Simulation of Spent Nuclear Fuel loading into a Final Waste Repository

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Introduction

Previous Work

Previous work towards studying repository loading have used:

- spent nuclear fuel (SNF) with an **average burnup composition** [1, 5]
- a **lumped capacitance thermal model** for calculating temperature in a Cyclus repository model [2]

Motivation

The goal of this work is to improve on the repository models and use U.S. historical SNF inventory data in simulations to more accurately study the loading of a waste repository.

These goals will be achieved by:

- using UNF-ST&DARDS Unified Database (UDB) [6] that has **historic assembly-specific data** (e.g, isotopic composition, heat) in Cyclus simulations
- implementing a **more accurate thermal model** within a Cyclus repository model

Objectives

- Create a Cyclus spent fuel conditioning model that packages spent fuel bundles into packages which have user-defined properties.
- Create a Cyclus medium-fidelity repository model that gives accurate time and spatial dependent temperature values and loads the repository based on a user-selected loading strategy.

Cyclus

Cyclus is an agent-based extensible framework for modeling flow of material through user-defined nuclear fuel cycles [4]. In Cyclus, each facility in the fuel cycle is modeled individually and the facilities interact with one another as independent *agents*.

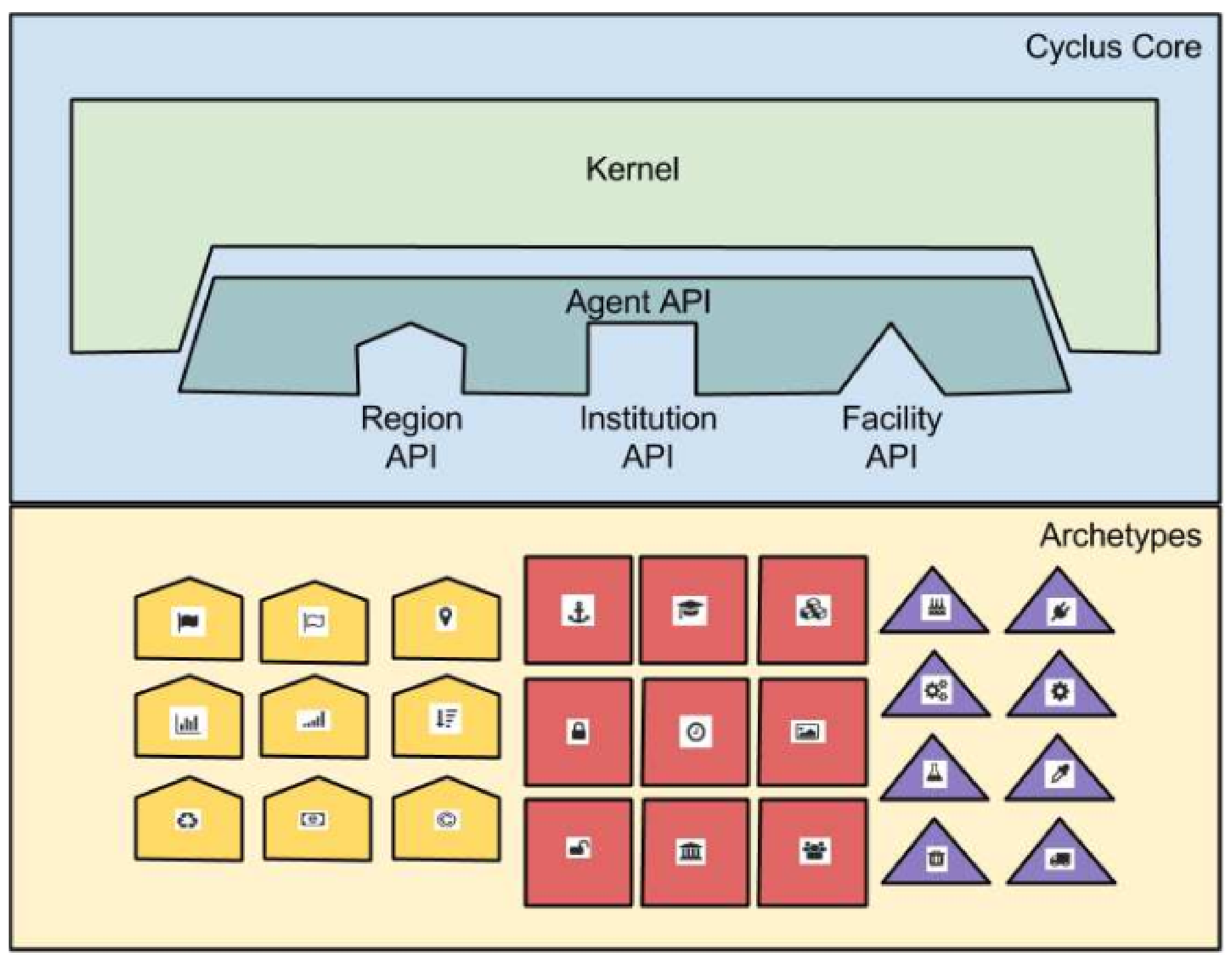

Figure: Cyclus API allows for modular build of simulations [4]

Spent Fuel Conditioning Model

The spent fuel conditioning model accepts spent fuel bundles and puts them into a cylindrical waste package.

In the spent fuel conditioning model, the user can define variables:

For each layer,

- radius
- thermal conductivity
- thermal diffusivity

For each package,

- Number of spent fuel bundles
- Radius and height

Waste Repository Model

The waste repository model accepts waste packages and emplaces them into available positions within the waste repository based on a thermal criteria. The thermal criteria is a temperature limit at the interface between the waste package surface and the host geology, that is set based on the repository's host geology.

Table: Temperature limit at waste package surface, thermal conductivity and thermal diffusivity for each host geology [7]

Rock Type	T_{limit} [°C]	k [$\frac{W}{mK}$]	α [$\frac{m^2}{s}$]
Granite	100	2.5	1.13
Clay	100	1.75	6.45
Salt	200	4.2	2.07

In the waste repository model, the user can define the variables:

- Capacity
- Distance between waste packages
- Distance between drifts
- Repository host geology
- Loading Strategy

Thermal Model

After the addition of new waste packages at each time step, the waste repository model recalculates the temperature at each location in the repository. If the addition of this new package causes its temperature to exceed the thermal limit, it will be placed back into the buffer. A thermal model that relies on a transient 'outside' model and quasi-steady-state 'inside' model is used to accurately determine the temperature in the repository [7].

Transient 'Outside' Model

The 'outside' model assumes a homogenous medium with the Engineered Barrier System (EBS) replaced by the geologic medium. Figure 1 shows the conceptual layout of the central waste package and the adjacent point and line sources.

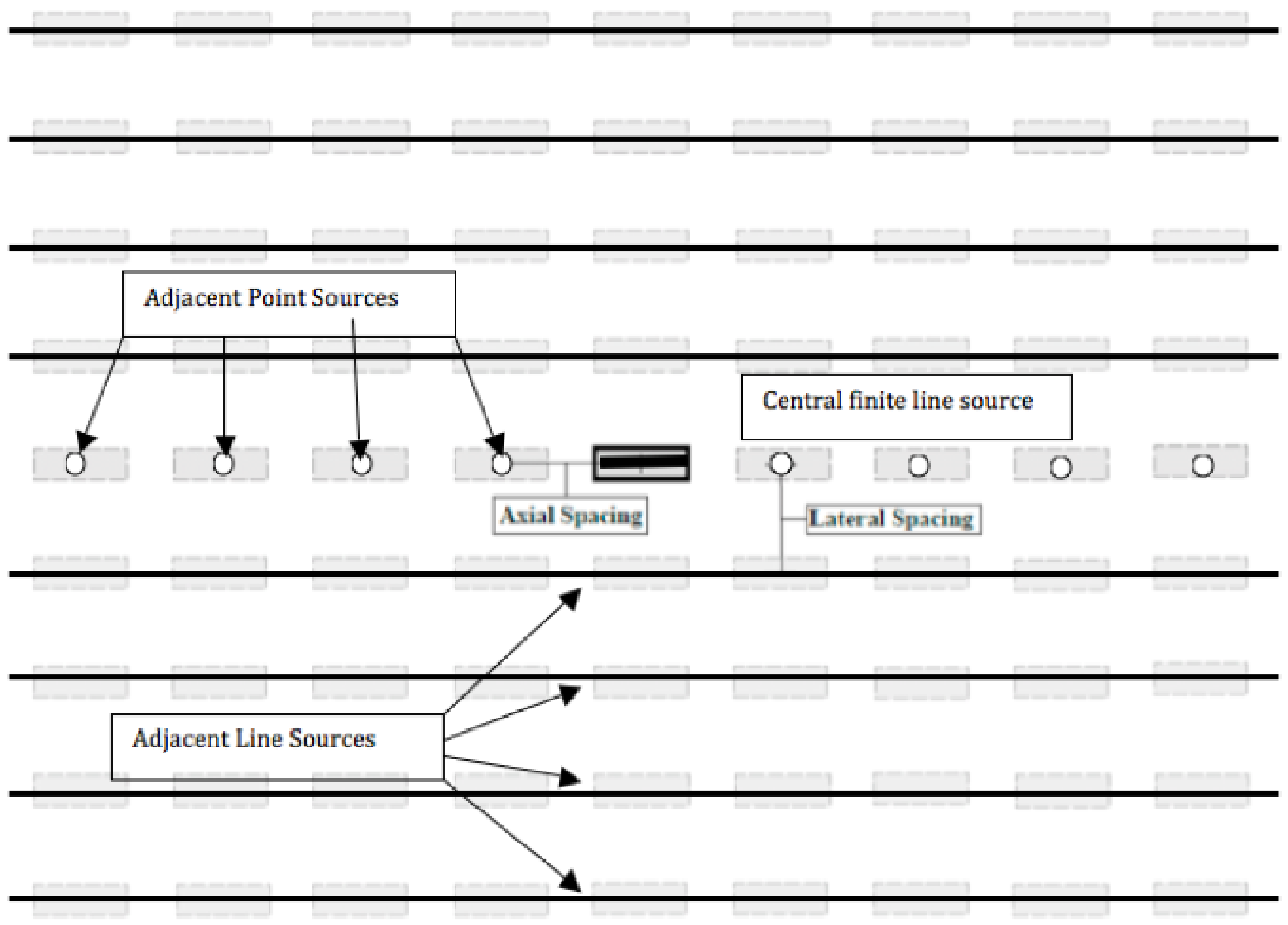

Figure: 'Outside' Model: Conceptual layout of the central waste package, its adjacent point sources and adjacent line sources [7]

Temperature solutions for the central waste package, adjacent point and line sources are superimposed to calculate the temperature at specific points in the repository. The equations for calculating temperature of each contributing component are included below [7, 1, 3].

The central drift consists of one finite line source which represents the central waste package.

$$T_{line}(t,x,y,z) = \frac{1}{8\pi k}\int_0^t \frac{q_L(t')}{t-t'} e^{\frac{-(x^2+z^2)}{4\alpha(t-t')}} \left[erf\left[\frac{1}{2}\frac{y+L/2}{\sqrt{\alpha(t-t')}}\right] - erf\left[\frac{1}{2}\frac{y-L/2}{\sqrt{\alpha(t-t')}}\right]\right]dt'$$

The central drift also consists of point sources that represent neighboring waste packages in the central drift.

$$T_{point}(t,r) = \frac{1}{8k\sqrt{\alpha}\pi^{3/2}}\int_0^t \frac{q(t')}{(t-t')^{3/2}} e^{\frac{-r^2}{4\alpha(t-t')}}dt'$$

The neighboring drifts are represented by infinite line sources.

$$T_{\infty line}(t,x,z) = \frac{1}{4\pi k}\int_0^t \frac{q_L(t')}{t-t'} e^{\frac{-(x^2+z^2)}{4\alpha(t-t')}}dt'$$

Waste Repository Model

Quasi-Steady-State 'Inside' Model

The 'inside' model is considered to be at a quasi-steady-state condition because EBS has a relatively low thermal mass compared to the infinite geologic medium [7]. The steady state calculation is performed at each time step with the heat source and interface temperature as boundary conditions. Figure 1 illustrates an EBS layout.

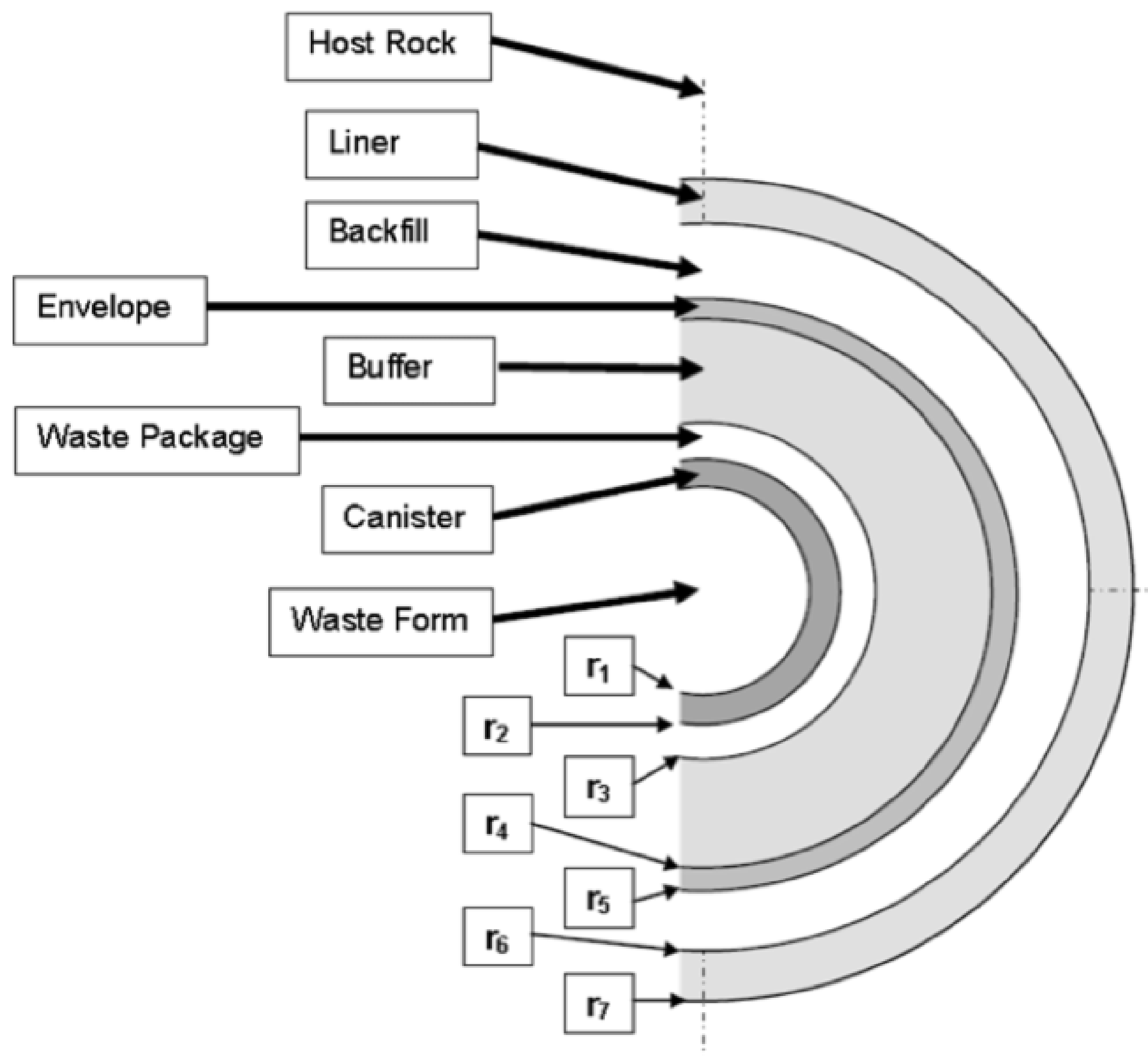

Figure: Layers in an Engineering Barrier System [7]

Future Work

- Run Cyclus simulations with U.S. historical SNF inventory data, the spent fuel conditioning and repository models to study how waste package acceptance strategies impact repository loading

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