British Energy

Graphite Research and Development

A.G. Steer
Graphite Core Project Team
Lifetime Management Branch

Graphite Research and Development

- Business Needs
- Strategic Funded Projects
- Direct Funded Work
- Magnox Projects
- BE/Magnox Collaboration
- Summary

Business Needs

- British Energy's business imperatives
  - **Operational excellence**
  - **Financial stability**
  - **Life extension**
- Leading to
  - Safe and reliable operation
  - Profitability
  - Long-term contribution to the energy needs of the UK

Business Needs

- Graphite Core Project Team's contributions
  - Maintain margins within the AGR core safety cases
  - Inspect and monitor the cores to provide relevant information about the effects of graphite degradation processes in a timely and cost effective manner
  - Improve understanding of core degradation processes and their consequences
  - Acquire material property data in advance of reactor operations

Business Needs

- Graphite Core Safety Cases are based on five legs:
  - Core and Component Condition Assessment (CCCA)
  - Damage tolerance
  - Inspection
  - Monitoring
  - Consequences
- Legs are constructed to be as independent of each other as possible

Business Needs

- New information
  - Material properties
  - Material property models
  - Fracture processes
- Validation
  - Whole core experiments

Business Needs

- Technique and Equipment Development
  - Core inspection
  - Monitoring
  - Material property measurements
  - Analytical methods for:
    - Static and seismic core models
    - Fuel and control rod movements
    - Stress analysis and structural integrity assessments

Strategic Funded Projects

- YAE 270 with a budget of:
  - £420k in FY06/07
  - ~£500k in subsequent FYs
- Build long-term relationships with academic centres specialising in
  - Fundamental crystal behaviour
  - Materials properties
  - Fracture
  - Assessment of monitoring data

Strategic Funded Projects

- Nuclear Graphite Research Group in the Material Performance Centre, The University of Manchester
  - Prof Andrew Sherry
  - Prof Barry Marsden
  - Dr James Marrow
  - Dr Paul Mummery
  - Dr Alex Fok
- University Post doctoral and Ph.D. Projects

Strategic Funded Projects

- Department of Chemistry, University of Sussex
  - Prof Malcolm Heggie
- Department of Engineering, University of Hull
  - Dr Gareth Neighbour
- Faculty of Engineering, University of Bristol
  - Prof David Smith
- Faculty of Engineering, University of Strathclyde
  - Dr Marcus Wheel
- University Post doctoral and Ph.D. Projects

Strategic Funded Projects

- Atomistic Modelling
  - First principles study of dislocations in graphite, GRA/GNSR/6008
  - Equivalent irradiation temperature and damage in graphite, GRA/GNSR/6010
  - Development of a theoretical approach to graphite properties, GRA/GNSR/6021
  - Fundamental Approach to Irradiation Creep in Graphite, GRA/GNSR/6038 – ***NEW***

Strategic Funded Projects

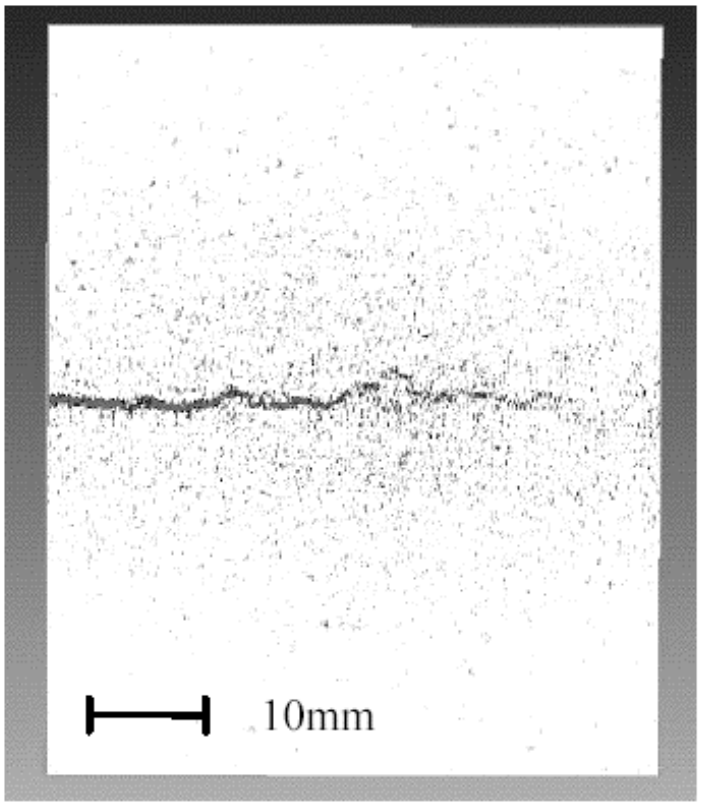
- Atomistic Modelling
  - Computer predictions from first principles of all graphite crystal elasticity terms – No need to invoke Van der Waal's forces
  - Revised understanding of crystal damage which explains low temperature irradiation behaviour of dimensional change and Wigner stored energy
  - Identification of high temperature irradiation dimensional change mechanism

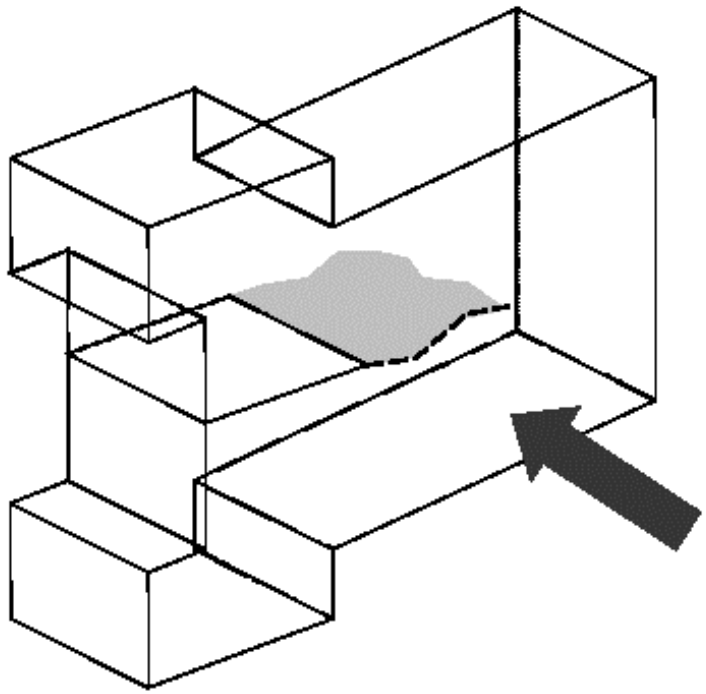
Strategic Funded Projects

- Micro-structural and Fracture Investigations
  - Modelling crack growth in complex heterogeneous brittle materials, GRA/GNSR/6007
  - Measurement of micro-structure strains in graphite, GRA/GNSR/6022
  - Micro-structural modelling of the elastic and strength properties of nuclear graphite, GRA/GNSR/6023
  - Experimental investigation into the crack initiation process in nuclear graphite, GRA/GNSR/6029
  - Microstructure/property relationships in unirradiated and irradiated AGR nuclear graphite, GRA/GNSR/6034 – ***NEW***

Strategic Funded Projects

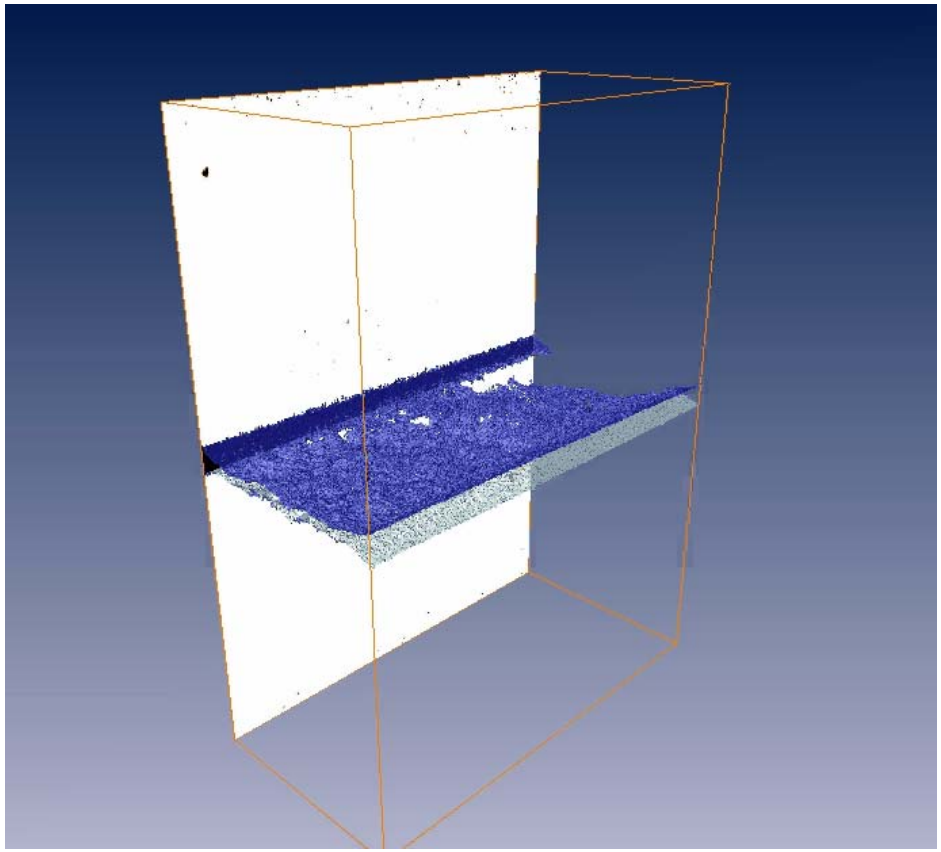
- Micro-structural and Fracture Investigations





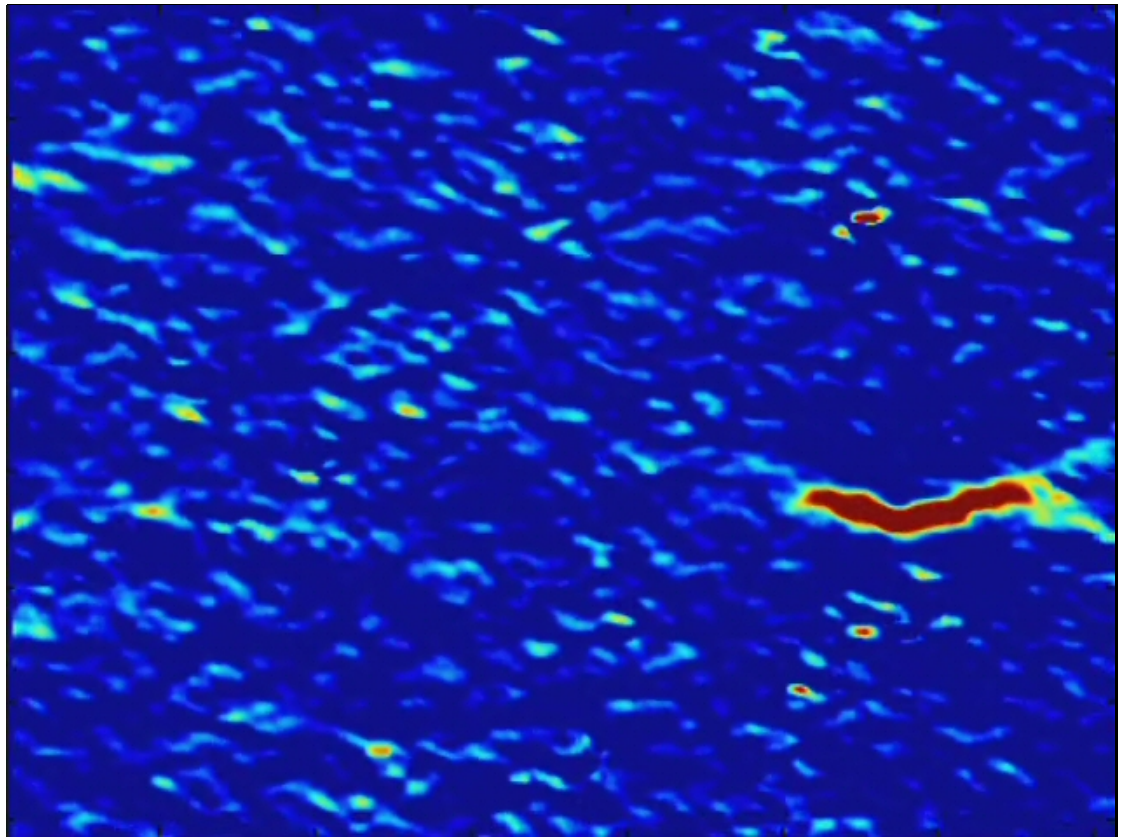
Strategic Funded Projects

- Micro-structural and Fracture Investigations



Strategic Funded Projects

- Micro-structural and Fracture Investigations



Strategic Funded Projects

- New and Improved Measurement Techniques
  - Feasibility study into the use of deep-hole drilling techniques to measure radial distributions of internal stress during in-core inspections of graphite fuel bricks, GRA/GNSR/6030
  - Feasibility study into the use of surface-hole drilling techniques to map internal brick stresses at the channel wall during in-core inspections of graphite fuel bricks, GRA/GNSR/6031
  - Scope for measurements on irradiated HTR graphite bricks, GRA/GNSR/6037 ***– awaiting proposal***

Strategic Funded Projects

- Dissemination of Information
  - Projects are expected to produce:
    - Interim reports
    - Final reports
    - External, refereed scientific papers
    - Contributions to conferences, seminars, technical specialist's meetings, e.g. INGSM, etc.
    - Presentations at Graphite Research Meetings
    - Presentations to the GCDMC for endorsement where appropriate

Direct Funded Work

- Review and assessment of irradiated sample measurements
  - Routine collection of trepanned samples from AGR core fuel bricks
  - Material property measurements
    - Density
    - Elastic modulus
    - Co-efficient of Thermal Expansion (CTE)
    - Strength
  - Development of new and improved techniques
  - Measurement of other material properties

Direct Funded Work

- Materials Test Reactor (MTR) programme
  - Accelerated ageing obtainable using high-flux reactor
  - Project objective is to provide data to improve the understanding of the future core component condition and assess plant lifetime.

Direct Funded Work

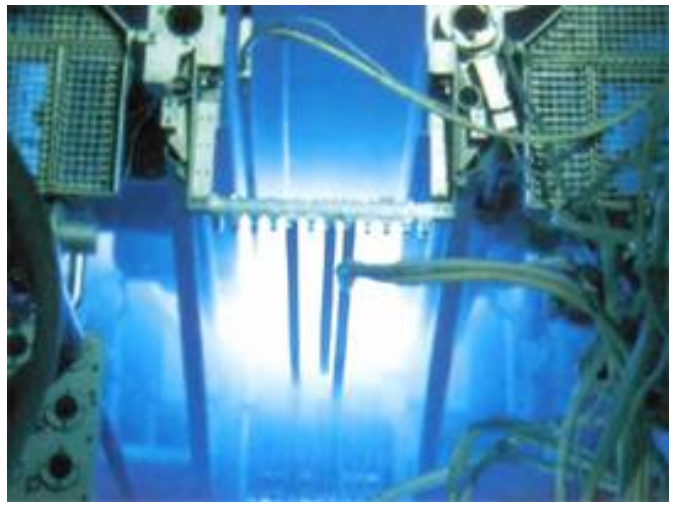
- Materials Test Reactor (MTR) programme
  - To do this the experiment must:
    - Extend the graphite material property database
    - Improve the understanding of graphite behaviour with combined oxidisation and irradiation, and creep
    - Produce results that are translatable to the AGR operational environment
    - Overlap with existing data
    - Produce data in time to provide maximum benefit

Direct Funded Work

- Materials Test Reactor (MTR) programme
  - Pilot irradiation has been sanctioned
  - Objectives of pilot irradiation are
    - Demonstrate experiment design & control of irradiation conditions
    - Confirm ability to interpret MTR results to AGR conditions
    - Cross-check with previous MTR experimental programmes

Direct Funded Work

- Materials Test Reactor (MTR) programme
  - Irradiation facility at NRG, Petten has been selected
  - Experiment design and sample collection underway
  - Start of irradiation planned for September 2007

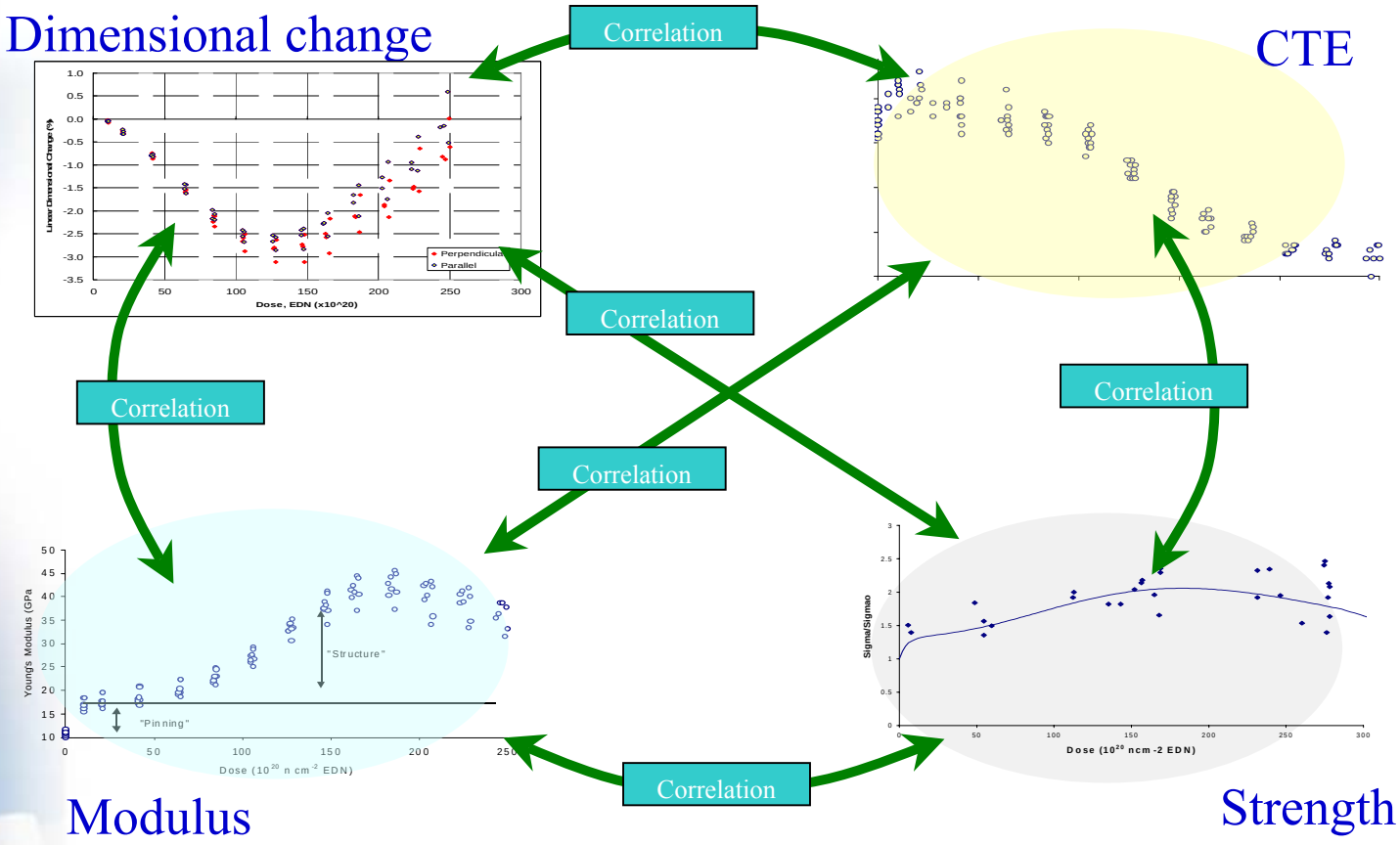


Direct Funded Work

- Methods development
  - Revised material property modelling
    - Driven by fundamental processes
      - Crystal dimensional change
      - Closure of porosity
      - Generation of micro-cracks
    - Creep model with recoverable strain

Direct Funded Work

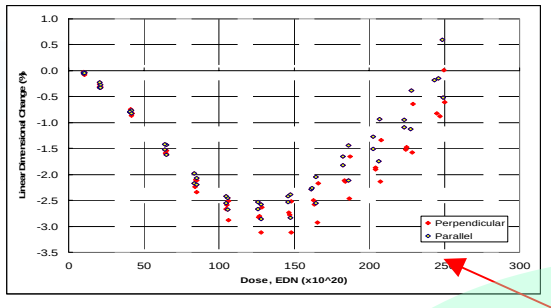
- Current material model



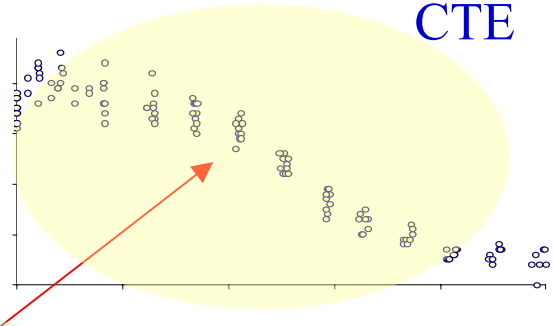
Direct Funded Work

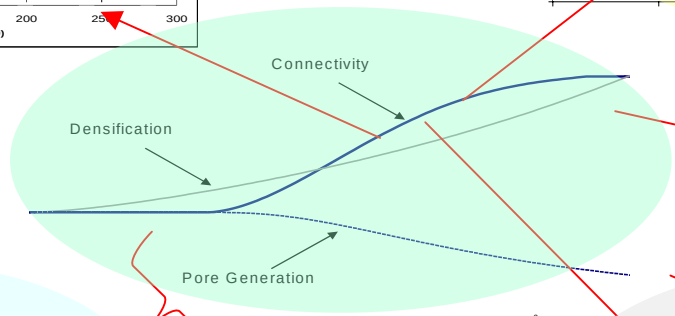
- Proposed material model

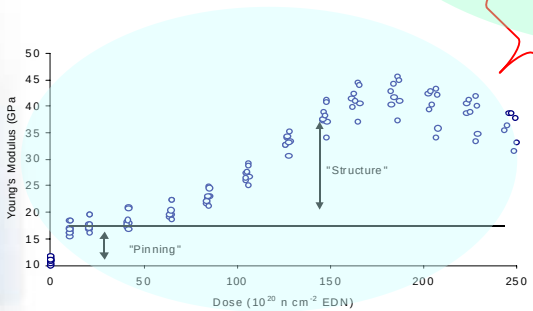
Dimensional change



CTE



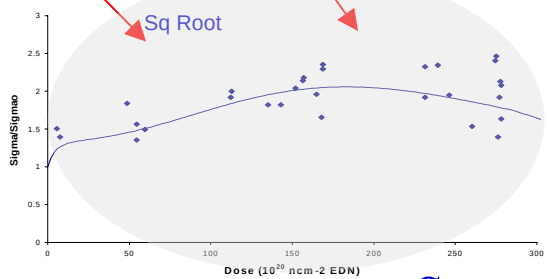




Modulus

Linear

Sq Root

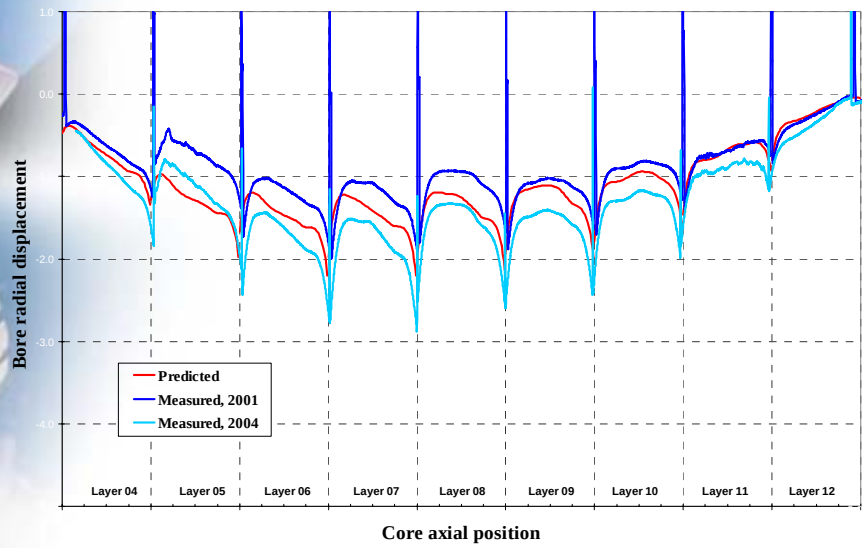


Strength

Direct Funded Work

- Methods development
  - Realistic and best-estimate stress analysis of graphite components that include:
    - Fuel End Dose Depressions
    - Concentric and eccentric fuel in channel
    - Effects of methane holes and bore cracks
    - Development of a general probabilistic assessment method

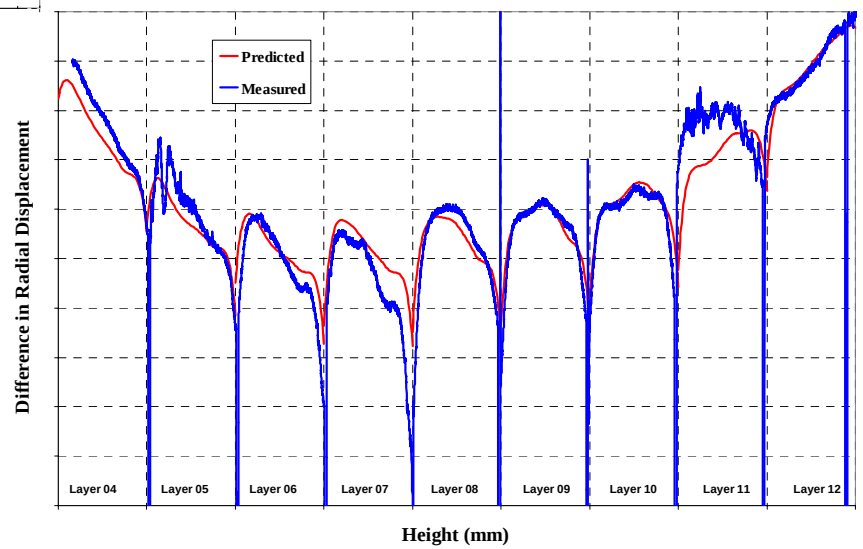
Direct Funded Work



- Channel Bore Diameter Profiles

▲Comparison with measured diameters in 2001 and 2004

Comparison with difference in measured diameters between 2001 and 2004►



Direct Funded Work

- Core inspections
  - Achieved
    - Improved reliability
    - Reduced dose during trepanning
    - Ability to trepan high weight loss samples
    - Ability to TV in CO_2 atmosphere
  - Under consideration
    - Ability to measure channel diameter profiles in CO_2 atmosphere
    - Volumetric survey using eddy currents

Direct Funded Work

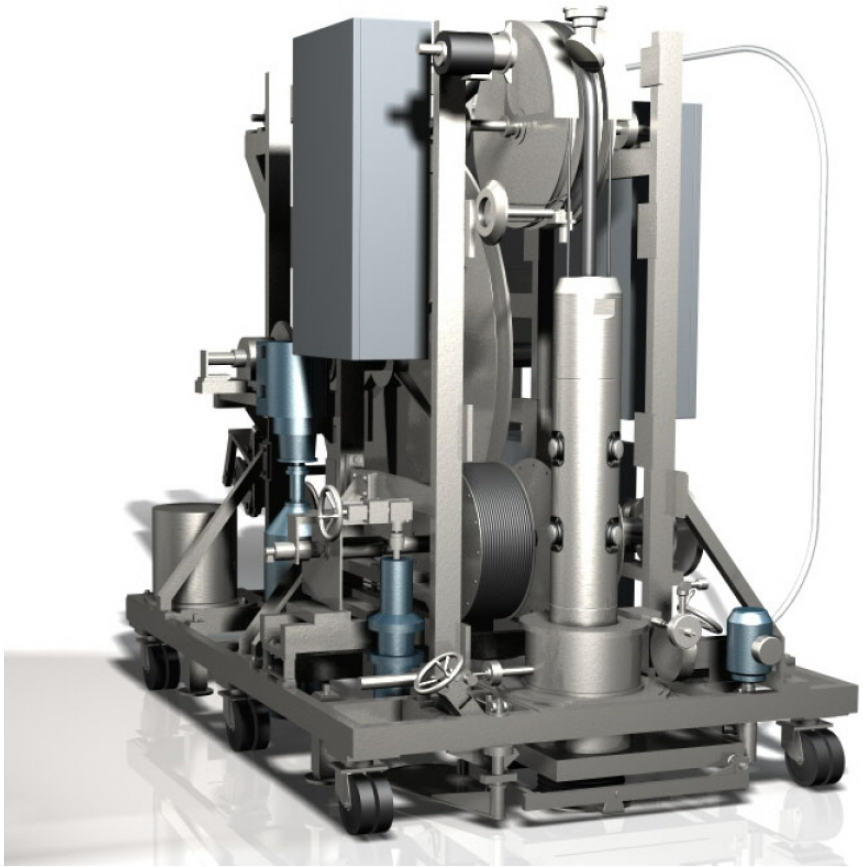
- Channel Bore Measurement Unit (CBMU)

Direct Funded Work

- Developed Graphite Trepanning Tool and Hoist

Direct Funded Work

- New Graphite Trepanning Tool and Hoist



Direct Funded Work

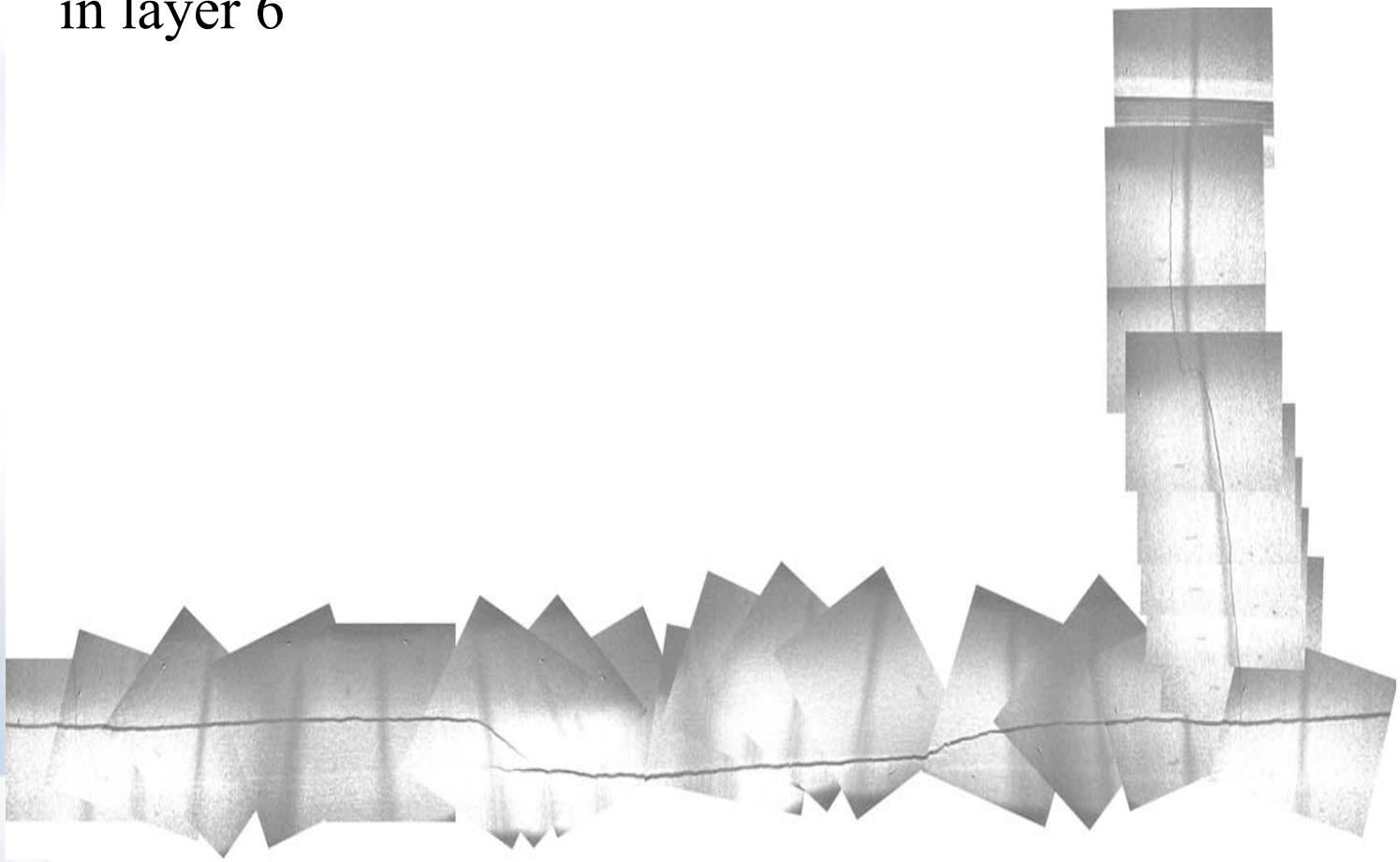
- Core condition monitoring
  - Class 1 parameters identified:
    - Fuel Grab Load Trace
    - Control rod movements
    - Change in channel power discrepancy
  - Investigation levels have been defined
  - Monitoring Assessment Panels established at Hinkley Point B and Hunterston B
    - Quarterly meetings which review reactor monitoring data with a view to inferring the condition of the graphite core (cracked bricks, channel straightness)

Direct Funded Work

- Fuel Grab Load Trace: Hunterston B R4 2688 crack in layer 6

Direct Funded Work

- Fuel Grab Load Trace: Hunterston B R4 2688 crack in layer 6

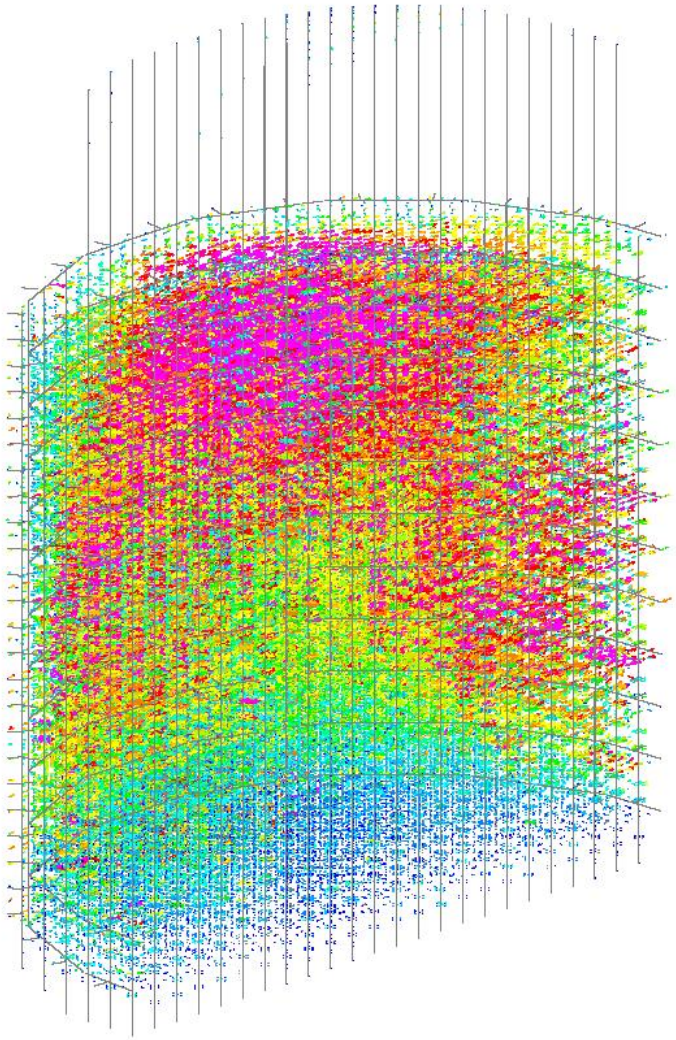


Direct Funded Work

- Whole core modelling and validation
  - Whole core static and dynamic models of AGR cores
    - Double axial cracked fuel bricks
    - Full/half symmetry, 3-D core models
    - Realistic core driving loads during normal operation
    - Combined graphite core and support/restraint structure in seismic models
  - Methods to assess
    - Freedom for control rod insertion and fuel stringer movements
    - Onset of inter-element gapping

Direct Funded Work

- Seismic model
  - 3-D, half symmetry
  - Total number of nodes >280,000
  - Number of beams, springs and dampers >250,000 each
  - Execution times of 24-36 hours
- Static models are comparable in size and scope

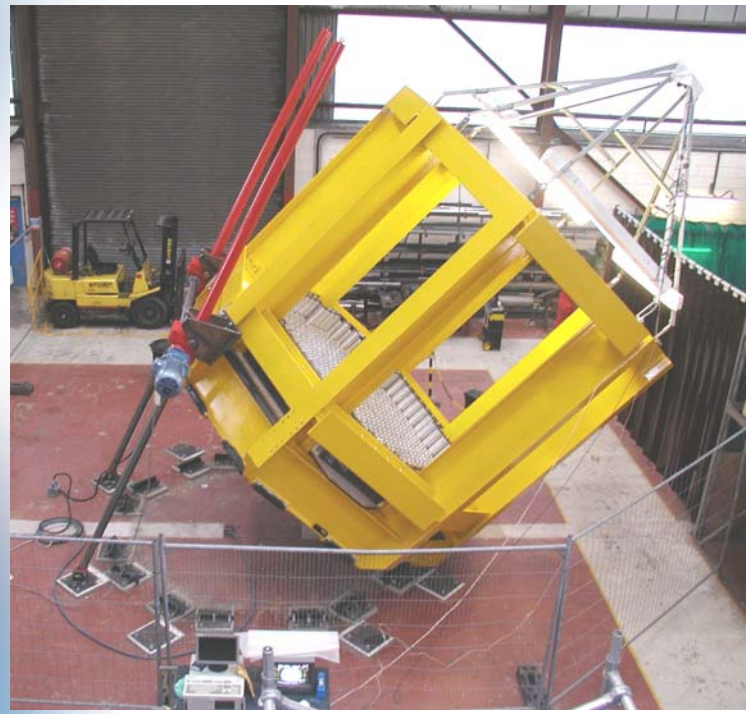


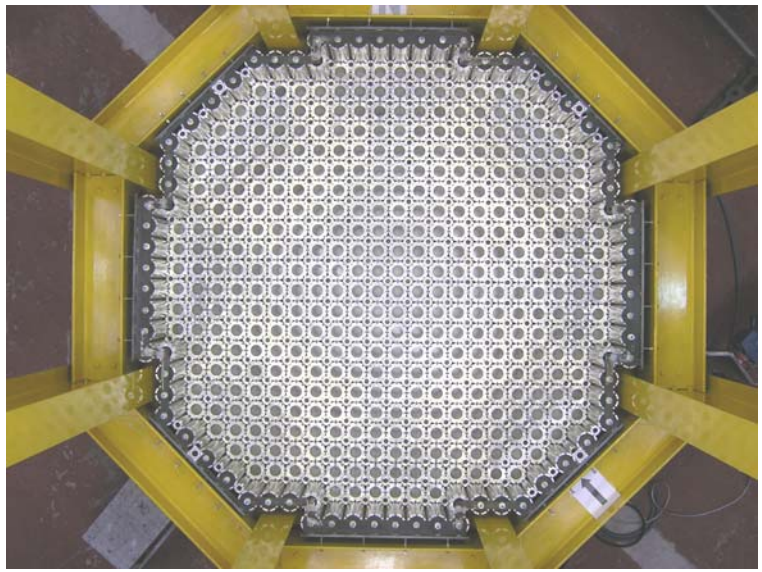
Direct Funded Work

- Whole core modelling and validation
  - Quarter-scale tilting core rig
    - Aluminium bricks
    - Scale clearances and dimensions
    - Design and construction complete
    - Being commissioned with a single layer of bricks
    - Bricks for additional layers are being procured
  - Supplements existing rigs
    - Small arrays with full-size components: “IMC Rig” and “Box-kite Rig”
    - Large array, eighth-scale plastic rig

Direct Funded Work

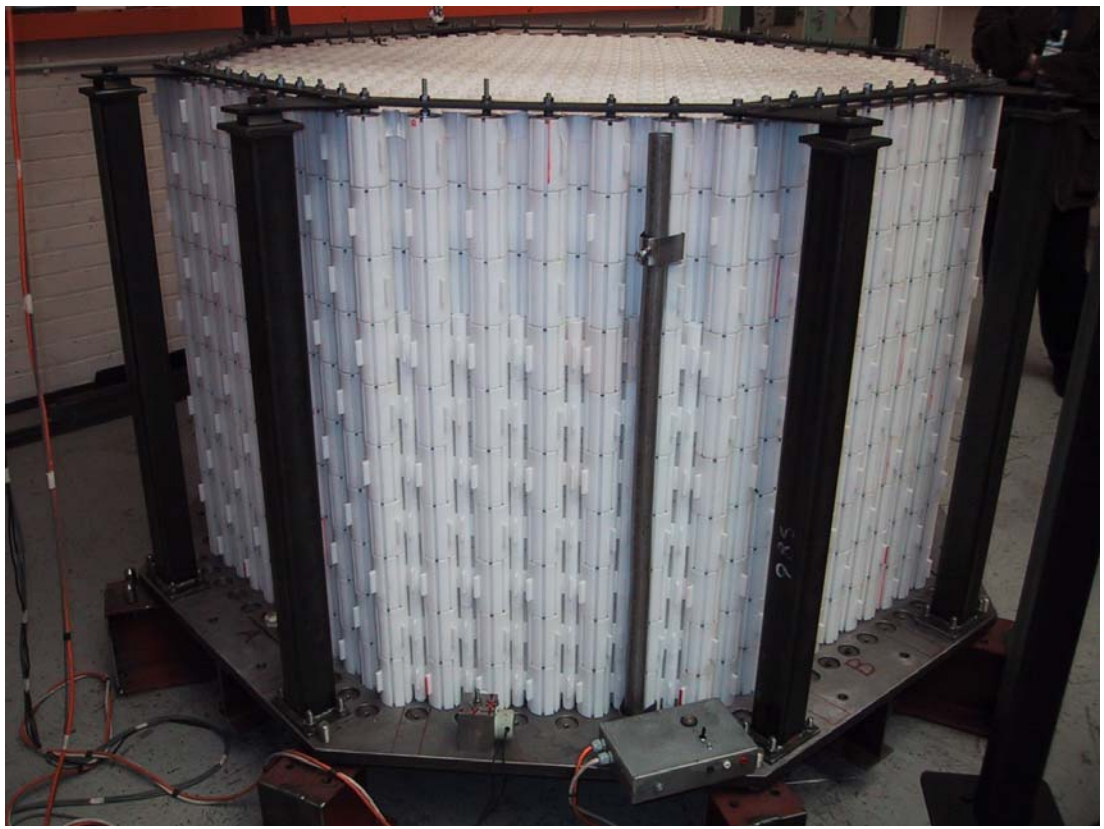
- Quarter-scale Rig – Aluminium bricks





Direct Funded Work

- Eighth-scale Rig – Plastic bricks



Direct Funded Work

- Box-kite Rig – Perspex and aluminium

Direct Funded Work

- IMC Rig – Full-size Graphite Bricks

Magnox Projects

- The Magnox Stations have relatively short remaining operating lives
  - Sizewell A and Dungeness A at the end of 2006
  - Oldbury at the end of 2008
  - Wylfa during 2010
- Research activities are targeted closely to safety case requirements where the main areas of study are:
  - The weight loss effects of radiolytic oxidation
  - Brick cracking

Magnox Projects

- Development of new inspection techniques in collaboration with British Energy
  - Targeting keyway root locations using eddy current techniques
- Review of International Creep models
  - Collaboration with Kurchatov Institute, Russia

Magnox Projects

- Feasibility studies into Poisson's ratio measurement
  - Digital Image Correlation (DIC)
  - Electronic Speckle Pattern Interferometry (ESPI)
  - Capacitive Displacement Transducers
  - Ultrasonic Time of Flight Techniques
- Micro-structural studies looking at changes in PGA microstructure due to radiolytic oxidation.

BE/Magnox Collaboration

- British Nuclear Group (Magnox Electric) buys into the results of a number of British Energy's university projects:
  - GRA/GNSR/6007
  - GRA/GNSR/6022
  - GRA/GNSR/6027
  - GRA/GNSR/6029
- British Energy has bought into two of their projects
  - Dynamic Young's modulus methods
  - Ultimate tensile strength methods

Summary for FY06/07

- Strategic programme - £420k
- Materials test reactor programme - £1M
- Direct funded monitoring and inspection projects - ~£200k
- Irradiated properties measurement development - ~£60k
- Whole core modelling and validation - ~£1.3M