Flowing-pebble depletion modeling in ORIGAMI

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Overview

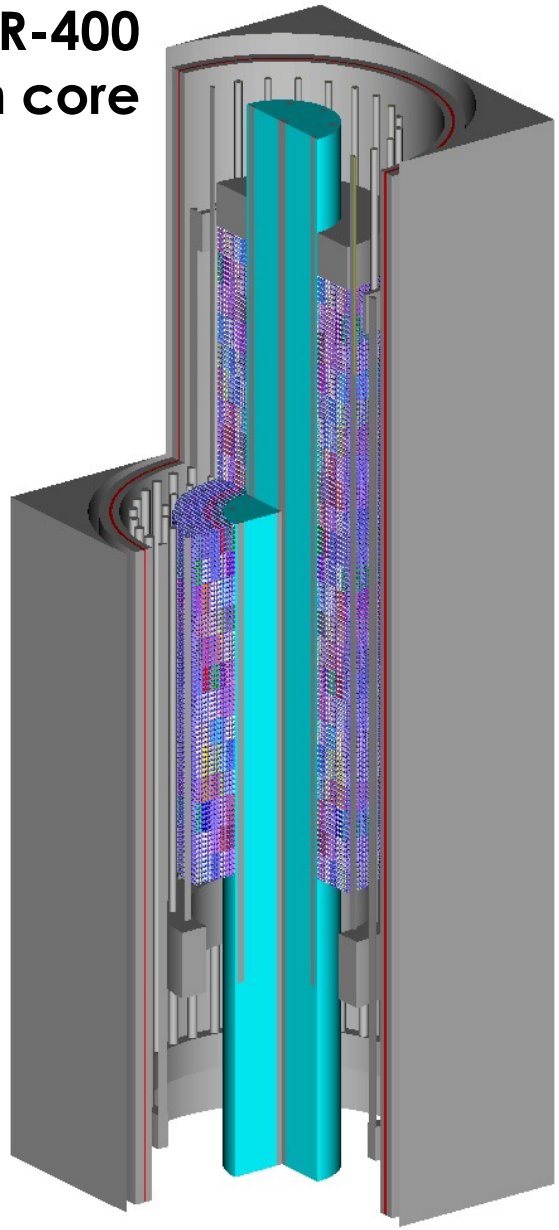
- Modeling strategy
  - What assumptions do we make in modeling flowing-pebble fuel?
  - What physical characteristics need to be captured?
- Implementation in ORIGAMI
  - Axial zone definition
  - “Transit”-based depletion
  - Applications to LWRs (“static” axial zones)

Modeling strategy for pebble-based reactors

HTGR analysis with SCALE: Overview

- **Main goals**
  - Evaluate neutronic characteristics
  - Generate individual pebble inventory within a core zone/batch (e.g., difference between fresh vs. once-through pebble in a single core zone)
  - Generate discharge pebble inventory/decay heat with sensitivity/uncertainty analysis

PBMR-400 equilibrium core



How do we do this for moving / reloading pebbles?

"Equilibrium" assumption for flowing fuel

For moving fuel, effectively add an advection term to the Bateman Equations:

Creation (fission)

Creation (decay)

Loss (decay)

$$\frac{\partial N_k}{\partial t} + \frac{\partial \boldsymbol{N_k}}{\partial \boldsymbol{z}} \boldsymbol{v_z} = \phi \sum_{i=l}^{m} N_i \sigma_f^i y_{i\to k} + \phi \sum_{s=r}^{q} N_s \sigma_s^a y_{s\to k} + \phi \sum_{j=n}^{p} N_j \lambda_j \alpha_{j\to k} - \lambda_k N_k N_k - \phi N_k \sigma_a^k$$

Advection

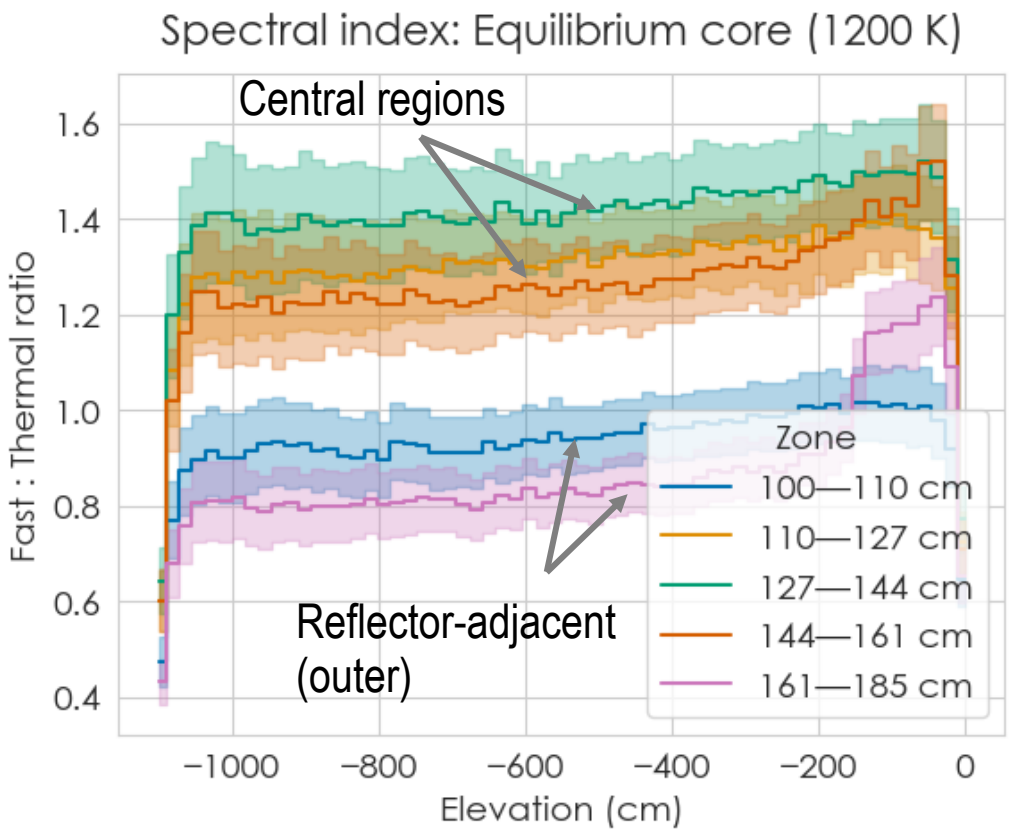
Creation (activation)

Loss (activation)

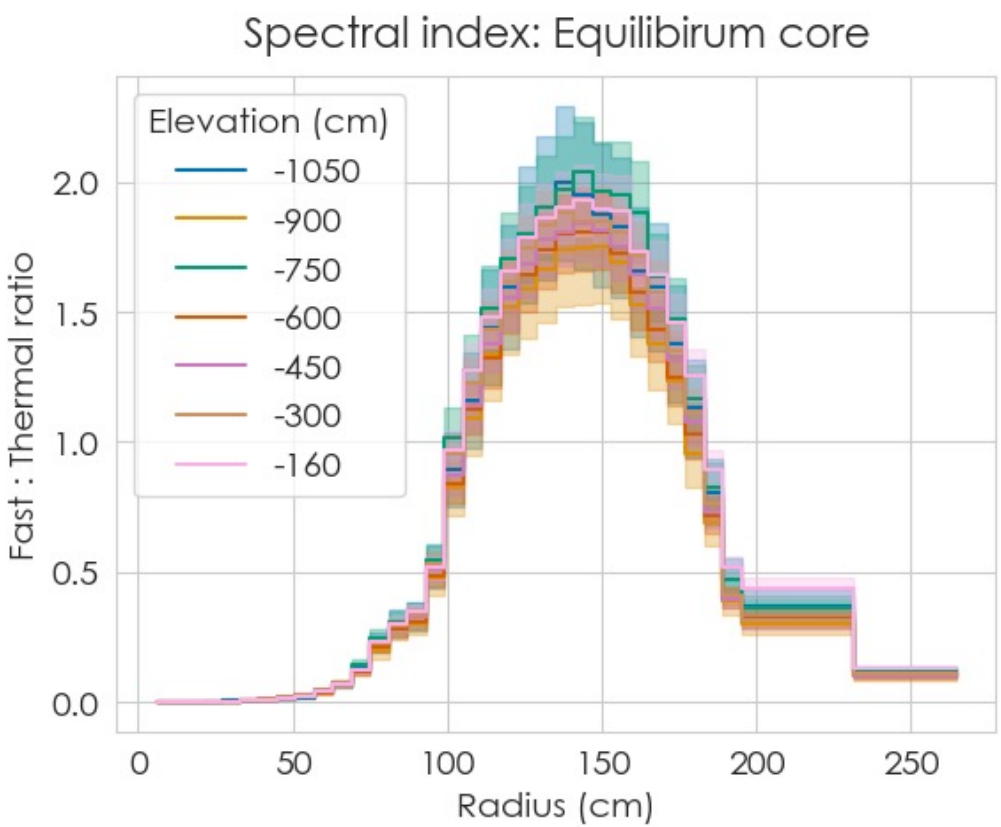
At equilibrium, compositions are invariant with respect to axial position: $\frac{\partial N_k}{\partial z} v_z \to 0$

Fast : thermal flux ratio (spectral index) sensitive to radial zone; relatively invariant axially

Axial

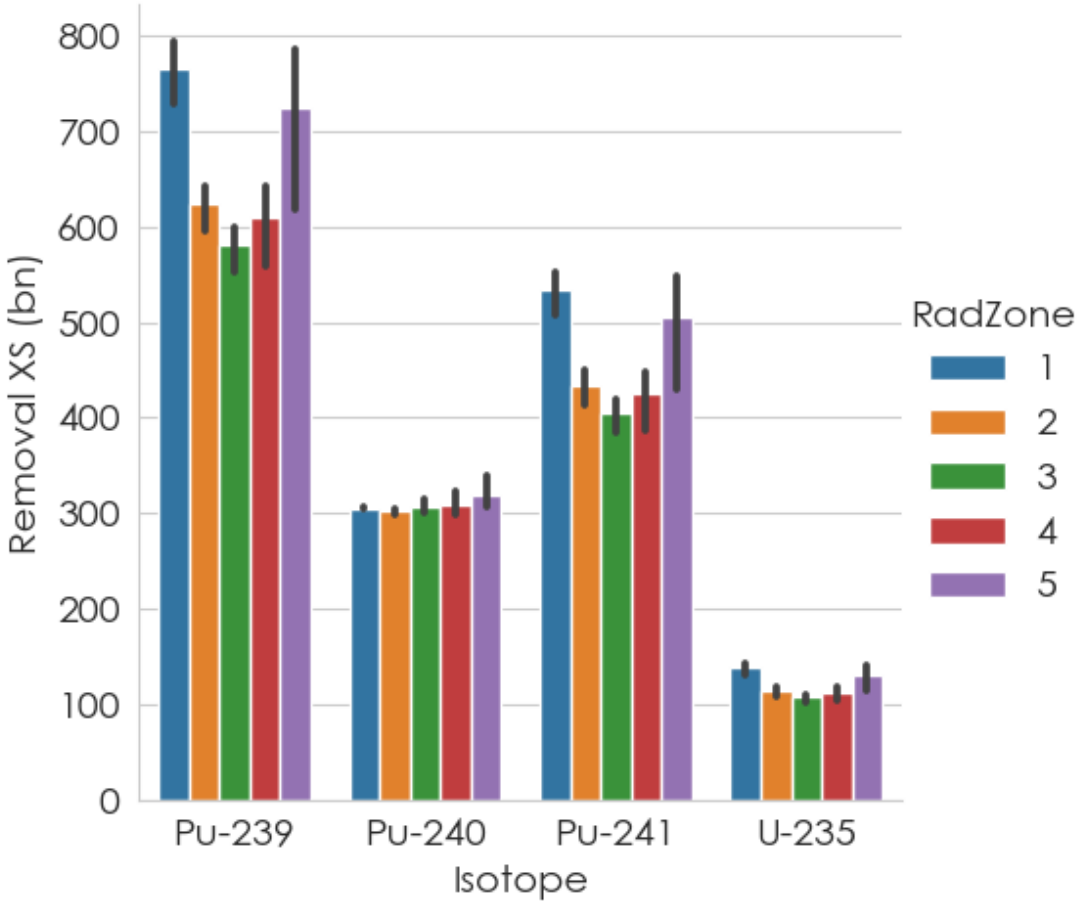


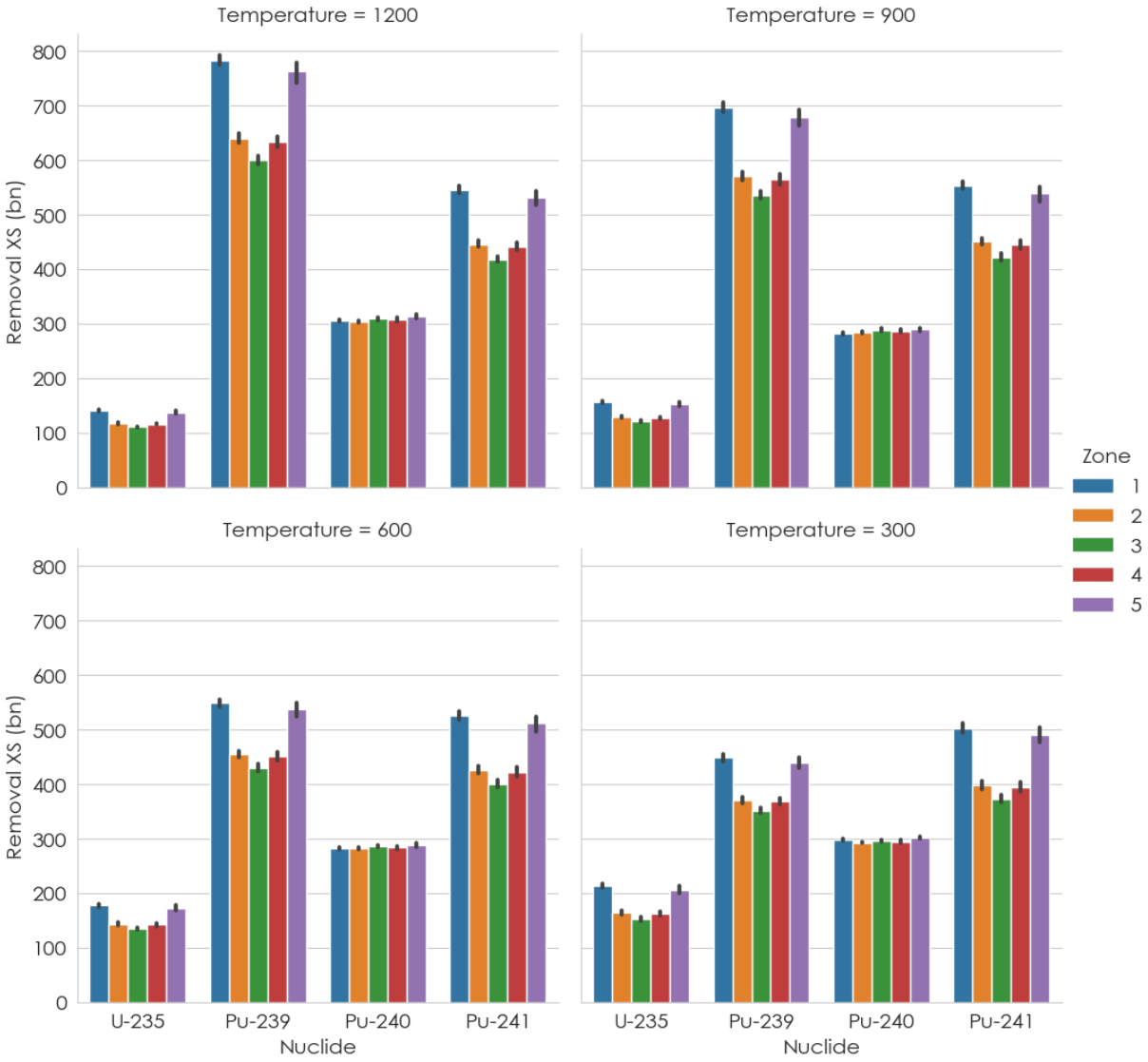
Radial



Major spectral shifts primarily occur across **radial** zones; i.e., primarily need **radial** zone ORIGEN libraries

Radial, temperature effects drive differences in ORIGEN library 1-group cross-sections





ORIGEN “Archive” format for multi-dimensional libraries

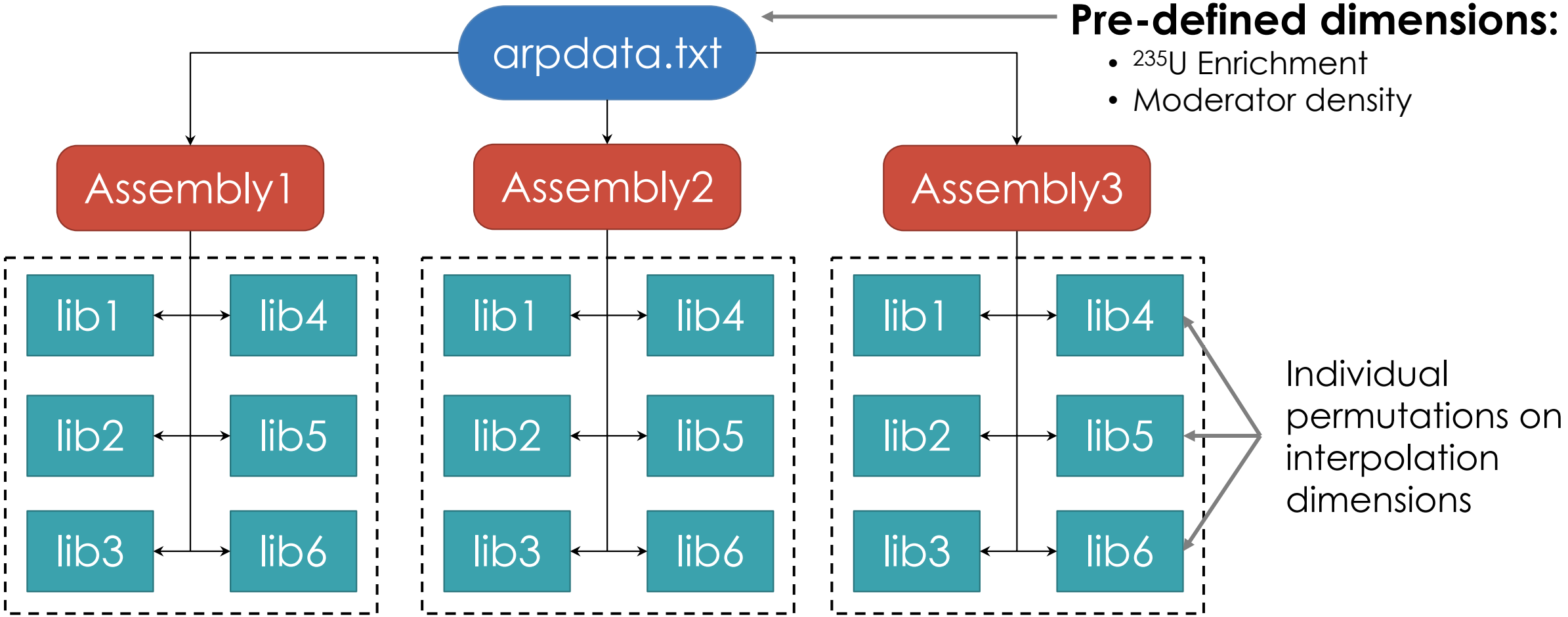
ORIGEN "Archive" format & ORIGAMI

- New ORIGAMI (SCALE 7.0) will rely exclusively on HDF5-formatted "Archives" with descriptive interpolation data written on the file
- Users can **convert** existing LWR libraries in `arpdata.txt` for use with ORIGAMI

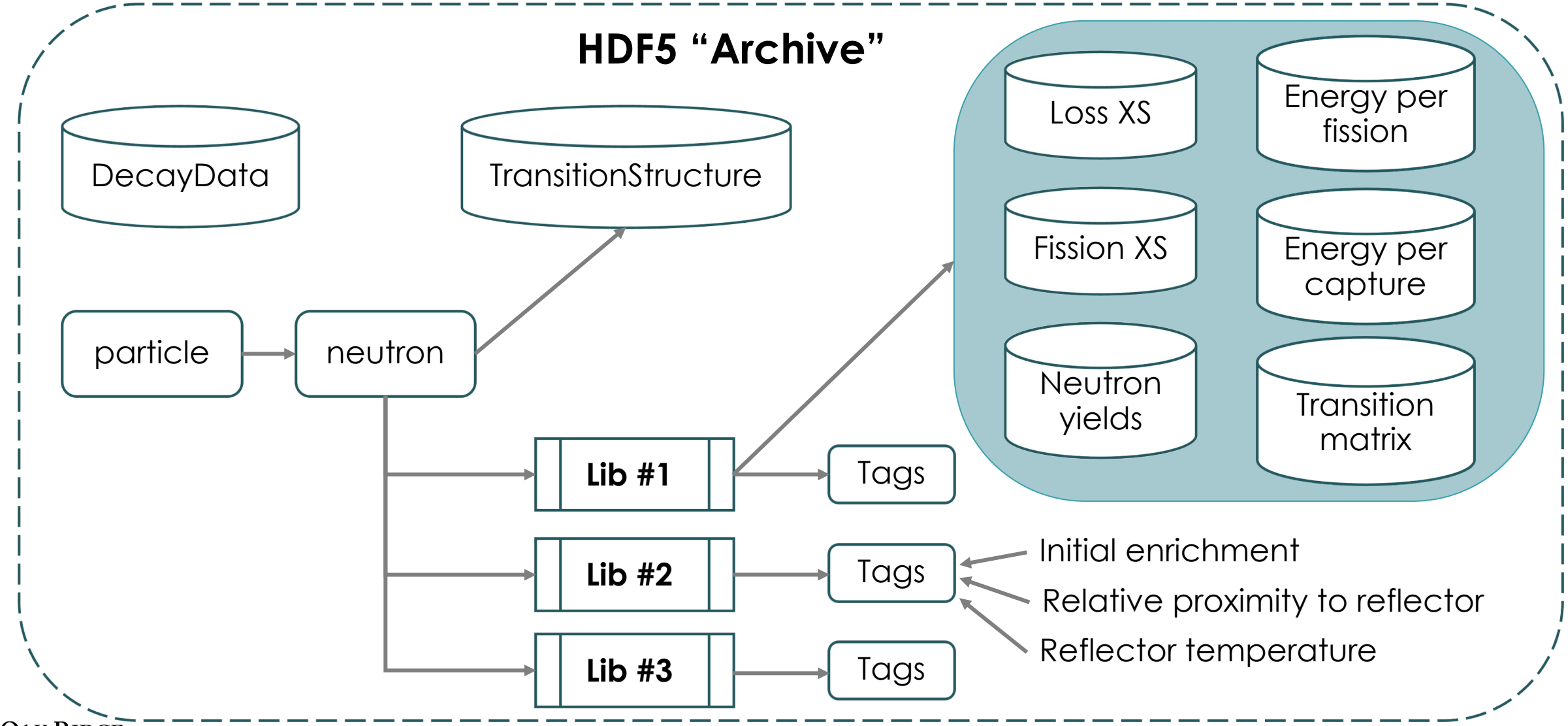
```
obiwan convert -format=hdf5 -alias=[lib_alias] [path_to_arpdata.txt]
```

- Flexible Archive data format allows for run-time specification & checking of interpolation parameters
  - Handled via a new "`state`" block

ORIGEN reactor data library interpolation relies on an ASCII database with hard-coded interpolation dimensions

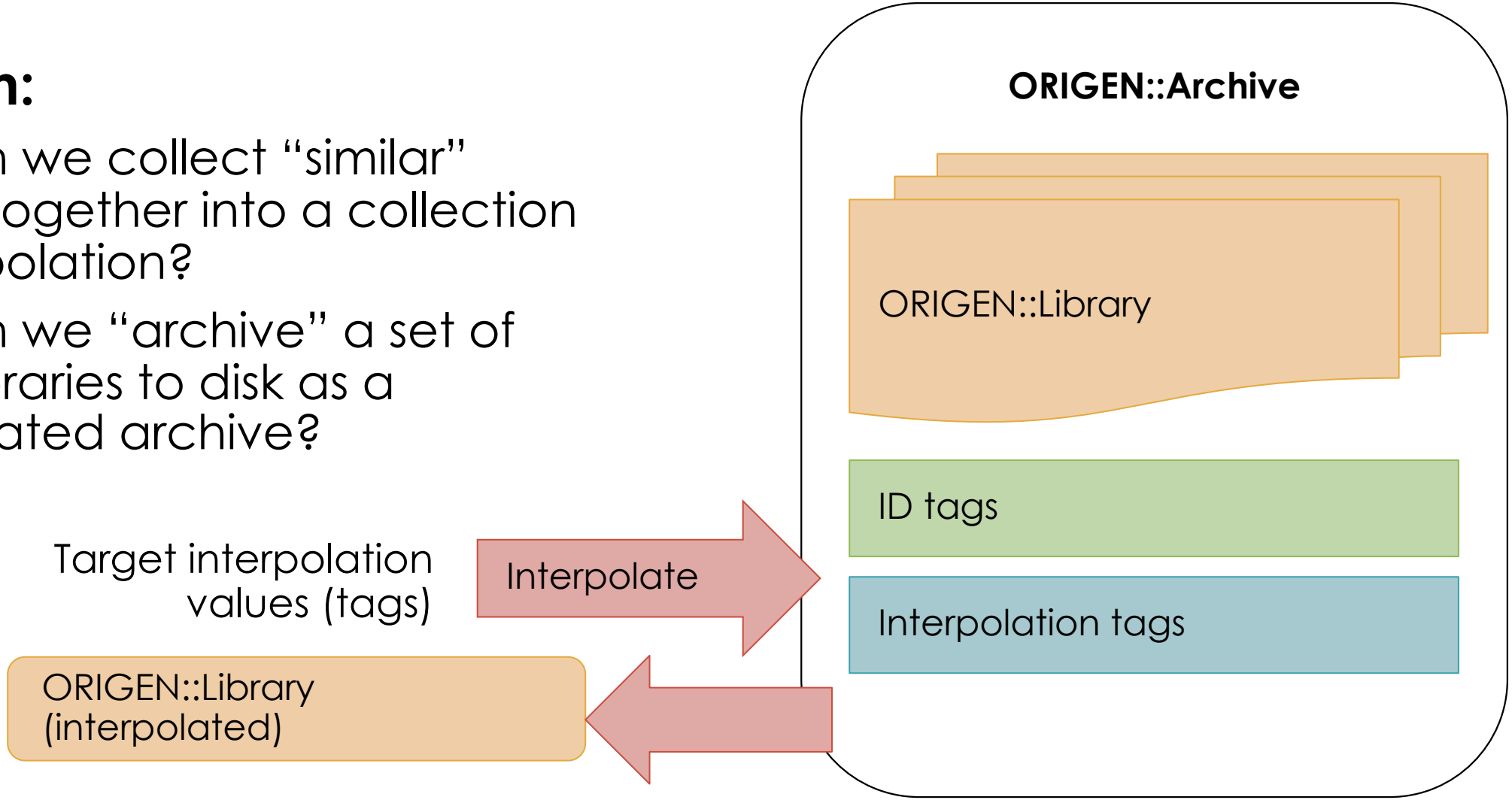


New HDF5-based "Archive" format designed to accommodate arbitrary interpolation dimensions

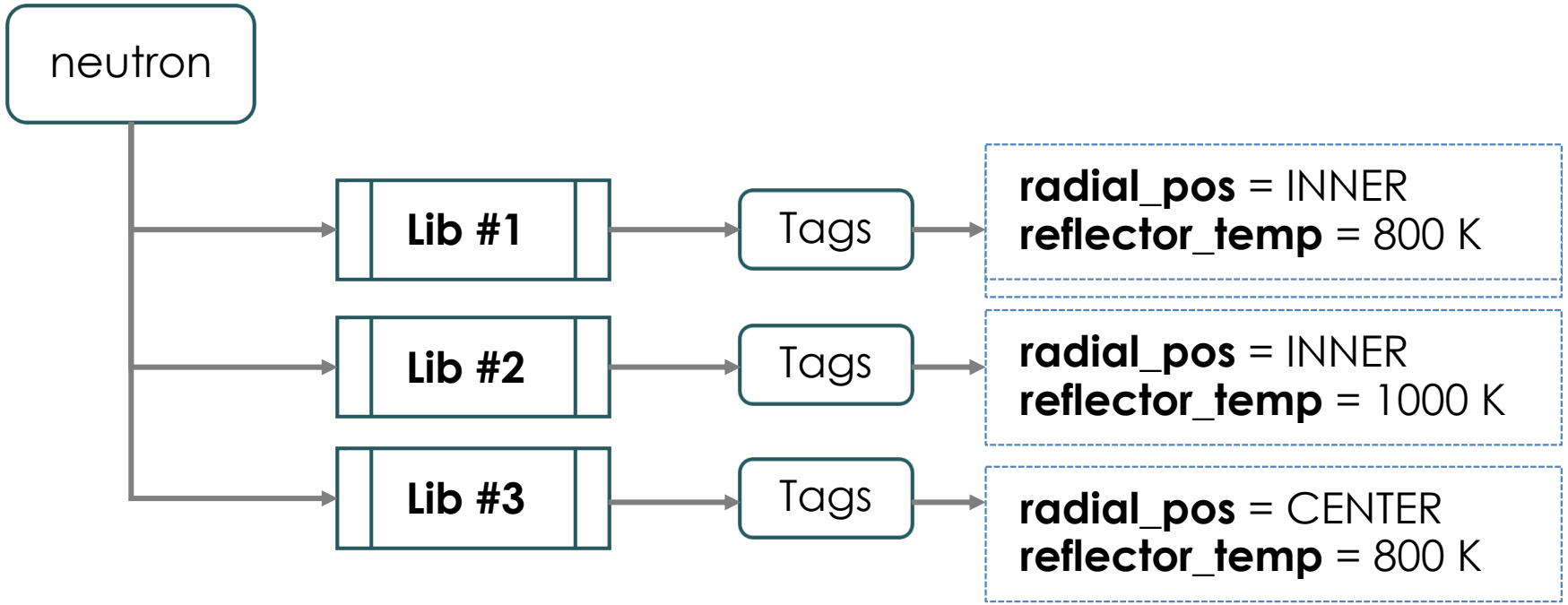


New ORIGEN "Archive" format will pair with HDF5 to facilitate consolidated storage & interpolation

- **Motivation:**
  - How can we collect "similar" libraries together into a collection for interpolation?
  - How can we "archive" a set of similar libraries to disk as a consolidated archive?



State block interpolation example



State block user input
(used for problem-specific interpolation)

```
state{
    radial_pos = INNER
    reflector_temp = 750.0
}
```

Library tags referenced directly as **keys**

Use only libraries from categorical (ID) tag **radial_pos**

Interpolate to 750 K for continuous tag **reflector_temp**

Flowing pebble depletion implementation in ORIGAMI

New ORIGAMI input based on using flexible "axial zone" definitions

- Two types of "zone" definitions
  - **Transit Zone:** Axial region where flowing pebbles will "transit" through as they flow through the core
  - **Static Zone:** Fixed spatial region of an (unmoving) assembly

Transit zone

Radial definitions of:

- Population distribution (PDF)
- Power shape
- Library interpolation parameters (e.g., position, temperature)

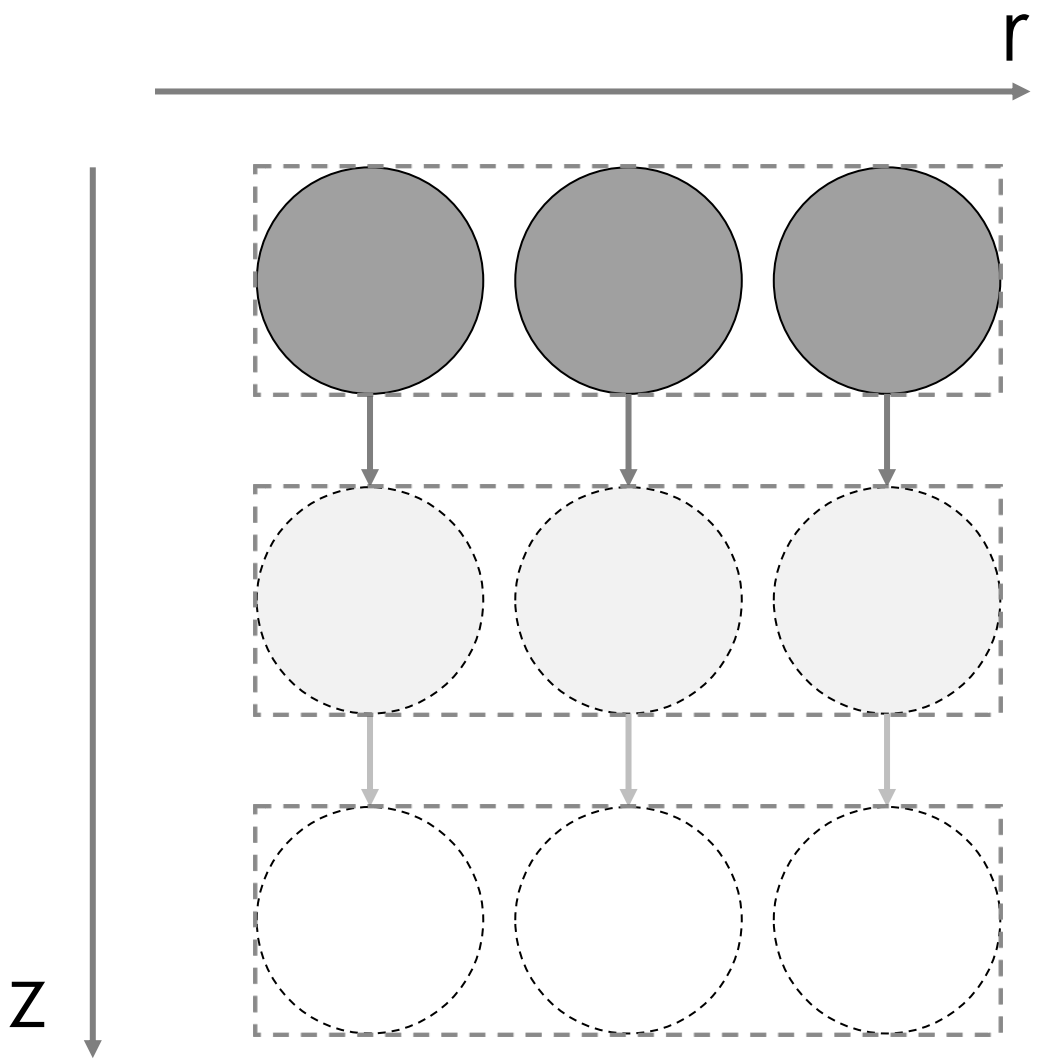
Static zone

x-y definitions of:

- Material composition (defined in fuel mixtures)
- Power shape
- Library interpolation parameters

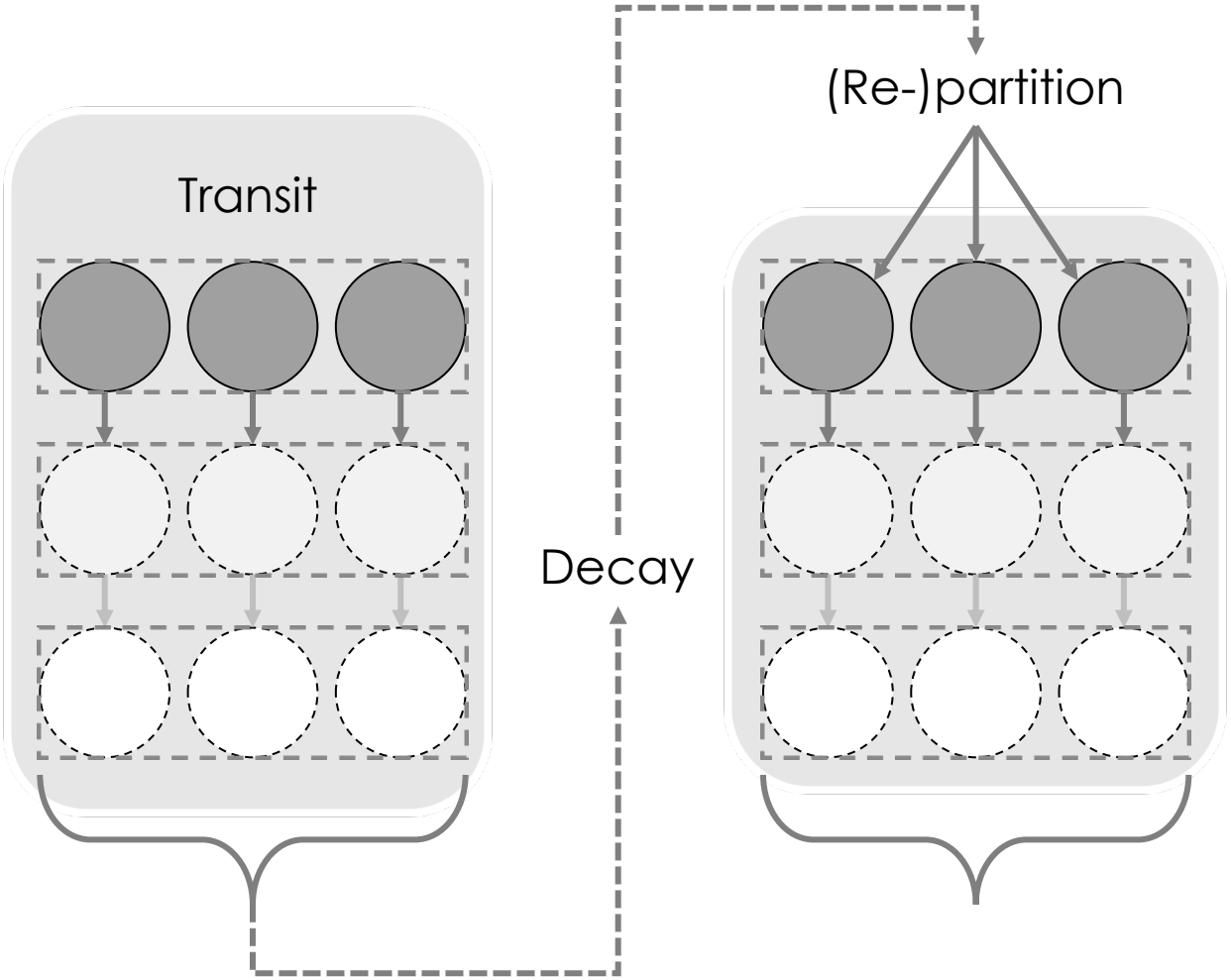
Transit-based depletion histories

- Depletion modeled in the core as a series of sequential transit "zones" corresponding to axial regions of the core
- Assumes fixed axial "streamlines" for now
  - i.e., constant radial probability distribution
- Independent radial characteristics for each axial "transit zone"



Combining core transits into a depletion history

- At the end of a core transit, radial region masses are summed, decayed, and redistributed according to the next radial probability distribution
- Process is repeated ("chained transits") throughout the entire pebble depletion history



Example: Defining a transit history

```
=origami
  axial_configs={
    transit_zone(top){
      rpower=[ 1.1 0.92 0.85 ]
      state{
        position=[ INNER CENTER OUTER ]
        temperature=[ 1100.0 1000.0 950.0 ]
      }
      pz=1.0
    }
    transit_zone(mid){
      …
    }
```

Transit zone identifier (key)

Radial power shape

Library interpolation tags
(1 per radial zone)

Example: Defining a transit history

```
=origami
  axial_configs={
    transit_zone(top){
    …
    }
  hist=[
    transit(first){
      power=100.0 burn=60.0 down=5.0
      rdist=[ 0.25 0.5 0.25 ]
      transit_path=[
        top={ frac=0.3 }
        mid={ frac=0.5 }
        bottom={ frac=0.2 }
      ]
    }
      …
 ]
```

Cross-reference transit zone by unique key

Radial probability (mass) distribution defined for each transit

Transit path through core defined as a sequence of transit zone objects

Chain together multiple "transits" to define the irradiation history

Summary of new features for flowing pebble depletion

- The new ORIGAMI (targeted for SCALE 7.0-beta1) will afford modeling of **flowing pebble** depletion via chained "transit zone" blocks & multiple transit passes through the core
- New features also include a new HDF5-based "Archive" format for libraries with descriptive metadata and generic interpolation capabilities
  - Necessary to represent unique neutron spectrum characteristics seen in non-LWR systems