Simulation and analysis to support decision making in the treatment and handling of radioactive waste

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The Low Level Waste Repository has used System Dynamics to make better decisions on handling and treating radioactive waste

- The Low Level Waste Repository Ltd (LLWR) manage and operate the national low level waste repository on behalf of the Nuclear Decommissioning Authority.
- System Dynamics was used by the LLWR to better understand and quantify the national low level waste system and to support detailed analysis of a particular type of low level waste.
- This poster describes how the models were used and the benefits associated with the System Dynamics approach.

① Background

Low Level Radioactive Waste

- Nuclear material has wide application in the UK, from generating power through to carrying out medical treatments.
- Some radioactive waste is unavoidable and must be managed appropriately.
- Low level wastes (LLW) are those which contain relatively low levels of radioactivity.
- Most LLW comes from the operation and decommissioning of nuclear facilities, and mainly consists of scrap metal items, paper and plastics. Some smaller amounts of LLW also come from hospitals and universities.
- Waste generators must make all reasonable efforts to prevent, minimise, reuse and/or recycle LLW generated. [03]

Figure1: Raw waste arisings of all LLW by waste producer (m^3) [02]

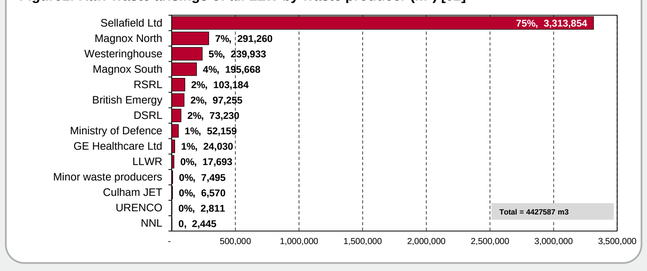
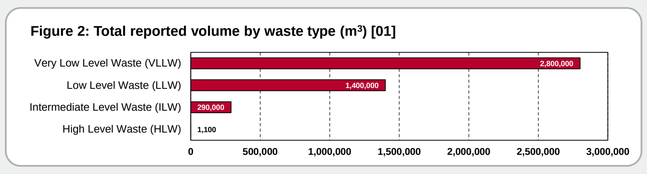


Figure 2: Total reported volume by waste type (m^3) [01]



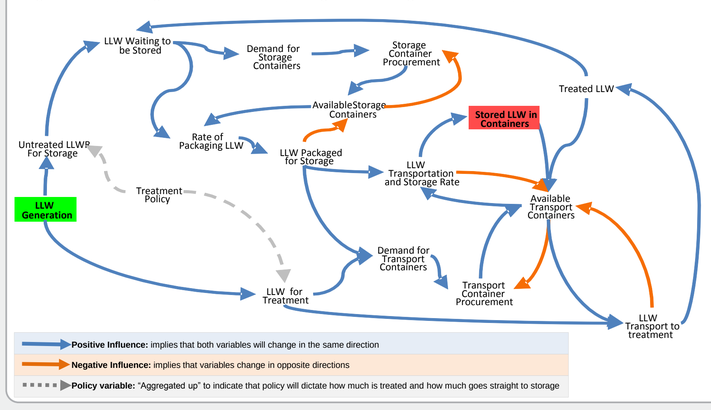
The Low Level Waste Repository

- The Low Level Waste Repository Ltd (LLWR) manage and operate the national low level waste repository on behalf of the Nuclear Decommissioning Authority.
- The repository, located in West Cumbria in England, is the UK's primary facility for the disposal of LLW, and has been in operation for over 50 years.
- The process of handling LLW in the UK, from creation, through transportation, to treatment, storage and disposal is a complex system which the LLWR needs to both understand and manage. Two key challenges for the LLWR are:
  1. The range of containers used for the transportation and storage/disposal of the LLW;
  2. The potential waste treatment methods and their impact on resources e.g. costs, containers, and storage volume.

Figure 3: Aerial view of the Low Level Waste Repository [04]

② Creating a shared understanding

Figure 4: Sample high level Causal Loop Diagram showing start and end points of the waste path

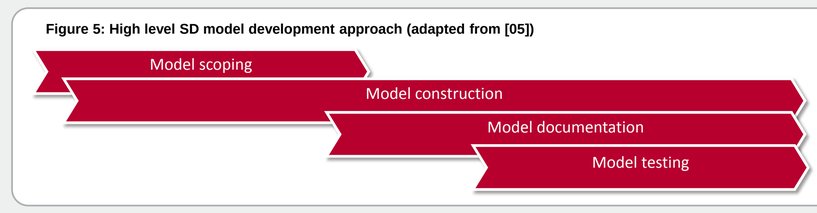


Creating a shared understanding

- Causal Loop Diagrams were used to help generate a clearer understanding of the LLWR systems being represented.
- These were created in facilitated workshops and interviews with leading engineers, designers, consignor support, finance, commercial and environmental subject matter experts.
- Gathering together this mix of stakeholders, who are split across two different sites and so have limited interaction, also ensured consensus and joint ownership of the resulting diagrams.
- The diagrams illustrated the complexity of the system, which is compounded by a range of factors that vary over time and are not within the control of the LLWR.
- The influence of these factors were understood and incorporated to ensure they reflected the reality of the UK LLW system.
- The process of developing these diagrams also helped to coalesce the understanding of people from across the LLW system.

③ Quantifying the system

Figure 5: High level SD model development approach (adapted from [05])

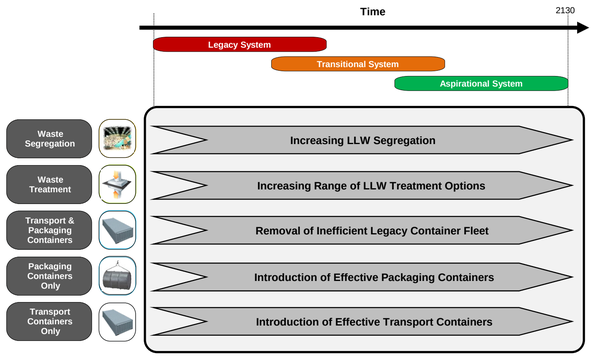


A robust approach to model development

- Quantitative models were developed based on SD best practices [05-11]
- Model scoping included defining the purpose of the model and model assumptions.
- Model construction included data acquisition and calibration.
- The models were then formally documented and tested.
- The quantitative models were developed using Powersim and MS Excel.
- Stakeholders were involved throughout the process, for example to get agreement on the model representation and to "sanity check" model results.

④ Quantitative modelling 1 - Analysis of national treatment and disposal strategies

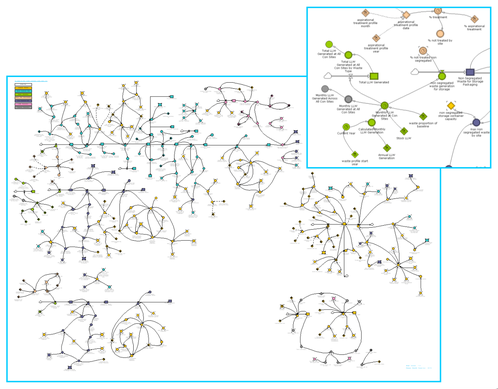
Figure 6: Improving the Low Level Waste System over time



Requirement

- At the heart of the approach to handling LLW is the fleet of containers used to safely transport, store and dispose of the waste.
- LLWR wished to better understand and quantify the transition from the current (or "legacy") fleet of containers to a new (or "aspirational") fleet of containers by 2130 via an interim (or "transitional") fleet.
- The aspirational and transitional fleets incorporate new containers and methods for waste segregation and treatment.
- The modelling needed to allow different transportation strategies to be explored, and incorporate national waste generation projections which run to 2130.

Figure 7: Low Level stock and flow representation of the system



Outcome

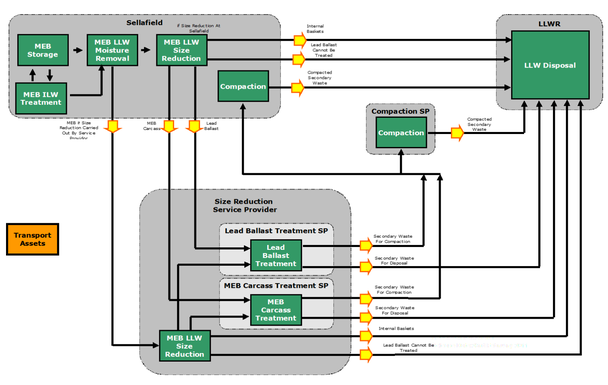
- The Powersim model allowed variations on the container fleet, with associated treatment and disposal characteristics to be examined.
- The model calculated key outcomes such as waste volumes, asset usage and financial metrics.
- The model had a user friendly interface that allowed the inputs to be amended and different scenarios compared.
- The resulting model was used to ensure a robust business case for LLWR's future waste treatment and container strategy.
- The model also enabled the exploration of different initiatives, such as different treatment strategies and container fleets and the resulting impact on costs and LLWR performance ratios.

⑤ Quantitative modelling 2 - Multi Element Bottles (MEB) treatment and disposal

Requirement

- LLWR was developing a multi-million pound business proposal to treat and dispose of two types of Multi Element Bottles (MEB) from Sellafield.
- MEBs are containers used to hold irradiated Light Water Reactor fuel in cooling ponds prior to reprocessing.
- MEBs can be considered to consist of three primary components, the carcass mass, a lead mass and an internal basket mass. These components require different treatment and handling.
- LLWR required a model to validate their proposed method of handling the MEBs, and also enable different handling strategies to be explored and costed.

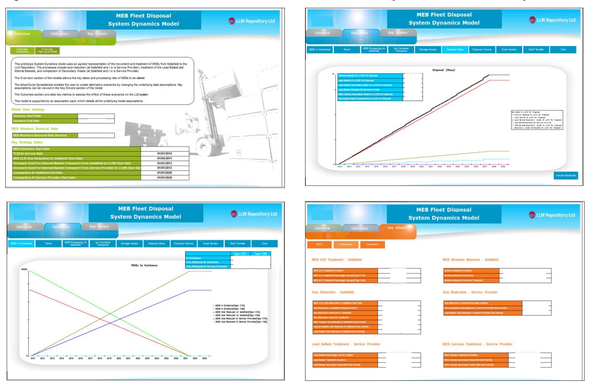
Figure 8: Processes represented in the MEB model



Outcome

- The model was based on the various MEB treatment and disposal options, and enabled the different strategies to be evaluated out to 2030.
- The model calculated the rate at which the MEBs were removed from Sellafield and their subsequent treatment and disposal rates. These treatment and disposal rates were dependent upon the actual treatment processes that were selected, and the available container fleet.
- Cost, volume and worker radiation dosages were key model outputs.
- The model was successfully used to validate the LLWR business proposal, with a particular benefit being that it offered a very visual representation of the planned treatment and disposal strategy [19,20]

Figure 9: Screenshots from the MEB model User Interface (redacted data used)



⑥ Conclusions

- Qualitative and quantitative methods have been applied to support real world strategic issues associated with the treatment and disposal of low level radioactive waste.
- Although there has been some modelling of radioactive waste [12-18], models that describe the specifics of radioactive waste transportation, disposal and treatment have not previously been described in the literature.
- The qualitative models ensured an agreed, stakeholder owned, understanding of the system under study.
- The quantitative models allowed robust investment decisions based on sound, objective data for the procurement of critical LLW assets and infrastructure. In addition, the quantitative models allowed rapid analysis of strategic options, where key performance metrics such as storage space requirements, costs, and staff radioactivity dosages could be readily viewed and assessed through user friendly interfaces.
- Of particular note was that the System Dynamics models enabled this complex system, which has a large combination of possible treatment, container options and transportation options, to be represented in a more efficient manner than is possible using Excel. The System Dynamics models also enabled the model structure to be more easily validated as all the cause and effect relationships were visible in the stock and flow diagrams.

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