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Fission Materials Overview

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"Energy Materials: Meeting the Challenge"
Loughborough University, U.K.
9 - 10th October 2008

Introduction

The challenge

- Energy policy has shifted significantly in recent years with new nuclear power emerging as a key component of the UK energy mix

  –Security and diversity of supply

  –Low carbon

- Government support for new nuclear build in 2008

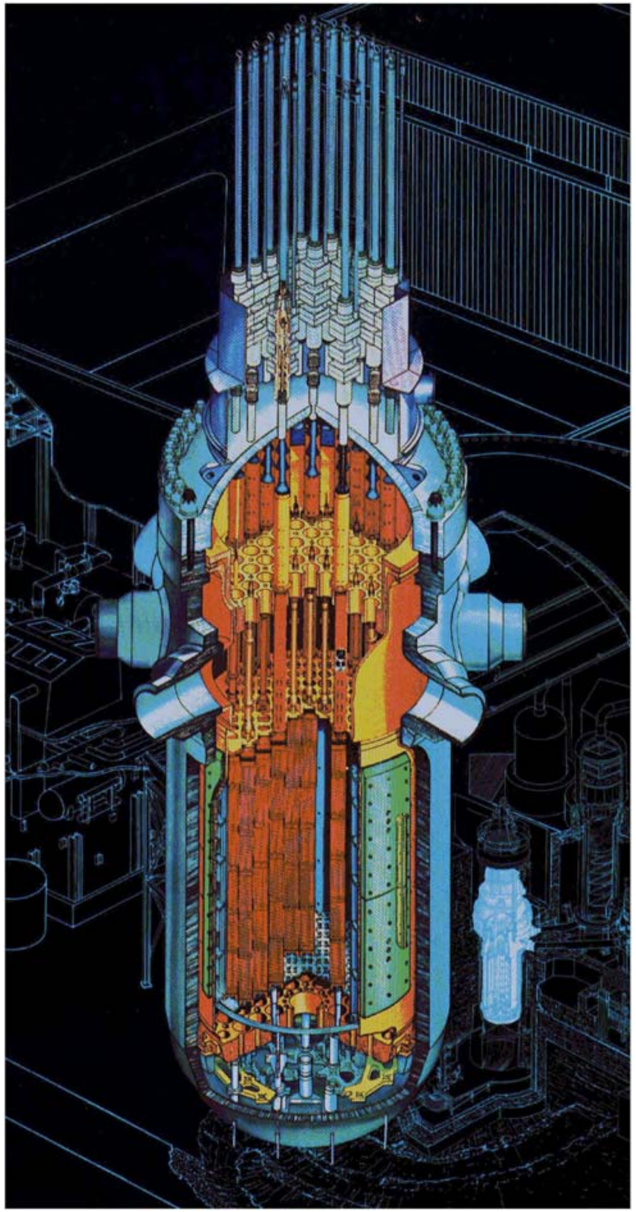
  "… the Government has today concluded that nuclear should have a role to play in the generation of electricity, alongside other low carbon technologies"

- This has been followed by the creation of the Office for Nuclear Development (OND)

  To enable operators to build and operate new nuclear power stations in the UK from the earliest possible date

- The National Skills Academy for Nuclear

  To create, develop and promote world class skills and career pathways to support sustainable future for the UK nuclear industry



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Introduction

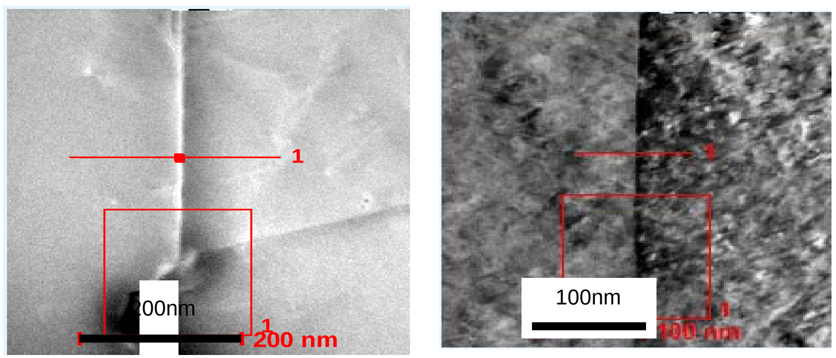
The Grand Challenge

- Understanding and predicting materials performance in the extreme environments of nuclear applications is fundamental to support the nuclear renaissance
  - Fuels
  - Fuel cladding
  - Core materials
  - Pressure Vessels
  - Steam Generator
  - Pressuriser
  - Pumps
  - Pipes and welds

- High temperatures, irradiation fields and corrosive environments

Understand and predict changes in:

- microstructure)
- properties) Safety and reliability
- loading)

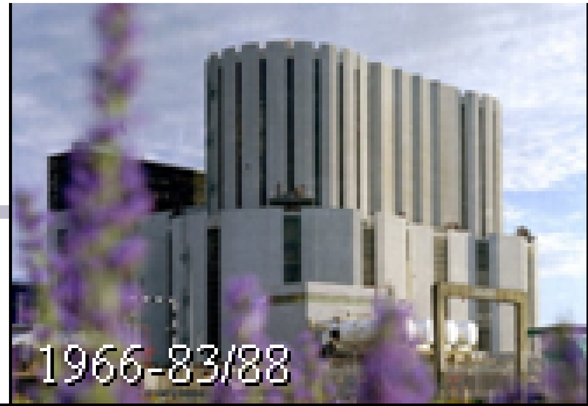


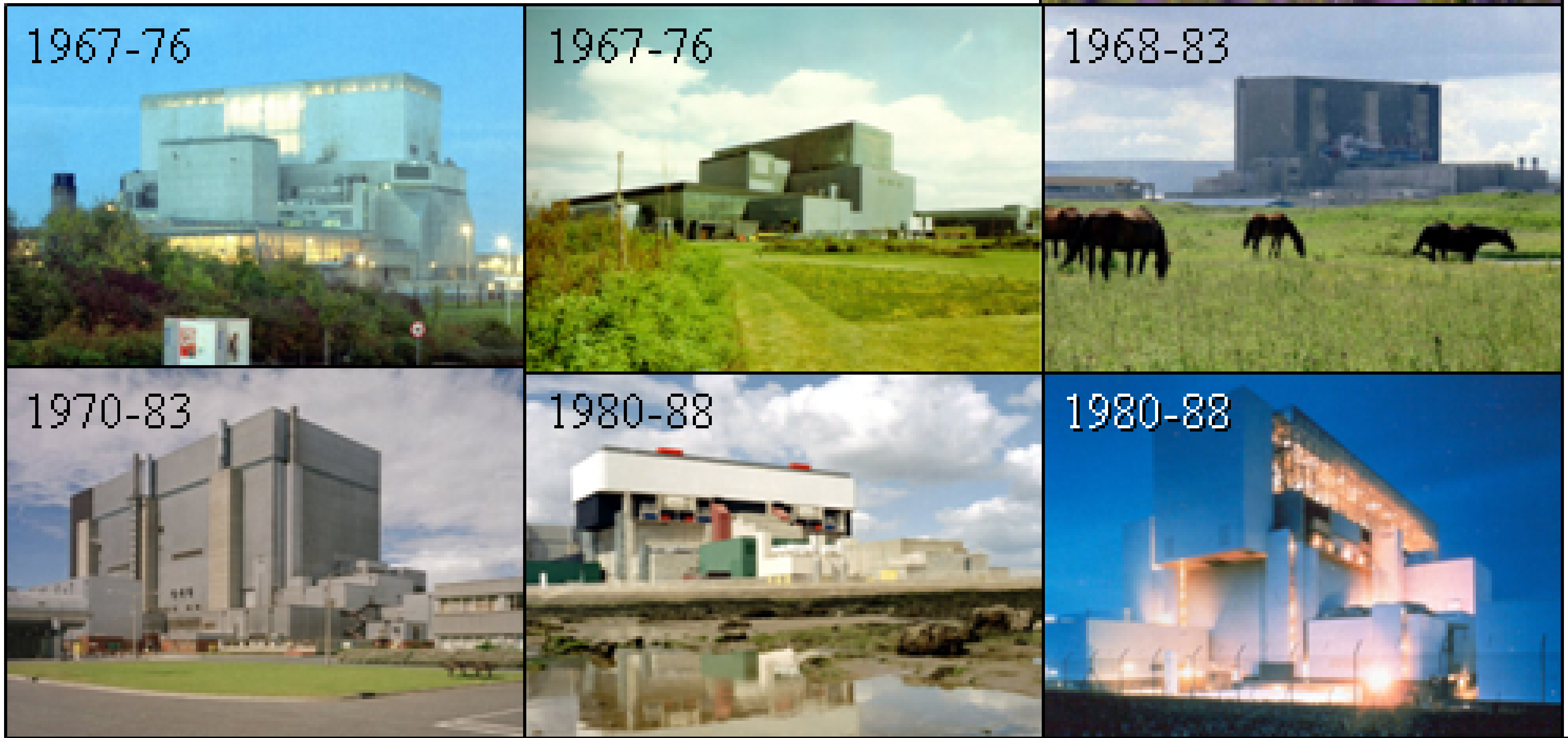
20/25 stainless steel fuel cladding before and after proton irradiation

AGR Plant Life Extension

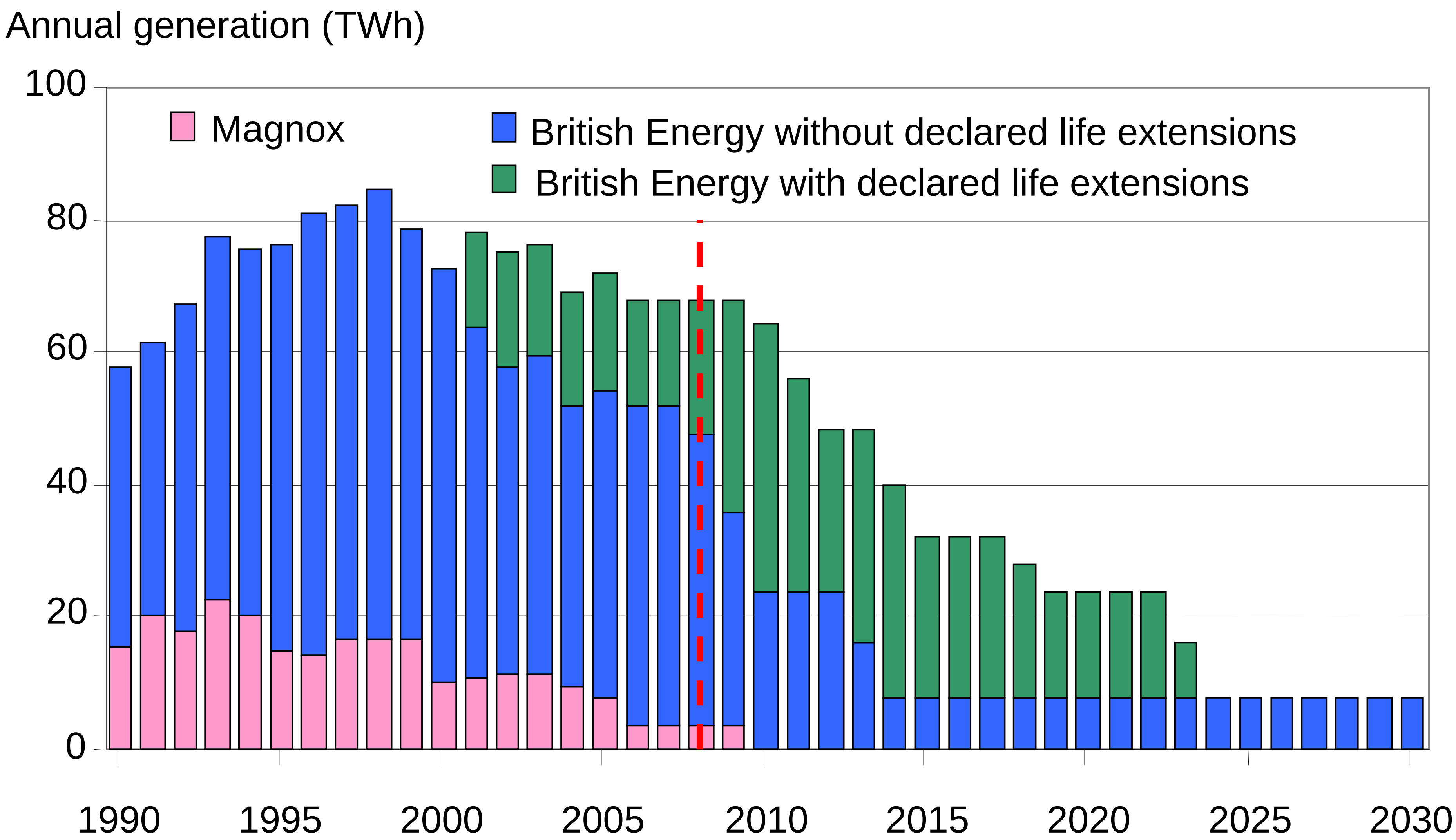
British Energy's AGR Reactors

(Construction Dates)

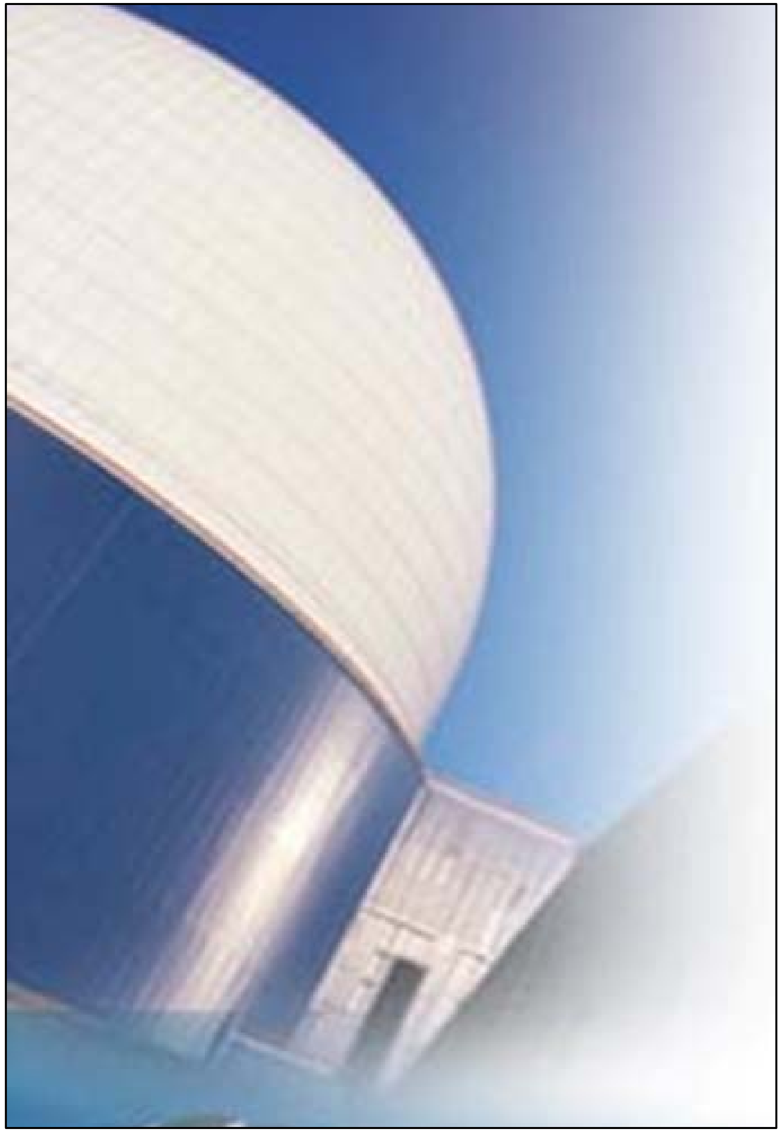




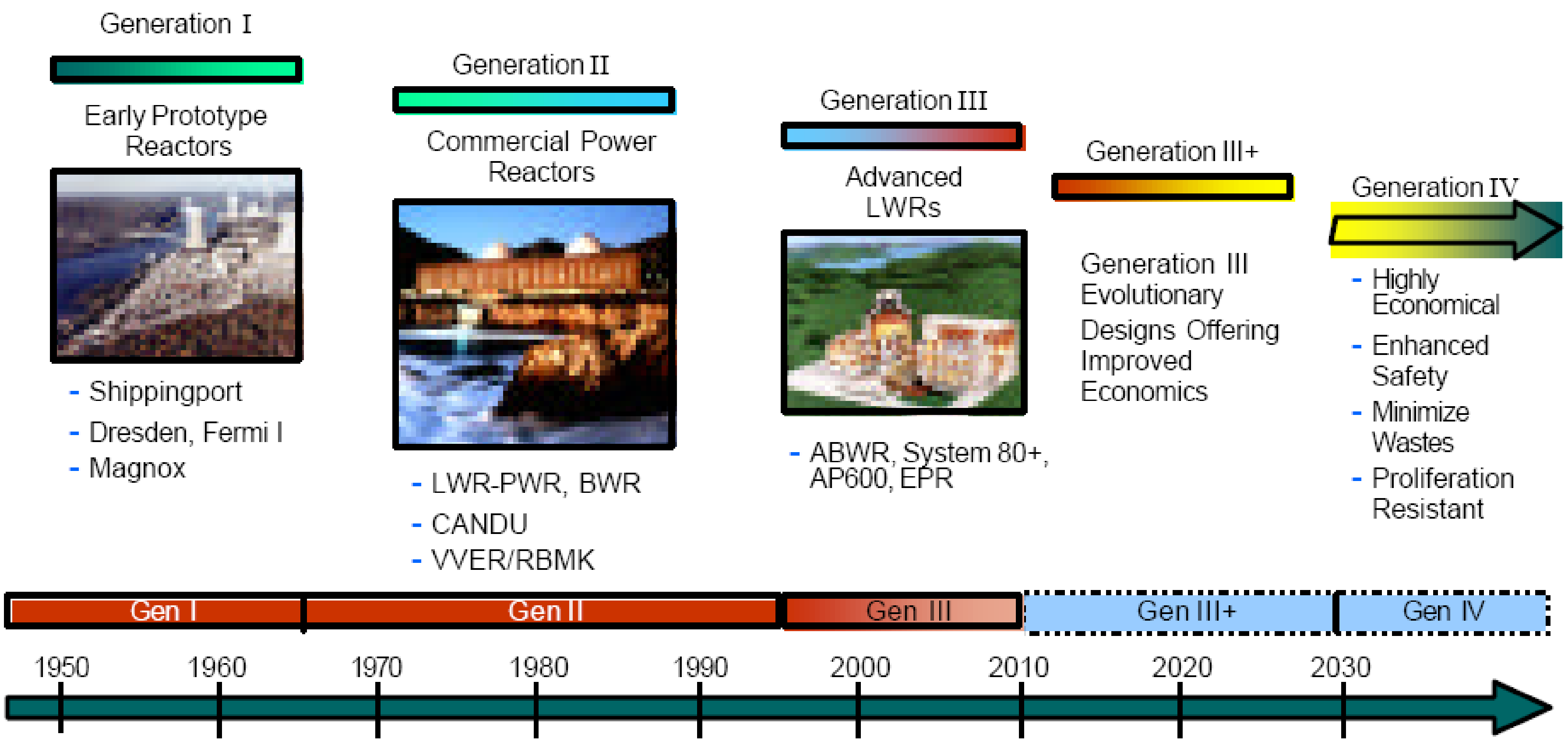
AGR Plant Life Extension



PWR Operation, Life Extension and New Build



Generation IV Reactor Designs



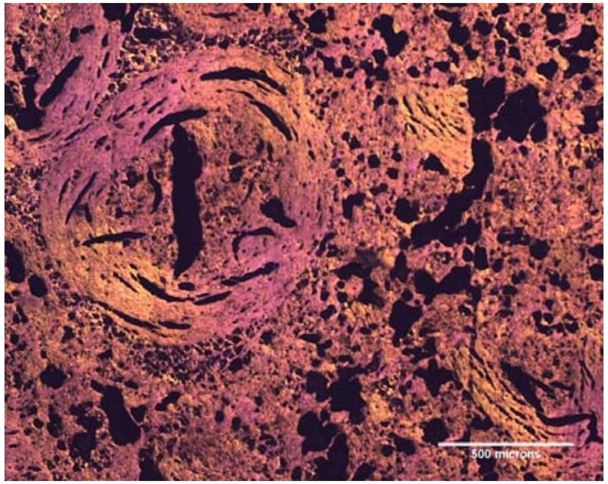
Fission Materials

The fission materials challenge

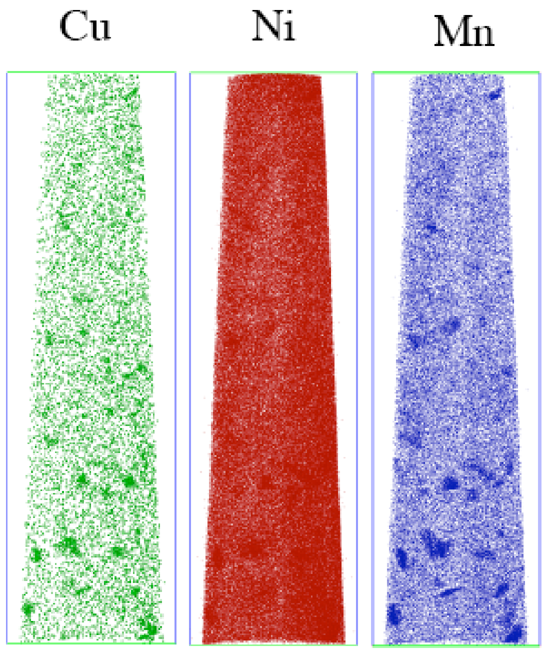
- Materials operate in extreme environments
  - High temperatures
  - Irradiation field
  - Corrosive environments

- Microstructural changes in service from the atomic scale upwards influence component performance

- The regulatory environment within the UK is non-prescriptive
  - requires a mechanistic approach to predict component

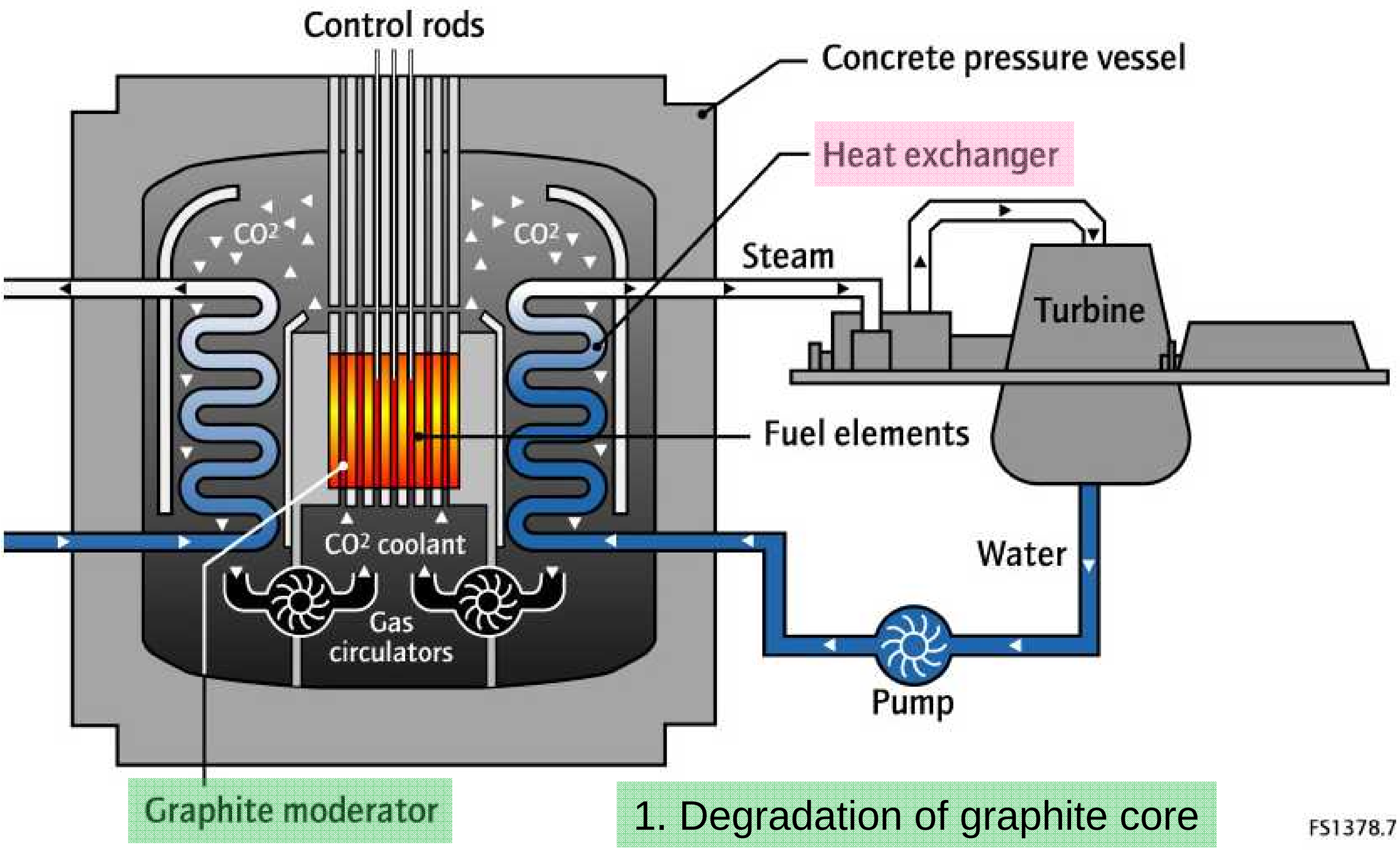


Microstructure of AGR graphite



Cu-rich clusters observed in 3D Atom Probe, Odette, 2004

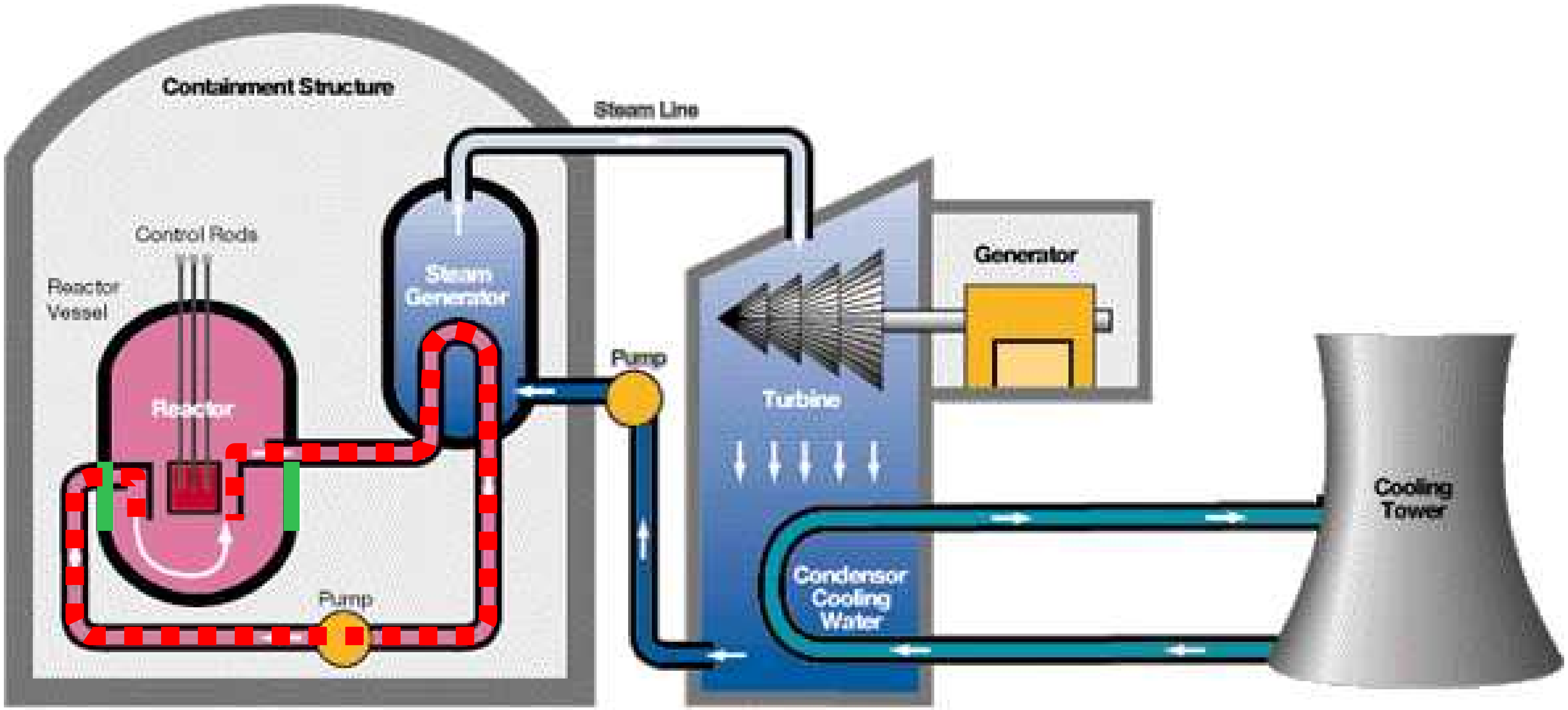
AGR Plant Life Extension



1. Degradation of graphite core

2. Degradation of high temp. welds

PWR Plant Issues



3. Irradiation embrittlement of RPV

4. Environmentally assisted cracking

Fission Materials

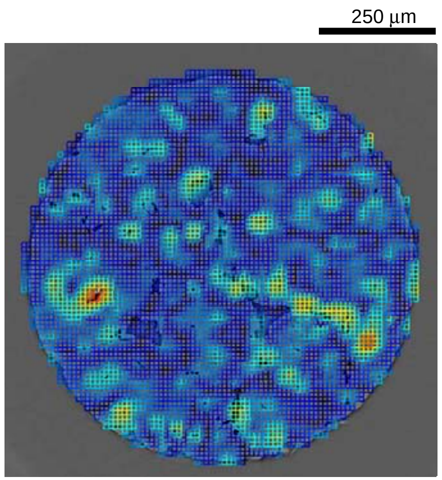
The fission materials challenge

		High Temperature	Neutron Irradiation	Oxidation / Corrosion
AGR	Graphite Core	✓	✓	✓
	Boiler Welds	✓	✗	✓
PWR	RPV Embrittlement	✓	✓	✗
	Env. Ass. Cracking	✓	(✓)	✓

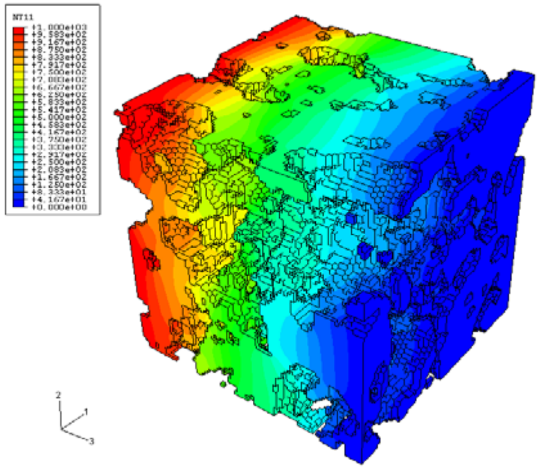
AGR Plant Life Extension

1. Degradation of AGR graphite core

- During service the microstructure, properties and stress state of the graphite core change due to the combined effect of:
  - Fast Neutron irradiation
    Changes in dimension, physical and mechanical properties
  - Radiolytic oxidation
    Changes in density (weight loss), physical, elastic properties and strength
  - Irradiation creep reduces internal stresses generated by dimensional change



Distribution in thermal expansion within AGR graphite (image correlation + tomography)



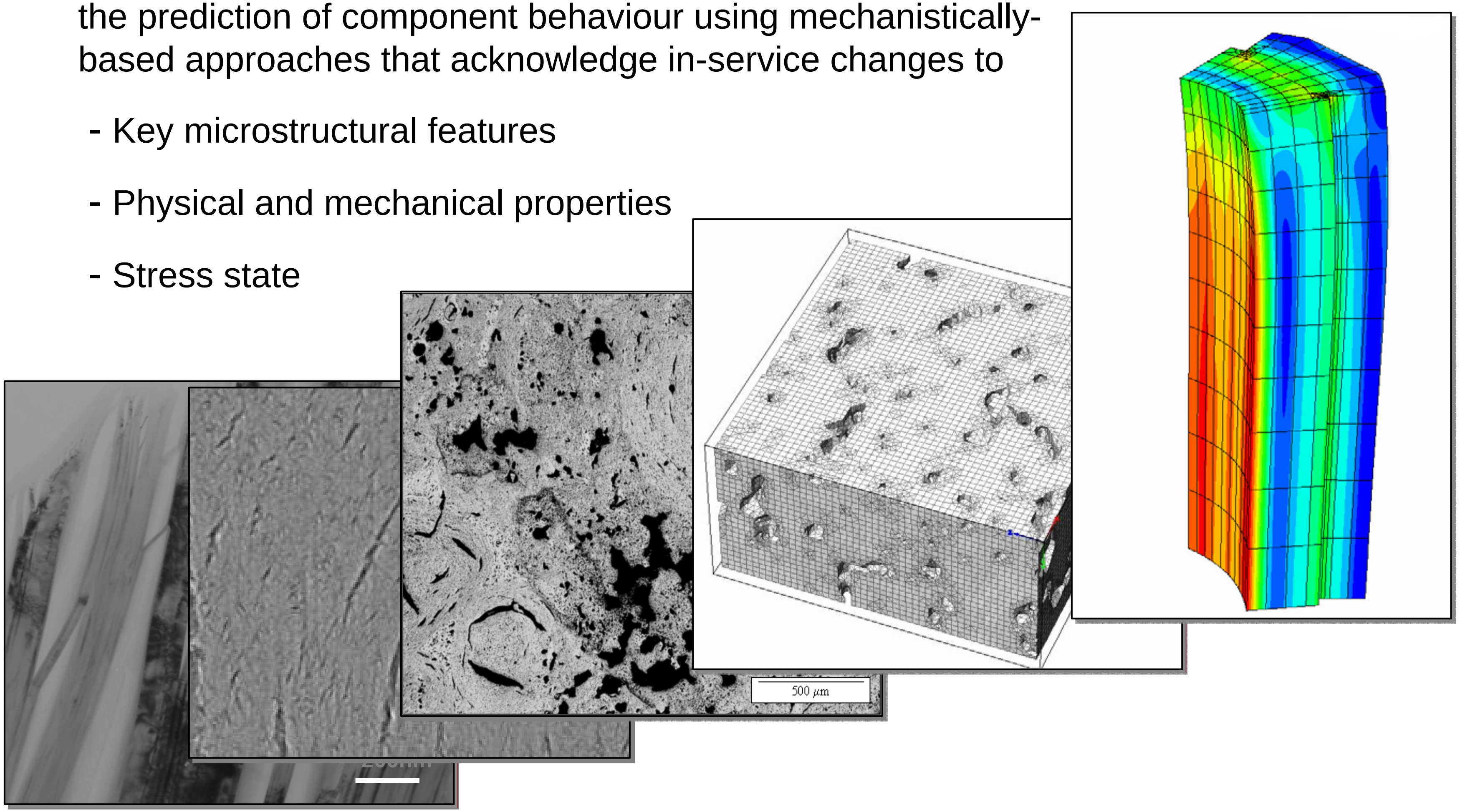
Predicted temperature distribution in AGR graphite sample (tomography + FEA)

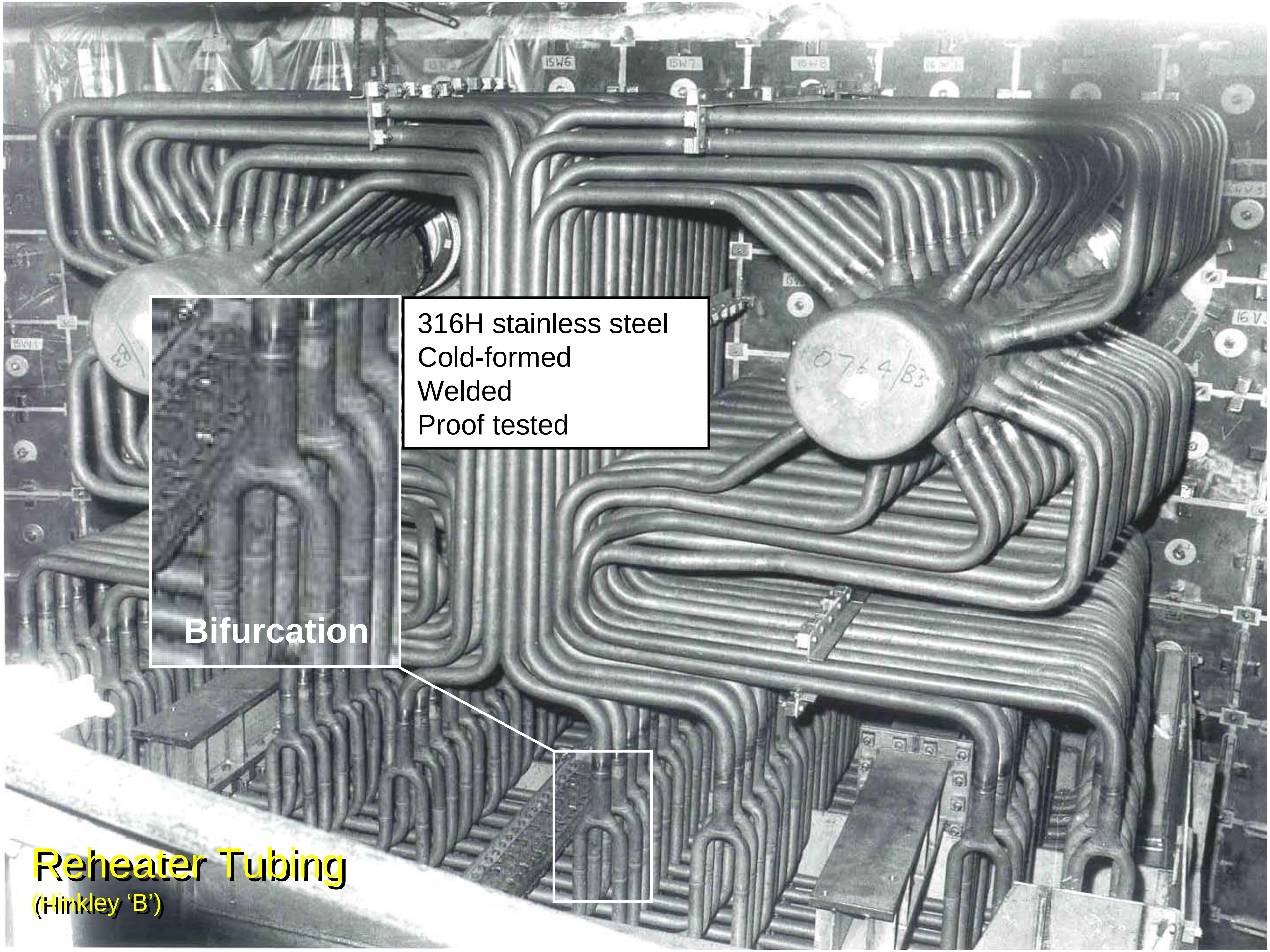
AGR Plant Life Extension

1. Degradation of AGR graphite core

• The materials challenge includes
the prediction of component behaviour using mechanistically-based approaches that acknowledge in-service changes to

- Key microstructural features
- Physical and mechanical properties
- Stress state

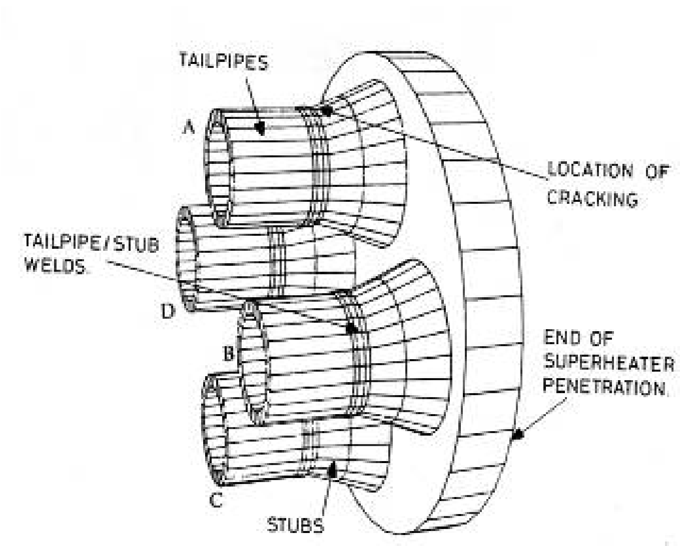


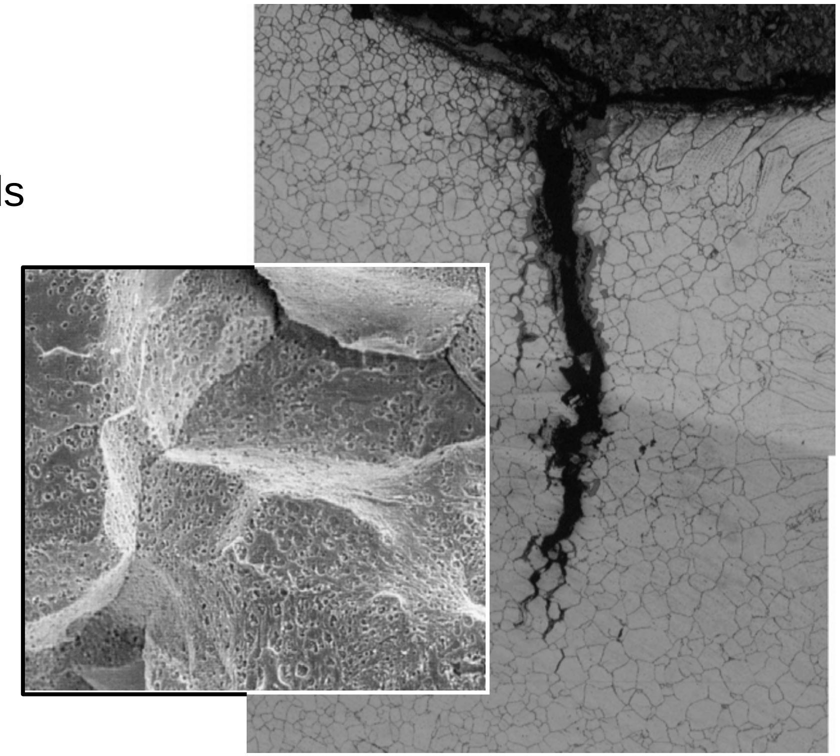

316H stainless steel
Cold-formed
Welded
Proof tested
Bifurcation
Reheater Tubing
(Hinkley 'B')

AGR Plant life extension

2. Degradation of high temperature welds

- Degradation mechanism relates to:
  - Accumulation of creep strain due to relaxation of weld residual stresses
  - Formation of grain boundary creep cavities within the heat- and strain-affected zone of non-stress relieved welds
  - Linkage of cavitation leads to micro and then macrocracks





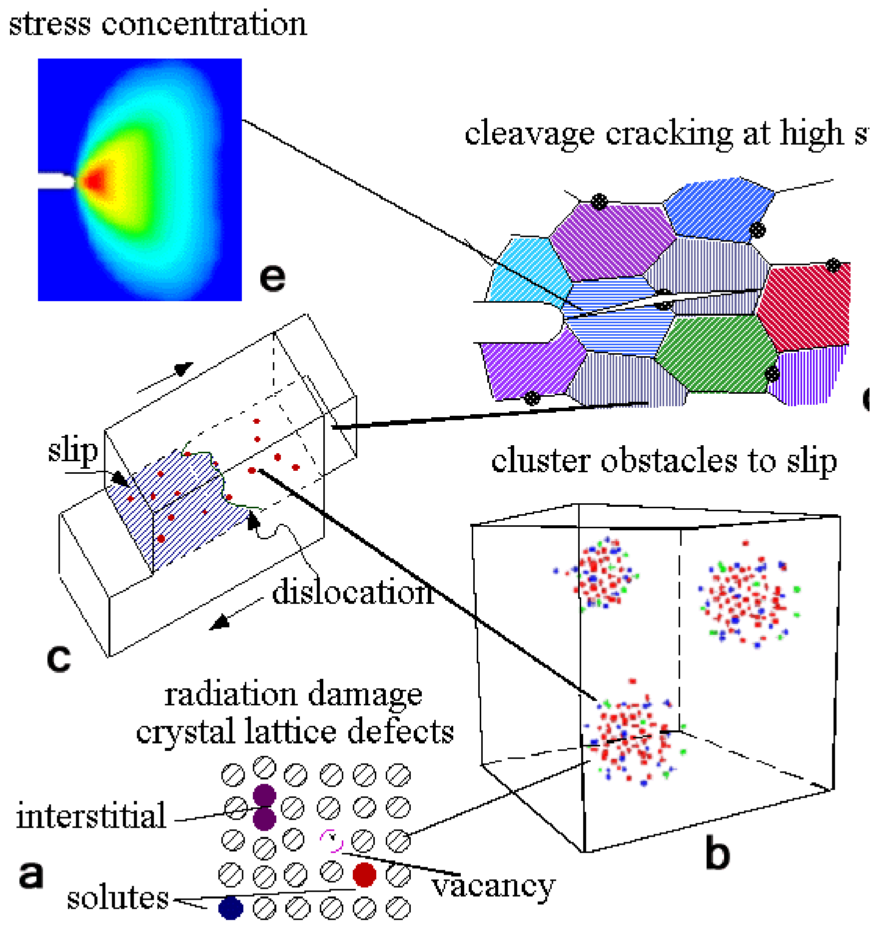
AGR Plant Life Extension

2. Degradation of high temperature welds

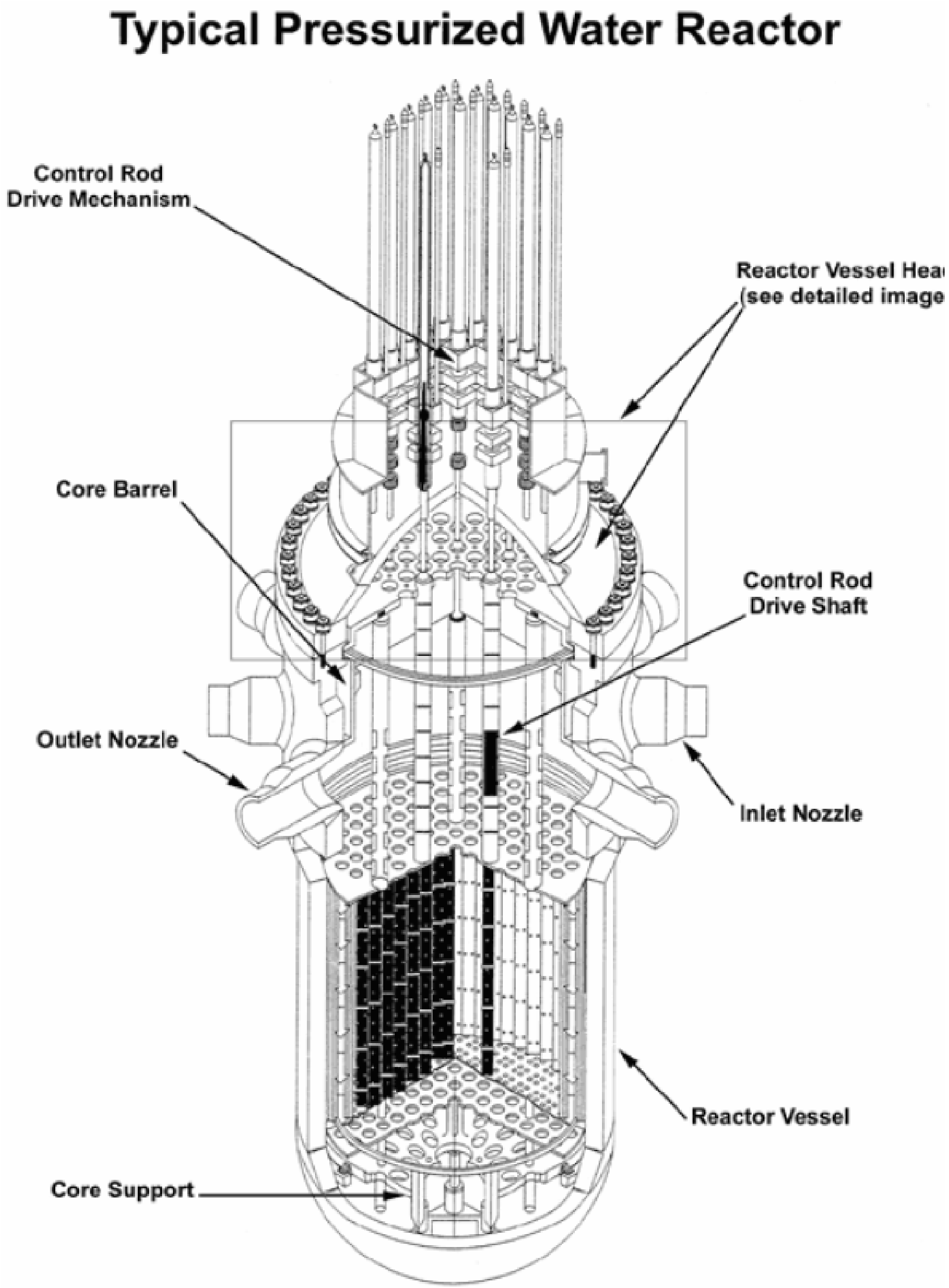
- The materials challenge includes
  - Measurement, modelling and treatment of residual/secondary stresses and associated strains
  - Long-term effects of ageing, irradiation, history (manufacturing and in-service) on creep ductility
  - Creep-fatigue damage evaluation (initiation)
  - Creep-fatigue crack assessment (growth)
  - Multiaxial stress effects creep ductility and consequent effect on fracture toughness (constraint)

PWR Plant Issues

3. RPV Embrittlement

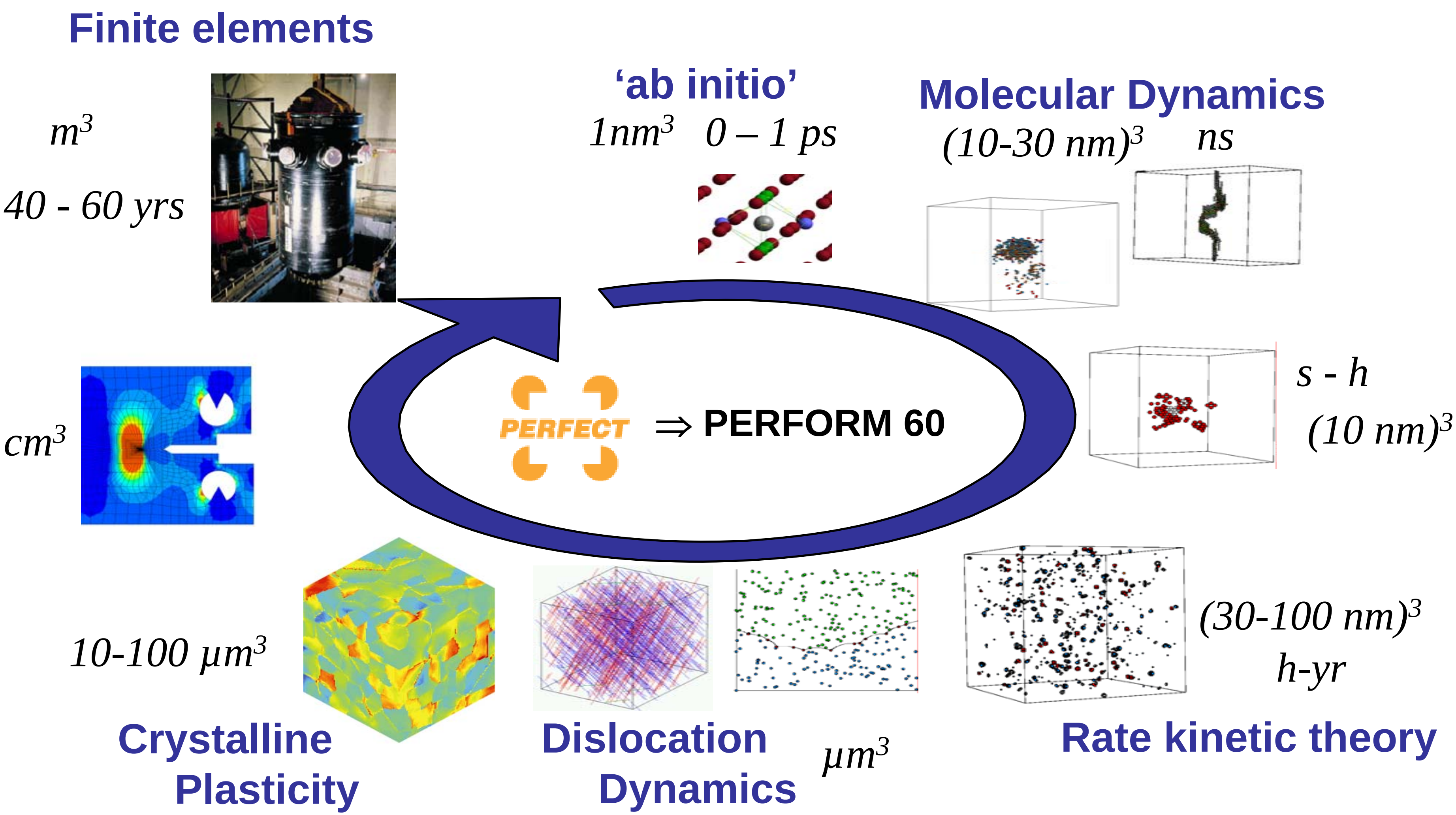


Odette & Lucas, 2001



PWR Plant Issues

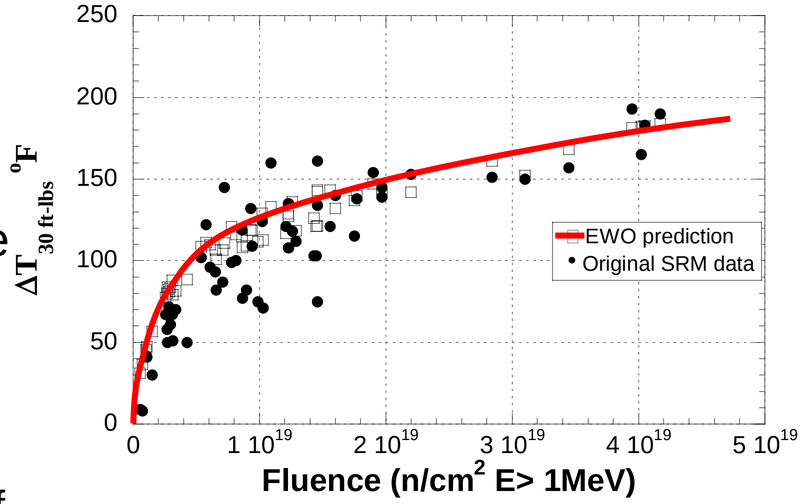
3. RPV Embrittlement

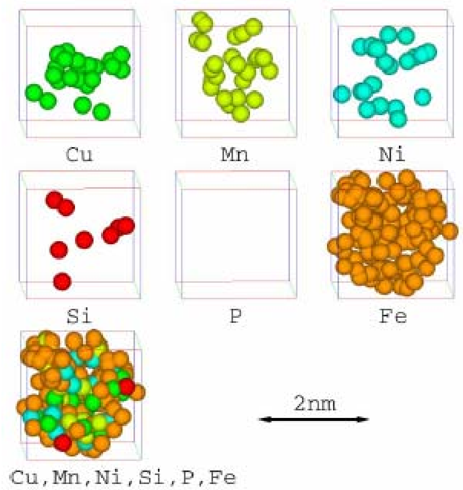


PWR Plant Issues

3. RPV embrittlement

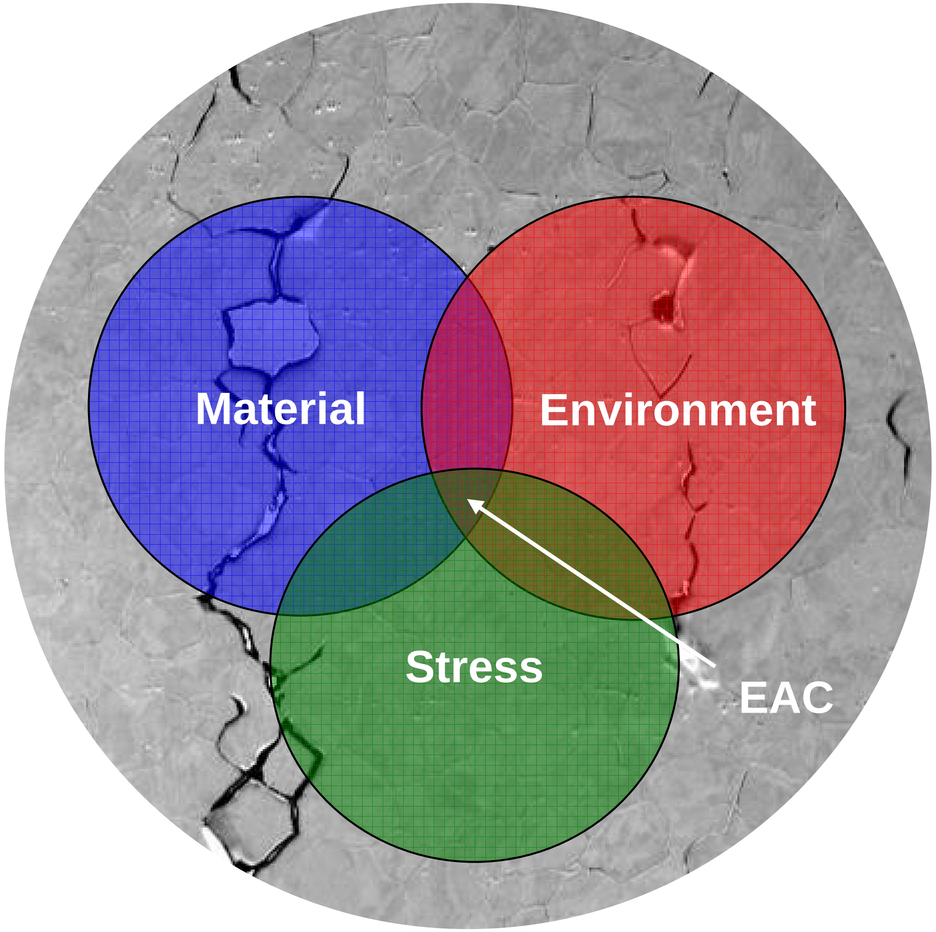
- The materials challenges include:
  - The measurement and modelling of neutron irradiation on the microstructure and properties of RPV materials
    - Development of mechanistically based correlations that predict embrittlement of operating vessels, e.g. LWRs in the USA
    - High resolution microscopy and atom probe studies to assess so-called “late-blooming phase” development
    - Development of multi-scale models that:link atomic-scale damage to component properties

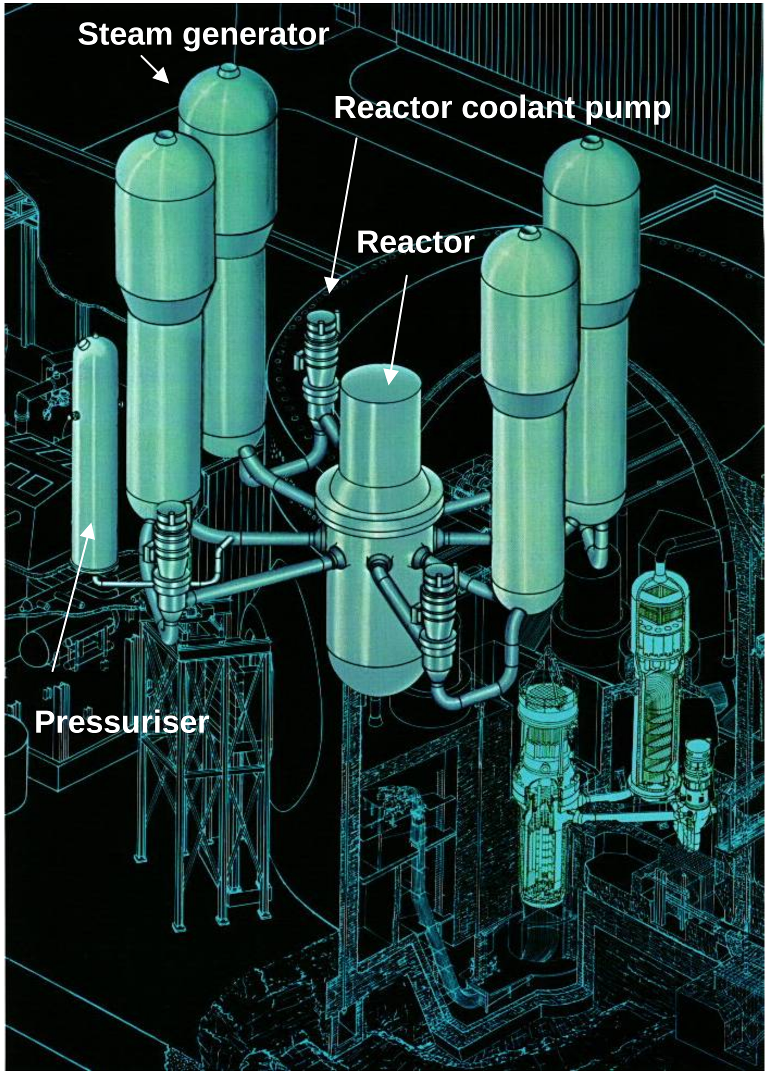




PWR Plant Issues

4. Environmentally-assisted cracking

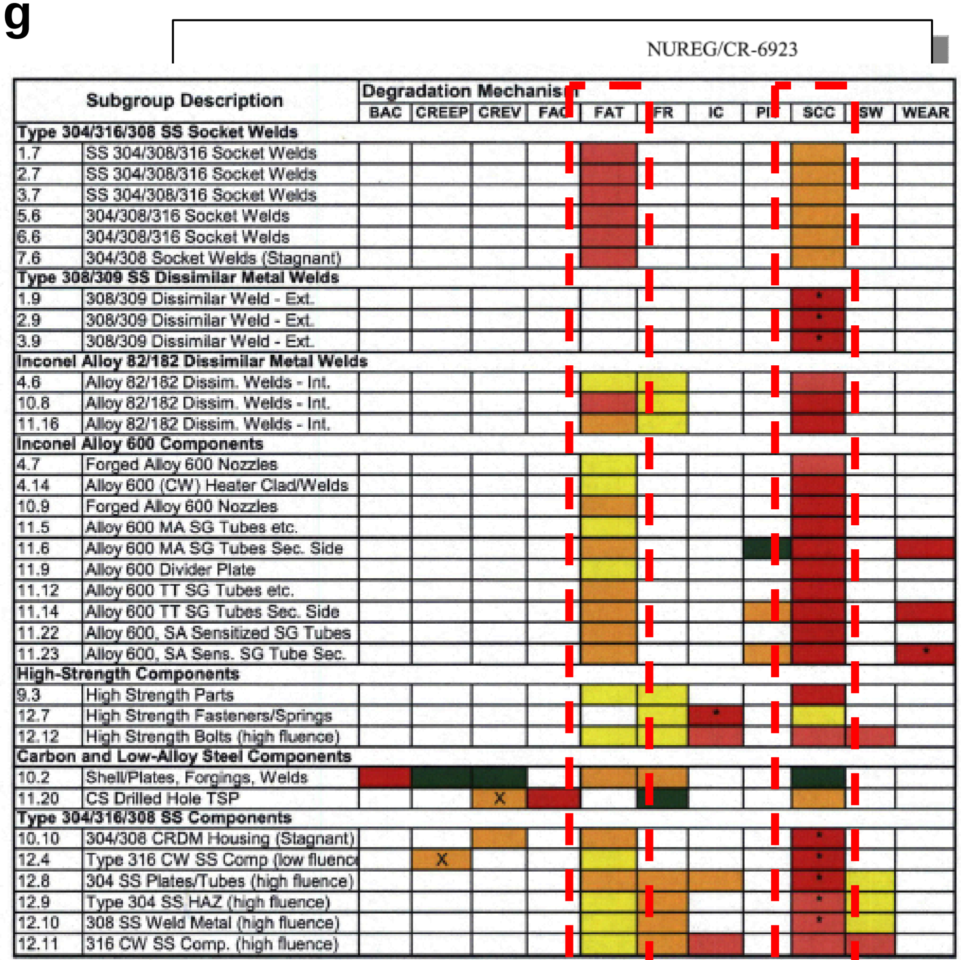




PWR Plant Issues

4. Environmentally-assisted cracking

- In depth assessment of materials degradation of PWR components undertaken in 2006
- Expert Panel assessed ~ 50 groups, ~350 components and 11 degradation mechanisms
- Highest priority issues ranked:
  - Susceptibility index
  - State of current knowledge
- Many of the highest priority issues related to EAC in PWR water



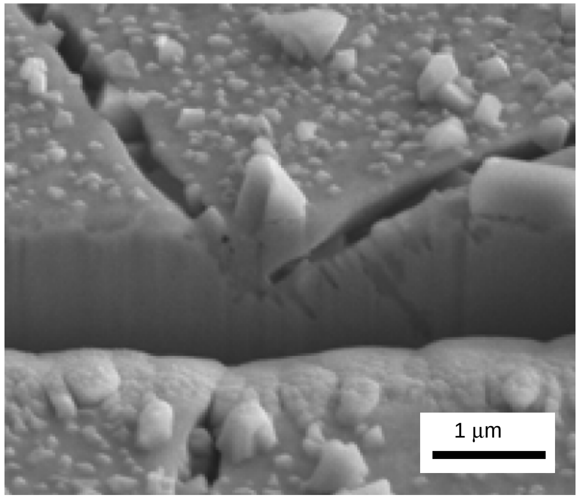
NOTES: * Susceptibility at color interface with one or more scores higher than this interface; * Susceptibility inside color box with one or more scores higher than color box interface.

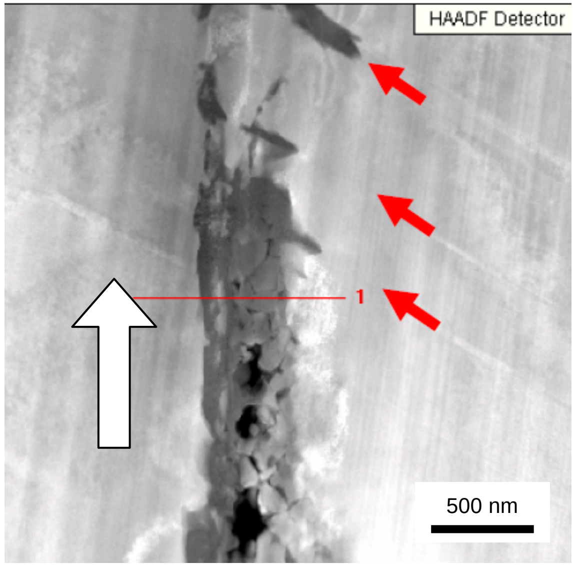
Figure 3.6 Modified Rainbow Chart Showing Red Subgroups in PWR Reactor Coolant System

PWR Plant Issues

4. Environmentally-assisted cracking

- The materials challenges include:
  - development of improved mechanistic understanding and predictive models
    - SCC in non-sensitized stainless steels where cold work increases susceptibility
    - Corrosion-fatigue in high temperature water
    - Irradiation-assisted SCC including the effect of radiolysis, deformation mechanisms and sensitisation
    - Non stress-relieved welds, including dissimilar metal welds





SCC crack in CW 304 stainless steel

Fission Materials

Key lessons

- Nuclear graphite
  - Understanding the interaction between changes in microstructure, stress state and properties has improved predictive capability
- Boiler Welds
  - Understanding distribution of residual stress and strain on high temperature welds has improved assessment of where and when degradation will occur
- RPV Embrittlement
  - Improved mechanistic understanding at the atomic level has improved predictive methodologies that influence the operation of PWR plant.
- EAC
  - Experimental approach has provided valuable data to assess plant susceptibility but highlights need for mechanistic understanding of cold work, corrosion-fatigue and irradiation effects on EAC.

Fission Materials Roadmap

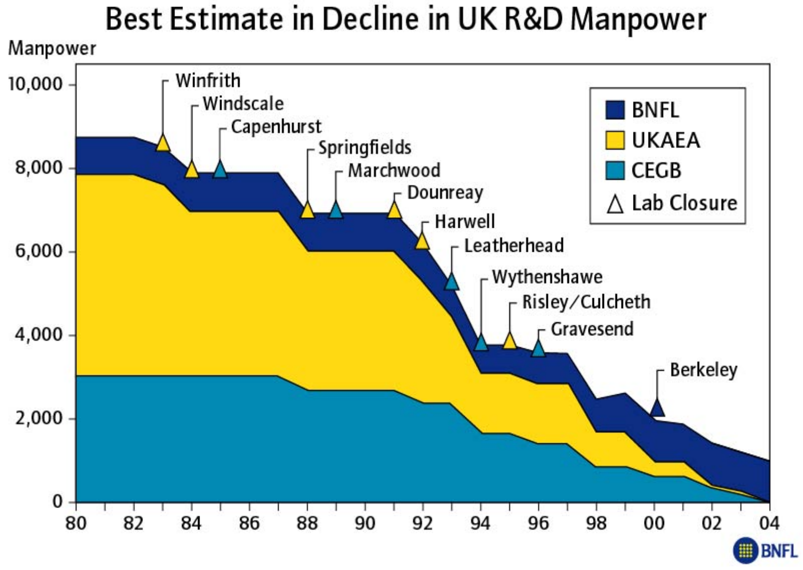
National Nuclear Goals	Short-term (2009-2015)			Medium-term (2015-2020)			Long-term (2020-2060)		
	Life ext'n AGRs	Selection of Gen III+ reactors	Decom. Reproc. Storage Disposal	Emergent issues Gen III+ reactors	Design & materials for Gen IV	Decom. Reproc, Storage Disposal	Life ext'n Gen III+ issues Gen IV	Design & materials for fusion reactors	Decom. Reproc, Storage Disposal.

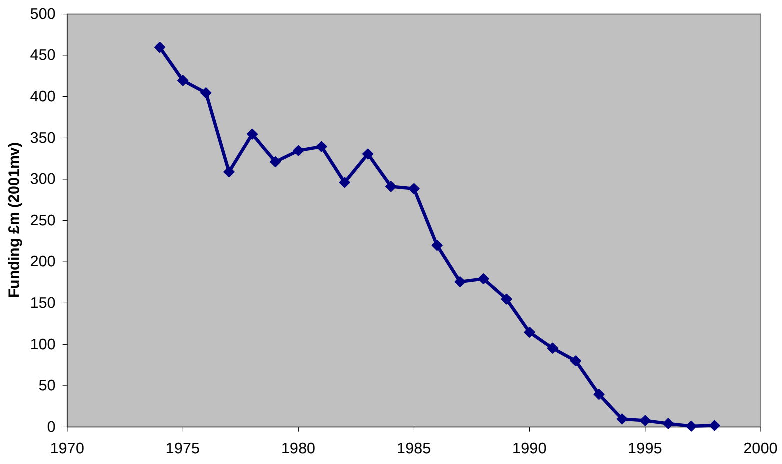
U.K. Nuclear Research Capability

Fission materials skills

- Significant skills challenge to support the nuclear power renaissance
- The decline in U.K. nuclear R&D manpower has led to an impoverished research community.
- Nuclear materials research has not been supported within nuclear organisations

To establish a stable critical mass of research expertise within key technology areas with the necessary continuity of support





U.K. Nuclear Research Capability

Fission materials facilities

- Significant capability challenge to support the nuclear power renaissance
- The closure of U.K nuclear research laboratories has led to relatively few key facilities which are scattered widely across the U.K. – fragmentation.
- The use of fragmented and expensive facilities has reduced – utilisation.

To establish a network of key facilities and access arrangements necessary to deliver solutions to priority nuclear materials research issues

U.K. Nuclear Research Capability

What has changed recently?

- Clear benefit from developments in:
  - New training and research programmes
    - Postgraduate education (NTEC)
    - Research Council funding (KNOO, EngD)
    - Industry-University partnerships,
      e.g. NDA/NNL URAs, BE University Partnerships)
    - Naval propulsion programme
  - Facilities development including
    - Establishment of UK NNL
    - Manchester-NDA £20m investment in new facilities in study radiation sciences

Fission Materials

Meeting the challenge

- Increase and maintain funding for fission materials R&D to address short, medium and long-term national nuclear goals

- Build and sustain partnership between academic institutions, industrial stakeholders and Government to:
  - Provide strategic focus to ensure nuclear goals are met through targeted R&D
  - Enhance the aggregation and utilisation of existing national nuclear facilities and the creation of new facilitates, where necessary
  - Connect the best materials scientists and structural engineers within the UK and overseas to deliver and deploy research outputs in a timely manner
  - Ensure benefit gained from knowledge transfer
  - Expand skills development and career pathways for nuclear materials scientists and structural engineers

- Enhance international cooperation in research and skills development through European Framework programmes and targeted strategic links with Nuclear Centres of Excellence worldwide