Non-algorithmic Capability Gaps for Cyclus and Cycamore Transition Analyses

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Non-algorithmic Capability Gaps for CYCLUS and CYCAMORE Transition Analyses

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1 Introduction

As part of NEUP-FY16-10512, fuel cycle transition scenarios were simulated using CYCLUS and existing CYCAMORE archetypes. The purpose of this study is to identify current non-algorithmic gaps in the capabilities necessary for key transition scenarios. The gaps identified through this exercise mainly pertain to the greedy exchange model, and the manual, static parameter of fuel cycle facilities. The scenarios are from the Idaho National Laboratory Nuclear Fuel Cycle Evaluation and Screening Report (Hereby E&S Report) [2]. The transition scenarios begin with EG01 and transition to EG23, EG24, EG29, EG30, separately. The descriptions of each fuel cycle appear in table 1.

Fuel Cycle	Description
EG01	Once-through using uranium oxide (UOX) fuel in Light Water Reactors (LWRs)
EG23	Continuous recycle of U/Pu with new natural U fuel in fast critical reactors
EG24	Continuous recycle of U/TRU with new natural U fuel in fast critical reactors
EG29	Continuous recycle of U/Pu with new natural U fuel in both fast and thermal critical reactors
EG30	Continuous recycle of U/TRU with new natural U fuel in both fast and thermal critical reactors

Table 1: Evaluation groups identified by the E&S report.

2 Simulation Specifics

The transition scenarios in this study follow a common set of base-case parameters and assumptions, adopted by the Fuel Cycle Options Campaign [1].

The reactor specifications (mass of core, batch, refueling cycle) follow those given by the E&S report appendix B [2].

For the compositions of the fresh and spent fuels, various models give different answers. As will be discussed later, the recipe (more specifically the Breeding Ratio of the Sodium-Cooled Fast Reactor (SFR)), plays a crucial role in the rapidity and success of the transition.

2.1 Important Parameters

For a successful transition, there must be enough fissile materials in store prior to transition to start new advanced reactors. Also, enough surplus fissile materials have to be produced during the transition to support the start of new reactors.

To satisfy such conditions, the important simulation parameters identified are listed in table 2.

Parameter	EG23	EG24	EG29		EG30	
Breeding Ratio	1.059	1.014	1.26	0.70	1.56	0.70
Transition Initiating Time [Month]	1596	1848	2101		1178	
Reprocessing Capacity [MTHM/month]	1*E*100 for all EGs					
Reprocessing Buffer [MTHM]	1*E*100 for all EGs					
Fabrication Throughput [MTHM/month]	1*E*100	1*E*100	2,000	3E6	4,000	900
Fabrication Buffer [MTHM]	1*E*100	1*E*100	1	100	9,000	1,000

Table 2: Parameters for different Evaluation Groups. The left column of EG29 and EG30 are FR values, and the right MOX LWR values.

This is assuming that the following parameters are fixed:

1. Reactor Specifics (listed in tabel 3).
2. Separation Efficiency (99.8%)
3. Increase Rate of Power Demand (1% annual growth in energy demand)

2.2 Recipes

The REACTOR archetype in CYCAMORE uses recipes to approximate transmutation in the Reactor facility, where the spent fuel composition is user-defined and constant.

The recipe from appendix B of the E&S report does not take into account additional deployment of reactors from increased power demand (the

Specification	LWR	MOX LWR	FR
Lifetime [y]	60	80	80
Cycle Time [mos.]	18	18	14
Refueling Outage [mos.]	1	1	1
Rated Power [MWe]	1000	1000	400
Batch mass [kg]	30,106	33,115	6,519
Batches per core	3	3	3
Initial Fissile Composition	4% ^{235}U	9% Pu	Varies by EG

Table 3: Important reactor specifications are listed. The initial fissile composition for FRs vary by evaluation group, as it did for the original evaluation and screening study [2]. The compositions can be found in appendix B of the original report.

breeding ratio of SFRs in the appendix are low), which means that there is no (or very little) extra fissile material (Pu or TRU) produced. For EG23 and EG24, the breeding ratios are a little over breakeven (1.01), which makes deployment of additional reactors solely dependent on fissile material inventory from legacy LWR Used Nuclear Fuel (UNF). For EG29 and EG30, the Breeding Ratios are big higher (1.29 and 1.05, respectively) to feed the mixed oxide (MOX) LWRs, but still does not accumulate fissile material inventory for additional reactor deployment.

To solve this problem, we used an ORIGEN-generated depletion recipe. This recipe has a fresh fuel plutonium composition of 12.9%, and a BR of 1.16. This breeding ratio allows complete SFR transition in 2170 for EG23 and EG24. For EG29 and EG30, the BRs have to be higher to feed the MOX LWRs.

3 Gaps

The test-runs with CYCLUS and CYCAMORE revealed various non-algorithmic gaps of the current CYCAMORE archetypes as well as minor gaps in the CYCLUS framework itself.

3.1 Gap: Static Facility Parameters

The most fundamental issue is that the capacity and deployment (thus the supply) is not demand-driven, but static. All of the parameters for fuel support facilities (FUELFAB, MIXER, SEPARATIONS) remain static throughout the simulation. This is not desirable, especially given the dynamic nature of transition scenarios.

Various parameters, most notably throughput and capacity values of the fuel cycle support fleet, need to adjust according to demand. In transition scenarios with increasing power demand, the demand for fuel and fissile material generally increases over time. The current workaround is to either have a facility with infinite capacity, or to set the capacity to a manually-calculated (look-back method) maximum fuel demand. The infinite capacity method fails for EG29 and EG30, due to the greedy exchange model. The look-back method allows a complete simulation, but inefficiencies occur with the distribution of fissile material, since the facility with the higher demand has to fill up first in order for the facility with the lower demand to receive fissile material.

Figure 1 and fig. 2 plot the fuel demand of MOX LWRs and SFRs, respectively, in an EG29 scenario. This is an example of the look-back method, where, initially, an infinite source of fuel (both MOX and SFR fuel) was deployed to estimate how much the fuel fabrication throughput should be, for a successful simulation. A second simulation then would have a fuel fabrication plant with throughputs that correspond to the maximum value of fuel demand in a timestep (2,000 for MOX, 1900 for SFR fuel).

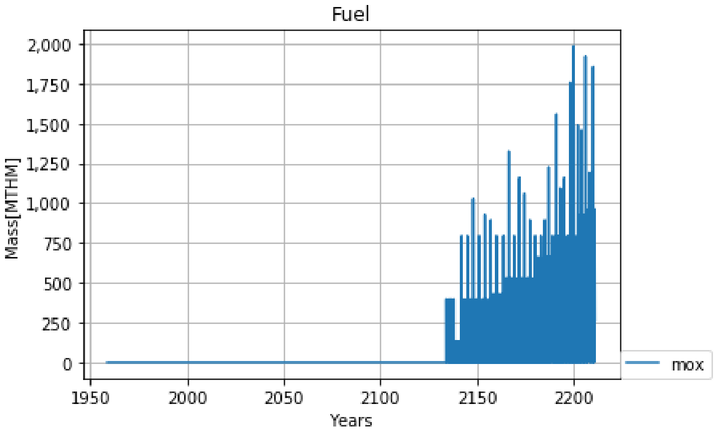

Figure 1: MOX fuel demand for EG29

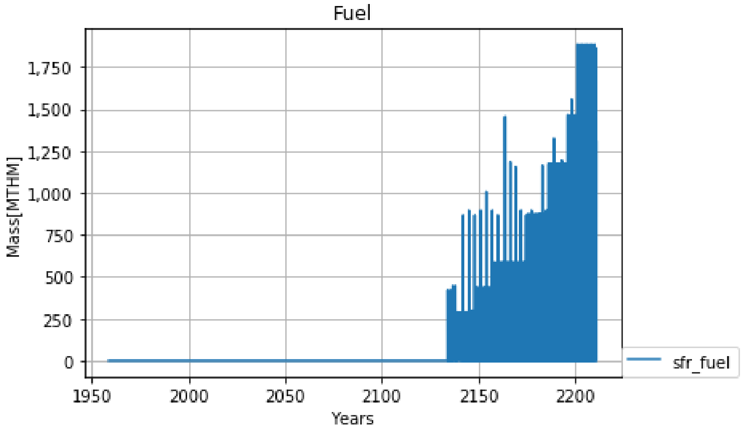

Figure 2: SFR fuel demand for EG29

A fix for this is to have a dynamic throughput that adjusts according to predicted fuel demand, or, more realistically, deploy an archetype with fixed, reasonable, throughput/buffer when fuel demand outpaces existing throughput.

3.2 Greedy Exchange Model

The CYCLUS Dynamic Resource Exchange, is "greedy". That is, if there isn't enough supply for all demands, the bigger demand gets filled first. This "greedy" modeling decision sought to mimic real markets in which large capacity buyer receive preferential treatment. In EG23 and EG24, there is one archetype that receives separated fissile materials. That archetype can have infinite buffer/throughput because it is the only archetype with the demand for that commodity. However, EG29 and EG30 has two archetypes that compete for the fissile materials (ie. MOX fuel fab competes with SFR fuel fab for separated plutonium). In this case, if both fabrication plants have infinite buffer/throughput, one fabrication takes all the separated fissile material, leaving the other plant idle.

3.3 Individual Demand Estimation

Currently, the CYCLUS framework's market is completely agent-based. At every timestep, each agent 'submits' its demand and supply and the trade is made. However, this individual frame can cause inefficiencies mentioned previously. A more efficient process would be to set all demands proportional to the fuel demand. An example is illustrated in fig. 3.

3.4 A Need For Market-Peeking

The CYCLUS framework can benefit greatly from a market-peeking capability, where each agent can query the market (previous transactions or demand) to adjust its parameters. For example, fuel fabrication agents could query the previous (or, eventually, expected) demand of fuel and adjust their throughputs to meet the demand. The market-peeking capability is essential for demand-prediction models.

Moreover, with the market-peeking capability, support facilities could estimate adjust their capacities by estimating the demand of fuel/fissile material proportional to power demand (‘power’ is a market commodity in CYCLUS).

3.5 Irresponsible deployment

The DEPLOYINST model deploys prototypes in a user-defined time period. With infeasible input specs, it still deploys reactors without checking fuel availability. The deployed reactor is remains idle if the fuel supply is short. Deploying new reactors without sufficient fissile material to support them can cause other already-deployed reactors without fuel, causing a cascade of shutdowns. Using the market-peeking or feedback capability, new reactors could be deployed only if there is sufficient fuel to support the startup of the reactor as well as currently deployed reactors.

4 Additional Possible Improvements

Though not critical to the current goal, having the following capabilities may increase the accuracy of simulations.

4.1 Blanket capability for REACTOR

For SFRs, the blanket and the driver have different effective fuel residence times, meaning that they should (ideally) be discharged and loaded separately. However, with current capabilities, the option is to average the mass and composition of driver and blanket to treat it as one commodity.

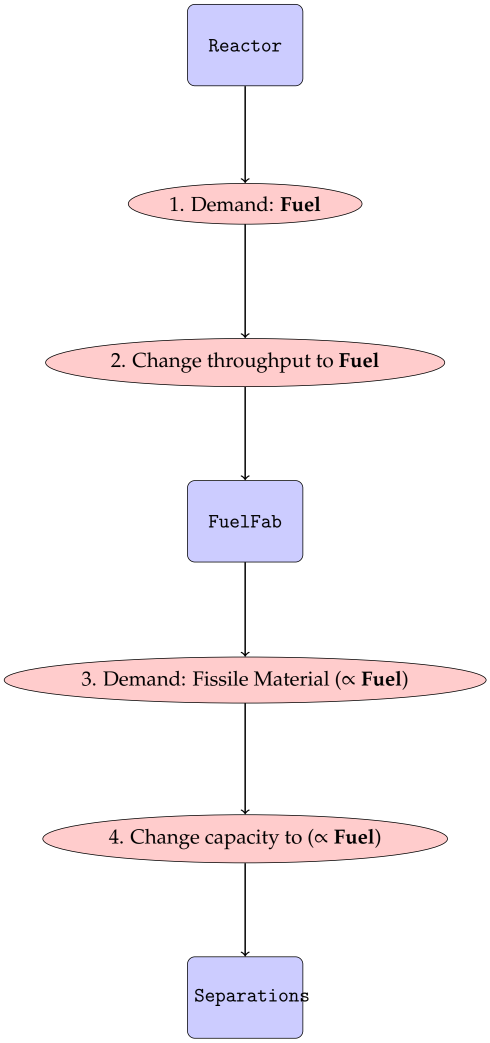

Figure 3: Fuel-centered Demand Logic Flow

4.2 Depletion Calculations

Depletion calculations are done outside of the simulation. However, if advanced reactor models like CYBORG or BRIGHT-LITE are utilized, there could be more accurate depletion calculations and perhaps dynamic Breeding Ratio modeling.

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