Graph representation of a fuel cycle for acquisition pathway analysis

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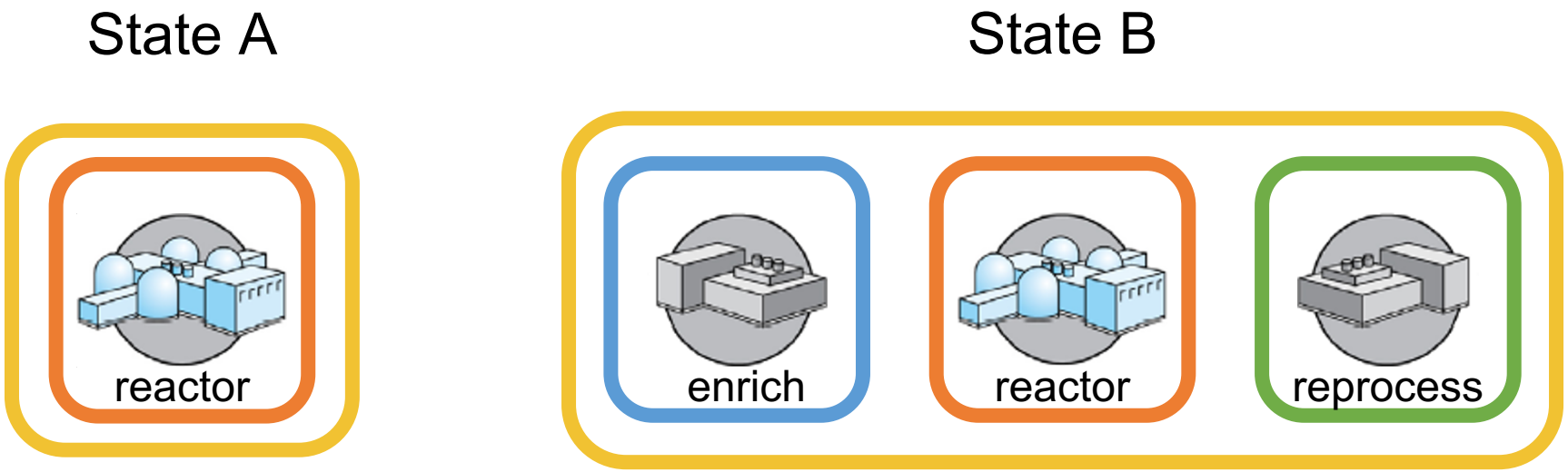
Katie Mummah
University of Wisconsin-Madison
Department of Engineering Physics
Rising 4th year graduate student
Paul P.H. Wilson

Introduction and Motivation

- Safeguards implemented at facility level until 1991
- Additional Protocol was developed, and eventually the “State-level Concept” was born
  - States should be treated holistically when applying safeguards
  - maximize efficient use of safeguards resources



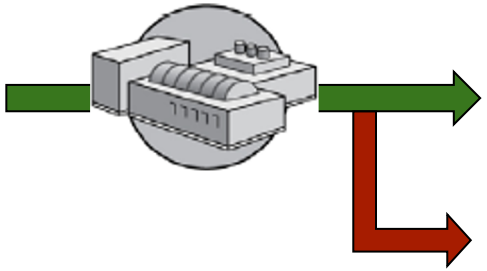
Introduction and Motivation

APA is "the analysis of all plausible acquisition paths or acquisition strategies for a state to acquire nuclear material usable for the manufacture of a nuclear explosive device"

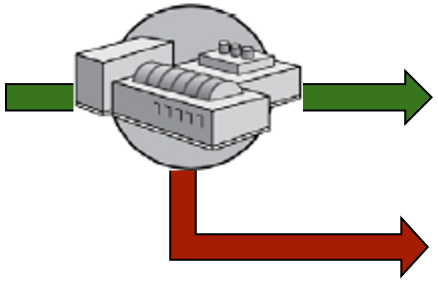
- Goal: extend Cyclus fuel cycle simulator to conduct APA
  - Leverage Cyclus ability to model pathway throughput, time-dependent analysis

Types of path steps to be captured

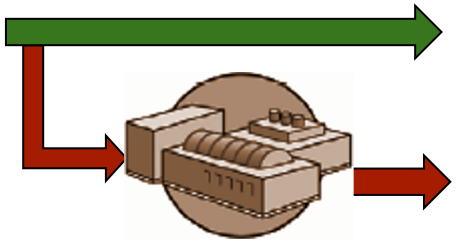
Diversion of declared material



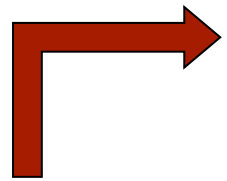
Misuse of declared facility



Clandestine Facility

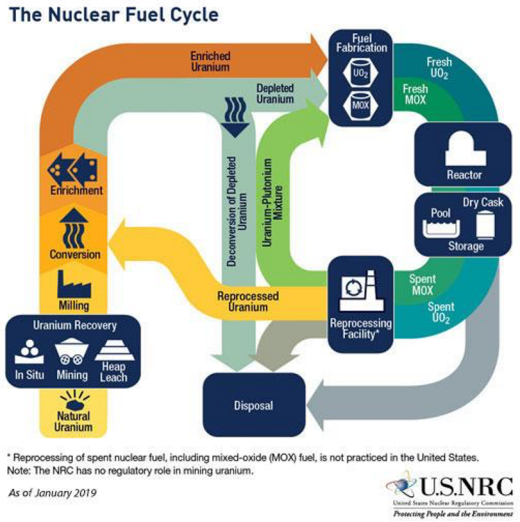


Undeclared import



Mission Relevance

- Improving global material security through quantifying State-level fuel cycle safeguardability
- Addresses IAEA R&D objective V.2.R1 to enhance state evaluation capabilities

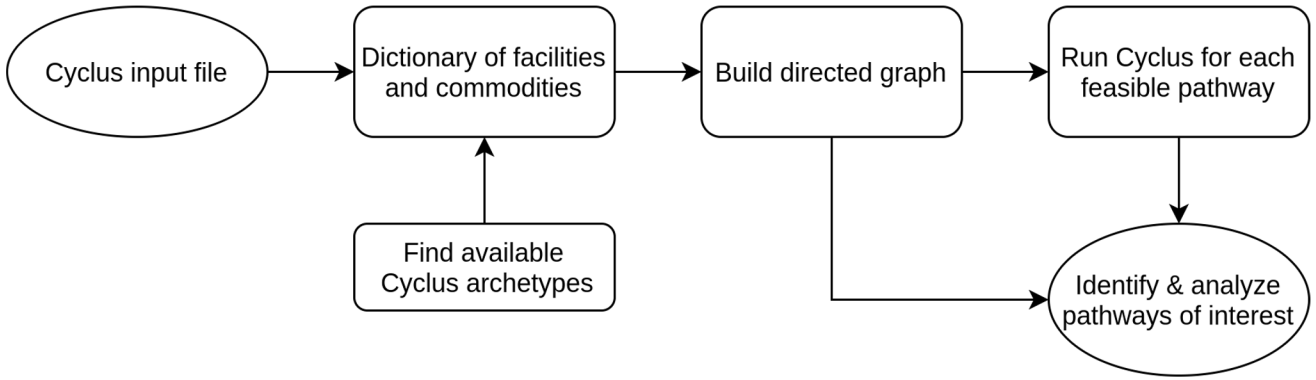


P. Pavlicek/IAEA

IAEA Imagebank

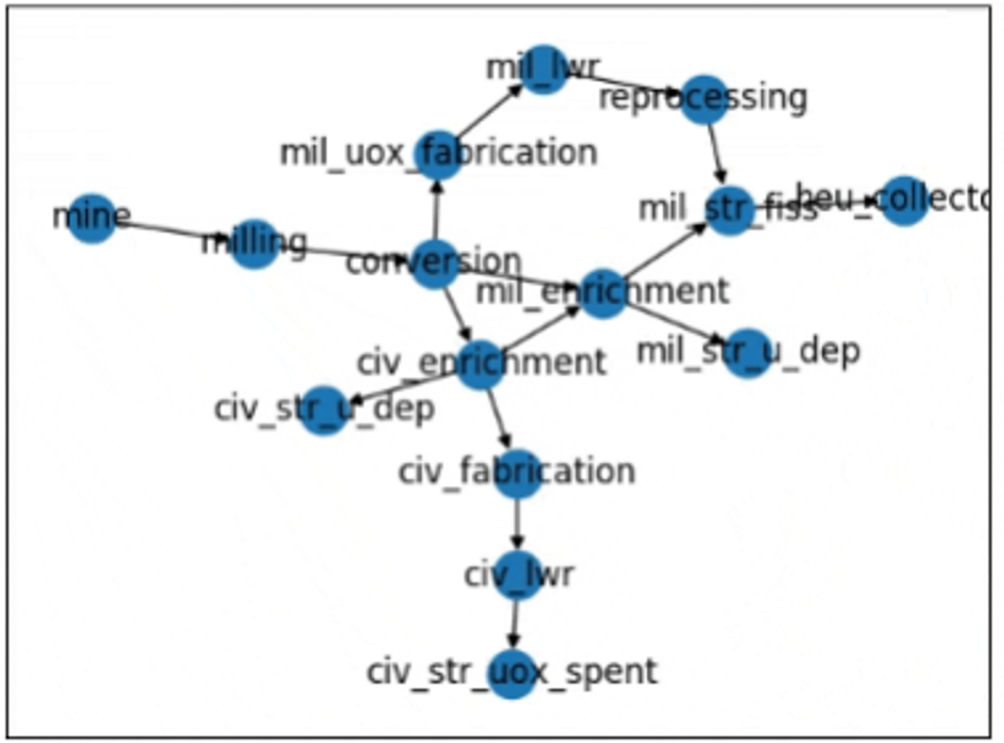
Technical Approach

- Cyclus treats the fuel cycle as a competitive market, only connects the optimum path
- Solution: build tool Trailmap on top of Cyclus
  1. Trailmap reads Cyclus input file of facilities and commodities, creates a directed graph of potential material flows
  2. All pathways from a root “Source” node are enumerated.
  3. Output sorted for parameters of interest, e.g.
     a. Shortest pathway
     b. Highest throughput
     c. All pathways that go through a facility of interest



Results

- Simple example: civilian and military fuel cycles with diversion at enrichment
- Cyclus can enumerate and sort pathways



Pathways

- ('mine', 'milling', 'conversion', 'civ_enrichment', 'civ_fabrication', 'civ_lwr', 'civ_str_uox_spent'),
- **('mine', 'milling', 'conversion', 'mil_enrichment', 'mil_str_fiss', 'heu_collector'),**
- ('mine', 'milling', 'conversion', 'civ_enrichment', 'mil_enrichment', 'mil_str_u_dep'),
- **('mine', 'milling', 'conversion', 'civ_enrichment', 'mil_enrichment', 'mil_str_fiss', 'heu_collector'),**
- ('mine', 'milling', 'conversion', 'civ_enrichment', 'civ_str_u_dep'),
- ('mine', 'milling', 'conversion', 'mil_enrichment', 'mil_str_u_dep'),
- **('mine', 'milling', 'conversion', 'mil_uox_fabrication', 'mil_lwr', 'reprocessing', 'mil_str_fiss', 'heu_collector')**

Expected Impact

- Streamlines identification of material diversion pathways for any State or hypothetical fuel cycle
  - Objective and reproducible
- Brings expertise in modeling material flows through the nuclear fuel cycle into the nonproliferation community

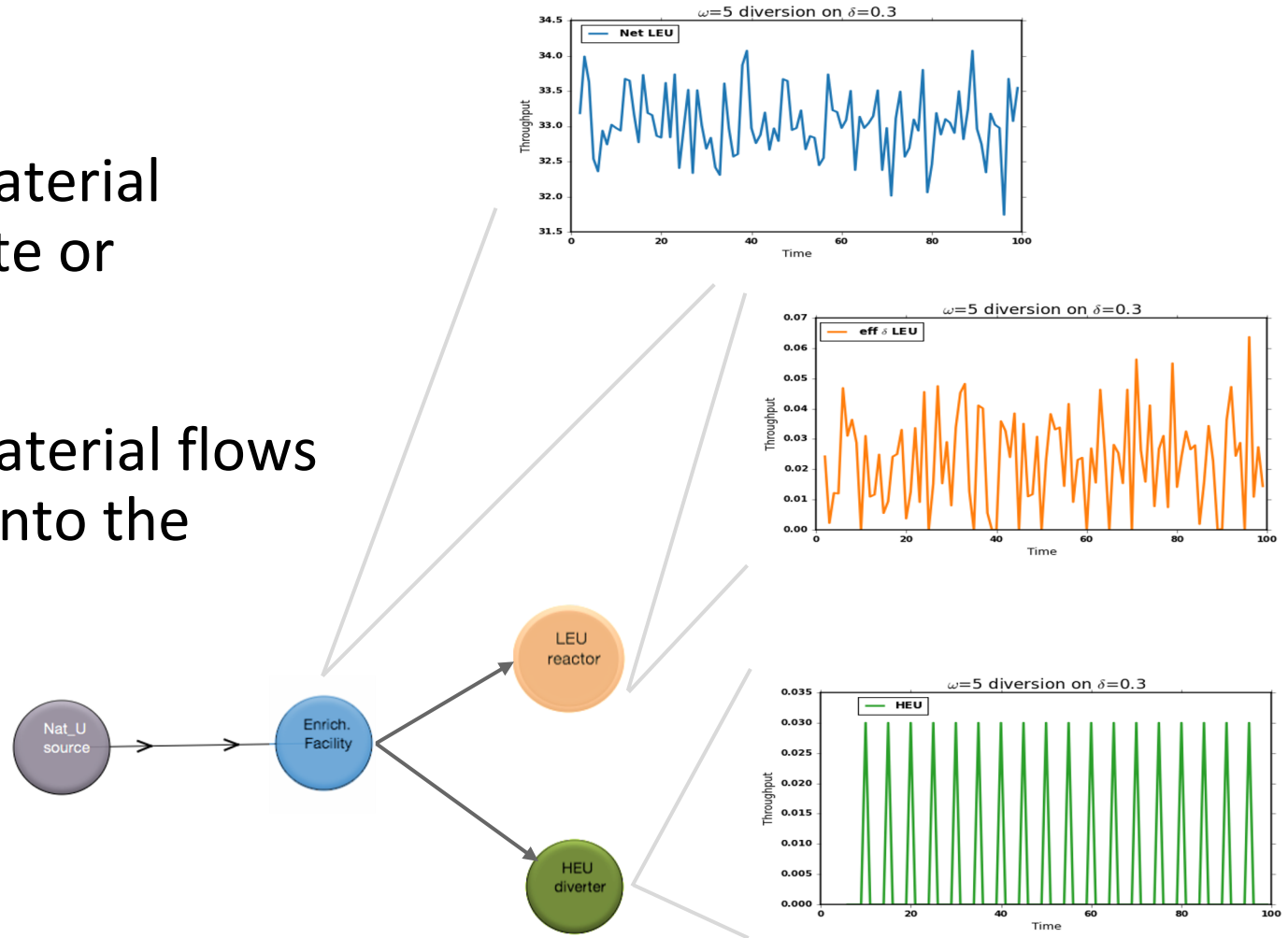


diagram: Cyclus development team

MTV Impact

- Project developed out of CVT internship at Los Alamos
- Will spend 3-6 months at Los Alamos in 2021 working on this project
- Potential future partnership with Vienna University of Technology
- Built network from 2019 MTV fuel cycle facility modeling workshop at UW
  - Lead to internship offer from ORNL
- 2020 MTV meeting student-national lab luncheon

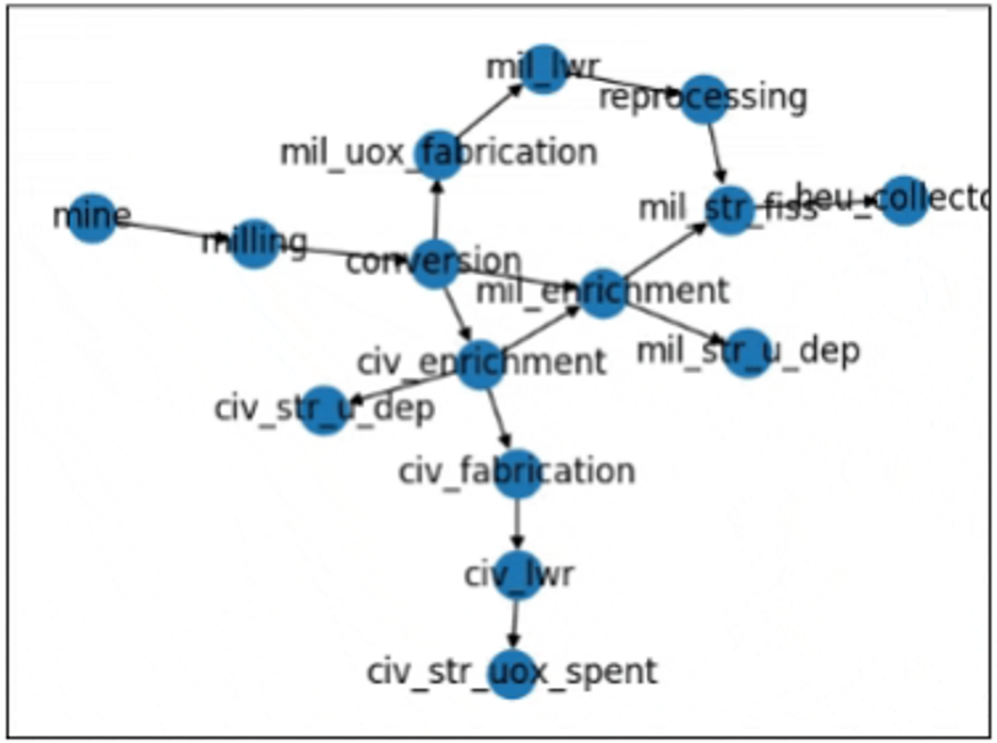
Conclusion and Next Steps

Cyclus can conduct APA

- APA automates a process that was previously conducted by experts by hand
- Addresses IAEA R&D objective V.2.R1
- Improving global material security through quantifying State-level fuel cycle safeguardability

Next Steps

- Determine features that will be most useful to the end user
- Add higher fidelity to Cyclus facility models
- Run Cyclus to obtain information such as path throughput/capacity
- Eventually: add “safeguards” to Cyclus models



Acknowledgements

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