Modeling Post-JCPOA Cascade Performance with Cyclus

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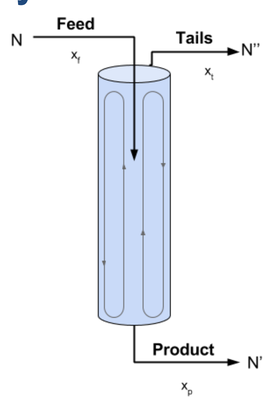
Background

The Joint Comprehensive Plan of Action (JCPOA)[1] agreement

- Severely limits Iran's ability to enrich Uranium
- Lifts many of the economic sanctions that had been placed on Iran.

This analysis introduces a facility with parameters consistent with the JCPOA-defined capacity and explores its performance when asked to enrich material above JCPOA limits using Cyclus.
The Cyclus fuel cycle simulator is designed to support the dynamic addition of novel facility models into fuel cycles with both declared and undeclared facilities.

Analytical Solution of a Gas Centrifuge



$$\theta = \frac{N'}{N}$$

$$\alpha = \frac{x_p}{1-x_p}\frac{1-x_f}{x_f}$$

$$\beta = \frac{x_f}{1-x_f}\frac{1-x_t}{x_t}$$

$$\delta U = \frac{\theta}{1-\theta} L \frac{(\alpha-1)^2}{2}$$

$$\delta U_{Rätz}(L, F, \theta, Z_P)$$

CascadeEnrich

The CascadeEnrich archetype[2] was developed to model gas centrifuge enrichment cascades at a higher fidelity than previous Cyclus enrichment models, relying on individual centrifuge and cascade design parameters to build an ideal cascade configuration instead of integral facility parameters.

1. Design the first stage, determine θ0, such that α0 = β0 using δU.
2. Other stages, determine θi, such as αi = βi = α0 → θi, (i.e. δU → θi).
3. Adds stripping and enriching stages until tails assay < targeted tail assay, and product assay > targeted product assay.
4. Determine material flow from the cut at each stages.

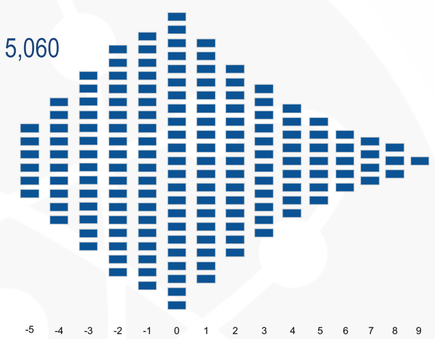
JCPOA-Compliant Cascade

The JCPOA

- Limits Iran's enriching centrifuges to 5,060
- Using only the older IR-1 design
- Maximum 30 total cascades.

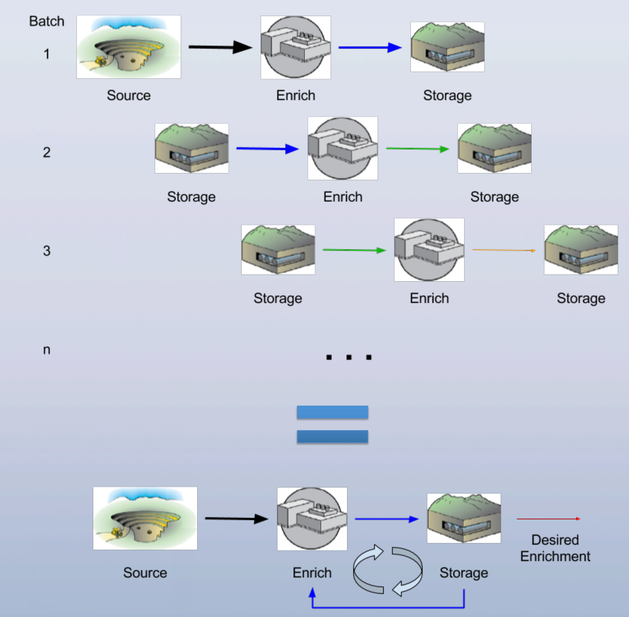
The deployed `CascadeEnrich` cascade determines

- A 15-stage, 166-centrifuge cascade
- Cascade response to non-ideal feed enrichments in batches 2 to *n*
- More centrifuges in stripping stages than similar analyses[3][4][5].



Single Cascade Analysis

- Considers only a single cascade
  - Assumes all 29 other cascades operate identically
- Uses batch recycling I
  - One cascade simulation per batch, with the feed of a particular batch matching the product of the previous batch.

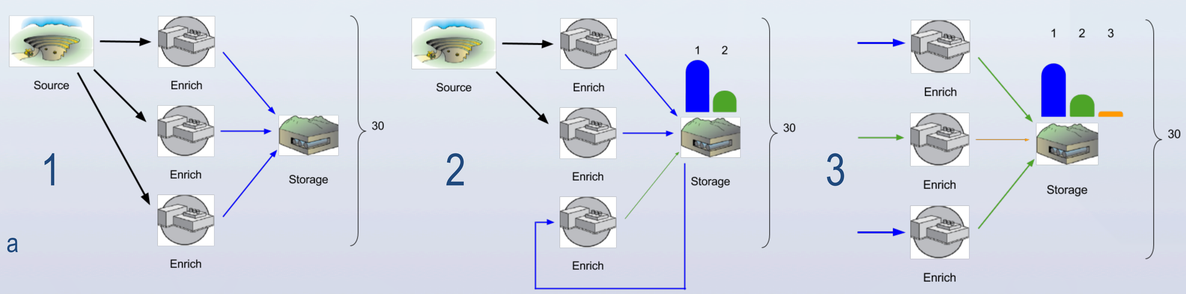


Batch	Feed	Product	Feed Flow	Product Flow
1	0.72%	3.8%	1 kg	133 g
2	3.8%	17.3%	133 g	17.7 g
3	17.3%	53.1%	17.7 g	2.35 g
4	53.1%	85.9%	2.35 g	0.31 g
5	85.9%	>97%	313 mg	41.7 mg

Future Work

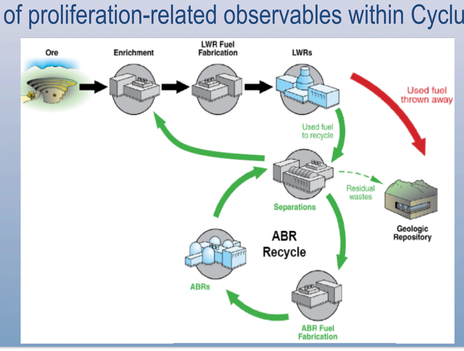
In reality, the quickest way to achieve over 90% enriched Uranium would be for each of the 30 cascades to act individually. A realistic model of the full would optimize the strategy for each cascade:

1. Natural Uranium receives the highest priority (10)
2. When there is no longer enough feed for all cascades, a cascade must start pulling the next batch from storage
3. The next highest priority (9) is given to the final batch *n*, with each batch below *n* receives a successively lower priority, ensuring cascades prioritize enriching higher batches when enough feedstock is available



Batch	Feed Source	Priority
1	Mine	10
…	Storage	…
n-2	Storage	7
n-1	Storage	8
n	Storage	9

`CascadeEnrich` enables the detection of a richer set of proliferation-related observables within Cyclus



References

[1] U.S. Department of State, "Joint Comprehensive Plan of Action", Vienna, Austria, 2015.
[2] McGarry, Meghan; Mouginot, Baptiste (2017): mbmore. figshare. https://doi.org/10.6084/m9.figshare.5097694 Retrieved: 17:16, Nov 22, 2017 (GMT)
[3] Alexander Glaser, 2008, "Characteristics of the Gas Centrifuge for Uranium Enrichment and Their Relevance for Nuclear Weapon Proliferation". Science and Global Security 1–25. https://doi.org/10.1080/08929880802335998
[4] Albright, D., Brannan, P., Walrond, C., 2011. "Critique of Gregory Jones's Breakout Estimates at the Natanz Fuel Enrichment Plant (FEP)". Institute for Science and International Security.
[5] Ralph Langner, 2013. "To Kill a Centrifuge: A Technical Analysis of What Stuxnet's Creators Tried to Achieve". Langner Group.

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