Digital Twin of Nuclear Waste Management Facilities

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Why do we Need Digital Twins?

Digital Twin of Nuclear Waste Management Facilities

Informed decision making

Knowledge

Certainty

Simulation

Models

Information/ Data

Level of exactness of model

Level of improvement in decision making

Decision Makers

Researchers / Technical
NDA Mission

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Sellafield Site Effluent Treatment

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Effectiveness of SIXEP and EARP
Effluent treatment on Sellafield Site

Donor Plants

SIXEP Plant
Waste Retrieval from MSSS
**Liquor Management**

Discharge via Sentencing tank

Buffer storage

Liquor Activity Reduction

Liquor top-ups Washings etc

Liquor level fluctuates, decreasing at the end

Solid decreases
Idealised view of feeds & Outputs for an operating plant

As Designed
Normal operations

Decommissioning

Radioactivity

Uncertainty

Rolling Average Feed

Past

Present

Future
Introduction to Digital Twins

Real World Plant

Real Time
Operational Data

Digital Twin

Operational History
Mechanistic Models
Statistical Models

Data Management
Stewardship

Execution

Platform (SaaS & PaaS)
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Moving towards a digital twin

Design Information
- Historic sample data and inventory records
- Interviews with former staff
- Plant drawings and layout

Mechanistic Models
- Chemical knowledge captured into thermodynamic & kinetic models
- Dynamic simulations of the effluent recovery and treatment process
- Many models already exist

Real Time Operational Data
- Sampling from plant – Daily samples (at least) for 40+ years + operational parameters (temperature/ flow rates) (lots of data).
- Smart sensors/ IoT? Nice to have in future but unlikely to be practical in this application for decades

Statistical Models
- Trending plant data to provide an insight into current and future operations ‘lead and learn’
Integrated Digital Twin

(Service Layer) REST APIs

JSON for message passing

SQL and Mongo Database

Distributed micro-servers hosted on HPC
Mechanistic Models

Key mechanistic information is captured in kinetic and thermodynamic models.

Thermodynamic – Solubility limit for species to set hard limit for what can exist in solution.

Kinetic – Rate of reactions (e.g., Carbonation) that impacts on pH.

Inclusion of chemistry builds confidence in model and implements robust boundary conditions.

Release rate (generalised) of absorbed radionuclides:

\[ \frac{\partial C_{aq}}{\partial t} = k_b C_{sorb} - k_r C_{aq} \]

8 Different chemical reactions
30+ different chemical species
22 compartments (5 compartment groups)
Statistical Models

R-shiny interface allows models to be created

Trending analysis currently using standard tools in ggplot2

JSON interface to transfer data between web-API and R-shiny server

Example plot of change in quantity of beta-emitter with time
Simulating Retrievals

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Process Model Developed in gPROMS

This animation shows the solid and liquor levels in the compartments throughout retrievals.
Process & operational Modelling

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Comparison with plant data

This plot shows the rate of activity removal during retrievals.

Example prediction from the process model for change in quantity of beta-emitter with time

Single simulation 38 hrs
Need to investigate means of accelerating to deal with UQ
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Stewardship/ Quality assurance

Workflows have been developed for operations

No circular references – linear data flows (needs scalable platform)

UI is web based creating an ‘app’ type interface for all the capabilities

Workflow for creating a set of initial conditions.
Conclusions

We have taken several major steps towards building a digital twin. First version (trending only) already in use by plant operators.

Collaborative working needed between chemists, process engineers, data scientists, developers.

We have learned about the importance of data - this is a valuable asset that needs to be managed.

Expandability of the framework will allow us to build in additional functionality as required.
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