An Integrated Used Fuel Disposition and Generic Repository Model

A Nuclear Engineering and Engineering Physics PhD Preliminary Report

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Outline

Future Fuel Cycle Options

Domestic Fuel Cycle Options

Title	Description	Challenges
Open	Once Through	High Temperatures, Volumes
Modified Open	Partial Recycling	Both high volumes and myriad fuel streams
Closed	Full Recycling	Myriad fuel streams

Table: Domestic Fuel Cycle Options

Abstraction

Outline

Top Level Fuel Cycle Simulators

Need For an Integrated Repository Model

Clay Disposal Environments

Clay Repository Features

Hydrology	Geochemistry	Design Concepts	Thermal Behavior
Very low conductivity High porosity (up to 0.5) Low effective porosity Slow water velocity diffusion dominated	Reducing Saline Saturated	no/bentonite/concrete backfill $\sim 100m$ deep closed horizontal or vertical emplacement	alteration limited $100^\circ C$ limit

Table: Clay geological repository concept demonstrates certain dominant physical phenomena.

Granite Disposal Environments

Granite Repository Features

Hydrology	Geochemistry	Design Concepts	Thermal Beha
Low porosity (~ 0.01) High Fracturation Low permeability High Water Velocity	Reducing in Near Field Slightly Oxidizing in Far Field Increasing saline with depth [?] Cement causes alkalinity [?] Saturated or Unsaturated	Single WP tunnels Carbon-Steel [?]or Copper overpack Bentonite buffer Crushed granite backfill [?] $\sim 100m$ deep	Closed Bentonite Lim

Table: Granite repository concepts demonstrate certain dominant physical phenomena.

Salt Disposal Environments

Salt Repository Features

Hydrology	Geochemistry	Design Concepts	Thermal Beh
Dry Waste Package	Reducing in Near Field	Alcove Emplacement	$180^\circ C$ limit
Dry Backfill	Far Field Slightly Oxidizing	Crushed Salt Backfill	Heat induced
Saturated Far Field	Very saline brines	$\sim 100 m$deep	Closed
Very low permeability		Multiple Packages	limited data
Brine pockets in far field		Breached only from intrusion	

Table: Salt geological repository concept demonstrates certain dominant physical phenomena.

Deep Borehole Disposal Environment

Borehole Repository Features

Hydrology	Geochemistry	Design Concepts	Thermal Beh
Crystalline rock	Reducing at depth	$\sim 5km$ deep	cracking unim
Low porosity (~ 0.01)	Less Reducing at surface	disposal in lower 2km	may affect flo
Limited fracturation at depth	limited solubility	1km betonite seal	high conducti
Rock Permeability ($\sim 10^{-19}$)	enhanced sorption	bentonite grout	high density
EBS Permeability ($\sim 10^{-16}$)	high salinity	bentonite plugs	
Very Limited Upward Flow		400 packages per borehole	
	saturated	closed	

Table: Borehole geological repository concept demonstrates certaindominant physical phenomena.

Waste Form Release Models

Waste Package Failure Models

Transport Through Buffer Material

Transport Through Geology

Impact of Repository Designs

Heat Limits In Geology

Analytical Models

Detailed Techniques

Lumped Parameter Technique

Outline

Cyclus Modular Architecture and Open Development

The combination of modular encapsulation within the software architecture and an open development paradigm allows for collaboration at multiple levels of simulation detail and data security.

Encapsulation

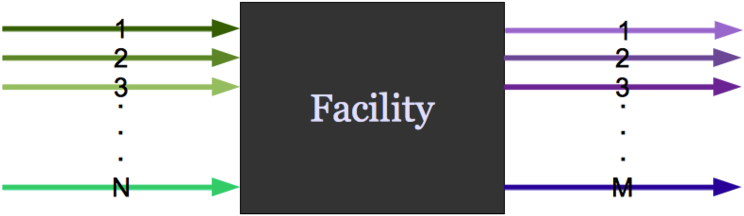


Figure: Regions, Institutions, Facilities, and Markets are all black boxes.

Module Interfaces

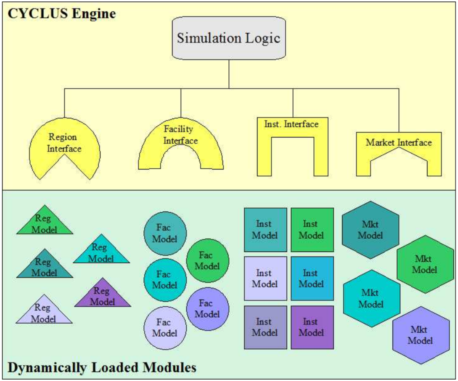


Figure: Well defined model interfaces facilitate model interchange. The user may choose the model at their desired level of detail.

Facilities Are Black Boxes

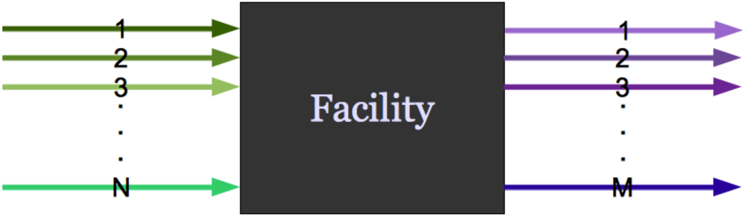


Figure: Each facility in the simulation makes requests and offers to fill its stocks and empty its inventory respectively.

Facilities Are Black Boxes

Figure: A facility might only make offers.

Facilities Are Black Boxes

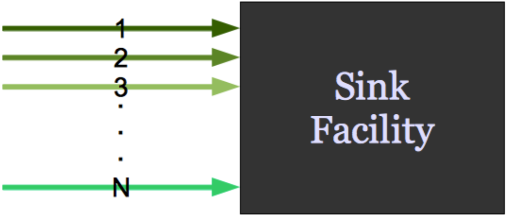


Figure: A facility might only make requests.

Each Commodity is Associated with a Market

Figure: A market receives offers and requests concerning its commodity.

The Market Solves the Matching Problem

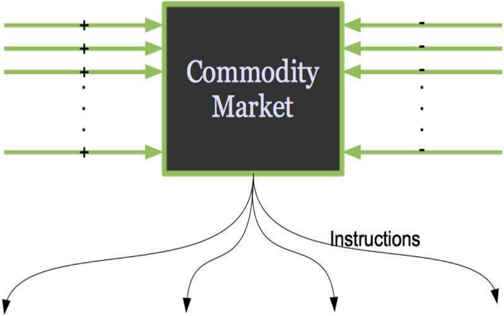


Figure: When the Market's arbitrary algorithm solves the matching problem, the Market sends instructions to the offering facilities.

A Simple Example

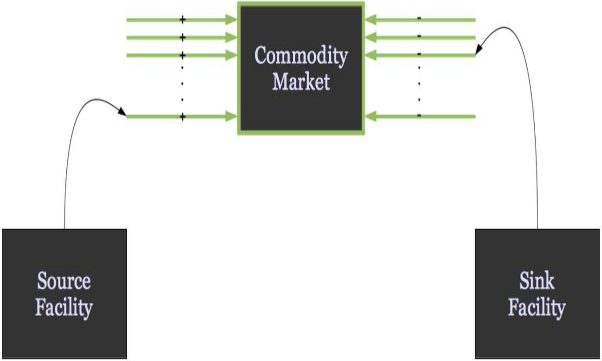


Figure: The source sends an offer and the sink sends a request.

A Simple Example

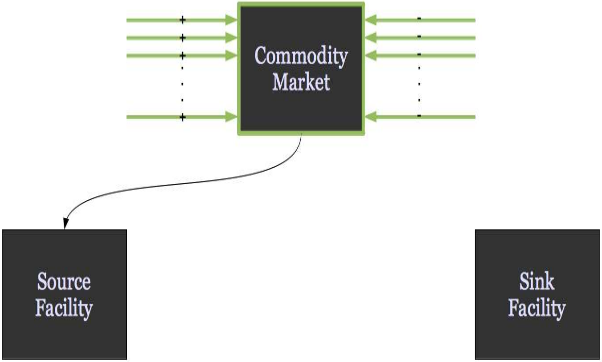


Figure: The Market solves the problem and instructs the source facility to send a certain amount to the sink facility.

A Simple Example

Figure: The source facility sends the material directly to the sink facility.

This Market Model Scales for Complex Systems

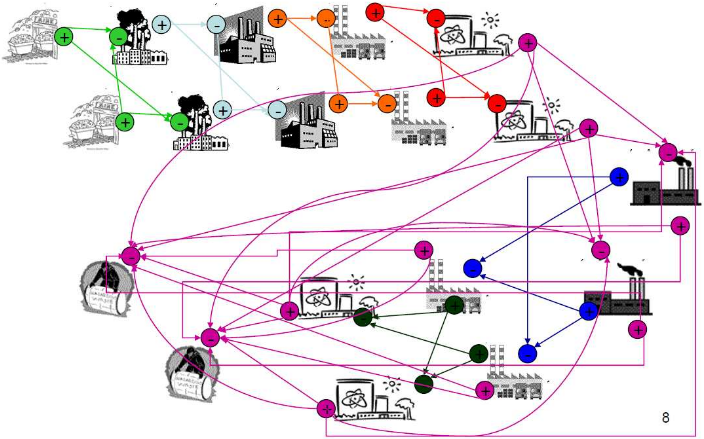


Figure: Well designed interfaces and strict encapsulation support scalability of the Market-based simulation paradigm [?]

Dynamic Module Loading : Developer

With a dynamic, plug-in implementation, the simulation logic is independent of the available models and models are loaded as shared libraries at runtime.

Model.cpp

```
#include Model.hpp
#include dlfcn.h
    .
    .
    .
 mdl_ctr* loadModel(name){
      void* model = dlopen(name.c_str(), RTD_LAZY)
      mdl_ctr* new_model = (mdl_ctor*) dlsym(model,"construct");
    .
    .
    .
 return new_model;
}
```

RecipeReactor.cpp

```
#include RecipeReactor.hpp
      .
      .
      .
  extern "C" Model* construct() {
      return new RecipeReactor();
  }
      .
      .
      .
```

Figure: Dynamic c library loading separates simulation logic from knowledge of available models, supporting extensions by developers with minimal lines of code.

Dynamic Module Loading : User

With a dynamic, plug-in implementation, the simulation logic is independent of the available models and models are loaded as shared libraries at runtime.

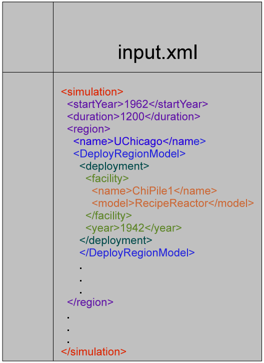
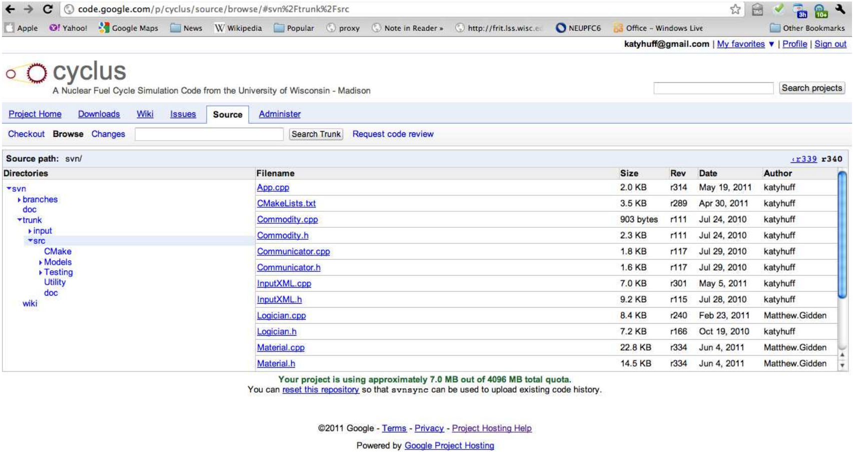


Figure: XML input parsing and a relaxNG schema provide a simplified XML interface is available for the end user to define available module implementations.

Open Source Repository

This open source repository provides a centralized location for documentation, developer history, and unhindered developer access.



'Modified Open' Source

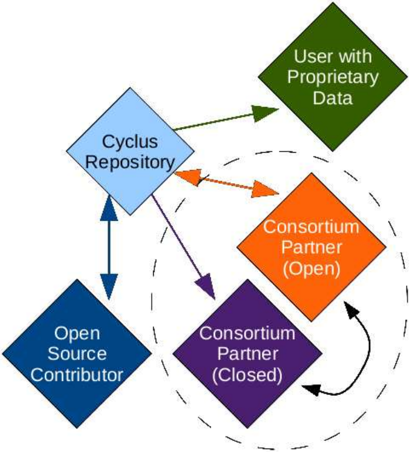
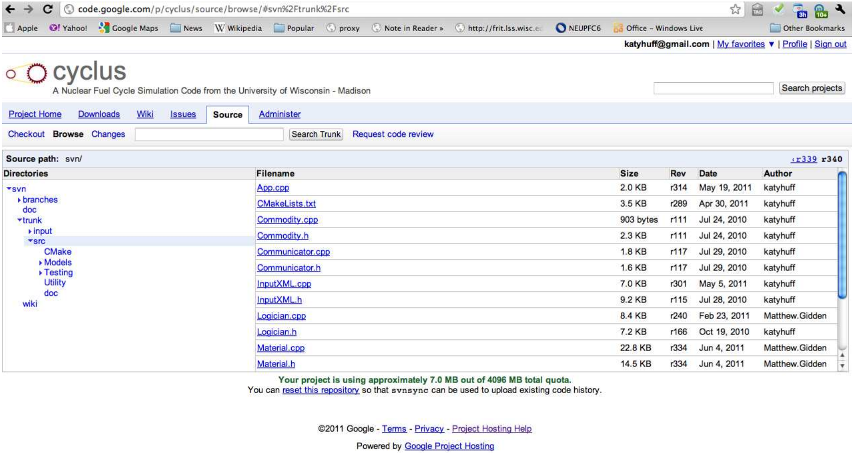


Figure: License, architecture, and development paradigm allow varying levels of code sharing and data security.

Version Control

This open source repository employs a version control system for provenance, developer access, and reproducibility of results.



Testing Framework

A testing framework built on a cross-platform, multi-language build system (CMake) allows developers to incorporate unit and integration tests into their code before it is commited.

Nested Components

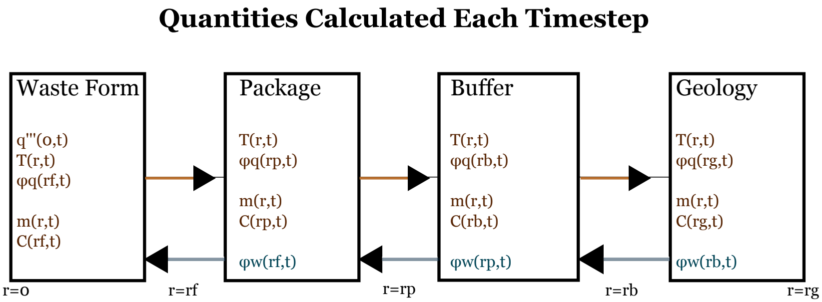


Figure: The nested components supply thermal flux and concentration information to each other at the boundaries.

Waste Stream

Waste Form

Waste Package

Buffer

Geological Environment

Outline

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Demonstration Case : Concept

Demonstration Case : Testing

Base Case : Component Abstraction

Base Case : System Level Abstraction

Base Case : Concept

Base Case : Testing

Extensions : Abstraction

Extensions : Testing

References I

[1] ANDRA.
Granite: Evaluation de la faisabilite du stockage geologique en formation granite.
Technical report, Paris, 2005.

[2] W. von Lensa, R. Nabbi, and M. Rossbach.
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Forschungszentrum Julich, 2008.