Validation of Spent Nuclear Fuel Output by Cyclus, a Fuel Cycle Simulator Code

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Outline

Nuclear Waste Repository Model

Long Term Goal

Run simulations to determine how varying certain variables in the nuclear fuel cycle impacts the mass loading of a nuclear waste repository for the U.S. nuclear fuel cycle.

Variables

- used fuel allocation strategies
- waste package material properties
- repository parameters
- presence of interim facilities

Cyclus

`Cyclus` is an agent-based nuclear fuel cycle simulator with a modular architecture.

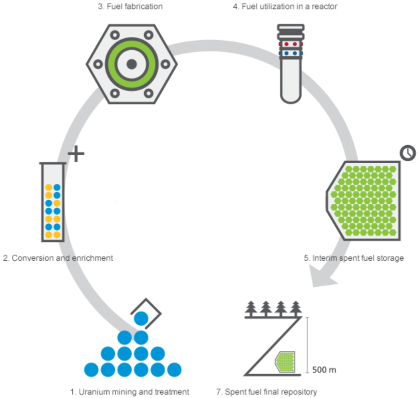


Figure 1: Once Through Nuclear Fuel Cycle [1]

Barriers in a Waste Repository

The main constraint for loading of a waste repository is the **thermal constraint** set by the material properties of the repository.

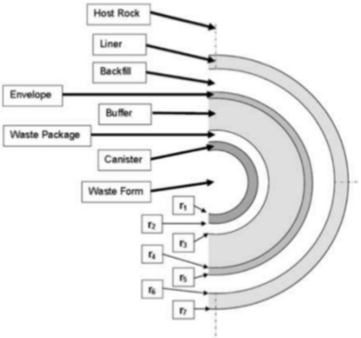


Figure 2: Layers of Waste Repository Barrier System

Heat Flux through Barriers in a Waste Repository

Waste package thermal evolution depends on the **decay heat contribution from each isotope** in the spent fuel.

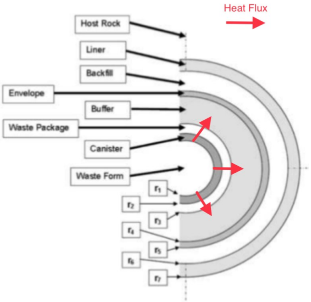


Figure 3: Layers of Waste Repository Barrier System

Significant isotopes for **long term** decay heat contribution [5]

- ^{240}Pu
- ^{241}Am
- ^{239}Pu

Significant isotopes for **short term** decay heat contribution [5]

- ^{238}Pu
- ^{244}Cm
- ^{90}Sr
- ^{137}Cs

Motivation for conducting the Validation

Reason for Validation:

Check if the cyclus simulation gives total spent fuel masses and isotopic compositions that closely replicates reality.

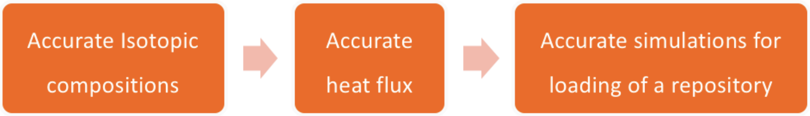


Figure 4: Accurate simulations for loading of a waste repository relies on accurate heat flux and isotopic composition information

Outline

Cyclus Simulation of historic U.S. nuclear fuel cycle

A CYCLUS **simulation of the U.S. nuclear fuel cycle** was created using historic United States reactor deployment data obtained from the Power Reactor Information System (PRIS) database [4].

Simulation Assumptions

Facilities present in the simulation: mine, mill, enrichment plant, fuel fabrication facility, 112 historic commercial reactors in the U.S, dry storage facility and a final waste repository.

Recipe Reactor Facility Assumptions

- *Refueling time*: 1 month
- *Cycle length*: 18 months
- *Single Spent Fuel Recipe*: 33 or 51 GWDt/MTU burnup (depletion calculations done using ORIGEN)
- *Assembly size, Core size, Batch size*: dependent on the reactor type
- *Power cap, Location*: specific to each reactor from PRIS data

CycMap: Cyclus Simulation of historic U.S. nuclear fuel cycle

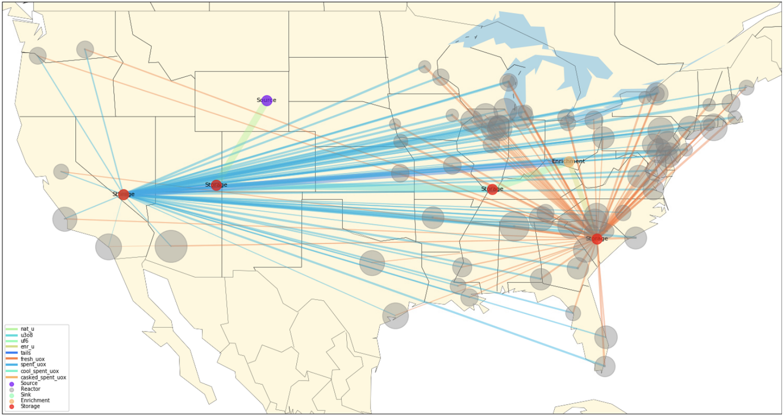


Figure 5: Cycmap of the historic Cyclus U.S nuclear fuel cycle simulation [3]

Power demand: Cyclus Simulation of historic U.S. nuclear fuel cycle

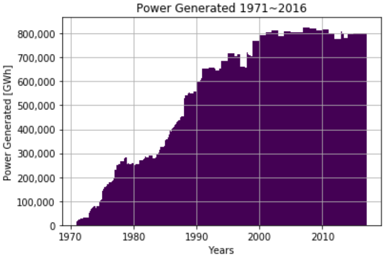


Figure 6: Power generated between 1971 and 2016 from the CYCLUS simulation

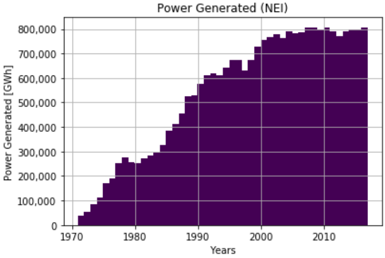


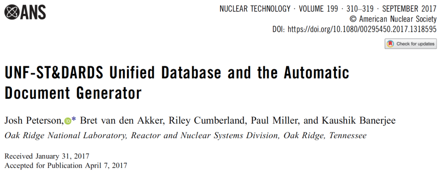
Figure 7: Power generated between 1971 and 2016 as published by the NEI [2]

Comparison of Cyclus Simulation against Unified Database

The total spent fuel mass and specific isotopic compositions from the CYCLUS simulation and Unified Database were **compared**.

Unified Database is part of a larger engineering analysis tool, the Used Nuclear Fuel Storage, Transportation & Disposal Analysis Resource and Data System (UNF-ST&DARDS).

It contains **commercial SNF information** from 1968 through 2013. [4].



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UNF-ST&DARDS Unified Database and the Automatic Document Generator

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Figure 8: UNF-ST&ARDS Unified Database and the Automatic Document Generator Journal Article

Outline

Cyclus vs. Unified Database: Total Spent Fuel Mass

General Conclusion: Cyclus simulation overpredicts total spent fuel mass before 2000 and underpredicts total spent fuel mass after 2000.

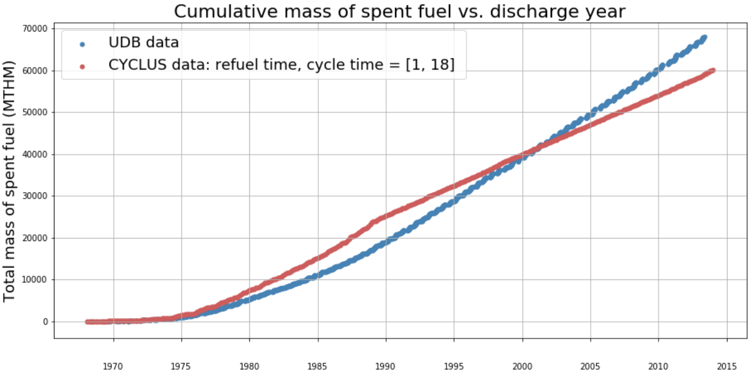

Figure 9: The cumulative spent fuel mass against discharge time for Cyclus and Unified Database data from 1968 through 2013.

Varying Refueling durations in Cyclus Simulation

General Conclusions: Longer reactor refueling durations shifts Cyclus simulation results closer to UDB results before the year 2000.

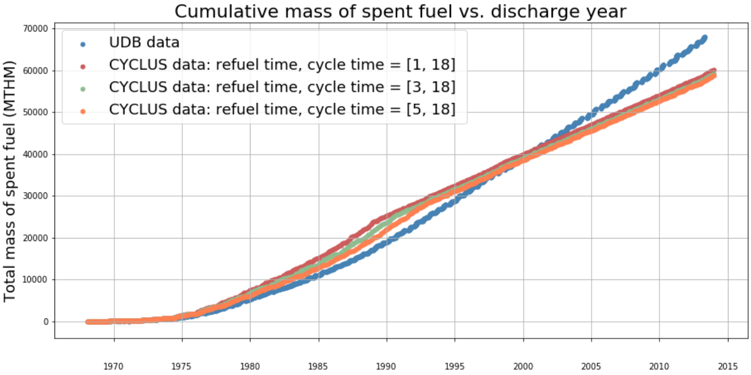

Figure 10: The cumulative spent fuel mass against discharge time for Cyclus and Unified Database data from 1968 through 2013 for varying **refueling durations**.

Varying Cycle durations in Cyclus Simulation

General Conclusions: Shorter reactor cycle lengths shifts Cyclus simulation results closer to UDB results after the year 2000.

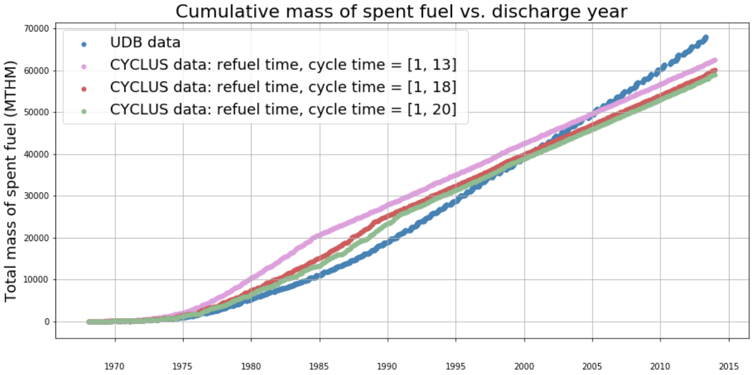

Figure 11: The cumulative spent fuel mass against discharge time for Cyclus and Unified Database data from 1968 through 2013 for varying **cycle durations**.

Cyclus vs. Unified Database: Major Isotopic Composition

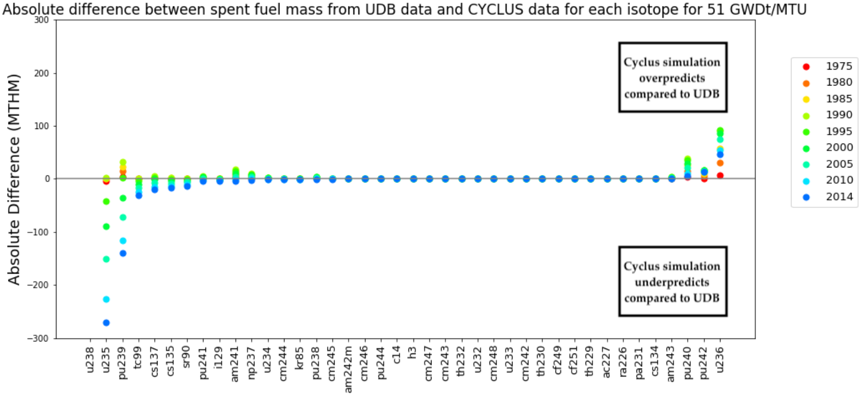

Figure 12: The absolute difference between cumulative spent fuel mass calculated by Unified Database and CYCLUS for each isotope. Spent fuel burnup of 51 GWD/MTU is used in the CYCLUS simulation. Positive difference indicates CYCLUS mass estimate is larger.

Cyclus vs. Unified Database: Major Isotopic Composition

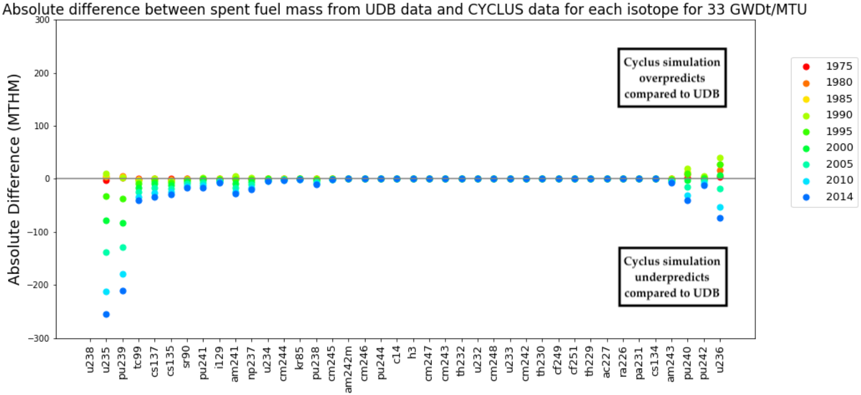

Figure 13: The absolute difference between cumulative spent fuel mass calculated by Unified Database and CYCLUS for each isotope. Spent fuel burnup of 33 GWD/MTU is used in the CYCLUS simulation. Positive difference indicates CYCLUS mass estimate is larger.

Burn up of Spent Nuclear Fuel

In 1990, Burnup = 33.215 GWDt per MTU

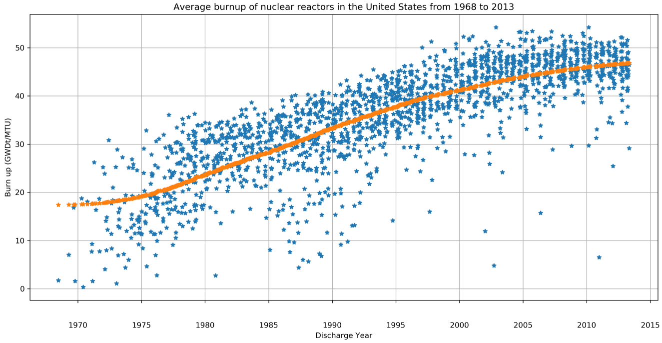

Figure 14: The average burnup for U.S. nuclear reactors from 1968 to 2013 [4].

Cyclus vs. Unified Database: Major Isotopic Composition

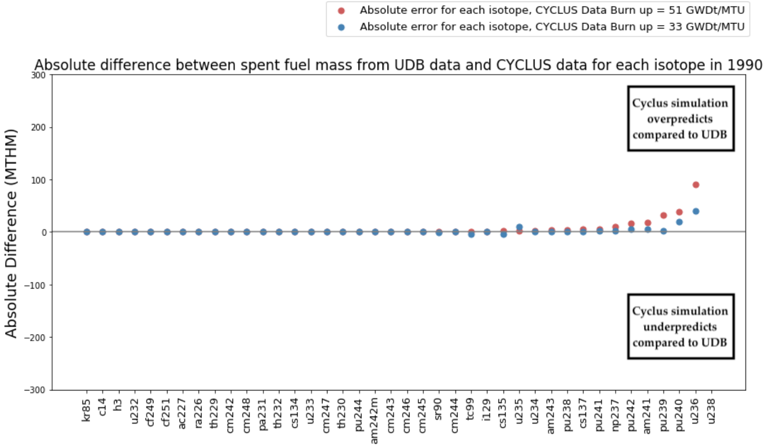

Figure 15: The absolute difference between cumulative spent fuel mass calculated by Unified Database and CYCLUS for each isotope at year 1990. Positive difference indicates CYCLUS mass estimate is larger.

Cyclus vs. Unified Database: Major Isotopic Composition

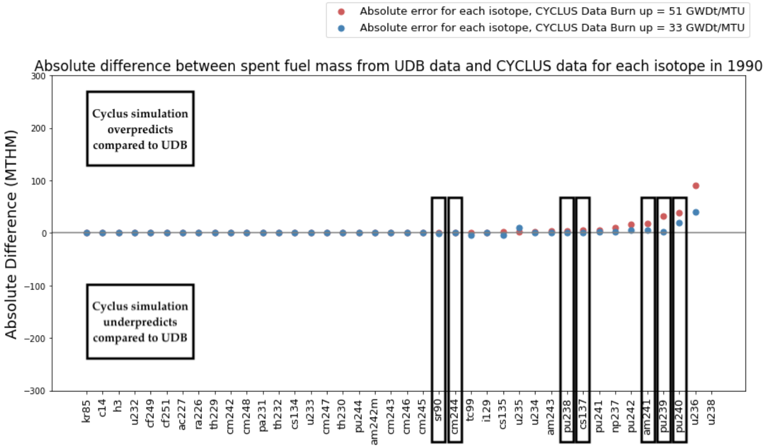

Figure 16: The absolute difference between cumulative spent fuel mass calculated by Unified Database and CYCLUS for each isotope at year 2000. The boxed isotopes are the major decay heat contributors.

Cyclus vs. Unified Database: Decay Heat Contribution

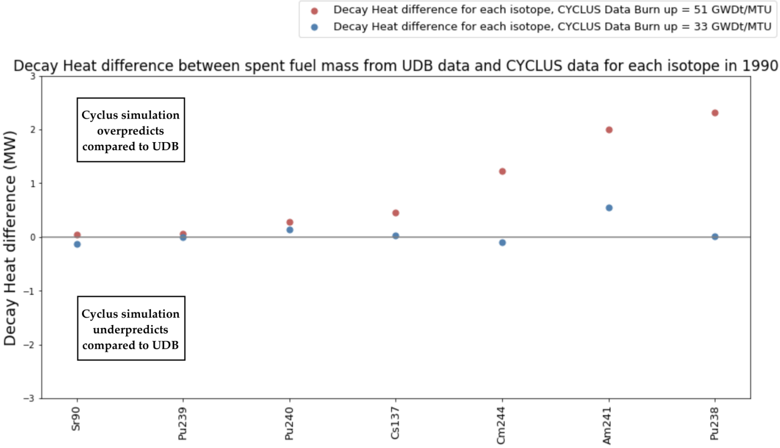

Figure 17: The absolute difference between decay heat calculated by Unified Database and CYCLUS for each significant isotope at year 2000.

Outline

Conclusion

These results demonstrate that the spent fuel mass calculated by the Cyclus simulation for the US nuclear fuel cycle follow **similar trends** as the real world metrics. However, there are significant mass differences in the important isotopes that contribute to decay heat.

Deviations from the real world metric can be explained by issues with the reactor facility in the CYCLUS model:

- only accepting constant values for cycle and refueling durations
- single spent fuel recipe

Future Work

To more accurately model isotopic concentrations in the Cyclus simulation, these capabilities could be implemented in Cyclus:

- Reactor facility that is tied to a database of varying spent fuel recipes based on burnup + Toolkit that gives the functionality of varying cycle time and refuel duration values
- Reactor facility that is tied to the Unified database to give different spent fuel recipes based on the burnup of a specific spent fuel bundle

Acknowledgement

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