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ASME Grappling with the Concept of Component Failure

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Changing the World's Energy Future

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GAS-COOLED REACTOR
ADVANCED REACTOR TECHNOLOGIES PROGRAM

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ASME – Grappling with the Concept of Component Failure

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What does failure mean?

- The term ‘failure’ without context is meaningless.
- From a UK nuclear regulator perspective, the use of the term failure in the context of nuclear reactor components is emotive and unhelpful when communicating with the public.
- Generally, failure is qualified as **loss of component functionality.**
- Component functionality in a nuclear context means satisfying nuclear safety requirements.

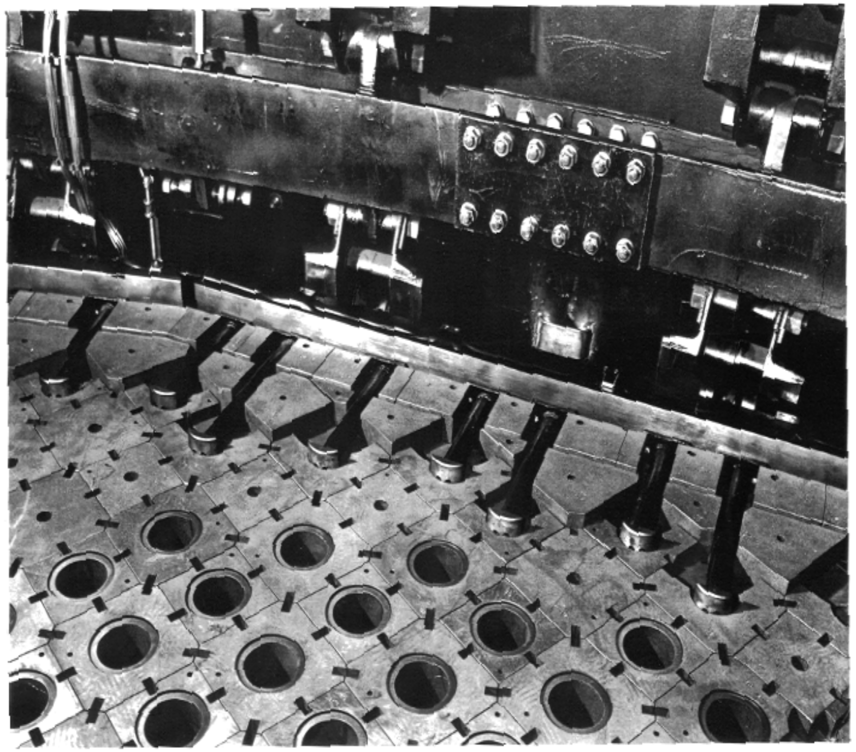
Component functionality

- 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.
- For graphite components in gas-cooled reactors, functionality refers to the structure meeting defined nuclear safety requirements:
  - To allow the unimpeded movement of control rods and fuel
  - To direct the flow of coolant gas so as to ensure adequate cooling of the fuel and the core structure both in normal and fault conditions

Damage tolerance

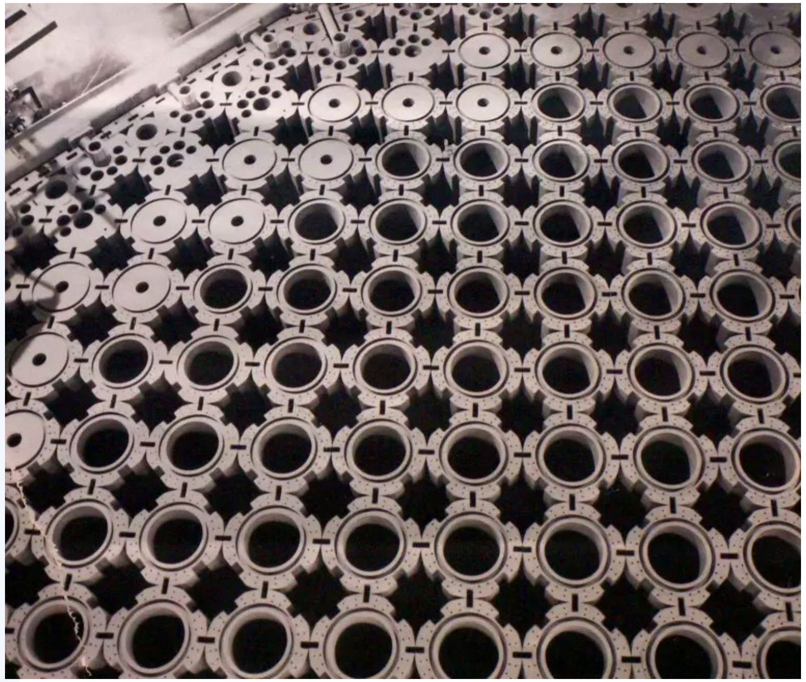
- This depends critically upon reactor design.
- Damage tolerance assessments for advanced gas-cooled reactors are currently the proprietary information of vendors and designers.
- It is instructive to be aware of UK experience for two types of gas-cooled reactors that appear similar but have significant design differences.

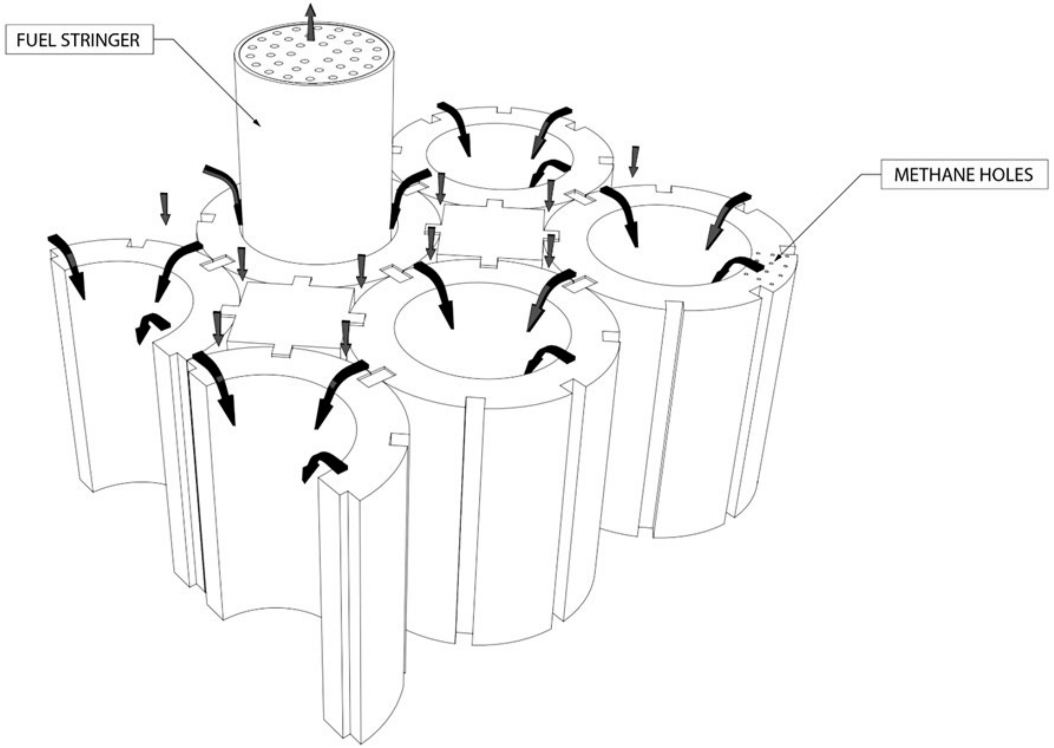
Damage tolerance – Magnox reactors



- Single pass gas flow up the channel transfers heat away from the fuel
- If a fuel brick cracks radially, coolant gas can leak from the channel
- This potentially starves fuel higher in the channel from coolant gas
- This could potentially lead to a fuel melt
- **Brick cracking cannot be tolerated**
- **No cracked bricks observed after more than 40 years operation**

Damage tolerance – AGRs (1)

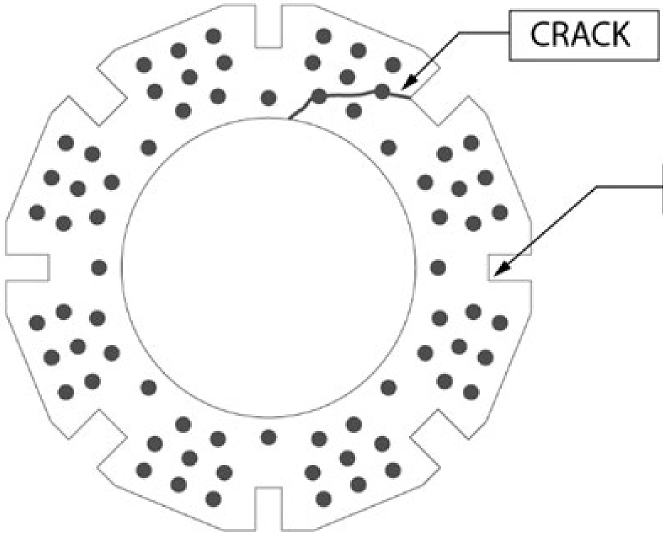


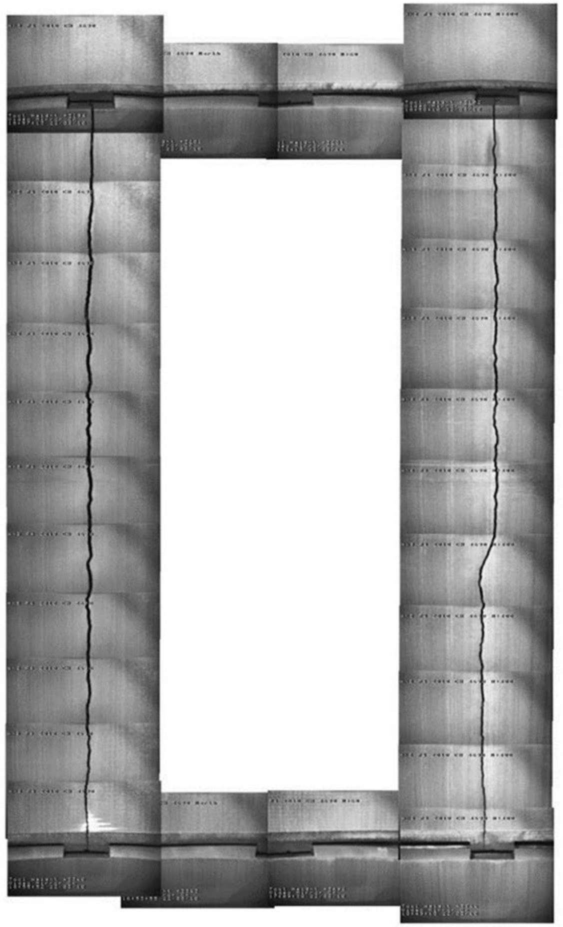


The arrangement of fuel bricks looks similar to a Magnox core but now the fuel is sleeved with a re-entrant flow configuration.

Damage tolerance – AGRs (2)

- Unexpected cracking observed early in reactor life at fuel channel wall
- Followed by extensive radial and axial cracking with many bricks breaking into two separate C-pieces
- Gas flow over the fuel and fuel temperatures broadly unaffected because of intact graphite sleeves





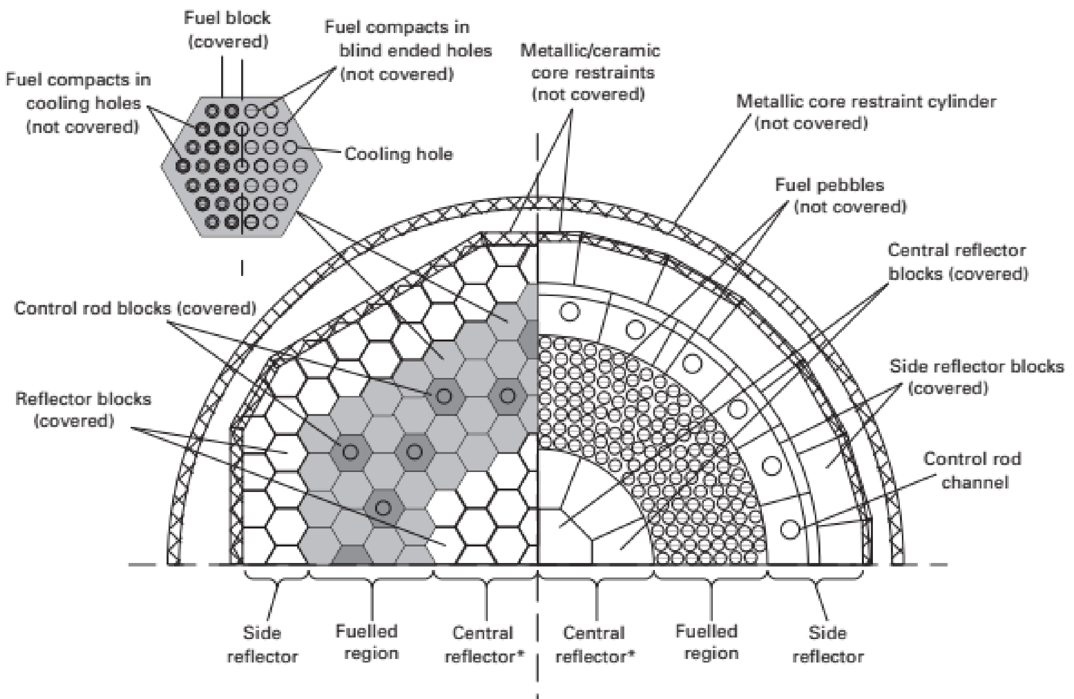
- **Brick cracking regarded as benign**
- **Continued reactor operation dependent upon regular extensive inspections and comparison of inspection findings with predictive models**

How is ASME addressing damage tolerance?

- This issue is relevant to two sections of the ASME code
  - SECTION III - Rules for Construction of Nuclear Facility Components, Division 5: High Temperature Reactors
  - SECTION XI - Rules for Inservice Inspection of Nuclear Reactor Facility Components, Division 2: Requirements for Reliability and Integrity Management (RIM) Programs for Nuclear Reactor Facilities

Section III Division 5 Design

Figure HHA-1400-1
Jurisdictional Boundary for Graphite Core Components and Assemblies — Circumferential Section View



* Some designs may not have a central reflector i.e., the fuelled region extends to the core centerline

Prismatic and Pebble Bed type designs

Gas and salt heat transfer mediums

Section III Division 5 - Classification

- All graphite components are assigned to a Structural Reliability Classification (SRC) by the Owner.
- SRC-1: The Structural Reliability of components in this class is important to safety. These parts may be subject to environmental degradation.
- Integrity assessments focus on these components only.

Section III Division 5 – Reliability Target for SRC-1 Components

- The requirements for component acceptability are set by a Reliability Target through analysis by means of a simple or full assessment methodology.
- In the case of SRC-1 components, the Reliability Target is set at a *Probability of Failure* of 10^{-4}.
- This target is given no physical explanation – why this value and what is failure
- Assessment outputs for the simple and full methods of analysis are not equivalent as will be seen later.

Section III Division 5 – Basic analysis approach

- The analysis employs Maximum Deformation Energy Theory.
- This allows for an arbitrary stress state at a point to be converted to an equivalent stress that can be compared directly to the results of a uniaxial strength test.
- It only applies to ductile materials. Graphite is a quasi-brittle material.
- There may be justification for this approach……

Section III Division 5 – Simple assessment

- Stresses in a complex component geometry are represented as a single equivalent tensile stress in a standard dog-bone test specimen.
- The maximum equivalent stress is compared with the allowable stress based on a Weibull strength distribution for standard dog-bone test specimens. The allowable stress si calculated from:
- BUT the evaluated probability of failure relates to constant uniaxial tensile stress and this will not be the stress state in a complex component geometry.
- At best, the assessment provides the user with a Probability of Crack Initiation, but offers no insight into crack propagation and loss of component functionality (failure).

Section III Division 5 – Full assessment

- The full stress distribution is modelled across discreet volumes within the component. (as with the simple assessment).
- Equivalent stresses are assessed against a Weibull strength distribution to evaluate Probabilities of Survival. These are grouped and combined using a modified Weakest Link Theory to evaluate an associated Probability of Failure, which can be compared with the 10^{-4} target reliability for an SRC-1 component.
- If a Reliability Target is not met based upon Weakest Link Theory, then, unlike the simple assessment, by definition this will lead to crack initiation and propagation between external surfaces of the component (at zero stress).
- BUT this probability relates to the formation of a through crack in an undefined direction which differs from the simple assessment criterion.
- The assessment provides the user with a Probability of Through-Crack Formation but offers no insight into its direction and potential loss of component functionality (failure).

Section III Division 5 – Assessment outputs

- The simple assessment will inform the user on the likelihood of crack initiation based upon an approximation of its geometry to a uniaxial tensile strength test specimen, but offers nothing on the significance of this event.
- The full assessment will inform the user on the likelihood of a through-crack in the component, but not on the potential significance of this event.

Section III Division 5 – Analysis summary

- There is no clarification on the use of the term ‘Failure’.
- Depending upon the assessment method chosen, the likelihood of meeting the same Reliability Target will have different meanings. Designers will need to qualify the significance of assessment outputs.
- The assessment methods do not provide a predictive tool to assess potential loss of component functionality needed to support reactor operation.

Section III Division 5 – Reference to Reliability and Integrity Management

- No reference to Section XI Division 2 as this currently only addresses metallic components
- Very limited reference to inspection and monitoring:
  - “design should consider in-service inspection, operational monitoring, component repair or replacement, as appropriate”
  - addresses machining, examination and testing pre-assembly
  - addresses installation and examination
- Guidance/requirements on the design to cover RIM during **reactor operation** are non-existent

Section XI Division 2 – Strategy for graphite components

- As reported last year, a Task Group has been set up to consider how non-metallic components in advanced reactors should be addressed.
- A strategy of first addressing graphite components in high temperature gas reactors has been approved comprising a new Supplement for Section XI Division 2 preceded by a Code Case to highlight damage mechanisms and RIM options.
- RIM strategies will need to be supported and guided by an understanding of component functionality and damage prediction models.

Summary

- This presentation makes no comment on ASME design assessment methodologies.
- The design code rules should be revised to provide greater clarity on the significance of assessment outputs and what is meant by failure if this term is used in the text.
- Ideally, Section III Division 5 should be providing a focus for Section XI Division 2 on how inspection and monitoring should be managed, identifying damage tolerance and expected levels of damage during operation.

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Thank you for your attention.

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