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API RP 579 (Fitness for Service) and Application in the Refining and Petrochemical Industries

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ABSTRACT

An overview of API 579 *Recommended Practice For Fitness-For-Service* [1], which was released in the 1st quarter of 2000, is presented. The API Recommended Practice 579 is intended to supplement and augment the requirements in API 510 (Pressure Vessel Inspection Code) [2], API 570 (Piping Inspection Code) [3], and API 653 (Aboveground Storage Tank Inspection Code) [4]: to ensure safety of plant personnel and the public while older equipment continues to operate; to provide technically sound Fitness-For-Service (FFS) assessment procedures; to ensure that different service providers furnish consistent remaining life predictions; and to help optimize maintenance and operation of existing facilities to maintain availability of older plants and enhance long-term economic viability. In addition, API 579 compliments the API 580 Recommended Practice For Risk-Based Inspection [5] that was recently (June 2002) released to provide minimum guidelines for risk assessment, and prioritization for inspection and maintenance planning for pressure-containing equipment.

Motivations to create API 579 and the activities of a Materials Properties Council (MPC) Joint Industry Project (JIP) to initiate development of the new FFS technologies included in this publication are discussed. An overview of the Recommended Practice is given which covers applicability of assessment procedures, overall organization, the general assessment methodology used for all flaw and damage types, options for different assessment levels, remaining life and rerating issues, and the relationship with other existing FFS codes and standards. A review of current FFS technology development efforts, the results of a technical gap analysis on the first edition of API 579, and plan for future technology enhancements are provided. Plans for a joint API and ASME standard, and future directions of the API in-service inspection codes relative to API 579 and equipment integrity are also covered.

INTRODUCTION

The ASME and API design codes and standards for pressurized equipment provide rules for the design, fabrication, inspection, and testing of new pressure vessels, piping systems, and storage tanks. These codes do not address the fact that equipment degrades while in-service and deficiencies due to degradation or from original fabrication may be found during subsequent

inspections. FFS assessments are quantitative engineering evaluations, which are performed to demonstrate the structural integrity of an in-service component containing a flaw or damage. API 579 has been developed to provide guidance for conducting FFS assessments of flaws commonly encountered in the refining and petrochemical industry, which occur in pressure vessels, piping, and tankage. However, the assessment procedures can also be applied to flaws encountered in other industries such as the pulp and paper industry, fossil fuel utility industry, and nuclear industry. The guidelines provided in API 579 can be used to make run-repair-replace decisions to ensure that pressurized equipment, containing flaws identified during inspection, can continue to be operated safely.

API 579 DEVELOPMENT BACKGROUND

The initial impetus to develop a FFS standard that could be referenced from the API inspection codes was provided by a JIP administered by the MPC. The driving force behind this development was plant safety. The methodology provided for in this document, together with the appropriate API inspection code/s, ensures that equipment integrity can be safely maintained though aged, or containing flaws or damage, and could also be used to demonstrate compliance with US OSHA 1910 PSM Legislation.

A review of the existing international FFS standards by the members of the MPC JIP was undertaken in 1991 as the starting point for the development of a new FFS standard. Based on the results of this review, it was determined that a comprehensive FFS standard covering many of the typical flaw types and damage mechanisms found in the refining and petrochemical industry did not exist. In addition, the existence of many company-based FFS methods, the complexity of the technology that no single company can solve on its own, and the need to gain acceptance by local jurisdictions in the US further indicated the need for a new standard. Therefore, the JIP decided to start the development of the required FFS technology that would be needed to write a comprehensive FFS standard for the refining and petrochemical industry. The results of this work were documented in a MPC FFS JIP Consultant's Report [6], and this document was subsequently turned over to the API Committee On Refinery Equipment's (CRE) FFS Task Force charged with development of the FFS standard.

In terms adopted by the API CRE FFS Task Group developing API 579, a FFS assessment is an engineering analysis of equipment to determine whether it is fit for continued service. The equipment may contain flaws, may not meet current design standards, or may be subjected to more severe operating conditions than the original or current design. The product of a FFS assessment is a decision to operate the equipment as is, alter, repair, monitor, or replace; guidance on an inspection interval is also provided. FFS assessments consist of analytical methods to assess flaws and damage and usually require an interdisciplinary approach consisting of the following:

- Knowledge of damage mechanisms/material behavior
- Knowledge of past and future operating conditions & interaction with operations personnel
- NDE (flaw location and sizing)
- Material properties (environmental effects)
- Stress analysis (often finite element analysis)
- Data analysis (engineering reliability models)

Based on this definition, the API CRE FFS Task Group modified and greatly enhanced the initial efforts of the MPC JIP to produce the first edition API 579. The MPC JIP continued to provide valuable technical contributions throughout this development effort and essentially became the technical development arm of the API Task Group. The MPC FFS JIP is still in existence and continues to provide FFS technology development while working closely with the needs of the API CRE FFS Task Group.

OVERVIEW OF API RP 579

Applicable Codes

API 579 provides guidelines for performing FFS assessments that can be used in conjunction with the API Inspection Codes (API 510, API 570 and API 653) to determine the suitability for continued operation. The assessment procedures in this recommended practice can be used for FFS assessments and/or rerating of components designed and constructed to the following codes

- ASME B&PV Code, Section VIII, Division 1
- ASME B&PV Code, Section VIII, Division 2
- ASME B&PV Code, Section I
- ASME B31.3 Piping Code
- ASME B31.1 Piping Code
- API 650
- API 620

Guidelines are also provided for applying API 579 to pressure-containing equipment constructed to other recognized codes and standards, including international and internal corporate standards.

Organization

API 579 is a highly structured document designed to facilitate use by practitioners and to facilitate future enhancements and modifications by the API CRE FFS Task Group. Section 1 of the document covers: introduction and scope; responsibilities of the owner-user, inspector, and engineer; qualification requirements for the inspector and engineer; and references to other codes and standards. An outline of the overall FFS assessment methodology that is common to all assessment procedures included in API 579 is provided in Section 2 of the document. The organization of Section 2 is shown in Table 1. This same organization is utilized in all subsequent sections that contain FFS assessment procedures.

Starting with Section 3, a catalogue of FFS assessment procedures organized by damage mechanism is provided in API 579. A complete listing of the flaw and damage assessment procedures currently covered is shown in Table 2. These damage mechanisms can be grouped at a higher level to form a degradation class (see Figure 1). This higher level of organization is useful in that it provides insight into how the assessment procedures of different sections may be combined to address complex flaws in a component. As shown in Figure 1, several flaw types and damage mechanisms may need to be evaluated to determine the FFS of a component. Each section in API 579 referenced within a degradation class includes guidance on how to perform an assessment when multiple damage mechanisms are present.

When assessment procedures are developed for a new damage mechanism, they will be added as a self-contained section to maintain the structure of API 579. Currently, new sections are being developed to address HIC/SOHIC damage, local hot spots, assessment procedures for riveted components, and creep crack growth.

A series of appendices are provided which contain technical information that can be use with all sections of API 579 that cover FFS assessment procedures. The majority of the information in the appendices covers stress analysis techniques, material property data, and other pertinent information that is required when performing a FFS assessment.

Assessment Methodology

The API 579 FFS assessment method used for all damage types is shown in Table 3. The organization of each section of API 579 that covers assessment procedures is consistent with this methodology. This consistent approach to the treatment of damage and the associated FFS assessment procedures facilitates use of the document. If a practitioner is familiar with one section of the document, it is not difficult to utilize another section because of the common structure. This assessment methodology has proven to be robust for all flaw and damage types that have been incorporated into API 579. Because of this success when new sections are added to API 579, the template used for the development will be based on this assessment methodology.

FFS Assessment Levels

Three levels of assessment are provided in API 579 for each flaw and damage type. A logic diagram is included in each section to illustrate how these assessment levels are interrelated. In general, each assessment level provides a balance between conservatism, the amount of information required for the evaluation, the skill of the practitioner performing the assessment, and the complexity of analysis being performed. Level 1 is the most conservative, but is easiest to use. Practitioners usually proceed sequentially from a Level 1 to a Level 3 assessment (unless otherwise directed by the assessment techniques) if the current assessment level does not provide an acceptable result or a clear course of action cannot be determined.

A general overview of each assessment level and its intended use are described below:

- *Level 1* – The assessment procedures included in this level are intended to provide conservative screening criteria that can be utilized with a minimum amount of inspection or component information. The Level 1 assessment procedures may be used by either plant inspection or engineering personnel.
- *Level 2* – The assessment procedures included in this level are intended to provide a more detailed evaluation that produces results that are less conservative than those from a Level 1 assessment. In a Level 2 assessment, inspection information similar to that required for a Level 1 assessment are required; however, more detailed calculations are used in the evaluation. Level 2 assessments are typically conducted by plant engineers or engineering specialists experienced and knowledgeable in performing FFS assessments.
- *Level 3* – The assessment procedures included in this level are intended to provide the most detailed evaluation that produces results that are less conservative than those from a Level 2 assessment. In a Level 3 assessment the most detailed inspection and component information is typically required, and the recommended analysis is based on numerical techniques such as

the finite element method. The Level 3 assessment procedures are primarily intended to be used by engineering specialists experienced and knowledgeable in performing FFS evaluations.

Equipment Remaining Life Determinations And Re-rating

The FFS assessment procedures in API 579 cover both the present integrity of the component given a current state of damage and the projected remaining life. If the results of a FFS assessment indicate that the equipment is suitable for the current operating conditions, the equipment can continue to be operated at these conditions if a suitable inspection program is established. If the results of the FFS assessment indicate that the equipment is not suitable for the current operating conditions, calculation methods are provided in API 579 to rerate the component. For pressurized components (e.g. pressure vessels and piping) these calculation methods can be used to find a reduced Maximum Allowable Working Pressure and/or coincident temperature. For tank components (i.e. shell courses) the calculation methods can be used to determine a reduced Maximum Fill Height. The remaining life calculation in API 579 is not intended to provide a precise estimate of the actual time to failure. Alternatively, the remaining life calculation is used to establish an appropriate inspection interval in conjunction with the governing inspection code and/or in-service monitoring plan, or the need for remediation.

Relationship To Other FFS Standards

As previously discussed, members of the MPC FFS JIP reviewed existing international FFS standards to determine the suitability for use in the refining and petrochemical industry. Although a single comprehensive standard did not exist, technology contained in these international standards was identified that could be utilized for certain flaw types. Where possible, parts of these methodologies were incorporated into API 579, and in many cases they were significantly enhanced. In some cases, where the technology was not directly incorporated, the API CRE FFS Task Group members felt that alternate approaches may be desirable for use by more advanced practitioners. Therefore, the Level 3 assessment in API 579 permits the use of alternative FFS assessment methodologies. For example, the Level 3 assessment in Section 9 of API 579 covering crack-like flaws provides references to Nuclear Electric R-6 [7], BS 7910 [8], SAQ/FoU-Report 96/08 [9], WES 2805 [10], and EPRI J-Integral methodology [11].

TECHNOLOGY DEVELOPMENT FOR API 579

Currently, the driving force behind the new technology development efforts for FFS technology in the US is the MPC FFS JIP. This organization has continued to fund and develop significant technology enhancements to the FFS assessment procedures in API 579. Currently, the MPC FFS JIP is sponsoring technology development in the following areas:

- Fracture toughness prediction for in-service materials
- Stress intensity factor and reference stress solutions
- Partial safety factors for crack-like flaws
- NDE round-robin on detection/sizing of environmental damage
- Validation of LTA and crack-like flaw assessment techniques
- HIC-SOHIC damage

In addition, API is sponsoring a program to evaluate NDE sizing reliability, and the Pressure Vessel Research Council (PVRC) is sponsoring FFS technology development in the following areas:

- White paper on assessment methods for crack-like flaws
- White paper on assessment methods for LTA's, pitting, shell misalignment and shell out-of-roundness
- Development of assessment methods for LTA's at shell discontinuities (this project is also being sponsored by the National Board and the MPC JIP)
- Recommendations for in-service operating margins

The API CRE FFS Task Group performed a gap analysis of the technology incorporated into the assessment procedures in the initial publication of API 579 to determine areas where new developments are required to enhance FFS analysis capabilities. The API CRE FFS Task Group is producing a plan to work with the MPC FFS JIP and the PVRC Committee on Flaw Evaluation to prioritize the technology needs identified in the gap analysis and to establish a funding mechanism to address these needs. The focus of all future development efforts will be to produce additional sections for API 579.

API AND ASME FFS ACTIVITIES

In the area of FFS, API and ASME have created a new standards committee that will jointly produce a single FFS standard in the US that can be used for pressure containing equipment. API 579 will form the basis of the joint API/ASME standard that will be produced by this committee. The initial release of the new standard will include all topics currently contained in API 579 and will also contain an FFS assessment procedure for the evaluation of creep crack growth. This assessment procedure is currently being developed by the PVRC Committee on Flaw Evaluation and is sponsored by the Edison Electric Institute.

The agreement to produce a joint standard on FFS technology is a landmark decision that will focus resources in the US to develop a single document that can be used in all industries. This will help avoid jurisdictional conflicts and promote uniform acceptance of FFS technology. It also provides an opportunity for pooling of resources of API, ASME, PVRC, and MPC to develop new FFS technology as required by the standards committee.

FUTURE DIRECTIONS OF THE API IN-SERVICE INSPECTION CODES

The in-service inspection codes in the US for pressure containing equipment comprise of:

- API 510 – Pressure Vessels
- API 570 – Piping
- API 653 – Tankage
- ANSI NB-23 [12] – Pressure Vessels & Piping

Currently, these inspection codes have empirical rules used for metal loss and pitting damage, do not permit crack-like flaws, and provide minimum guidance on other flaws and damage types (e.g. blisters, creep, and fire damage). In addition, these codes impose an inspection interval based on equipment condition with a maximum inspection interval cap. In the future, the owner-user will be able to evaluate metal loss and pitting damage with technology-based rules that can be used to rerate components with damage if necessary. Crack-like flaws in components may be

acceptable pending an FFS assessment, and better guidance on assessment procedures for common types of damage mechanisms found in the refining and petrochemical industry will be provided. Moreover, the in-service inspection codes will permit use of FFS assessments to develop an appropriate inspection interval based on the level of damage at the option of the owner-user.

The first edition of API 579 is being published as a recommended practice; jurisdictional acceptance is obtained by reference from an inspection code or standard. Currently, API is working to modify API 510, API 570, and API 653 to provide this reference and remove existing empirical FFS assessment rules contained in these codes or modify them such that API 579 can be used as an alternative. The benefits of having a comprehensive FFS document that is tightly integrated with the API inspection codes are:

- Ease of use in assessing flaws and damage mechanisms including jurisdictional acceptance
- Extended safe operation of damaged equipment based on industry accepted assessment methods (API/ANSI)
- New basis for inspection planning
- Flexibility in developing tactics for repair and/or replacement of damaged equipment
- Turnaround support decision making with a goal to minimize turnaround scope and length

Integration of the FFS assessment procedures with the in-service inspection codes also facilitates effective use of the emerging RBI technologies to maximize equipment availability and to improve sustainable maintenance performance. The FFS and RBI relationship depends upon the type of RBI study. In a RBI study using a qualitative evaluation, FFS assessment procedures can be used to alter the risk ranking of equipment based on the level of damage and the results of the assessment. In a RBI study using a quantitative evaluation, the FFS assessment procedures provide a model for flaw and damage analysis that can be used to establish a probability of failure. The probability of failure can be combined with a consequence of failure model to produce risk that can be subsequently utilized in the RBI study. Work is underway to identify areas to improve API 579 to facilitate use with the API in-service inspection codes and API 580. When work is complete, API 580 can be used to set the scope, method of inspection, and inspection interval for a piece of equipment. If damage is found, the inspection interval can be modified based on the results of a FFS assessment performed in accordance with API 579.

CONCLUSIONS

Fitness-For-Service (FFS) assessments are quantitative engineering evaluations that are performed to demonstrate the structural integrity of an in-service component containing a flaw or damage. API 579 has been developed to provide guidance for conducting FFS assessments of equipment in the refining and petrochemical industry. The assessment procedure can also be applied to flaws encountered in other industries such as the pulp and paper industry, fossil fuel utility industry, and nuclear industry. The guidelines provided in this recommended practice can be used to make run-repair-replace decisions to ensure that pressurized equipment containing flaws that have been identified by inspection can continue to be operated safely.

API 579 is intended to supplement and augment the requirements in API 510, API 570, and API 653. In addition, API 579 will also be used in conjunction with API 580 to provide guidelines

for risk assessment, and prioritization for inspection and maintenance planning for pressure-containing equipment.

FFS is a powerful technology that can be used to extend the useful life of aging equipment or in some cases allow new equipment with flaws and/or damage to enter service without repairs. In many cases, significant savings can be realized because FFS enables the owner-user to operate equipment until the next scheduled downtime without compromising safety thereby minimizing unscheduled downtimes. In many cases repair or replacement can be avoided. The landmark decision by API and ASME to produce a single joint standard will promote jurisdictional acceptance and permit pooling of resources with other technical organizations such as PVRC and MPC which will greatly enhance the ability to develop new FFS technology.

REFERENCES

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- [12] NBIC, *National Board Inspection Code*, ANSI/NB-23, National Board, Columbus Ohio, 1995.
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Table 1 – Organization Of Each Section In API 579

| Section Subparagraph Number | Title | Overview |
|------------------------------------|--|---|
| 1 | General | The scope and overall requirements for an FFS assessment are provided. |
| 2 | Applicability and Limitations of the FFS Assessment Procedures | The applicability and limitations for each FFS assessment procedure are clearly indicated; these limitations are stated in the front of each section for quick reference. |
| 3 | Data Requirements | The data requirements required for the FFS assessment are clearly outlined; these data requirements include: <ul style="list-style-type: none"> • Original equipment design data • Maintenance and operational history • Required data/measurements for a FFS assessment • Recommendations for inspection technique and sizing requirements |
| 4 | Assessment Techniques and Acceptance Criteria | Detailed assessment rules are provided for three levels of assessment: Level 1, Level 2, and Level 3. A discussion of these assessment levels is covered in the body of this paper. |
| 5 | Remaining Life Evaluation | Guidelines for performing a remaining life estimate are provided for the purpose of establishing an inspection interval in conjunction with the governing inspection code. |
| 6 | Remediation | Guidelines are presented on methods to mitigate and/or control future damage. In many cases, changes can be made to the component or to the operating conditions to mitigate the progression of damage. |
| 7 | In-Service Monitoring | Guidelines for monitoring damage while the component is in-service are provided, these guidelines are useful if a future damage rate cannot be estimated easily or the estimated remaining life is short. In-service monitoring is one method whereby future damage or conditions leading to future damage can be assessed or confidence in the remaining life estimate can be increased. |
| 8 | Documentation | Guidelines for documentation for an assessment are provided; the general rule is - <i>A practitioner should be able to repeat the analysis from the documentation without consulting an individual originally involved in the FFS assessment.</i> |
| 9 | References | A comprehensive list of technical references used in the development of the FFS assessment procedures is provided; references to codes and standards are provided in this Section. |
| 10 | Tables and Figures | Tables and Figures including logic diagrams are used extensively in each section to clarify assessment rules and procedures. |
| 11 | Example Problems | A number of example problems are provided which demonstrate the application of the FFS assessment procedures. |

Table 2 – Overview of Flaw and Damage Assessment Procedures

| Flaw or Damage Mechanism | Section In API 579 | Overview |
|---|--------------------|--|
| Brittle Fracture | 3 | Assessment procedures are provided to evaluate the resistance to brittle fracture of in-service carbon and low alloy steel pressure vessels, piping, and storage tanks. Criteria are provided to evaluate normal operating, start-up, upset, and shutdown conditions. |
| General Metal Loss | 4 | Assessment procedures are provided to evaluate general corrosion. Thickness data used for the assessment can be either point thickness readings or detailed thickness profiles. A methodology is provided to guide the practitioner to the Local Metal Loss assessment procedures based on the type and variability of thickness data recorded during an inspection. |
| Local Metal Loss | 5 | Assessment techniques are provided to evaluate single and networks of Local Thin Areas (LTAs), and groove-like flaws in pressurized components. Detailed thickness profiles are required for the assessment. The assessment procedures can also be utilized to evaluate blisters. |
| Pitting Corrosion | 6 | Assessment procedures are provided to evaluate widely scattered pitting, localized pitting, pitting which occurs within a region of local metal loss, and a region of localized metal loss located within a region of widely scattered pitting. The assessment procedures can also be utilized to evaluate a network of closely spaced blisters. The assessment procedures utilize the methodology developed for Local Metal Loss. |
| Blisters and Laminations | 7 | Assessment procedures are provided to evaluate either isolated, or network of blisters and laminations. The assessment guidelines include provisions for blisters located at weld joints and structural discontinuities such as shell transitions, stiffening rings, and nozzles. |
| Weld Misalignment and Shell Distortions | 8 | Assessment procedures are provided to evaluate stresses resulting from geometric discontinuities in shell type structures including weld misalignment and shell distortions (e.g. out-of-roundness, bulges, and dents). |
| Crack-Like Flaws | 9 | Assessment procedures are provided to evaluate crack-like flaws. Recommendations for evaluating crack growth including environmental concerns are also covered. |
| High Temperature Operation and Creep | 10 | Assessment procedures are provided to determine the remaining life of a component operating in the creep regime. The remaining life procedures are limited to the initiation of a crack. |
| Fire Damage | 11 | Assessment procedures are provided to evaluate equipment subject to fire damage. A methodology is provided to rank and screen components for evaluation based on the heat exposure experienced during the fire. The assessment procedures of the other sections of this publication are utilized to evaluate component damage. |

Table 3 – API 579 FFS Assessment Methodology For All Damage Types

| Step In FFS Assessment Procedure | Description |
|---|---|
| 1 | <i>Flaw and Damage Mechanism Identification</i> – The first step in a Fitness-For-Service assessment is to identify the flaw type and cause of damage. FFS assessments should not be performed unless the cause of the damage can be identified. The original design and fabrication practices, materials of construction, service history, and environmental conditions can be used to ascertain the likely cause of the damage. Once the flaw type is identified, the appropriate section of this document can be selected for the assessment. |
| 2 | <i>Applicability and Limitations of the FFS Assessment Procedures</i> – The applicability and limitations of the assessment procedure are described in each section, and a decision on whether to proceed with an assessment can be made. |
| 3 | <i>Data Requirements</i> – The data required for FFS assessments depend on the flaw type or damage mechanism being evaluated. Data requirements may include: original equipment design data; information pertaining to maintenance and operational history; expected future service; and data specific to the FFS assessment such as flaw size, state of stress in the component at the location of the flaw, and material properties. Data requirements common to all FFS assessment procedures are covered in Section 1. Data requirements specific to a damage mechanism or flaw type are covered in the section containing the corresponding assessment procedures. |
| 4 | <i>Assessment Techniques and Acceptance Criteria</i> – Assessment techniques and acceptance criteria are provided in each section. If multiple damage mechanisms are present, more than one section may have to be used for the evaluation. |
| 5 | <i>Remaining Life Evaluation</i> – An estimate of the remaining life or limiting flaw size should be made. The remaining life is established using the FFS assessment procedures with an estimate of future damage rate (i.e. corrosion allowance). The remaining life can be used in conjunction with an inspection code to establish an inspection interval. |
| 6 | <i>Remediation</i> – Remediation methods are provided in each section based on the damage mechanism or flaw type. In some cases, remediation techniques may be used to control future damage associated with flaw growth and/or material degradation. |
| 7 | <i>In-Service Monitoring</i> – Methods for in-service monitoring are provided in each section based on the damage mechanism or flaw type. In-service monitoring may be used for those cases where a remaining life and inspection interval cannot adequately be established because of the complexities associated damage mechanism and service environment. |
| 8 | <i>Documentation</i> – The documentation of an FFS assessment should include a record of all data and decisions made in each of the previous steps to qualify the component for continued operation. Documentation requirements common to all FFS assessment procedures are given in section 2 of API 579. Specific documentation requirements for a particular damage mechanism or flaw type are covered in the section containing the corresponding assessment procedures. |

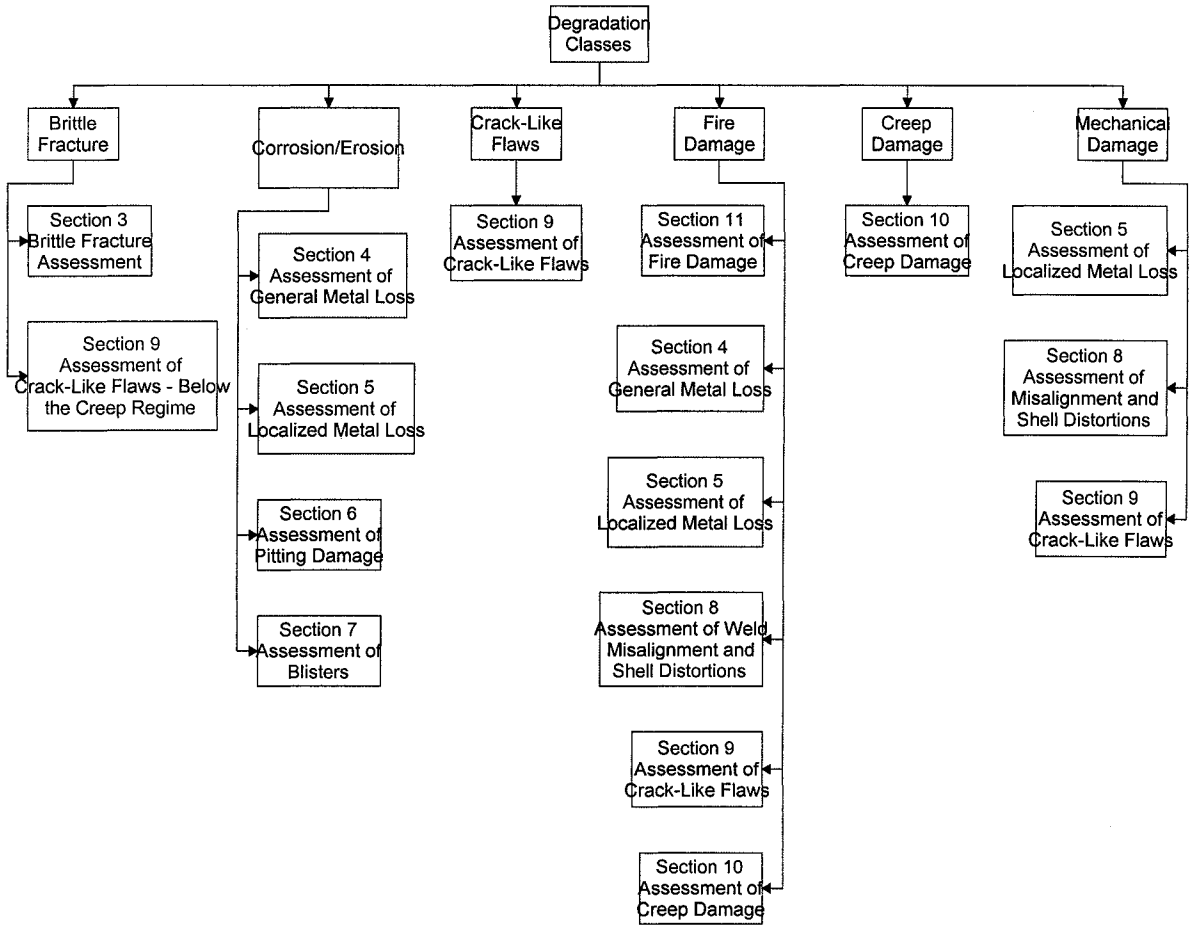


Figure 1 – Degradation Classes In API 579