NATIONAL NUCLEAR LABORATORY

The future role of nuclear fuel cycle technology in the UK

Cambridge Lecture - 21 February 2013

Dr Fiona Rayment, Director Fuel Cycle Solutions
National Nuclear Laboratory

Outline

NATIONAL NUCLEAR LABORATORY

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

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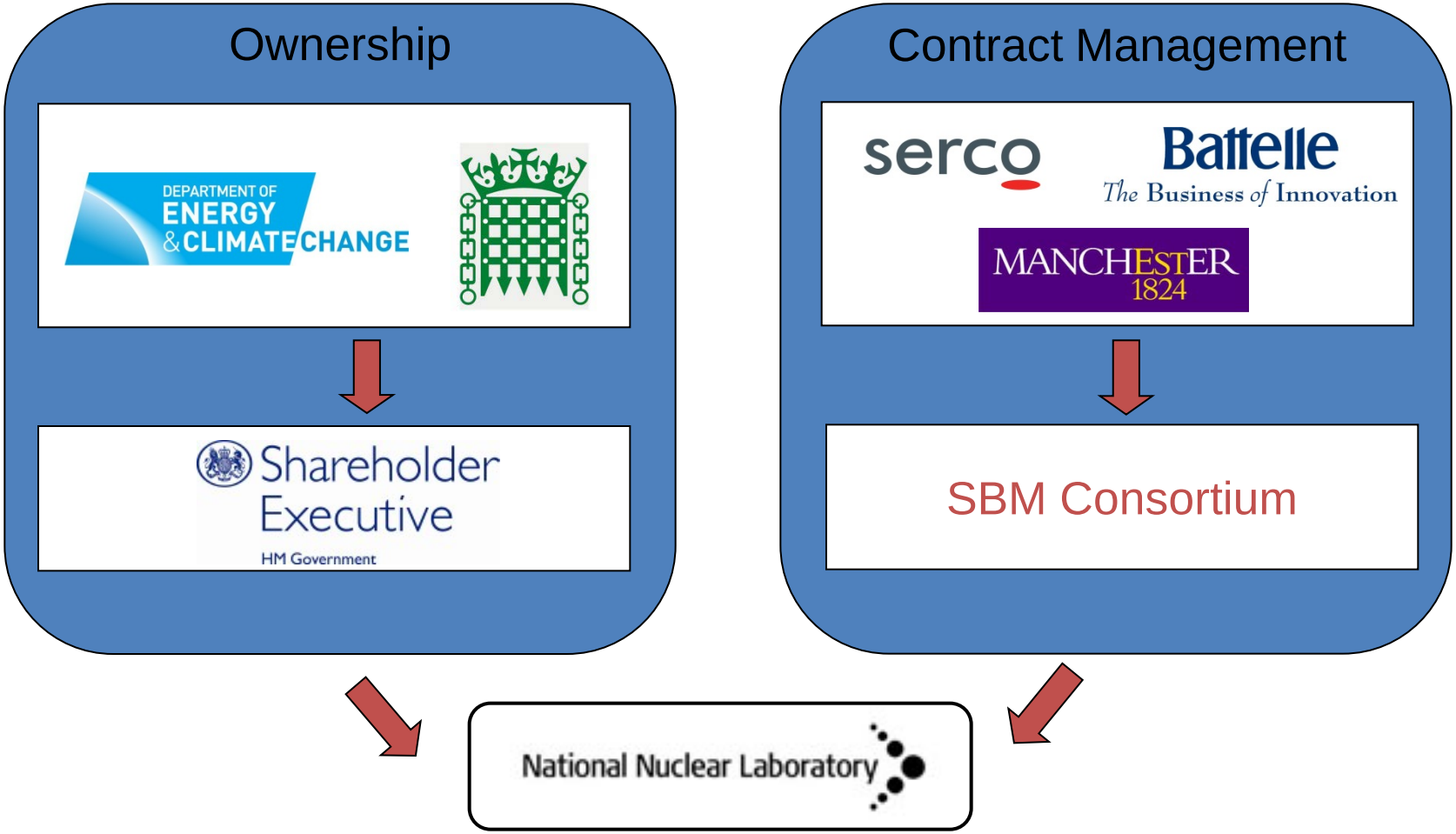
National Nuclear Laboratory Overview

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



Current National Nuclear Laboratory Remit

NATIONAL NUCLEAR LABORATORY

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

NNL's Key Customers:

EDF ENERGY

DEPARTMENT OF ENERGY & CLIMATE CHANGE

MINISTRY OF DEFENCE

Sellafield Ltd

Office for Nuclear Regulation
An agency of HSE

NDA Nuclear Decommissioning Authority

babcock
trusted to deliver ™

Rolls-Royce

Environment Agency

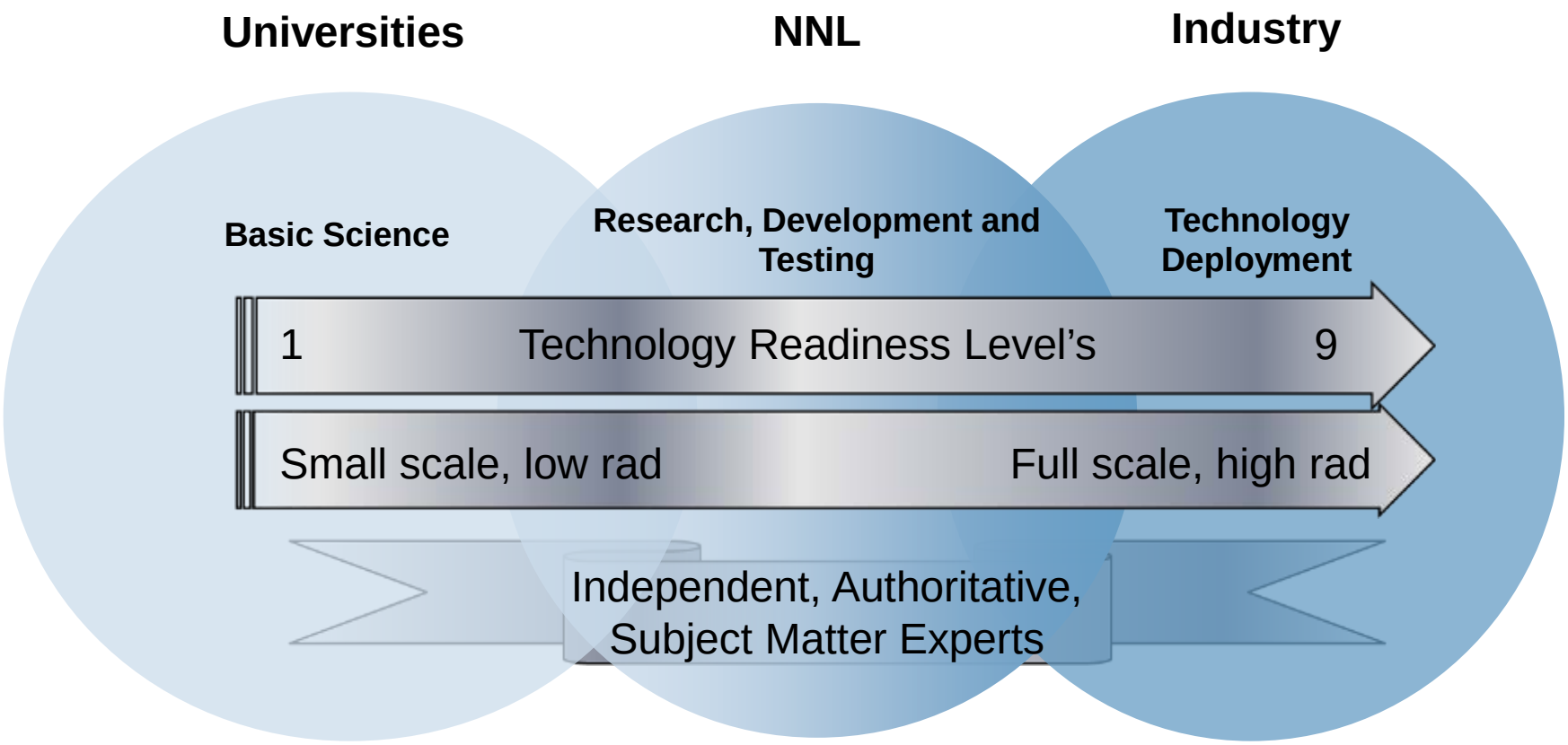
Westinghouse

Magnox

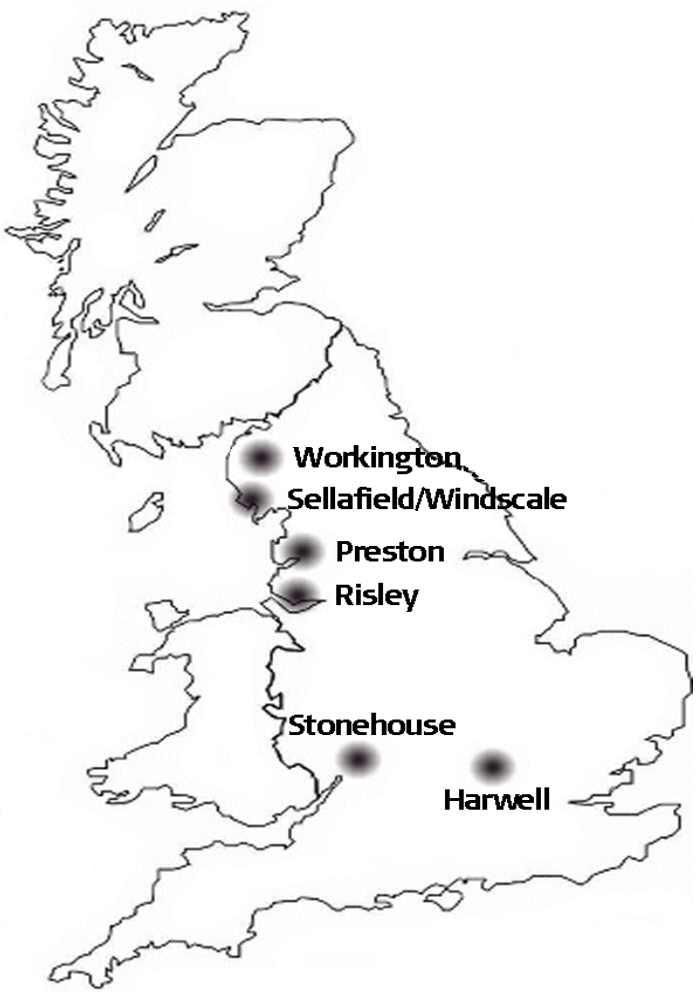
HORIZON NUCLEAR POWER
A UK Company of E.ON and RWE

- Compete for work – no baseline funding.
- Operating model internationally unique

NNL Science to Solutions



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)

Facilities - Central Laboratory

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

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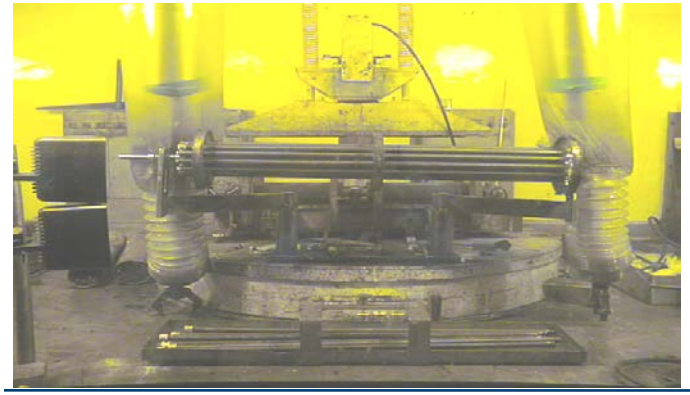
- Active Handling and Inspection
- Large Shielded Cells
- Remote Operations Capability
- Core Capability:
  - Post Irradiation Examination (PIE)
  - Sample preparation
  - X-radiography
  - Source handling
  - Waste segregation, packing & despatch



NNL supports all nuclear programmes

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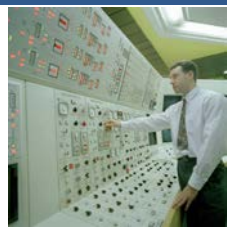
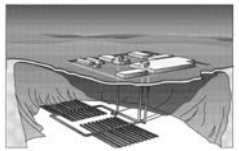
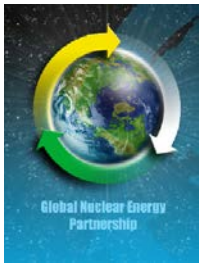
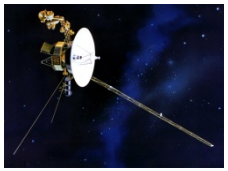
- Continued operation of existing reactors & fuel cycle facilities (fuel fabrication, reprocessing)
- Legacy waste management / decommissioning
- New nuclear build
- Geological disposal
- Plutonium stockpile disposition
- Naval propulsion support
- Advanced reactor & fuel cycles
- Space propulsion systems
- Security, non-proliferation & safeguards



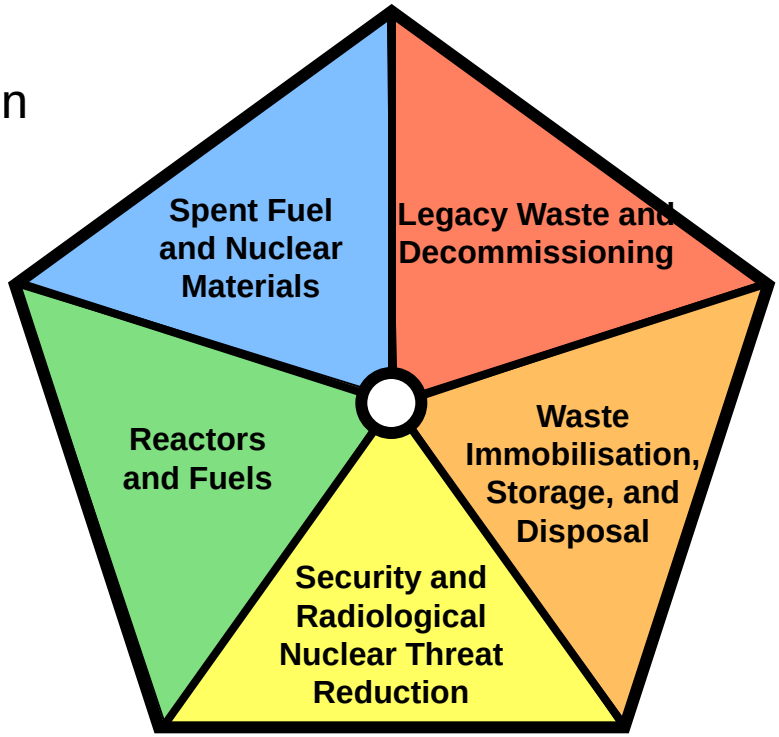






NNL Internally Funded R&D Programmes

- Five "*Signature*" Research Areas align with UK Strategic issues / needs
- Medium to long term research programmes
- Entrepreneurial investment in technology development
- Technology Transfer
- Collaborations



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UK Industry Context

First commercial nuclear power station – Calder Hall 1956

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UK civil nuclear programme evolved from weapons

Design to operation over 4 year period

Uranium metal fuel with CO_2 cooling

Classified as Generation I

Capacity 200MWe

UK Nuclear Generation

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Magnox Reactor

Advanced Gas Reactor (AGR)

Pressurised Water Reactor

- Sizewell 'B'

UK Experience of Different Systems

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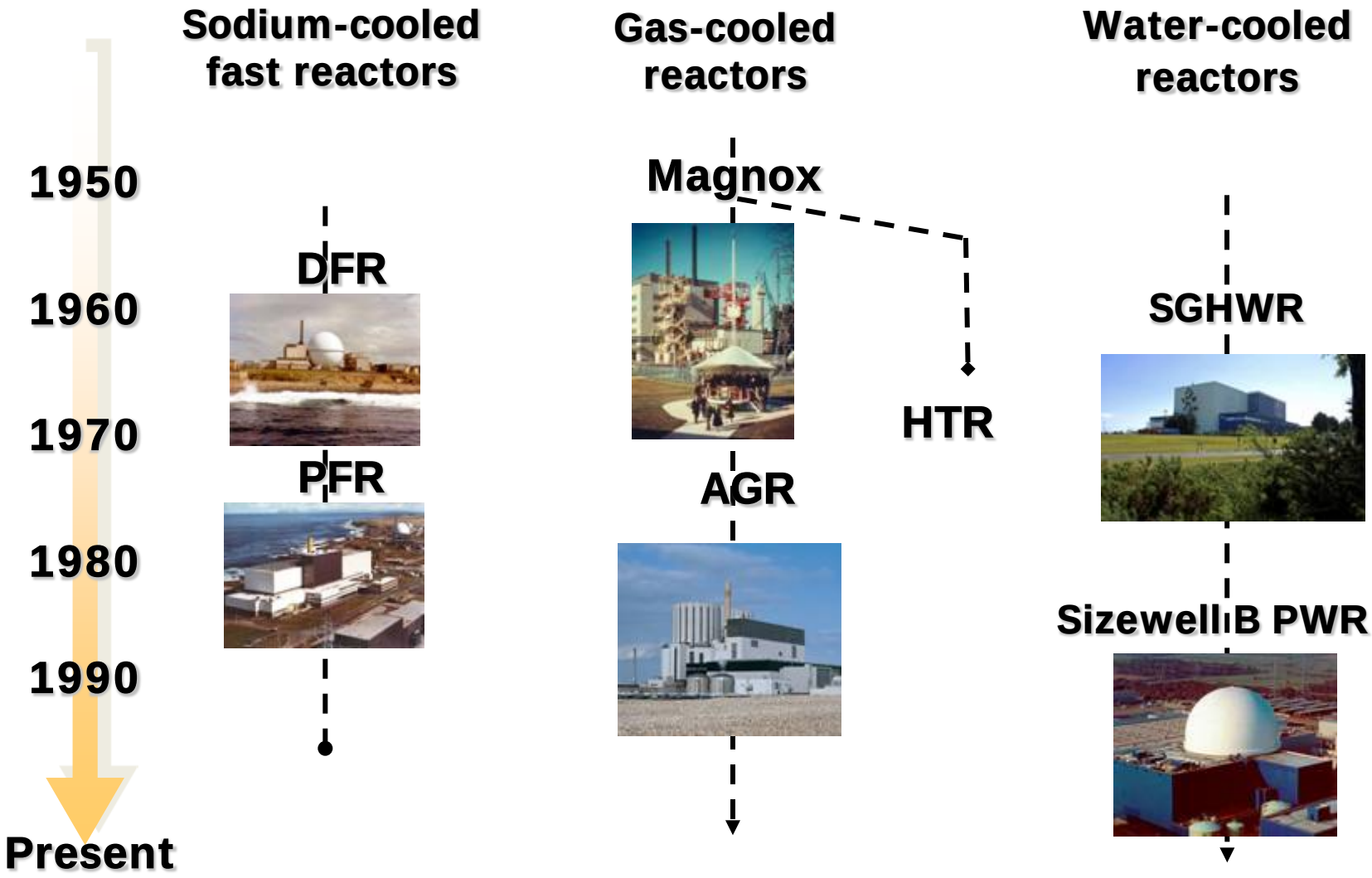

Fuels

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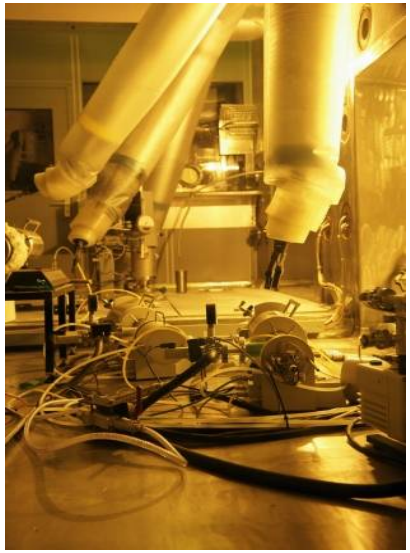
Experience with a range of different fuels:

- metallic, UO_2, MOX, carbides, nitrides, coated particles
- fuel development manufacturing facilities

In-reactor performance analysis



PIE for used fuel

Recycle / Reprocessing in the UK

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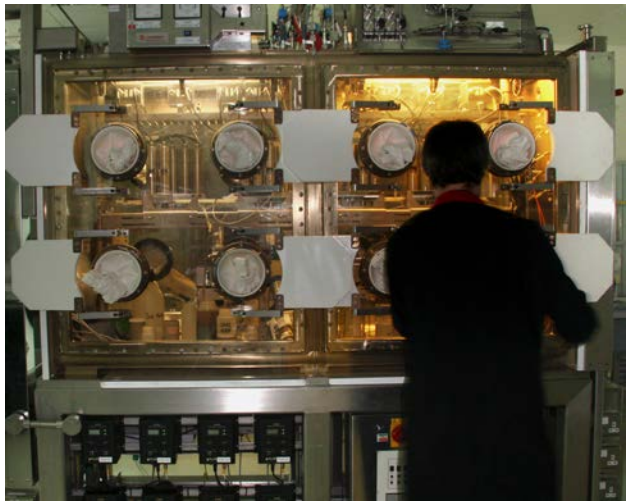
1951 - 1972	Windscale	Reprocessing plant for metal fuel
1960 - 1993	Dounreay	Fast reactor fuel
1964 – 2017*	Magnox	Sellafield - Commercial Magnox clad uranium metal fuel
1994 – 2018*	THORP	Sellafield - Commercial thermal oxide (AGR/LWR) fuel
>2018*	None	Open Fuel Cycle in UK Interim storage



Legacy waste management

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Range of facilities from early nuclear programme – examples at Sellafield

–Fuel storage ponds
–Waste silos
–Waste storage tanks
–Windscale Pile
–1st Reprocessing Plant

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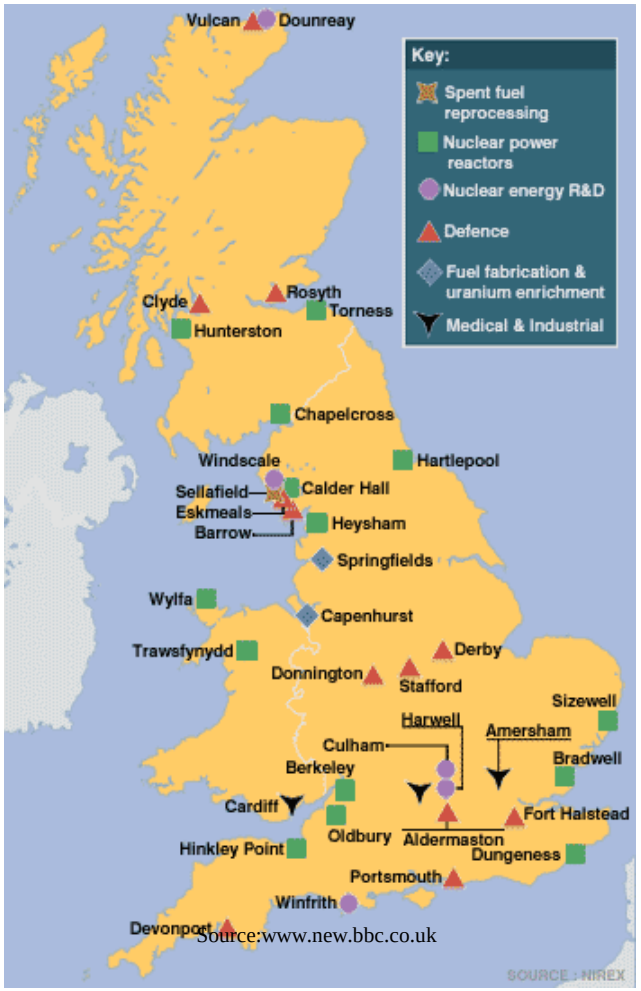
UK Nuclear R&D Review

Current nuclear programme



Source:www.new.bbc.co.uk

- 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

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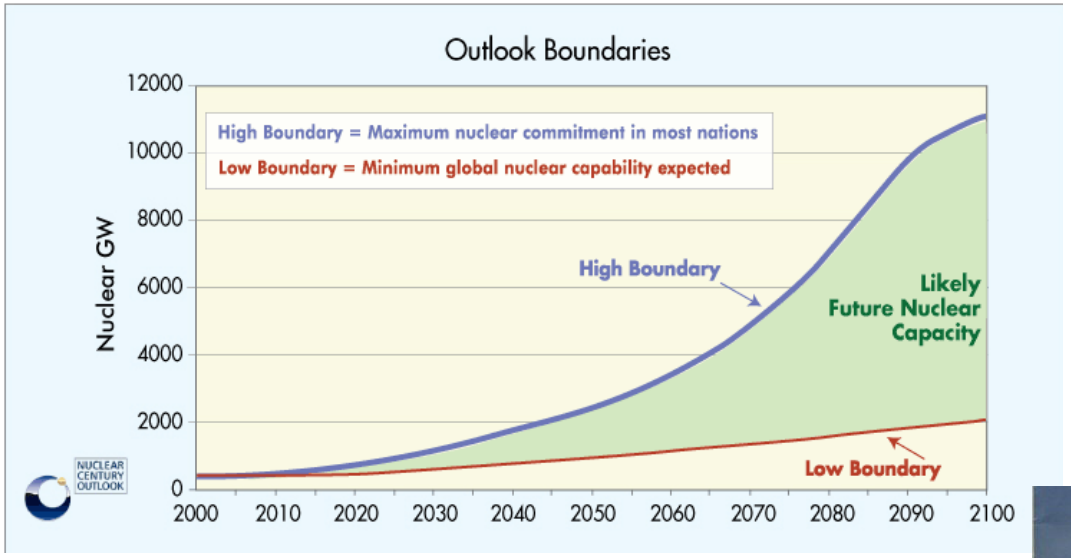

- Low Carbon Technology
- Security of supply
- Safety
- Base load Generation
- Waste Management
- Economics

Review of UK Nuclear R&D: Royal Society / HOL

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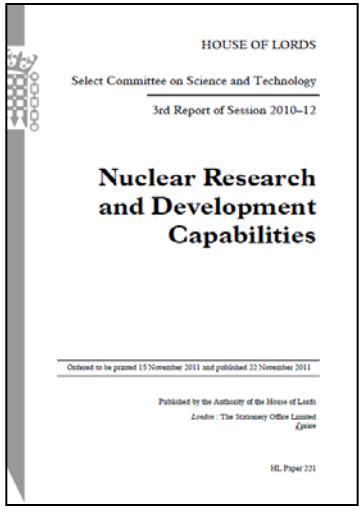
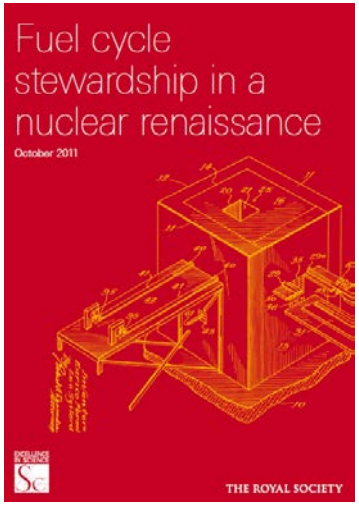
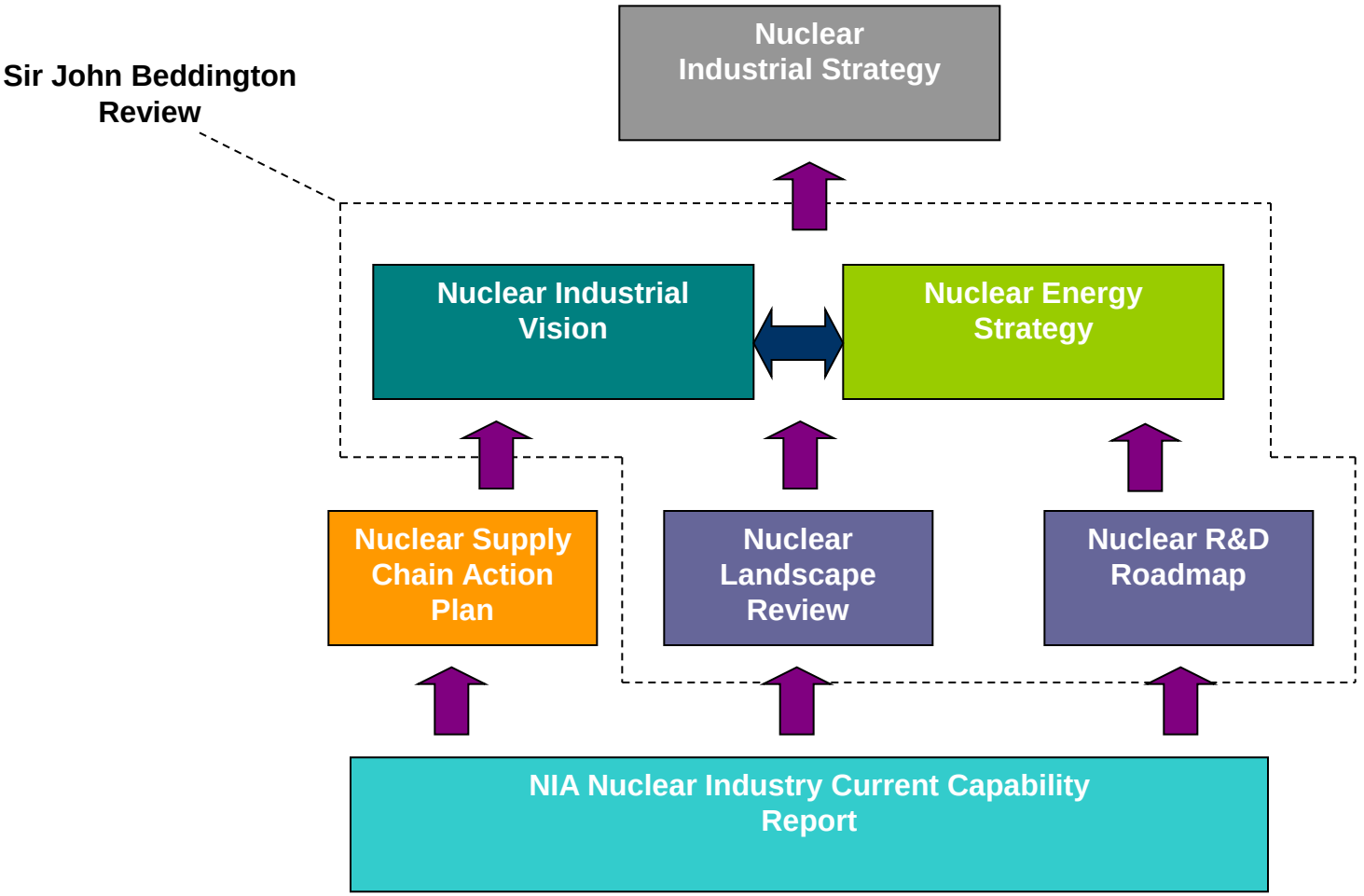
- Establish long-term nuclear energy strategy
- DECC lead long term R&D roadmap
- Establish Nuclear R&D Board with funding
- National strategic R&D programmes on Gen IV and advanced fuel cycles
- Broaden role of NNL to undertake national applied R&D programmes under Nuclear R&D Board

• 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



UK Civil Fission Nuclear Grand Challenges

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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

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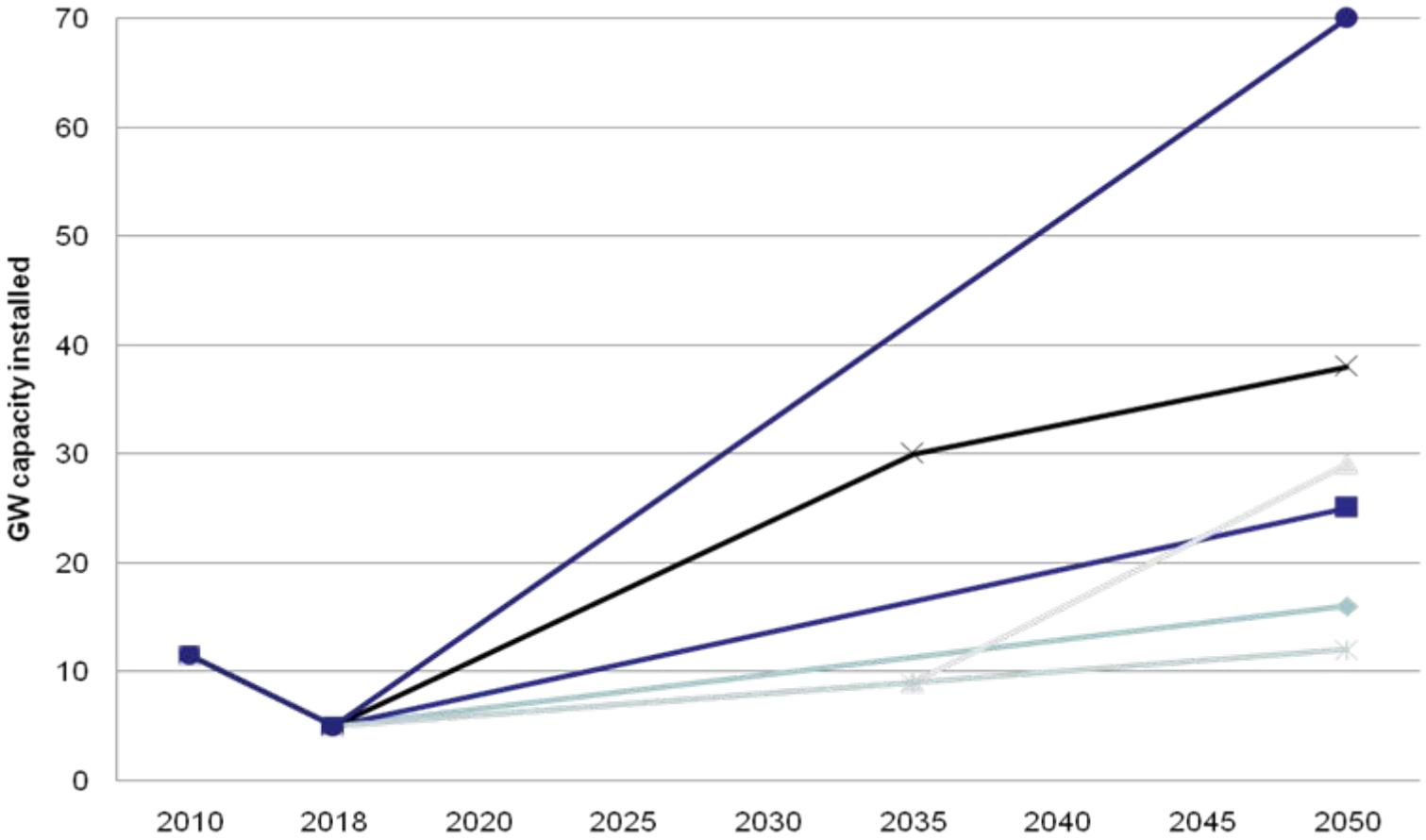
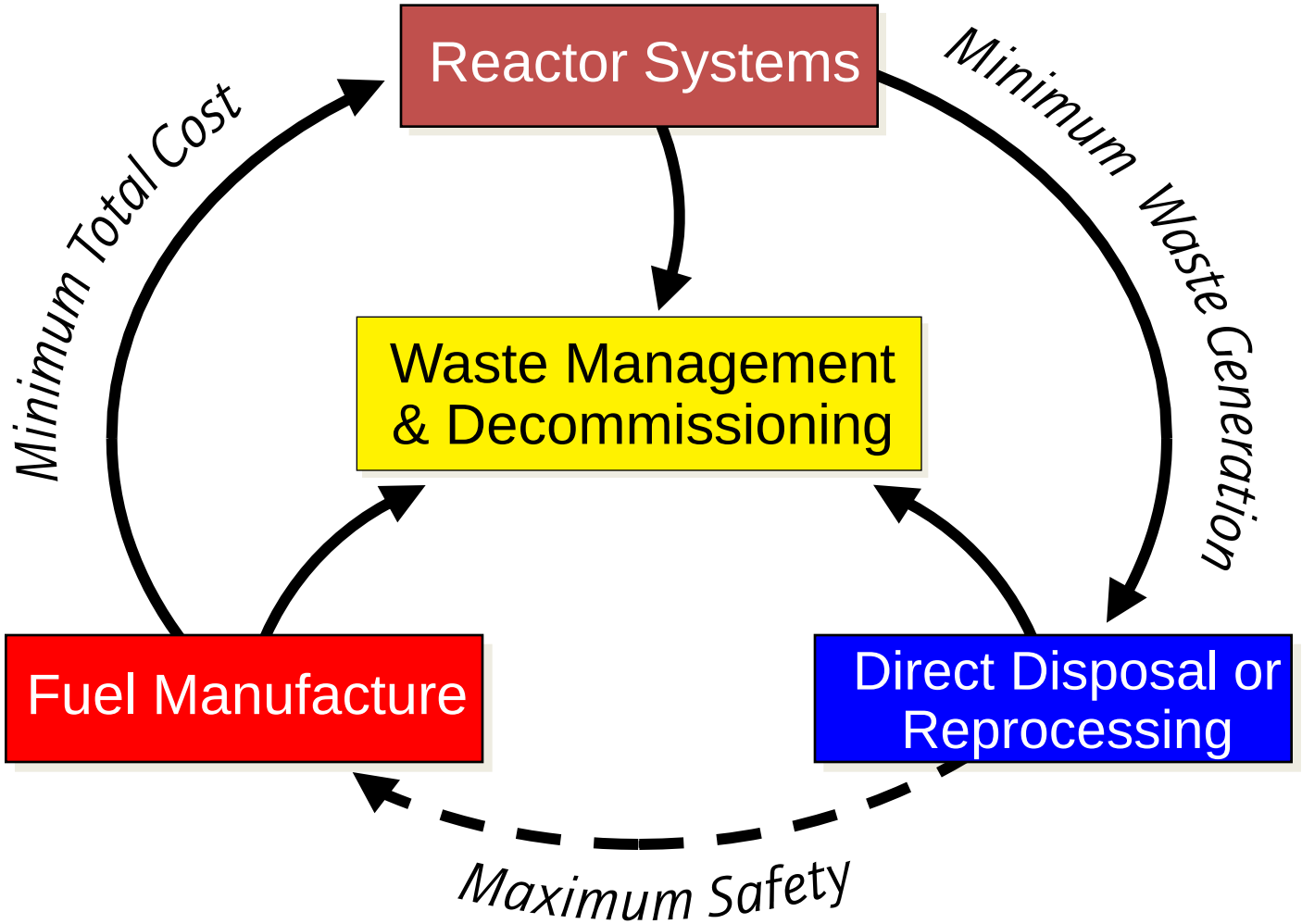


Deliver long term secure energy on the way to a low carbon energy future

Fuel Cycle: Holistic Approach



What Influences Fuel Cycle Options?

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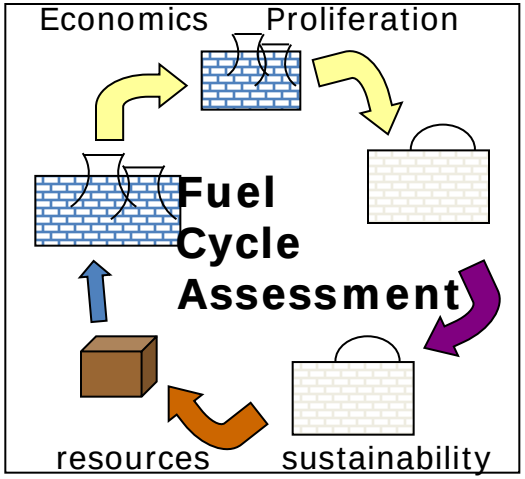
- Balance of number of parameters including:
  - Economics
  - Proliferation
  - Technology viability and readiness level
  - Fuel supply
  - Use of nuclear energy
  - Spent fuel storage
  - Geological disposal – heat loading, size of repository
  - Sustainability – resource utilisation



- Worldwide growth of nuclear will impact on UK

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Future Nuclear Fission R&D

UK R&D Background

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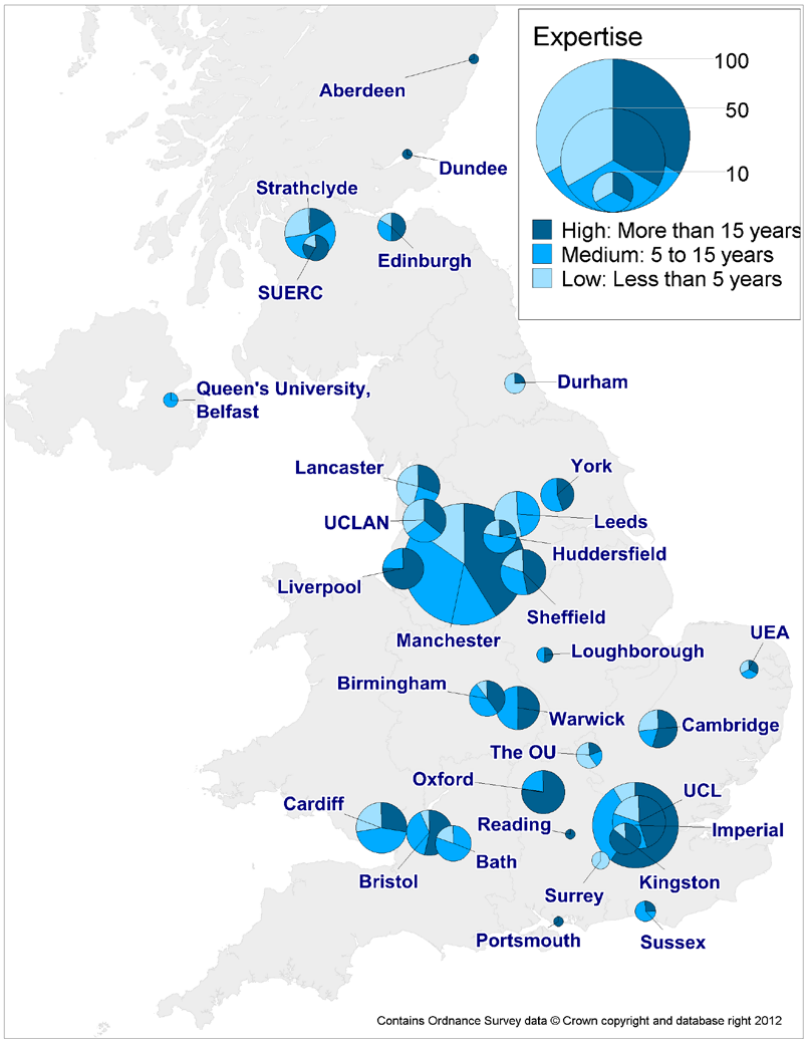
- UK long history of nuclear energy
- R&D over past 60 years has underpinned nuclear development
- Significant R&D programmes ongoing within National Laboratories and industry
- Over 25 Universities in UK undertake nuclear research
- Nuclear is a key part of the energy strategy for the future

UK Nuclear Universities



The size and experience of the academic (excluding post-doctoral researchers) nuclear R&D workforce in the UK

Critical Skills

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- 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

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Programme	Fuel	Reactors	Recycle
Technology	•Uranium •Plutonium •Thorium •Inert Matrix •Oxide / Carbide / Nitride / Metal	•LWRs •Gen IV •SMRs	•Aqueous based processing •Molten salt pyroprocessing
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

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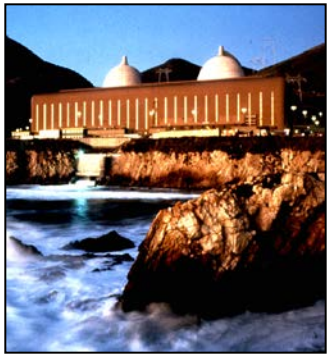
Generation I

Early Prototype Reactors

- **Magnox**
- Shippingport
- Dresden

Generation II

Commercial Power Reactors



- LWRs: PWR, BWR
- CANDU
- **AGR**

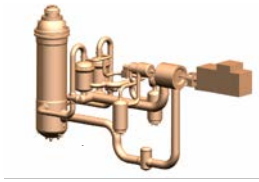
Generation III

Advanced LWRs

- **ABWR**
- **AP1000**
- **EPR**

Generation III+

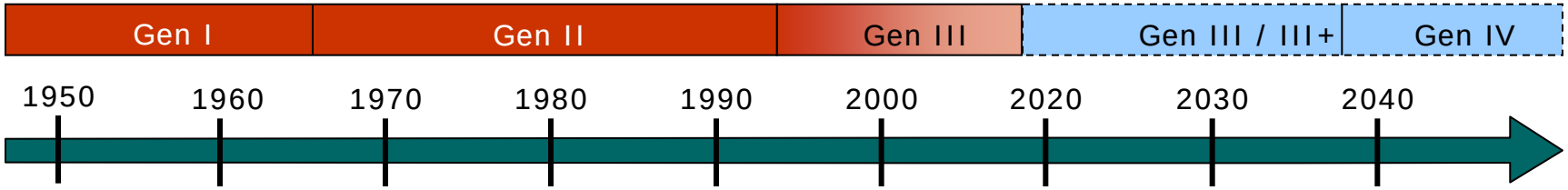
Evolutionary Designs



- SMR
- NGNP

Generation IV

- Highly Economical
- Enhanced Safety
- Minimize Wastes
- Proliferation Resistant



Advanced Reactor Systems

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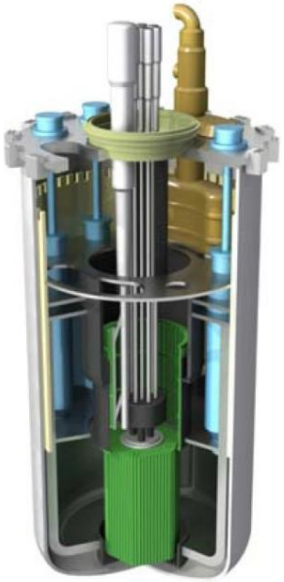
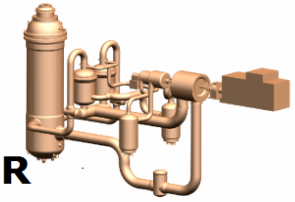
Beyond “new build” of AP-1000 and EPR PWRs, there are “advanced reactors”
- large and small modular reactors
- fast and thermal

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



Present → 2050 ?

Advanced Test Fuel Research

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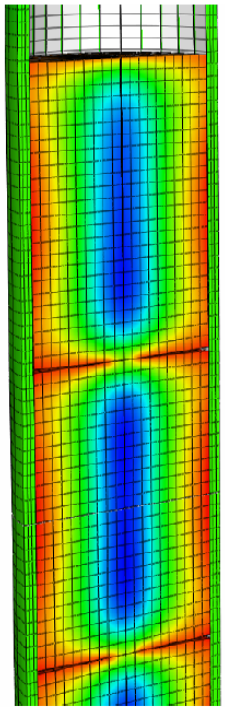
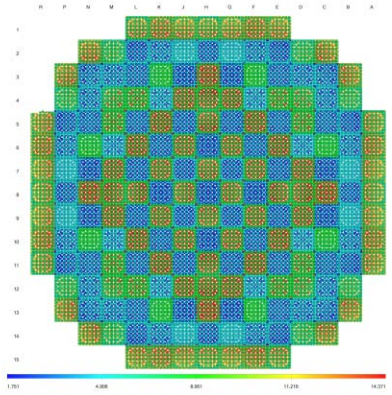
- **Test Fuel Manufacture**
  - –Dry powder pellet production;
    - •Pu/Th MOX fuel
    - •Oxide / Carbide / Nitride Fuel
  - –Gel Sphere Precipitation test rig (SiCarbide fuel)
- **Test Fuel Assembly**
  - –Test rod assembly for a variety of fuel types
- **Fuel Material Properties**
  - –Ceramographical Examination
  - –Inspection and X – Ray
  - –Autoradiograph, thermogravimetric analysis
- **Fuel performance using state-of-the-art computer code suite**



Temperature distribution in LWR fuel rod (BISON)

Test Fuel Fabrication Laboratory



Map of rod internal pressure (MPa) in every rod of a 4-loop (51,000 rod) PWR core (NEXUS)

Fuel Manufacture and Performance: International Collaboration

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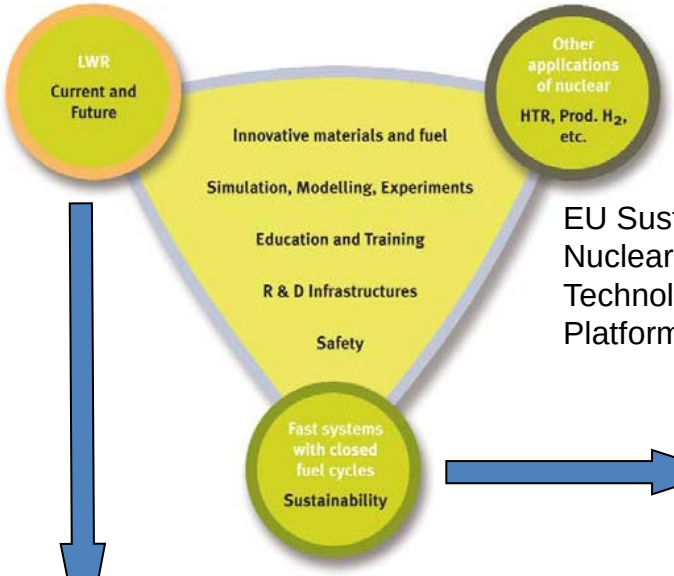
NNL expertise and facilities supporting UK and international initiatives

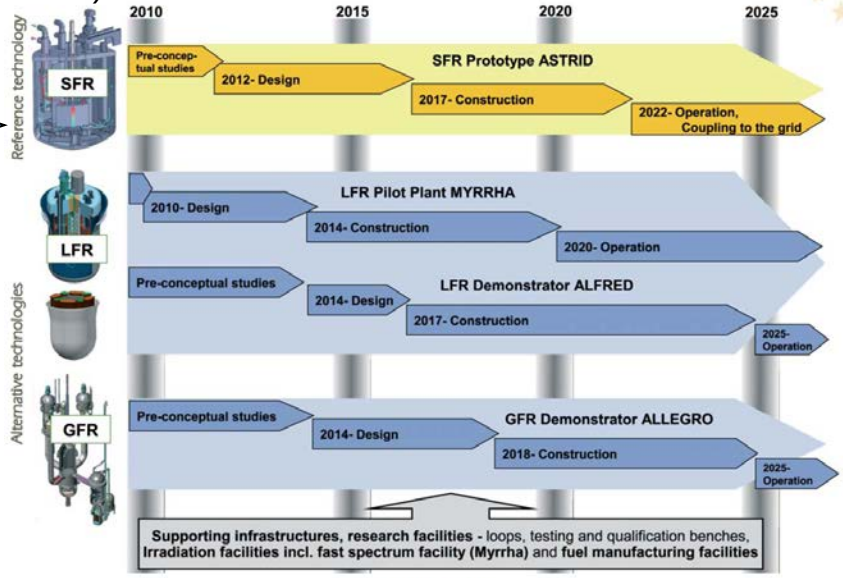


EU Sustainable Nuclear Energy Technology Platform (SNETP)

GoFastR

ASGARD

NNL is participating in these two ESNII-related programmes



European Sustainable Nuclear Industrial Initiative (ESNII)

NUGENIA
NUclear GENeration II & III Association

NNL is one of several EU organisations providing Technical Area leadership

Advanced reprocessing

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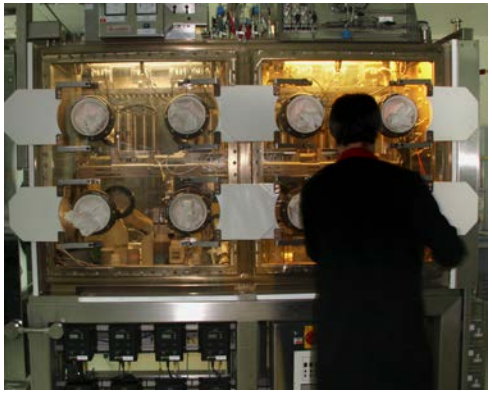
- Programmes in UK for past 20 years
- UK involvement in international programmes including EU
- Collaboration in future important



ACSEPT
innovative solutions for sustainable nuclear energy

GANEX Flowsheet, Pu Dissolution

Waste Management R&D

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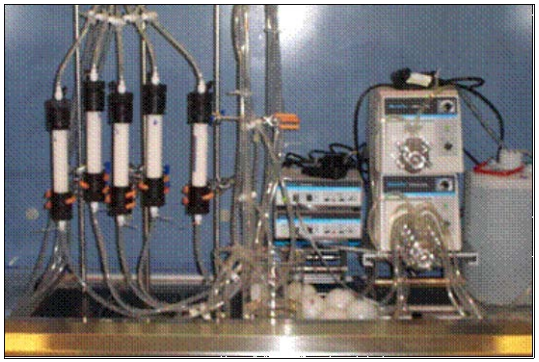

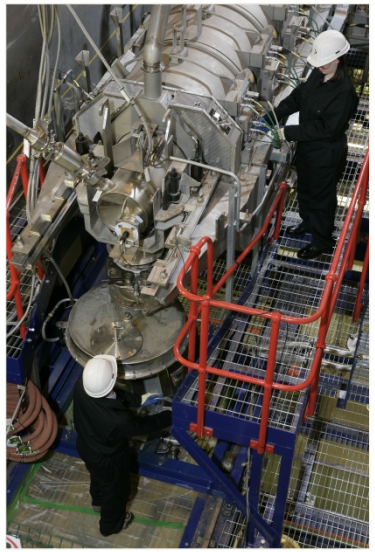

Geological disposal of wastes

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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

How harmful is the dose?

Toxicity

And so on into the far distant future...

Human uptake

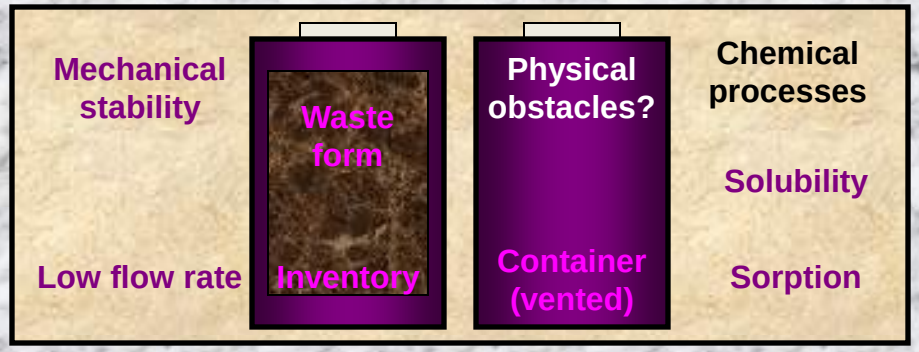
What routes give a dose?

Environmental behaviour

What needs to be considered?

How does rock delay movement?

- Groundwater flow
- Rock matrix diffusion
- Sorption
- Diffusion and dispersion

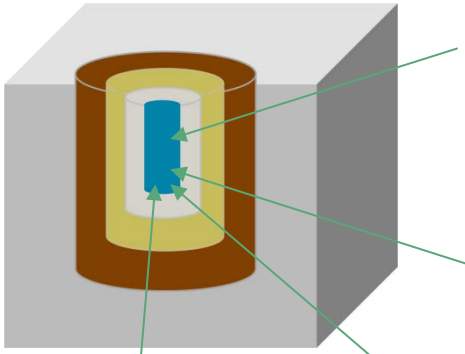


How can the rock be 'short circuited'?

- Gas
- Human intrusion
- Natural disruptive events

0 | 100 | 1000 | 10 000 | 100 000 | 1 million | Time (years)

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

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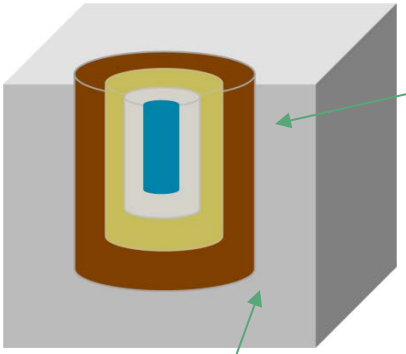
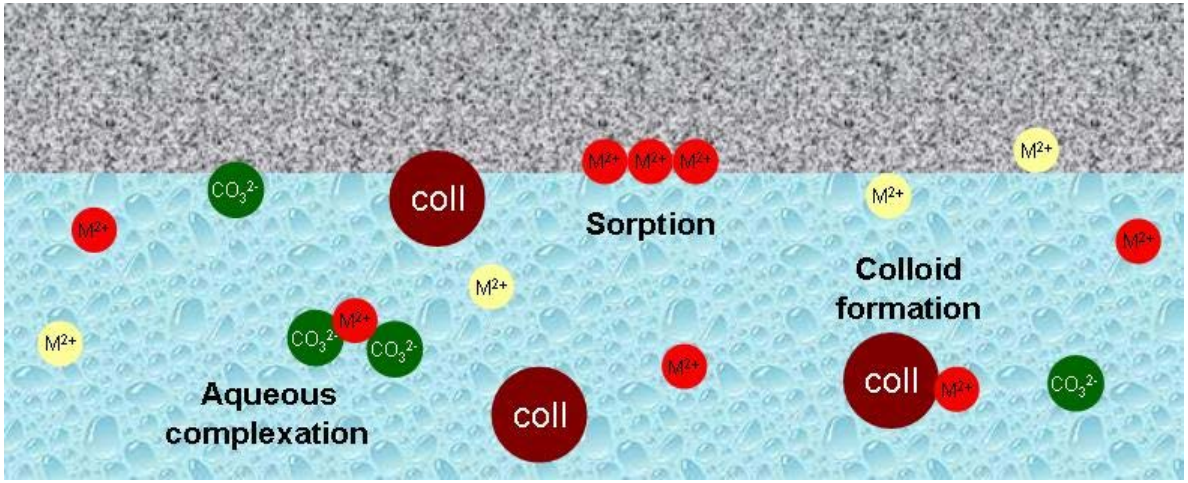


International Programmes
Cement – Rock Interactions
Gas Migration in Clay
Thermal Modelling in Natural systems

Radionuclides in the Environment
Data validation
Complexation
Solubility
Sorption



Innovative Solutions

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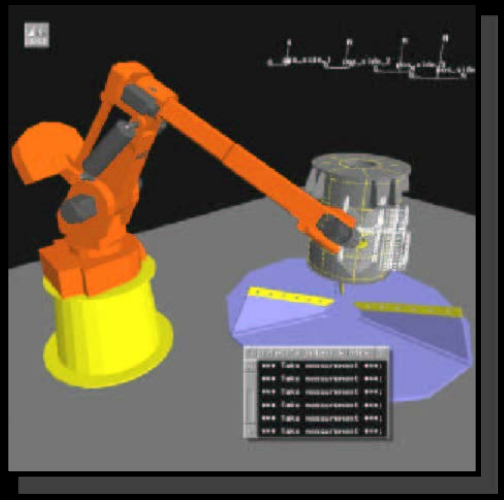
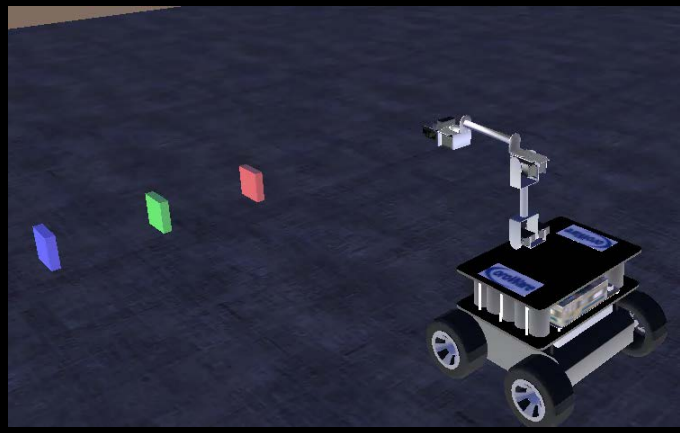
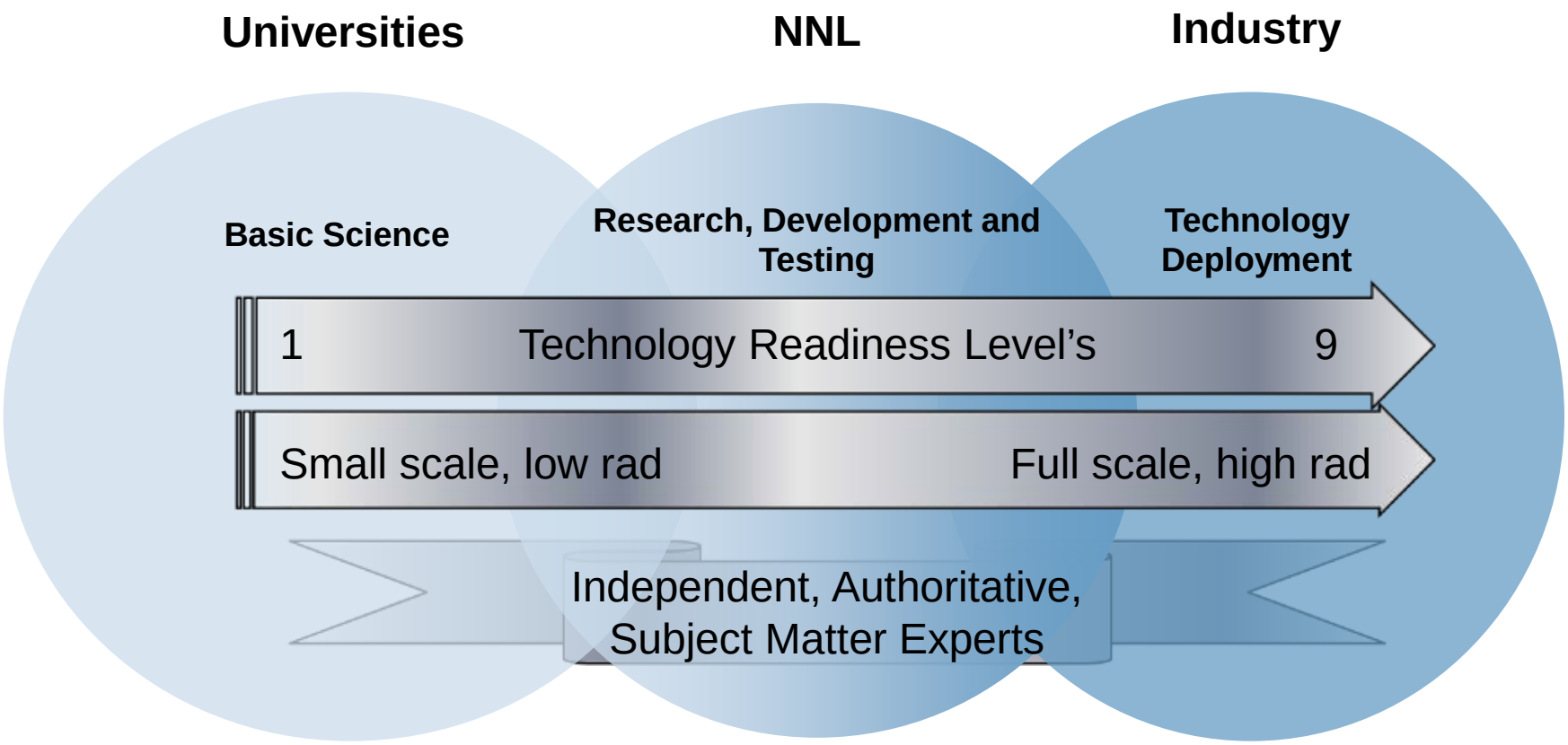




NNL Science to Solutions



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Summary and Conclusions

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- 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?