NUCLEAR INNOVATION AND RESEARCH ADVISORY BOARD

Realising Nuclear Energy's True Potential: Reaching Beyond the Challenges of Today

Dame Sue Ion FREng FRS
NIRAB Chair: Hon President NSAN

Tuesday February 28th 2017

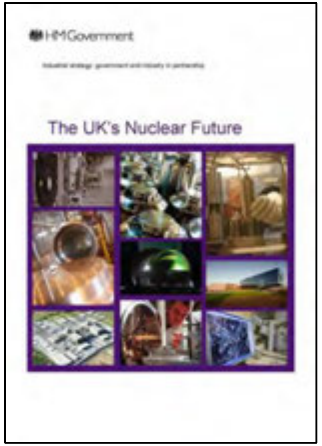
A bright future for the Nuclear sector?

- 2016 was an important year for the future of nuclear power in the UK.
- The go-ahead for construction of the two EPRs at Hinkley Point C was given.
- The Department of Energy and Climate Change (DECC) awarded a grant to the High Temperature Facility (HTF) alliance to build an open access materials testing laboratory.
- The Government opened a competition to choose an SMR that could be developed and deployed in the UK and possibly world-wide.
- The end of Magnox reactor operation in December 2015 now puts the emphasis on defuelling and reprocessing the fuel
- Sellafield has started the process of cleaning-up several of the old legacy plants from the 1940s and 1950s.

Role of NIRAB

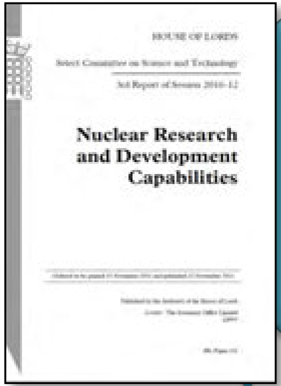
- To advise Ministers, Government on priorities for UK nuclear R&D and innovation.
- Develop new R&D and innovation programmes to underpin policy (e.g. energy and industrial policies).
- To foster greater cooperation across the UK research and innovation landscape.
- To oversee the development of a coordinated international engagement strategy.

Implementing the Government's Nuclear Industrial Strategy



The long term objectives:

- Maximise commercial opportunities and provide a platform to build sustainable exports.
- To be a partner of choice in commercialising reactor technologies .
- A secure, low carbon, affordable energy future.
- Re-establish the UK as a top-table nuclear nation.



HOUSE OF LORDS

Select Committee on Science and Technology

3rd Report of Session 2010–12

Nuclear Research and Development Capabilities

*"In a few years time there will be **crucial gaps in capabilities**"*

"The Government's view that the need for R&D capabilities and expertise in the future will be met without Government intervention is troublingly complacent."

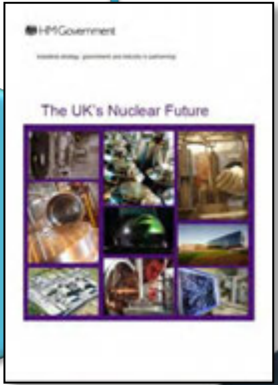
"We recommend:

*The Government should set out **a long term strategy for nuclear energy**…*

*The development and implementation of **a long term R&D roadmap**…*

*Government should establish a … **Nuclear R&D Board**..."*

2011 | **2012** | **2013**

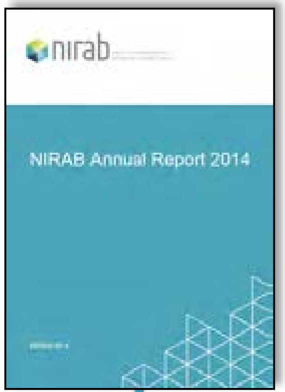


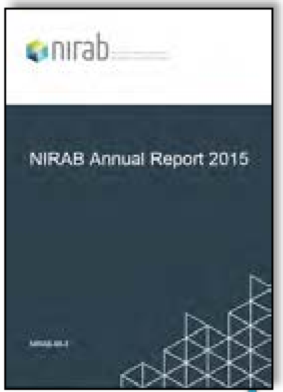
HM Government

The UK's Nuclear Future

"A vibrant UK nuclear industry that is an area of economic and strategic national strength, providing the UK with a safe reliable and affordable supply of low-carbon electricity"

*"…the Government will **set up a Nuclear Innovation Research Advisory Board** comprising of Government scientific advisors, academic experts, the Research Councils, TSB, NDA, and business leaders."*





2014 | 2015 | 2016

nirab

Independent advisory board

Members appointed by ministerial invitation, drawn from academia, industry, research organisations and funding bodies.

Established by Government in January 2014 to:

Advise Ministers, Government Departments and Agencies on **priorities for UK nuclear R&D and innovation**

To support the **development of new R&D and innovation programmes** to underpin energy and industrial policy

To foster greater **cooperation and coordination** across the UK research and innovation landscape

To oversee the development of a **coordinated international engagement strategy**

Supported by NIRO (Nuclear Innovation and Research Office)

Context for NIRAB advice – long term aims

Identify the research needed to ensure that:

- The UK is a key partner of choice in commercialising Generation III+, IV and SMR technologies worldwide
- The UK is a respected partner contributing to appropriate international research programmes
- The UK is a ‘top table’ nuclear nation

Context for NIRAB advice – Government policy drivers

Energy policy			Industrial policy		
Affordable energy	Sustainable low carbon energy	Security of supply	Economic growth	Skills / capability	World class science
Ensure nuclear remains cost competitive in the long term	Develop / evaluate technology options to deliver up to 50GW nuclear power by 2050	Development of technologies capable of improving sustainability and security of supply	Enhance the competitiveness of UK companies. Export into huge future global markets.	Maintaining and developing specialist nuclear skills and capabilities	Carrying out programmes to deliver world class / cutting edge science

Why is Government funding needed?

NIRAB has focussed on areas where Government intervention is needed

Industry cannot or will not invest in development of next generation reactor systems:

- Long lead times
- High development costs
- Uncertainty over policy for deployment of advanced systems

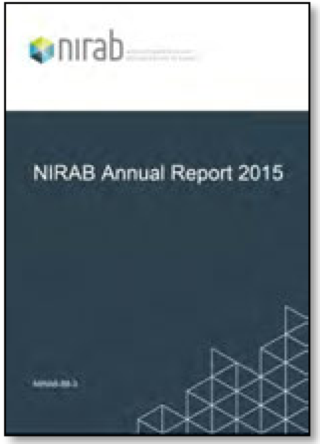
Need for Government funding until Industry is able to step up to fund commercialisation at an appropriate time.

Important that research leads to deployable technology that aligns with industrial interest

Nuclear Energy Innovation – NIRAB's Recommendations

- The 2015 annual report contains strategic recommendations
- NIRAB published Programme recommendations alongside the 2015 annual report
- The programme recommendations identify five projects as a basis for a new national programme of nuclear R&D over the period of the Spending Review

- Total cost of delivering the five year recommended programme estimated at ~£250m



http://www.nirab.org.uk/our-work/annual-reports/

NIRAB recommendations for research in 5 areas

Future Fuels	Making more efficient, safer fuels of the future
21st Century Nuclear Manufacture	Advanced materials and manufacturing - modular build in nuclear factories of the future.
Reactor design	Delivering the people, processes and tools to make the UK the partner of choice as the world designs SMRs and 4th generation nuclear power plants.
Recycling Fuel for Future Reactors	Cost effective technologies to deliver a secure and sustainable low carbon fuel supply.
The UK's Strategic Toolkit	Informing and underpinning decisions on which emerging nuclear technologies could be brought to market to give the best economic return for the UK

NIRAB recommendations → BEIS Programme

NIRAB recommendations		BEIS Programme
Future Fuels	→	Advanced Nuclear Fuels
21st Century Nuclear Manufacture	→	Advanced Nuclear Manufacturing and Materials
Reactor design	→	Digital Nuclear Reactor Design
	→	Nuclear Safety and Security Engineering
Recycling Fuel for Future Reactors	→	Nuclear Fuel Recycle and Waste Management
The UK's Strategic Toolkit	→	Nuclear Facilities and Developing a Strategic Toolkit

BEIS 2016-18 programme addresses initial phase of NIRAB recommended priority research

UK's strength – The range of reactor technologies that we have and are helping deploy in the UK and potentially internationally.

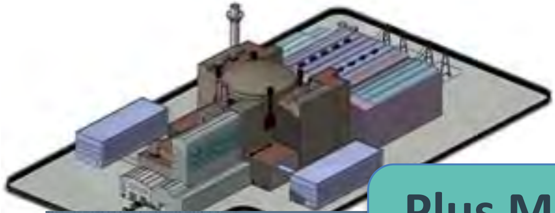
Current



Planned



Potential




Plus Many More!

Full Fuel Cycle Industrial Experience

Sellafield
Reprocessing , Waste management
And decommissioning

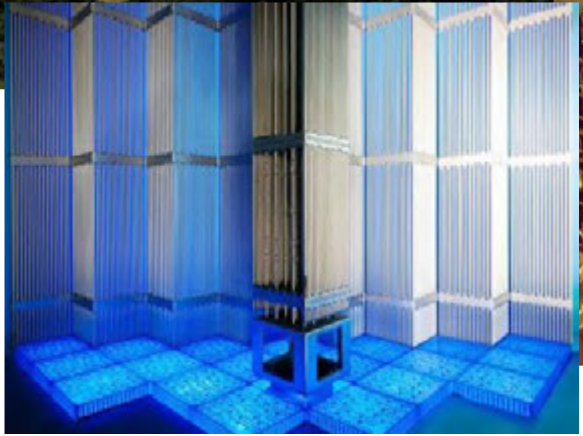
Westinghouse
Springfields Fuels Ltd

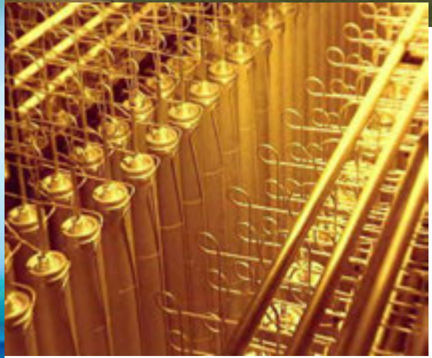
Springfields
Fuel Manufacture

urenco

Capenhurst
Enrichment

Operating and Maintaining the Fleet

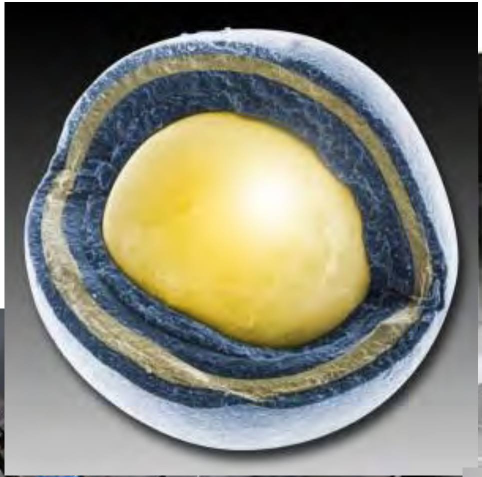


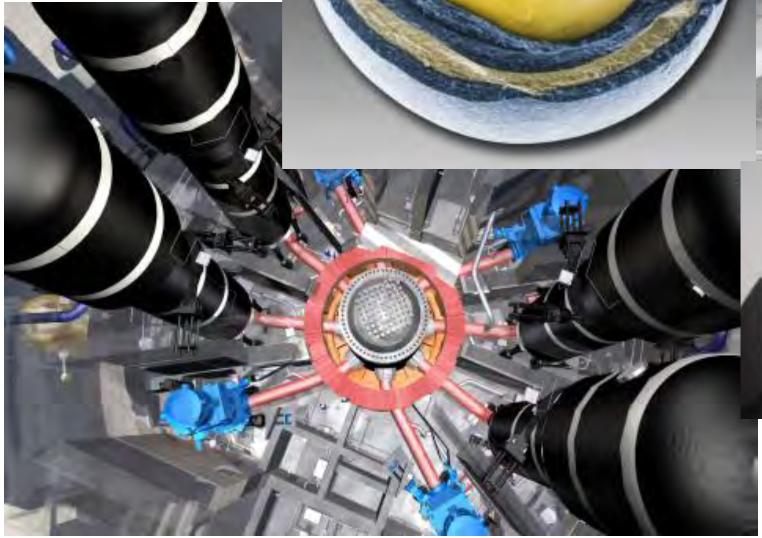


Waste Management and Decommissioning

New Nuclear Generation

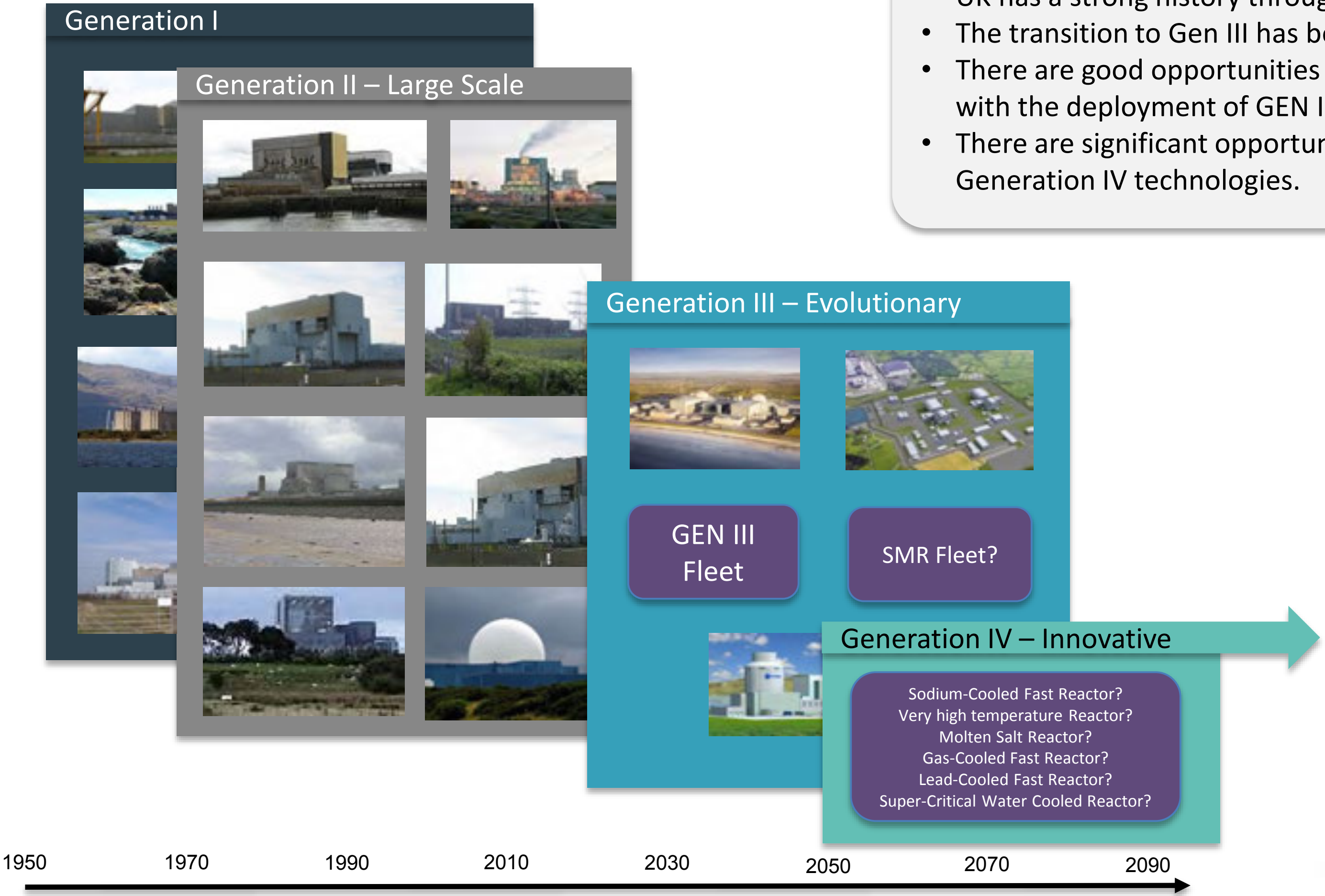
Innovation and R&D





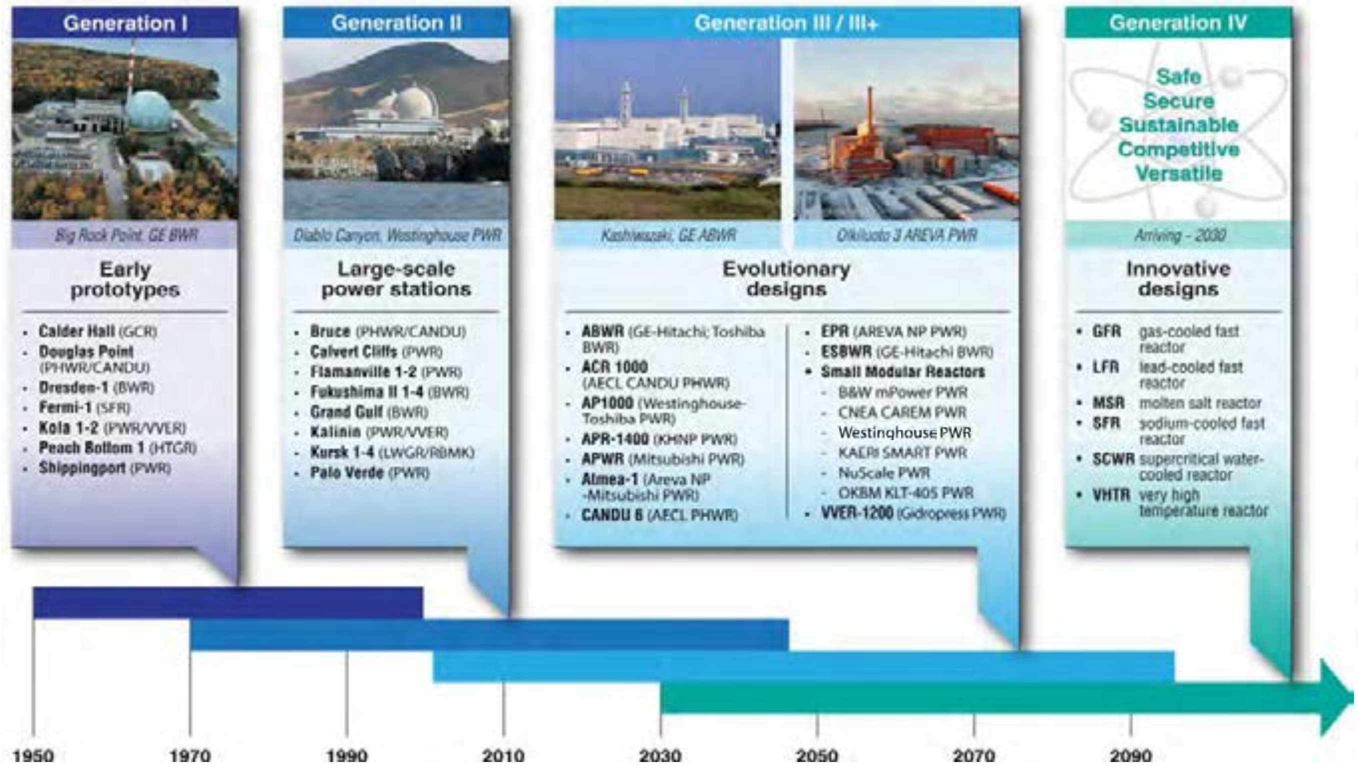
Reactors in the UK

- UK has a strong history through Generation 1 & 2.
- The transition to Gen III has begun and will continue.
- There are good opportunities for the UK to be involved with the deployment of GEN III SMRs and other GEN III+.
- There are significant opportunities to gain important IP in Generation IV technologies.



UK's strength – Strong Government Support

Industry | Industry and Government | Government



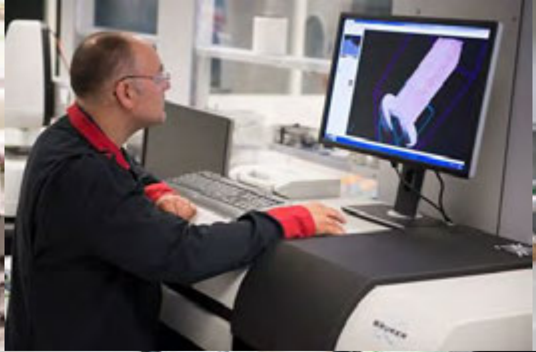
From www.gen-4.org

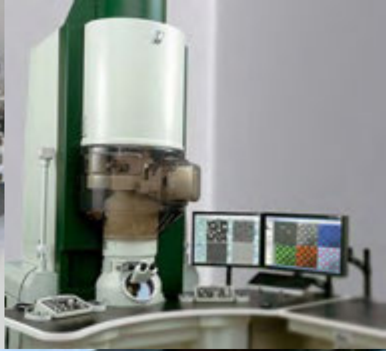
Current Funders of Research and Innovation

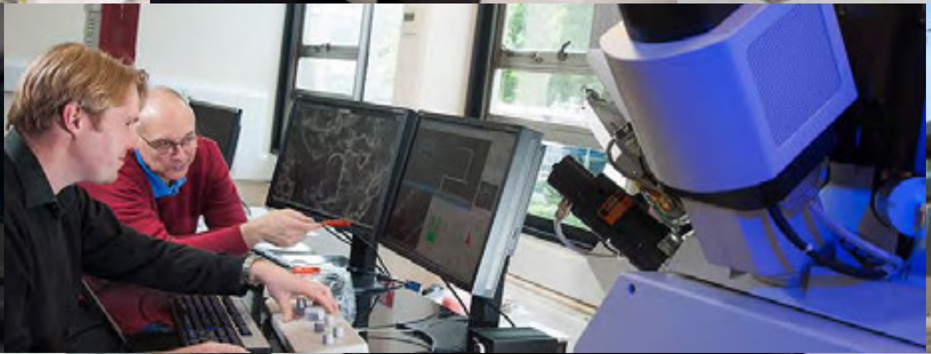
The UK's current nuclear industrial strategy and market driven electricity market mean that funding for near term innovation opportunities are industry led, medium term opportunities are partnerships whilst long term opportunities are mostly Government funded.

UK R&D Nuclear Facilities

- Europe’s largest cave-line
- An investment of over £350M in world-leading nuclear R&D centre
- Dedicated Mixed Oxide (MOX) Fuel Development Laboratories
- High-active modular cells
- Active & Inactive solvent extraction labs






UK Nuclear R&D Facilities

Opportunities – International collaborations to design the next generation of nuclear power stations and the fuel cycles which underpin them.

Sodium-Cooled Fast Reactor (SFR)

Very-High Temperature Reactor (VHTR)

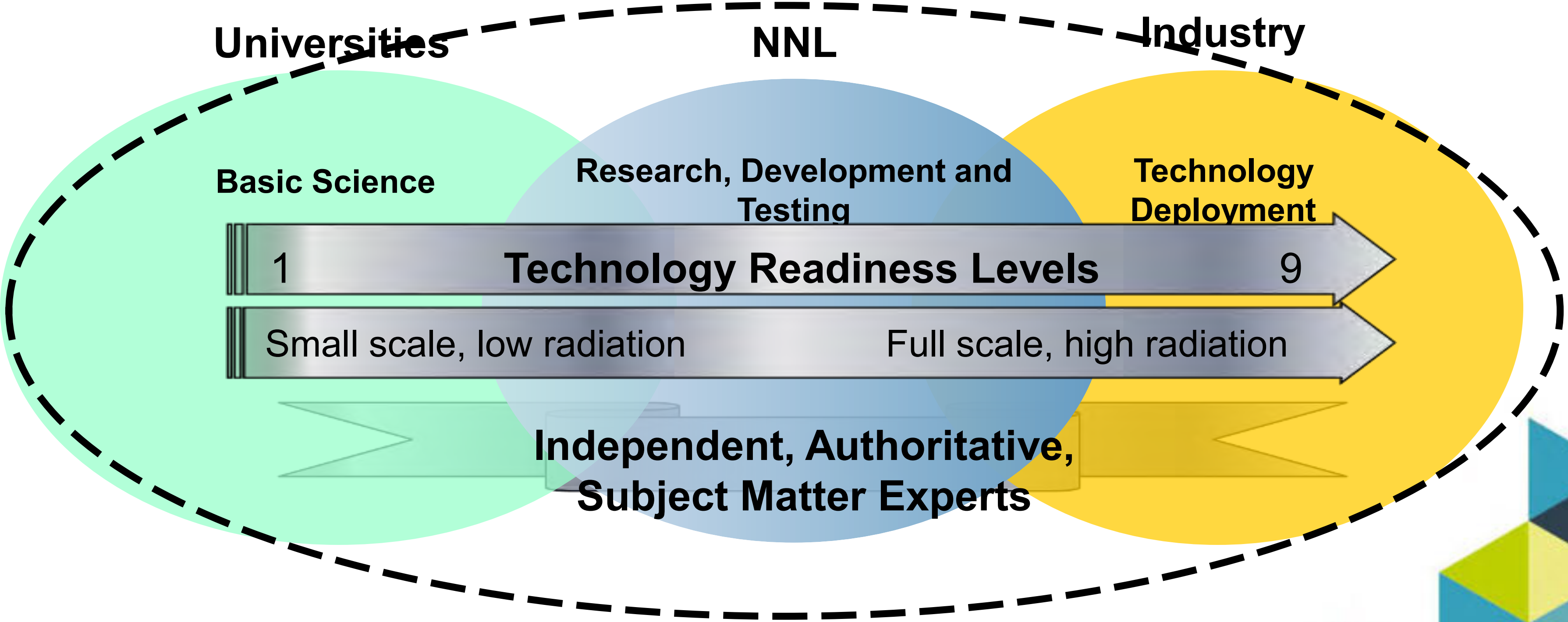
Molten Salt Reactor (MSR)

GEN IV International Forum

Supercritical-Water-Cooled Reactor (SCWR)

Gas-Cooled Fast Reactor (GFR)

Lead-Cooled Fast Reactor (LFR)



Universities
NNL
Industry
Basic Science
Research, Development and Testing
Technology Deployment
1
Technology Readiness Levels
9
Small scale, low radiation
Full scale, high radiation
Independent, Authoritative,
Subject Matter Experts

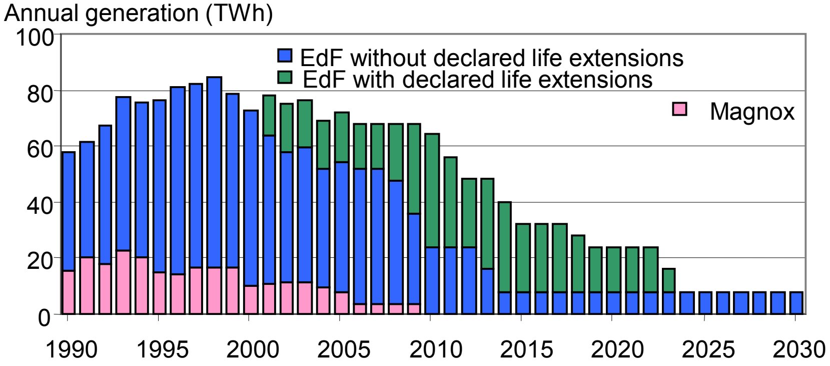
In the Public Eye

Nuclear Energy and Society

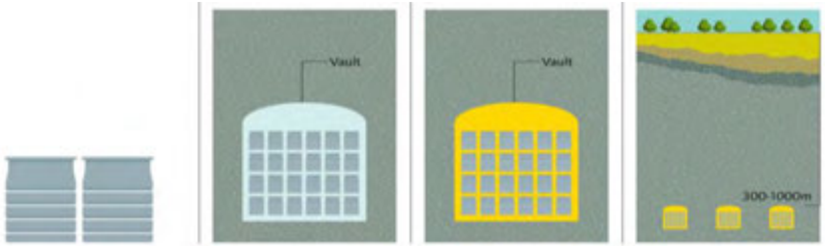
Image courtesy of EDF Energy

The Grand Challenges

- The UK must now translate policy into practice
- Understanding and predicting performance in nuclear applications is fundamental to support the nuclear renaissance
  - to ensure the safe life-extension of existing AGR stations and (at a later stage) Sizewell B
  - to support the operation of current reactors and the design, build and commissioning of next generation reactors
  - to develop new materials for next generation reactor concepts
  - to facilitate decommissioning, safe management & disposal of nuclear waste



UK Nuclear Regulators
New Reactor Assessment

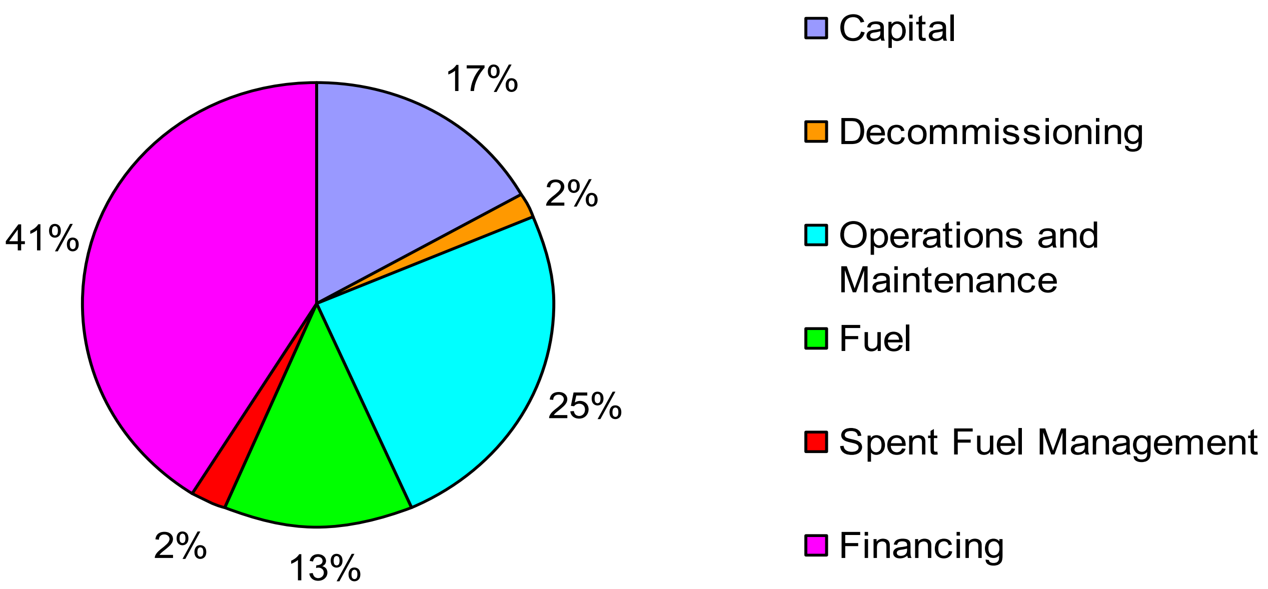


The two biggest challenges

- Cost and delivery of the first wave of new nuclear plants
- Significant progress in remediation of the very difficult legacy facilities at Sellafield

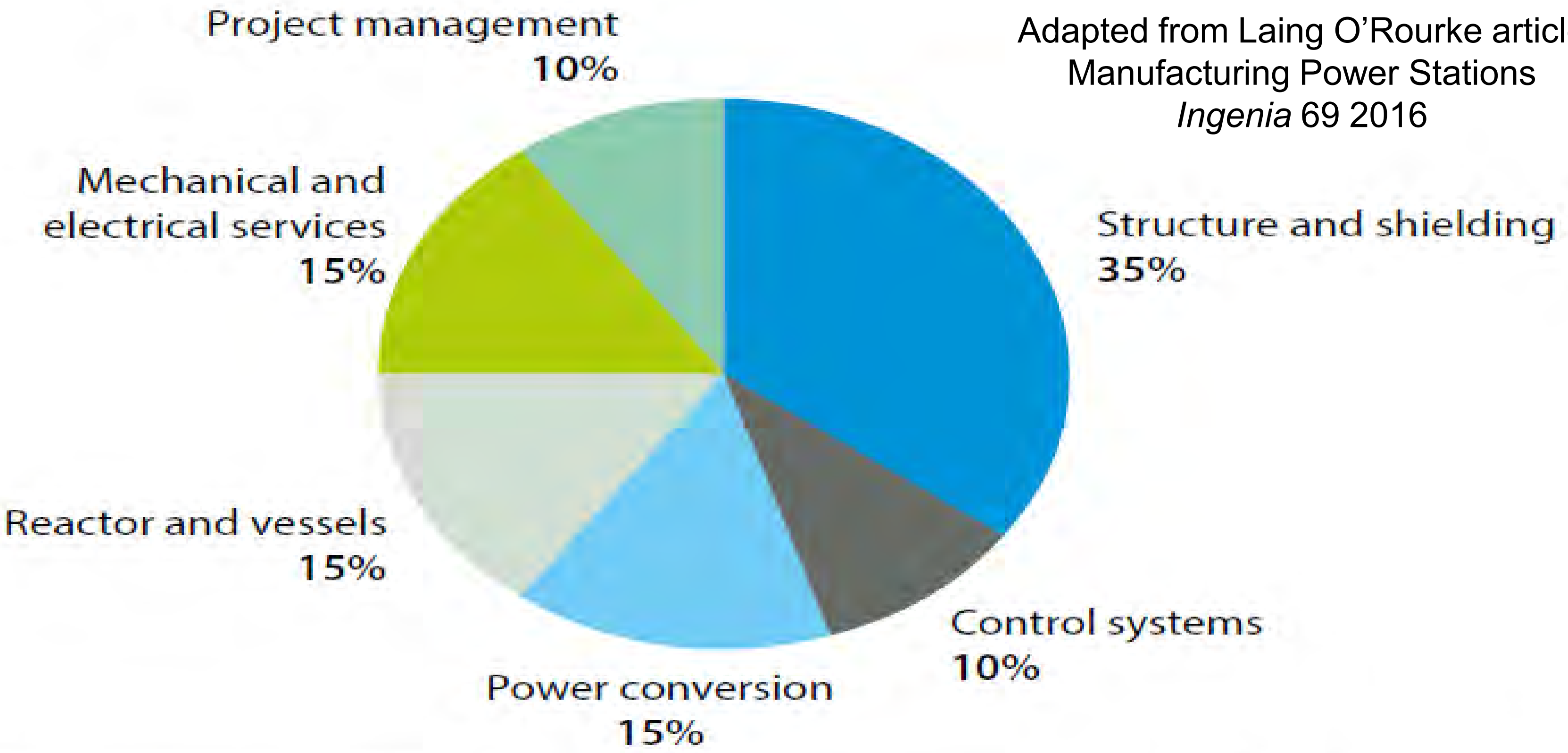
Recent Sellafield Progress

Nuclear Reactor Capital and Finance Costs



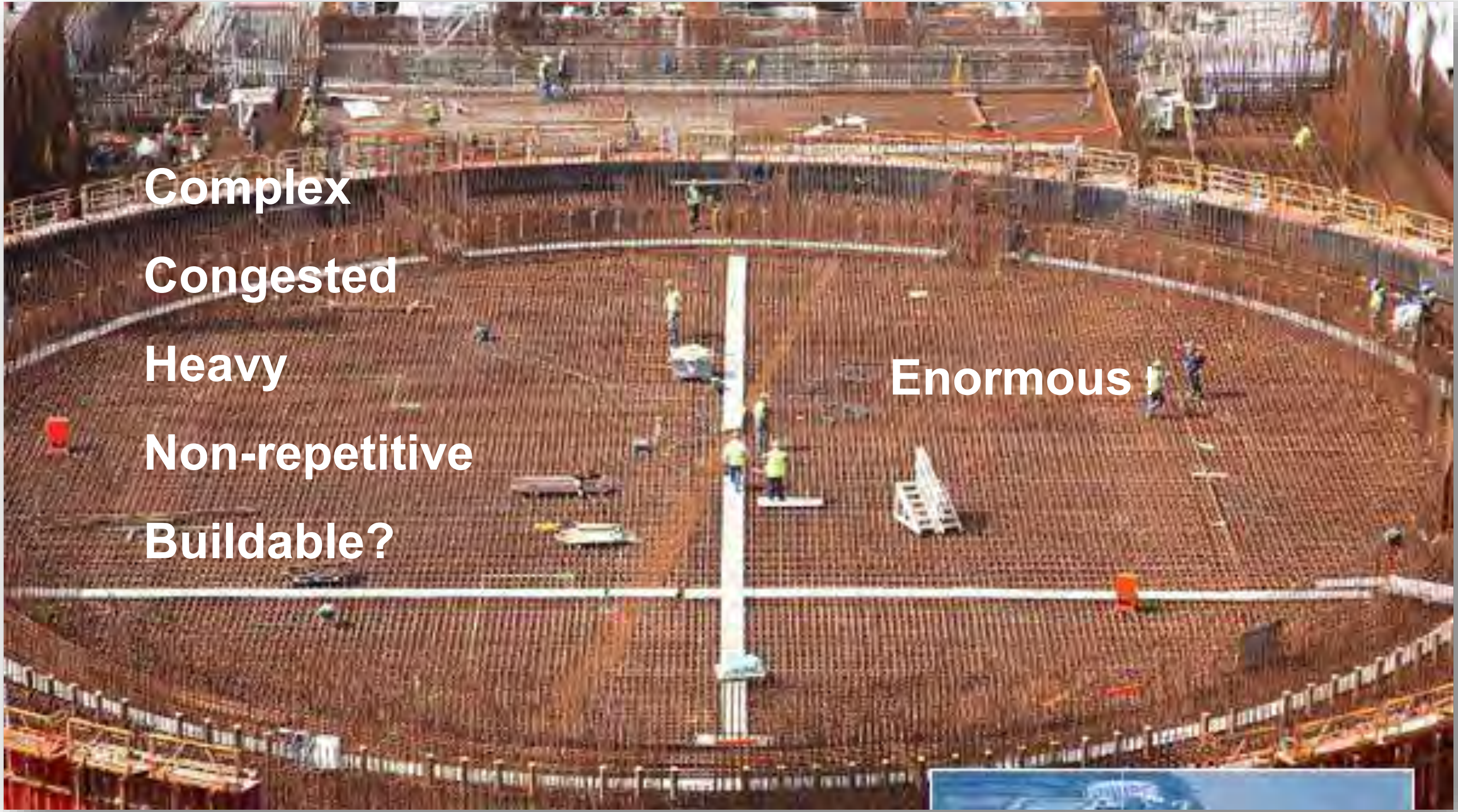
Costs dominated by capital to construct and timescale to finance before returns flow

Adapted from Laing O'Rourke article
Manufacturing Power Stations
Ingenia 69 2016



Typical SMR cost breakdown. Structure and shielding is often not a priority in construction of SMRs yet represents 35% of the cost (figures from the Cambridge Nuclear Energy Centre – TRaC)

The Challenge



The Challenge

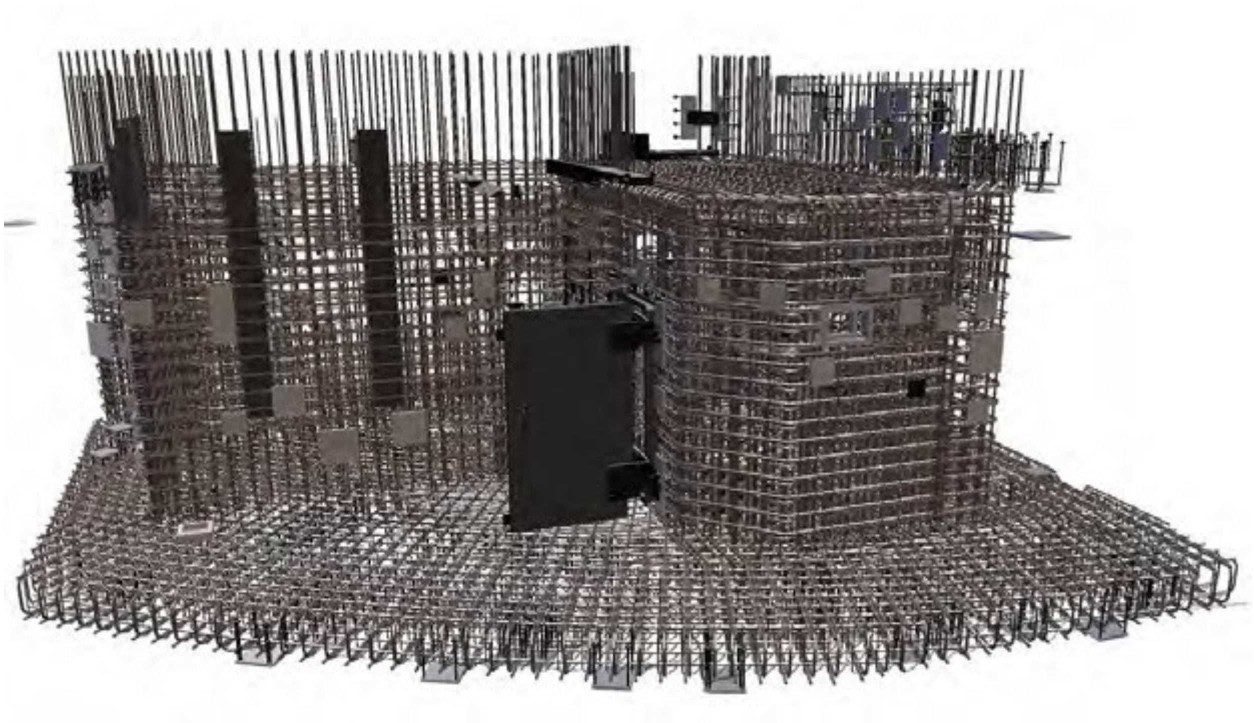
Nuclear Concrete

- Key element of NPP construction and subject of RAE Lessons learned

- HPC concretes utilise latest admixture technology to support high quality placing and long service life

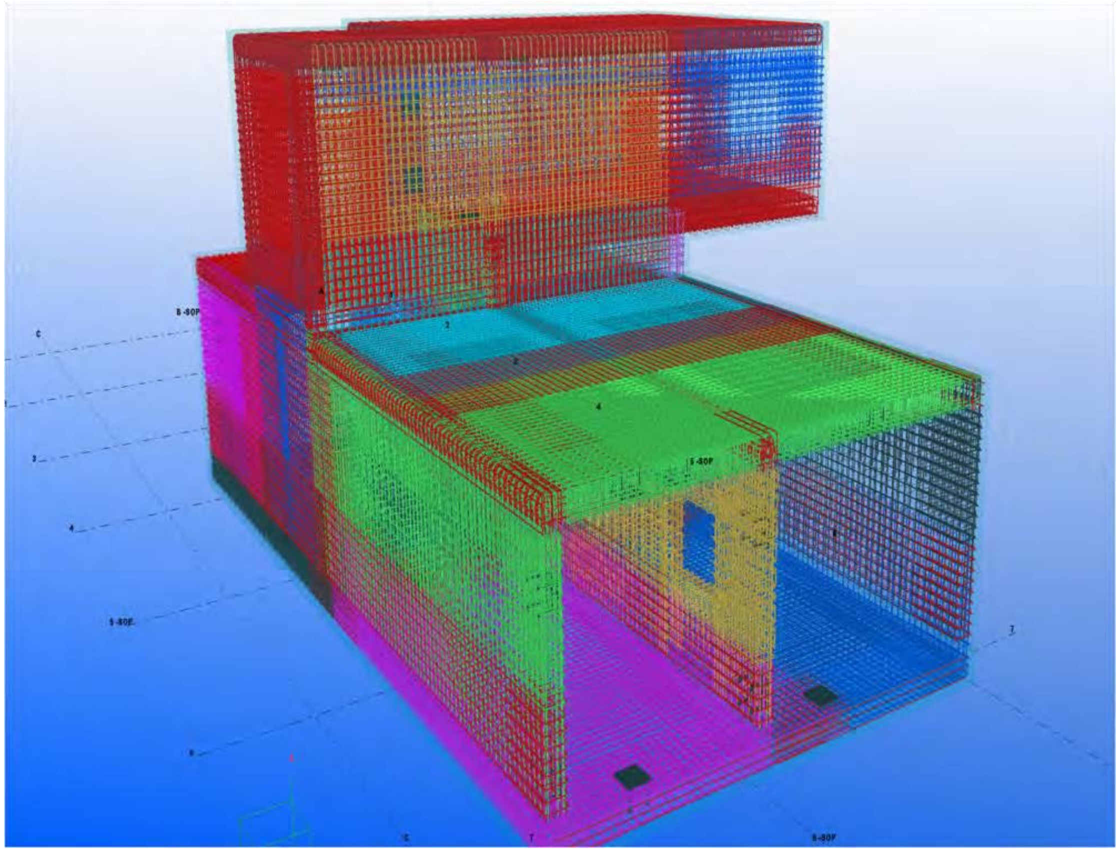
- Rigorous Two year development process from first trial mix to formal approval

Digital Reinforcement

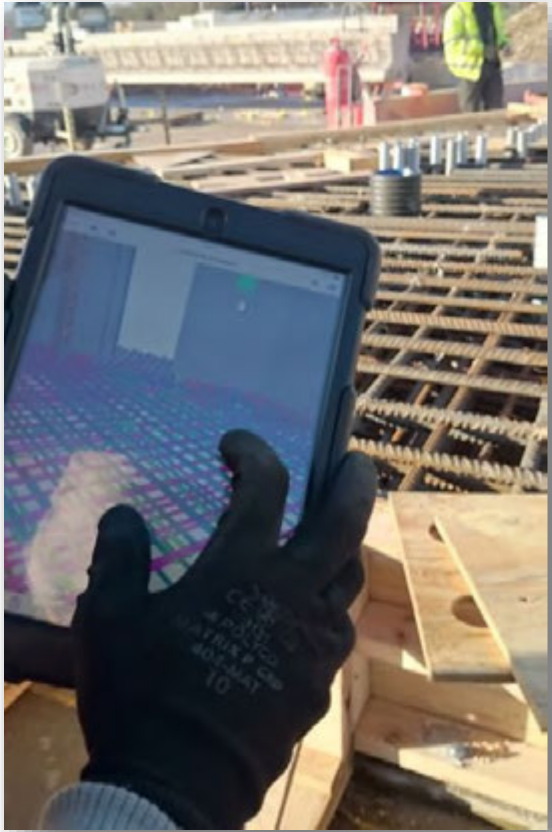


- Use of 3D techniques to produce clash free and buildable reinforcement details

Digital Reinforcement



Digital Reinforcement

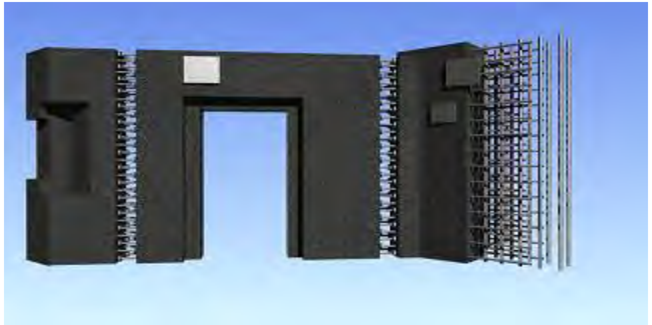


LAING O'ROURKE

Design for Manufacture and Assembly

Design criterion: Model and coordinate all rebars in 3D. Fix rebars.

– Optimisation of Large DfMA Structures for the Nuclear Industry
- Research DfMA components; sub & superstructures
- Optimise large scale structures logistics; e.g. Hinkley
- Trial units for Galleries & Superstructure designed manufactured assembled and tested,
- Robotic Manufacturing trials
- Digital Engineering Outputs
- Parametric models (Tekla/Solidworks) to test assembly methodology and calculate cost and time
- Optimisation algorithms for manufacture transport and assembly



Project Partners:

Innovate UK
Technology Strategy Board

explore MANUFACTURING

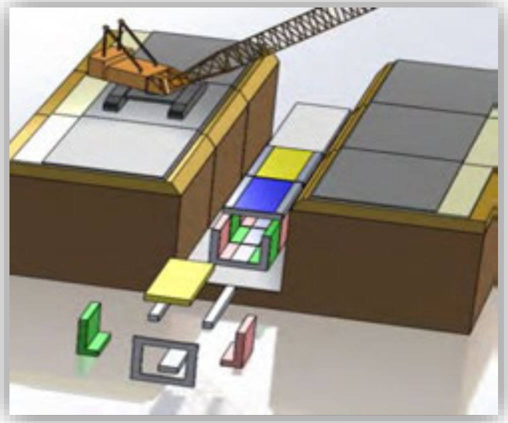
ARUP

LAING O'ROURKE

bre

EnEx·G

Imperial College London



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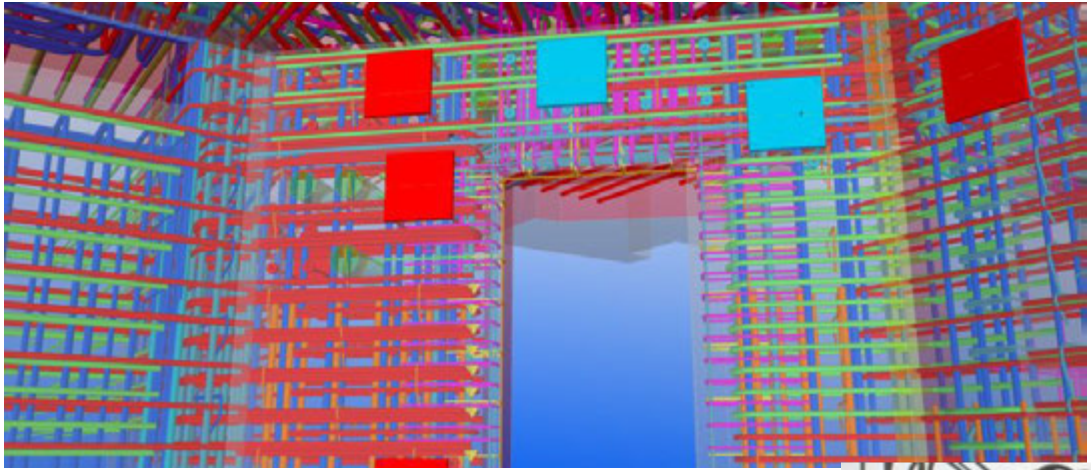


<u>To fix 3 walls</u>

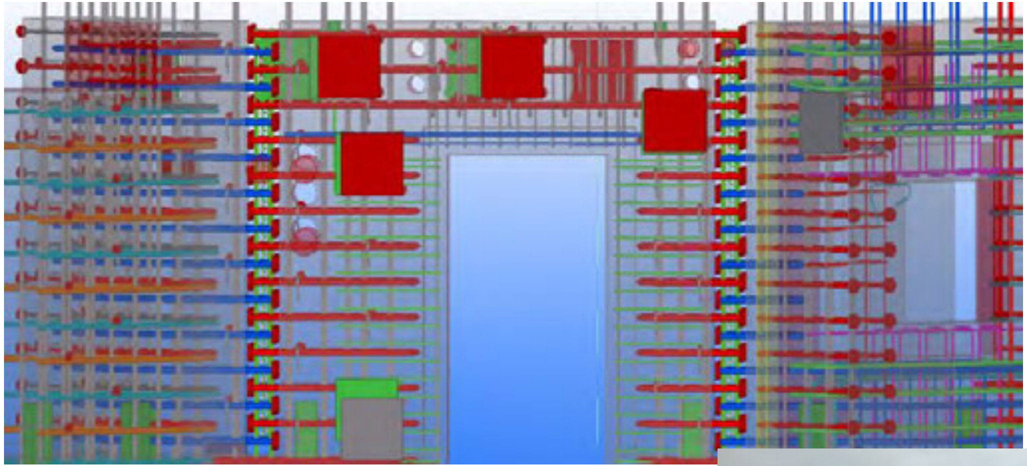
Site time: 5 days

Site labour: 87 man-hours

Imperial College London   bre   ARUP

Design for Manufacture and Assembly

- Design criterion: Modular design into precast components.



<u>To erect 3 walls</u>

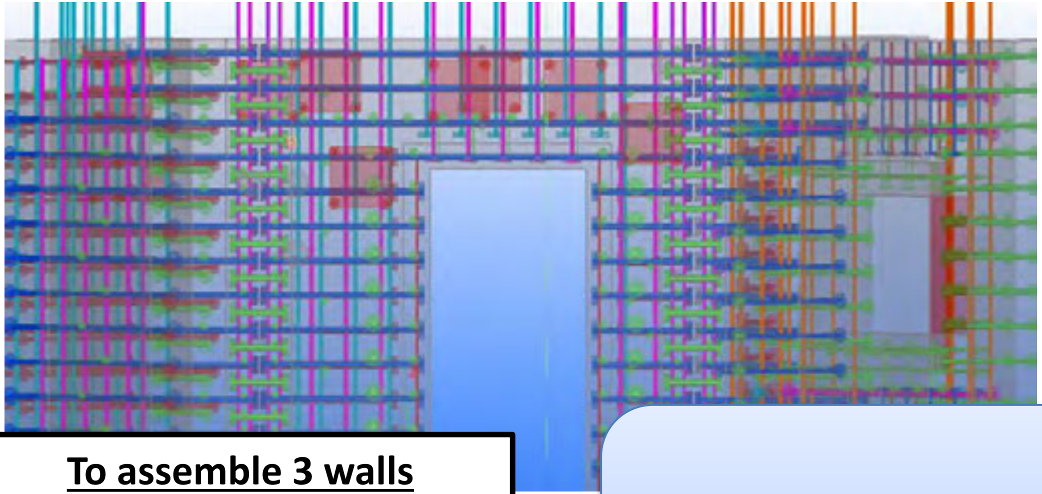
Site time: 1 day

Site labour: 18 man-hours

LAING O'ROURKE

Design for Manufacture and Assembly

- Design criterion: Replace all bent bars with headed straight bars



<u>To assemble 3 walls</u>

Site time: 4 hours

Site labour: 12 man-hours

(estimated)

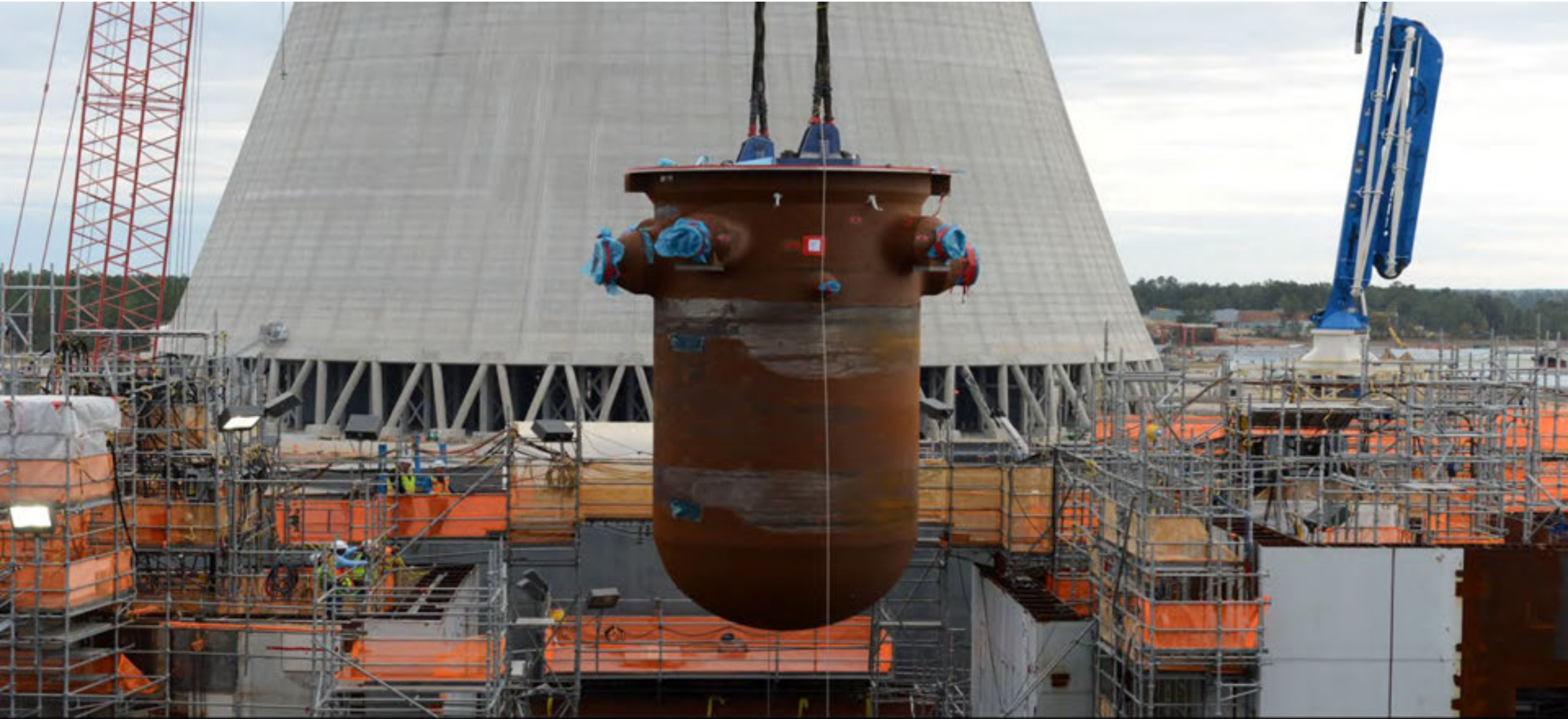
(In progress...)

Aerial view of the Vogtle 3 and 4 construction site

January 2017

Aerial view of the Vogtle 3 and 4 construction site.

January 2017

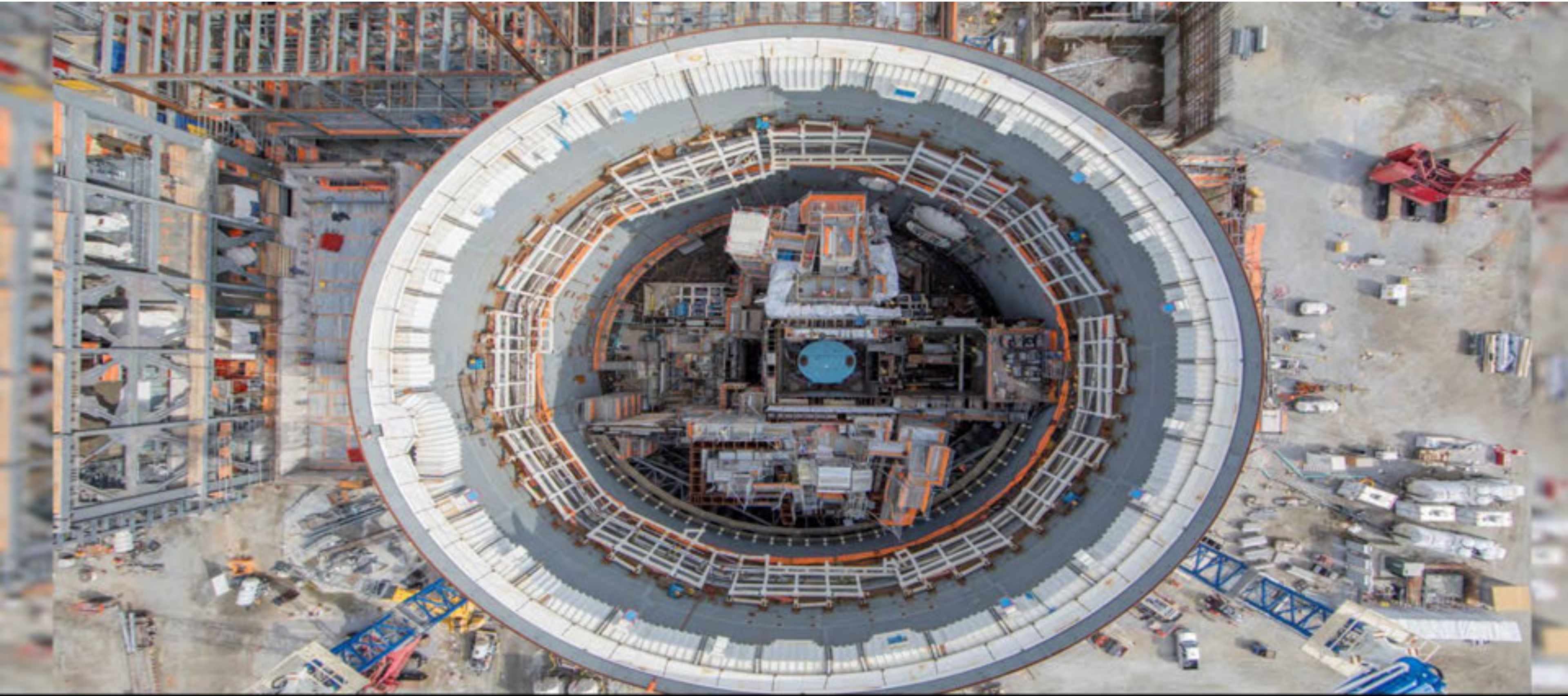


The 306-ton Vogtle Unit 3 reactor vessel is placed inside the nuclear island.

December 2016

The 306-ton Vogtle Unit 3 reactor vessel is placed inside the nuclear island.

December 2016



Aerial view looking inside Vogtle Unit 3 containment.

January 2017

Aerial view looking inside Vogtle Unit 4 containment

January 2017

Construction of the Vogtle Unit 3 east shield building wall continues to progress.

January 2017

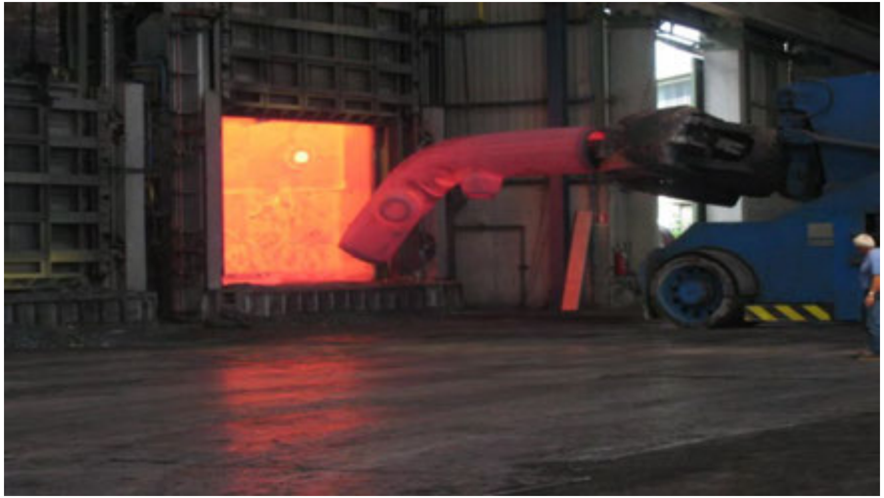
New Plant Technology
Validation of New Component Supply

High Performance Pressure Boundary Components Require :

- Uniform Chemistry and Structure
- Validated Mechanical Properties – Strength and Toughness
- Properties must be Exhibited in All Sections

Supplier as well as component development

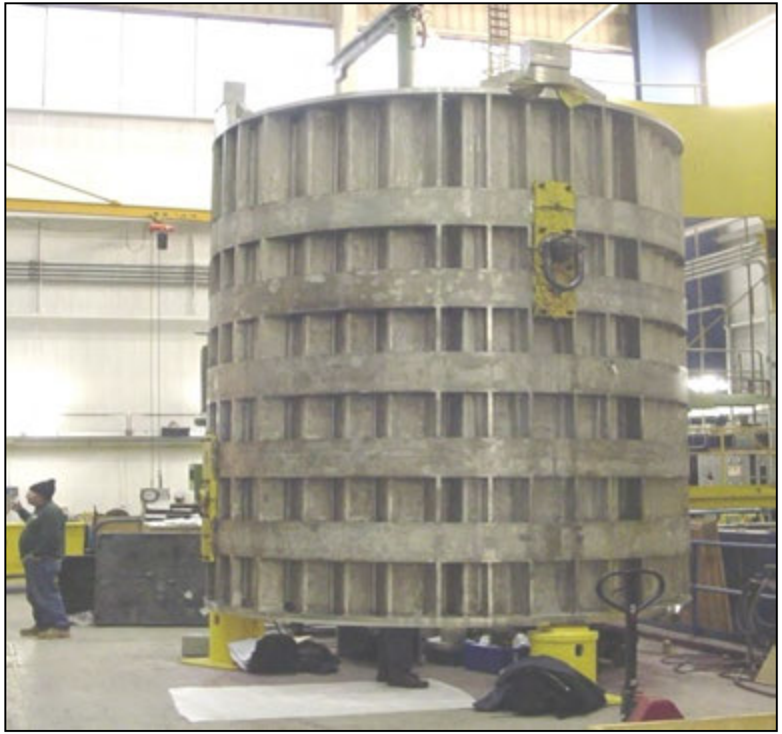
High Performance Production Parts Require :
Materials Qualification Tests to Support Piece Acceptance



Integrally Forged Piping Segments During Processing

New Plant Technology Component Fabrication

- Large Welded Structures need processes to minimize residual stresses and avoid sensitization



Materials Technology and Basic Science Needs for New Build Plants

	Existing Plants	New Build
Plant Operations	Relicence Existing Gen III Plants	Build New Gen III+ Plants
Materials	Standard Materials – 30 year vintage	Standard Materials – 2010 Vintage
Materials Technology Required	Understand aging and degradation of properties. Quantify long time dependent behavior Inspection & Analysis tools Repair and Replace Options	Validation of new materials variants (e.g S level 0.002% spec as <0.030) Extension of property database Validate modern processing routes

Basic science drivers will be similar to those for existing plants – similar lifing technology will take us out to service beyond 2100 !!

Beyond 16 GW …

- There is a wide range of new technologies that have the ability to inspire the next generation of scientists and engineers.
- Not just new technologies but expectations of lifetimes that may rise to 80-100 years.

What other Innovative Systems can we foresee?

- FR’s
- SMR’s
- HTR’s
- MSR’s
- Micro systems

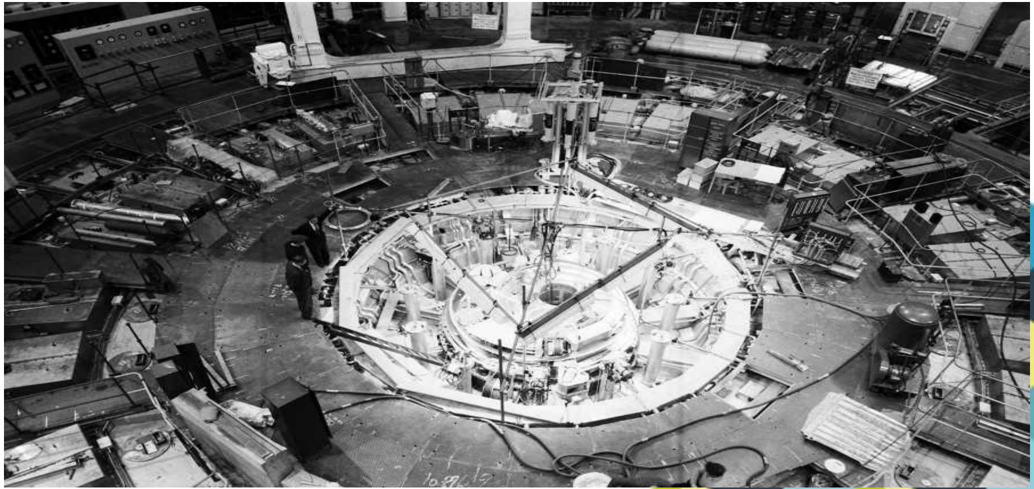
Fast reactors …

Dounreay 1946

UKAEA Engineers at the DFR Site

The main men: Major-General S.W. Joslin, Works General Manager, and T.G. Williams, the site's Resident Engineer.


TM 609
TM 609







Dounreay

UK fast reactors

- Dounreay Fast Reactor (DFR) – metal fuel, highly enriched U235/U238 fuel, sodium-potassium eutectic liquid metal coolant, 72MWth (1959-1977).

- Prototype fast reactor (PFR), also at Dounreay – mixed oxide fuel, Pu/U238, sodium liquid metal coolant, 600MWth (1974-1994).

- Both now shut down and partially decommissioned.
- Project just initiated to capture as much of the historical knowledge as possible

Fast Reactors

Why were more not built?

Fast reactors .....

Fast Reactors started with early promise but so far have not achieved commercial reality.

Are they:-

"An expensive and dangerous mistake from the past"

or

"The only proven safe and sustainable solution for the future"

?

Fast reactors….

- Seen as essential in terms of Pu production while also generating electricity
- Sustainable therefore for the very long term
- A means for countries to obtain ‘independence’ in terms of access to fissile and fertile material

Expensive ?

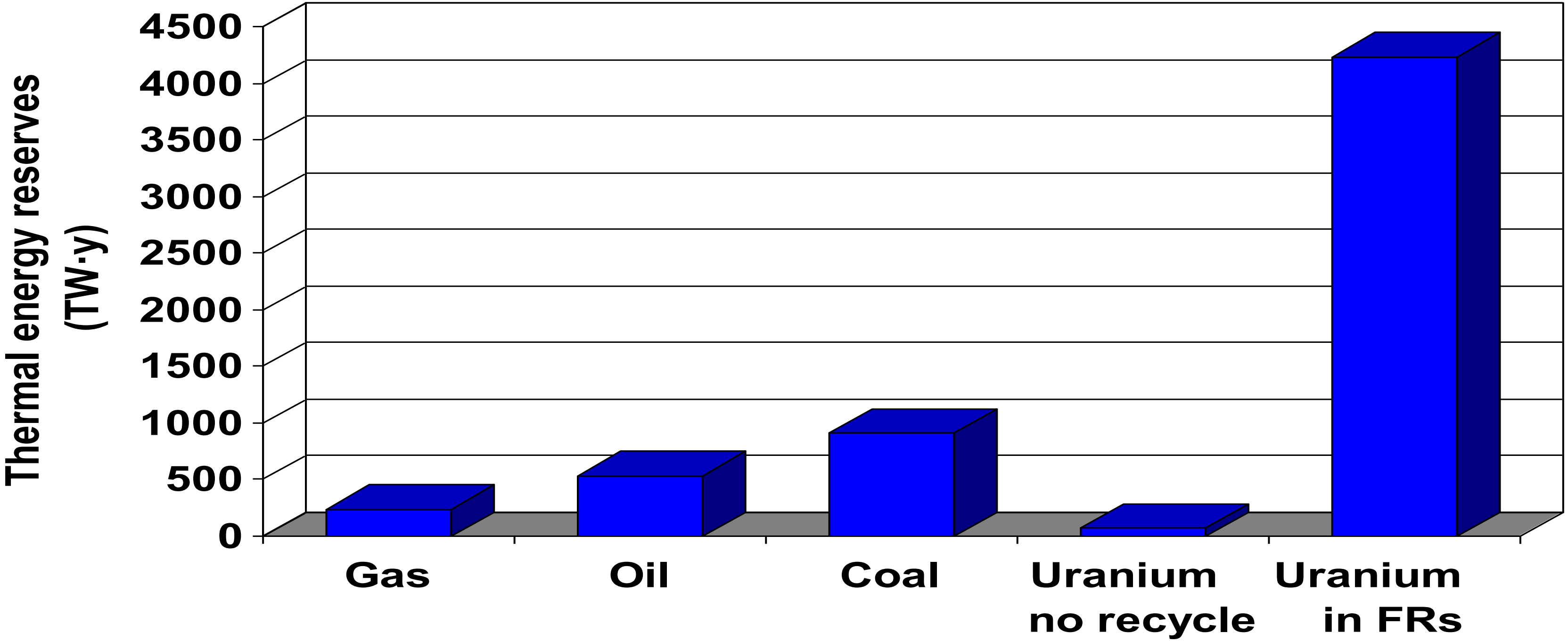
- Fast reactors offer a greater technological challenge than thermal systems
- No commercial series of fast reactors has ever been built, so like-for-like cost comparisons are difficult
- The most comprehensive commercial-scale design, the European Fast Reactor, underwent a **detailed economic comparison with ALWRs** in 1990s
  - **Series build capital cost 10%-27% higher**
  - **Fuel cycle costs lower**
  - **Life-time generating costs comparable**

- Some key factors have not been fully accounted for in previous economic analyses (costs of environmental impact, value of security of supply, value of ability to destroy MA's (Minor Actinides) and LLFPs (Long Lived Fission Products)

Dangerous ?

- PFR and DFR operated safely throughout their lives, despite representing huge technological advances, and accommodating a wide variety of different experiments
- World-wide safety performance of fast reactors has also been highly satisfactory
  - Sodium-water and sodium-air leaks have been shown to be containable, with manageable consequences
  - Reactor protection systems have operated well
- Operation of PFR, Phénix, (France) (EBR-II) and especially BN-600 (Russia/Kazakstan) have all demonstrated the ability of prototype-scale fast reactors to be operated safely and reliably
- The limited experience with SPX (France) suggested that a similarly good performance can be expected from commercial-scale SFR systems

Sustainable use of resources ?



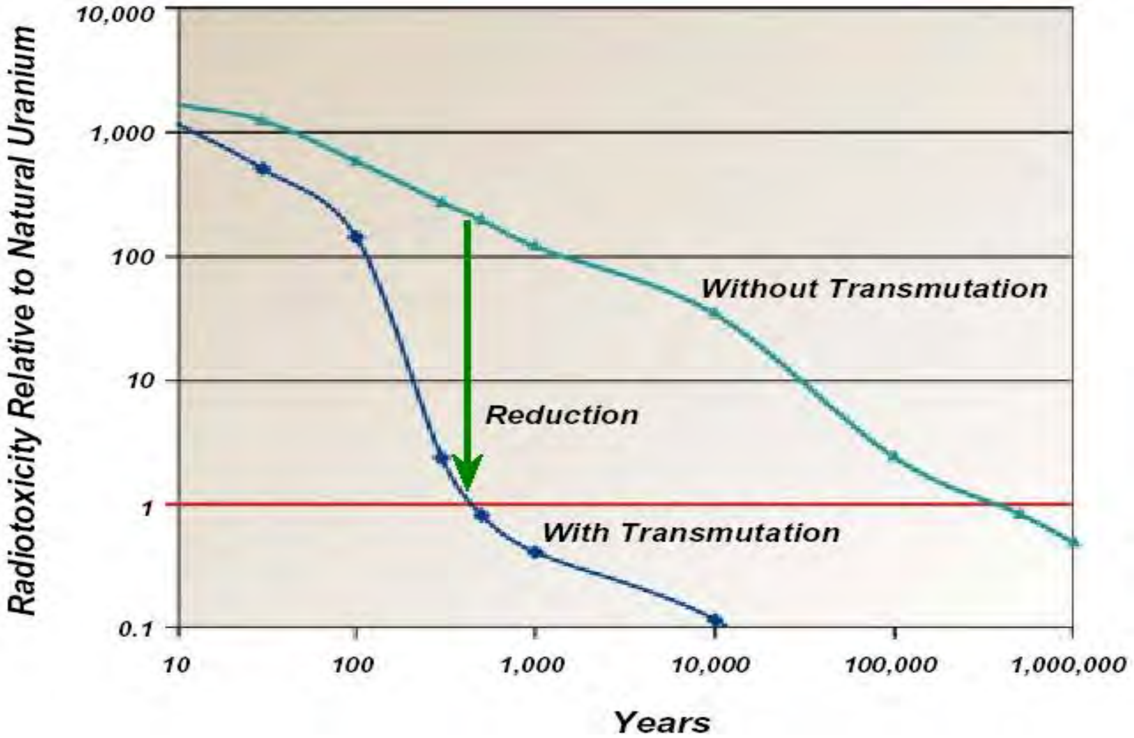
Source: US DOE Energy Information Administration "International Energy Outlook 2004", DOE/EIA-0484(2004)

Note: Gas and Oil include speculative reserves; Coal and Uranium do not

Environmentally sustainable ?

- Fast Reactors are able to significantly reduce the radio-toxic burden sent for final disposal
- This ability is driving current US interests, with the aim of reducing or avoiding the need for further repositories

Yucca Mountain, Nevada



Proven ?

Experimental

JOYO

DFR

PFR

MONJU

Prototype

PHENIX

Commercial

SUPER PHENIX

EBR-II

BN600

Demonstrated good performance over a range of scales and designs

So why are we not building fast reactors ?

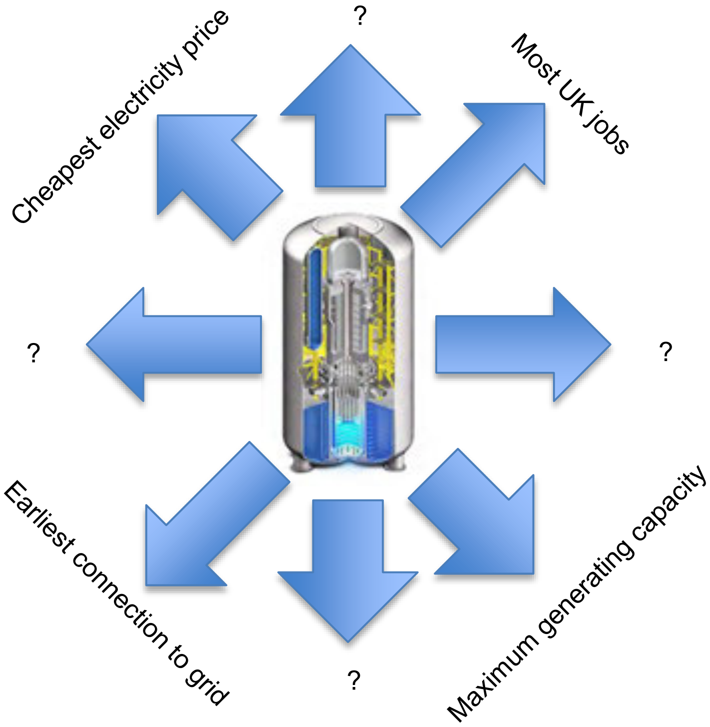
- Nations with the highest anticipated growth in energy demand (China, India) <u>are</u> building prototype fast reactors to gain experience with the technology
- In Russia, where BN-600 is operated as one of the best performing power reactors on the grid, BN-800 first criticality achieved but not yet operating. Plans for BN-1200
- In the West, the technical feasibility of prototype- and even commercial-scale SFRs is regarded as having been demonstrated

BUT

- Capital costs cannot yet compete with ALWRs
- Uranium prices have not yet reached levels where the lower FR fuel cycle costs can offset the utilities' preference for well-known technology

What about Small Modular Reactors?

Need to be clear what we want of SMRs AND a route to market



Opportunities – Small Modular Reactors

- Drastically reduced cost of capital (compared to large reactors)
  - Smaller designs maximise the extent to which construction can be undertaken in a controllable factory setting using 21st century manufacturing techniques.
  - Capital cost per item is greatly reduced.
  - Shorter construction periods with lower risk.
- Conceived to be built in significant numbers enabling cost reduction to be achieved by learning through doing (in contrast to small numbers of large reactors).
- SMRs can be built on sites not suitable for larger reactors.
- A flexible means of continuing to deliver a baseload of low carbon energy to complement renewables.
- The easiest opportunity for UK manufacturers to gain entry to a reactor market.
  - No established global suppliers
  - Potential for a large global market
  - Benefit of being first to market
- The SMRs that are closest to market are all PWRs – not novel technology, though can be novel configuration in some cases.

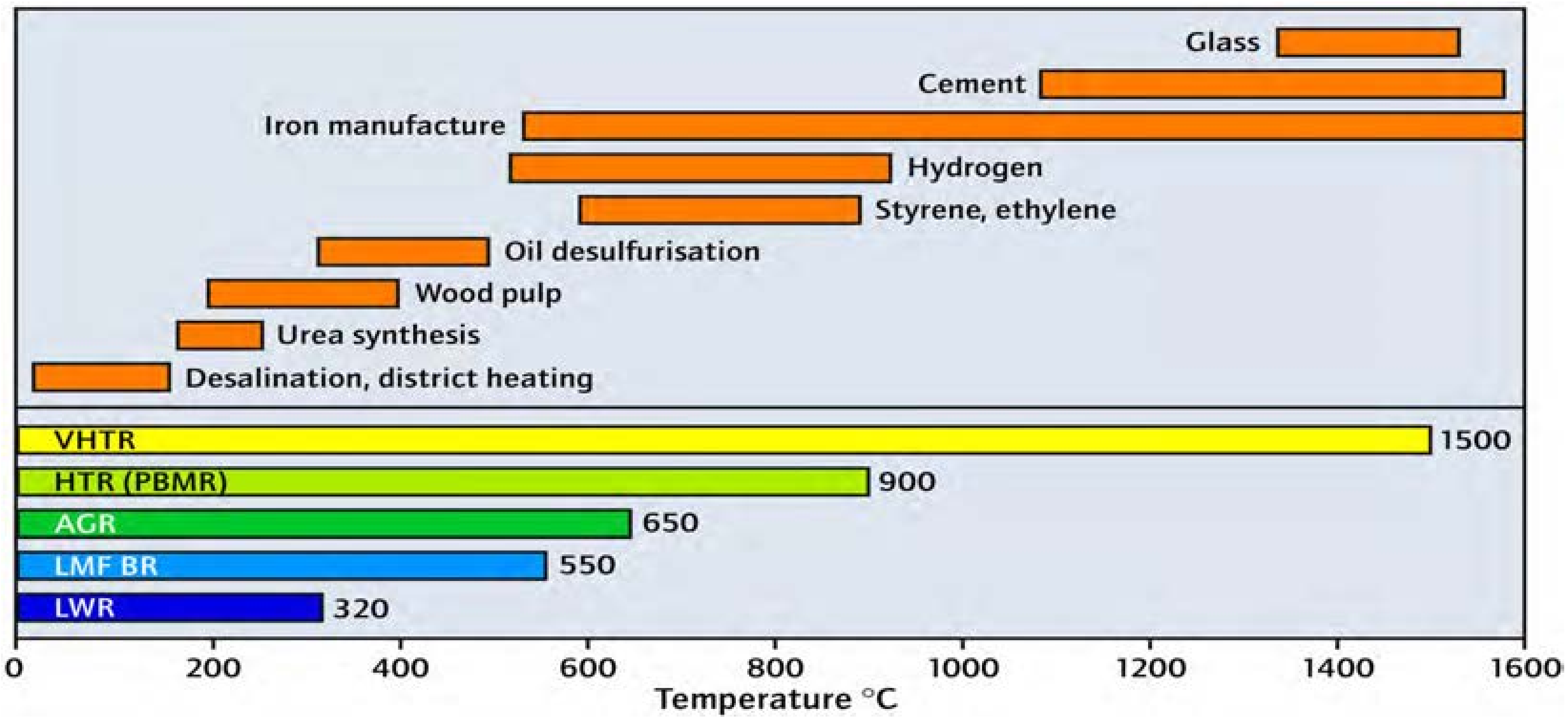
Medium and Small (25 MWe up) reactors with development well advanced

Name	Capacity	Type	Developer
KLT-40S	35 MWe	PWR	OKBM, Russia
VK-300	300 MWe	BWR	Atomenergoproekt, Russia
CAREM	27-100 MWe	PWR	CNEA & INVAP, Argentina
IRIS	100-335 MWe	PWR	Westinghouse-led, international
Westinghouse SMR	200 MWe	PWR	Westinghouse, USA
mPower	125-180 MWe	PWR	Babcock & Wilcox + Bechtel, USA
HI-SMUR	140 MWe	PWR	Holtec, USA
SMART	100 MWe	PWR	KAERI, South Korea
NuScale	45 MWe	PWR	NuScale Power + Fluor, USA
CAP-100/ACP100	100 MWe	PWR	CNNC & Guodian, China
HTR-PM	2x105 MWe	HTR	INET & Huaneng, China
PBMR	80 MWe	HTR	Eskom, South Africa
GT-MHR	285 MWe	HTR	General Atomics (USA), Rosatom (Russia)
SC-HTGR (Antares)	250 MWe	HTR	Areva
BREST	300 MWe	FNR	RDIPE, Russia
SVBR-100	100 MWe	FNR	Rosatom/En+, Russia
Hyperion PM	25 MWe	FNR	Hyperion, USA
Prism	311 MWe	FNR	GE-Hitachi, USA
FUJI	100 MWe	MSR	ITHMSO, Japan-Russia-USA


Living quarters
Adjustable ballast
Turbine sector
Control room
Platform double hull
Reactor hull
Containment
Skirt

What about High Temperature Reactors?

Heat Applications & Temperatures:
The Potential for Dual Mission Nuclear Plants



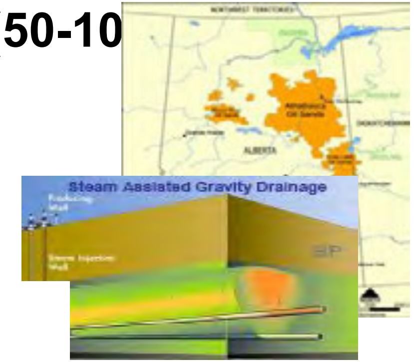
The Potential Market… > 600 Reactors?

Petrochemical (150)

Petroleum Refining (50-10

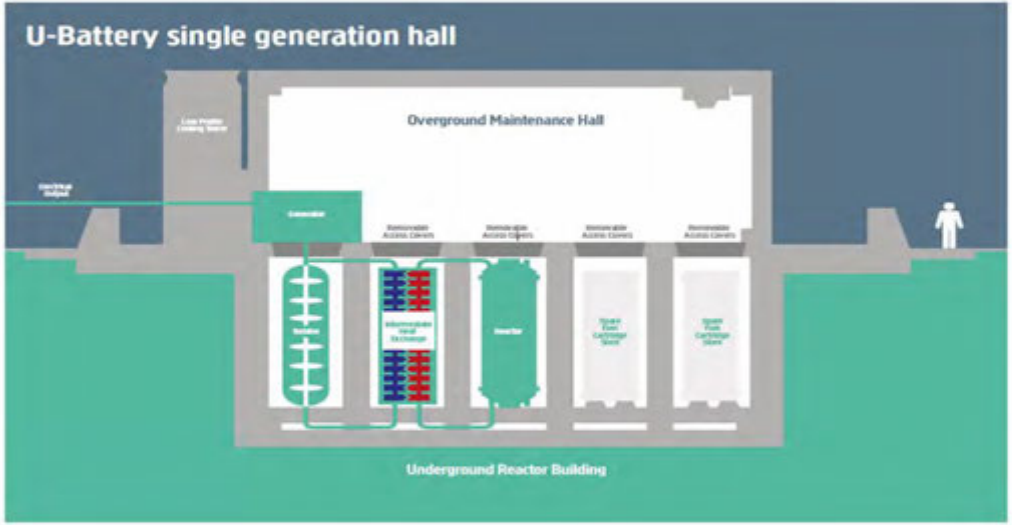
Fertilizers/Ammonia (100+)

Coal-to-Liquids (100s)



Oil Sands/Shale (200+)

MICRO Reactor Opportunity U-Battery

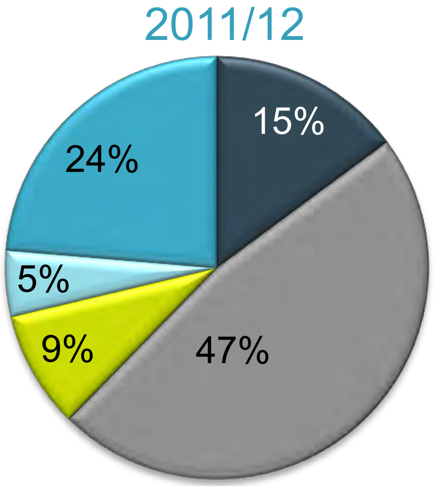


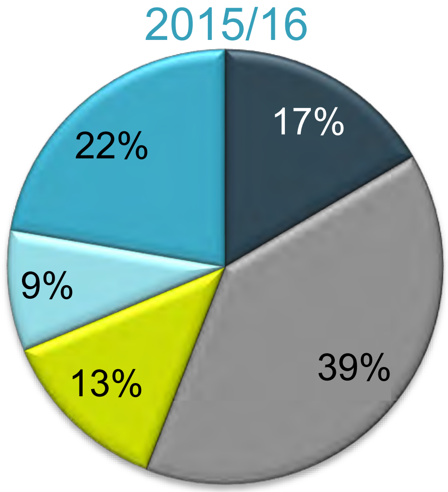
- Micro nuclear modular reactor.
- Provides local power and heat (800°C).
- Single unit 10MWt, 4MWe.
- Fits in volume of two squash courts.
- Overall installation has 60 year life.
- Gas cooled, helium in primary circuit, helium/nitrogen in secondary circuit driving turbine.
- Inherently safe TRISO fuel (up to 20% enriched 235-U).
- Fuel cartridge lasts five years.
- Spent fuel cartridge fits in international standard Excellox spent fuel transport flask.

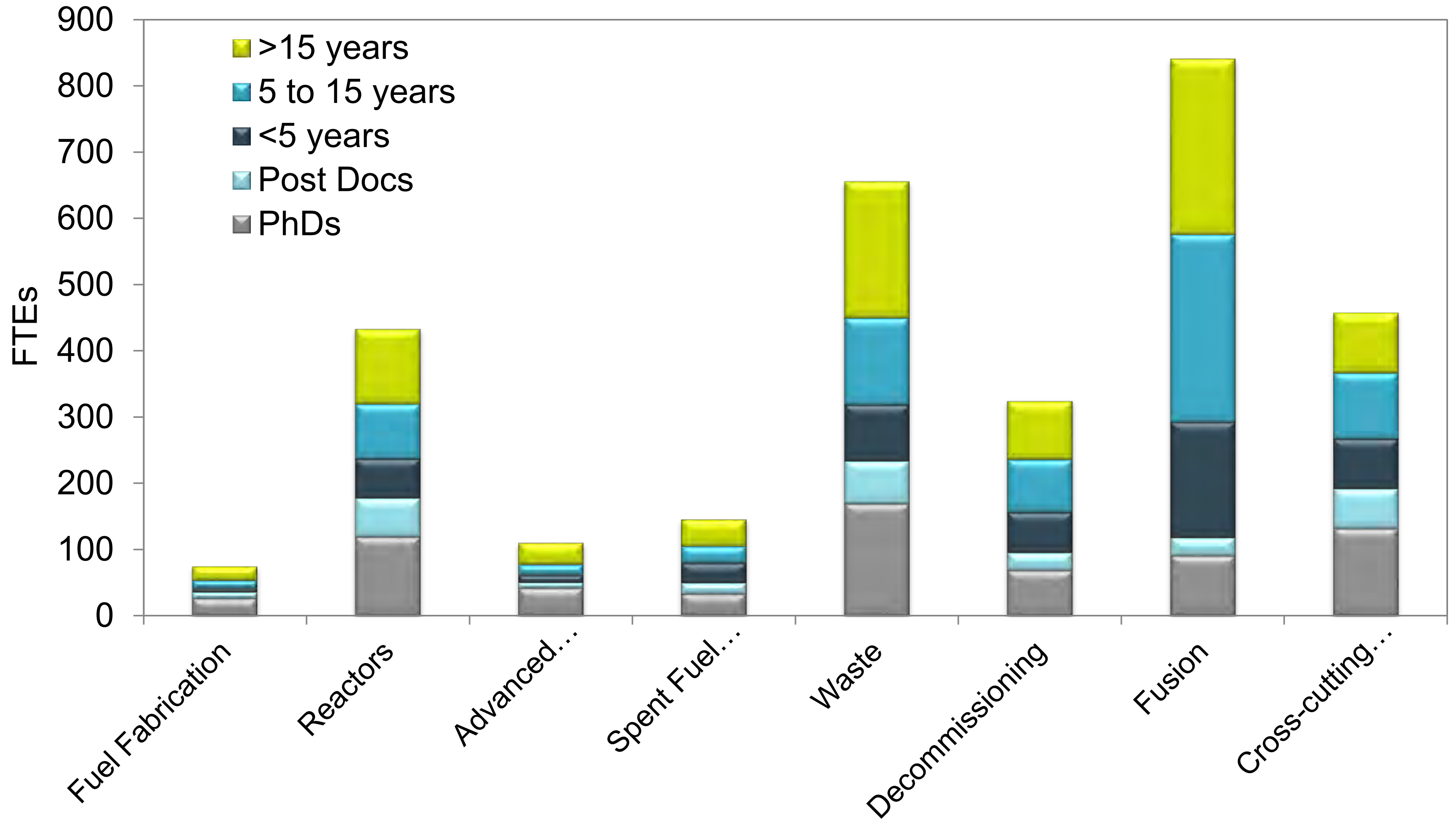
Realisable New Reactor Designs

- Many challenges
- Some longstanding issues
- Some new
- All requiring in depth, detailed, evidence based assessments and solutions
- A long term secure skill base and supply chain

	2011/12 FTEs	2015/16 FTEs	Difference
Industry	394	503	+109
National Laboratory	1260	1200	-60
University	1000	1344	+344
Staff	238	391	+153
UK University breakdown Post Docs	134	274	+140
PhD Students	628	679	+51
Total	2654	3047	+393

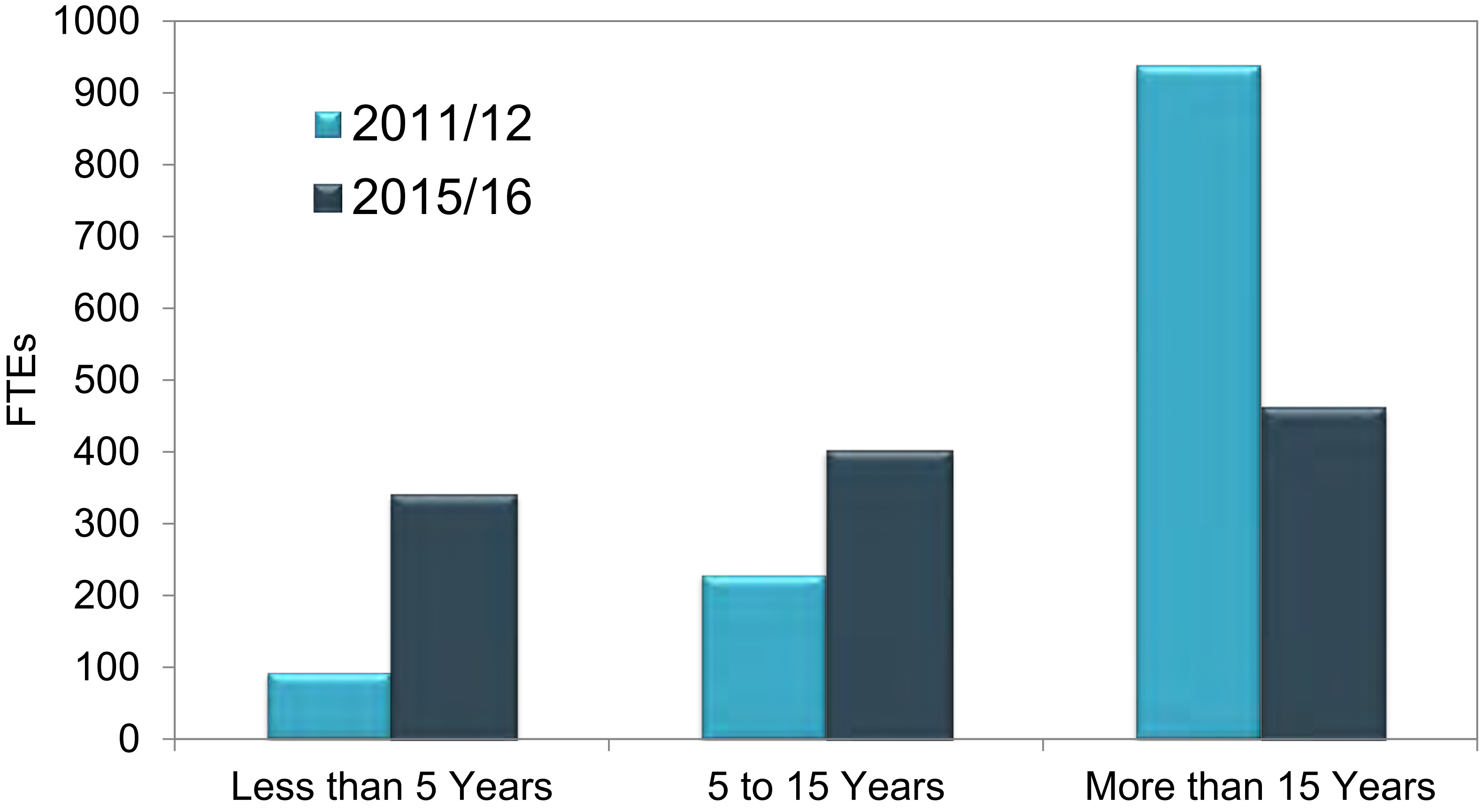




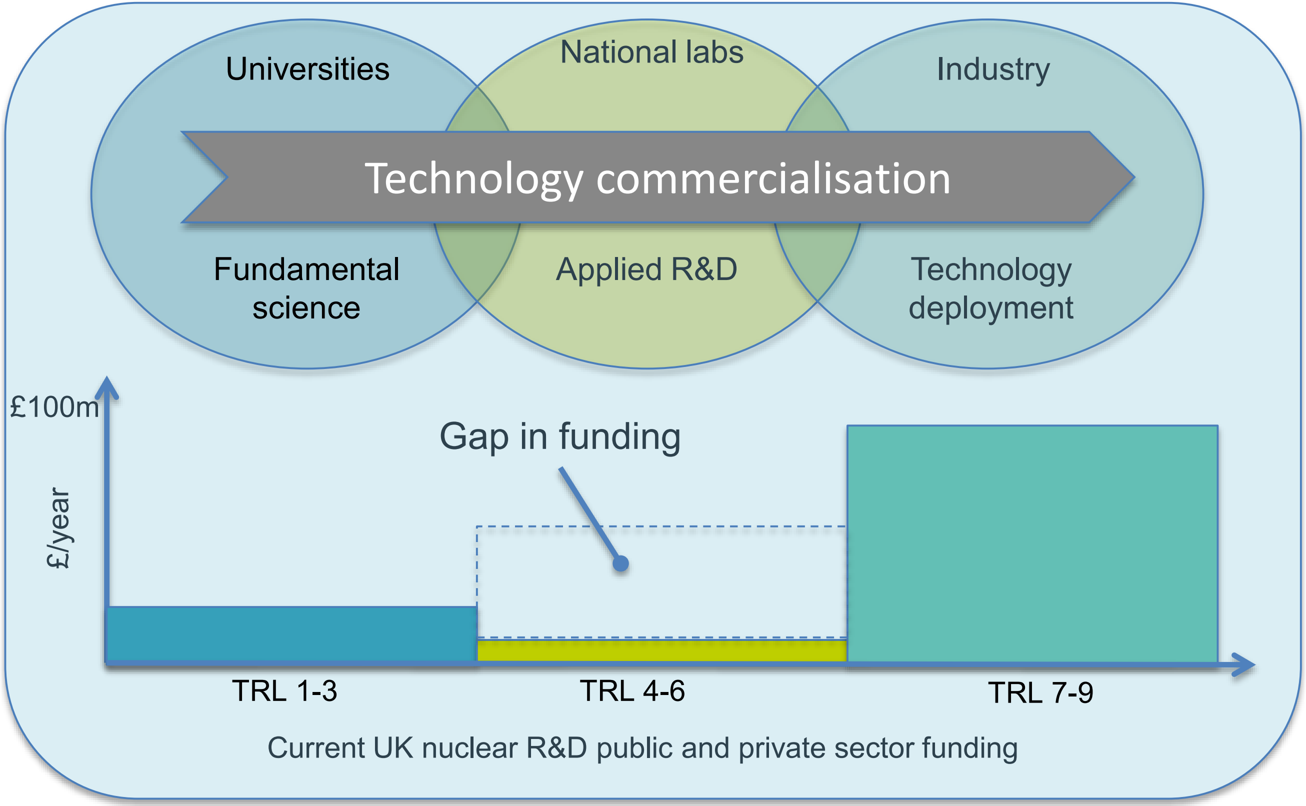


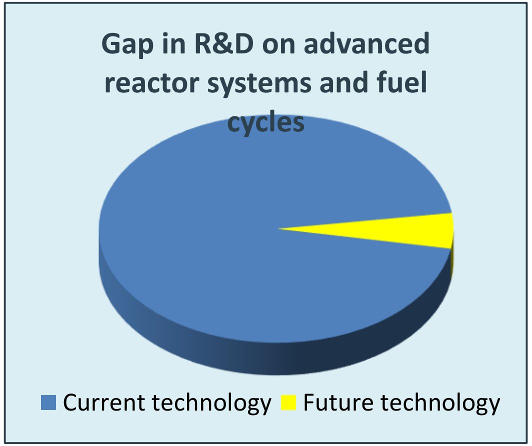
900
800
700
600
500
400
300
200
100
0
FTEs
>15 years
5 to 15 years
<5 years
Post Docs
PhDs
Fuel Fabrication
Reactors
Advanced…
Spent Fuel…
Waste
Decommissioning
Fusion
Cross-cutting…

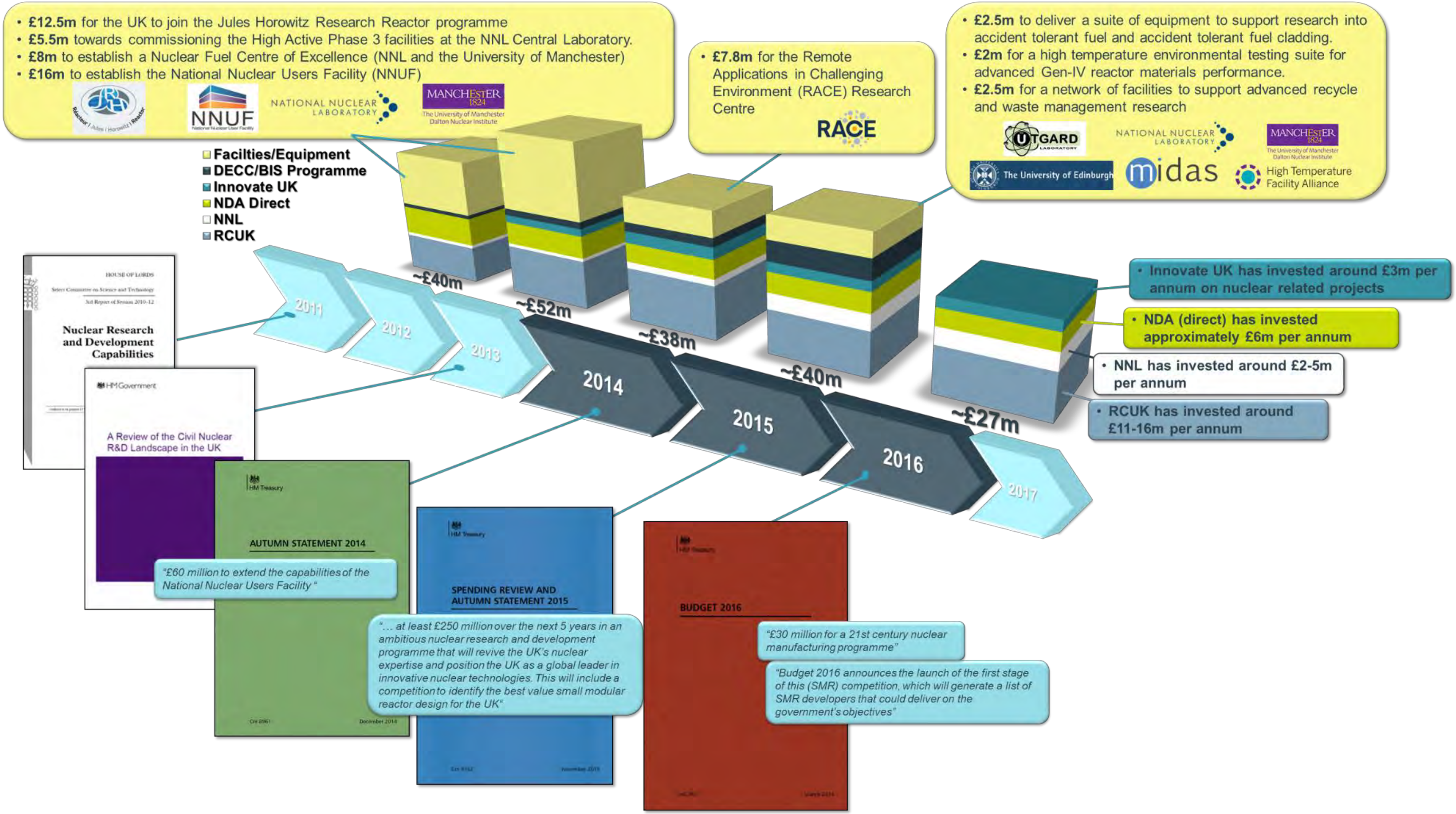
Loss of Subject Matter Experts in National Labs



There is a gap in *applied R&D* funding in national / mid TRL lab space

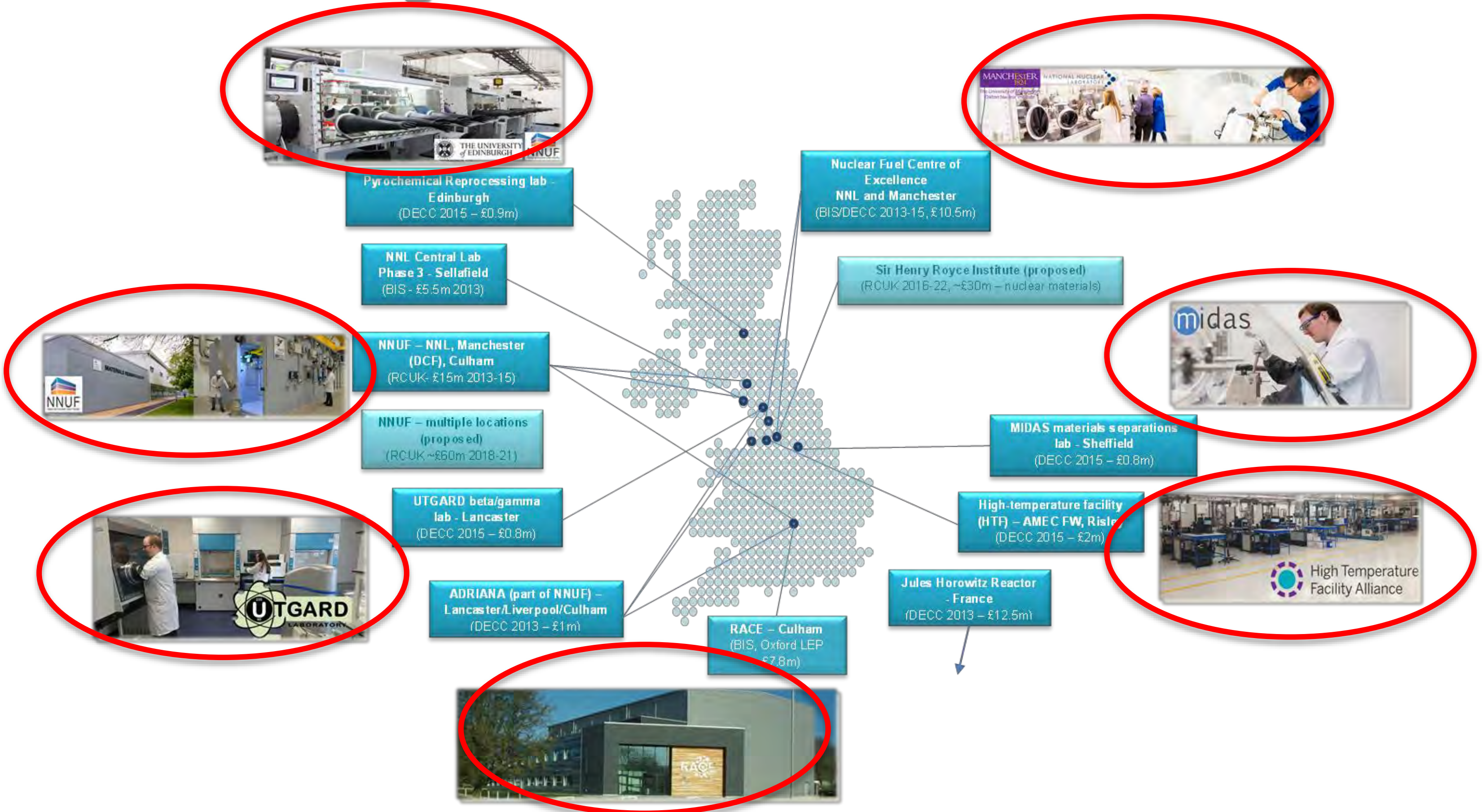




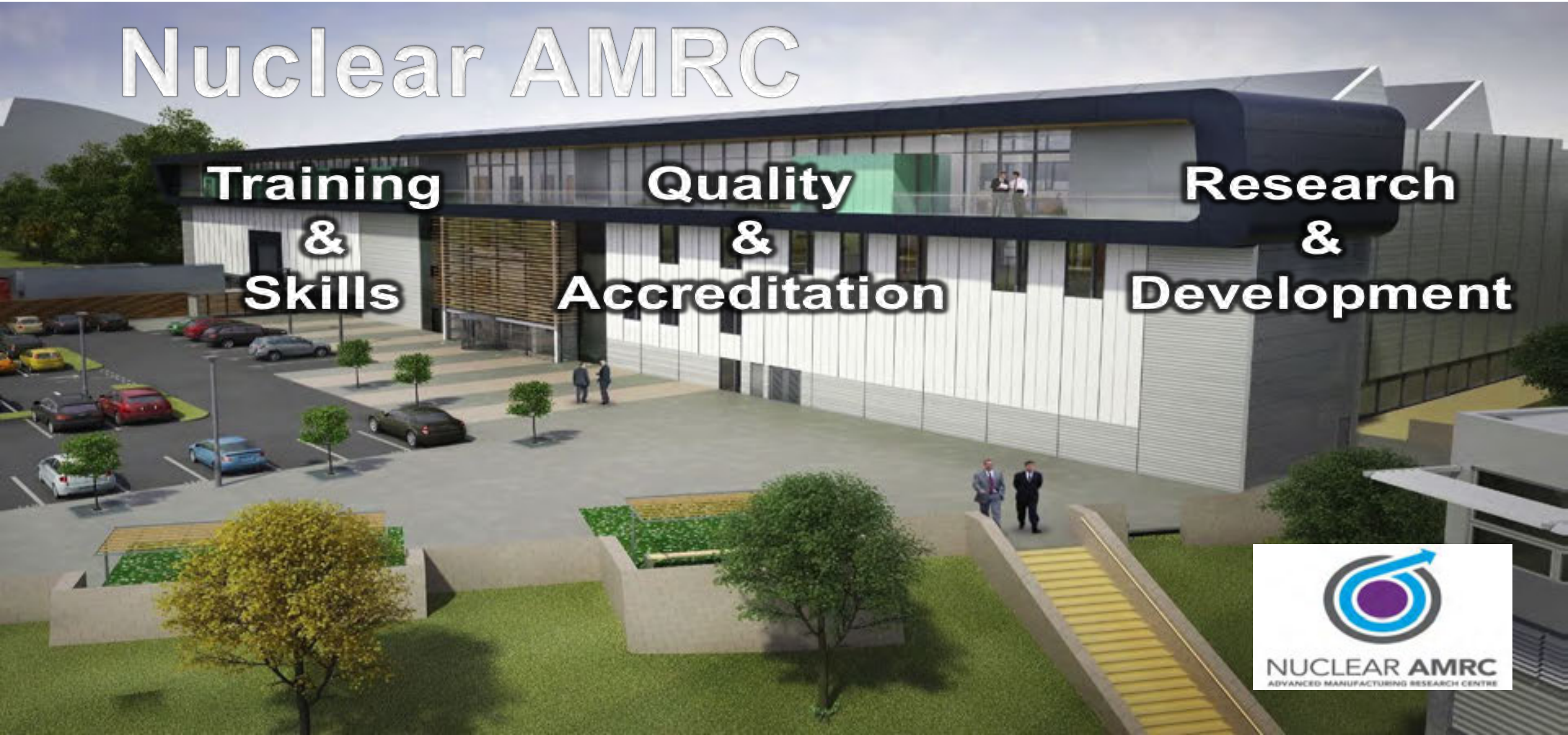


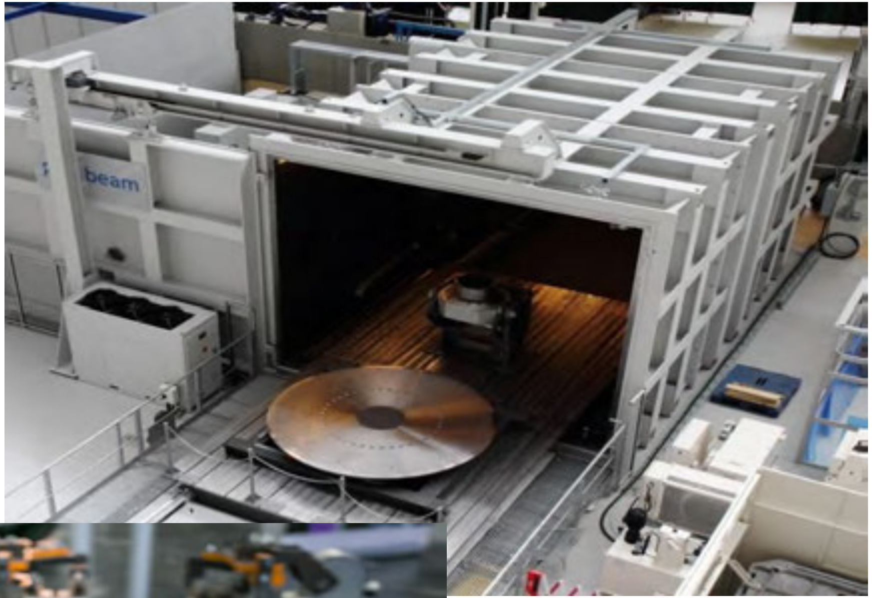
• £12.5m for the UK to join the Jules Horowitz Research Reactor programme
• £5.5m towards commissioning the High Active Phase 3 facilities at the NNL Central Laboratory.
• £8m to establish a Nuclear Fuel Centre of Excellence (NNL and the University of Manchester)
• £16m to establish the National Nuclear Users Facility (NNUF)
Réacteur Jules Horowitz Reactor
NNUF
National Nuclear User Facility
NATIONAL NUCLEAR LABORATORY
MANCHESTER 1824
The University of Manchester
Dalton Nuclear Institute
• £7.8m for the Remote Applications in Challenging Environment (RACE) Research Centre
RACE
• £2.5m to deliver a suite of equipment to support research into accident tolerant fuel and accident tolerant fuel cladding.
• £2m for a high temperature environmental testing suite for advanced Gen-IV reactor materials performance.
• £2.5m for a network of facilities to support advanced recycle and waste management research
UTGARD LABORATORY
NATIONAL NUCLEAR LABORATORY
MANCHESTER 1824
The University of Manchester
Dalton Nuclear Institute
The University of Edinburgh
midas
High Temperature Facility Alliance
Facilties/Equipment
DECC/BIS Programme
Innovate UK
NDA Direct
NNL
RCUK
~£40m
~£52m
~£38m
~£40m
~£27m
2011
2012
2013
2014
2015
2016
2017
• Innovate UK has invested around £3m per annum on nuclear related projects
• NDA (direct) has invested approximately £6m per annum
• NNL has invested around £2-5m per annum
• RCUK has invested around £11-16m per annum
HOUSE OF LORDS
Select Committee on Science and Technology
3rd Report of Session 2010-12
Nuclear Research and Development Capabilities
HM Government
A Review of the Civil Nuclear R&D Landscape in the UK
HM Treasury
AUTUMN STATEMENT 2014
"£60 million to extend the capabilities of the National Nuclear Users Facility"
Cm 8961
December 2014
HM Treasury
SPENDING REVIEW AND AUTUMN STATEMENT 2015
"… at least £250 million over the next 5 years in an ambitious nuclear research and development programme that will revive the UK's nuclear expertise and position the UK as a global leader in innovative nuclear technologies. This will include a competition to identify the best value small modular reactor design for the UK"
BUDGET 2016
"£30 million for a 21st century nuclear manufacturing programme"
"Budget 2016 announces the launch of the first stage of this (SMR) competition, which will generate a list of SMR developers that could deliver on the government's objectives"

World-Leading Research Facilities



Advanced Manufacturing Research and Innovat




beam

MANCHESTER 1824
The University of Manchester
Dalton Nuclear Institute

Dalton Cumbrian Facility

Academic gateway to NNL

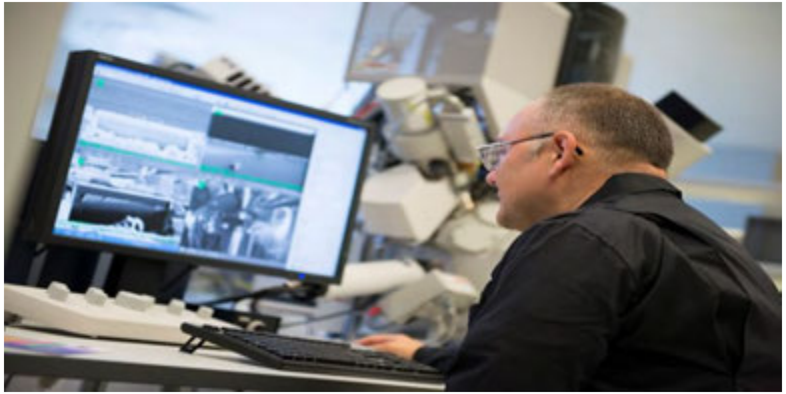
Engineering decommissioning

Radiation Science


NATIONAL NUCLEAR
LABORATORY
Central Laboratory




NNL
Central Laboratory



High Temperature Facility Alliance

University of BRISTOL

The Open University

UNIVERSITY OF OXFORD

CCFE

MANCHESTER 1824
The University of Manchester

Imperial College London

amec foster wheeler

NATIONAL NUCLEAR LABORATORY

U BATTERY
Local Modular Energy

EDF ENERGY

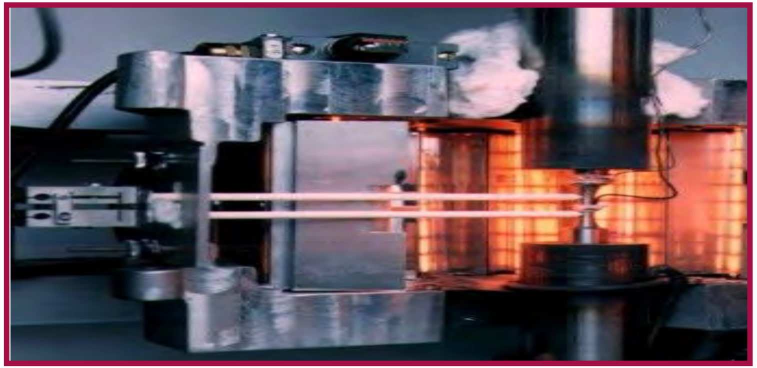
High Temperature Facility Alliance

Project Objectives

- ► Establish an open access high temperature materials R&D facility
- ► Develop and deliver an exploitation plan that helps the UK play a leading role in advanced reactor technology

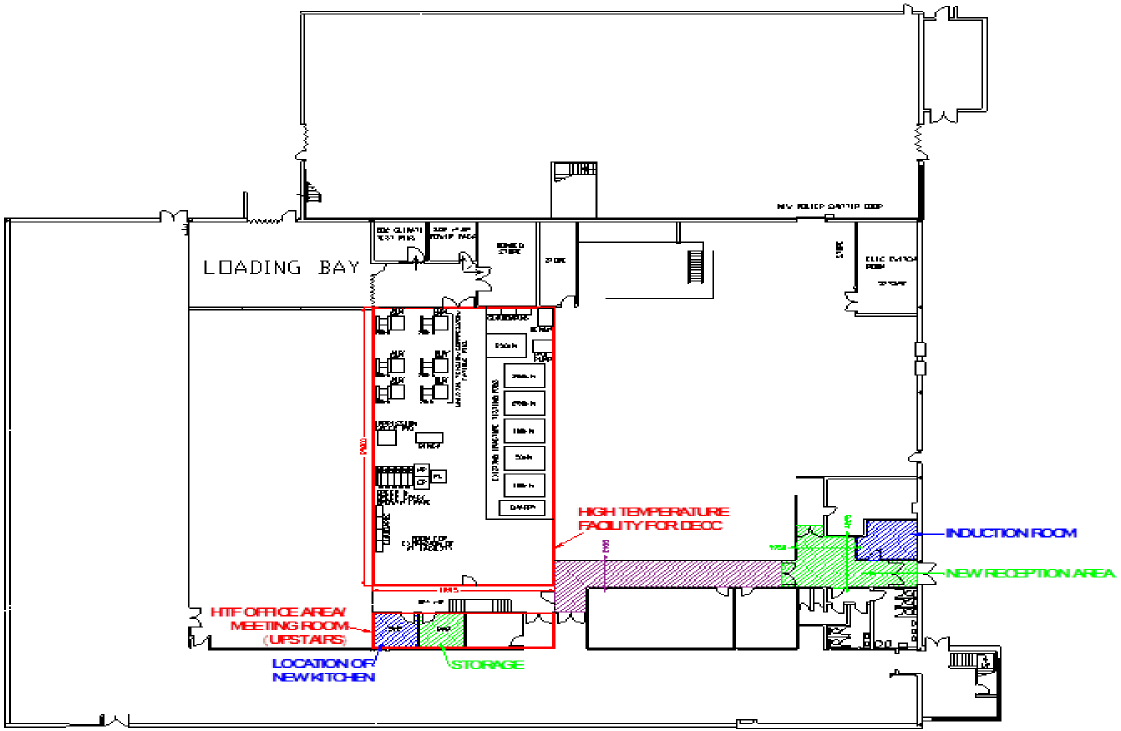
DECC/BEIS grant

- ► £2m to set up facility
- ► Project launched September 2015
- ► Construction complete April 2016
- ► Official launch September 2016



Access and accommodation

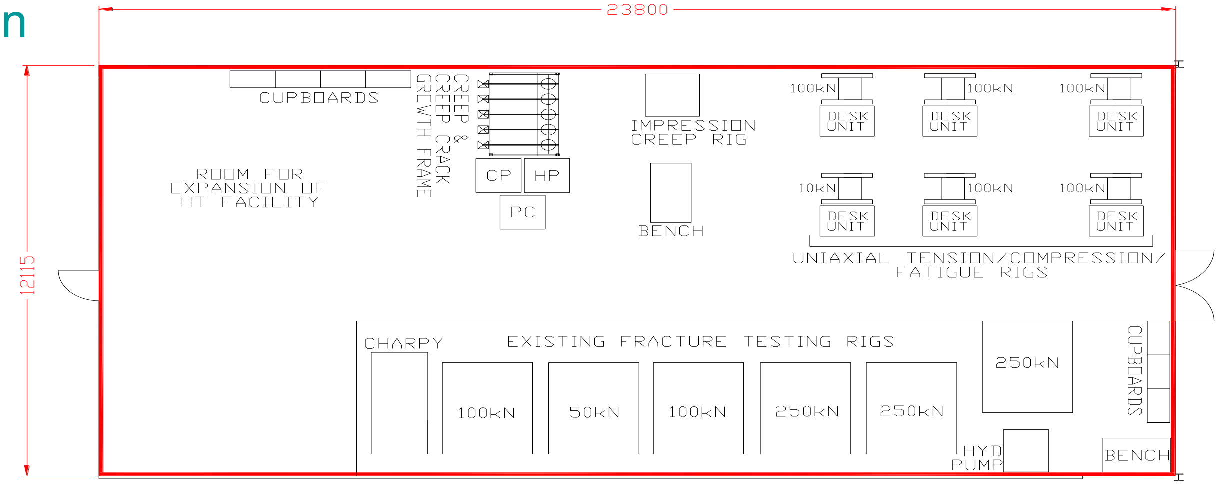
- Newton House key elements
  - Reception area and induction room
  - Office space with connectivity for 6 users
  - Specimen and materials store
  - Kitchen area
  - Main lab



NEWTON HOUSE GROUND FLOOR PLAN 2015

Lab layout

- Main features
  - 280 m^2 of temperature and humidity controlled lab space
  - New High Temperature facilities
  - Access to fracture lab and other Amec Foster Wheeler facilities
  - Space for expansion



What was built

- 5 servo-electric loading rigs for low cycle fatigue
- 5 weight-loaded frame for measuring creep / creep crack growth
- 1 servo hydraulic loading rig for high cycle fatigue

6 fracture toughness test rigs (currently owned by AMEC)

Test rigs can operate at 1000˚C and elevated pressure

Compatible with future testing in liquid metals

DIC and AE instruments to measure surface degradation/strain

Thermo-mechanical fatigue capability

Facility housed in controlled temperature and humidity room

Operational Mode

Technology hotel – lab space to test high temperature materials

Lab fund charge based on rig-year occupancy.

Staff made available to operate rigs, or to supervise safe operation

- Motivation
- Provides access to Amec Foster Wheeler expertise with state-of-the-art high temperature materials research facility to support nuclear and non-nuclear programmes.

Technical Governance

AMEC FW, CCFE, EDF Energy, NIRAB, NNL,

Bristol, Manchester, Imperial, Open, Oxford Universities

Identify and engage with funders, provides technical direction and ensures compliance with NIRAB priorities and national policy.

Envisaged Use of Facility at Launch

Generation IV reactor programmes

- EPSRC funded calls to universities
- Innovate UK call to corporations, SMEs and universities
- EU-funded programmes
- International programmes

Reactor Development projects

- Small Modular Reactors
- U-Battery initiative

AGR fleet support

JRIC collaboration with China

Non-nuclear gas turbine support

Automotive advanced materials

Feb 2017 – Committed Projects in HTF

- Areva - Fracture toughness testing of segregated RPV Steel for Flamenville PWR
- EDF Energy – High temperature creep fatigue tests for AGR
- EDF Energy – Interrupted creep tests for AGR

Feb 2017 – Quotations Awaiting Client Funding Decision for Projects in HTF

- BEIS / NNL - Coupon exposure tests for advanced fuel cladding materials in support of BEIS fuel programme
- INNOVATE UK – Testing of advanced materials and associated fabrication methods for Gen IV, SMR, LWR, AGR reactors
- UKAEA Culham for Fusion programme
  - Lead-lithium tensile, creep and corrosion tests on 316 stainless steel and Eurofer for fusion programme
  - Vacuum fatigue testing of copper
  - Testing of sensors under high cycle fatigue conditions
- University of Manchester – vacuum creep measurements for aerospace alloy

Feb 2017 – Prospective Projects in HTF

The following opportunities have been discussed with clients and invitations to tender or opportunities to engage further are expected.

- Areva - Fracture toughness testing of Steam Generator Steel for Flamenville PWR
- Areva - Fracture toughness testing of Steel for Hinkley C PWR
- NNL/CNNC- Several propositions for prospective work supported by JRIC have been discussed with both NNL and CNNC
- Rolls-Royce – Verification and validation testing of materials associated with their SMR initiative.

Next Steps: Additional Challenges and Opportunities

- Nuclear Industry Council
- Son (or daughter!) of NIRAB
- BREXIT
- BREXATOM
- China