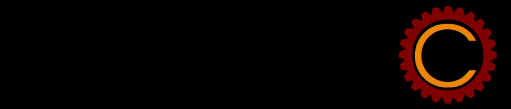


Fuel Cycle Modeling Choices:

Facility and Time Discretization Effects

By Robert Carlsen

Technical Workshop on Fuel Cycle Simulation
Paris - July 6-8, 2016

Modeling Choices: Facility Discretization

Fleet Reactors:

- Single-group behavior
- Faster simulation
- Never offline
- Incremental refueling
- No fuel competition
- Proportional shutdown

Individual Reactors:

- Independent behaviors (noise)
- Slower simulation
- Refueling outages
- Batched refueling
- Fuel competition
- Discrete shutdown

Modeling Choices: Time Discretization

- Trade frequency*
- Trade size*
- On-hand inventory size
- Simulation run times

* effects depend on facility discretization

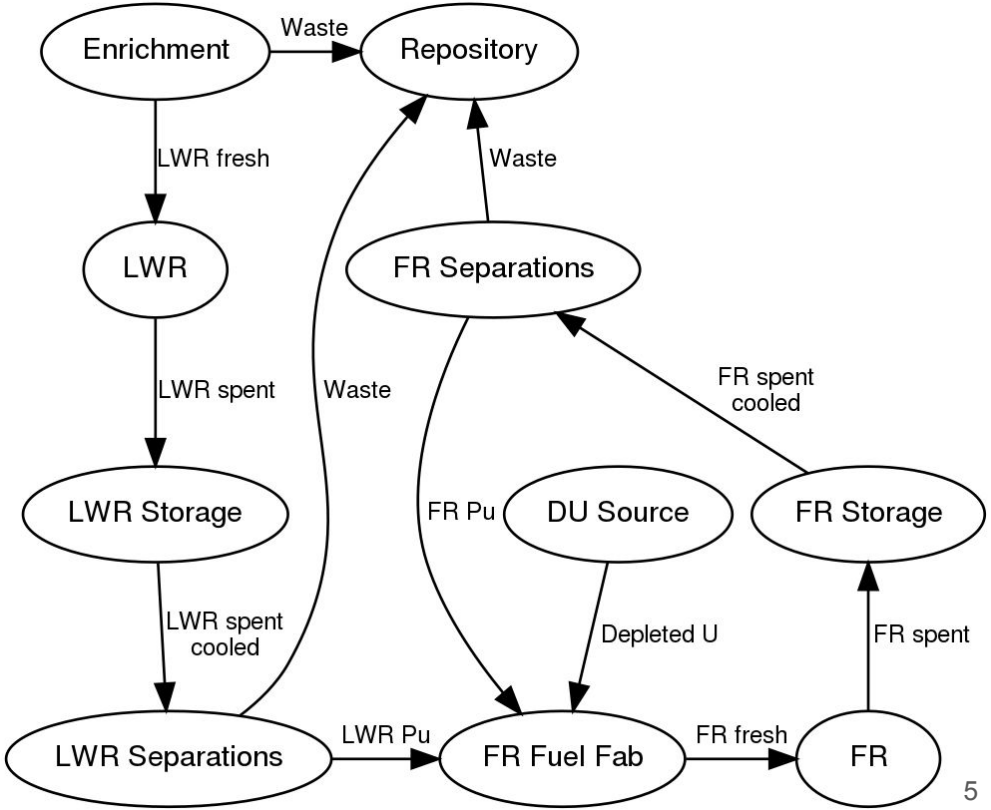
Scenario Details

Four Cases:

- Case MI: Monthly time steps, Individual reactors
- Case MF: Monthly time steps, Fleet reactors
- Case QI: Quarterly (3-month) time steps, Individual reactors
- Case QF: Quarterly time steps, Fleet reactors

Scenario

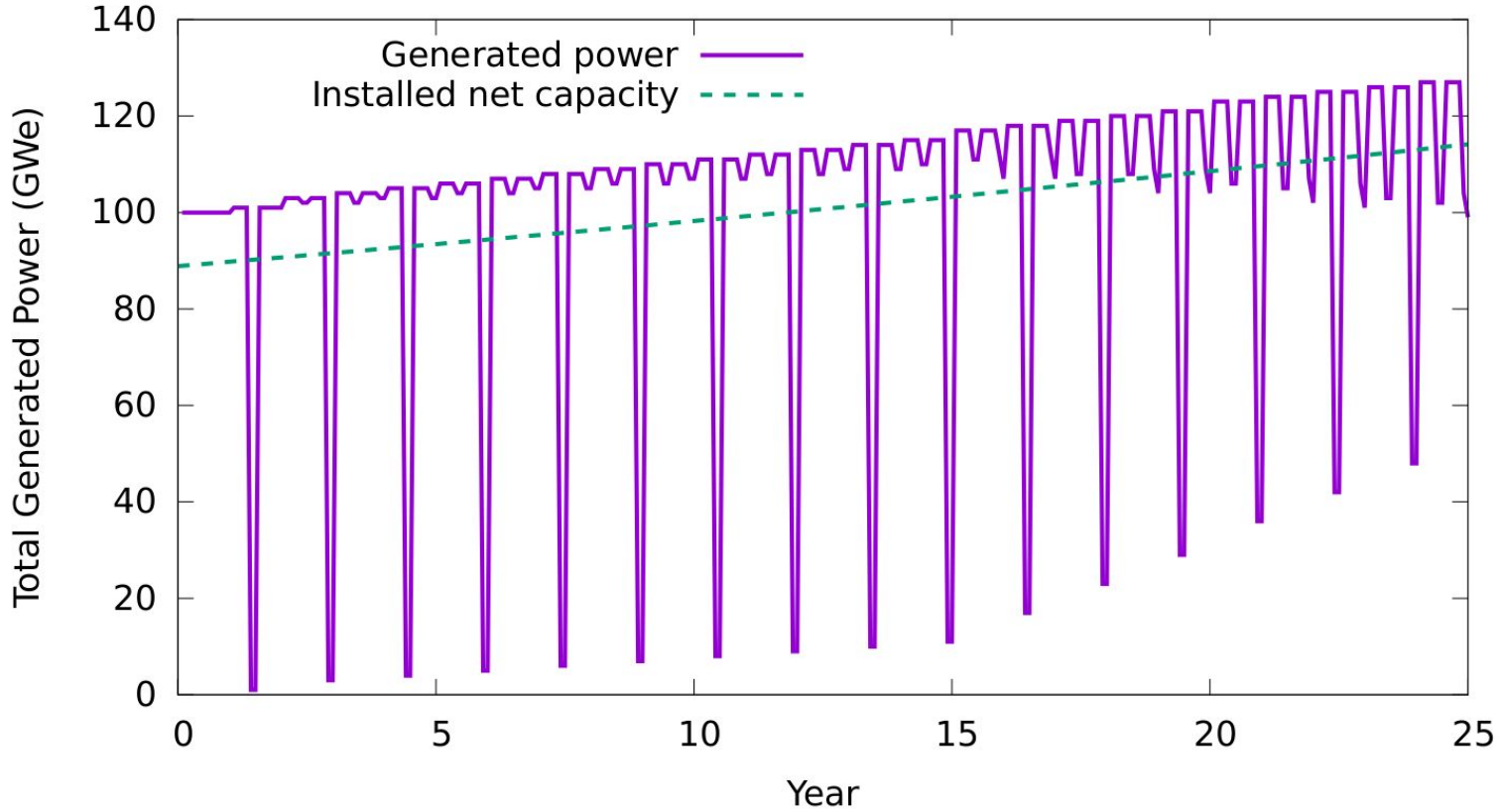
- Transition from 100 LWRs to all SFRs
- SFRs use recycled fuel
- SFRs available in year 35+
- 200 years
- 1% annual electricity demand growth with +/- 10% bounds



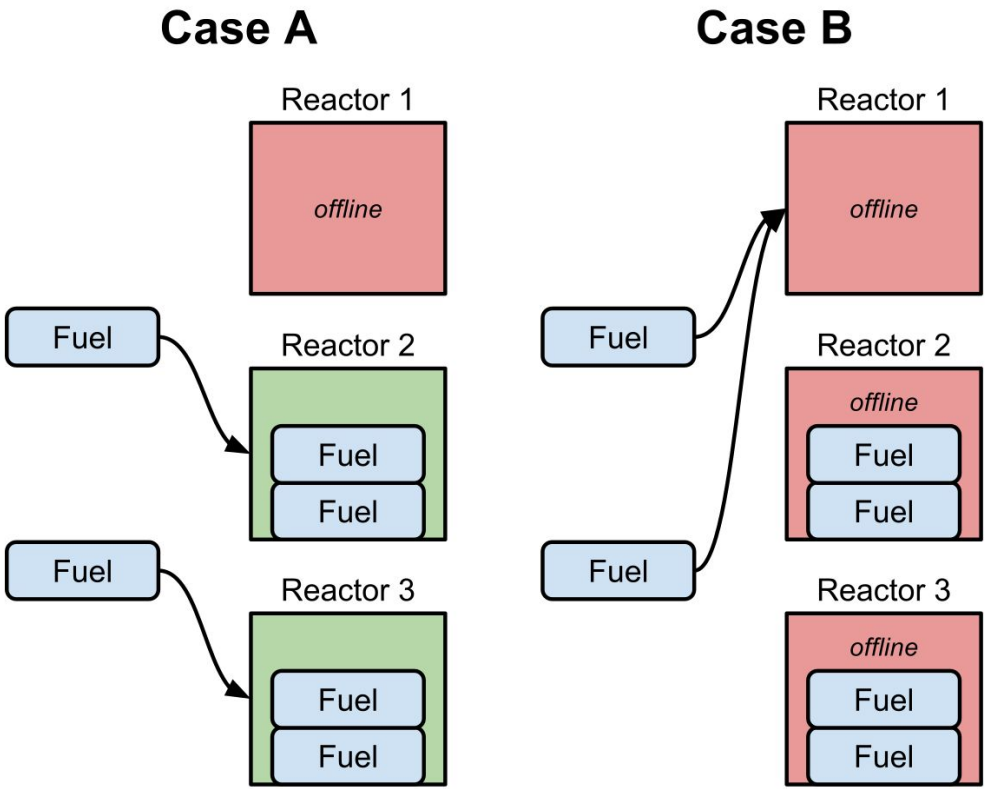
Reactor Configuration Invariants

	LWR	SFR
Discharge Rate ($\frac{\text{kg·HM}}{\text{month}}$)	1642.5	535
Burnup ($\frac{\text{MWe·month}}{\text{kg·HM}}$)	0.547945	0.672897
Effective Power (MWe)	900	360
Core Size (kg · HM)	88695	40125

Modeling Effects: Cycle Staggering



Modeling Effects: Fuel Sharing



Modeling Effects: Drawdown and Quantized Shutdown

Inventory Drawdown:

Larger time step

⇒ Larger withdrawals

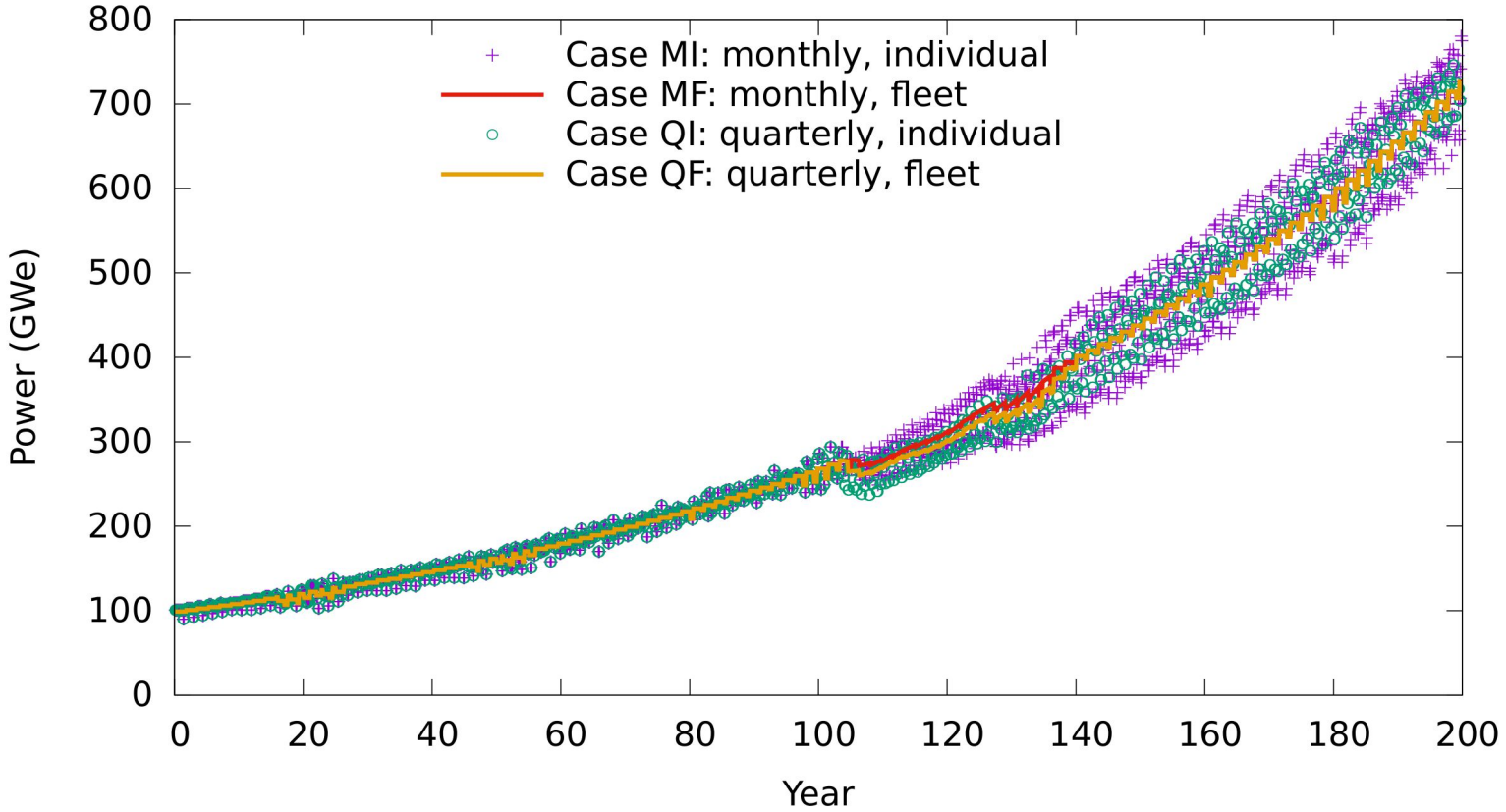
⇒ Keep more on-hand

⇒ More dead-weight inventory

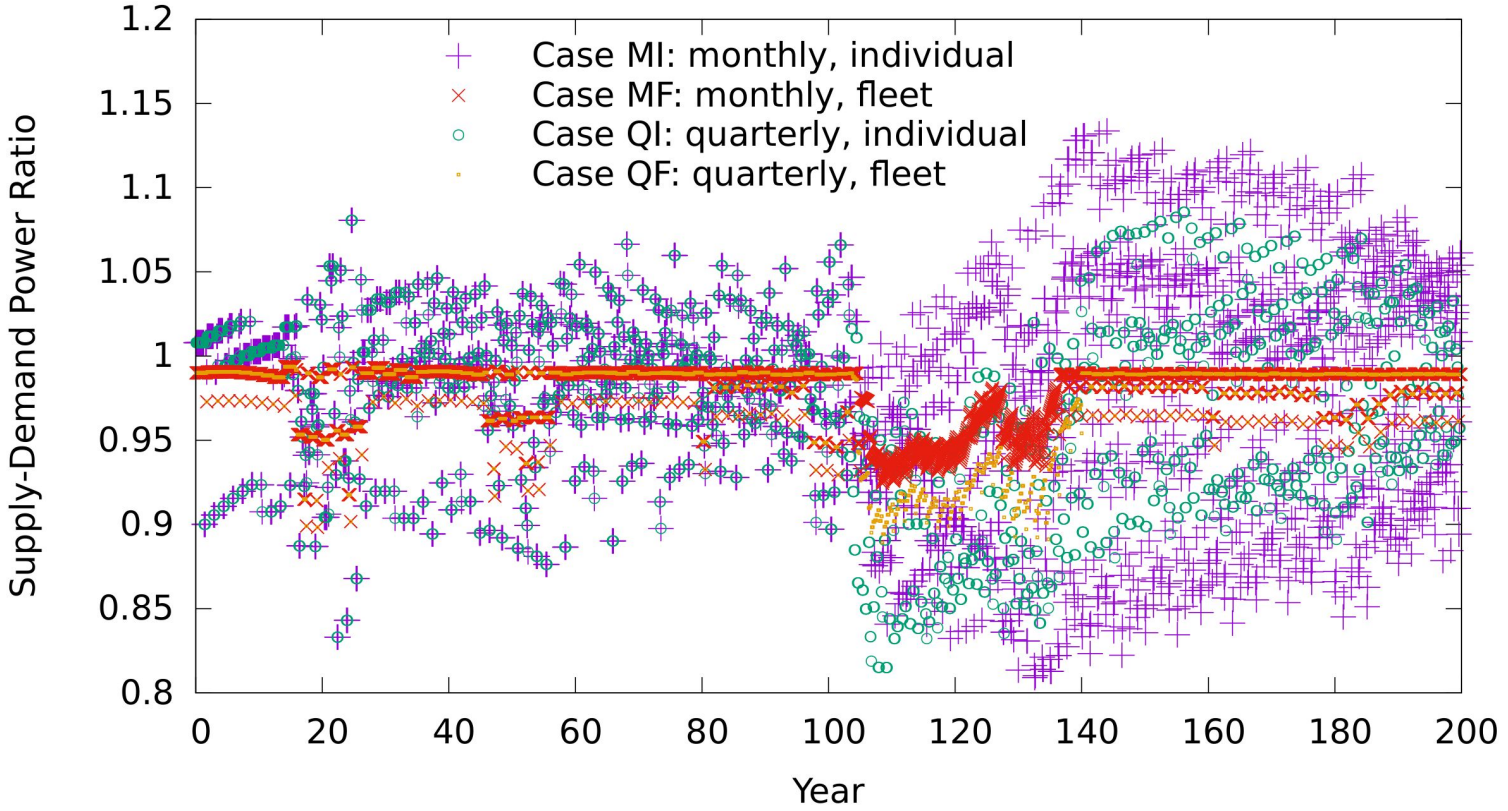
Quantized Shutdown:

- All-or-nothing reactor operation
  - Missing a bit of fuel ⇒ all off
  - Affects individually modeled facilities
- Outages bounded by time step duration
  - Missing a bit of fuel ⇒ off until next time step
  - Affects all facility types

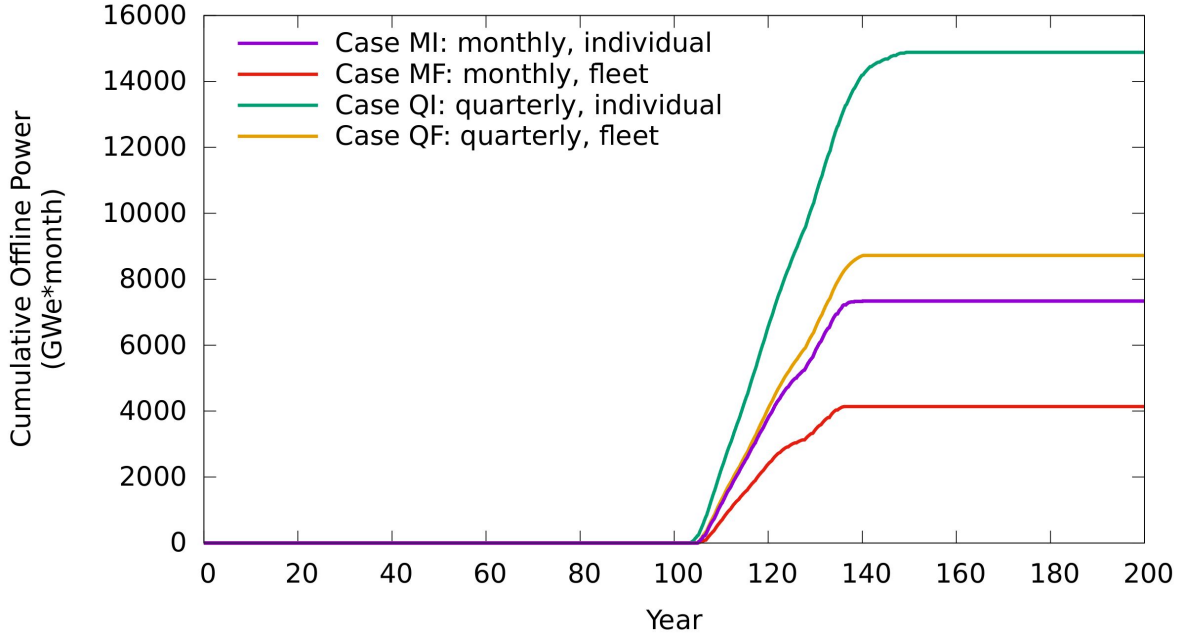
Generated Power



Relative Generated Power

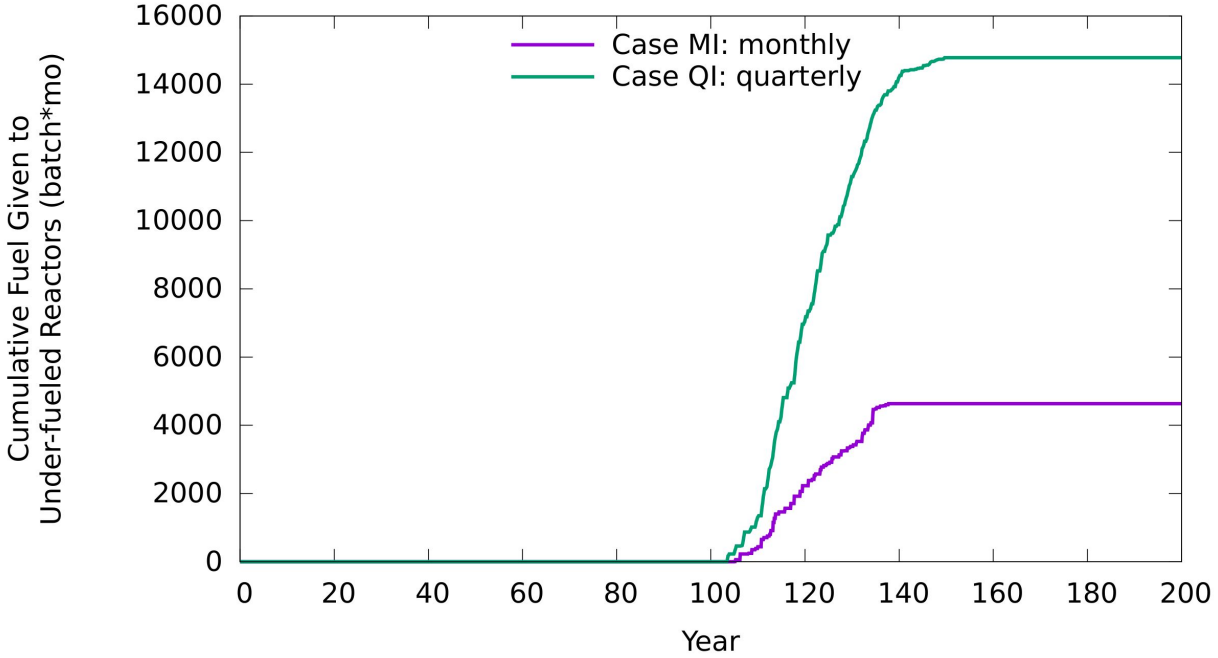


Fuel Shortages



$$P_{outage}(t) = \sum_{r \in R_t} C_r \cdot H[t - S_{sched}(t,r)] \cdot [1 - O(t,r)]$$

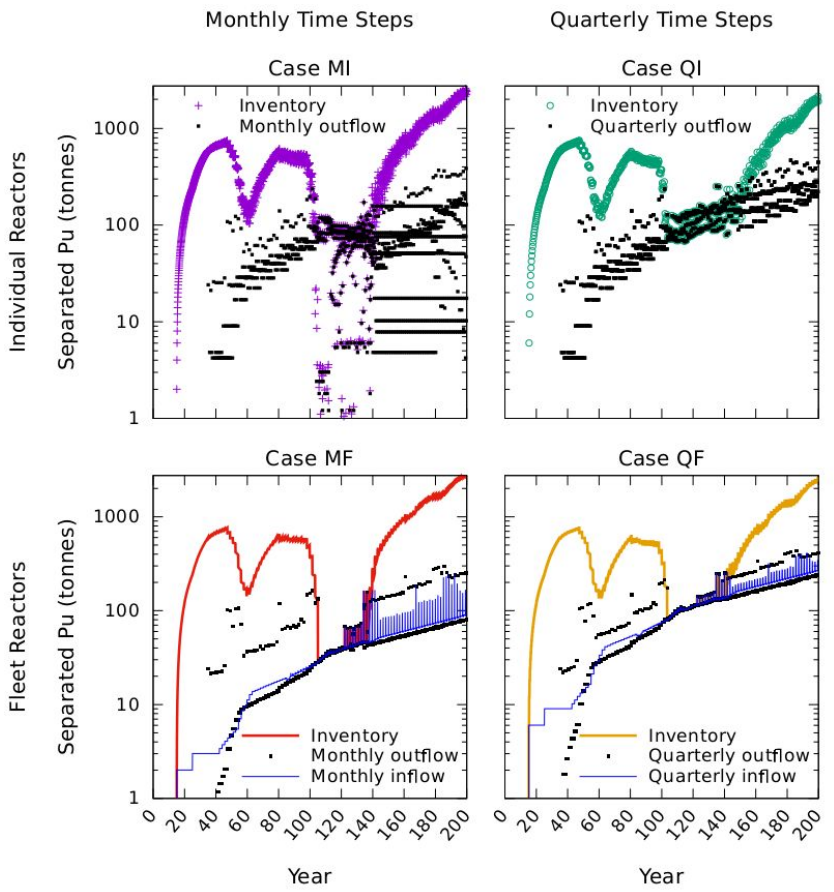
Wasted Batches (poor fuel sharing)



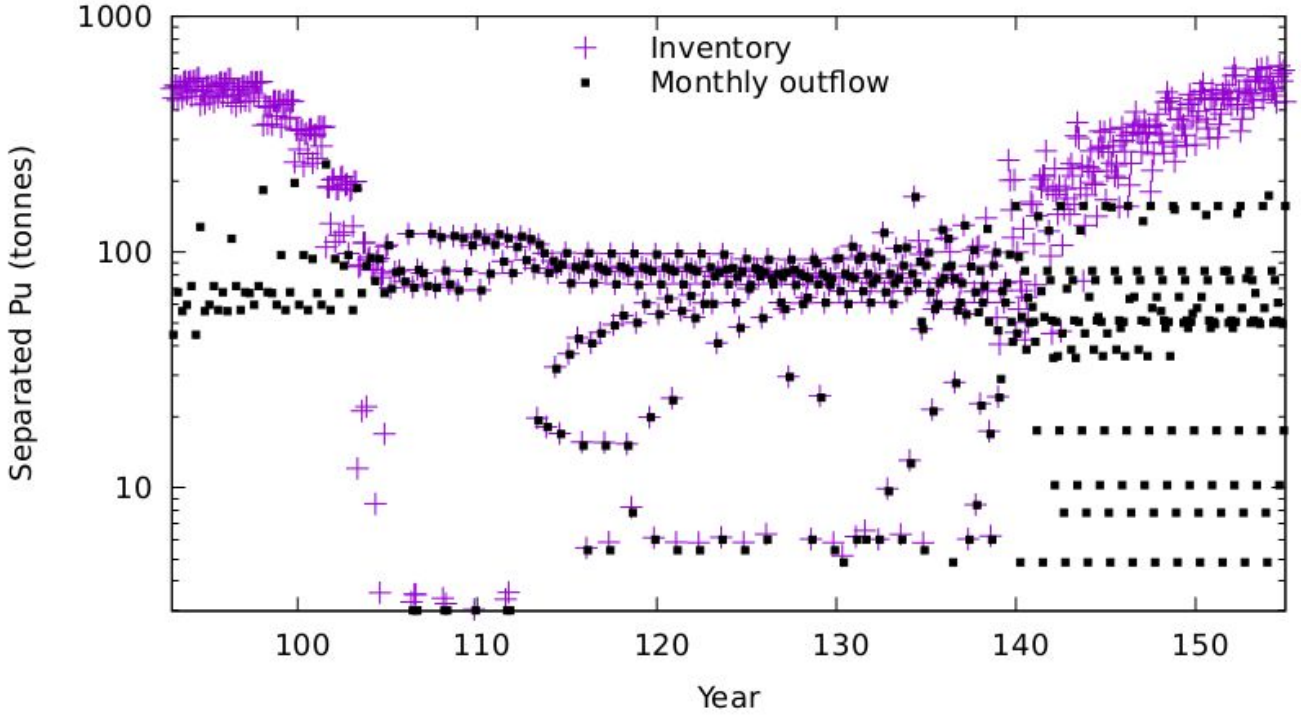
$$N_{wasted}(t) = \sum_{r \in R_t} \left(H[t - S_{sched}(t,r)] \cdot [1 - O(t,r)] \sum_{t'=F_{prev}(t,r)}^{t} N_b(t',r) \right)$$

Pu Inventory and Flow

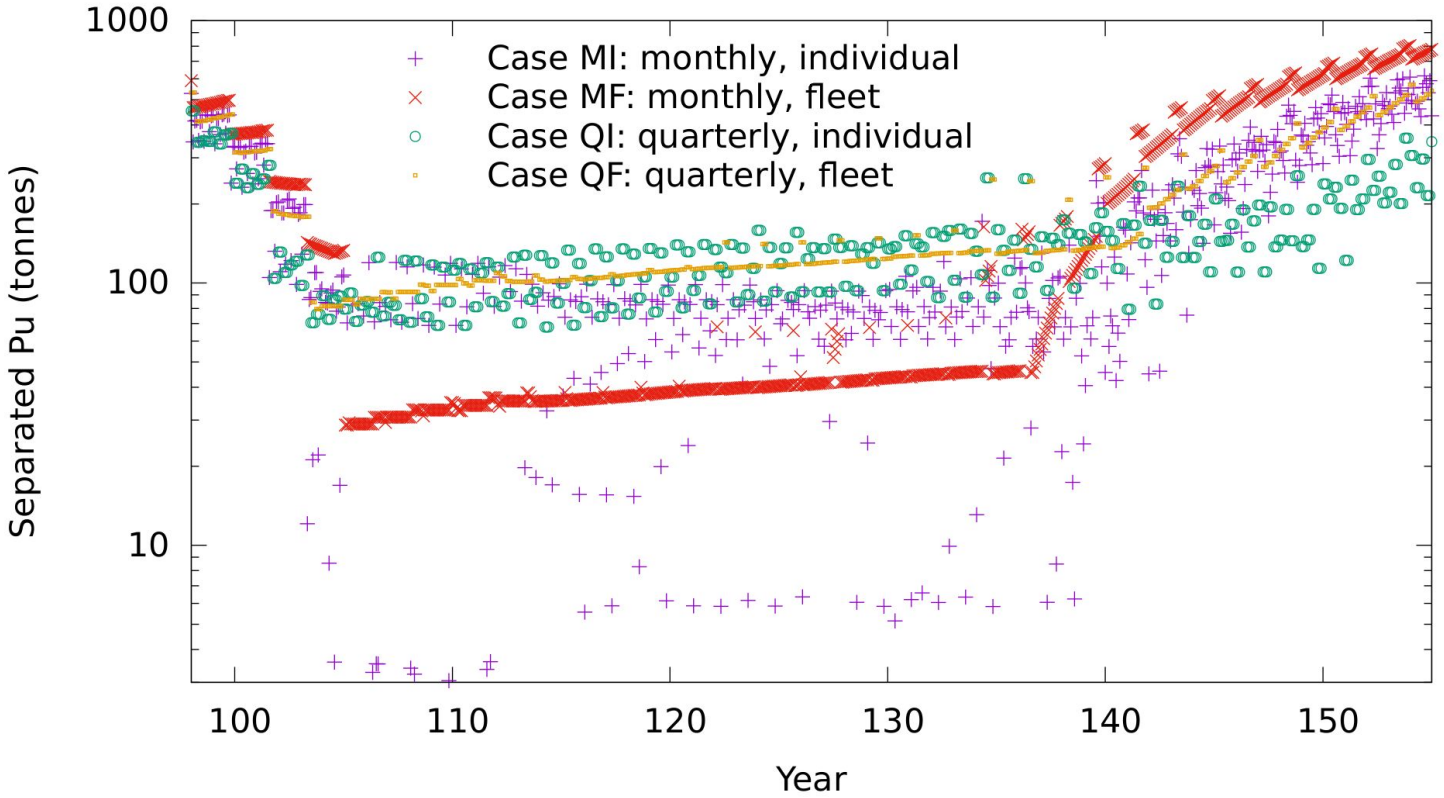
- Shows separated Pu Inventory ready for fabrication
- QI, QF have higher shortage inventory (*Drawdown Effect*)
- In-flow peaking in year ~120+ for MF, QF is from start of recycled cores from SFR decommissioning



Pu Inventory and Flow: Case MI Zoom



Pu Inventory and Flow: Shortage Zoom

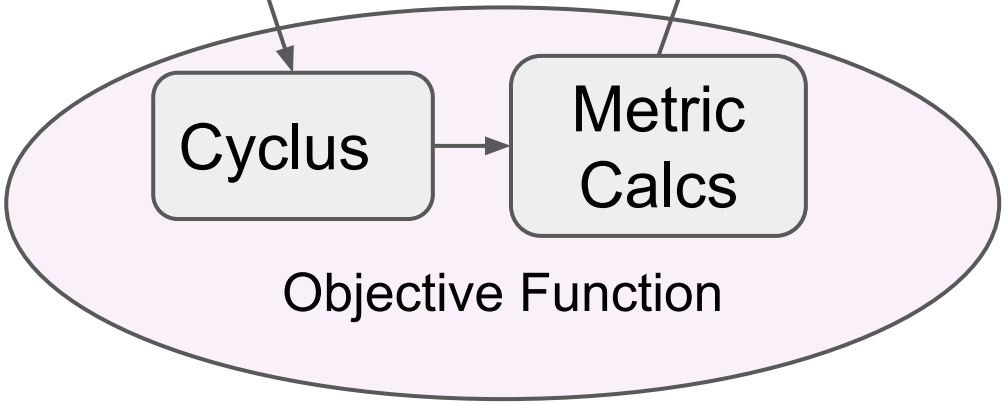


Effects on Optimization

Fuel Cycle Optimization: Basics

Facility	LWR				Repository			Fuel Fab	Objective
Year	1	2	3	…	1	2	…	…	
Trial 1	5	1	3	…	0	1	…	…	233.6
Trial 2	3	1	2	…	0	0	…	…	

Optimizer



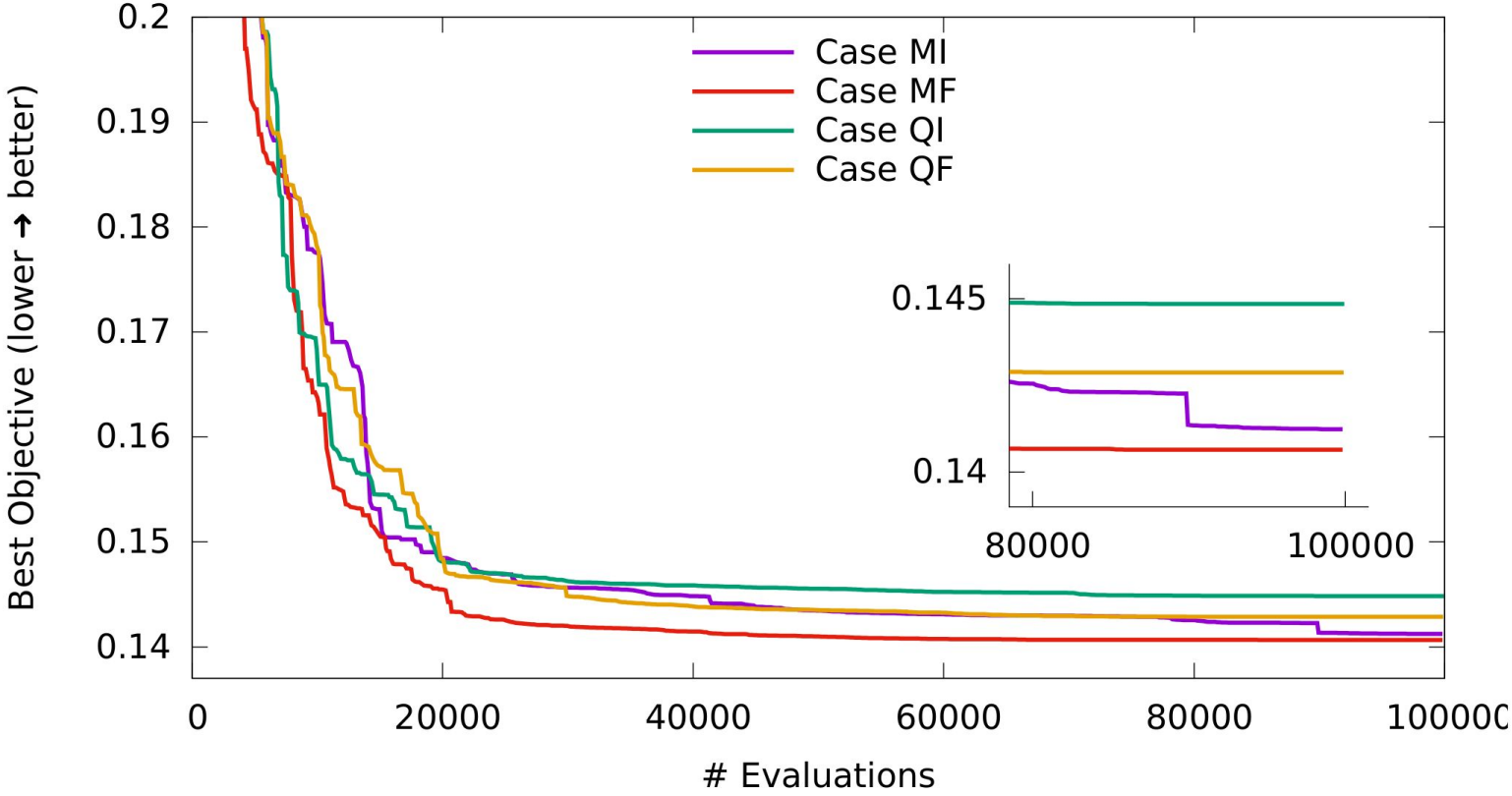
Distributed computing for >100 full simulations per minute!!

Objective Function

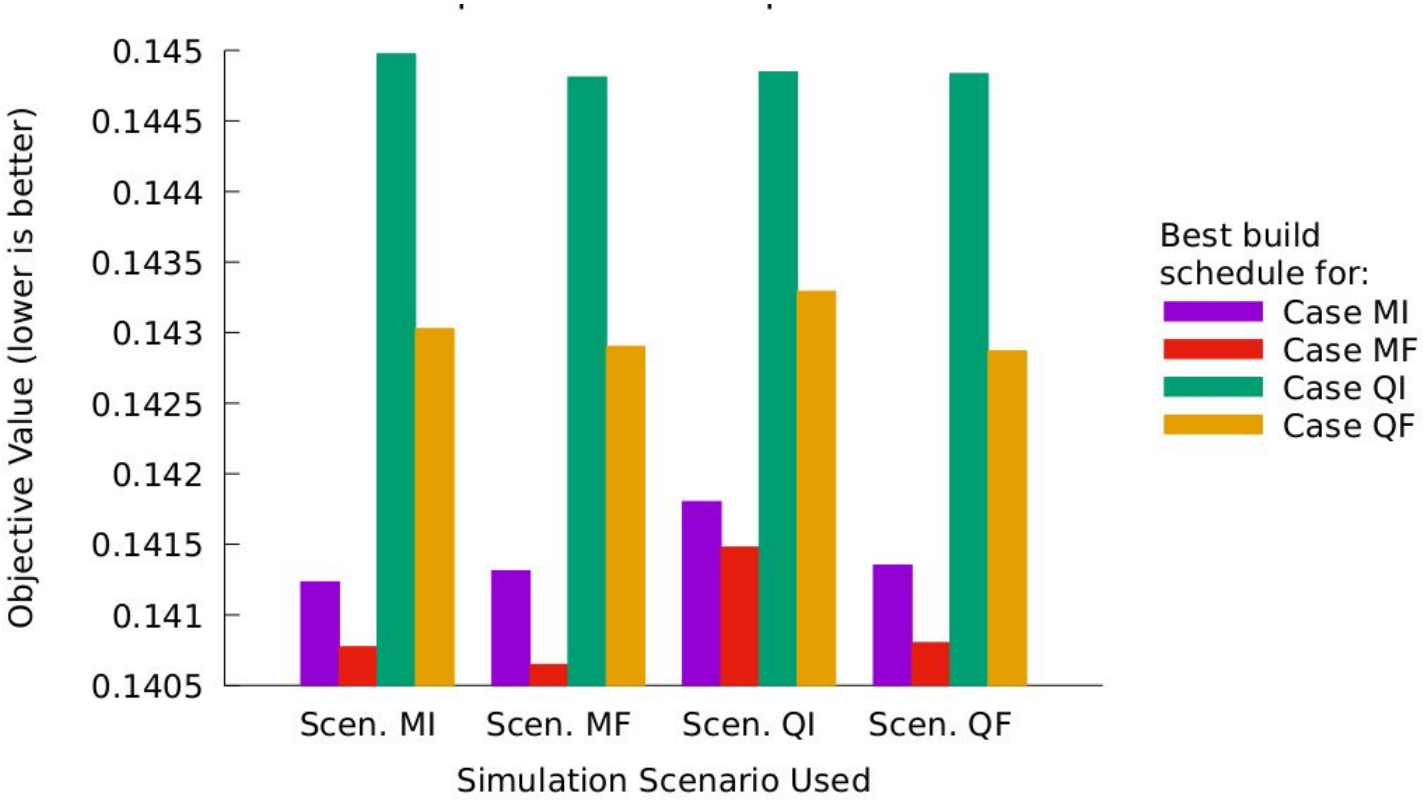
- Penalize LWR energy
- Reward FR energy
- Indirect unfueled FR penalty

$$O_{sim} = \frac{\sum_{t \in sim} E_{t,\,LWR}}{\sum_{t \in sim} E_{t,\,tot}}$$

Results: Optimization Convergence



Results: Optima Cross Comparison



Summary

- Demonstrated Cyclus as a method for comparing fuel cycle modeling choices.
  - Implemented variable time step duration.
  - Created a fleet reactor model.
- Investigated and quantified time step duration and facility discretization effects.
  - Quantified inefficiencies such as fuel sharing and drawdown.
  - Runtime affects.
- Looked at effects on optimization.

Acknowledgements

Questions