Acquisition Pathway Analysis using Fuel Cycle Simulators

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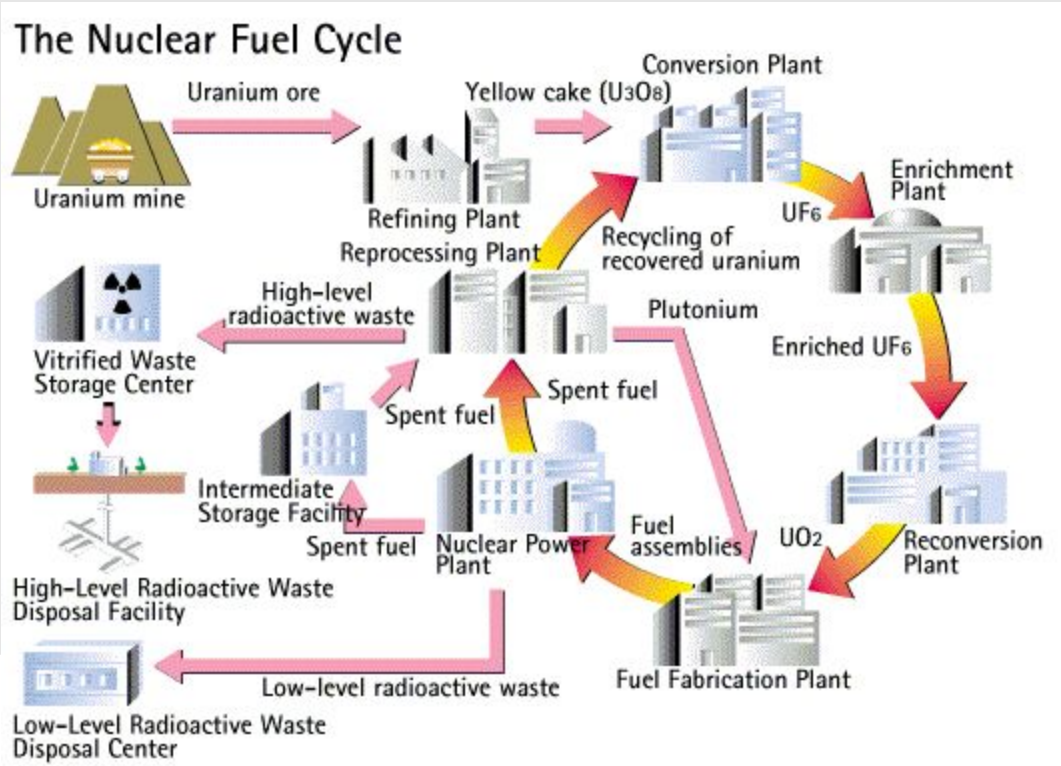
Motivation behind APA

- In applying safeguards, a State should be considered holistically
- Need: objective method of analyzing an entire fuel cycle and applying safeguards



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”

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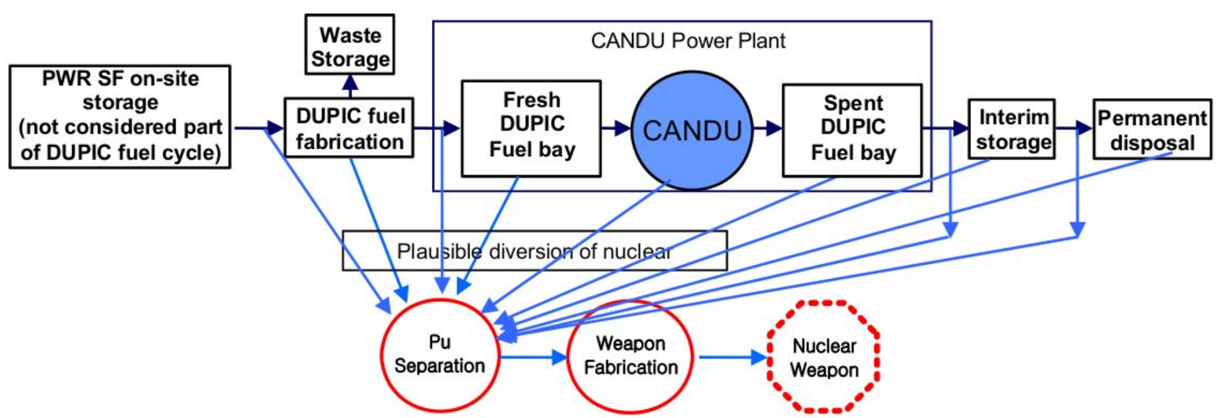
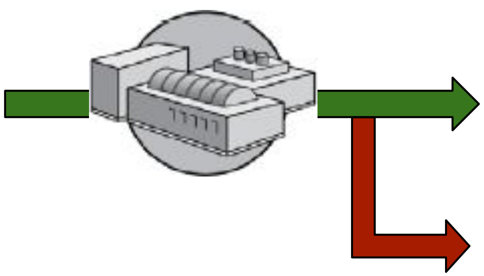
- Describe facilities that exist in a State
  - Some information at a sub-facility level
- Describe flows of material within & among facilities
- Creates a directed graph of information
  - Graph analysis provides information about plausible pathways
- Assess time, throughput, and technical capacity to complete a path



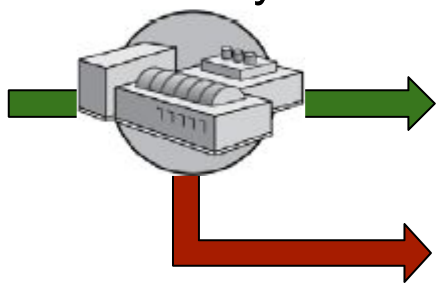
DUPIC material flow, possible diversion points, and coarse pathways considered [Fig 5., IAEA-TECDOC-1684]

Types of path steps to be captured

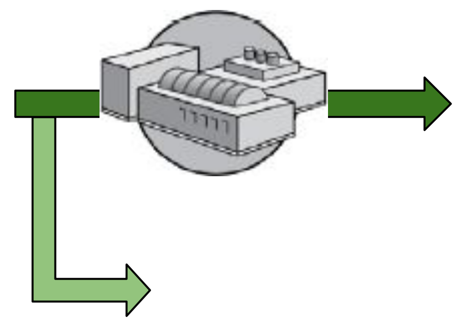
Diversion of declared material



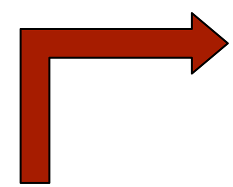
Misuse of declared facility



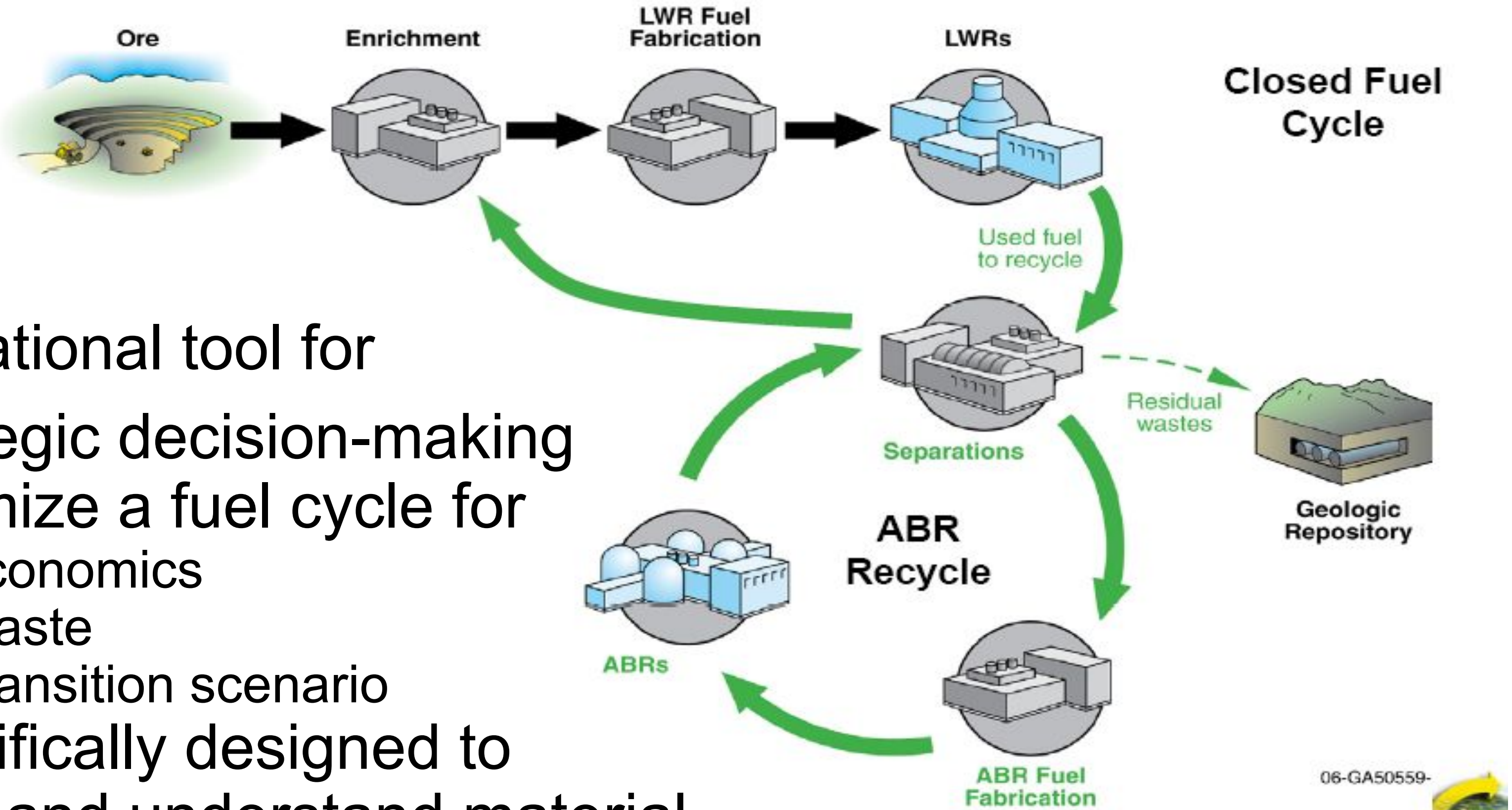
Produce Undeclared Material in a Clandestine Facility



Undeclared import



Fuel Cycle Simulators



Computational tool for

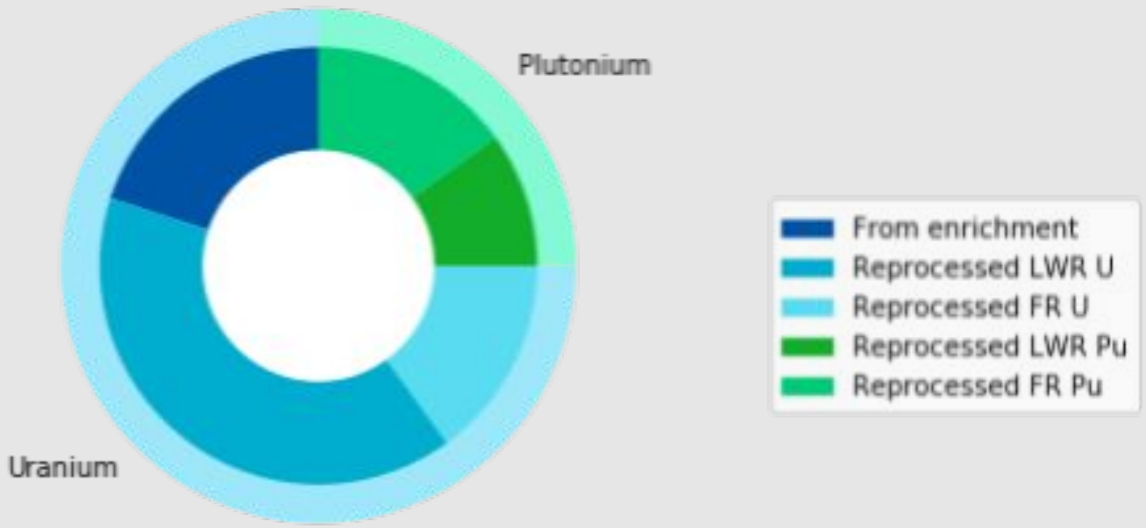
- Strategic decision-making
- Optimize a fuel cycle for
  - Economics
  - Waste
  - Transition scenario
- Specifically designed to track and understand material flows in a given fuel cycle

A variety of NFC Simulators already exist

- USA
  - Vision (INL)
  - DYMOND (ANL)
  - CAFCA (MIT)
  - NFCSim (LANL)
  - Cyclus (UW)
  - VEGAS (UT-Austin)
- South Korea
  - FUTURE
- Hungary
  - SITON
- France
  - COSI
  - CLASS
- Russia
  - DESAE
- Other International
  - NFCSS/Vista (IAEA)
  - SMAFS (OECD/NEA)
  - DANESS (Nuclear-21)

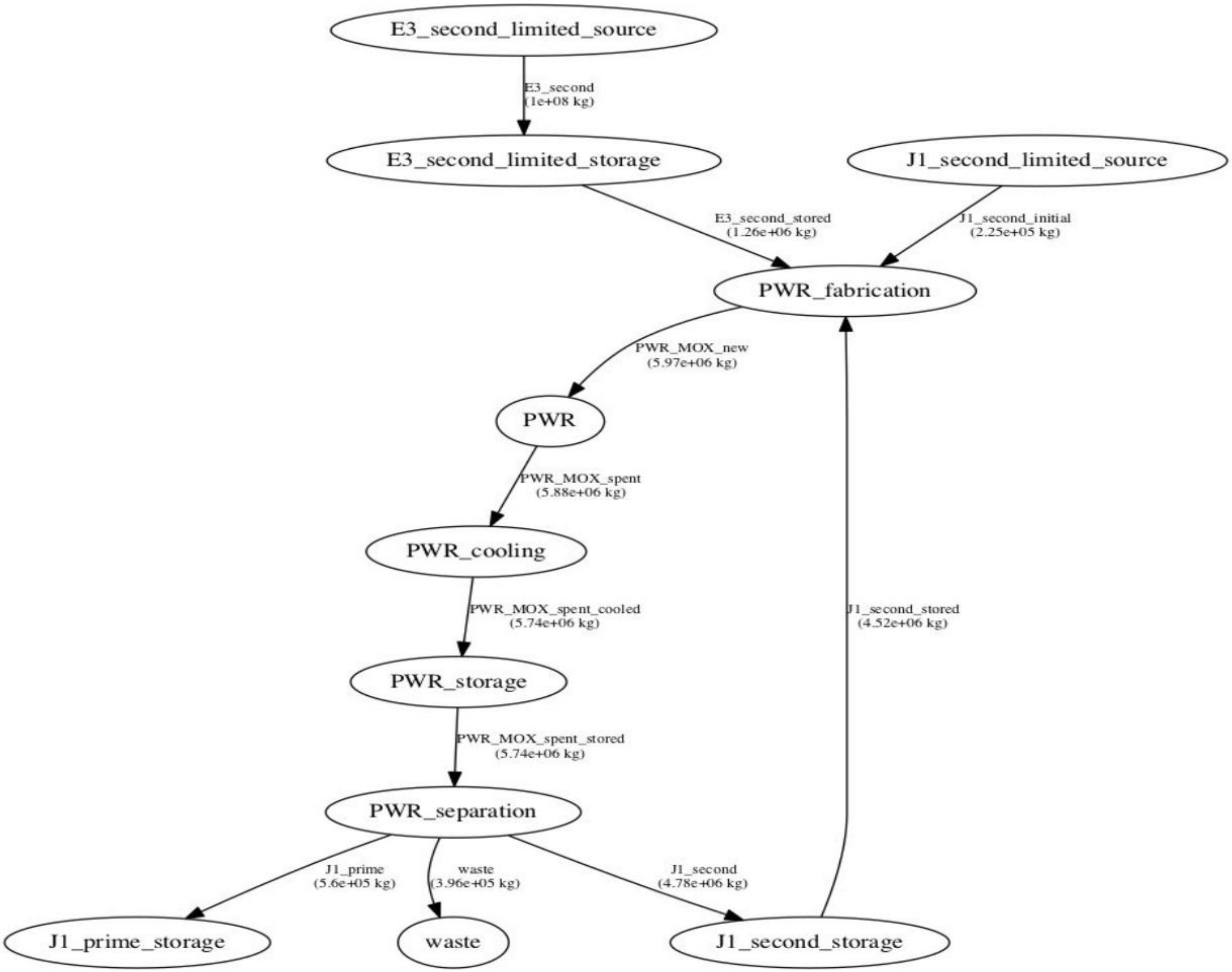
Materials tracking and throughput

- Theoretical throughput of any path
- Discrete materials tracking allows for full path history to be saved and analyzed.
  - Analyze several paths undertaken together
- Uncertainty propagation such as in [1]



[1] G. Krivtchik, "Analysis of uncertainty propagation in nuclear fuel cycle scenarios," Grenoble, 2014.

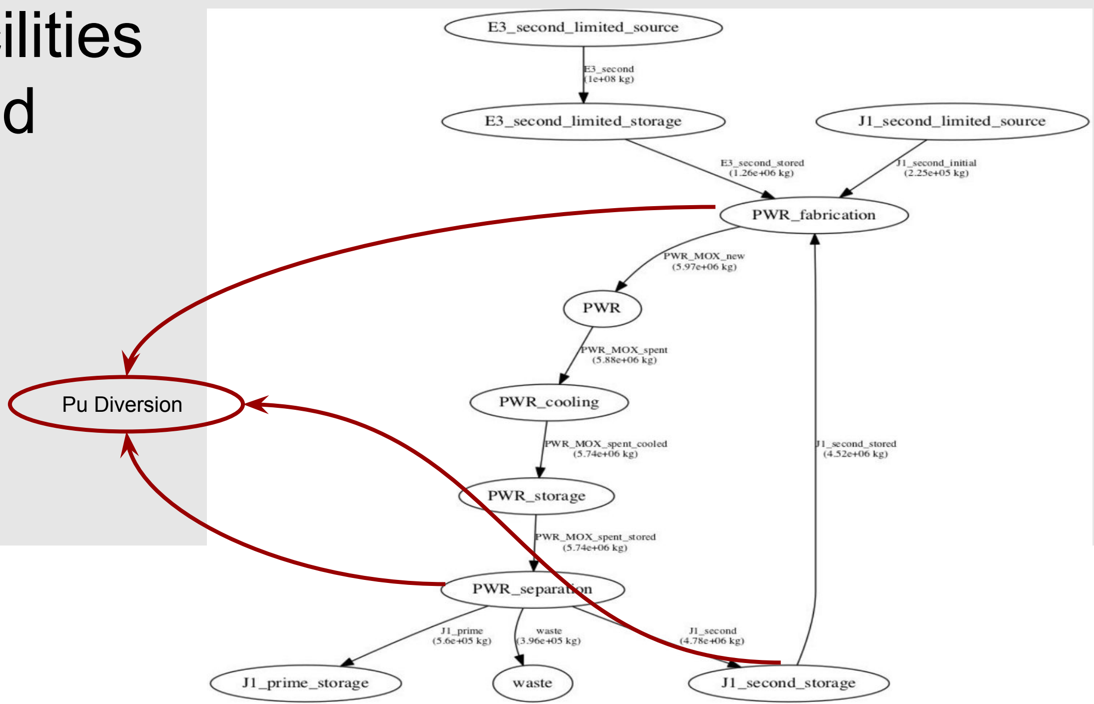
Simulation Specification



CYCLUS

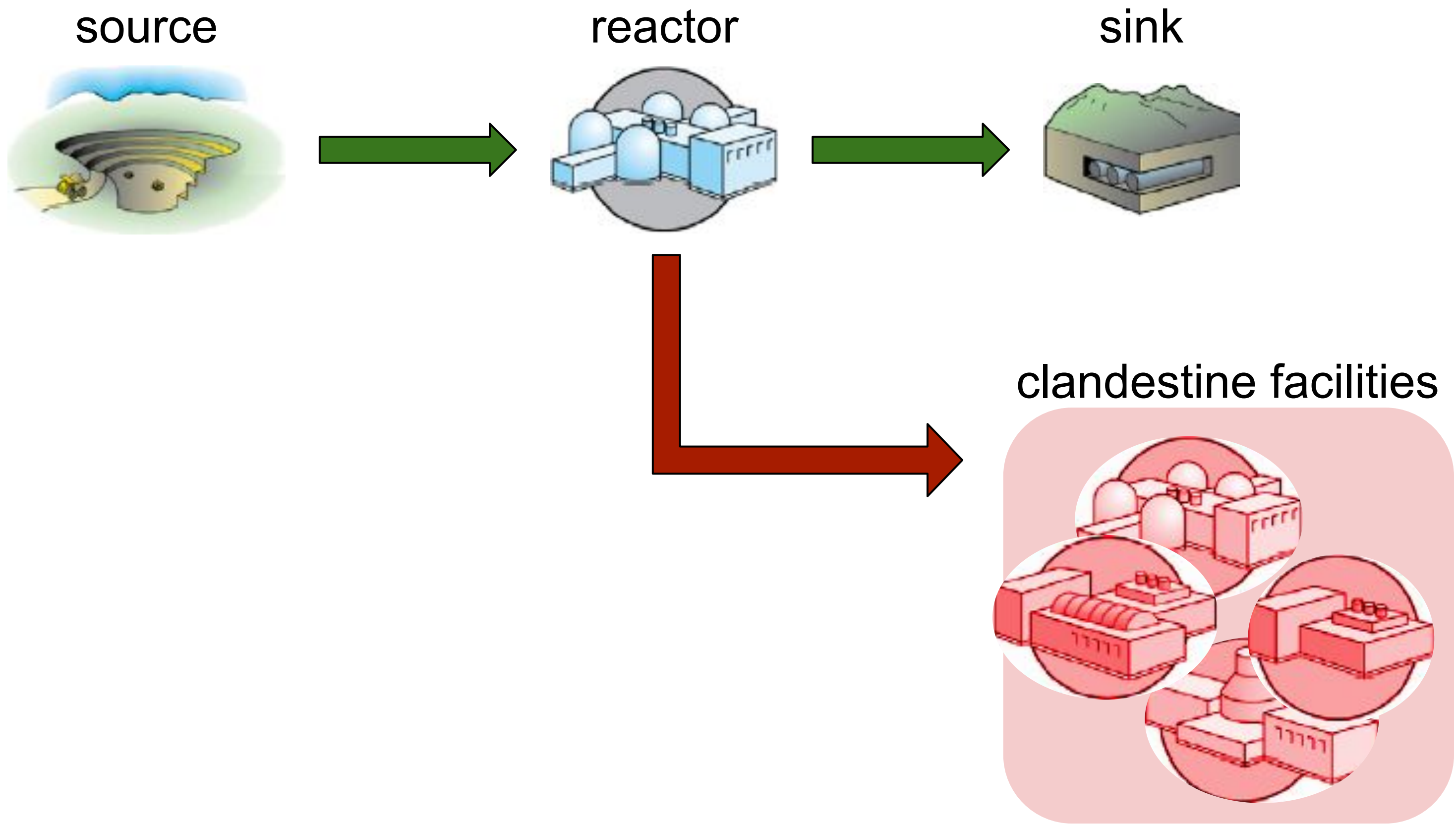
CYCLUS Simulation

- Prototypes are deployed as facilities over time
  - Facilities can enter and leave simulation dynamically
- Materials change composition and/or form within facilities
  - Discrete material tracking
- Material flow between facilities according to market-based model
- May include clandestine facilities

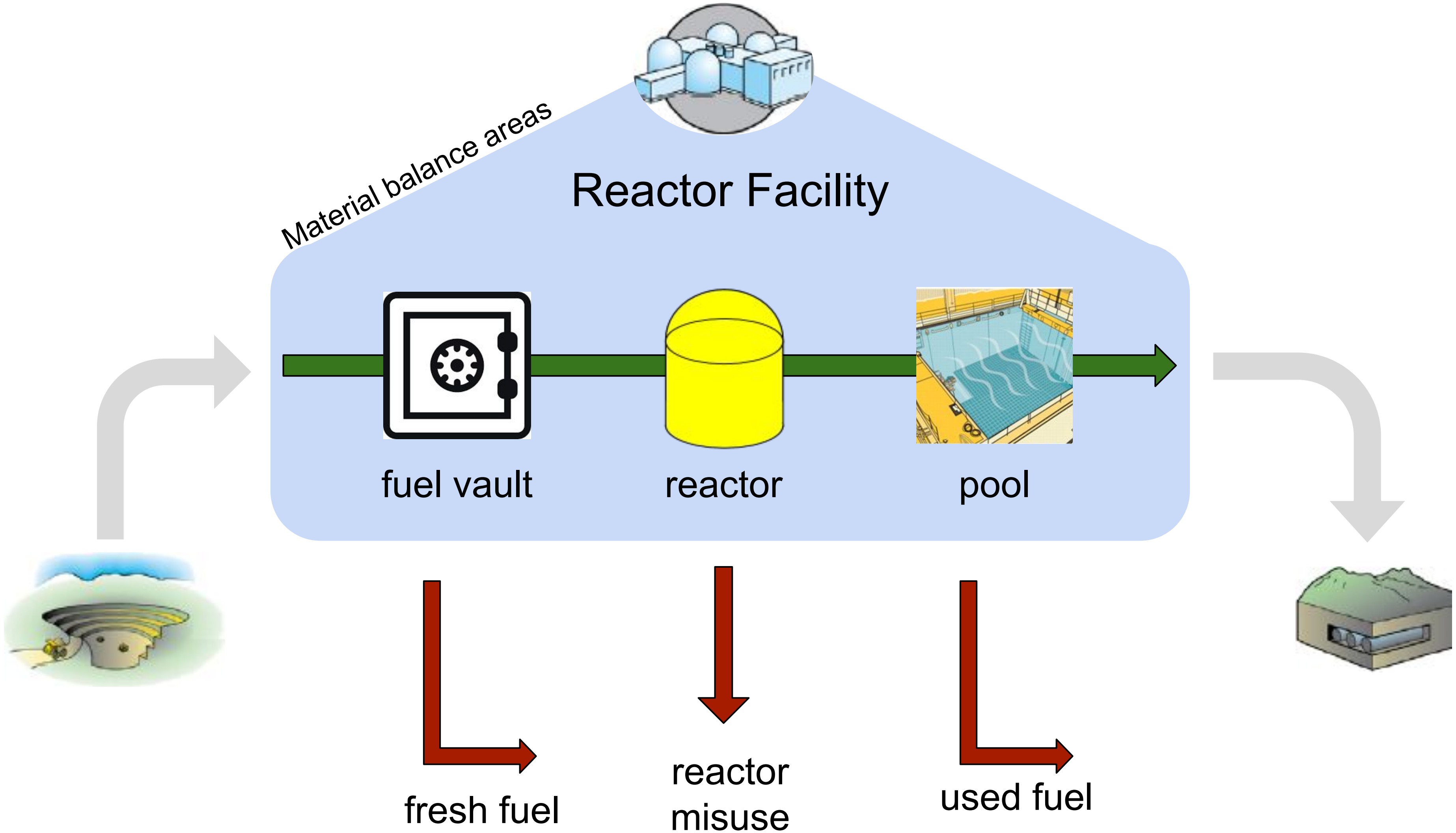


Current material flow in CYCLUS

- Cyclus facilities aren't currently detailed enough to conduct a useful APA



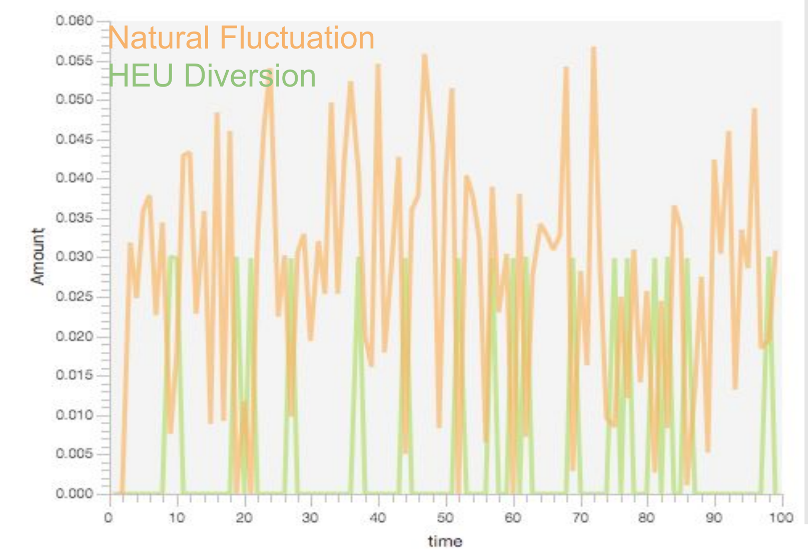
Desired future fidelity



Summary

- Fuel cycle simulators can conduct APA
- Building this capability into Cyclus
  - Early work to produce all paths
  - Assess throughput and time needed to complete paths
  - Expand on facility models, develop material balance areas
  - Add “safeguards” to facilities across the fuel cycle

Expected Fluctuation or HEU Diversion?



Acknowledgements & References

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2. Renda, G. *et al.* The potential of open source information in supporting Acquisition Pathway Analysis to design IAEA State Level Approaches. in *IAEA International Safeguards Symposium* (2014).
3. K. D. Huff *et al.*, "Fundamental concepts in the Cyclus nuclear fuel cycle simulation framework," *Advances in Engineering Software*, vol. 94, pp. 46–59, Apr. 2016.
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Brute Force Approach

- Represent each MBA or inventory KMP as a separate “facility”
  - Define commodities that ensure material only flows within real-world facilities
  - Create extra *sink* facilities that can receive fissile material from all locations
- Provides pathway analysis with very little modification to Cyclus
- Doesn’t scale well for material flow information with deployment of many real-world facilities
  - Conflict between commodity naming and intra-facility flow restrictions
  - Market-based material transfer mechanism grows

Resource Buffer Approach

- Most facility archetypes already use internal notion of *Resource Buffers*
  - Currently used to allow inventories of feed, product and waste streams
- Internal flows to/from Resource Buffers not exposed for either
  - Graph generation/pathway analysis
  - Throughput analysis
- Enhance/extend Resource Buffers to support needs of pathway and throughput analysis
  - Expose internal flows of materials to graph generation
  - Record flows in/out of Resource Buffers in output data
- May be need for process modeling at Resource Buffer level
  - Currently only implement storage

Sub-Facility Approach

- Hybrid between brute force and Resource Buffers
- Extend agent hierarchy to allow sub-facilities that operate as part of larger facility archetypes
- Improved scaling in simulations with many facilities
  - Commodity naming only needs to be unique in local scope of parent facility
  - Sub-facilities don't participate in market-based material transfer process (DRE)
  - Sub-facility archetypes can include physical process models