Graphite D&D Options, Risks & Opportunities

Ignalina R3 Reactor D&D Workshop
15th November 2018

woodplc.com

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Graphite D&D, options, risks and opportunities

- A few facts about Wood
- A few facts about graphite and core degradation
- Wood support to UK Advanced Gas-cooled Reactors
- International collaboration
- Options & risks for core dismantling and graphite disposal:-
  - RBMK specific dismantling and disposal issues
  - International collaboration on graphite and decommissioning
  - Dismantling options and graphite treatment
- Opportunities

A few facts about Wood

delivery across broader market and sector spread


Oil & Gas

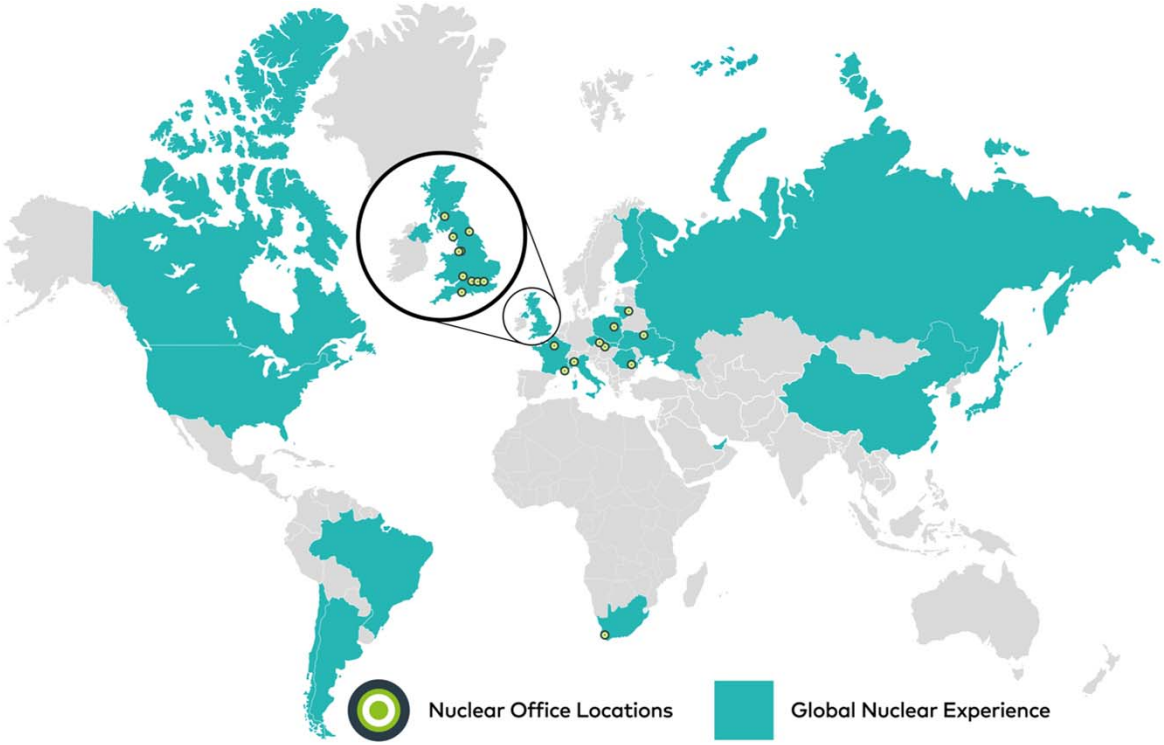

Alternative Energy


Mining & Minerals


Power & Utilities


Process & Chemicals

A few facts about Wood - our nuclear business

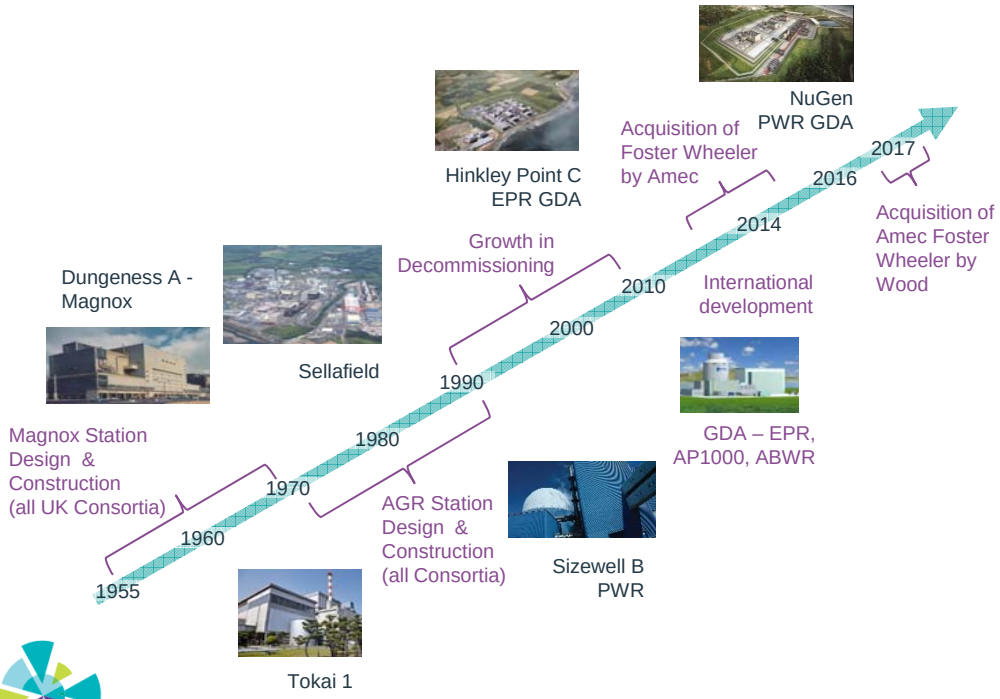


- 2000 people
- 21 regional offices
- Over 20 site offices
- Across UK, Europe and South Africa plus customers in Japan and China.

A few facts about Wood - 60 year nuclear heritage

- The nuclear business has played a key role in the design and build of every civil nuclear power station in the UK; and is playing a significant role on new build programmes, operations and decommissioning across the globe.

- Alongside this heritage, we continue to drive investment in technology and innovation, to help shape the future of nuclear energy.



wood. = WOOD GROUP + amec foster wheeler

A few facts about Wood - Graphite Operations & Decommissioning

Operations

Providing customers with:

- Graphite core neutronics and thermal hydraulic modelling
- Graphite component and core modelling/analysis to support operational safety cases.
- Full scale and small scale core rigs to validate computational models.
- Remote handling and in core inspection services.

Decommissioning

- Involved with decommissioning of the Jason reactor at Royal Naval College at Greenwich
- Carried out a feasibility study of the decommissioning options for Tokai Mura in Japan
- Produced major bid for decommissioning the Windscale Piles

EDF ENERGY

Magnox

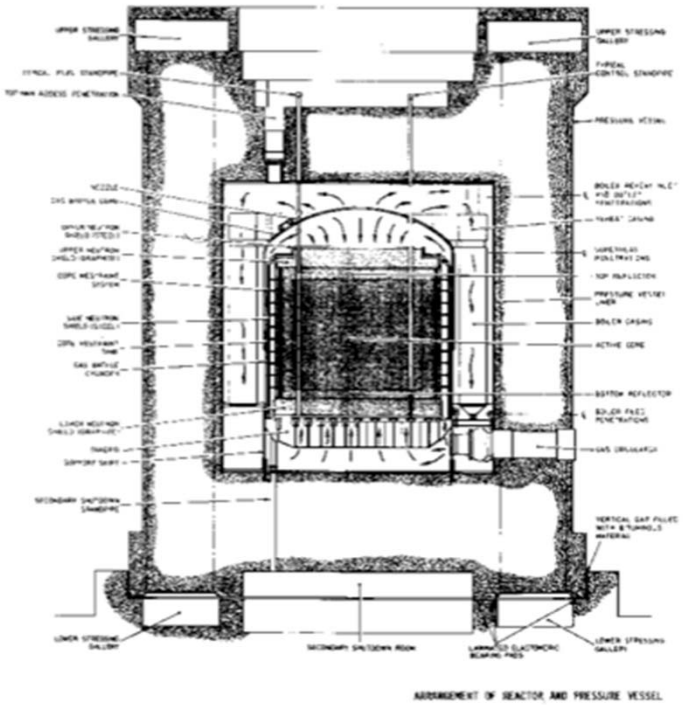
Radioactive Waste Management

IAEA

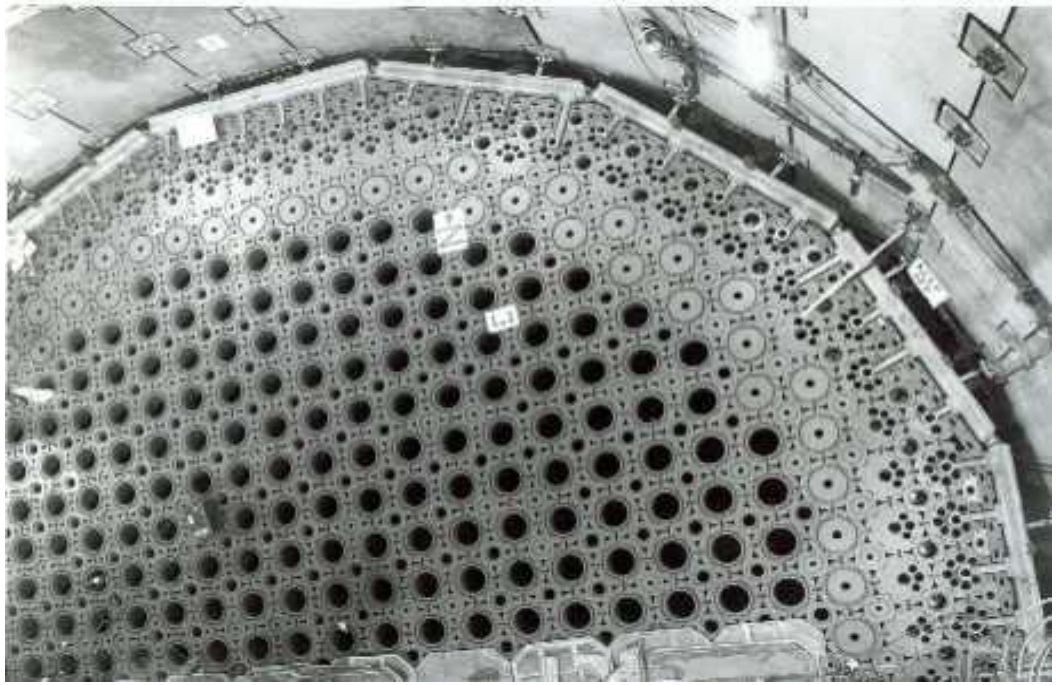
A few facts about Graphite

- In excess of 250,000t of irradiated graphite world-wide. 3,400t at Ignalina
- Graphite is ‘damaged’ by neutron irradiation… graphite components may therefore become distorted, cracked, and so difficult to extract conventionally:
- Wigner Energy could be present if irradiation was at low temperature
- Impurities will have become activated during operation with ^{14}C produced from ^{13}C and ^{14}N : also ^{3}H from moisture and fuel and, in some cases, contamination from failed fuel fission products
- If cooled by air or carbon dioxide, graphite components/core structure also weakened over life by chemical oxidation (weight loss)
- An issue not only for major historical producers (*e.g.* UK, Russia, France) but also for any country with small reactors containing graphite reflectors or thermal columns

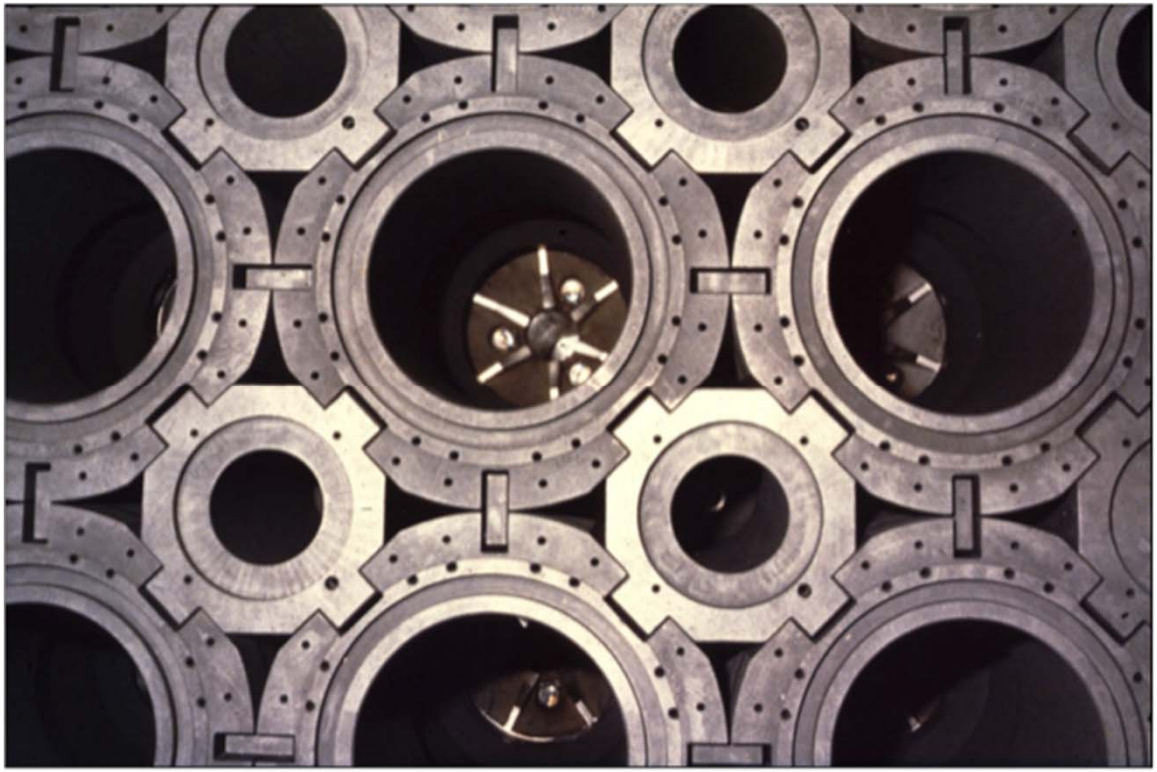
Heysham 2/Torness AGR

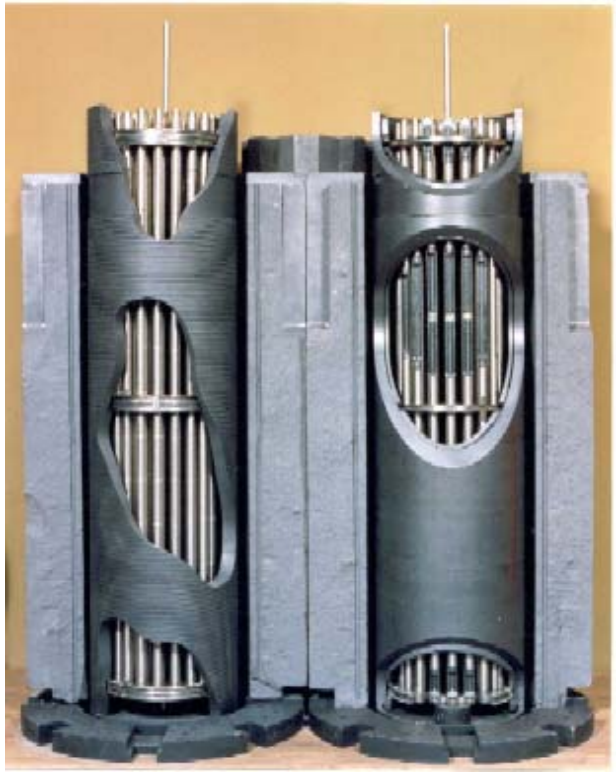


ARRANGEMENT OF REACTOR AND PRESSURE VESSEL

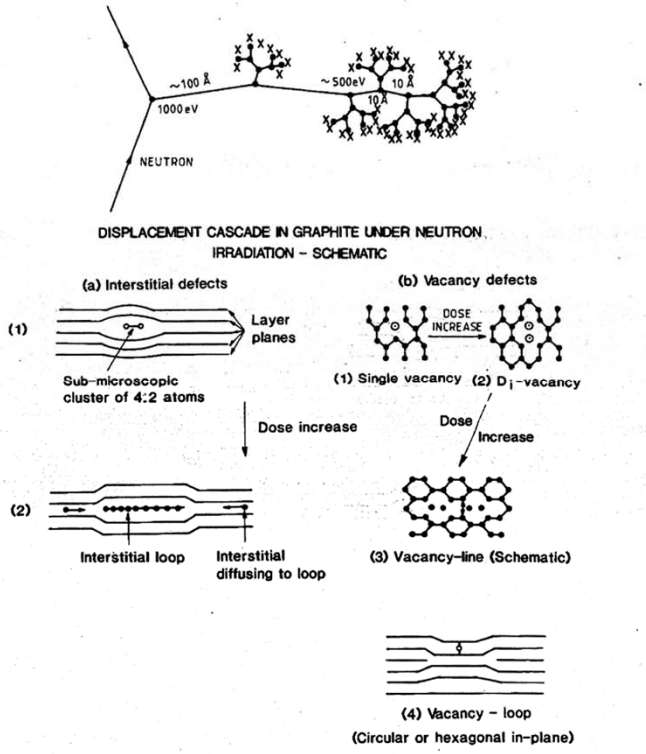


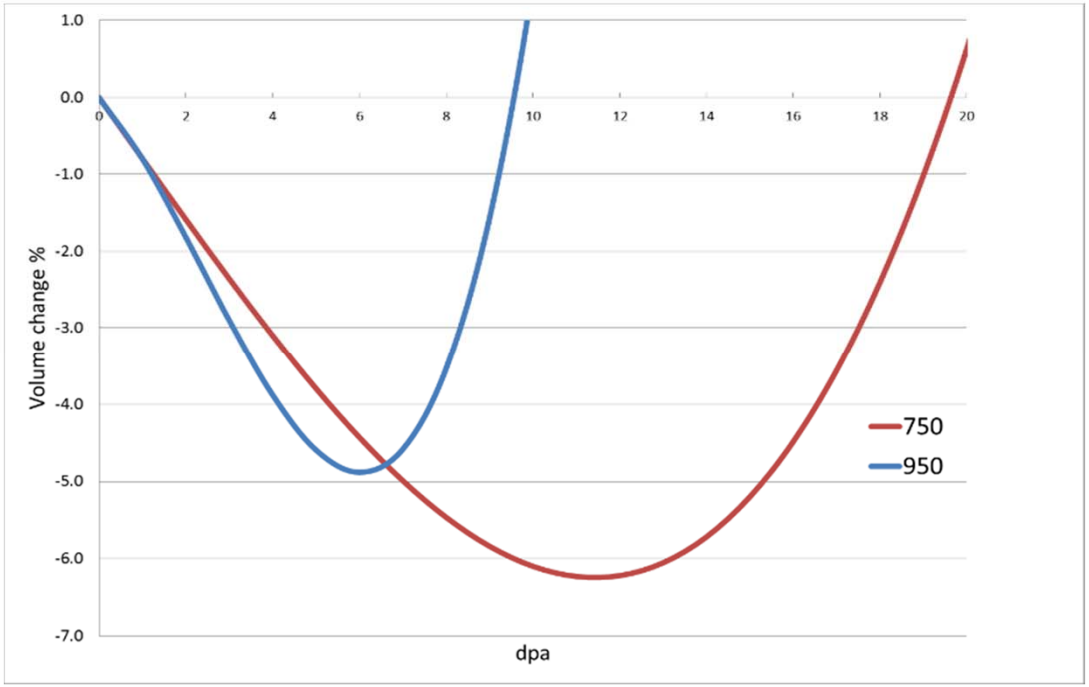
AGR graphite core bricks (Heysham 2/Torness)



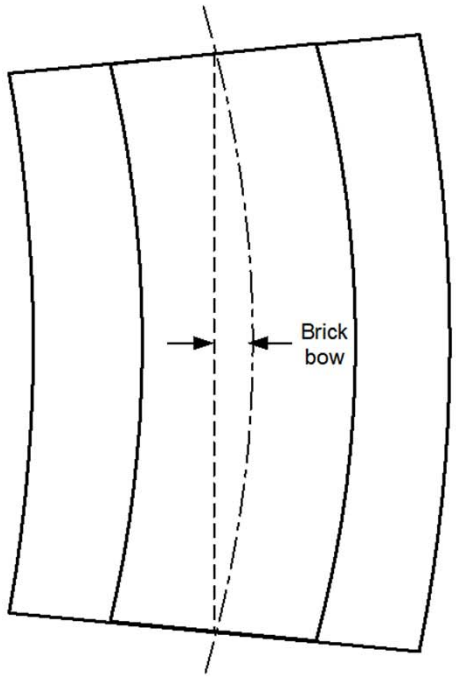


Graphite dimensional change

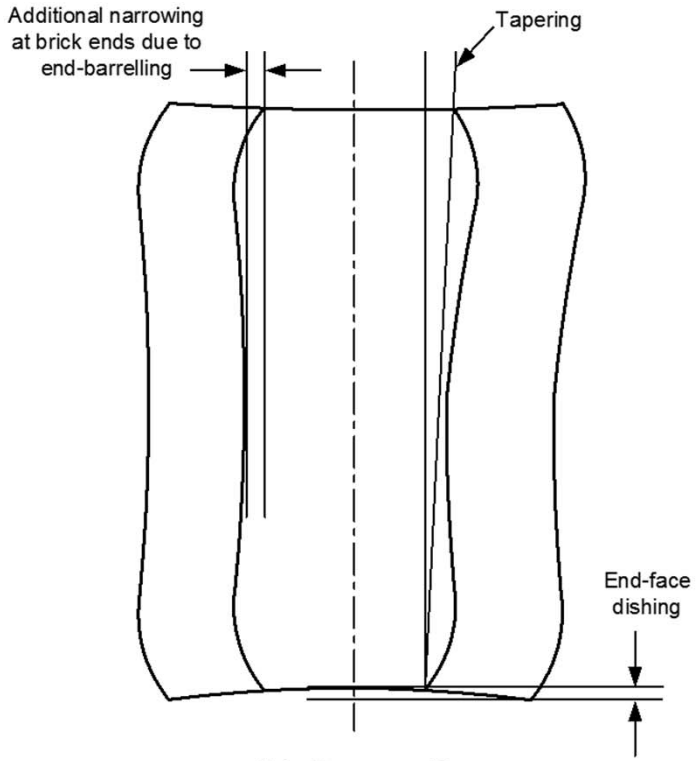




AGR brick distortion due to graphite dimensional change (1)

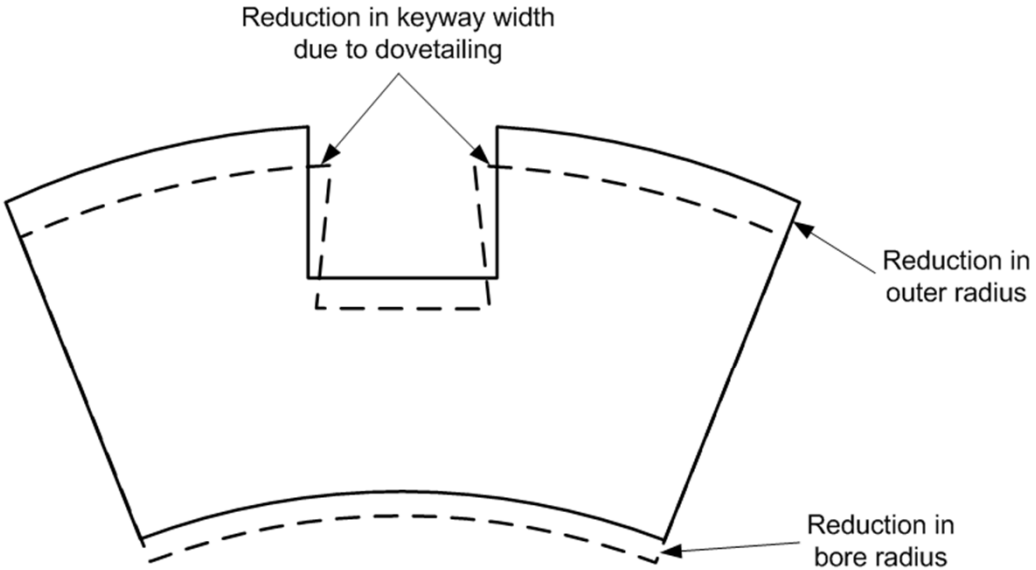


(a) Brick bow

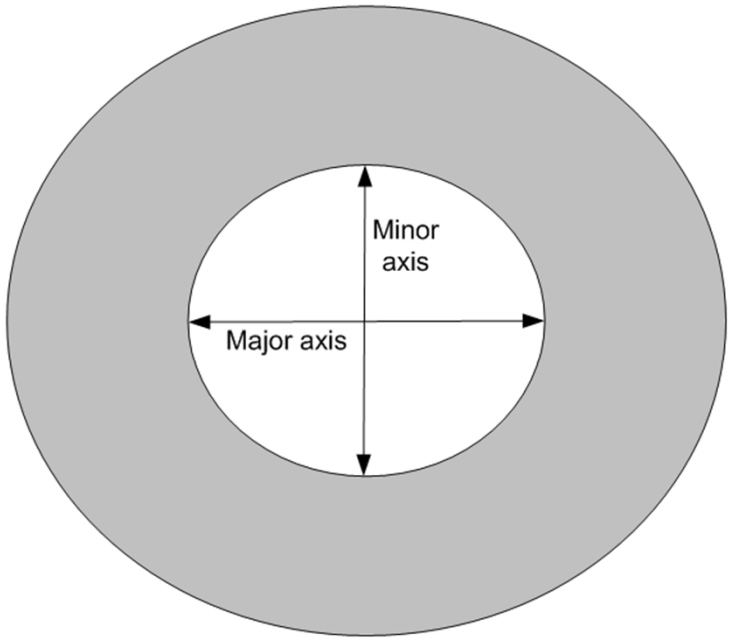


(b) Bore profile

AGR brick distortion due to graphite dimensional change (2)

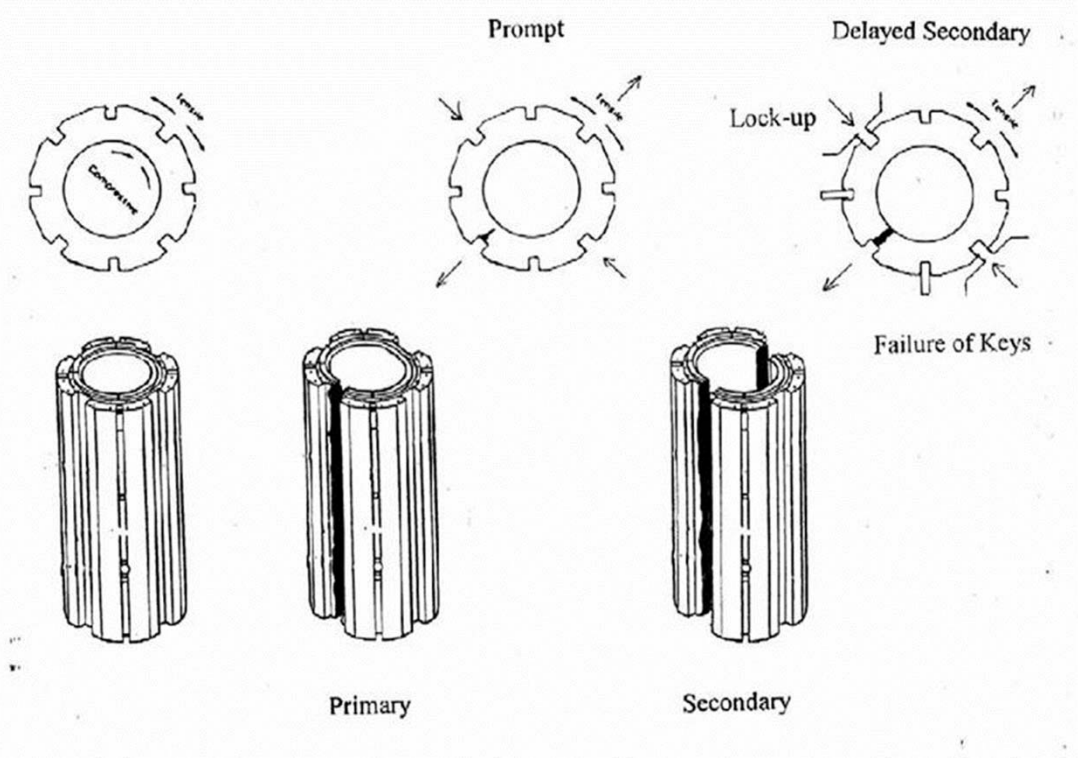


(a) Keyway dovetailing and brick radial shrinkage

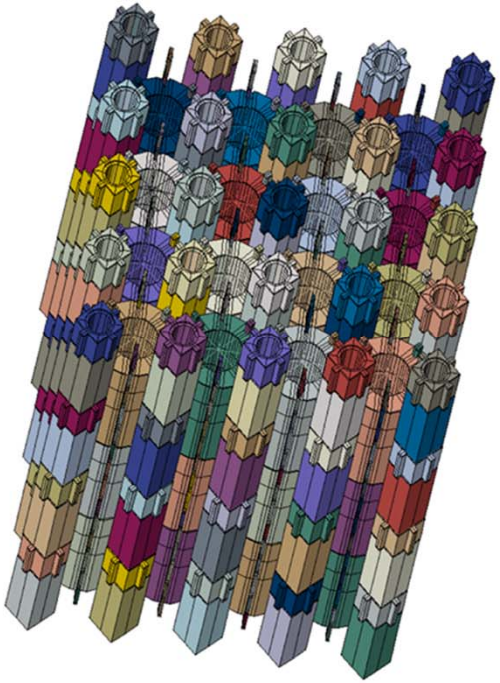


(d) Brick ovality

AGR brick cracking



Solid model of a brick array

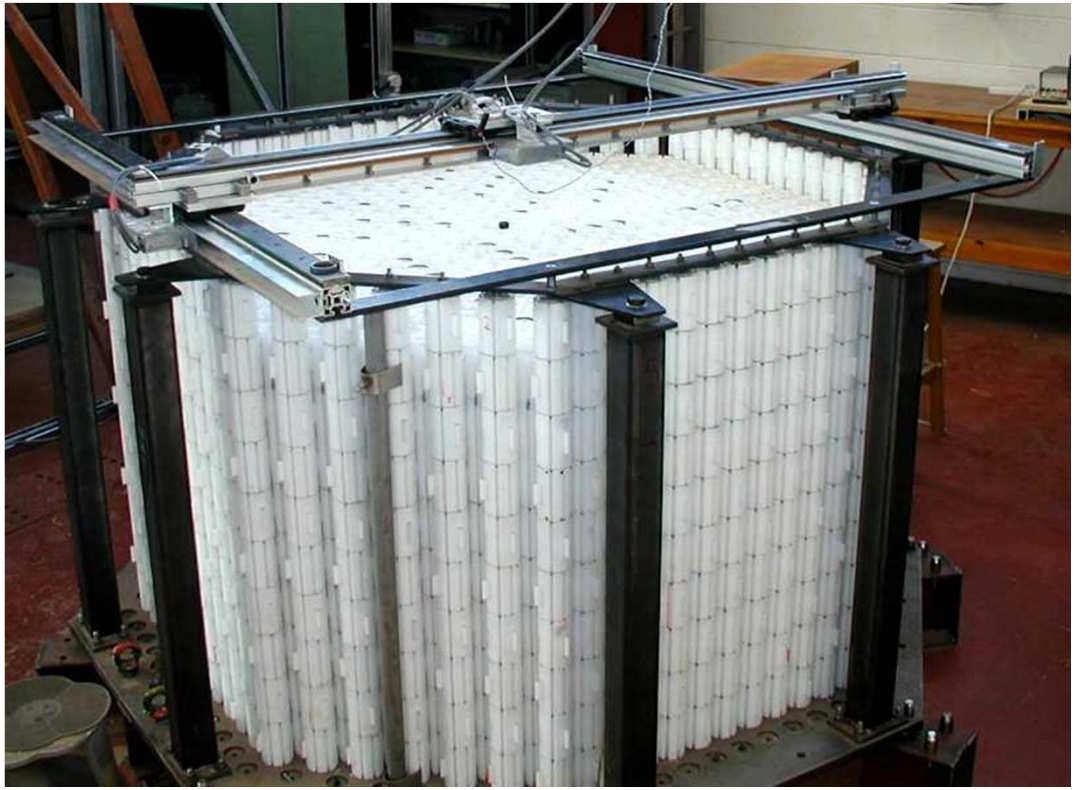


3D full scale rig

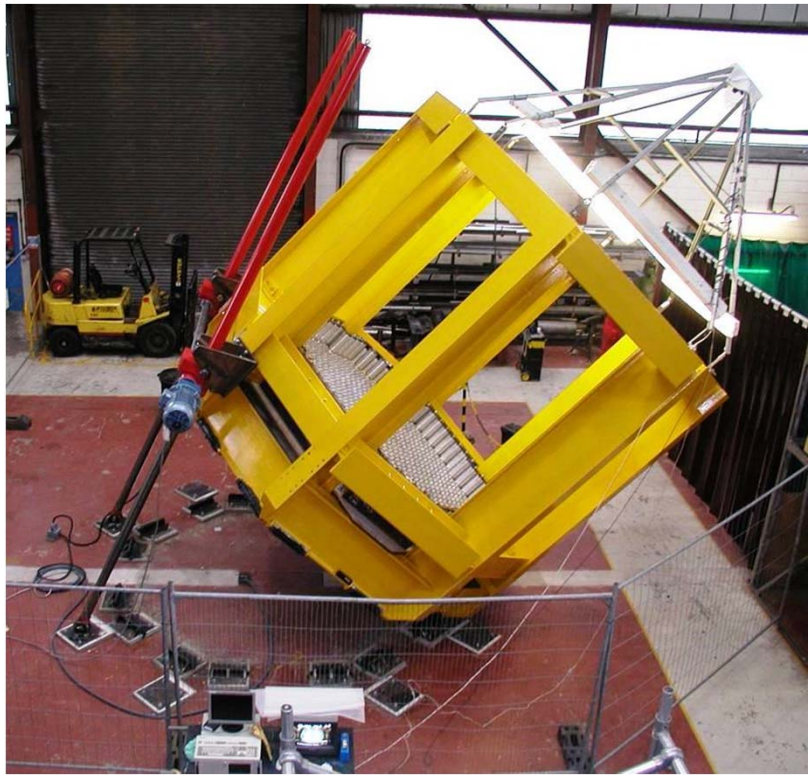
2D slice rig (1)

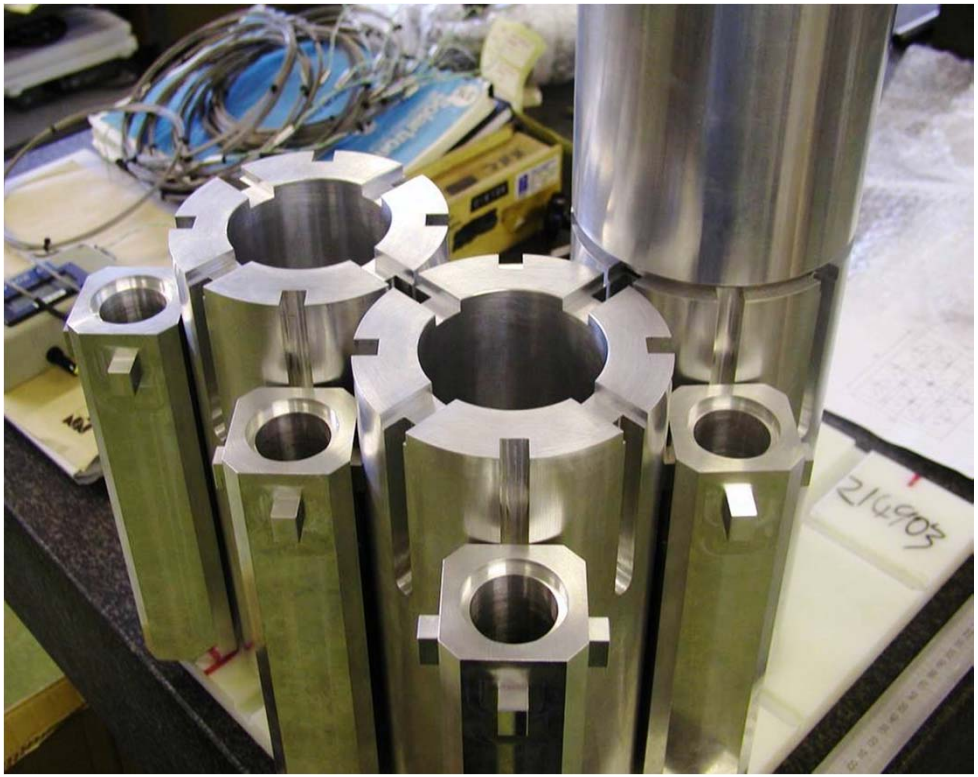
2D slice rig (2)

1/8th scale rig

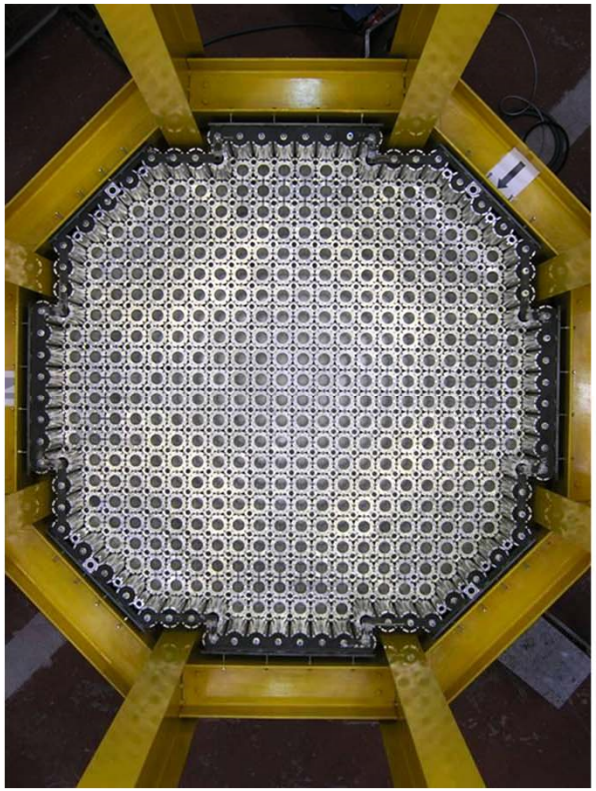


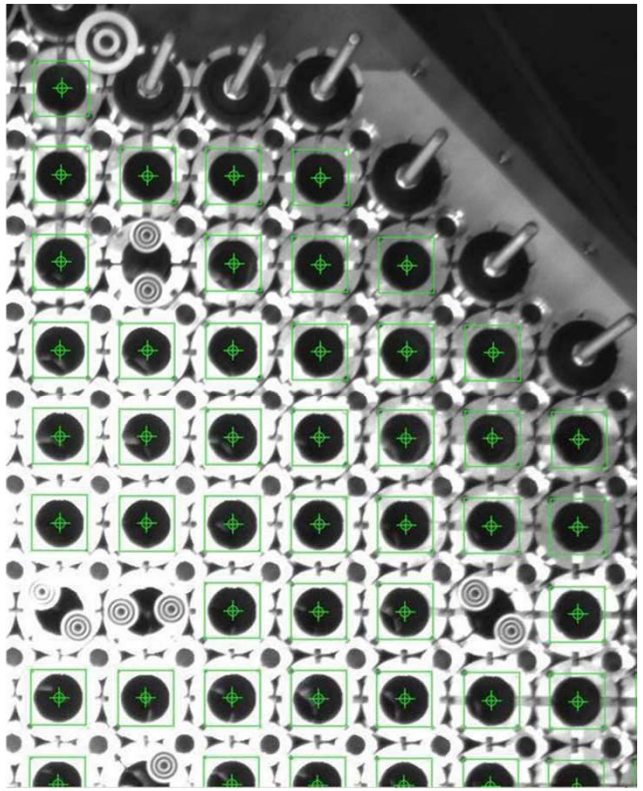
Quarter scale rig (1)



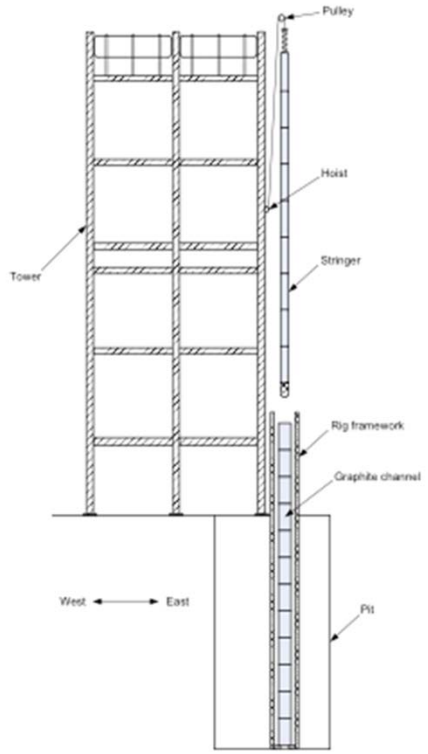


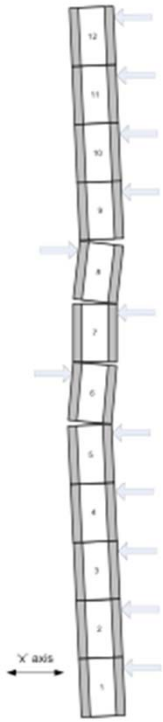
Quarter scale rig (2)



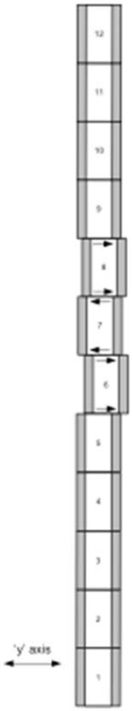


Fuel channel rig (1)





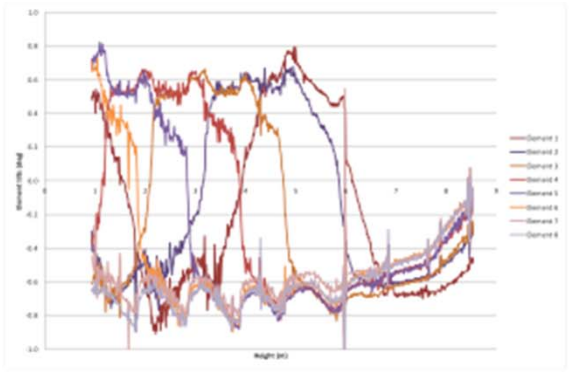
'x' brick displacement with no 'x' brick shear

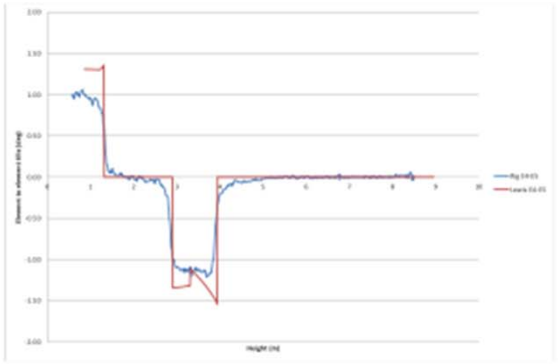


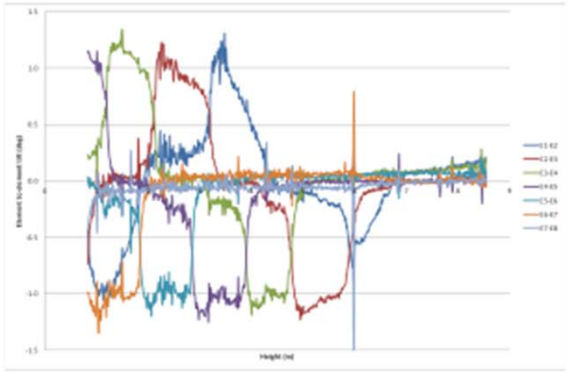
'y' brick shear

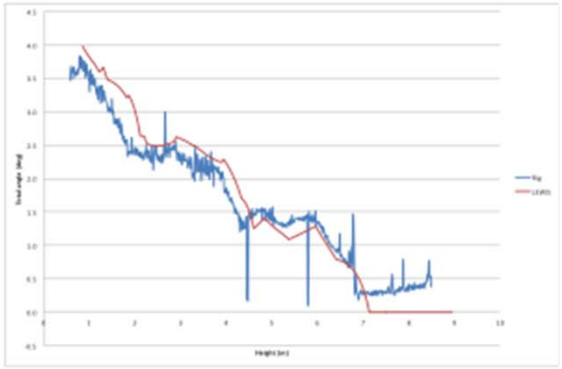
Fuel channel rig (2)

Fuel channel rig – comparison of model predictions and measurements





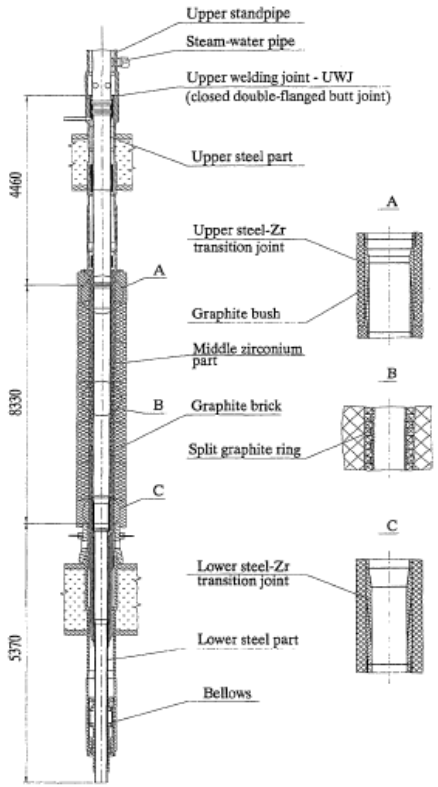




Core integrity/degradation in RBMKs (1)

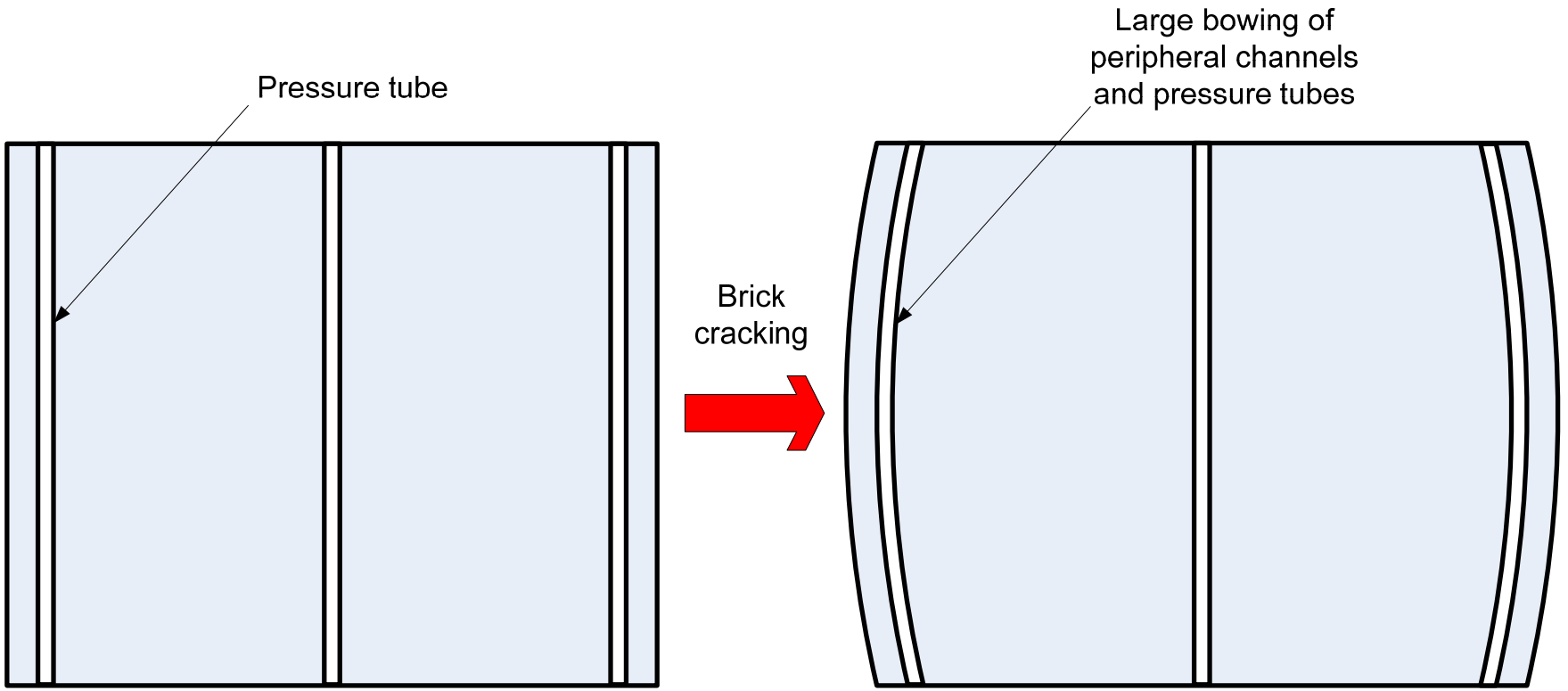
- ‘Graphite moderator lifecycle behaviour’. Bath University, 1995. IAEA TECDOC 901 Three papers on RBMKs:
  - ‘Radiation damage and life-time evaluation of RBMK graphite stack’
  - ‘Assessments of the stresses and deformations in an RBMK graphite moderator brick’
  - ‘The state of the graphite stack at Leningrad NPP Unit 2 after 16.5 fpy of operation’
- ‘RBMK fuel channel integrity’. IAEA-EBP-RBMK-05, January 1999

Core degradation in RBMKs (2)



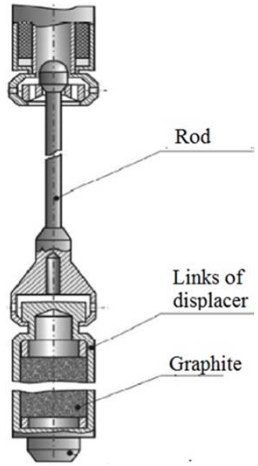
- Brick cracking in an RBMK will eventually occur in the same way as for the AGRs.
- Subsequent expansion causes a gap to appear between the rings and the bricks which increases the brick temperature..
- The bricks push on each other and this increases the core diameter.
- This causes bowing of the fuel channels and hence the pressure tubes. The effect increases with core radius.
- The predicted time of operation for brick cracking to start at Ignalina NPP was 22 years

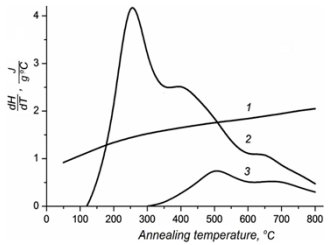
Core degradation in RBMKs (3)



RBMK specific dismantling and disposal issues

- Possible brick cracking and core instability during/after pressure tube removal leading to difficulty with graphite block removal
- Possible high Wigner Energy levels in the graphite associated with the control rods which will have operated at low temperature
- Possible high ^{14}C levels formed from the nitrogen in the gas blanket
- There have been, and still are, a number of international collaborations on graphite and decommissioning concerning dismantling options and graphite treatment prior to disposal





International collaboration on graphite and decommissioning

- CARBOWASTE – ‘Treatment and Disposal of Irradiated Graphite and other Carbonaceous Waste’ – April 2008 to March 2013
- GRAPA - ‘Irradiated **GRA**phite **P**rocessing **A**pproaches’ – Ongoing
- IAEA Co-ordinated Research Projects - TECDOCs
- International Nuclear Graphite Specialists Meetings – held annually in September
- GenIV International Forum – (Very) High Temperature Reactors and Molten Salt Reactors

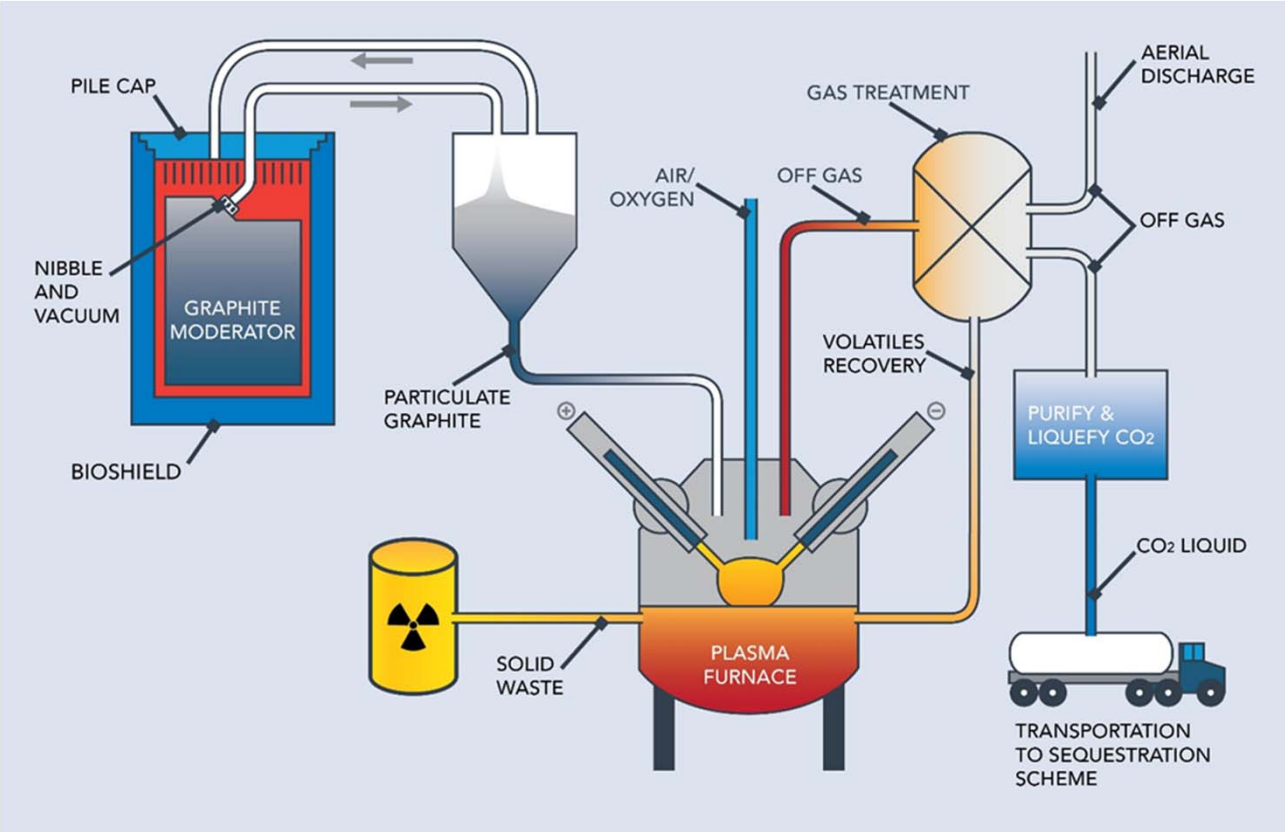
Dismantling Options

- Conventional Handling and Cutting
- Under water (reasons which have been advanced include shielding and concern over dust behaviour);
- Special techniques integrated with disposal philosophy

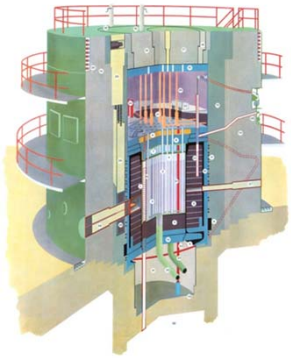
Conventional Handling and Cutting

‘Nibble and Vacuum’

Integrated Dismantle and Treat Option

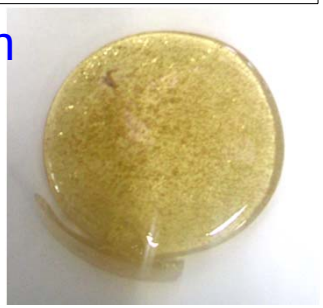


Treatment Options - Immobilisation



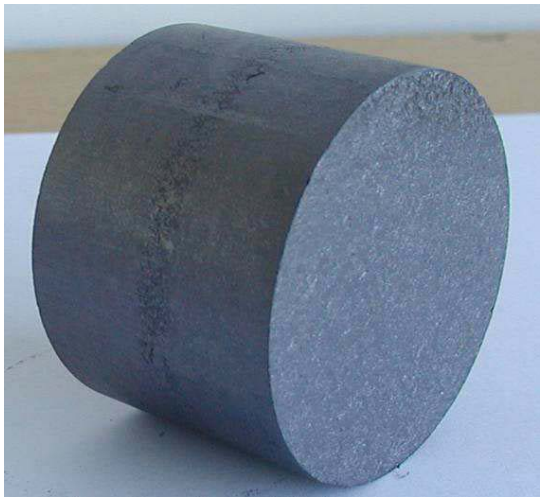
Cementation
Paul Scherrer Institute
Switzerland
DIORIT (research reactor)
45 t Graphite treated

Vitrification in
Molten Salt

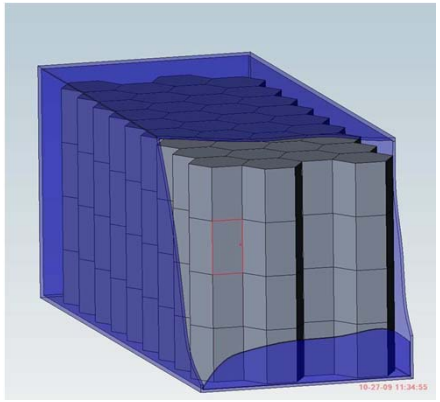


Treatment Options - Immobilisation

Graphite-Loaded Glass

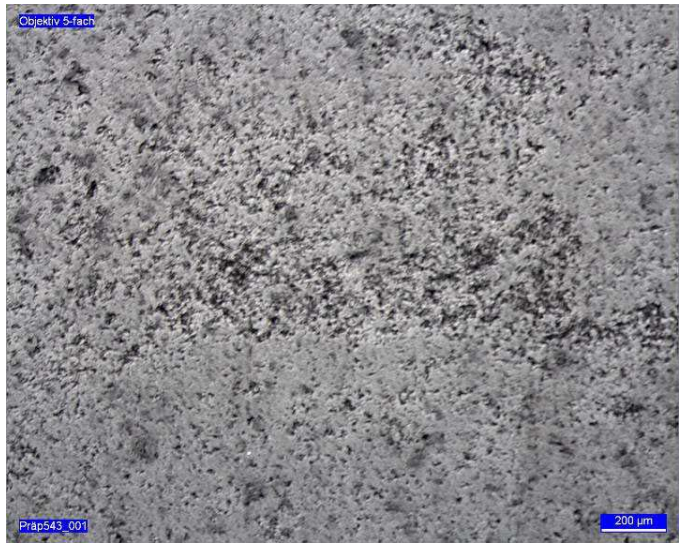


High density (2.23 g.cm^{-3}) – regarded as ‘impermeable’ and non-corrodible



IGM density ~ 2.2 t/m³
graphite density within the block ~ 1.6– 1.7 t/m³
graphite package density in container ~ 1.5 t/m³
80,000t graphite
~50,000m³

80% graphite currently, used to Immobilise Other Radwaste (FNAG, Germany)



Treatment Options - Incineration

Fluidised-Bed Incineration

Treatment Options - Reduce Radioactivity Content (Leaching and Washing)

- Leaching rates in a repository or storage environment need to be extremely low: data in ‘alkaline liquors’ are most relevant but timescale of tests <<<<< repository life (geological timescales)
- ...*but*: valuable to explore ‘washing’ options in other aqueous environments in order to facilitate isotope removal/recovery ahead of disposal

Treatment Options – Heat treatment

- Most of the induced activity of the graphite will have decayed away within ~70 years after plant closure. However, the remaining ^{14}C concentration, which will be potentially much higher in the RMBK graphite than other reactor graphites due to the activation of the ^{14}N in the gas blanket, means that it is classified as intermediate level waste.
- Removing a significant amount of the ^{14}C content may allow it to be reclassified as low level waste which could lead to large reduction in disposal costs
- Work undertaken under Carbowaste showed that heat treatment was one of the best options. The UK is investigating this form of treatment further with INNOVATE UK funding

Opportunities

- **Storage or Recycling ?**
- Future market for nuclear graphite ?
- High cost to store and to dispose, so if it is industrially feasible it makes sense to recycle. Options with real graphite waste currently under investigation.
- Two major graphite manufacturers participating in the EU CARBOWASTE programme established that the process is feasible but requires significant investment in a production plant to handle moderately radioactive feedstocks.


wood.