



C. PROCEDURE APPLICATION (FITNET)



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- **INTRODUCTION**
- **ASSESSMENT OF SCC**
- **ASSESSMENT OF CORROSION FATIGUE**
- **STRESS CORROSION AND CORROSION FATIGUE ANALYSIS**
- **ASSESSMENT OF LOCAL THINNED AREAS**



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INTRODUCTION

INTRODUCTION

The FITNET FSS Procedure provides guidelines on the appropriate steps to take when a stress corrosion or a corrosion fatigue crack as well as local thin area (LTA) has been detected in service and an assessment has to be one of the implications for structural integrity. Such an evaluation should be made in the context of the perceived consequences of failure using appropriate risk-based management methodologies. Since this is plant/component specific it is beyond the scope of this procedure.



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INTRODUCTION

Hence, this section deals primarily with the Fitness-for-Service assessments of damage types due to ;

a) Environmental assisted cracking (EAC)

a1) Stress corrosion cracking,

a2) Corrosion fatigue and

b) Local Thinned Area (LTA)

in metallic components with or without welds.



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ASSESSMENT OF EAC

ASSESSMENT OF ENVIRONMENTAL ASSISTED CRACKING

Introduction

When assessing the integrity of structures with cracks or crack-like defects, it is necessary to consider whether sub-critical crack growth is a potential factor. If so, an estimate of the amount of tolerable growth during the design lifetime or between in-service inspections is required.

Therefore, structural integrity evaluations have to take into account the peculiarities of the damage processes when Environmental Assisted Cracking (EAC) is likely to occur. The basic tool for the characterization of EAC processes is the Fracture Mechanics, which has to be used with different criteria depending on the problem being assessed.

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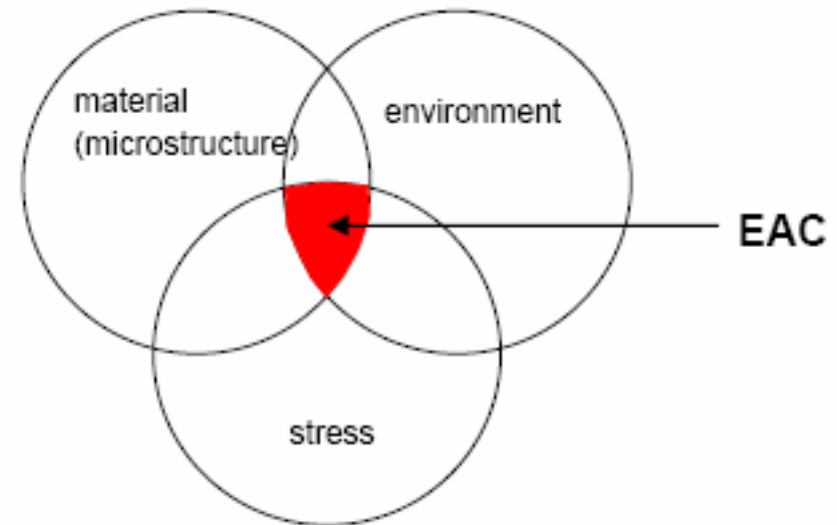
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ASSESSMENT OF EAC

**ASSESSMENT OF ENVIRONMENTAL
ASSISTED CRACKING**

Introduction (cont.)

Three conditions are necessary in order EAC to occur, either at global or local level, as shown in the Figure: a susceptible material associated to the presence of an aggressive environment and loading conditions over a characteristic threshold level.





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ASSESSMENT OF EAC

ASSESSMENT OF ENVIRONMENTAL ASSISTED CRACKING

Introduction (cont.)

In this section, subcritical crack growth due to stress corrosion cracking and corrosion fatigue (both of them EAC processes) is considered, with crack growth rate prediction in service based principally on the application of fracture mechanics in terms of either stress intensity factor (K) in the case of stress corrosion cracking, or the range of stress intensity factor (ΔK), in corrosion fatigue.

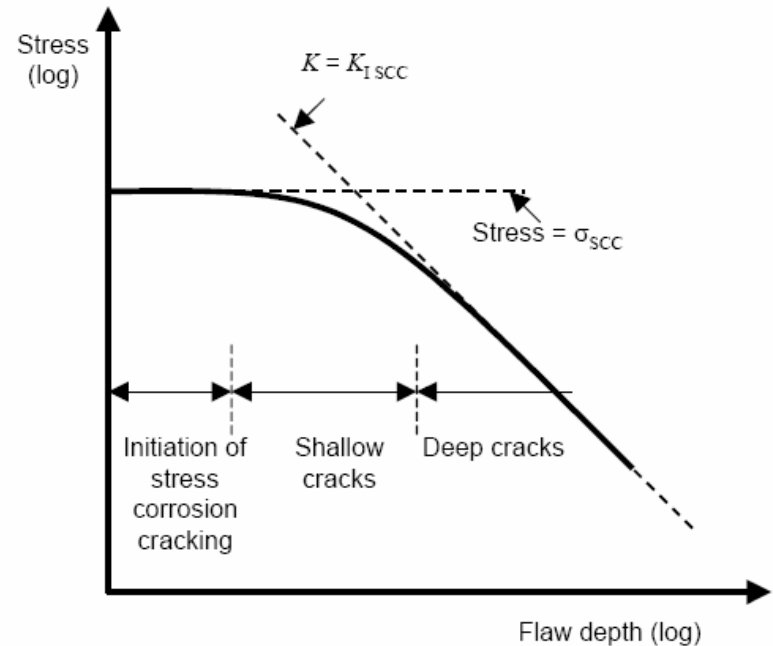


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ASSESSMENT OF EAC

ASSESSMENT OF ENVIRONMENTAL ASSISTED CRACKING

Introduction (cont.)

Underlying that assumption is the presumption that the flaws or cracks are of a dimension that allows a description of the mechanical driving force by linear elastic fracture mechanics. In practice, for some systems, a significant amount of life may occur in the short crack regime. The figure illustrates the transition in mechanical driving force with flaw size for a stress corrosion crack; similar behaviour is observed for corrosion fatigue cracks.



Schematic diagram of the two parameter approach to stress corrosion cracking



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ASSESSMENT OF EAC

ASSESSMENT OF ENVIRONMENTAL ASSISTED CRACKING

Introduction (cont.)

Different uncertainties (loads, environment,...), allied to expert judgment, feed into the risk assessment when adopting a risk-based inspection methodology. In FITNET, a procedural approach to evaluating the evolution of damage due to environment assisted cracking is presented that includes:

- [STEP 1- Characterise the nature of the crack](#)
- [STEP 2- Establish cause of cracking](#)
- [STEP 3- Define the material characteristics](#)
- [STEP 4- Establish data for stress-corrosion cracking assessment](#)
- [STEP 5- Undertake structural integrity assessment](#)



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ASSESSMENT OF EAC

ASSESSMENT OF ENVIRONMENTAL ASSISTED CRACKING

STEP 1- Characterise the nature of the crack

Once a crack has been detected, a first step is to develop a complete physical evaluation in terms of its shape and dimensions, with any uncertainty in size from the particular detection method taken into account. This evaluation should include an assessment of the crack location in relation to local stress concentrators, welds, crevices (e.g. at fasteners, flanges), and also the details of the crack path and crack orientation, if feasible. If more than one crack is present, the crack density and the spacing between the cracks should be noted in view of possible future coalescence.



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ASSESSMENT OF EAC

ASSESSMENT OF ENVIRONMENTAL ASSISTED CRACKING

STEP 2- Establish cause of cracking

Identifying the cause of cracking in terms of the mechanistic process, i.e. stress corrosion or corrosion fatigue, may be challenging unless service conditions allow ready discrimination; for example, an absence of significant cyclic loading. Characterising the crack as a stress corrosion crack may be possible from visible observation, e.g. significant crack branching (although such branching would preclude simple stress analysis and warrant removal of the crack).

Where cyclic loading is apparent, corrosion fatigue should be considered to be the primary mechanism of crack growth. However, the loading frequency is a key factor with the influence of the environment on crack propagation decreasing in significance as the frequency increases and for many systems often being insignificant at frequencies greater than about 10 Hz.



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ASSESSMENT OF EAC

ASSESSMENT OF ENVIRONMENTAL ASSISTED CRACKING

STEP 2- Establish cause of cracking (cont.)

The service conditions that need to be defined include the stress state and the environmental conditions:

- Stresses (see 9.1.2.2.1.1)
- Service environment (see 9.1.2.2.1.2)
 - Development of local environments (crevicing, hideout/evaporation, deposits) (see 9.1.2.2.1.2.1)
 - Excursions (see 9.1.2.2.1.2.2)
 - Corrosion (or system) monitoring (see 9.1.2.2.1.2.3)



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ASSESSMENT OF EAC

ASSESSMENT OF ENVIRONMENTAL ASSISTED CRACKING

STEP 3- Define the material characteristics

The first step is to ensure that the material of relevance actually corresponds to that specified at the design stage. In essence, this relates primarily to the quality control aspects of fabrication and installation and means assessing the traceability of the materials selection and welding process relative to the design specification. In some cases, in-situ measurement such as hardness may be undertaken. There are a number of factors that may subsequently affect the performance of the material.

For further information see Section 9.1.2.3 of the Procedure and the [Basic Concepts on Environmental Effects](#) provided on this Training Package.



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ASSESSMENT OF EAC

ASSESSMENT OF ENVIRONMENTAL ASSISTED CRACKING

STEP 4- Establish data for stress-corrosion cracking assessment: K_{ISCC} determination

The concept of K_{ISCC} is not trivial and the value is sensitive to the environmental conditions, temperature and loading characteristics. Accordingly, data obtained for one condition should not be transposed to another.

Initiation and growth can occur in the domain for which linear elastic fracture mechanics is inapplicable. The growth rate in the short crack domain and its relation to the relevant mechanical driving force is poorly characterised in stress corrosion cracking and needs further research.



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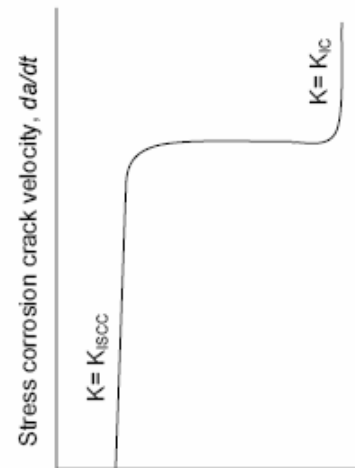
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ASSESSMENT OF EAC

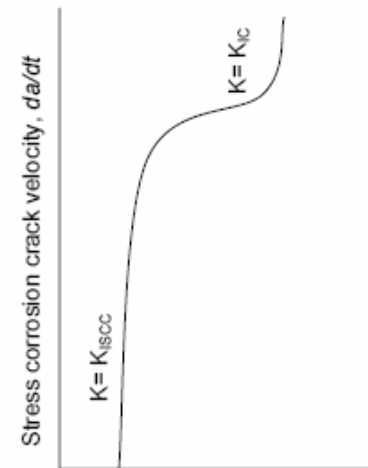
ASSESSMENT OF ENVIRONMENTAL ASSISTED CRACKING

STEP 4- Establish data for stress-corrosion cracking assessment: K_{ISCC} determination

When the crack is of a length commensurate with the application of fracture mechanics, a threshold stress intensity factor for stress corrosion crack propagation, K_{ISCC} , is often defined. For long cracks, the behaviour is typically as represented in the Figure.



a) Stress intensity factor, K



b) Stress intensity factor, K

Further information is provided in Section 9.1.2.4.1



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STEP 4- Establish data for stress-corrosion cracking assessment: Stress corrosion crack growth determination

The crack velocity during stress corrosion testing of pre-cracked fracture mechanics specimens can be measured using the procedures given in ISO 7539-6 and the crack monitoring methods given in BS7910. It is most relevant to obtain crack growth rate for the conditions of practical relevance and to fit the data with a growth law appropriate to the data. For example:

$$\frac{da}{dt} = C(K_I)^n \quad K_{ISCC} \leq K \leq K_C$$



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ASSESSMENT OF ENVIRONMENTAL ASSISTED CRACKING

STEP 4- Establish data for corrosion-fatigue assessment: ΔK_{th} determination

The threshold value of the stress intensity factor range (ΔK_{th}) in corrosion fatigue is influenced by crack size and by the stress ratio. FITNET provides reference for guidance on determination of ΔK_{th} .

In the short crack regime, where LEFM becomes invalid, cracks can grow at ΔK values seemingly below ΔK_{th} , because the latter is commonly determined from long crack measurement.



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STEP 4- Establish data for corrosion-fatigue assessment: ΔK_{th} determination (cont.)

Also, in the long crack regime, increasing the stress ratio, $R = \sigma_{min} / \sigma_{max}$, will usually reduce the threshold value because of diminished impact of crack closure. For that reason a high R value for the threshold is a sensible conservative assumption.

In the same context as stress corrosion cracking, it is important to simulate sensibly the service conditions in terms of the environment and loading conditions, particularly, frequency and waveform.



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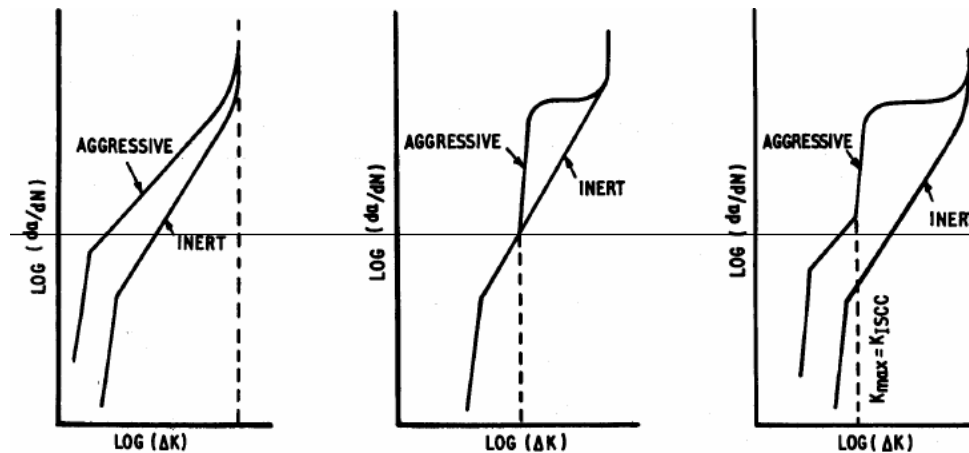
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ASSESSMENT OF EAC

ASSESSMENT OF ENVIRONMENTAL ASSISTED CRACKING

STEP 4- Establish data for corrosion-fatigue assessment: Crack growth determination

The form of the crack growth rate curves cannot be generalised as they are system specific. Some schematic examples for constant amplitude loading are shown in the Figure.



Basic types of corrosion-fatigue crack growth behaviour.



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STEP 4- Corrosion fatigue crack growth data

The procedure provides recommended fatigue crack growth laws for steels in marine environment, as well as recommended fatigue crack growth thresholds for assessing welded joints (see 9.1.2.4.3.3)



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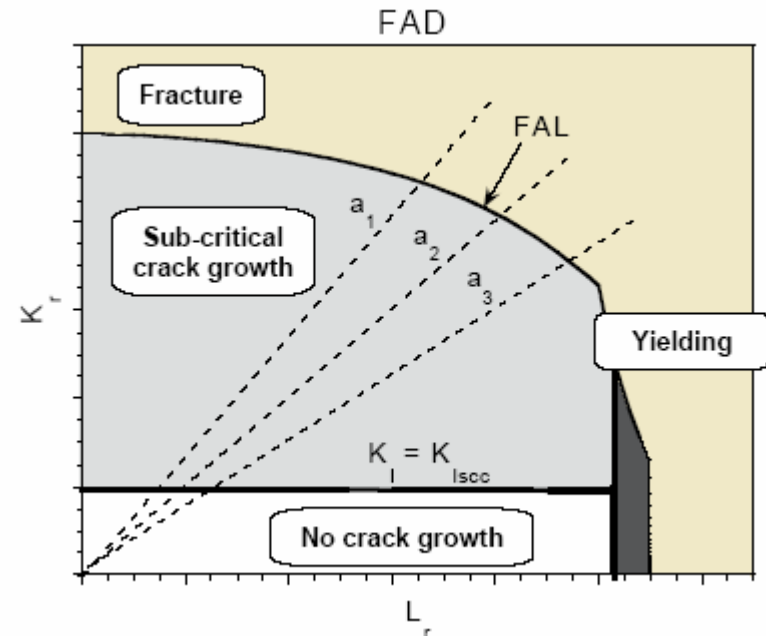
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ASSESSMENT OF ENVIRONMENTAL ASSISTED CRACKING

STEP 5: Undertake structural integrity assessment

This Figure shows the cracking related areas in the universal FAD plot.

The global FAD representation could be used to define areas related to different cracking micro-mechanisms (IG, TG by cleavage or tearing...) if the constitutive equation to differentiate them is known.





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ASSESSMENT OF CORROSION FATIGUE

ASSESSMENT OF ENVIRONMENTAL ASSISTED CRACKING

STEP 5: Undertake structural integrity assessment

STEP 5a- Perform a fracture assessment for the initial crack size, based on the measured detected value or upon a maximum value reflecting the uncertainty in detection.

STEP 5b- If effective remedial measures are not possible and/or slow subcritical crack growth can be tolerated, then apply sections 9.1.2.1 9.1.2.3 to fully characterise the nature of the crack and the service conditions driving it.

STEP 5c- Compute the stress at the flaw, including any dynamic components, based on anticipated future operating conditions.

STEP 5d- Determine the evolution of the crack size based on the previous flaw size, or value and crack growth laws.

STEP 5e- Determine the time or number of stress cycles for the current crack size (a_0 , c_0) to reach the limiting flaw size in relation to the FAD or LBB criteria.



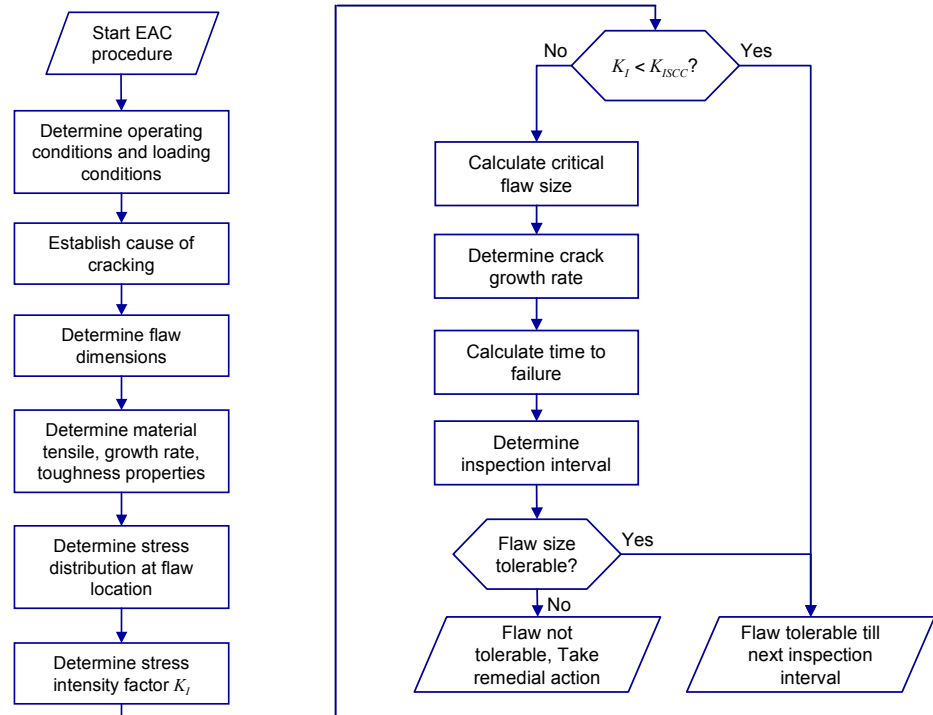
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STEP 5: Undertake structural integrity assessment

The methodology is summarised in the following flowchart:

For further information see Section 9.1.2.5 in the Procedure.





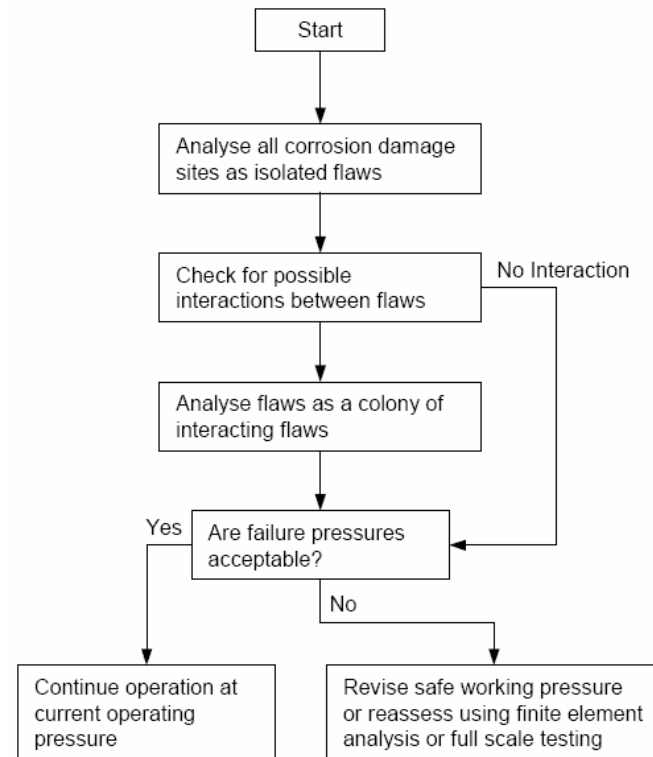
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ASSESSMENT OF LOCAL THINNED AREAS

ASSESSMENT OF LOCAL THINNED AREAS (LTA)

The methods specified in FITNET FFS procedure may be used to assess Local Thinned Area (LTA) flaws in pipes and pressure vessels that have been designed to a recognized design code.

The guidance does not cover every situation that requires a fitness for purpose assessment and further methods may be required.

A flowchart of the procedure is shown in the figure:





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ASSESSMENT OF LOCAL THINNED AREAS

ASSESSMENT OF LOCAL THINNED AREAS (LTA)

The steps, as defined by the procedure, are the following:

STEP 1- Establish cause of wall thinning (corrosion, erosion, grinding damage...)

STEP 2- Define service condition

STEP 3- Collect material properties

STEP 4- Analysis



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ASSESSMENT OF LOCAL THINNED AREAS

ASSESSMENT OF LOCAL THINNED AREAS (LTA)

The procedure defines the type of defects to which the procedure can be applied and provides formulation for the assessment of specific geometries and loading conditions:

- Cylindrical body (Section 9.2.5.3)
- Sphere and vessel end (Section 9.2.5.4)
- Elbow (Section 9.2.5.5)
- Nozzles (Section 9.2.5.6)

The procedure provides guidance on the rules in order to take into account the interaction among adjacent LTA flaws (Section 9.2.5.7)