Modeling Pyroprocessing Safeguards in Cyclus

A Brief Summary

Advanced Reactors and Fuel Cycles Group

University of Illinois at Urbana-Champaign

January 28, 2020

ILLINOIS

Outline

Education

MISSOURI S&T

ILLINOIS
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

WASHINGTON UNIVERSITY IN ST. LOUIS • 1853 •
Per Veritatem Vis

Washington University

Figure: Dr. S. Murty Goddu - Radiation Oncology

Figure: Washington University's Proton Therapy

CNEC - UIUC

CNEC
Consortium for Nonproliferation Enabling Capabilities

- NNSA funded consortia:
  - Frequent workshops/conferences.
  - Lab interaction.
- IAEA NDA training:
  - Introduction to NDA techniques.
  - Safeguard applications - UNCL.
- Software Development - Cyclus

Figure: Professor Katy Huff

Outline

Introduction

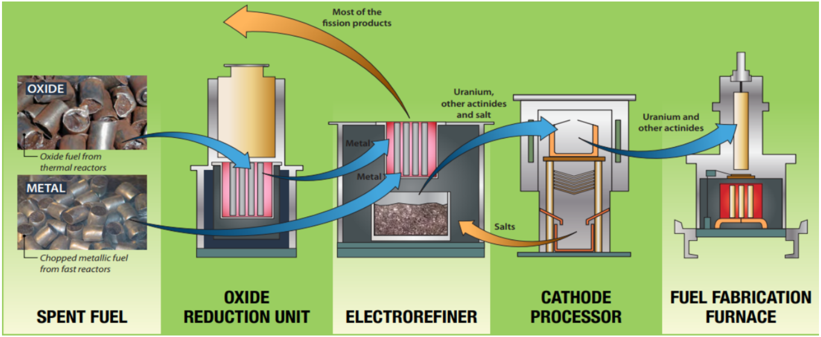

Figure: Argonne demonstration of a basic pyro plant [3].

Motivation/Goals

Motivation

- Safeguard by design
- Model diversion inside facilities
- Transition from LWR to SFR

Goals

- Detect diversion using signatures and observables.
- Determine optimum detector and inspection locations in pyroprocessing
- Characterize detection sensitivities

Inspiration

ANS

NUCLEAR TECHNOLOGY · VOLUME 197 · 248–264 · MARCH 2017

DOI: http://dx.doi.org/10.1080/00295450.2016.1273713

Approaches to a Practical Systems Assessment for Safeguardability of Advanced Nuclear Fuel Cycles

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Received August 16, 2016
Accepted for Publication November 29, 2016

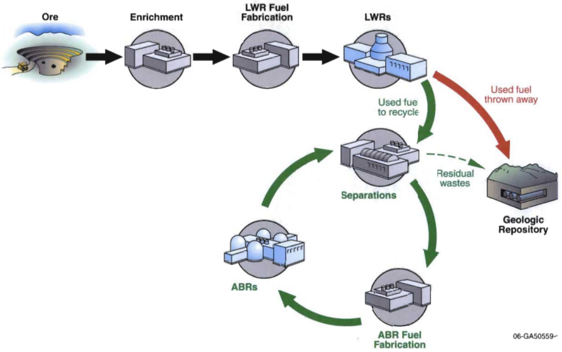
Abstract — *Many nations are expanding or initiating nuclear energy programs as part of a national energy portfolio. Transitioning to advanced nuclear energy systems improves sustainability and promotes energy independence. These advanced nuclear energy systems also must be shown to enhance safety, safeguards, and security in order to be realistically deployed. This is of particular concern to non–nuclear weapons states, to assure compliance with International Atomic Energy Agency treaty obligations.*

Outline

Cyclus

What is Cyclus?

Cyclus is a modular agent based fuel cycle simulator for tracking commodity transactions between facilities.



Why Cyclus?

Cyclus allows the construction of specific scenarios through the addition of archetypes. These archetypes are modular and the transactions can be tracked.

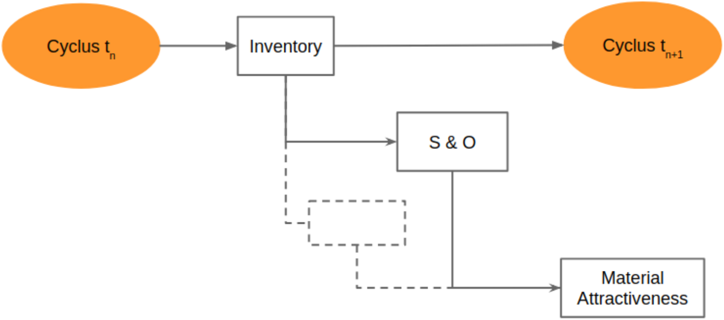


Figure: Diversion detection methods within Cyclus.

Assumptions

Cyclus Requirements

- Modular.
- Time step $\geq$ 1 month
- Streams must be in a trade-able form.
- Parameters are constant for the simulation.
  - Equation input toolkit under development.
- Diversion detection must be added after.

Subprocesses - Voloxidation

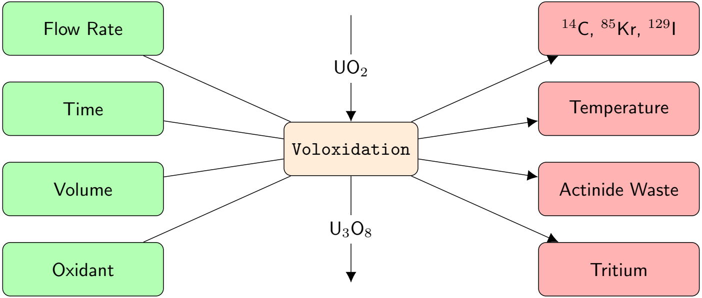


Figure: Voloxidation material balance area [1].

Subprocesses - Electroreduction

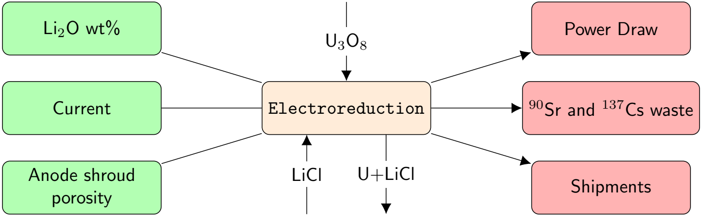
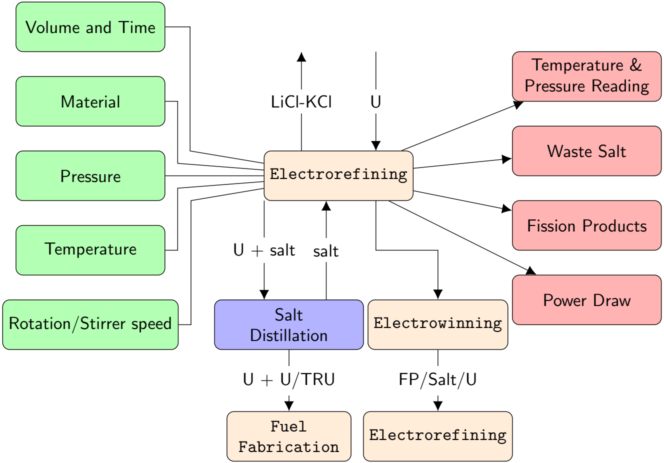


Figure: Reduction material balance area [2].

Subprocesses - Electrorefining



Subprocesses - Electrowinning

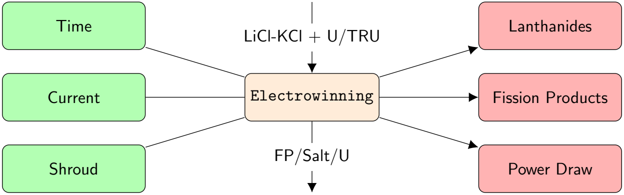
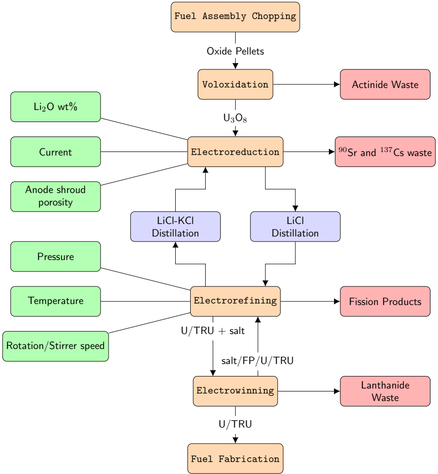


Figure: Winning material balance area.

Outline

Pyre Archetype

- Facility containing multiple sub-processes:
  - Separately handled.
  - Independent transactions, possibility of diversion.
- Operation setting impact efficiency.
- Generic facility:
  - Multiple types of pyro plants.
  - LWR vs SFR.



Pyre - Diversion Options

Material diversion occurs in two different modes: **nefarious** or **operator**.

- **Nefarious Diversion** imagines diversion by a single bad actor with facility access.
- **Operator Diversion** imagines undeclared production.

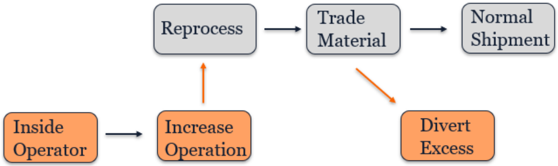


Figure: Operator vs nefarious diversion.

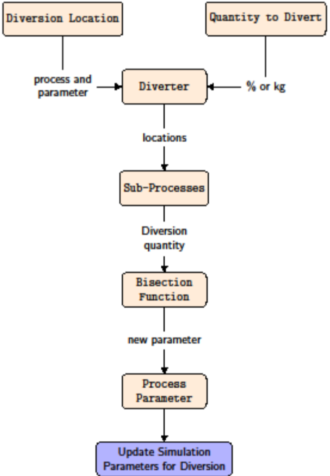
Diverter Class

Inputs:

- Location
  - Sub-process
  - Operation Setting
- Quantity
- Frequency
- Number of Diversions

Purpose

The goal of a separate diverter class is to allow this method to be used by facilities other than pyre through a toolkit.



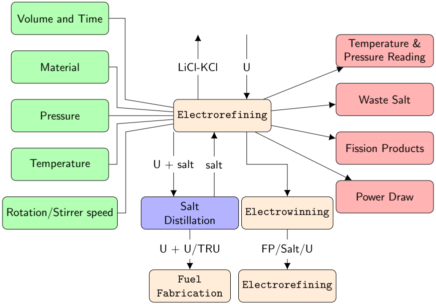
Diversion Detection

Diversion Detection

Material transactions are no longer a reliable method. Instead we use signatures and observables:

- Temperature, power draw, etc.

A Cumulative Sum change algorithm is used to detect any significant changes.



Transition Scenario

A main attraction of pyroprocessing is the ability to handle LWR and SFR waste.

- To verify this capability in PyRe, we ran an EG01 – EG24 transition scenario.
- We want to observe the following:
  - Appropriate deploying of PyRe
  - Ability to meet demand of new SFRs
  - Diversion capabilities
  - Accurate transition from UOX to SFR fuels

Transition Scenario - Setup

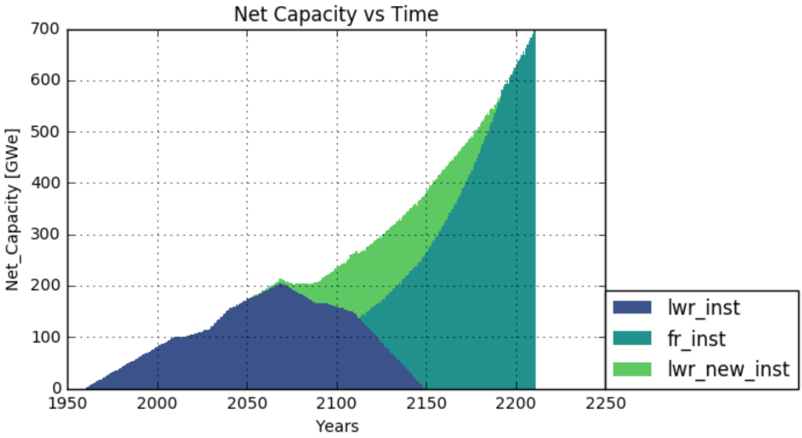
Legacy:

- 200 LWRs
  - 50% 60yr lifetime
  - 50% 80yr lifetime
- LWR Pyre

Transition:

- 200 LWRs starting in 2015
  - 80yr lifetime
- SFR starts in 2050
  - 80yr lifetime
- SFR Pyre

Transition Scenario - Results



Diversion Settings

Two Pyre prototypes:

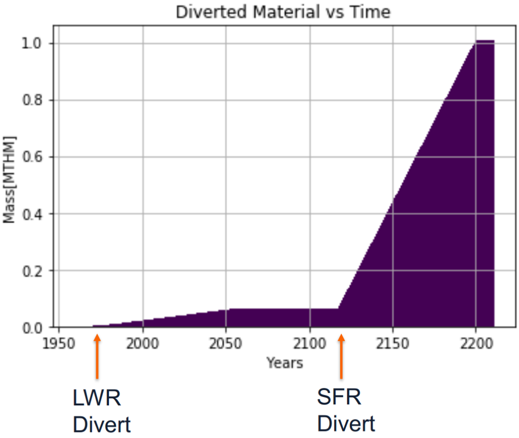
- LWR vs SFR

LWR Pyre:

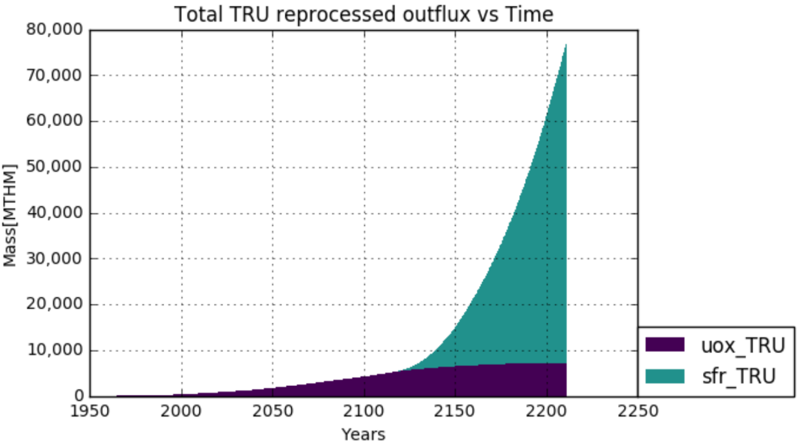
- Fewer diversions
- More material per instance
- Less frequent

SFR Pyre:

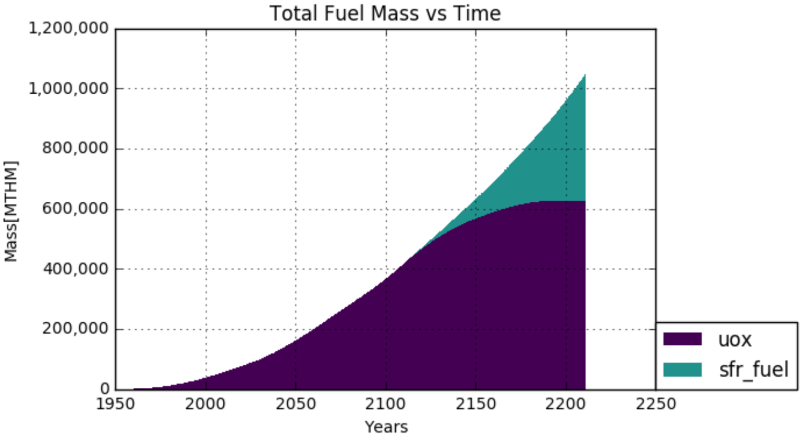
- Frequent diversion
- Small quantities



Transition Scenario - Utilization



Transition Scenario - Utilization



Outline

Sensitivity Analysis

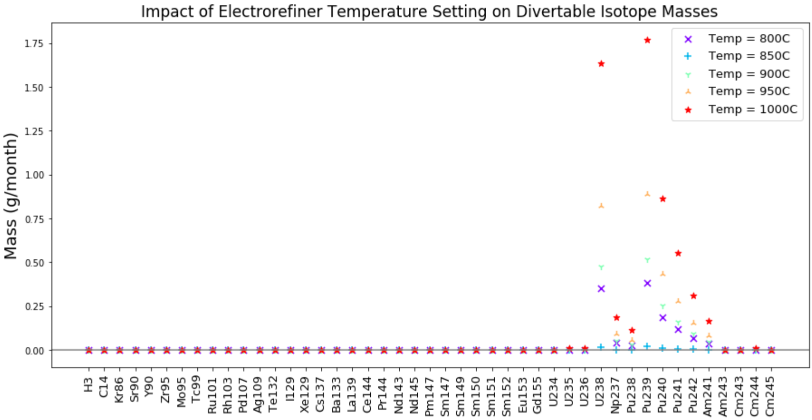
Dakota was wrapped around Cyclus to randomly sample various parameters for critical sub-processes:

- Electrorefiner
- Electrowinner

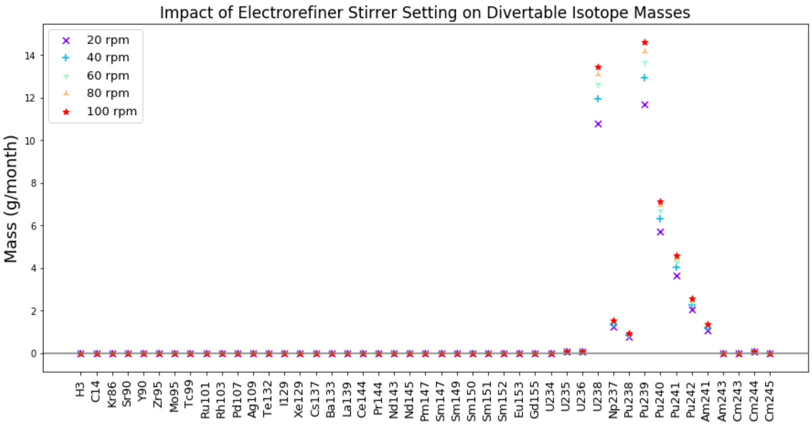
Parameter	Lower Bound	Upper Bound	Units
Electrorefiner Temp	750	1000	$^{\circ}C$
Electrorefiner Pressure	100	760	mTorr
Electrorefiner Stirrer Speed	0	100	rpm
Electrowinner Current	5	10	Amps
Electrowinner Flow Rate	2	4.5	cm/s
Electrowinner Process Time	1	4	hours

Table 4.1: Range of each sensitivity analysis parameter sample.

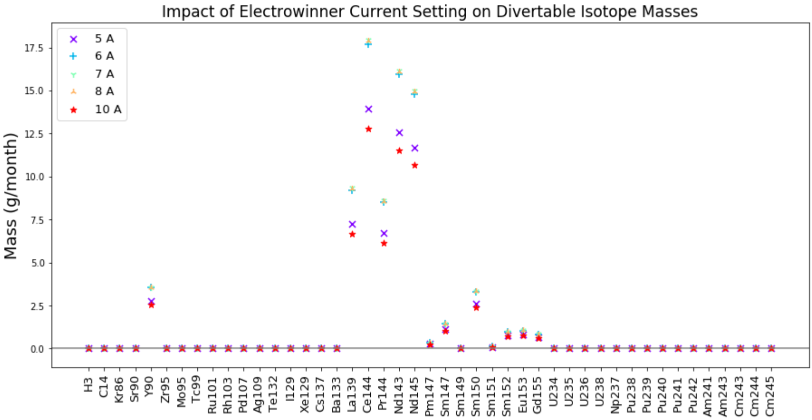
Electrorefiner - Temperature



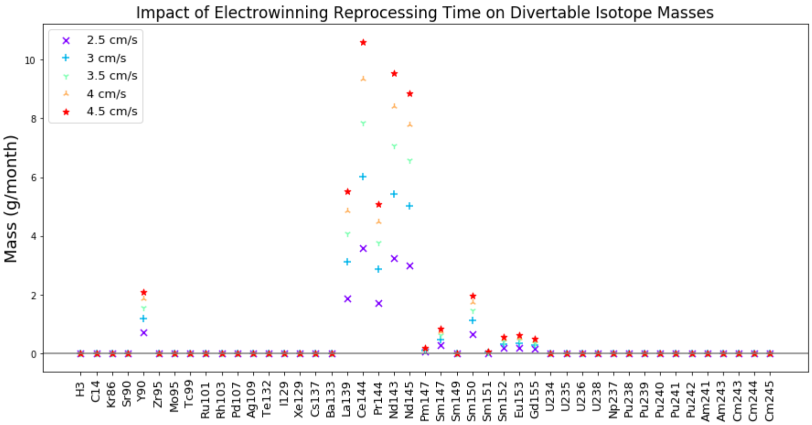
Electrorefiner - Stirrer



Electrowinner - Current



Electrorefiner - Process Time



Sensitivity Results

Parameters that influenced interaction between eutectic and waste showed more significant impact on separation efficiency.

Sample	ER Temp	ER Pressure	ER Stir Speed	EW Current	EW Flow rate	EW Time
1	0.036	8.589	30.284	5.684	3.136	20.030
2	0.715	13.336	33.542	7.216	5.699	33.602
3	0.975	15.393	35.447	7.308	7.866	43.879
4	1.672	15.912	36.799	7.281	9.743	52.154
5	3.328	16.047	37.848	5.202	11.398	59.080

Table 4.2: Comparison of operational settings' impact on divertable material (shown in % difference compared to baseline values). Where ER and EW represent electrorefiner and electrowinner, respectively.

Outline

Conclusions

We have developed a customizable method of diverting material from inside Cyclus facilities.

- Work has been done on the detection of two different types of diversion: Nefarious and Operator

Pyre was demonstrated to function as both LWR and SFR reprocessing method

- Generic facility capable of modeling multiple facility layouts

Key measurement points were identified with sensitivity analysis performed over the primary sub-processes.

Future Work

This work laid the groundwork for future research into sub-facility modeling and diversion detection. Future additions to this work could include:

- Reducing time step length for higher fidelity
- Expand on operational parameter relationships with further experimental data
- Incorporate multiple data points for CUSUM detection

Outline

Acknowledgement

This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number(s) DE-NA0002576 via the Consortium for Nonproliferation Enabling Capabilities.

Prof. Huff is supported by the Nuclear Regulatory Commission Faculty Development Program, the Blue Waters sustained-petascale computing project supported by the National Science Foundation (awards OCI-0725070 and ACI-1238993) and the state of Illinois, the NNSA Office of Defense Nuclear Nonproliferation R&D through the Consortium for Verfication Technologies and the Consortium for Nonproliferation Enabling Capabilities (awards DE-NA0002576 and DE-NA0002534), and the International Institute for Carbon Neutral Energy Research (WPI-I2CNER), sponsored by the Japanese Ministry of Education, Culture, Sports, Science and Technology.

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