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.
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.

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.
"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."
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

<table>
<thead>
<tr>
<th>Energy policy</th>
<th>Industrial policy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Affordable energy</td>
<td>Economic growth</td>
</tr>
<tr>
<td>Sustainable low carbon energy</td>
<td>Skills / capability</td>
</tr>
<tr>
<td>Security of supply</td>
<td>World class science</td>
</tr>
</tbody>
</table>

- **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**

### Recommendations
- **Co-ordinated activity**
- **Advice to Ministers**
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

**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
- Nuclear Fuel Recycle and Waste Management

**Recycling Fuel for Future Reactors**
- Nuclear Facilities and Developing a Strategic Toolkit

**The UK’s 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

Springfields
Fuel Manufacture

Capenhurst
Enrichment
Operating and Maintaining the Fleet
Waste Management and Decommissioning
New Nuclear Generation
Innovation and R&D
• 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.

**Generation I**

**Generation II – Large Scale**

**Generation III – Evolutionary**

- GEN III Fleet
- SMR Fleet?

**Generation IV – Innovative**

- Sodium-Cooled Fast Reactor?
- Very high temperature Reactor?
- Molten Salt Reactor?
- Gas-Cooled Fast Reactor?
- Lead-Cooled Fast Reactor?
- Super-Critical Water Cooled Reactor?
UK’s strength – Strong Government Support

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
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)
- Supercritical-Water-Cooled Reactor (SCWR)
- Lead-Cooled Fast Reactor (LFR)
- Gas-Cooled Fast Reactor (GFR)
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
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
Costs dominated by capital to construct and timescale to finance before returns flow.
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

- Complex
- Congested
- Heavy
- Non-repetitive

Buildable?

Enormous
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
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:
Design for Manufacture and Assembly

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

To fix 3 walls

Site time: 5 days

Site labour: 87 man-hours
Design for Manufacture and Assembly

- Design criterion: Modular design into precast components.

To erect 3 walls
Site time: 1 day
Site labour: 18 man-hours
Design for Manufacture and Assembly

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

To assemble 3 walls

Site time: 4 hours
Site labour: 12 man-hours
(estimated)

(In progress...
Aerial view of the Vogtle 3 and 4 construction site
Aerial view of the Vogtle 3 and 4 construction site.
The 306-ton Vogtle Unit 3 reactor vessel is placed inside the nuclear island.
The 306-ton Vogtle Unit 3 reactor vessel is placed inside the nuclear island.
Aerial view looking inside Vogtle Unit 3 containment.
Construction of the Vogtle Unit 3 east shield building wall continues to progress.
High Performance Pressure Boundary Components Require:
- Uniform Chemistry and Structure
- Validated Mechanical Properties – Strength and Toughness
- Properties must be Exhibited in All Sections

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

Supplier as well as component development

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

<table>
<thead>
<tr>
<th></th>
<th>Existing Plants</th>
<th>New Build</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Plant Operations</strong></td>
<td>Relicence Existing Gen III Plants</td>
<td>Build New Gen III+ Plants</td>
</tr>
<tr>
<td><strong>Materials Technology Required</strong></td>
<td>Understand aging and degradation of properties.</td>
<td>Validation of new materials variants (e.g S level 0.002% spec as &lt;0.030)</td>
</tr>
<tr>
<td></td>
<td>Quantify long time dependent behavior</td>
<td>Extension of property database</td>
</tr>
<tr>
<td></td>
<td>Inspection &amp; Analysis tools</td>
<td>Validate modern processing routes</td>
</tr>
<tr>
<td></td>
<td>Repair and Replace Options</td>
<td></td>
</tr>
</tbody>
</table>

*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.
UK fast reactors


• 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/Kazakhstan) 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?


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

- Fast Reactors are able to significantly reduce the radioactive 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?

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) are 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

<table>
<thead>
<tr>
<th>Name</th>
<th>Capacity</th>
<th>Type</th>
<th>Developer</th>
</tr>
</thead>
<tbody>
<tr>
<td>KLT-40S</td>
<td>35 MWe</td>
<td>PWR</td>
<td>OKBM, Russia</td>
</tr>
<tr>
<td>VK-300</td>
<td>300 MWe</td>
<td>BWR</td>
<td>Atomenergoproekt, Russia</td>
</tr>
<tr>
<td>CAREM</td>
<td>27-100 MWe</td>
<td>PWR</td>
<td>CNEA &amp; INVAP, Argentina</td>
</tr>
<tr>
<td>IRIS</td>
<td>100-335 MWe</td>
<td>PWR</td>
<td>Westinghouse-led, international</td>
</tr>
<tr>
<td>Westinghouse SMR</td>
<td>200 MWe</td>
<td>PWR</td>
<td>Westinghouse, USA</td>
</tr>
<tr>
<td>mPower</td>
<td>125-180 MWe</td>
<td>PWR</td>
<td>Babcock &amp; Wilcox + Bechtel, USA</td>
</tr>
<tr>
<td>HI-SMUR</td>
<td>140 MWe</td>
<td>PWR</td>
<td>Holtec, USA</td>
</tr>
<tr>
<td>SMART</td>
<td>100 MWe</td>
<td>PWR</td>
<td>KAERI, South Korea</td>
</tr>
<tr>
<td>NuScale</td>
<td>45 MWe</td>
<td>PWR</td>
<td>NuScale Power + Fluor, USA</td>
</tr>
<tr>
<td>CAP-100/ACP100</td>
<td>100 MWe</td>
<td>PWR</td>
<td>CNNC &amp; Guodian, China</td>
</tr>
<tr>
<td>HTR-PM</td>
<td>2x105 MWe</td>
<td>HTR</td>
<td>INET &amp; Huaneng, China</td>
</tr>
<tr>
<td>PBMR</td>
<td>80 MWe</td>
<td>HTR</td>
<td>Eskom, South Africa</td>
</tr>
<tr>
<td>GT-MHR</td>
<td>285 MWe</td>
<td>HTR</td>
<td>General Atomics (USA), Rosatom (Russia)</td>
</tr>
<tr>
<td>SC-HTGR (Antares)</td>
<td>250 MWe</td>
<td>HTR</td>
<td>Areva</td>
</tr>
<tr>
<td>BREST</td>
<td>300 MWe</td>
<td>FNR</td>
<td>RDIPE, Russia</td>
</tr>
<tr>
<td>SVBR-100</td>
<td>100 MWe</td>
<td>FNR</td>
<td>Rosatom/En+, Russia</td>
</tr>
<tr>
<td>Hyperion PM</td>
<td>25 MWe</td>
<td>FNR</td>
<td>Hyperion, USA</td>
</tr>
<tr>
<td>Prism</td>
<td>311 MWe</td>
<td>FNR</td>
<td>GE-Hitachi, USA</td>
</tr>
<tr>
<td>FUJI</td>
<td>100 MWe</td>
<td>MSR</td>
<td>ITHMSO, Japan-Russia-USA</td>
</tr>
</tbody>
</table>
What about High Temperature Reactors?
Heat Applications & Temperatures:
The Potential for Dual Mission Nuclear Plants
The Potential Market… > 600 Reactors?

- Petrochemical (150)
- Petroleum Refining (50-100)
- Fertilizers/Ammonia (100+)
- Coal-to-Liquids (100s)
- Oil Sands/Shale (200+)

- Coal-to-Liquids (100s)
- Petrochemical (150)
- Petroleum Refining (50-100)
- Fertilizers/Ammonia (100+)
- 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
### UK University breakdown

#### 2011/12
- **Industry**: 394 FTEs
- **National Laboratory**: 1260 FTEs
- **University**: 1000 FTEs

#### 2015/16
- **Industry**: 503 FTEs
- **National Laboratory**: 1200 FTEs
- **University**: 1344 FTEs

#### Difference
- **Industry**: +109 FTEs
- **National Laboratory**: -60 FTEs
- **University**: +344 FTEs

#### UK University breakdown

<table>
<thead>
<tr>
<th></th>
<th>2011/12 FTEs</th>
<th>2015/16 FTEs</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Industry</td>
<td>394</td>
<td>503</td>
<td>+109</td>
</tr>
<tr>
<td>National Laboratory</td>
<td>1260</td>
<td>1200</td>
<td>-60</td>
</tr>
<tr>
<td>University</td>
<td>1000</td>
<td>1344</td>
<td>+344</td>
</tr>
<tr>
<td>Staff</td>
<td>238</td>
<td>391</td>
<td>+153</td>
</tr>
<tr>
<td>Post Docs</td>
<td>134</td>
<td>274</td>
<td>+140</td>
</tr>
<tr>
<td>PhD Students</td>
<td>628</td>
<td>679</td>
<td>+51</td>
</tr>
<tr>
<td>Total</td>
<td>2654</td>
<td>3047</td>
<td>+393</td>
</tr>
</tbody>
</table>
Loss of Subject Matter Experts in National Labs

- **2011/12**
- **2015/16**

<table>
<thead>
<tr>
<th>Experience Period</th>
<th>2011/12</th>
<th>2015/16</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 5 Years</td>
<td>FTEs</td>
<td>FTEs</td>
</tr>
<tr>
<td>5 to 15 Years</td>
<td>FTEs</td>
<td>FTEs</td>
</tr>
<tr>
<td>More than 15 Years</td>
<td>FTEs</td>
<td>FTEs</td>
</tr>
</tbody>
</table>
There is a gap in applied R&D funding in national / mid TRL lab space.
World-Leading Research Facilities
Advanced Manufacturing Research and Innovation

Nuclear AMRC

Training & Skills

Quality & Accreditation

Research & Development
Dalton Cumbrian Facility

Academic gateway to NNL
Engineering decommissioning
Radiation Science
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
Lab layout

- Main features
  - 280 m² 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