Economic Benefits of Higher Enriched Assays for 24-Month Cycle Length

Coral Kazaroff, Andrew Johnson, Dan Kotlyar

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Background and Objectives

Background:

- The current fuel enrichment is restricted to 5% in commercial LWRs
- The fuel cycle length is typically between 12 to 18 months

Objectives:

- Examine enrichment required to extend cycle length to 24 months
- Assess economic benefit or penalty

Constraints

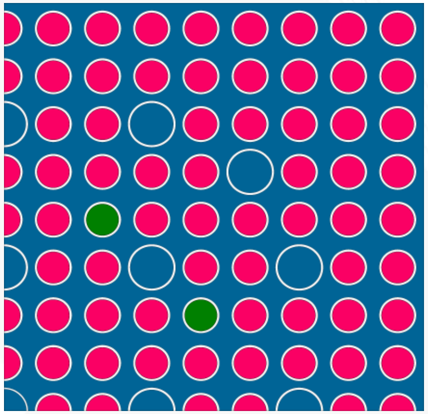
- Limiting pin burnup
  - Accident-tolerant fuels
  - Limit of 62 → possible shift
- Increase fuel enrichment to align with industry efforts
- Maintain reactivity control requirements
  - Burnable poison design
  - Critical boron concentration (CBC)

General Approach and Model

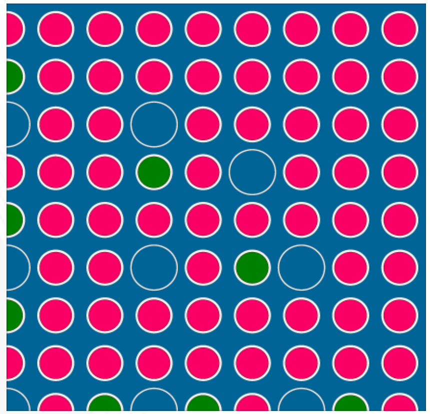
- 17x17 PWR
  - Varying enrichments from 4.0 w/o through 6.7 w/o
  - Gadolinia (Gd_2O_3) burnable absorbers
- 3-batch management scheme for full-core analysis
  - 80 fresh, 80 once-burned, 33 twice-burned
- For each enrichment, use NLRM to obtain
  - Core reactivity
  - Core boron worth
  - Critical boron concentration

Fuel Assembly Configurations

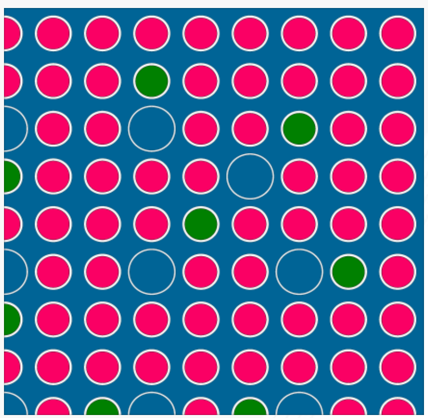
8 BP



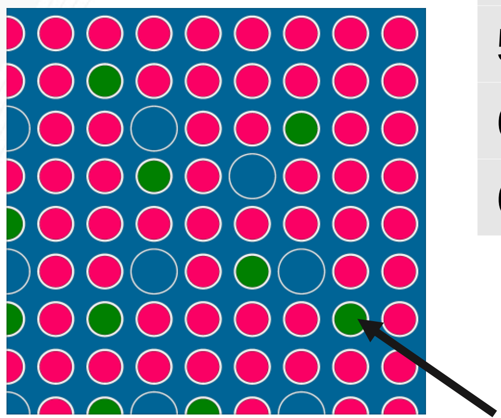
20 BP



24 BP



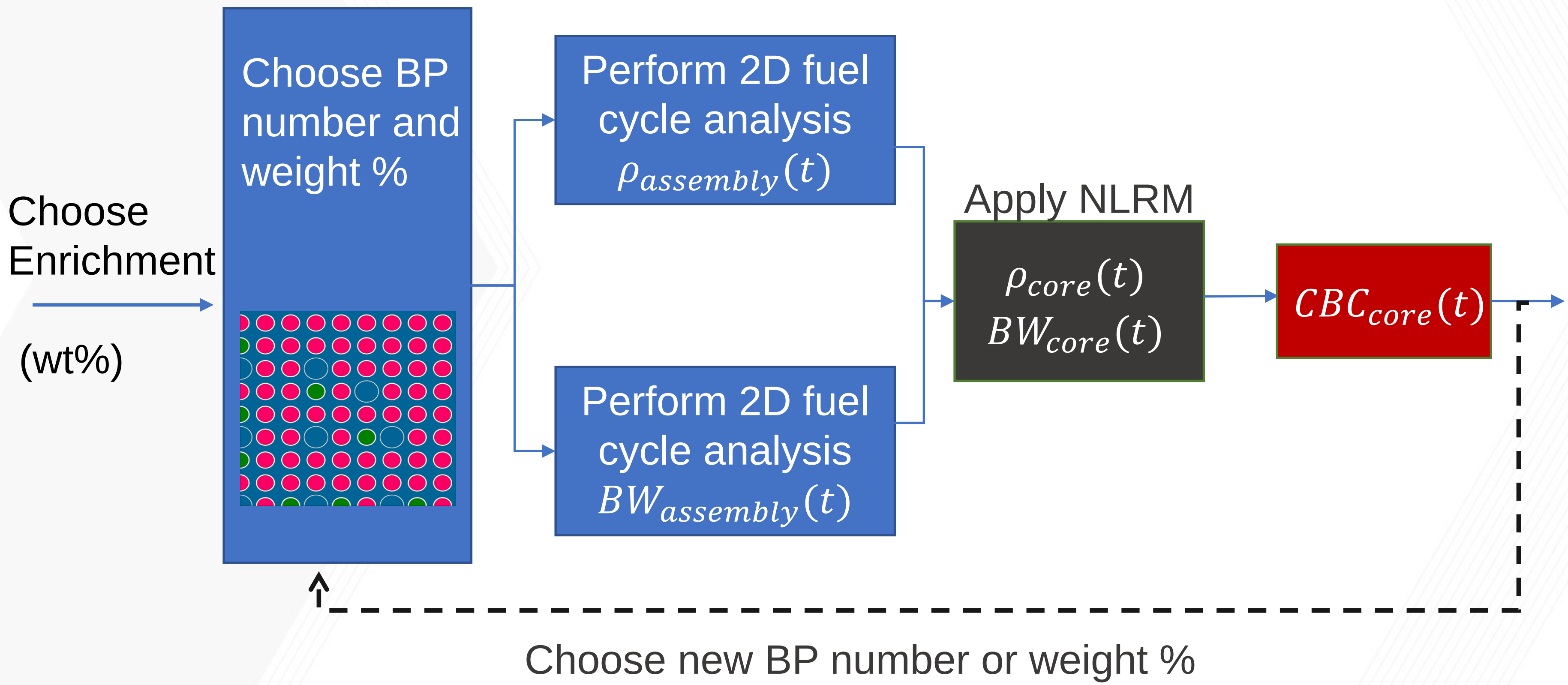
32 BP



$Gd_2O_3+UO_2$

U235 wt%	Gad wt%	# Burnable Pins
4	6	8
4.45	6	12
4.9	6	16
5.35	8	20
5.8	8	24
6.25	8	28
6.7	8	32

Methodology



Non-Linear Reactivity Model (NLRM)

$$\rho(t) = a_0 + a_1 t + a_2 t^2 + a_3 t^3$$

- The discrete points of reactivity vs. time are fitted into a polynomial

  - Burnable absorbers make reactivity non-linear; in our case this was the most suitable polynomial

- The first points are not used for the fitting procedure

- Using the polynomial and leakage assumption, the cycle length T_c can be evaluated:

$$\frac{80 \times \rho(1T_c) + 80 \times \rho(2T_c) + 33 \times \rho(3T_c)}{193} = 0.03$$

Core Reactivity Estimation

$$\rho_{core}(t) = \frac{1}{N}\sum_{i=0} N_i \rho(t + iT_c) - \rho_L$$

- A ***three-batch*** scheme was adopted ($0 \leq i \leq 2$)
- N – total number of fuel assemblies
- $\rho(t + iT_c)$ - reactivity of the fuel assembly at different time
- T_c is the cycle length (days) that is iteratively calculated
- ρ_L - leakage (assumed as 3%)
- Similar procedure for boron worth

$$BW_{core}(t) = \frac{1}{N}\sum_{i=0}^{N-1} N_i \cdot BW(t + iT_c)$$

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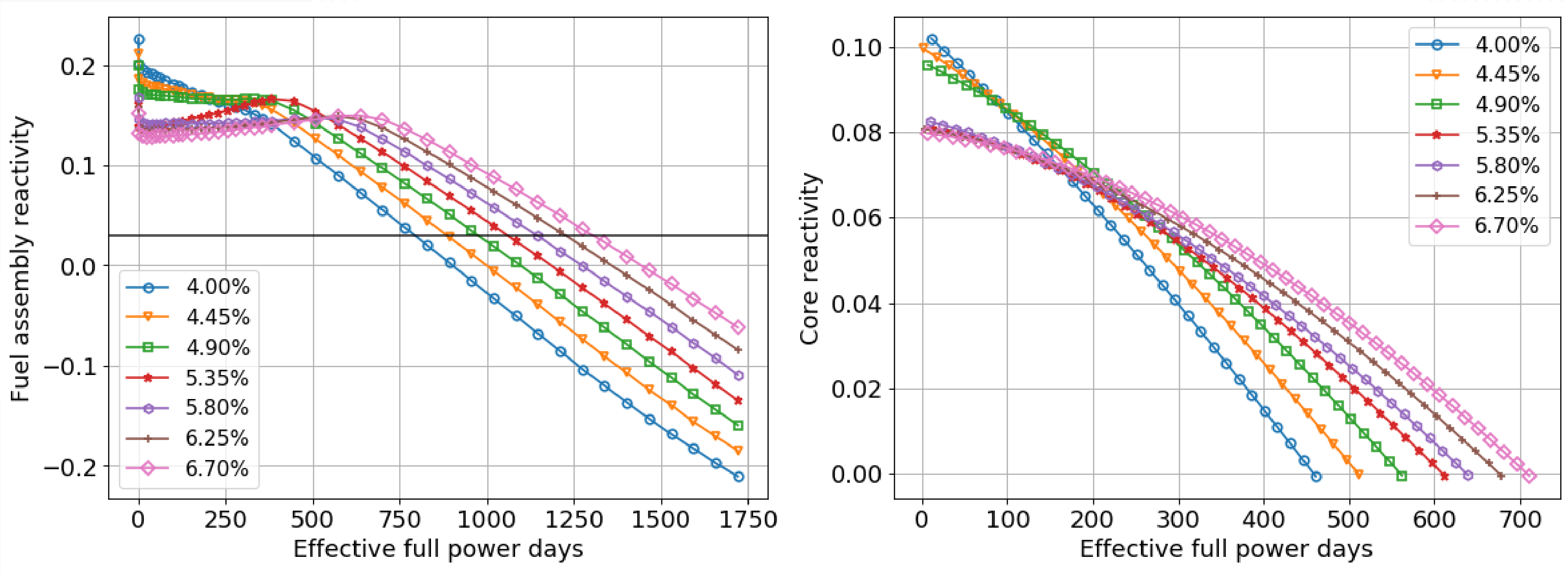
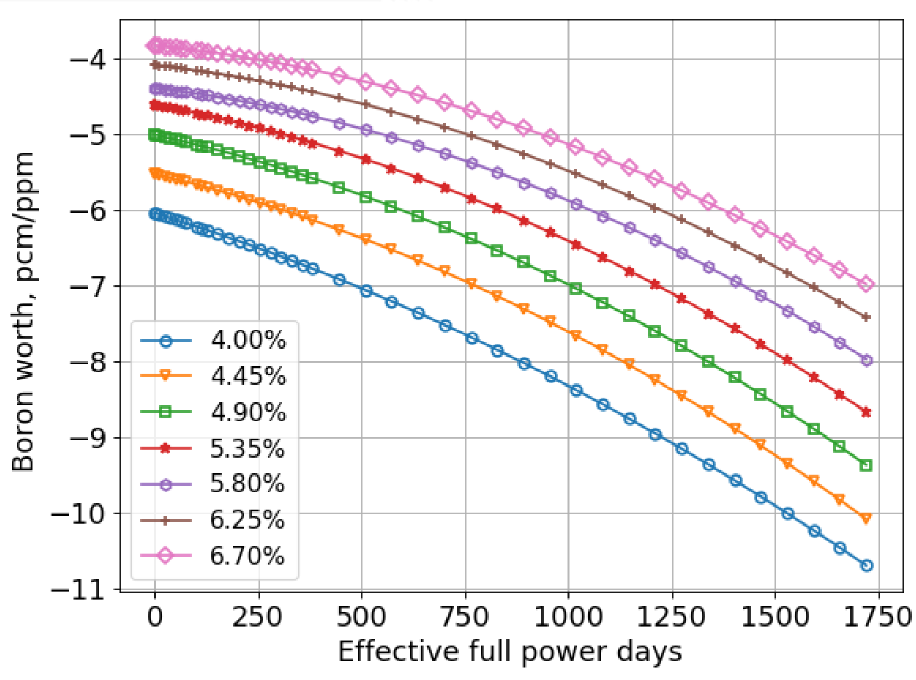
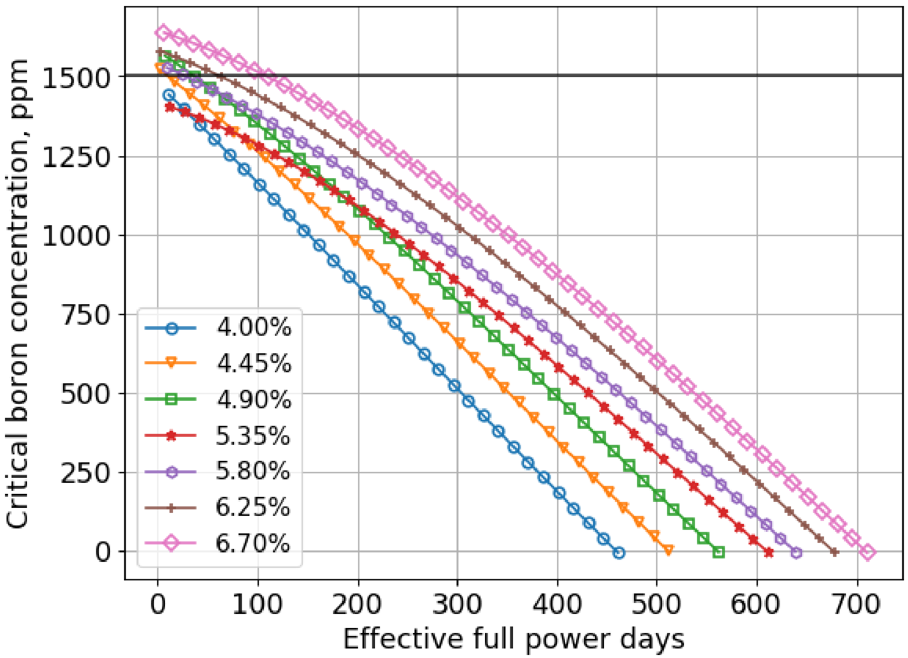
Assembly and Core Reactivity



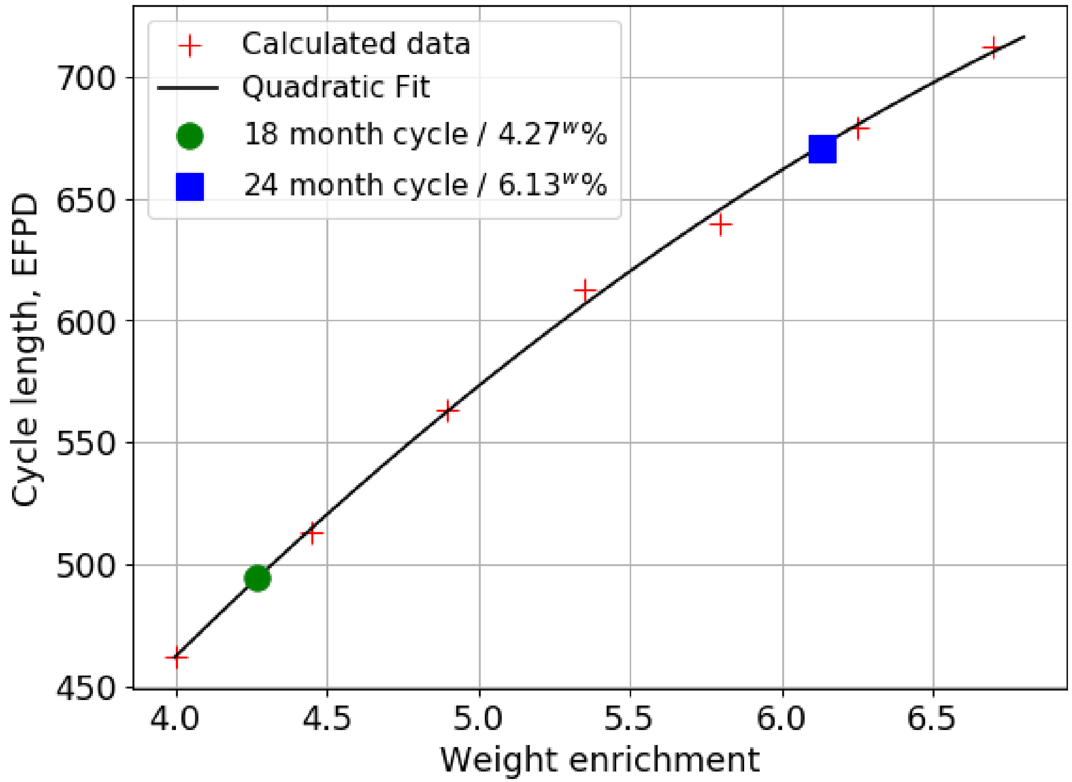
Boron Worth and CBC





Cycle Length

- Fit enrichment to cycle length
- 4.27 w/o → 18 month cycle length
- 6.13 w/o → 24 month cycle length



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Fuel Cycle Costs per kg U

Process	4.27 wt% U235		6.13 wt% U235	
	Requirement	Cost	Requirement	Cost
U3O8	8 kg	451.80	11.6 kg	659.00
Conversion	8.0 kg	117.40	11.6 kg	171.20
Enrichment	7.2 SWU	307.60	11.5 SWU	495.20
Fabrication		400.0		400.0
Total	**1276.90**		**1725.50**	

Economic Analysis

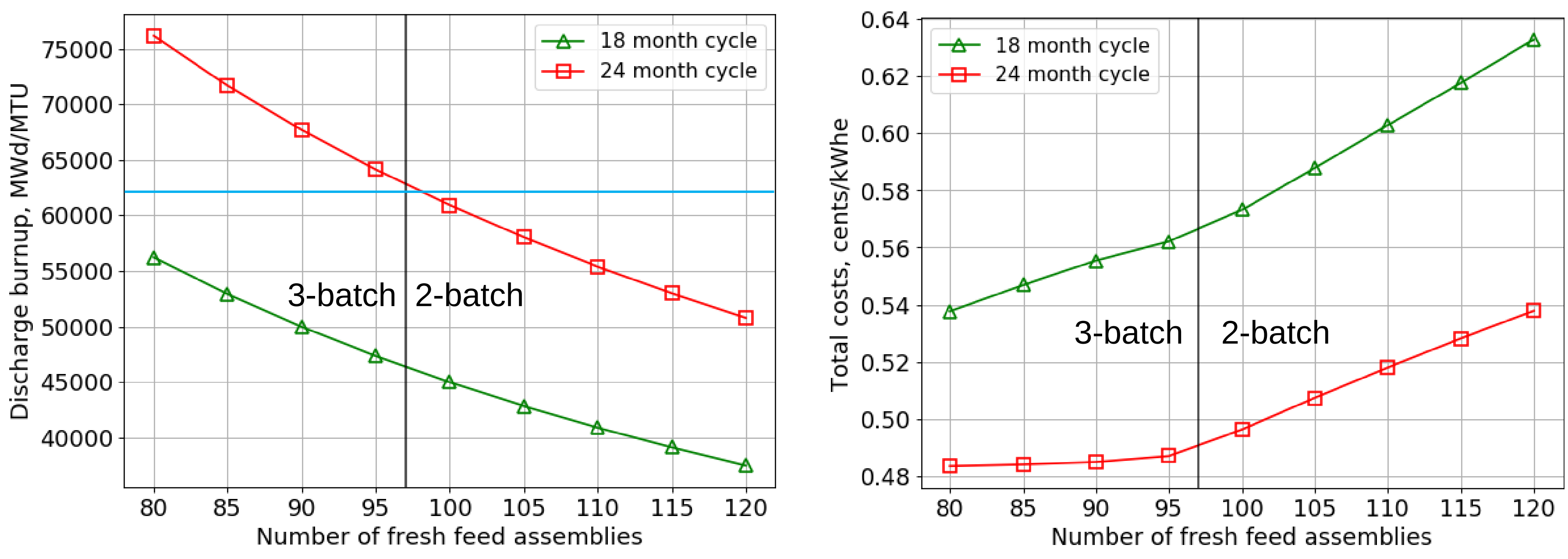
- Compute total fuel cost per kg-U
- Compute fuel and outage costs per ¢/kWhe
- Fuel costs = $\frac{Total\ cost\ of\ outage}{Power \times T_c \times \eta}\left[\frac{¢}{kWh_e}\right]$
- Outage costs = $\frac{P_T}{B_d \times \eta}\left[\frac{¢}{kWh_e}\right]$

Parameter	Value
Uranium ore, $/kg	56.80
Conversion , $/kg	$14.75 /kgU
SWU ,$	$43.00
Fabrication , $/kg	$400.00 /kgU
Electric efficiency	34%
Fixed outage cost, $	$30 million

Economic Results

Parameter	Value – 4.27 wt%	Value – 6.13 wt%
Cycle length	18 mo	24 mo
Assembly burnup [GWd/MTU]	46.8	63.5
Max pin burnup [GWd/MTU]	56.2	76.1
Fuel cost, $[\boldsymbol{cent/kWh_e}]$	0.334	0.333
Outage cost, $[\boldsymbol{cent/kWh_e}]$	0.204	0.150
Fuel cycle cost, $[\boldsymbol{cent/kWh_e}]$	**0.538**	**0.484 [-10 %]**

Limiting Pin Burnup



- Pin burnup < 62 GWd/tU, but keep 6.13 enriched fuel
- Vary number of fuel assemblies
- Two-batch system keeps burnup below 62

Summary

- Fuel cycle analysis with higher enrichments
  - Single assembly, non-linear reactivity → full core
- Recover near-standard 18 mo cycle with 4.27 wt% enrichment
- Obtain 24 month cycle with 6.13 wt% enrichment
- Potential fuel cycle cost savings of 10%
- ATF progress, NRC licensing

Future Work

- 3D full-core analysis
- Optimize loading pattern with enrichment and gadolinia configurations

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Thank you very much!

Questions?

coralkazaroff12@gatech.edu
ajohnson400@gatech.edu
dan.kotlyar@me.gatech.edu

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