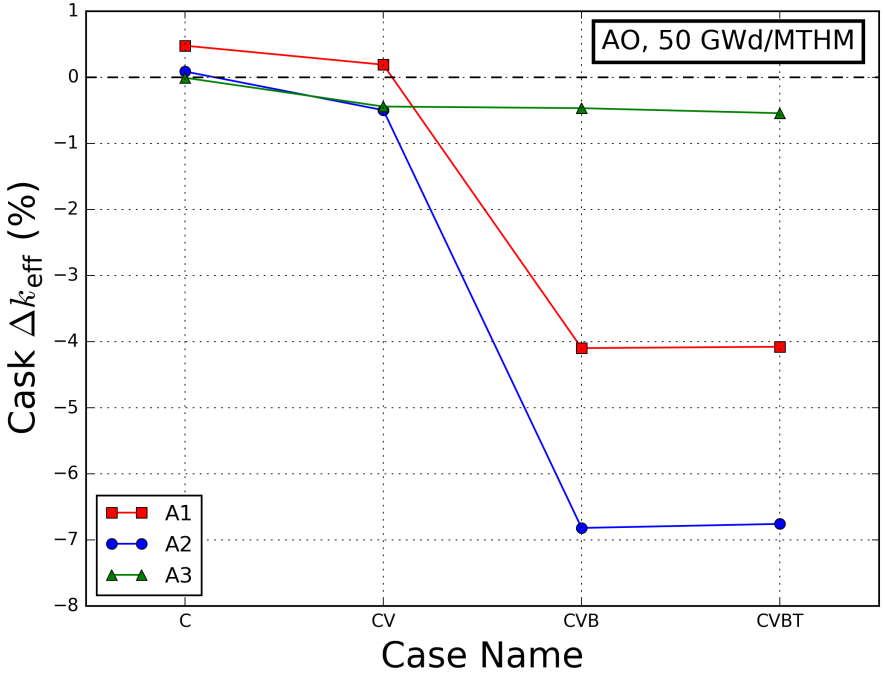
[a] Standard deviation is 0.00010 for k_{eff} and 0.00014 for Δk_{eff} in all cases
[b] Δk_{eff} relative to Base

50 GWd/MTHM

Case ID	A1 k_{eff}[a]	A2 k_{eff}[a]	A3 k_{eff}[a]	A1 Δk_{eff}[b]	A2 Δk_{eff}[b]	A3 Δk_{eff}[b]
Base	0.83834	0.83834	0.83834	0.00%	0.00%	0.00%
C	0.84310	0.83919	0.83824	0.48%	0.08%	-0.01%
CV	0.84022	0.83334	0.83389	0.19%	-0.50%	-0.44%
CVB	0.79733	0.77012	0.83364	-4.10%	-6.82%	-0.47%
CVBT	0.79754	0.77073	0.83288	-4.08%	-6.76%	-0.55%

[a] Standard deviation is 0.00010 for k_{eff} and 0.00014 for Δk_{eff} in all cases
[b] Δk_{eff} relative to Base





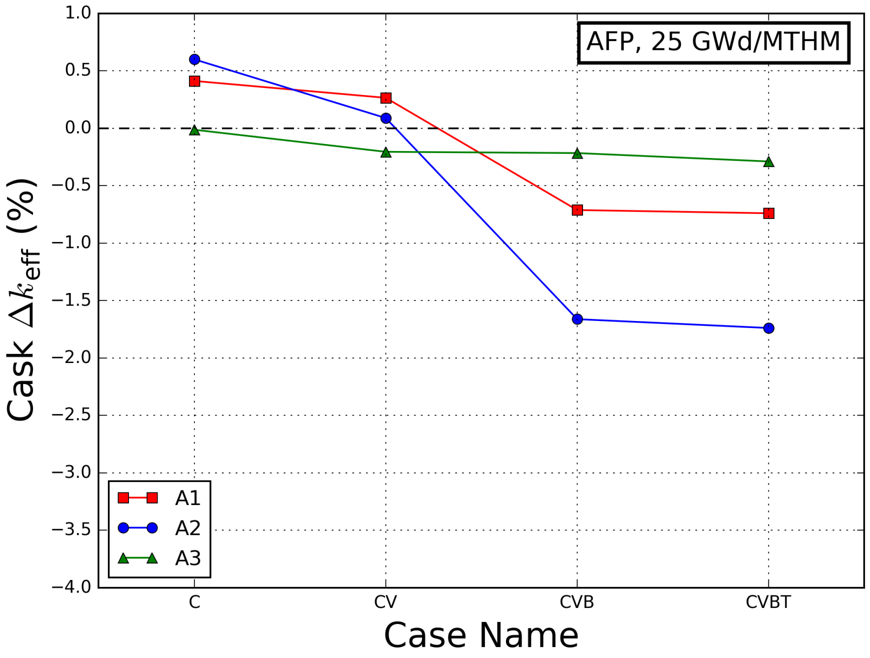
Actinide + Fission Product (AFP) Results

25 GWd/MTHM

Case ID	**A1 k_{eff}**[a]	**A2 k_{eff}**[a]	**A3 k_{eff}**[a]	**A1 Δk_{eff}**[b]	**A2 Δk_{eff}**[b]	**A3 Δk_{eff}**[b]
Base	0.81705	0.81705	0.81705	0.00%	0.00%	0.00%
C	0.82116	0.82304	0.81691	0.41%	0.60%	-0.01%
CV	0.81969	0.81793	0.81499	0.26%	0.09%	-0.21%
CVB	0.80992	0.80042	0.81488	-0.71%	-1.66%	-0.22%
CVBT	0.80964	0.79965	0.81415	-0.74%	-1.74%	-0.29%

[a] Standard deviation is 0.00010 for k_{eff} and 0.00014 for Δk_{eff} in all cases

[b] Δk_{eff} relative to Base

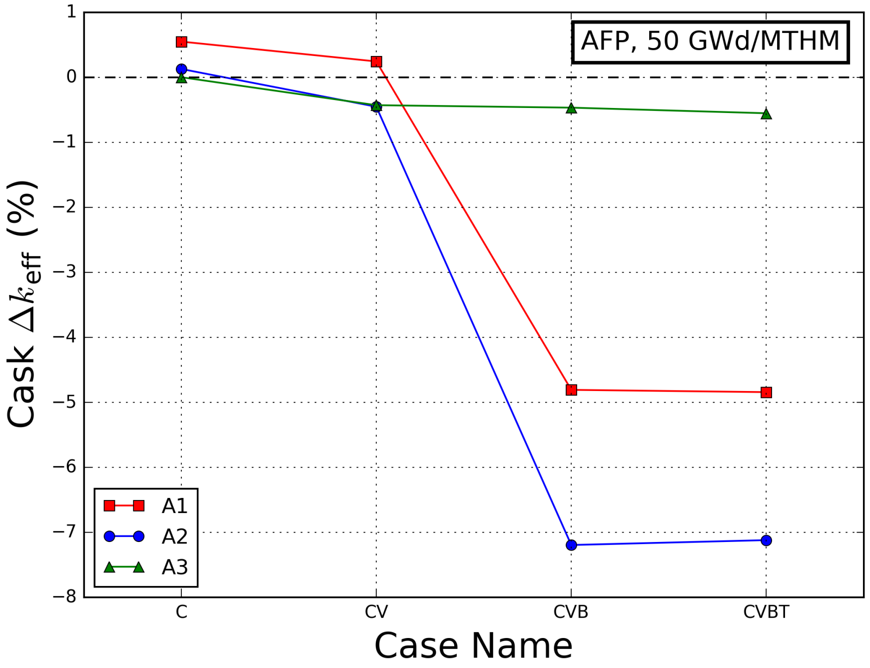


50 GWd/MTHM

Case D	**A1 k_{eff}**[a]	**A2 k_{eff}**[a]	**A3 k_{eff}**[a]	**A1 Δk_{eff}**[b]	**A2 Δk_{eff}**[b]	**A3 Δk_{eff}**[b]
Base	0.76000	0.76000	0.76000	0.00%	0.00%	0.00%
C	0.76547	0.76126	0.75999	0.55%	0.13%	0.00%
CV	0.76242	0.75545	0.75569	0.24%	-0.46%	-0.43%
CVB	0.71189	0.68802	0.75531	-4.81%	-7.20%	-0.47%
CVBT	0.71154	0.68877	0.75445	-4.85%	-7.12%	-0.55%

[a] Standard deviation is 0.00010 for k_{eff} and 0.00014 for Δk_{eff} in all cases

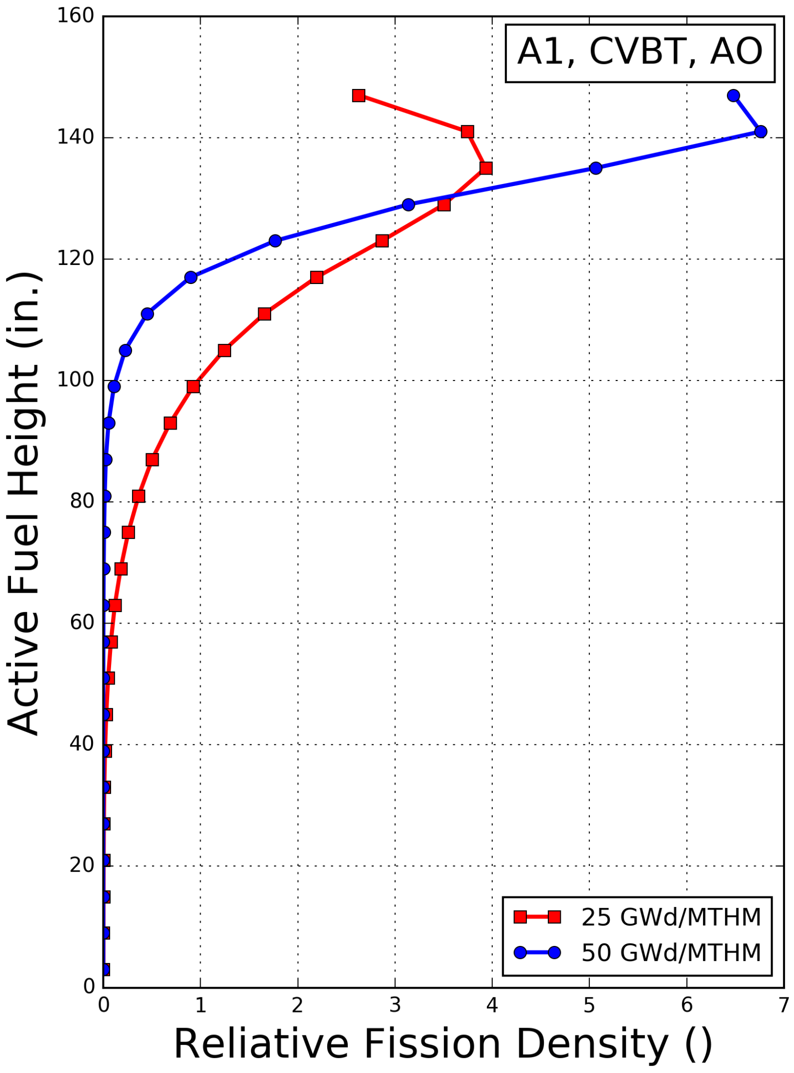
[b] Δk_{eff} relative to Base

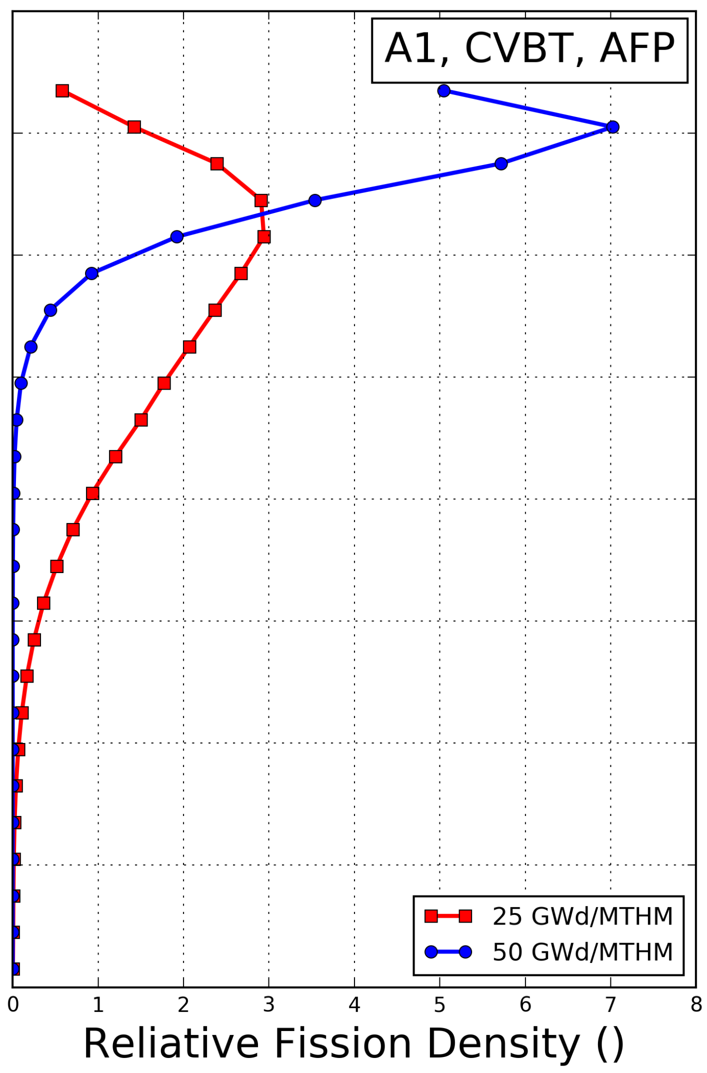


Assembly-Specific Results

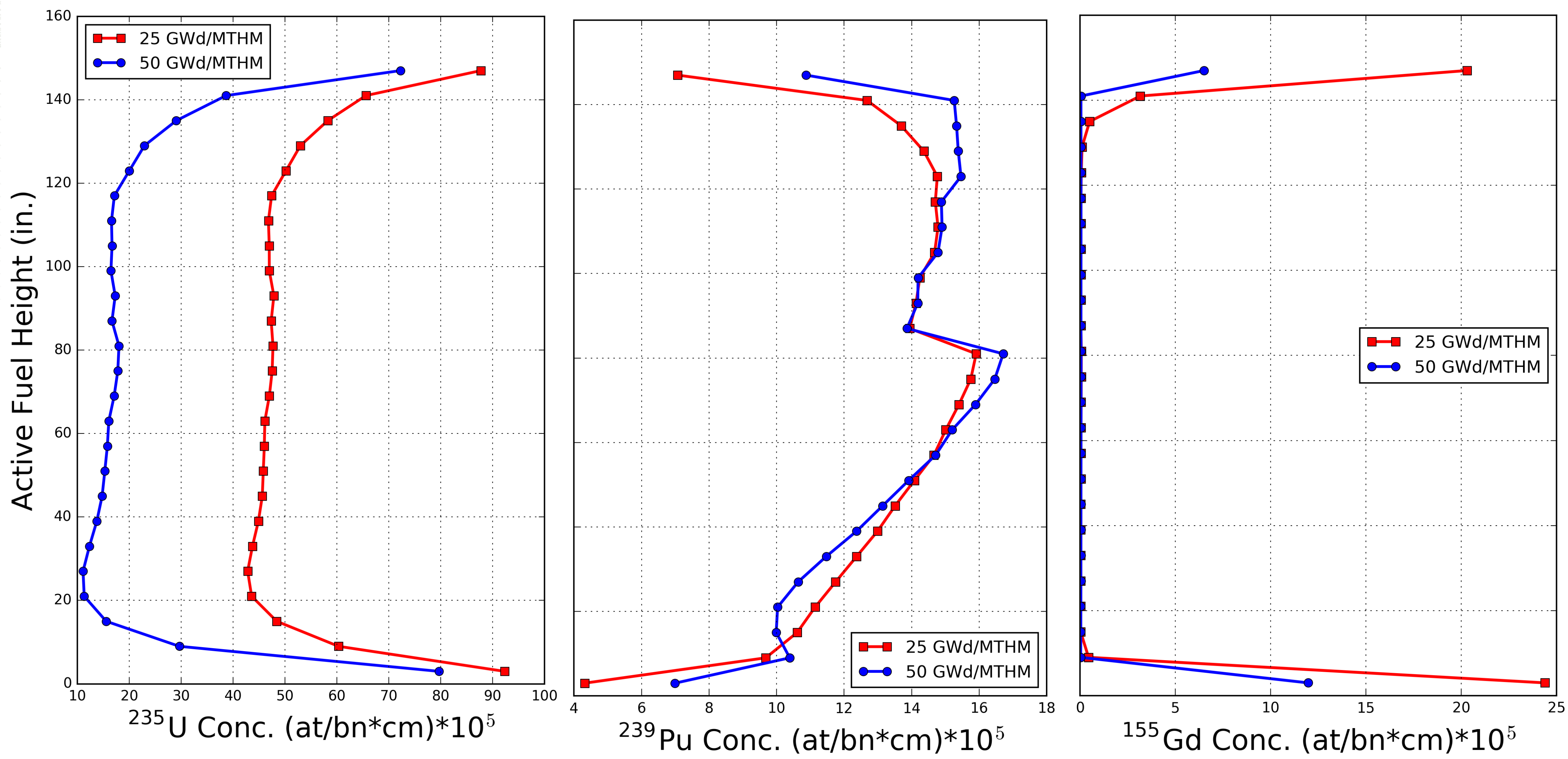
- The impact of adding the assembly-specific burnup profile is more significant at 50 than at 25 GWd/MTHM.
- The impact of assembly-specific conditions is similar for AO and AFP at 50 GWd/MTHM, but the impact is larger for AO than AFP at 25 GWd/MTHM.

<u>Both of these differences are caused by the shape of the fission distribution!</u>





Isotopics for A1 CVBT Case



Summary

- Using limiting conditions for individual conditions (control blade history, coolant density, and burnup profile) is conservative compared to using correlated assembly-specific data
  - Magnitude of this conservatism measured in this study varies from 0.5% to more than 7% Δk_{eff}
  - Magnitude depends on the fuel assembly, isotope set, burnup, etc.
- Consistent with previous findings, using the assembly-specific burnup profile has the most significant impact on cask reactivity
- The impact of assembly-specific conditions on cask reactivity is largest for assemblies with significant control blade insertion.
  - Usage of the control blade during operation changes the axial shape of the coolant density and burnup profile. Insertion of the control blade leads to less limiting coolant density and burnup axial profiles.
- The impacts of assembly-specific conditions on cask reactivity are larger for high discharge burnups than for low discharge burnups