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ASME Non-metallic Component Degradation and Failure Task Group

DOE ART Gas-Cooled Reactor (GCR) Review Meeting
Virtual Meeting
July 25 – 27, 2023

ART Advanced Reactor Technologies

Background to the formation of the Task Group

- ASME Section III Division 5 Rules for the Construction of Nuclear Facility Components for High Temperature Reactors has been undergoing revisions to the Graphite Subsection text to clarify the meaning of ‘**component failure**’, ‘**component functionality**’ and ‘**damage tolerance**’.
- These definitions and concepts are vital to ASME Section XI Division 2 Rules for Inservice Inspection – Reliability and Integrity Management. While these rules are applied once the construction code has been satisfied, designers need to be aware of them as they could influence the design. **This section currently provides no guidance for non-metallics**.
- This omission has been recognized by both Section III and Section XI and the Task Group has been set up to address this, commencing with **graphite components in high temperature gas reactors**.
- This scope will later be expanded to cover molten salt and liquid metal reactors and other nonmetallic materials.

Component failure and component functionality

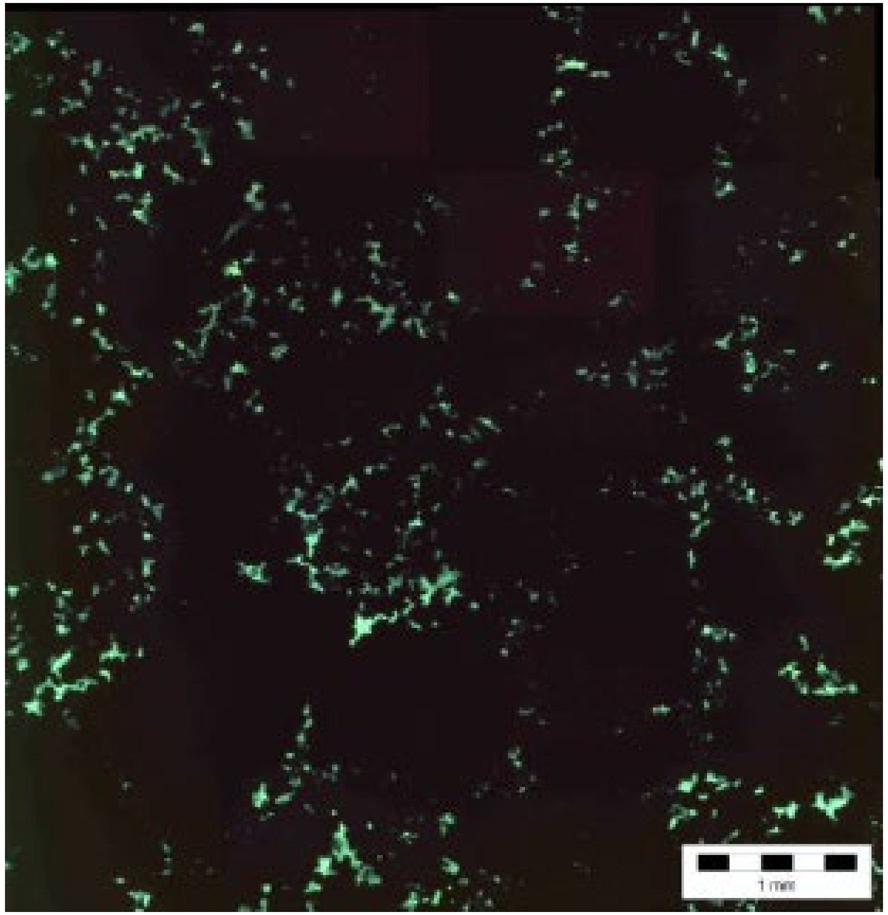
- Assessment methodologies presented in the Section III Design Rules ambiguously refer to outputs as '**probabilities of component failure**'.
- While the methodologies are technically correct, they in fact quantify '**probabilities of crack initiation within a component**'.
- This is a very important distinction.
- Crack initiation within a metallic component can generally be regarded as failure. For graphite components, may be completely benign depending upon the design of the facility and the **functionality** of the component.
- Functionality is assessed in terms of **damage tolerance**: the ability of a component or array of components to fulfil design function with the progressive development of flaws and damage.
- *Revisions to the Section III text to address these issues have been proposed and they are currently going through the ASME approval process*.

The nature of graphite

- **Graphite is not a perfect homogeneous material**

- Porosity which will vary depending upon raw materials and the manufacturing process

- Manufacturing process leads to a high defect population at both nano- and micro- length scales including:
  - Calcination cracks
  - Porosity from the release of volatile gases
  - Cracks arising from anisotropic contraction following graphitisation



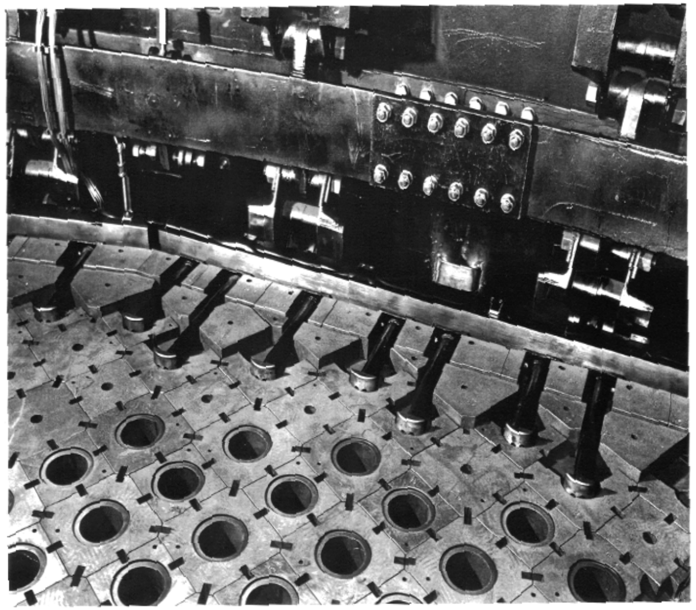
Damage tolerance (1)

The designer needs to assess the damage tolerance of components – *the ability of a component to fulfil its design and safety function* – in the context of the inherent defect-rich nature of graphite

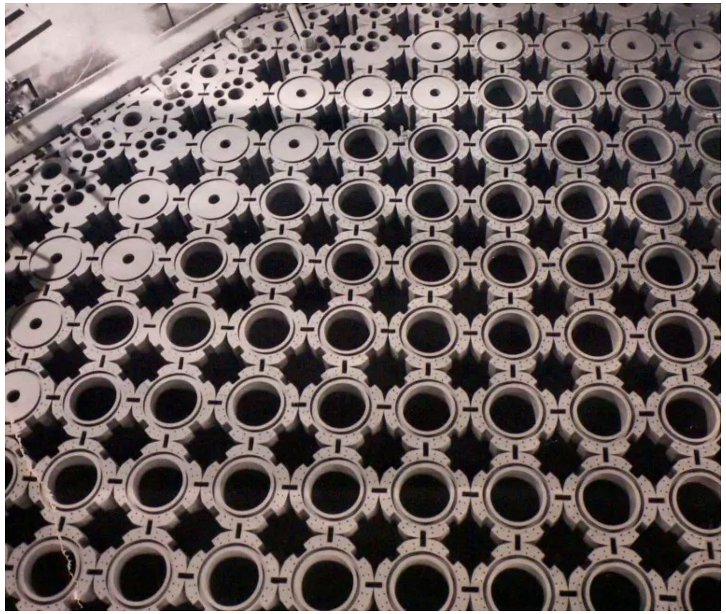
- The presence of defects, microcracks and porosity does not prevent graphite from being selected as a structural material
- While these features can act as crack growth initiators leading to damage that may impact design function, they are benign in the absence of stress drivers
- If cracks develop, their significance can vary significantly depending upon the reactor design

Damage tolerance (2)

UK experience operating gas-cooled graphite moderated power reactors provides a good illustration of how the significance of damage depends on core/component design.

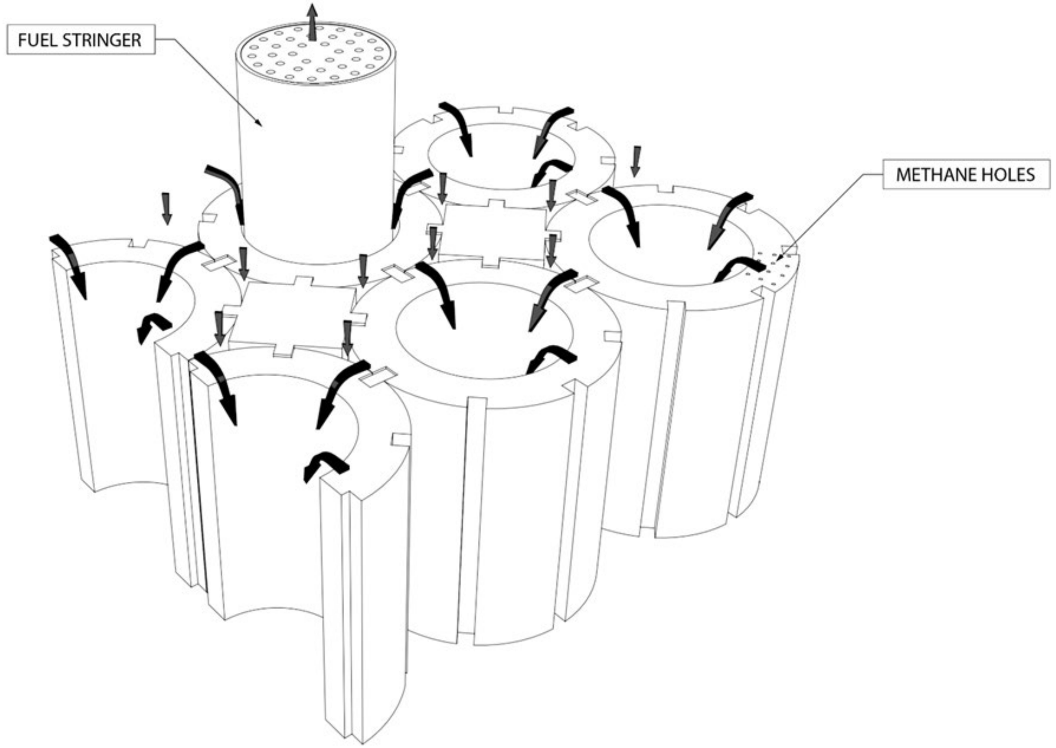


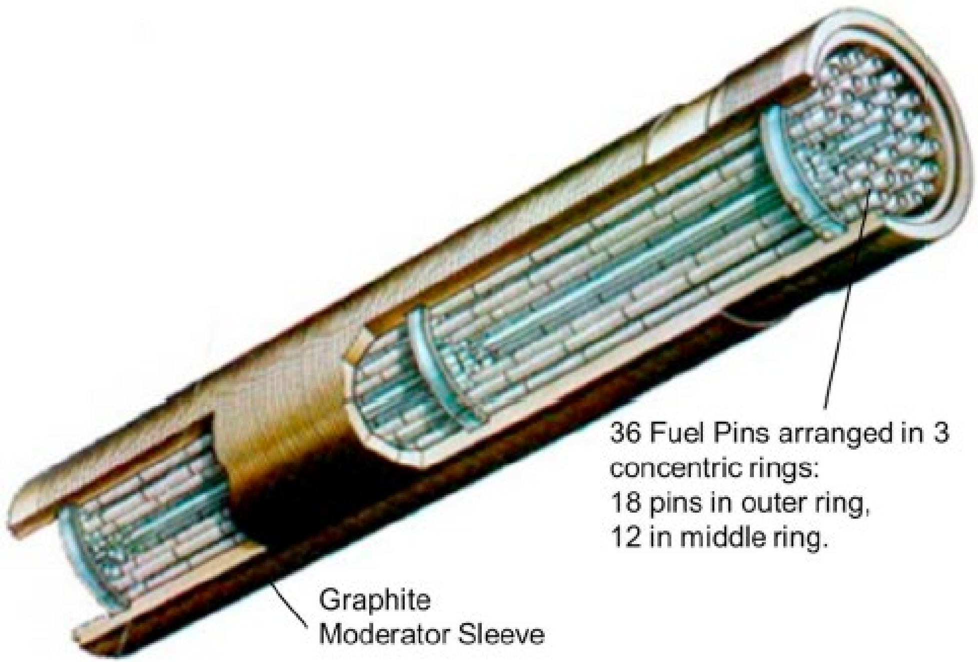
Magnox reactor



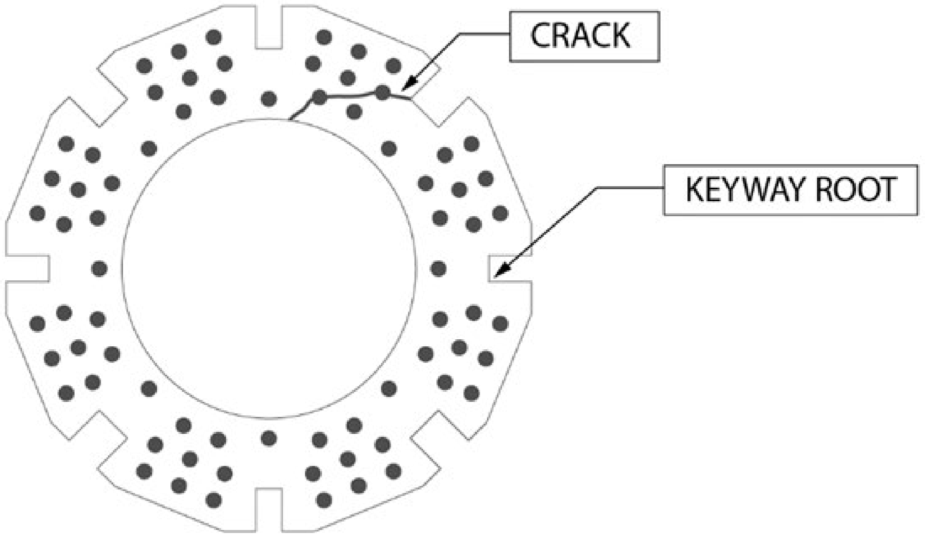
Advanced gas-cooled reactor

AGR design

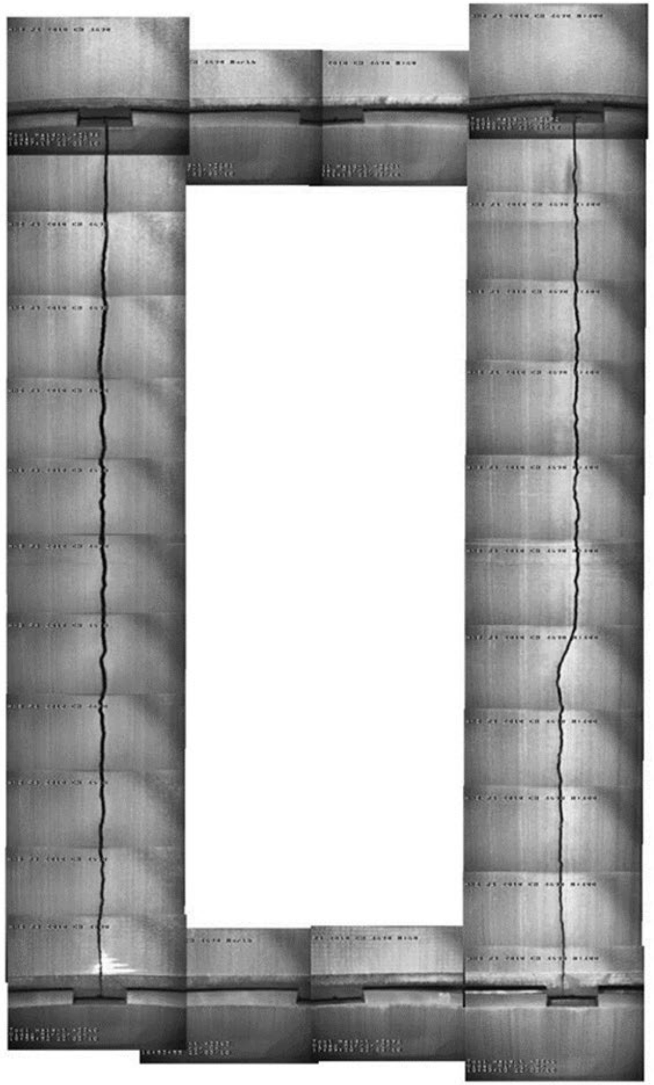

FUEL STRINGER
METHANE HOLES


36 Fuel Pins arranged in 3
concentric rings:
18 pins in outer ring,
12 in middle ring.
Graphite
Moderator Sleeve

Damage tolerance (3)



Cracking in a UK AGR: bricks that have cracked into two separate pieces are not deemed to have 'failed' – these bricks still fulfil their design function



Damage tolerance review

A review of UK experience, commissioned by INL to provide a reference for ASME rules for design and for reliability and integrity monitoring

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Damage tolerance in the graphite cores of UK power reactors and implications for new build

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ABSTRACT

The United Kingdom has been operating graphite-moderated gas-cooled commercial nuclear power reactors for more than 60 years. Both Generation I Magnox reactors and Generation II Advanced Gas-cooled Reactors have operated beyond their nominal design lifetimes and the safety cases for continued operation have had to address the issue of damage tolerance of the graphite cores. This review describes the designs of the reactors and the methodologies employed for their assessment. Emerging issues arising from extended operation and ageing of the cores are discussed together with the evolution of assessment methodologies to address predicted and observed damage. The UK nuclear regulator perspective is summarised and some conclusions are drawn on the implications for new build.

1. Introduction

The United Kingdom has been operating commercial nuclear power reactors since 1956, when the world's first commercial power-producing reactor was commissioned, up to the present day. The Generation I Magnox-type plant have all now ceased power production but the Generation II Advanced Gas-cooled Reactors (AGRs) continue to operate. Whilst significant advances have been made since then in the design of new graphite-moderated gas-cooled reactors, the experience accumulated and the challenges faced by both the UK operators and the UK nuclear regulator provide vital insights into lifetime management and nuclear safety when compiling design codes for new plant. In the case of the UK designs, the graphite cores were regarded as one of the life-limiting features of the plant and the approach to component integrity and the tolerance to failures has been and continues to be an extensively researched and critical issue.

The objective of this paper is to describe the UK approach to damage

In providing this assessment of damage tolerance, it must be appreciated that much of the documentation around this topic remains restricted. In preparing this review, the author has cited published work and recovered some documentation through the UK Freedom of Information Act, but also has had to refer back to his own experience over 40 years working in the UK nuclear industry working principally on graphite core safety case management. So, while some information presented cannot be verified against published and peer reviewed documents, the issues and opinions raised may provide a useful focus for designers and assessors of new nuclear plant containing graphite components.

2. Design of Magnox and AGR cores

The descriptions provided in this section have been extracted in part from an earlier document, compiled by the author (Banford et al., 2009) and references therein (Hart et al., 1972), (Davies, 1996), (Steer, 2007).

Non-metallic component degradation and failure task group

- provide an over-view of damage mechanisms and phenomena that could change the functionality of a component and/or array of components,
- provide monitoring and surveillance options appropriate to identified, component damage mechanisms/displacement mechanisms/property changes
- propose links between BPV III-5 and BPV XI-2,
- assess potential non-metallics inputs to the MANDE Working Group (Monitoring and Non-Destructive Examination).

NOTE: Ideally, designers would provide appropriate information identifying components/design features for a particular design that would merit monitoring. This would be based upon the their own assessments of functionality and damage tolerance in the context of nuclear safety and operational lifetimes. This has not been possible due to proprietary issues.

Task group progress

- Draft supplement prepared specifically for graphite in high temperature nuclear facilities
- Graphite degradation mechanisms identified
- Guidance provided on component monitoring and non-destructive examination
- Supplement to be distributed within ASME for formal comment and review in July 2023

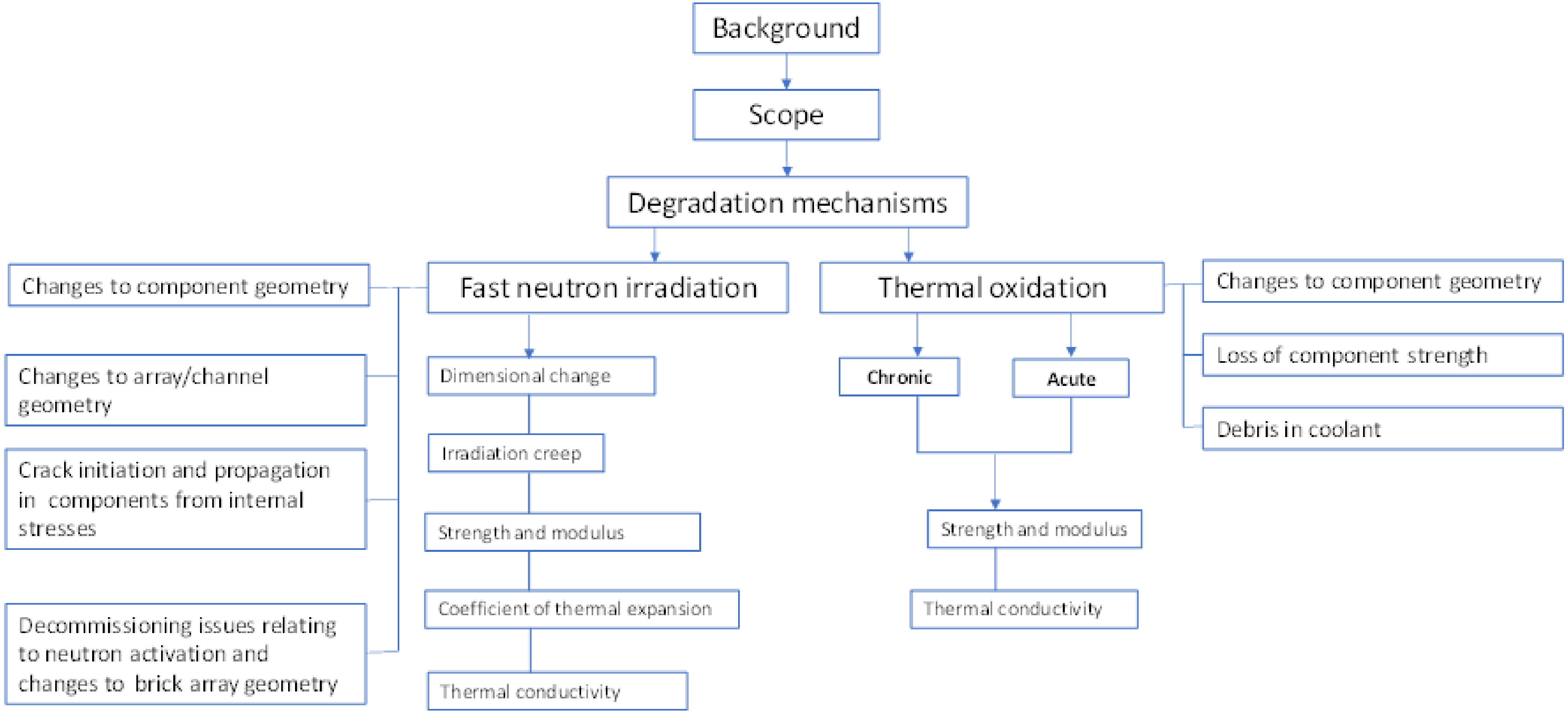
Monitoring and examination

- Monitoring is principally an in-service activity requiring consideration as part of the facility design. It is the systematic process of observing, tracking, and recording activities or data for the purpose of evaluating component conditions.

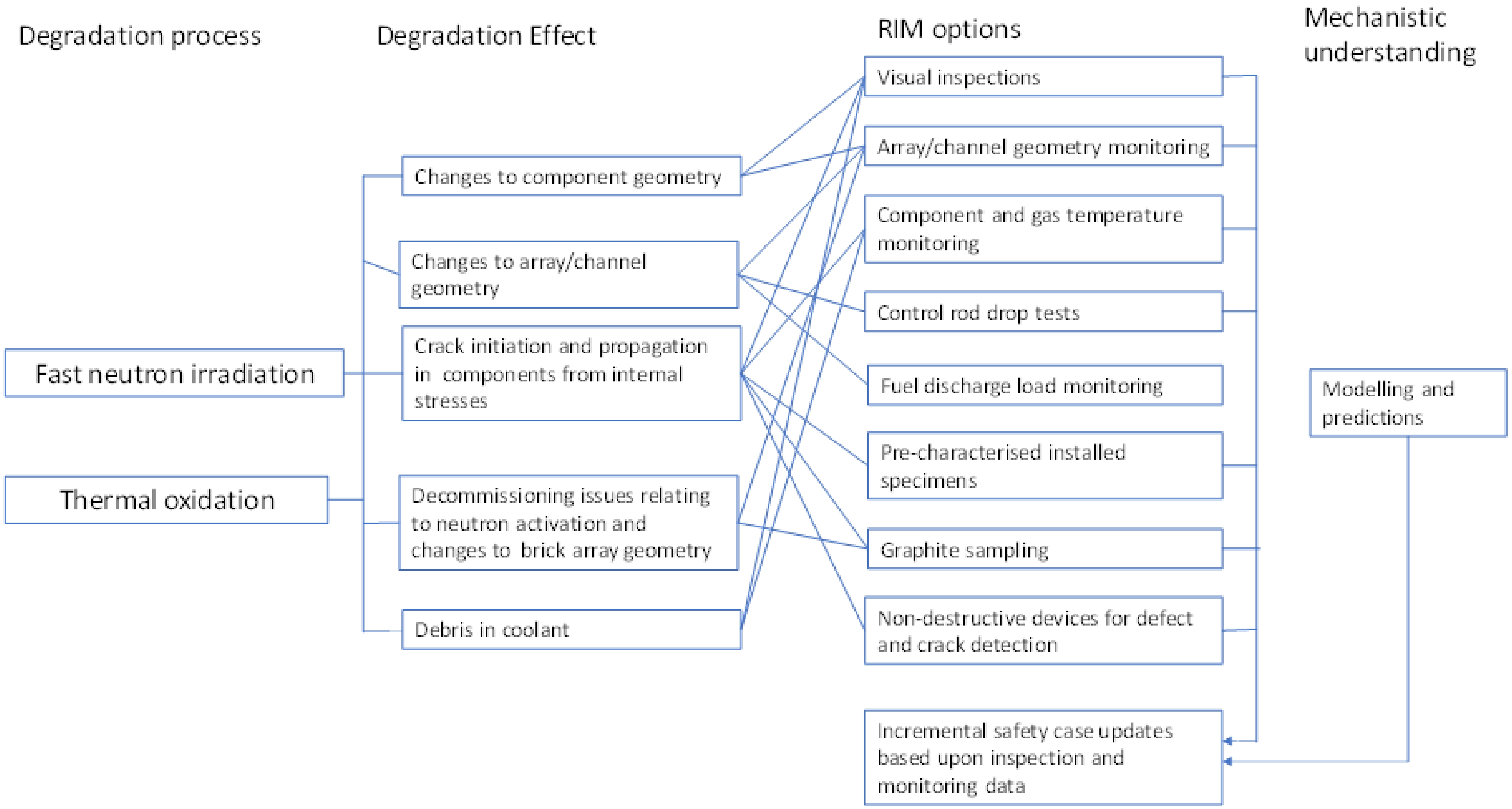
- Examination is an activity during a reactor facility outage that could involve removal of surveillance samples but also NDE, visual examinations, remote measurements and invasive sampling.

- Depending upon the facility design, examinations may not be outage dependent and, for some designs, outages may not be planned over the lifetime of the facility.

Link between degradation processes and their impact on core components and the array of graphite components



Link between degradation processes and RIM options



Way forward

- Revisions to the ASME code are slow and inclusion of the graphite supplement is not expected until at least 2025 and more likely 2027.
- Designers of graphite core components need guidance on reliability and integrity management on a much shorter timescale.
- ASME Code Cases can be approved and issued relatively quickly.
- In parallel with issue of the graphite supplement, a Code Case mirroring the supplement will be prepared to provide early guidance.