

# Decommissioning and waste management challenges

Barney Whyte, Myrian Wood Sean Clarke *Waste Management* 

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# Decommissioning and waste management challenges



Range of facilities from early nuclear programme

R&D required to:

- Underpin safety
- Reduce radioactive hazard
- Accelerate the programme
- Innovative solutions
- Reduce the costs

NNL is utilising

- Skill base
- Facilities
- Investing through signature research
- Collaboration with academia and the supply chain



# The Challenge Projected UK nuclear waste



•ILW baseline processing predominantly encapsulation in cement

•HLW uses Thermal processing

•Package volume reduction = saving ~£1bn based on £10k/m3 GDF costs.

•£8bn waste costs at Sellafield

•£4bn for final disposal



Excluding reactor graphite, ~75% of all UK nuclear waste is at Sellafield

# The Benefits from Thermal Treatment





1 Reduced final volume

Co-disposal of wastes





Contingency rework process for cemented

3 Insensitivity to feed properties

Typical heterogeneous low level waste



# The Barriers to Thermal Treatment in the UK



- Process and Operational Complexity
  - Engineering vs. cement encapsulation plant
  - Management of organics
  - Many years experience with WVP
- Volatile Radionuclides H-3, C-14, I-129, Cs-137, Tc-99
  - Requires suitable off gas system & operational envelope
- Technology Maturity
  - Thermal plants for higher activity wastes operating or under construction in Switzerland, US, Russia and Australia
  - Thermal treatment of LLW carried out in most countries with nuclear power
- Lifetime Waste Management Cost
  - More detailed study required with real data (short term treatment costs vs. lifetime costs)





Thermal treatment technologies

- Joule heated in container vitrification
- Plasma processing
- Calcination and Hot Isostatic Pressing
- Calcination and continuous fed joule heated induction melting
- Cold crucible induction melting
- Incineration
- Steam reforming
- Pyrolysis

# Track Record Thermal Treatment of Nuclear Waste





HLW: WVP at Sellafield



LLW/ILW: Zwilag, Switzerland

France, Russia, Korea, Japan, Belgium, Sweden

Geomelt: US Mixed waste LLW & ILW

Maralinga Nuclear Weapons test site in Australia





# Example 1 Synroc using HIP

- Making rock Process developed by ANSTO and uses proven geological rock structures stable for 2 billion years
  - -zirconolite for high Pu content streams -pyrochlore for MOx
  - -hybrid glass ceramics for mixed waste
- Excellent long term environmental performance -100 fold improvements in leach rate compared with pure glass formulations.
- Wide waste feed envelope
   -no requirement to pour
- Reduced secondary wastes.
- Highly uniform product.
- Batch process
  - -simplifies accountancy control.
- Can be located outside of a glovebox.







# Synroc process for Pu residues Concept design phase





# Example 2 Vitrification





# WVP - New feed challenges Co-processing POCO and HAL



# Yellow phase forms in presence of reprocessing waste at high MoO<sub>3.</sub>

### Undesirable due to:-

Water soluble phase
Partial volatility in melt
Corrosive to melter





Recent studies have established optimum feed rates, melt temperatures & waste/glass ratios

# Example 3 - Geomelt NNL Collaboration with Kurion

- Partnering with Kurion
  - Building on existing trials with SL
- Install full (1Te) scale active Geomelt rig in active rig hall in Central Lab
- Carry out trials
  - Process conditions, Product quality, Volatiles/off gas
    - Caesium, Ruthenium etc.
- Progress to treatment of actual waste
  - LLW asbestos, orphan wastes
- Inform design for plant-based or mobile systems.







## 2009/10 - Full Scale Inactive Demonstrator Trials









PCM & Magnox Sludge simulants

Sand/Clino & PFCS Waste







# Processing, Removal & Waste form









•All materials stabilised:

- •~130kg glass/metal product
- •10 x leach resistance required by DOE limits

# Active Trials & Demonstrations



- Pond Sludges
- Simulated Solid Wastes
- Magnox Sludge
- Sand Clinoptilolite
- PCM wastes
- Demolition materials (β/γ and/or PCM)

Doped with U & Isotopes

- Waste delivery / Pretreatment
- Vent system / off gas treatment
  - Caesium-137
  - Technetium-99
  - Ruthenium-103/106
  - Carbon-14
  - Hydrogen-3
- Product quality



Treat real Low Level & Orphan wastes

# 2015 - Full Scale Inactive Equipment





#### Workington Laboratory

## Wasteform Example – NDA Soils









# 2016 - Central Laboratory Active Rig Hall





## Central Lab Highly Active Cells





Geomelt Rig

Miscellaneous Beta / Gamma Waste Store

"416 Liner"



# Exciting times to establish new thermal treatment processes

NATIONAL NUCLEAR

- Current & Legacy ILW projections
  - 287,000 m<sup>3</sup> waste & 488,000 m<sup>3</sup> packaged waste
  - Broad front decommissioning mixed wastes
  - Thermal offers significant volume reductions
- GDF disposal for ILW/HLW
  - Financial savings
  - Contingency rework process
  - Environmental, Safety Security benefits
- Opportunity for problematic wastes
  - Reactive metals (AI/U/Pu)
  - Organics
  - Powders
  - Asbestos
- Innovation/Technology transfer...









# **Integrated Project Team**



NATIONAL NUCLEA

LABORATO



- Combine thermal initiatives to take advantage of commonalties in needs
- Manage a sustained programme of support to push thermal treatment of ILW up the TRL scale
- Establish an active demonstration centre in the NNL Central Laboratory
- Thermal treatment must become part of a broader toolkit to treat problematic wastes
- Collaborate with EU partners through a Horizon 2020 project inc. active trials.

# Horizon 2020 Thermal Submission

- NATIONAL NUCLEAR
- Proposal to be issued in June '16 with a likely focus on soft decommissioning wastes and ion exchange media
- The project will aim to carry out active waste trials at partner facilities (UK, France and possibly Belgium). NNL are expected to lead the project
- A variety of technologies may be used;
- Joule heated in container vitrification
- Plasma processing
- Hot Isostatic Pressing
- Calcination
- Cold crucible induction melting



 Supporting partners will be involved in scientific trials and studies where there is an interest in the target waste streams

# Graphite Case Studies



### Removal of Graphite (Central Laboratory)

- To support the removal of the irradiated graphite from the Dounreay Materials Test Reactor (DMTR) NNL are providing a clearer understanding of the stability of the material
- Physical and mechanical characteristics of the graphite are being measured (ductile and tensile strength measurements)
- The data arising from this work will enable Dounreay to confirm how the material should be handled during the dismantling of the DMTR

### Waste Management (Preston Laboratory)

- Graphite has stored energy which can be released under perturbing conditions that may be imposed during waste processing (Wigner Effect) - led to Windscale fire in 1950's.
- NNL will determine the waste stability via an assessment of WE using a thermo-gravimetric analyser equipped with differential scanning calorimeter sample head.
- The elucidation of Wigner energy is a fundamental the site need to understand to determine the strategy for waste management of this material. NNL will also determine Tritium and Carbon-14 release during any potential graphite annealing processes.

# Legacy Waste Characterisation & Sampling











# BEP - Challenge



- BEP will treat legacy wastes from a number of facilities
- Operations due to commence 2020
- Technical programme aimed at demonstrating how BEP will produce a product suitable for disposal utilising robots.
- Technical Challenge
  - Wide variety of wastes from a number of different donor plants
  - Reactive materials content
  - Fissile considerations.
  - Sludge and effluent content.
  - Data recording needs
  - Disposability considerations.
- NNL Solution
  - Multi- disciplinary team, experts from a number of organisations
  - Integration and co-location with the customer
  - DQO approach to work scope definition
  - In active trials in Workington rig hall
- Benefit
  - SL PBI achieved in Dec 2014
  - Programme continues to optimise waste treatment technology and develop conditions for disposable product









## NATIONAL NUCLEAR BEP – Inactive Demonstration trails





- Standard Kuka KR500-F industrial robots, configured for 'proof of principle' trials. Mostly off-the-shelf tools, adapted for use with the robots Demonstration of off-shelf effluent treatment technologies ۰
- •
- Demonstration of product quality and waste product suitable for disposal





# Support to RWM Ltd



- Broad Range of projects
  - Practical trials
    - Evolution of NRVB and waste encapsulation grouts
    - Corrosion of Magnox
    - Fuel corrosion and C-14 release
    - Gas venting through NRVB
  - Modelling
  - Effect of waste components in GDF Decontamination reagents
- Secondment of specialist staff
- Workshops
- Strategy In situ Encapsulation options for ILW
- Peer Review

# Geochemistry and Microbiology



- Extensive track record of undertaking projects related to the geochemical and microbial ("biogeochemical") aspects of nuclear waste disposal
- Work programmes have been delivered through a combination of laboratory experiments, modelling and field studies
- Lab experiments include:
  - Sorption and solubility experiments
  - Long term waste degradation experiments
  - Leaching experiments from waste material
  - Characterisation (including DNA sequencing) of microbial populations, including from highly active samples

# Geochemistry and Microbiology – Modelling



- Use of industry standard software such as PHREEQC, PHAST, ToughReact etc
- Developed own software tools, particularly GRM (Generalised Repository Model)
  - Coupled reactive-transport model, developed for studies of the chemical evolution (pH, Eh), gas generation and radionuclide speciation
  - Detailed kinetic representation of anaerobic microbial processes:
  - Eh determined from dominant microbial process
  - Equilibrium chemical speciation, mineral and gas reaction
  - Advective and
     Finestep increment
     Finestep loop for each cell

# Biogeochemical Modelling Examples





#### Modelled pH evolution at LLWR



Low-Level Waste Repository, UK

Long term evolution of disposal area Modelled gas and aqueous release Modelling of sorption in near and far field **Geological Disposal Facility, UK Cement Evolution Modelling** Gas generation model testing and validation Modelling behaviour of lead Modelling sorption onto bentonite **TVO**, Finland Modelling long term gas generation expts **ANDRA**, France Modelling of evolution of bitumen waste in a deep geological repository Mont Terri, Switzerland

Modelling microbial behaviour

Modelled nitrate concentration, Mont Terri

# Biogeochemical Experiments Examples





#### SEM image of U precipitating on calcite



Experimental results of sorption of Sr onto geological material

Low-Level Waste Repository, UK Long term waste Degradation Experiments Gas generation experiments Sorption of radionuclides Characterisation of microbial population Geological Disposal Facility, UK Cellulose degradation and impact on rad behaviour Long-term (10yrs+) evolution of cement backfill C-14 release from waste material Leaching from encapsulated products Leaching from spent fuel **SERAW**, Bulgaria Sorption of radionuclides onto geological material

#### BIGRAD – Biogeochemical gradients and NATIONAL NUCLEAR radionuclide transport

- Independent research council (NERC) funded consortium
  - University of Manchester
  - British Geological Survey
  - Loughborough University
  - University of Sheffield
  - NNL
- Biogeochemistry of the alkali disturbed zone
  - Focussed on the UK concept for ILW
  - Cement-rock interaction
  - Microbial studies of alkaline systems
  - Radionuclide interactions, Tc, U, Np
  - Modelling





**Blogeochemical Gradients** and **RADionuclide** transport

LABORATOR

# Biogeochemical Research (Joe Small)



- Vision: To further develop NNL's reputation in microbiological and geochemical aspects of Geological Disposal
- Topics include effects of sulphate reducing bacteria on corrosion, consumption of H<sub>2</sub>, mediation of CH<sub>4</sub>, radioelement solubility, organics degradation to innocuous end products (e.g. HCO<sub>3</sub><sup>-</sup>)
- Builds on NNL's Biogeochemical modelling capability
  - LLWR safety case
  - NERC Bigrad
  - Gas Generation modelling (FI)
  - Mont Terri Underground Laboratory (CH)
- Key collaborators:
  - Uni of Manchester, BGS (UK)
  - SCK-CEN (BE)
  - ANDRA (FR)
  - VTT, TVO (FI)
  - SKB, Micans (SE)



Concept diagram of Horizon 2020 proposal Microbiology in Nuclear Disposal (MIND). WP1 led by NNL concerns microbiological processes in intermediate level waste





- Small particles in the size range 1 1000 nm, that will remain suspended in solution
- Can be a radionuclide phase or a stable phase with radionuclides incorporated – act as a vector for transport
- Work programmes have been delivered for both waste disposal and waste treatment processes

# Colloids - Examples



# LLWR – sampling and characterisation of colloids



- Oxygen-free sampling techniques
- Determined presence of organic and inorganic colloids (primarily ironbased) in near-field, associated with anaerobic, near-field environment
- Colloids unstable in more aerobic far field environment

# Sellafield - Determination of colloid population in waste.



- Real samples taken from legacy waste ponds - highly
- Colloid population determined through sequential filtration and zeta potential
- Results indicated that uranium exists predominantly as small, real colloids, with implications for downstream ion exchange effluent treatment

# Colloid Behaviour Strategic Research Programme



# Vision: To develop a world leading capability in radionuclide colloid behaviour

- Initial investigations include effect of U and Ca concentrations on colloid formation and on Cs, Sr mobility
- Progress to Np and Pu
- Formation of uranium and transuranic colloids at alkaline pH.
- Colloid transport in porous media: experiment and modelling.
- Developing capability in colloid characterisation.



# Decontamination



- Assessing paint for "decontaminatability" (next slide)
- Fundamental research into radionuclide surface interactions, including use of synchotron techniques
- Research into new techniques including
  - graphene,
  - electrochemical scabbling,
  - foam decontamination
- Development of an electrochemical technique to destroy decontamination agents following application
- Work programmes for both LLWR and RWM to consider the impact of disposing decontamination agents in LLW and ILW repositories

# Case Study: Compliance Testing



#### **Paint System Performance**

With the need to find an alternative to the 'System 6' paint system currently used on various types of transport flask within the UK nuclear industry and the onset of the new-build reactor programme there is a requirement to find and develop paint system products specifically for use in the nuclear industry.

One of the key drivers in assessing / developing paints and coatings for the nuclear industry is the need for the material to be resistant to the sorption of radionuclides, such that anv surface painted with the coating can withstand the presence of harsh chemicals and radioactive materials without causing any deterioration in the integrity of the surface. In addition, the painted surface must be easily cleaned to residual remove any contamination.

Undertake decontamination testing on samples of paint system products in accordance with accepted standards, to ascertain their suitability for use by the nuclear industry.

- (ISO) 8690: Decontamination of radioactively contaminated surfaces

   Method for testing and assessing ease of decontamination.
- French National Standard NF T 30-901 - Performance Test to Evaluate Susceptibility to Contamination and Fitness for Decontamination.





pH 7 all Paints

Summary of each stage of the experimental programme expressed as a percentage of the initial amount of activity taken up by each of the paint systems at pH 7  $\,$ 



Summary of each stage of the experimental programme expressed as a percentage of the initial amount of activity taken up by each of the paint systems at pH 11.7

Undertake comparative testing and analysis of paint systems to ascertain the degree of activity uptake and ease of decontamination to enable informed selection of appropriate paint systems for different materials and environments.

# Remote Laser Characterisation; NNL's Research and Development





NNL and the University of Manchester have established a research laboratory to develop the use of at a distance laser characterisation techniques within the nuclear industry to aid in the assessment and characterisation of decommissioning materials and wastes.

#### **Currently 3 interdisciplinary research areas:**

- 3D LiDAR/laser scanning, UAV/drone surveying and 3D/4D visualisation of materials and environments
- 2D and 3D In-situ, miniaturised, stand-off laser spectroscopy of nuclear materials and environments
- In-line and off line laser characterisation and analysis, sensors and optical instrumentation

#### NNL are currently focused on developments in LIBS, LiDAR and Raman.

# Waste Management Discussion





Hot Isostatic Pressing

### Liquid effluent treatment





### Grouting Test Facilities







### Geomelt