

<b>REGULATORY OBSERVATION</b>	
<b>REGULATOR TO COMPLETE</b>	
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<b>Resolution of Regulatory Observation required by:</b>	To be determined by the Hitachi-GE Resolution Plan
<b>TRIM Ref.:</b>	2014/135593
<b>Related RQ / RO No. and TRIM Ref. (if any):</b>	
<b>Observation title:</b>	Avoidance of Fracture – Margins based on the size of Crack-Like Defects
<b>Technical area(s)</b> 12. Structural Integrity	<b>Related technical area(s)</b>
<b><i>Regulatory Observation</i></b>	
<p>The Preliminary Safety Report on Structural Integrity, GA91-9901-005-00001 Rev. A dated 4 December 2013 (TRIM Ref. 2013/449504) notes that there will be some failure modes where it is not reasonably practicable to provide protection and failure would not be tolerable. In these circumstances there will be a need for the safety case to claim that the likelihood of gross failure of the component is very low, which the report judges to be below <math>10^{-7}</math>/year, termed Very High Integrity Components (VHICs) by Hitachi-GE.</p> <p>Thus the safety case will need to identify those components and failure modes which fall into this category through the structural integrity classification process (as outlined in GA91-9901-005-00001 Rev. A dated 4 December 2013) and then provide a demonstration that the likelihood of gross failure is so low that it can effectively be discounted from the deterministic safety analyses.</p> <p>This is an onerous route to constructing a safety case and an in-depth explanation of the measures over and above normal practice will be needed to support and justify these 'highest reliability components' as discussed in paras 243-247 of ONR's Safety Assessment Principles (SAP). ONR will judge the demonstration for the VHICs against the specific SAPs for the 'highest reliability components' EMC.1 to EMC.3. Hitachi-GE may also define some High Integrity Components (HICs) with reliability claims less than VHICs, but beyond normal code compliance. These will be judged against similar criteria.</p> <p>EMC.1 states that the safety case should be especially robust in order that engineering judgement can be made on two key requirements: a) the metal component should be as defect free as possible; and b) the metal component or structure should be tolerant of defects. This Regulatory Observation on 'Avoidance of Fracture – Margins based on the size of Crack-Like defects' is intended to provide guidance on ONR's expectations on the latter aspect of demonstrating that the component should be tolerant of defects.</p> <p>Avoidance of failure by propagation of crack-like defects is based on a 'defence in depth' approach of:</p> <ol style="list-style-type: none"> <li>1. absence of crack-like defects at the end of the manufacturing process - confirmed by examinations during manufacture;</li> <li>2. material toughness offering good resistance to propagation of crack-like defects - underpinned by minimum material toughness requirements in Equipment Specifications;</li> <li>3. absence of in-service sub-critical crack growth mechanisms that could lead to the increase in the size of pre-existing defects; or in the extreme, nucleation and growth of defects from an essentially defect-free initial condition.</li> </ol>	

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Usually the main locations of concern are welds, but some base material areas may also be relevant. The dominant in-service, sub-critical defect growth mechanism is expected to be some form of fatigue.

A measure of the 'margin' implied by the above 'defence-in-depth' approach, and one based directly on defect size is:

$$DSM = ELLDS / (QEDS + LFCG)$$

where:

DSM - Defect Size Margin

ELLDS - End of Life Limiting Defect Size, is the size of defect which is calculated to give a fracture driving force equal to an end-of-life fracture toughness criterion. The fracture toughness criterion is intended to be a 'lower bound' to the true fracture toughness. Hence the term 'limiting defect size' is used rather than 'critical defect size', the latter implying actual failure;

QEDS - Qualified Examination Defect Size, is the defect size that can be detected, sized and characterised with high confidence. The claim for defect size would be supported by qualification of the examination. The extent of qualification depends on the difficulty and novelty of the examination;

LFCG - Lifetime Fatigue Crack Growth, is the calculated fatigue crack growth over the lifetime of the component, starting with an initial crack size equal to the Qualified Examination Defect Size (QEDS).

This defect size margin approach requires manufacturing examinations capable of detecting and sizing crack-like defects of concern. The basic logic of this approach is to underwrite the claim that the component enters service with either no crack-like defects or at least defects sufficiently small for there to be a substantial margin to the limiting defect size; the margin being expressed as the Defect Size Margin (DSM).

The approach in the UK has been to seek a target DSM of 2.

Thus if a defect of the QEDS size was in a component on entering service and grew by the LFCG amount by the end of life, the resulting defect would still not be capable of precipitating failure.

A margin based on defect size is preferred over, for instance, one based on load margin. Fracture of a component is caused by the presence of a crack.

In practice the dependence on manufacturing examinations usually means use of ultrasonic techniques. This approach may require ultrasonic examinations during manufacture that are not required by the applicable design/fabrication code or standard. The examinations referred to here are those conducted during manufacture. The role of in-service examination is not considered here.

For this approach, there are some fundamental supporting requirements:

**Materials Toughness:** There needs to be a basis for a conservative (lower bound) value of fracture toughness for end of life conditions. In some cases (e.g. shells of Reactor Pressure Vessel), this might be based on worldwide data, with minimum requirements in the component Equipment Specification to ensure the specific materials of manufacture are within the worldwide dataset, or it may be based on company specific data but again with minimum requirements in the component Equipment Specification.

**Qualification of Manufacturing Examinations:** Ultrasonic examination is the predominant means of examination for crack-like defects. The European Network on Inspection Qualification (ENIQ) provides a framework for such qualification.

As input to the qualification, a definition is required for the nature and size of defects to be found with high confidence. Usually, the qualification requirement will not be set at the theoretical smallest defect the technique can find. Instead the requirement is to set the qualification defect size less than the limiting defect

size, by some margin.

Whilst qualification will ultimately require the production of geometry specific test pieces and practical trials, this will not be required within GDA. For GDA there will be a need to describe the qualification process and include Technical Justifications to justify the examination approaches being proposed. It is expected that the inspection requirements derived from this process will be in addition to standard code based requirements, and there will be a need to show that they are sufficiently diverse and redundant.

Crack-like defects are usually characterised by a depth (component through wall direction) and a length (along the component wall direction). Surface breaking defects at either the inner or outer surfaces of components will usually give the highest crack driving force for a given set of conditions. In determining limiting defect conditions, the analyses should consider the crack front at the deepest through-wall position and at the surface points. For this deterministic approach, a representative crack shape aspect ratio is required. To cover a range of likely possibilities, 1:10 and 1:2 depth to length ratios might be chosen. There should be consistency between defect aspect ratios included in the qualification, and those used in the fracture mechanics analyses for limiting defect sizes, recognising that limiting defect depth is likely to be derived from an elongated defect.

Limiting Defect Size Analyses: All relevant materials are ductile thus the analyses need to make use of elastic-plastic fracture mechanics methods.

All design basis load conditions need to be considered, from normal operation to fault (loads for which ASME III Service Levels A, B, C and D apply).

For analyses of loads for which Level A and B Limits apply, initiation fracture toughness is expected to be used. For analyses of loads for which Levels C and D Limits apply, fracture toughness based on a limited amount of stable tearing would be acceptable, so long as the level of toughness and stable tearing is supported by test data. This load/toughness combination balances likelihood of occurrence of the load with the margin on toughness to actual failure.

Whatever measure of fracture toughness is used, it should be representative of end of life conditions.

The fracture analyses should include primary and secondary stresses, including weld residual stresses.

All potential locations for crack-like defects should be included in the fracture mechanics analyses. In practice the assessment of the demonstrably limiting locations with each component has been shown to be sufficient for GDA purposes, but more extensive analyses may be required prior to operation.

It is reasonable to use bounding loading conditions to limit the volume of analysis work, however care is needed. For example, an analysis for a load for which Level D limits apply that used stable tearing would not bound an analysis for a load for which Level A limits applied and where initiation toughness was used (the Level D load would bound the level A load, but the tearing toughness would exceed the initiation toughness and so would not be bounding).

To implement the approach outlined above requires a number of Regulatory Observation Actions.

### ***Regulatory Observation Actions***

RO-ABWR-0001.A1

#### **Material Properties**

There are two specific deliverables:

1. A materials property handbook suitable for supporting the fracture mechanics assessment including minimum toughness values, with allowances for through life degradation, with reference to supporting sources.
2. A strategy for undertaking fracture toughness testing on relevant material as part of the manufacturing

process (forgings and welds) to underpin the minimum toughness values assumed in the material handbook, and to include such minimum values in the Equipment Specifications for the components.

*Resolution required by:* To be determined by the Hitachi-GE Resolution Plan

RO-ABWR-0001.A2

**Fracture Assessment**

There are two specific deliverables:

1. Identification of limiting locations for each component requiring a highest reliability claim.

(It is assumed that the structural integrity classification process outlined in 'The Preliminary Safety Report on Structural Integrity' GA91-9901-005-00001 Rev. A dated 4 December 2013 will have already identified those components requiring a VHIC or HIC claim).

2. Limiting defect size analysis for limiting locations using elastic-plastic fracture mechanics methods with bounding transients and estimates of fatigue crack growth through life.

*Resolution required by* To be determined by the Hitachi-GE Resolution Plan

RO-ABWR-0001.A3

**Manufacturing Inspection**

There are two specific deliverables:

1. The strategy for manufacturing inspections using techniques of established capability and providing sufficient redundancy, diversity and independence. In the case of critical locations (eg welds) the most rigorous inspections will be expected. The ENIQ methodology, which incorporates the concept of technical justifications, provides a suitable framework for achieving inspection qualification for such critical locations.
2. Detailed inspection proposals, with technical reasoning, to demonstrate that the target defect sizes can be reliably detected taking into account their potential location, morphology and orientation.

*Resolution required by* To be determined by the Hitachi-GE Resolution Plan

RO-ABWR-0001.A4

**Overall Avoidance of Fracture Demonstration**

This should bring together the outputs from the material testing proposals, fracture assessment and manufacturing inspection to make the overall avoidance of failure demonstration by showing that structurally significant defects would be reliably detected using suitably redundant, diverse and where appropriate qualified inspection techniques, and that the minimum toughness properties assumed in the analysis work will be substantiated through fracture toughness testing of relevant material.

*Resolution required by* To be determined by the Hitachi-GE Resolution Plan

**REQUESTING PARTY TO COMPLETE**

**Actual Acknowledgement date:**

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RP stated Resolution Plan agreement date:	
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