The future role of nuclear fuel cycle technology in the UK

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National Nuclear Laboratory
Outline

- NNL Overview
- UK Industry Context
- UK Nuclear R&D Review
- Future Nuclear Fission R&D
- Summary and Conclusions
National Nuclear Laboratory Overview
NNL Overview

• Created July 2008
• Turnover £85m, 800 staff with >60% STEM trained
• Operate unique national facilities
• SBM Managing Contractor Appointed April 2009
• DECC Objectives:
  • International nuclear R&D centre of excellence
  • Safeguard nuclear expertise, facilities and skills
  • Deliver value for customers
  • Trusted advisor
  • Collaborations/Partnerships/Links
  • Socio-economic focus
Ownership and Management

Ownership

Contract Management

SBM Consortium
To deliver the best nuclear science and technology solutions in the world

NNL’s Key Customers:

• Compete for work – no baseline funding.
• Operating model internationally unique
NNL Science to Solutions

Universities

Basic Science

Research, Development and Testing

Technology Readiness Level’s

1

Small scale, low rad

Independent, Authoritative, Subject Matter Experts

NNL

Industry

Technology Deployment

9

Full scale, high rad
National Nuclear Laboratory Locations

- **Sellafield** (429 people)
  - Central Laboratory (288)
  - Windscale Laboratory (141)
- **Workington Laboratory** (51)
- **Springfields**
  - Preston Laboratory (139)
- **Risley** (144)
- **Stonehouse** (16)
- **Harwell** (14)
Central Laboratory: An investment of over £250M in world-beating nuclear R&D facilities

- Non active labs
- Active Labs
- High active alpha Labs
- Beta & gamma cells
- Plutonium and MOX facilities

- Solvent extraction glove-boxes
- Graphite labs
- Full scale test facilities
Facilities – Windscale Laboratory

- Active Handling and Inspection
- Large Shielded Cells
- Remote Operations Capability
- Core Capability:
  - Post Irradiation Examination (PIE)
  - Sample preparation
  - X-radiography
  - Source handling
  - Waste segregation, packing & despatch
NNL supports all nuclear programmes

- Continued operation of existing reactors & fuel cycle facilities (fuel fabrication, reprocessing)
- Legacy waste management / decommissioning
- New nuclear build
- Geological disposal
- Plutonium stockpile disposition
- Naval propulsion support
- Advanced reactor & fuel cycles
- Space propulsion systems
- Security, non-proliferation & safeguards
Five “Signature” Research Areas align with UK Strategic issues / needs

- Medium to long term research programmes
- Entrepreneurial investment in technology development
- Technology Transfer
- Collaborations
UK Industry Context
First commercial nuclear power station – Calder Hall 1956

UK civil nuclear programme evolved from weapons

Design to operation over 4 year period

Uranium metal fuel with CO\textsubscript{2} cooling

Classified as Generation I

Capacity 200MWe
UK Nuclear Generation

Magnox Reactor

Advanced Gas Reactor (AGR)

Pressurised Water Reactor
- Sizewell ‘B’
UK Experience of Different Systems

- Sodium-cooled fast reactors
  - DFR
  - PFR

- Gas-cooled reactors
  - Magnox
  - AGR

- Water-cooled reactors
  - SGHWR
  - HTR
  - Sizewell B PWR
Experience with a range of different fuels:
metallic, $\text{UO}_2$, MOX, carbides, nitrides, coated particles
fuel development manufacturing facilities

In-reactor performance analysis

PIE for used fuel
### Recycle / Reprocessing in the UK

<table>
<thead>
<tr>
<th>Period</th>
<th>Location</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1951 - 1972</td>
<td>Windscale</td>
<td>Reprocessing plant for metal fuel</td>
</tr>
<tr>
<td>1960 - 1993</td>
<td>Dounreay</td>
<td>Fast reactor fuel</td>
</tr>
<tr>
<td>1964 – 2017*</td>
<td>Magnox</td>
<td>Sellafield - Commercial Magnox clad uranium metal fuel</td>
</tr>
<tr>
<td>1994 – 2018*</td>
<td>THORP</td>
<td>Sellafield - Commercial thermal oxide (AGR/LWR) fuel</td>
</tr>
<tr>
<td>&gt;2018*</td>
<td>None</td>
<td>Open Fuel Cycle in UK Interim storage</td>
</tr>
</tbody>
</table>
Legacy waste management

Range of facilities from early nuclear programme – examples at Sellafield

- Fuel storage ponds
- Waste silos
- Waste storage tanks
- Windscale Pile
- 1st Reprocessing Plant
UK Nuclear R&D Review
Current nuclear programme

- Legacy waste and decommissioning programme
- Magnox, AGR and Sizewell PWR reactor operation
- Spent fuel management
- Disposition of Plutonium stockpile
- Deep geological disposal of radioactive waste
- Plans for new build reactors
Growth of Nuclear and Key Issues

- Low Carbon Technology
- Security of supply
- Safety
- Base load Generation
- Waste Management
- Economics

Outlook Boundaries

High Boundary = Maximum nuclear commitment in most nations
Low Boundary = Minimum global nuclear capability expected

Future Nuclear Capacity

Nuclear power’s new age
Review of UK Nuclear R&D: Royal Society / HOL

- Establish long-term nuclear energy strategy
- DECC lead long term R&D roadmap
- Establish Nuclear R&D Board with funding
- National strategic R&D programmes on Gen IV and advanced fuel cycles
- Broaden role of NNL to undertake national applied R&D programmes under Nuclear R&D Board

- Establish high level Civil Nuclear Power Council
- Need long term UK nuclear strategy & roadmap
- Implement roadmap R&D programme (NNL, Universities & research organisations) – Government funded
- Set up non-proliferation / nuclear security network
- Re-use Pu stockpile as MOX
The Vision in the wider context: A Nuclear Industrial Strategy

Sir John Beddington Review

Nuclear Industrial Strategy

Nuclear Industrial Vision

Nuclear Energy Strategy

Nuclear Supply Chain Action Plan

Nuclear Landscape Review

Nuclear R&D Roadmap

NIA Nuclear Industry Current Capability Report
UK Civil Fission Nuclear Grand Challenges

Current and new reactor systems
Decommissioning and clean up
Nuclear materials management (Pu & U)
Spent Fuel Management
Geological Disposal
Safeguards and security
Future nuclear energy systems and fuel cycle
Scenarios for UK deployment - future nuclear energy options

Deliver long term secure energy on the way to a low carbon energy future
Fuel Cycle: Holistic Approach

- Fuel Manufacture
- Reactor Systems
- Waste Management & Decommissioning
- Direct Disposal or Reprocessing

Minimum Waste Generation
Minimum Total Cost
Maximum Safety
What Influences Fuel Cycle Options?

- Balance of number of parameters including:
  - Economics
  - Proliferation
  - Technology viability and readiness level
  - Fuel supply
  - Use of nuclear energy
  - Spent fuel storage
  - Geological disposal – heat loading, size of repository
  - Sustainability – resource utilisation

- Worldwide growth of nuclear will impact on UK
UK R&D Background

• UK long history of nuclear energy

• R&D over past 60 years has underpinned nuclear development

• Significant R&D programmes ongoing within National Laboratories and industry

• Over 25 Universities in UK undertake nuclear research

• Nuclear is a key part of the energy strategy for the future
The size and experience of the academic (excluding post-doctoral researchers) nuclear R&D workforce in the UK.
Critical Skills

- Significant replenishment of skill base needed to support UK’s forward nuclear programme
- Generation of subject matter experts essential in many disciplines
- Strong link between SMEs, R&D and facilities
- Academic through to industrial experience is required
UK Fission R&D

Programme

Fuel
- Uranium
- Plutonium
- Thorium
- Inert Matrix
- Oxide / Carbide / Nitride / Metal

Reactors
- LWRs
- Gen IV
- SMRs

Recycle
- Aqueous based processing
- Molten salt pyroprocessing

Technology

Research & Development

- Material Properties
- Fuel Performance Modelling
- Safety and Performance Analysis
- Demonstration Test Fuels Manufacture
- Irradiation of Test Fuels
- Post Irradiation Examination

- Heat Transfer and Thermal Hydraulics
- Reactor physics
- Safety Case Analysis
- Materials Performance
- Reactor Chemistry
- Spent Fuel Inventory, Environmental Impact, Wastes
- Design Codes Validation

- Aqueous Flowsheet Development
- Molten Salt Flowsheet Development
- Active demonstration tests
- Alternative processes foresight analysis
- Waste management

Decommissioning / Disposal / Safeguards and Security
Generations of nuclear energy systems

**Generation I**
- Early Prototype Reactors
- **Magnox**
- Shippingport
- Dresden

**Generation II**
- Commercial Power Reactors
- LWRs: PWR, BWR
- CANDU
- AGR

**Generation III**
- Advanced LWRs
- ABWR
- AP1000
- EPR

**Generation III+**
- Evolutionary Designs
- SMR
- NGNP

**Generation IV**
- Highly Economical
- Enhanced Safety
- Minimize Wastes
- Proliferation Resistant

Timeline:
- Gen I (1950-1960)
- Gen II (1970-1990)
- Gen III (2000-2020)
- Gen III / III+ (2030-2040)
- Gen IV (2020-2040)
Advanced Reactor Systems

Beyond “new build” of AP-1000 and EPR PWRs, there are “advanced reactors”
  - large and small modular reactors
  - fast and thermal

Examples include:
- GE-Hitachi PRISM (FR)
- B&W mPower (PWR)
- NuScale (PWR)
- Holtec (PWR)
- ANTARES (HTR)
- Hyperion (FR)
- Molten Salt Reactors
- Th fuelled based systems

Long history of participation in international projects
- European Fast Reactor development
- Numerous European Framework 5, 6 & 7 projects
- South African PBMR project
- Generation-IV VHTR, SFR, and GFR systems
Advanced Test Fuel Research

• **Test Fuel Manufacture**
  – Dry powder pellet production;
    • Pu/Th MOX fuel
    • Oxide / Carbide / Nitride Fuel
  – Gel Sphere Precipitation test rig (SiCarbide fuel)

• **Test Fuel Assembly**
  – Test rod assembly for a variety of fuel types

• **Fuel Material Properties**
  – Ceramographical Examination
  – Inspection and X – Ray
  – Autoradiograph, thermogravimetric analysis

• **Fuel performance using state-of-the-art computer code suite**
NNL expertise and facilities supporting UK and international initiatives

NNL is one of several EU organisations providing Technical Area leadership.
Advanced reprocessing

- Programmes in UK for past 20 years
- UK involvement in international programmes including EU
- Collaboration in future important
Waste Management R&D
Geological disposal of wastes

Government’s framework for managing higher activity radioactive waste through geological disposal

Implementation of Geological Disposal Facility led by NDA (Radioactive Waste Management Division - RWMD)

R&D carried out to support the generic concept for a GDF
What needs to be considered?

- How well is it kept in the repository?
  - Waste form inventory
  - Container (vented)
  - Physical obstacles?
  - Mechanical stability
  - Low flow rate

- How harmful is it in the environment?
  - Chemical processes
    - Solubility
    - Sorption
  - Mechanical stability
  - Low flow rate

- How does the rock delay movement?
  - Groundwater flow
  - Rock matrix diffusion
  - Sorption
  - Diffusion and dispersion

- How does the rock keep it away from people?
  - Environmental behaviour
    - Human intrusion
    - Natural disruptive events

- How harmful is the dose?
  - Toxicity
  - Environmental behaviour
    - Human uptake
    - Gas

- How can the rock be ‘short circuited’?
  - Human intrusion
  - Natural disruptive events

And so on into the far distant future...

Time (years):
- 0
- 100
- 1000
- 10 000
- 100 000
- 1 million
Research Activities: Understanding the Wasteforms

- **Package Performance**
  - ILW evolution
  - Vitrified Product evolution
  - Abnormal Events

- **Understanding UK Inventory**
  - Spent Fuel
  - HLW

- **Waste Performance**
  - Post Closure
    - Glass Dissolution
    - C-14 generation
    - Gas generation
    - Organic behaviour

- **Novel Wasteforms**
  - Vitrified ILW
  - Low pH cements
  - Superplasticisers
Research Activities: Geosphere / Biosphere

### International Programmes
- Cement – Rock Interactions
- Gas Migration in Clay
- Thermal Modelling in Natural systems

### Radionuclides in the Environment
- Data validation
- Complexation
- Solubility
- Sorption

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**International Programmes**

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Summary and Conclusions
Summary and Conclusions

- Nuclear a key component of UK Energy mix
- UK has a pedigree of nuclear R&D for a variety of fuel types and reactor systems
- Significant R&D programmes are already ongoing in the UK across the full fuel cycle
- Fission R&D will play an important role within the UK nuclear renaissance
  - Informing key decisions
  - Maintaining and growing critical skills
  - Creating advanced technologies with underpinned solutions
Questions?