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Defect Tolerance Assessments

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What are we trying to prevent

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ONR SAPs

Engineering principles: Integrity of metal components and structures: Highest reliability components and structures	Safety case and assessment	EMC.1
The safety case should be especially robust and the corresponding assessment suitably demanding, in order that a properly informed engineering judgment can be made that: (a) the metal component or structure is as defect-free as possible; and (b) the metal component or structure is tolerant of defects.		

- Acceptance that real components are not perfect bodies and flaws / defects can and do exist.
- EMC.1 lays downs the expectation that SSCs which are where the highest levels of reliability are required should be tolerant of defects.
- The component should be tolerant of defects that are not reliably detected by qualified inspections.

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ONR SAPs Failure

Engineering principles: Integrity of metal components and structures: Design	Failure Modes	EMC.11
Failure Modes should be gradual and predictable		

Engineering principles: Integrity of metal components and structures: Design	Brittle Behaviour	EMC.12
Designs in which components of a metal pressure boundary could exhibit brittle behaviour should be avoided		

- ONR has an expectation that failure modes are gradual and predictable and brittle behaviour is to be avoided.
- The avoidance of brittle behaviour will, in the majority, be controlled by material selection but failure modes are an important consideration in defect tolerance assessments (DTA).
- DTAs can give confidence that defect growth is tolerable and not a significant threat to the component.

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ONR SAPs - Analysis

To meet Principles EMC.1 and EMC.2, the safety case should include appropriate evidence of the following:

(b) a detailed design loading specification covering normal operation, faults and accident conditions. This should include plant transients and internal and external hazards;
(c) consideration of potential in-service degradation mechanisms;
(d) analysis of the potential failure modes for all conditions arising from design specification loadings;

Engineering principles: Integrity of metal components and structures: Design	Loadings	EMC.7
The schedule of design loadings (including combinations of loadings) for components and structures, together with conservative estimates of their frequency of occurrence should be used as the basis for design against normal operation, fault and accident conditions. This should include plant transients and tests together with internal and external hazards.		

- Bounding Transients from within the design transient specification.
- Most in-service degradation mechanisms (FAC, Generalised Corrosion) and Stress Corrosion Cracking ruled out.
- Due to the presence of a flaw / defect fatigue crack growth cannot be dismissed.

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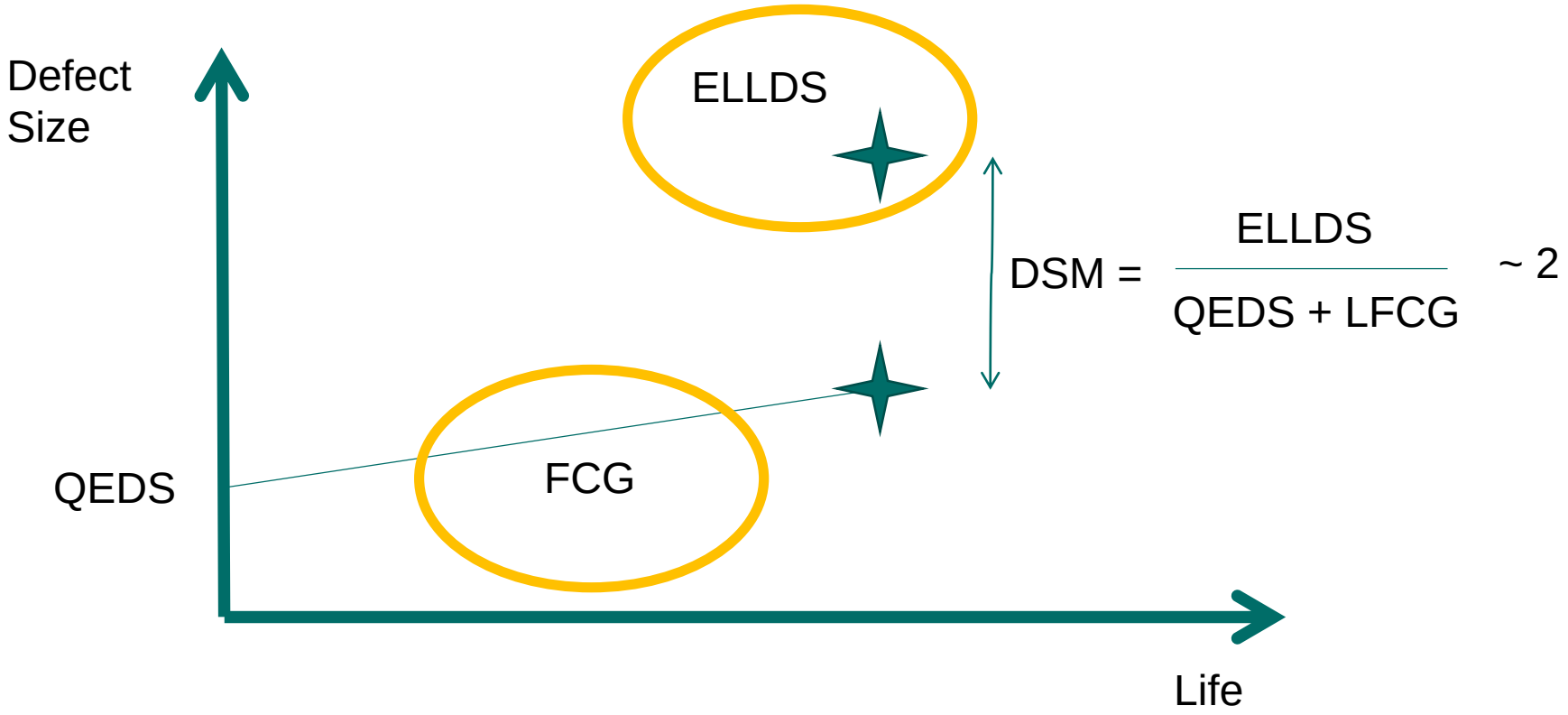
Defect Size Margin



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Code Based Fracture Assessments

- Provisions for estimate of proximity to fast fracture:
  - ASME = Brittle Fracture.
  - RCC-M = Brittle Fracture & Ductile Tearing.
- Used to determine operational pressure and temperature limits considering Level A & B transients.
- Simplified approach predominantly based on linear elastic fracture mechanics.
- Limited consideration:
  - No guidance on Level C and D transients.
  - No consideration of residual stress.
  - Single defect considered.
  - No account for in-service degradation.
  - No account for spatial variations in material properties.

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Beyond code expectations

Engineering principles: Integrity of metal components and structures: Analysis	Defect sizes	EMC.34
Where high reliability is needed for components and structures and where otherwise appropriate, the sizes of crack-like defects of structural concern should be calculated using verified and validated fracture mechanics methods with verified application.		

- Expectations:
  - Explicit link between QEDS and limiting defect size
  - Need to consider most onerous loading conditions.
  - Need to evaluate implication of degradation.
  - Analysis route should be demonstrably conservative.
- Analysis through standard code based fracture mechanics is limited and likely to be overly conservative.
- Analysis route should consider all design basis loads imparted on the component that (e.g. External Hazards, Jet impingement from design basis and residual stress).

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Defect Tolerance Assessments

- Failure processes more complex than simple brittle fracture calculations.
- Methods developed to provide a detailed understanding of the behaviour of defects under all transients.
- Codified approach to reduce calculation burden and improve consistency.
- Allows link to be made to QEDS.
- Includes:
  - Defect characterisation.
  - Consideration of plastic collapse.
  - Estimation and inclusion of Residual Stresses.
  - Interaction of primary and secondary stresses.
  - Ductile tearing arguments.
  - Fatigue crack growth.

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UK Methodology

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DTA Inputs

Engineering principles: Integrity of metal components and structures: Analysis	Use of Data	EMC.33
The data used in analyses and acceptance criteria should be clearly conservative, taking account of uncertainties in the data and their contribution to the safety case.		

- Assessment Locations:
  - Sufficient locations should be analysed to confirm the tolerance of the component to defects not reliably detect by inspections.
- Stress Analysis:
  - Conservative assumption of transient behaviour.
  - Conservative application of boundary conditions.
  - Uncertainties should be identified and accounted for.
  - Numerical models should be validated.
- Material Properties:
  - Must be a conservative prediction accounting for variations induced by the manufacture of the component.
  - Should represent end of life material properties taking account of potential degradation mechanisms (e.g. irradiation embrittlement, thermal ageing).
- SIF & Limit Load Solutions:
  - Selection must be justified and demonstrated to be conservative.

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Sensitivity Studies

315. In particular, the uncertainties associated with material properties affected by degradation should be taken into account.

316. Where appropriate, studies should be carried out to determine the sensitivity of analytical results to the assumptions made, the data used and the methods of calculation.

- ONR expectation is that where appropriate sensitivity studies are performed.
- What are the uncertainties in the Analysis?
- How sensitive is the estimated ELLDS to given inputs.
- Is there a potential Cliff Edge?

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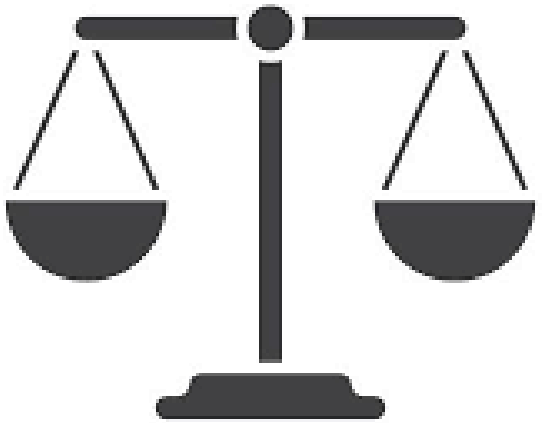
Safety Case Considerations

- Defect tolerance assessment (DTA) are not sufficient in isolation.
- Integration within the safety case (EMC.1, EMC 34 and Para 317) where DTA and QEDS must be supportive to provide confidence in the integrity of the component.
- If appropriate conservatisms can be challenged however care must be taken when removing conservatisms.
- A balance is required to ensure that neither material properties, DTA nor inspections are placed under undue burden.



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Questions