API 16A, TG #5, HPHT Update

Jim Raney
Director, Engineering & Technology
Anadarko Petroleum Corporation
API 16A, TG #5, HPHT Agenda

• Basis of Design
• HPHT Definition for 16A HPHT
• Guidelines (API, 30 CFR 250.807 and TAS)
• The Approach (Scope, Schedule and Contents)
  1. Design Philosophy
  2. Verification
  3. Validation
  4. Materials
  5. Quality
• Systems Approach to HPHT Design
  – System-Level HPHT Design
  – Subsystem-Level HPHT Design
  – Assembly-Level HPHT Design
• Details/Back up Slides
Basis of Design

Product Development Process For Existing or New Design Equipment

PER15K / 30 CFR 250.807
HPHT Definition for 16A, HPHT

• Various definitions in industry
  – Tier I, Tier II, Ultra-HPHT, etc.

• 30 CFR 250.807 also defines HPHT as:
  – >15,000 psi or >350° F

• Limit 16A, HPHT to:
  – <30,000 psi or <450° F
Guidance Currently Available

Numerous codes, standards, recommended practices, reports, etc. have been published. 30 API standards reviewed contain HPHT requirements. A partial listing is below:

• API
  – RP 75
  – Q1, Q2
  – S 53
  – Existing 15k codes (SC 6, 16, 17, 19, etc.) ← Can get us started (only)
  – 1PER15K-1
  – 17TR8 – AMSE Sect VIII, Div 2/3
  – API 14A SSSVs - Twelfth Edition (Published Jan 2015, effective Jan 2016)
  – API 11D1 Packers - Third Edition
  – API 14L Landing Nipples and Lock Mandrels


• Regulatory / CFR
  – 30 CFR 250 Subpart S (Mandatory)
  – 30 CFR 250.107 (Mandatory)
  – 30 CFR 250.807 (Mandatory)
  – 30 CFR 250 Subpart G (Proposed; not currently mandatory)
  – Technical Assessment Section (TAS) guidance notes, dtd 12-10-15
Approach

• Perform gap analysis of existing 16A 4th ed. ballot draft against 20A and other HPHT requirements

• Use as go-bys:
  – HPHT design philosophy
  – 1PER15K / 17TR8 / 16A
  – BOP functional specification
  – API 14A HPHT annex
  – BSEE TAS guidance

• Divide into sub-workgroups to draft content
  1. Design Philosophy
  2. Verification
  3. Validation
  4. Materials
  5. Quality
Organization and Schedule

- API has approved work group #5 for the development of the design specifications for an HPHT BOP system. It is anticipated that this document will be added as an ANNEX to the new API Spec 16A document after completion. After that the SC 16 committee can determine if this needs to be a stand alone document.
- This document will follow API 16A, TR PER15K-1, API 17 TR8 and other SC 19 and SC6 documents covering HPHT design specifications and apply these to BOP systems.
- The document will be an annex to be incorporated into API 16A latest addition as an annex including the following guidance:
  1. This annex will outline the requirements for the qualification of an HPHT BOP System for Deepwater GOM requirements.
  2. The draft scope is included in this document.
  3. This will be an HPHT annex therefore we will only cover additional requirements for HPHT and allow API Spec 16A (base document) cover those requirements that are the same.

### Draft Schedule:

<table>
<thead>
<tr>
<th>Date</th>
<th>Task</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aug 2015</td>
<td>Table of Contents</td>
</tr>
<tr>
<td>Sept 2015</td>
<td>Design Verification/Validation Testing Flow Charts</td>
</tr>
<tr>
<td>Oct-Dec 2015</td>
<td>Work on Draft</td>
</tr>
<tr>
<td>Jan 2016</td>
<td>Draft of major sections</td>
</tr>
<tr>
<td>Feb-May 2016</td>
<td>Work on the draft and fill in the details</td>
</tr>
<tr>
<td>Summer 2016</td>
<td>1st Ballot on draft</td>
</tr>
<tr>
<td>Fall 2016</td>
<td>Review comments</td>
</tr>
<tr>
<td>Winter 2016/2017</td>
<td>2nd Ballot</td>
</tr>
</tbody>
</table>
Scope

This standard specifies requirements for performance, design, materials, testing and inspection, welding, marking, handling, storing and shipping of drill-through equipment used for drilling for oil and gas. It also defines service conditions in terms of pressure, temperature and wellbore fluids for which the equipment will be designed.

This standard is applicable to and establishes requirements for the following specific equipment:
   a) ram blowout preventers;
   b) ram blocks, packers and top seals;
   c) annular blowout preventers;
   d) annular packing units;
   e) hydraulic connectors;
   f) drilling spools;
   g) adapters;
   h) loose connections;
   i) Clamps
   j) OEC-other end connections - e.g. Drilling spools; Adapters; Loose connections; Clamps;

Dimensional interchangeability is limited to end and outlet connections.
# Table of Contents of HPHT Annex to API 16A

Annex XX (normative) Qualification for an HPHT Drill-through Equipment

<table>
<thead>
<tr>
<th>Section</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>X.1 Scope</td>
<td></td>
</tr>
<tr>
<td>X.2 Normative References</td>
<td></td>
</tr>
<tr>
<td>X.3 Terms &amp; Definitions</td>
<td></td>
</tr>
<tr>
<td>X.4 HPHT Design Philosophy</td>
<td></td>
</tr>
<tr>
<td>X.5 HPHT Design Verifications Requirements</td>
<td></td>
</tr>
<tr>
<td>X.5.1 Size designation</td>
<td></td>
</tr>
<tr>
<td>X.5.2 Service conditions</td>
<td></td>
</tr>
<tr>
<td>X.5.3 Equipment-specific design requirements</td>
<td></td>
</tr>
<tr>
<td>X.5.4 Design methods</td>
<td></td>
</tr>
<tr>
<td>X.5.5 Design verification</td>
<td></td>
</tr>
<tr>
<td>X.6 HPHT Validation Testing Requirements</td>
<td></td>
</tr>
<tr>
<td>X.6.1 FEMCA</td>
<td></td>
</tr>
<tr>
<td>X.6.2 Validation Testing Design</td>
<td></td>
</tr>
<tr>
<td>X.6.3 Tests for BOP and hydraulic connector</td>
<td></td>
</tr>
<tr>
<td>X.6.4 Design temperature validation testing</td>
<td></td>
</tr>
<tr>
<td>X.6.5 Operating requirements</td>
<td></td>
</tr>
<tr>
<td>X.7 Material Requirements</td>
<td></td>
</tr>
<tr>
<td>X.7.1 General</td>
<td></td>
</tr>
<tr>
<td>X.7.2 Written specifications</td>
<td></td>
</tr>
<tr>
<td>X.8 Welding requirements</td>
<td></td>
</tr>
<tr>
<td>X.8.1 General</td>
<td></td>
</tr>
<tr>
<td>X.8.2 Weldment design and configuration</td>
<td></td>
</tr>
<tr>
<td>X.8.3 Welding controls</td>
<td></td>
</tr>
<tr>
<td>X.8.4 Welding procedure and performance</td>
<td></td>
</tr>
<tr>
<td>X.8.5 Other requirements</td>
<td></td>
</tr>
<tr>
<td>X.9 Quality control requirements</td>
<td></td>
</tr>
<tr>
<td>X.9.1 General</td>
<td></td>
</tr>
<tr>
<td>X.9.2 Measuring and testing equipment</td>
<td></td>
</tr>
<tr>
<td>X.9.3 Quality control personnel qualifications</td>
<td></td>
</tr>
<tr>
<td>X.9.4 Quality control requirements for</td>
<td></td>
</tr>
<tr>
<td>equipment and parts</td>
<td></td>
</tr>
<tr>
<td>X.9.5 Quality control requirements for</td>
<td></td>
</tr>
<tr>
<td>specific equipment and parts</td>
<td></td>
</tr>
<tr>
<td>X.9.6 Requirements for quality control</td>
<td></td>
</tr>
<tr>
<td>records</td>
<td></td>
</tr>
<tr>
<td>X.10 Storing and shipping</td>
<td></td>
</tr>
<tr>
<td>X.10.1 Storing for periods greater than 30</td>
<td></td>
</tr>
<tr>
<td>days</td>
<td></td>
</tr>
<tr>
<td>X.10.2 Shipping</td>
<td></td>
</tr>
<tr>
<td>X.11 Marking requirements</td>
<td></td>
</tr>
<tr>
<td>X.11.1 General</td>
<td></td>
</tr>
<tr>
<td>X.11.2 Types of identification stamping</td>
<td></td>
</tr>
<tr>
<td>X.11.3 Specific codification requirements of</td>
<td></td>
</tr>
<tr>
<td>equipment</td>
<td></td>
</tr>
<tr>
<td>X.11.4 Product description code (PDC)</td>
<td></td>
</tr>
</tbody>
</table>
1. Design Philosophy

- Incorporate 1PER15K / 17TR8 elements
- Design basis – user to generate load cases
- Functional / Technical specification
- Risk analysis
- Verification & Validation (other workgroups)
- Design review (I3P or other)
- Production & quality (other workgroup)

<table>
<thead>
<tr>
<th>First</th>
<th>Last</th>
<th>Company</th>
<th>Sub-team</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jim</td>
<td>Raney</td>
<td>Anadarko</td>
<td>Philosophy</td>
</tr>
<tr>
<td>Isaac</td>
<td>Shreef</td>
<td>Anadarko</td>
<td>Philosophy</td>
</tr>
<tr>
<td>Shafiq</td>
<td>Khandoker</td>
<td>Hess Corp</td>
<td>Philosophy</td>
</tr>
<tr>
<td>Kent</td>
<td>Grebing</td>
<td>NOV</td>
<td>Philosophy</td>
</tr>
<tr>
<td>Joshua</td>
<td>Robnett</td>
<td>Subsea Solutions</td>
<td>Philosophy</td>
</tr>
<tr>
<td>Jim</td>
<td>Kaculi</td>
<td>Dril-Quip</td>
<td>Philosophy</td>
</tr>
<tr>
<td>Richard</td>
<td>Biel</td>
<td>Stress Engineering</td>
<td>Philosophy</td>
</tr>
<tr>
<td>Chris</td>
<td>Johnson</td>
<td>NOV</td>
<td>Philosophy</td>
</tr>
<tr>
<td>Harish</td>
<td>Patel</td>
<td>ABS</td>
<td>Philosophy</td>
</tr>
<tr>
<td>Eric</td>
<td>Larson</td>
<td>GE</td>
<td>Philosophy</td>
</tr>
<tr>
<td>Jeff</td>
<td>Dieffenbaugher</td>
<td>Chevron</td>
<td>Philosophy</td>
</tr>
<tr>
<td>Tommy</td>
<td>Powers</td>
<td>Stress Engineering</td>
<td>Philosophy</td>
</tr>
<tr>
<td>Raj</td>
<td>Gadapa</td>
<td>ABS</td>
<td>Philosophy</td>
</tr>
<tr>
<td>Paul</td>
<td>Bunch</td>
<td>Cameron</td>
<td>Philosophy</td>
</tr>
<tr>
<td>William</td>
<td>Meeks</td>
<td>ExxonMobil</td>
<td>Philosophy</td>
</tr>
<tr>
<td>Eric</td>
<td>Larson</td>
<td>GE Oil &amp; Gas</td>
<td>Philosophy</td>
</tr>
</tbody>
</table>
API 16A, HPHT Learnings Thus Far

• HPHT Philosophy Apply sound engineering judgment to eliminate all foreseeable failures that present hazards with the primary failure modes are:
  • Structural failure due to overload (plastic collapse) Highly unlikely that plastic collapse will govern HP design that meets functional requirements. HT designs may suffer from reduced yield strength that need to be considered.
  • Structural failure due to cyclic loads (fatigue) This is the most likely failure mode for high pressure and the reason for the existence of VIII-3. FM is mandatory for HP equipment. It may be possible for HT designs to be assessed using S-N curves.
  • Failure of the pressure containing / controlling boundary (leakage) This is likely the most difficult failure mode to predict/analyze. Loose, integral, or bonded sealing elements are subject to damage that cannot be predicted.

• Understanding ASME, Sec VII, Div. 3 is critical Care should be used when cherry-picking features from VIII-3. Material requirements & inspections should reflect the needs to accommodate some high strains. Even if the substance of VIII-3 is somehow met, the resulting design may not be sufficient in all aspects. VIII-3 requirements are to be thought of as minimums and supplemental requirements may be needed.
  • Cyclic loading is a predominate mode of failures for BOP’s. Therefore, cyclic fatigue needs to be understood.
  • Leak-before-burst – Few designs can satisfy this requirement We should not fuss with any LBB tests as true high pressure equipment will not LBB. However, high temperature, low pressure equipment may fall into this category.
  • We need to understand autofrettage in these structures. For HP - at the intersection of large cross bores, high strains may be useful but may be harmful in some areas. VIII-3 sets an upper limit for test pressure.
  • We should worry about bolting. This is an area of major difference between ASME criteria and API practice. VIII-3 paragraph KD-623:

\[
S = \frac{1}{1.8} S_y
\]

(f) The average shear stress in the threads, calculated by dividing the design load by the appropriate thread shear area, shall be limited to 0.25\(S_y\) at the design temperature.

(g) The average bearing stress in the threads due to the maximum design loading shall be limited to 0.75\(S_y\) at the design temperature.
API 16A, HPHT Learnings Thus Far...............2

**Validation**
- The importance of common sequencing of loads and load paths is established.
- There should be 3 loads used on design: 1. Operational 2. Extreme; and 3. Survival. An ASME is committee is working this in parallel.
- More work is needed on connections (screw, flange or bracket)
- Fatigue life cycle remains a primary concern.
- PR4 appears to right for HPHT.
- Complete HPHT Design = Material testing in the environment + Design Ver. + FMECA + Validation.
- The Design Basis MUST address Operational Sequence of loads in the Functional Requirements.
- 16A, HPHT will have limits Temp max = 450 F; Pressure Max = 30 ksi.
- These limits need to be addressed in the preamble. Suggest that the opening paragraphs be a “Forward”.
- 16A, HPHT needs to state the Load Philosophy; i.e. Operational Load; Extreme Loads; Survival Loads defined. Tie back this to ASME standards. An ASME is committee is working this in parallel.
- Fatigue should be addressed in the design but then HPHT needs to have a Life Cycle Management program.
- Testing = 1.5 x Working Pressure. Is this damaging the fatigue life of the forging? This criterion should be weighed by the designer. Perhaps this requirement could be as low as 1.25 adjusted for rated temperature and as high as the designer needs for autofrettage. III-3 sets an upper limit for test pressure.

**Materials**
- More information on material is still needed by the industry.
  - Materials shall be “fit for purpose”
  - Materials wetted by well bore fluids must be acceptable for sour service under ANSI/NACE/ISO
  - Before HPHT material would be selected based upon immunity to the environment. In HPHT environment, the industry selects materials based upon adequate resistance from the environment.

**Risk section should give guidance and reference other standards**
Foundation for Design Philosophy

• Apply sound engineering judgment to eliminate all foreseeable failures that present hazards to people, environment, and assets

• In the context of drill-through equipment, the primary failure modes are:
  – Structural failure due to overload (plastic collapse)
  – Structural failure due to cyclic loads (fatigue)
  – Failure of the pressure containing / controlling boundary (leakage)

• Other failure modes must be considered on a case-by-case basis

• There is limited HPHT operating experience, so in order to protect people, environment, and assets, Standards and guidance are required to ensure proper design and performance assurance of equipment in HPHT service.

• The equipment will be designed to maintain integrity through the range of risks imposed by the environment, well and operations.

• The equipment will be designed with higher integrity than the well casing which will provide pressure relief to the open hole or downhole in the casing.

• The equipment will be designed to prevent discharge of hydrocarbons to the environment, but will not be designed to mitigate a blowout.

• The equipment is not permanent equipment, so inspection and life expectancy will be addressed to ensure equipment capability is not exceeded.

• Design analysis will be based on assuming proper usage and maintenance of equipment, and will not include situations involving gross negligence or willful misconduct.
Design Basis

- A design basis for the equipment must be received or compiled by the OEM based on one or more of the following:
  - Functional specification generated by the end user (most preferred)
  - Market studies of past or potential end users
  - OEM experience (least preferred)

- Design basis must specify:
  - Operating environment (pressure, temperature, fluids, water depth, etc.)
  - Operating, extreme, and survival (accidental) load cases
  - All foreseeable combinations of working fluids and their pressures, flowrates, and temperatures
  - Required equipment functionality
  - External interface definitions
  - Reliability target(s)
  - Applicable codes, regulations, and standards

- A formal document would capture the entire design basis (Design Specification).
Technical Specification

• The OEM must prepare a technical specification describing in detail how the design will satisfy the requirements of the design basis / functional specification. The technical specification must address:
  – Risk analysis & failure mode documentation
  – Verification analysis methodology for each failure mode
  – Validation testing methodology for each failure mode
  – Metallic & non-metallic materials selection (including welding)
  – Equipment ratings (pressure, temperature, external loads, depth)
  – Reliability & availability
  – Design review (third party, internal, or other)
  – Manufacturing & quality plan

• A formal specification would be prepared for approval (Technical Specification) or negotiations.
Hazard & Risk Analysis

• Choose risk analysis tools & methods appropriate to the design.
  – FMECA, FTA, HAZID, HAZOP

• Must be performed by a multidisciplinary team of competent personnel.

• Output must consist, at a minimum, of a set of identified failure modes / hazards which must be mitigated to an acceptable risk level via the design, verification and validation process.

• Should be iterative—as risks and hazards are mitigated, the analysis should be repeated and the results documented.

• A formal document would capture the final work (Hazard & Risk Summary).
Verification & Validation

• **Verification** is the process of examining the result of design and development output to determine conformity with specified requirements (API Q1 definition).
  – Example: Plastic collapse verification analysis may demonstrate acceptable margin against extremes of static external and internal load combinations.

• **Validation** is the process of proving a design by testing to demonstrate conformity of the product to design requirements (API Q1 definition).
  – Example: Successful thermal qualification testing to 350° F may demonstrate acceptable margin against a maximum design service temperature of 300° F

• V&V plan must be tied directly to mitigation of specific failure modes identified in the risk / hazard analysis.
Design Review

• A design review must be performed to assess the design output against the design basis / functional specification. The review shall formally assess:

  – Adequacy of risk / failure analysis
  – Adequate demonstration of failure mitigation via verification & validation activity
  – Adequacy of materials selection for specified service
  – Fulfilment of all functional requirements
  – Consistency of manufacturing & quality plan with design specification
Documentation

• The final design documentation should include, at minimum:
  – Design definition documents (e.g., basis of design)
  – Functional and technical specifications
  – Final risk analysis documentation
  – Reports from verification & validation activities
  – Final design drawings and manuals
  – Manufacturing inspection & test plans
  – Certificates of conformance

• A formal document would result (Design Report).
Issues in front of API 16A, HPHT..............................

• Can the criteria “leak before burst” be applied to BOP’s? How do we apply it and what is the criteria of leakage? LBB may be mathematically tied to the critical crack depth with a margin. Leakage is tough to predict.

• How do we define Operating, Extreme and Survival Loads? (Note: Unlikely that histograms can be developed due to the lack of data.)

• Validity of Fracture Mechanics due to sensitivity of input variables and complex geometry.

• Should bolting be considered in this specification? If so what is the criteria and how should it be applied? This is critical IMHO.

• What is the proper analysis to be performed? What design factors/safety factors/design margins are required? ASME committee working on this, but there a divergence of opinions (among the API folks!). [The ASME committee meets next week.]
2. Verification

- API-17 TR8 flowchart – modify as necessary?
- Verify all load cases
- Approach to strength analysis
- Approach to fatigue analysis
- Approach to gaskets / seals

<table>
<thead>
<tr>
<th></th>
<th>Joe</th>
<th>Liotta</th>
<th>NOV</th>
<th>Verification</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Andrew</td>
<td>Grohmann</td>
<td>Dril-Quip</td>
<td>Verification</td>
</tr>
<tr>
<td>3</td>
<td>Keith</td>
<td>Kaase</td>
<td>Lloyds Register</td>
<td>Verification</td>
</tr>
<tr>
<td>4</td>
<td>Dan</td>
<td>Kluk</td>
<td>Stress Engineering</td>
<td>Verification</td>
</tr>
<tr>
<td>5</td>
<td>Richard</td>
<td>Biel</td>
<td>Stress Engineering</td>
<td>Verification</td>
</tr>
<tr>
<td>6</td>
<td>Harish</td>
<td>Patel</td>
<td>ABS</td>
<td>Verification</td>
</tr>
<tr>
<td>7</td>
<td>Sean</td>
<td>Berg</td>
<td>GE</td>
<td>Verification</td>
</tr>
<tr>
<td>8</td>
<td>George</td>
<td>Ross</td>
<td>Stress Engineering</td>
<td>Verification</td>
</tr>
<tr>
<td>9</td>
<td>John</td>
<td>Chappell</td>
<td>Stress Engineering</td>
<td>Verification</td>
</tr>
<tr>
<td>10</td>
<td>William</td>
<td>Buchanan</td>
<td>ABS</td>
<td>Verification</td>
</tr>
<tr>
<td>11</td>
<td>Raj</td>
<td>Gadapa</td>
<td>ABS</td>
<td>Verification</td>
</tr>
<tr>
<td>12</td>
<td>Earl</td>
<td>Shanks</td>
<td>Consultant</td>
<td>Verification</td>
</tr>
<tr>
<td>13</td>
<td>John</td>
<td>Chappell</td>
<td>Stress Engineering</td>
<td>Verification</td>
</tr>
<tr>
<td>14</td>
<td>Lan</td>
<td>Hiscox</td>
<td>Cameron</td>
<td>Verification</td>
</tr>
<tr>
<td>15</td>
<td>Erman</td>
<td>Citirik</td>
<td>Cameron</td>
<td>Verification</td>
</tr>
</tbody>
</table>
16A HPHT Verification - Overview

• Should HPHT verification be included in 6X?

• 17TR8 is a valid starting point for HPHT analysis workflow

• 16A equipment categories will require some individual consideration
  – Example: Ram packers vs. Wellhead connectors

• Various technical challenges and analysis techniques to work through yet
16A HPHT Verification – Draft Flow Chart

• Addresses primary failure modes:
  – Failure of the pressure containing / controlling boundary (leakage)
  – Structural failure due to overload (plastic collapse)
  – Structural failure due to cyclic loads (fatigue)

• Inputs are FMECA driven

• Outputs may drive Validation
16A HPHT Verification – Challenges

• Fracture mechanics:
  – Are we there yet?
  – Ready to replace S-N?
  – Ideal for flat plates and uniform cylinders
  – Very sensitive to inputs and analysis techniques

• Mechanical properties on materials in solution:
  – Drastic effect on design life, especially in FM analyses
  – How to account for effects of temporary environmental exposure?
16A HPHT Verification – Challenges

• 17TR8 flow chart optional path
  – Should 20k be evaluated differently than 25k?

• Inclusion of bolting analysis in specification?
  – FMECA driven?
  – Elastic Plastic or liner elastic?

• Design factors:
  – 17TR8 in revision to include extreme (1.2) and survival (1.5)

• Local criteria analysis:
  – May never be the limiting factor

• Thermal loading
  – Reduction in material properties
  – Apply design factor to thermal gradient or thermal stresses?
Current proposal before the ASME Task Group on Subsea Applications

KG-311.8 Loadings - shall specify all expected combinations of coincident loading conditions as listed in KD-110 (Service Level A, B and C loadings)

KD-110 LOADINGS AND SERVICE LEVELS

– KD-110.1 Service Level A - The Service Level A loads correspond to normal and off-normal conditions (operating)

– KD-110.2 Service Level B - The Service Level B loads correspond to extreme or upset conditions. An extreme condition is an event with a frequency or return period of 100 years or less [P(0.01 < X < 0.1)].

– KD-110.3 Service Level C - The Service Level C loads correspond to a faulted survival condition. A survival condition is an event with a frequency or return period greater than 100 years [P(0.0001 < X < 0.01)].
Current proposal before the API 17 TR8 (Revision) Task Group on Subsea Applications

Draft 17TR8

Normal
See governing API product specifications.

Extreme
Extreme operating conditions include the unavoidable but predictable load conditions due the environmental and operating scenarios. The allowable number of extreme cycles should be determined based on the design life and combination of all loading. Extreme condition is such an event with a probability less than $10^{-1}$ and larger than $10^{-2}$, based on appropriate risk assessment, for the period under consideration.

Survival
Survival conditions include the unplanned, unavoidable and unpredictable load conditions due to the environmental, operating or any other scenarios whatsoever. Survival conditions are defined as events with a probability less than $10^{-2}$ and larger than $10^{-4}$, based on appropriate risk assessment, for the period under consideration. Certain events, while even beyond the probability of the survival definition, may be required by regulatory bodies to be included within the design of the system (worst case discharge may be an example of such a survival event).
# Global Plastic Collapse (API 17 TR8 (Revision))

<table>
<thead>
<tr>
<th>Operating Conditions</th>
<th>Linear-Elastic API 17G/2RD</th>
<th>Elastic-Plastic (LRFD) ASME Section VIII, Div. 2&lt;sup&gt;(1)&lt;/sup&gt;</th>
<th>Elastic-Plastic (LRFD) ASME Section VIII, Div. 3&lt;sup&gt;(1)&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>w/o Thermal Loads</td>
<td>w/ Thermal Loads</td>
</tr>
<tr>
<td>Normal</td>
<td>0.67 x $S_y$</td>
<td>2.4</td>
<td>2.1</td>
</tr>
<tr>
<td>Extreme</td>
<td>0.80 x $S_y$</td>
<td>2.0</td>
<td>1.75</td>
</tr>
<tr>
<td>Survival</td>
<td>1.00 x $S_y$</td>
<td>1.6</td>
<td>1.4</td>
</tr>
</tbody>
</table>

**NOTE:**

<sup>(1)</sup> The usage of the factors are defined as: LRFD $\times (P + D_x + T)$

Please do not distribute this information as it is a proposed chart.
Local Criteria (API 17 TR8 (Revision))

<table>
<thead>
<tr>
<th>Operating Conditions</th>
<th>Linear-Elastic API 17G/2RD</th>
<th>Elastic-Plastic (LRFD) ASME Section VIII, Div. 2&lt;sup&gt;(1)&lt;/sup&gt;</th>
<th>Elastic-Plastic (LRFD) ASME Section VIII, Div. 3&lt;sup&gt;(1)&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>N/A</td>
<td>1.70</td>
<td>1.28</td>
</tr>
<tr>
<td>Extreme</td>
<td>N/A</td>
<td>1.42</td>
<td>1.07</td>
</tr>
<tr>
<td>Survival</td>
<td>N/A</td>
<td>1.13</td>
<td>1.00</td>
</tr>
</tbody>
</table>

NOTE: (1) The usage of the factors are defined as: LRFD × (P + D<sub>x</sub>)

<table>
<thead>
<tr>
<th>Operating Condition</th>
<th>Allowable Membrane Stress</th>
<th>Elastic-Plastic (LRFD) ASME Section VIII, Div. 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>w/o Thermal Loads</td>
</tr>
<tr>
<td>Normal</td>
<td>Governing API Specification</td>
<td>?</td>
</tr>
<tr>
<td>Extreme</td>
<td>0.9 x S&lt;sub&gt;y&lt;/sub&gt; (per API 17G)</td>
<td>?</td>
</tr>
<tr>
<td>Survival</td>
<td>1.00 x S&lt;sub&gt;y&lt;/sub&gt;</td>
<td>?</td>
</tr>
</tbody>
</table>

Please do not distribute this information as it is a proposed chart.
3. Validation

- FMECA is used to develop validation

- Base 16A document focuses on functional performance. Augment with:
  - Strength validation
  - Fatigue validation

- Validation of FEA should also be performed

- Address work-arounds for difficult validation tests
  - Fracture mechanics validation
  - High-angle LMRP disconnect
Validation, Learnings

• Discussions on cycle estimates for BOP scope; what is realistic and expected

• Sequence testing and expected levels for a conservative sequence test

• Validation flow chart – proposed validation work chart similar to 16A 4th edition

• OEC’s to be added into the HPHT Validation Scope
Proposed Validation Flow Diagram

API 16a WG#5 HPHT Validation Flow Diagram

- (4.5.2) Tables 18-24 for Ram BOPs would be updated to include PR3-4
- (4.5.5) Ram blocks, packers, and top seals tests to be updated
- (4.5.3) Hydraulic Connector Test requirement to be updated
- Clamps testing for surface only
- OEC testing
- Finish Validation
16A HPHT V&V Draft Flow Chart

Failure Mode Verification

- Equipment Design Concept
- Leakage Screening
  - Passed
  - Yes
  - Plastic Collapse, Local Checks
    - Passed
    - Yes
    - Create Capacity Chart
      - Capacity Validation Plan
      - Fatigue Validation Plan
      - Proceed to Validation
      - Other Validation Plans
      - Passed
  - No
    - No
      - Re-evaluate Design
        - Pressure, Temperature, Survival External Loads, Leakage Requirement
        - Modulus & Yield or True-Stress/True-Strain

Functional Requirements

- Pressure, Temperature, O/E/S External Loads
- Load Histogram (Operational & External Cyclic Loads)
- SN Curves or Fracture Toughness & FCGR

Validated Material Properties (in environment)

- As Required
This overview attempts to capture in factory process, commissioning, then well operations and end of well periods fully. No large margins for conservatism have been included. The values are fairly accurate and relevant in my opinion.

To assist;
Pressure cycles refers to wellbore pressure in component
Open / Close cycles is function test of operating system.
Assumption is that lowest pipe ram, shear ram and annular are listed as these will see the most action wrt pressure cycles.

<table>
<thead>
<tr>
<th>Component</th>
<th>Expected Cumulative Cycles</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-COD</td>
</tr>
<tr>
<td>H4 Connector</td>
<td></td>
</tr>
<tr>
<td>Pressure cycles</td>
<td>50</td>
</tr>
<tr>
<td>Lock/Unlock cycles</td>
<td>124</td>
</tr>
<tr>
<td>Annular BOP</td>
<td></td>
</tr>
<tr>
<td>Open Pressure cycles (Body tests)</td>
<td>1</td>
</tr>
<tr>
<td>Closed Pressure cycles</td>
<td>9</td>
</tr>
<tr>
<td>Open/Close cycles</td>
<td>38</td>
</tr>
<tr>
<td>Shear RAM BOP</td>
<td></td>
</tr>
<tr>
<td>Open Pressure cycles (Body tests)</td>
<td>27</td>
</tr>
<tr>
<td>Closed Pressure cycles</td>
<td>5</td>
</tr>
<tr>
<td>Open/Close cycles</td>
<td>54</td>
</tr>
<tr>
<td>Pipe RAM BOP</td>
<td></td>
</tr>
<tr>
<td>Open Pressure cycles (Body tests)</td>
<td>27</td>
</tr>
<tr>
<td>Closed Pressure cycles</td>
<td>5</td>
</tr>
<tr>
<td>Open/Close cycles</td>
<td>54</td>
</tr>
<tr>
<td>C&amp;K Valve</td>
<td></td>
</tr>
<tr>
<td>Closed Pressure cycles</td>
<td>21</td>
</tr>
<tr>
<td>Open/Close cycles</td>
<td>66</td>
</tr>
<tr>
<td>C&amp;K Connector</td>
<td></td>
</tr>
<tr>
<td>Pressure cycles</td>
<td>6</td>
</tr>
<tr>
<td>Extend/Retract cycles</td>
<td>38</td>
</tr>
</tbody>
</table>
The proposed ‘Continuous Operating Temperature Design Validation’ test in 16A 4th edition is a proposed test that is yet unreleased. This test determines the ability of a BOP (including packers and seals) to maintain a wellbore pressure seal after repeated closings and openings at a continuously maintained elevated wellbore temperature. The test is performed by closing and opening the BOP three times and then performing a low and high pressure wellbore test. This sequence must be completed ten times in order to establish the equipment’s continuous operating temperature rating.

This test is a conservative new test that puts the equipment through a new level of scrutiny. Functioning and pressure testing a BOP and the associated elastomers at elevated temperature increases elastomer wear rates significantly when compared to ambient temperature fatigue testing. Weaknesses in design are exposed very quickly as rubber loss through extrusion points after a relatively low number of cycles simulates the wear experienced after a lengthy service at ambient conditions. If the equipment manufacturer selects a suitably high temperature to perform the test at, the packer will have very little service life towards the end of this test. In essence, the final pressure test will be performed on an elastomeric component that is ‘completely worn’.

This new test that is likely to be included for PR2 equipment in 16A, 4th ed. can be considered a conservative ‘sequence test’, analogous to that referred to in API 17TR8.
4. Materials

- Evaluate materials fitness for service in the context of intended service environment
  - Temperature
  - Strength Fatigue
  - Fluid environment (seawater, acids, brines, H₂S, CO₂, etc.)

- Material properties must be qualified at full scale

- Welding

- Consider statistical basis for
  - New design curves
  - Validation for use of existing design curves

<table>
<thead>
<tr>
<th></th>
<th>Kirk</th>
<th>Brownlee</th>
<th>Stress Engineering</th>
<th>Materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>William</td>
<td>Miller</td>
<td>GE</td>
<td>Materials</td>
</tr>
<tr>
<td>3</td>
<td>Matt</td>
<td>Hydecker</td>
<td>Stress Engineering</td>
<td>Materials</td>
</tr>
<tr>
<td>4</td>
<td>James</td>
<td>Burk</td>
<td>BP</td>
<td>Materials</td>
</tr>
<tr>
<td>5</td>
<td>Anil</td>
<td>Pitta</td>
<td>GE Oil &amp; Gas</td>
<td>Materials</td>
</tr>
<tr>
<td>6</td>
<td>Anil</td>
<td>Pitta</td>
<td>NOV</td>
<td>Materials</td>
</tr>
<tr>
<td>7</td>
<td>Ming</td>
<td>Huang</td>
<td>GE Oil &amp; Gas</td>
<td>Materials</td>
</tr>
<tr>
<td>8</td>
<td>Matt</td>
<td>Heidecker</td>
<td>Stress Engineering</td>
<td>Materials</td>
</tr>
<tr>
<td>9</td>
<td>Satya</td>
<td>Meruva</td>
<td>ABS</td>
<td>Materials</td>
</tr>
<tr>
<td>10</td>
<td>Lilia</td>
<td>Centeno</td>
<td>ABS</td>
<td>Materials</td>
</tr>
<tr>
<td>11</td>
<td>Arshad</td>
<td>Bajvani</td>
<td>Camron</td>
<td>Materials</td>
</tr>
<tr>
<td>12</td>
<td>Lan</td>
<td>Hiscox</td>
<td>Camron</td>
<td>Materials</td>
</tr>
</tbody>
</table>
Draft Flowchart for Materials Verification

1. Equipment Category
2. Materials BOD
3. Design Requirements
4. Qual’d Production Route?
   - Yes: Verify Old Route
     - Not Acceptable
6. Not Acceptable
7. Qualify New Prod Route
8. Initial (Qualification) Testing
   - Not Acceptable
   - Acceptable
9. QC Testing
10. Periodic Testing
    - Acceptable
    - Product
5. Quality

- Q1 shall be mandatory for all HPHT designs
- API monogram should be established for HPHT
- Additional documentation / data book requirements
- NDE
- Supplier quality requirements

<table>
<thead>
<tr>
<th></th>
<th>Ken</th>
<th>Peurifoy</th>
<th>Anadarko</th>
<th>Quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Jared</td>
<td>Frerking</td>
<td>GE</td>
<td>Quality</td>
</tr>
<tr>
<td>2</td>
<td>Ricardo</td>
<td>Robles</td>
<td>Lloyds Register</td>
<td>Quality</td>
</tr>
<tr>
<td>3</td>
<td>Shyam</td>
<td>Patel</td>
<td>Maersk Drilling</td>
<td>Quality</td>
</tr>
<tr>
<td>4</td>
<td>NOV</td>
<td>Stroubakis</td>
<td>ABS</td>
<td>Quality</td>
</tr>
<tr>
<td>5</td>
<td>Demetri</td>
<td>Raghunathan</td>
<td>ABS</td>
<td>Quality</td>
</tr>
<tr>
<td>6</td>
<td>Varun</td>
<td>Albrecht</td>
<td>ABS</td>
<td>Quality</td>
</tr>
<tr>
<td>7</td>
<td>Lesley</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Quality Philosophy

• Quality requirements should be basically the same as the current API Spec 16A 4th Edition Committee Draft.

   **Note:** A lot of good new and / or more detailed “Quality Requirements” have been added to 16A 4th Edition (e.g., bolting Spec 20E BSL requirements, volumetric NDE section, etc.)

• Additional Quality requirements for the HPHT Annex may be considered based on perceived need after most of the technical requirements finalized.

• Quality requirements should be “harmonized” with API Spec 16AR First Ed, API 6A 21St Edition, API Spec 17D, and API Spec 6AR Draft.

• Quality requirements should be added only by consensus of the WG and confirmed by TG prior to letter ballot.
Quality Philosophy

• Depending on the wording of the final BSEE Well Control Rule a requirement should be added to 16A to require “the organization shall establish, document, implement, and maintain at all times a QMS to an internationally recognized quality management system standard for all products ...” (just as contained in API 16AR).

• Additionally - Annex E - Minimum Requirements for Certificate of Conformance (COC) should also include a statement in the “Assurance” section that states the equipment has been manufactured under a QMS recognized by BSEE.
Quality Philosophy

• Other additional quality requirements should be considered based on the output of the other sub-teams.

  For example currently API 16A does not reference any of the 20 Series specifications on forging and based on a recommendation from the Materials Sub-team, a requirement / reference to API Spec 20B, or 20C (as appropriate) maybe considered.

• Re-Certification and Quality requirements for re-certification should be contained in 16AR, however we should consider a link to SC18 Life Cycle Management document.
Suggested HPHT Design Flowcharts
Development Process

1. Basis of Design
   - Surface Riser
   - Wellhead System Analysis
2. Design Specification
3. Design Equipment & Documentation
4. Design Meets FDS
5. Design Verification
6. Design Validation
7. Production
8. Functional Design
9. Specification

System Analysis
Specification Breaks

- Well Construction
- Well Completion
- Well Intervention
System Analysis Specification Breaks
System-Level HPHT Design

Start

System Definition
- Functional Requirements
- Environment
- System Architecture
- Applicable regulations

System-Level Hazard and Risk Assessment (e.g., FMECA, FTA, HAZOP)

Define Verification & Validation Requirements (using risk assessment output)

Initial System-Level (Global) Verification Analysis

Prepare Subsystem Functional Specifications

Subsystem Design
- Risk Assessment
- Subsystem Design
- Verification
- Validation

"Feedback loops" between System & Subsystem levels

Seek to minimize system-level validation loops

System-Level (Global) Verification Analysis (updated with subsystem details)

Verification requirements met?

No

Verify design iteration loop (preferred)

Yes

Perform System-Level Validation

Validation requirements met?

No

System-Level Operational Risk Mitigation

Develop performance-monitoring plan

Documentation: Risk Assessment, Design, V&V Results

End

See next slide for subsystem design details
Subsystem-Level HPHT Design

Functional Requirements
(from system analysis)
Includes:
- Normative standards/regulations
  - Environment
- Operational & external loads
- Verification & validation requirements
- External interface definitions

Subsystem Concept
Prepare Technical Specification

Subsystem Level Risk Assessment
(e.g., FMECA, FTA)

Develop Verification & Validation Plan

Define Assembly Functional Requirements

Assembly Design
- Risk Assessment
- Detail Design
- Verification
- Validation

See next slide for assembly design details

Validation design iteration loop

Performance requirements met?

Yes

Perform Subsystem Validation

No

Verification requirements met?

Yes

Verification design iteration loop

Subsystem Verification Analysis

Subsystem Verification Analysis

Develop performance-monitoring, training, & maintenance plans

Document Risk Assessment, Design, V&V Results
(submit to systems engineering personnel)
**Assembly-Level HPHT Design**

**Functional Requirements**  
*(from subsystem analysis)*  
*Includes:*  
- Normative standards/regulations  
- Environment  
- Operational & external loads  
- Verification & validation requirements  
- External interface definitions

**Assembly Design Concept**  
*Prepare Technical Specification*  
*(including initial materials selection)*

**Assembly-Level Risk Assessment**  
*(e.g., FMECA, FTA)*

**Materials Selection**

**Compile Environmental Materials Data**  
*(via historical data or project-specific tests)*

**Develop Verification & Validation Plan**

**Assembly Verification Analysis**

**Validation requirements met?**

- Yes
  - Perform Assembly Validation
  - **Validation design iteration loop**
  - Yes
  - No
    - **Verification requirements met?**
      - Yes
      - **Verification design iteration loop**
      - No
      - **Validation design iteration loop**

**Document Risk Assessment, Design, V&V Results**  
*(submit to subsystem engineering personnel)*
Flowchart Backups Slides
Engineered Methodology for Design Verification and Validation of Ultra-Deep High Pressure High Temperature Control Equipment

**Fig. 1**

1. **Equipment Materials Selection-Supplier**
   - Define Applicable Loads (MMR) to the equipment.
     - Conduct thermal stress analyses for various operational scenarios.
     - SCSSV (Subsurface Safety Valve), Wellhead/Tree, BOP ( Blowout Preventer), WPC (Wireline Pressure Control).
2. **Equipment Design-Supplier**
3. **MMR Materials Qualification**
4. **MMR Design Verification**

**Fig. 2**

1. **Material Qualification-MMR**
2. **True Stress-Strain I-R Curve da/dN vs. ∆K (All data obtained at temperatures ranging from 75 to 500°F)**
3. **Ripple SSRT or LCF in Environment**
4. **Conduct da/dN in Environment for Verification**
5. **SSC Tests (For carbon steels: Method A, Method D in appropriate environments) (For CRA materials: Galvanically coupled testing - Method A)**
6. **SSC Tests for CRA/s) C-Ring**
7. **No Further Testing Unless Local Plasticization Occurs**
8. **Passed SSRT**
9. **PASSED**
10. **YES**
11. **NO**
12. **Identify New Material**

**Flowchart Diagram**
Engineered Methodology for Design Verification and Validation of Ultra-Deep High Pressure High Temperature Control Equipment
API 17-TR8 – HPHT Design Flowchart

Figure 1—HPHT Design Flow Chart
Backups Slides

Product Development Process For Existing or New Design Equipment
API PER15K-1 / 30 CFR 250.807
Product Development Process For
Existing or New Design Equipment
API PER15K-1 / 30 CFR 250.807

Fit for Purpose Qualification Process
§ 250.807 Additional requirements for subsurface safety valves and related equipment installed in high pressure high temperature (HPHT) environments.

(a) If you plan to install SSSVs and related equipment in an HPHT environment, you must submit detailed information with your Application for Permit to Drill (APD), Application for Permit to Modify (APM), or Deepwater Operations Plan (DWOP) that demonstrates the SSSVs and related equipment are capable of performing in the applicable HPHT environment. Your detailed information must include the following:

1. A discussion of the SSSVs’ and related equipment’s design verification analysis;
2. A discussion of the SSSVs’ and related equipment’s design validation and functional testing process and procedures used; and
3. An explanation of why the analysis, process, and procedures ensure that the SSSVs and related equipment are fit-for-service in the applicable HPHT environment.

(1) The completion of the well requires completion equipment or well control equipment assigned a pressure rating greater than 15,000 psig or a temperature rating greater than 350 degrees Fahrenheit;

(2) The maximum anticipated surface pressure or shut-in tubing pressure is greater than 15,000 psig on the seafloor for a well with a subsea wellhead or at the surface for a well with a surface wellhead; or

(3) The flowing temperature is equal to or greater than 350 degrees Fahrenheit on the seafloor for a well with a subsea wellhead or at the surface for a well with a surface wellhead.

(c) For this section, related equipment includes wellheads, tubing heads, tubulars, packers, threaded connections, seals, seal assemblies, production trees, chokes, well control equipment, and any other equipment that will be exposed to the HPHT environment.

[FR Doc. 2010–124 Filed 1–8–10; 8:45 am]
BILLING CODE 4310–MR–P
Project Basis of Design

• Operational Specific Basis of Design
  • Equipment Location – Surface or Subsea
  • Location Environment – Max / Min
  • Pressure – Inside / Outside
    • Maximum / Minimum / Transient / Steady State
    • Various Flow Rates
  • Temperature – Inside / Outside
    • Maximum / Minimum / Transient / Steady State
    • Various Flow Rates
  • Environmental Exposure
    • Outside (seawater, drilling and completion fluids, etc)
    • Inside (seawater, drilling and completion fluids, etc)
    • Reservoir Surfaces Contact
    • Reservoir Chemistry
  • Anticipated Life Cycle Operating Requirements
    • Interventions, Work Over, Shutdowns, etc.
Functional Design Specification

- Operational Statement of Requirements
  - System Description
  - Operating Conditions based on Basis of Design
  - Known Applied Loads
  - System Analysis to Obtain all Component Loads
    - Include all Pertinent Equipment Interfaces
    - Study Installation and Removal Loads
    - Study Start-up, Steady State, Shut-down
  - Failure Modes & Effect Analysis of Components
  - Life Cycle Operations for System/Components
  - Environments in Contact w/ Wetted Surfaces
PER15K is a technical report that outlines various methods of analytical design verification intended for HPHT pressure-containing equipment in the petroleum and natural gas industries in HPHT environments.

Verification

This report focuses on analytical methods to achieve design verification by calculating the performance limits of a design, including its fatigue life. It is up to the equipment manufacturer and the end user to decide what design factors to apply to the equipment and what specific limits to apply to utilization of the equipment based on having the calculated performance limits of the equipment. As with most calculations, the advanced methods presented in this report provide estimates of the limits of the equipment, and it is up to the manufacturer and the end user to decide how to interpret these estimates.
Design Verification Analysis

Both Legs Must Be Performed

Design Verification

Design Analysis

LEFM Fatigue Analysis

Design Verified

No

Yes

Design Validation
Design Analysis

Design Verification Analysis
• Applies to pressure containing parts
• Does not apply to pressure retaining parts
• Does not apply to closure bolting
• Does not apply to ring gaskets

Design Analysis
- Plastic Collapse Analysis
  ASME VIII-2 Par 5.2.4
- Local Strain Limit Analysis
  ASME VIII-2 Par 5.3.3
- Ratcheting Analysis
  ASME VIII-2 Par 5.5.7
- Proven Analysis Method

LEFM Fatigue Analysis
ASME VIII-3 KD-4

S-N Fatigue Analysis
ASME VIII-3 KD-3

Leak Before Burst
Yes
No
Analysis required for each critical section
Assume initial crack size based upon NDE capability
Crack aspect ratio should be updated as crack grows
Use appropriate material crack growth rate data for environment and loading
Allowable crack size based upon ASME Div 3 KD-412 or Other Acceptable Criteria
Design Validation

• Design Test Program
  – Use Functional Design Specifications
  – Validate Design Verification
  – Insitu Temperature Requirements
    – Inside and Outside
    – Dynamic, Transient, and Steady-State
  – In-Service Load Conditions
    – Pressure & All Applied Loads (Tension, Bending, Etc)
    – Inside and Outside
    – Dynamic, Transient, and Steady-State
  – Measure and Monitor Peak Stresses
  – Establish Reliability Goals and Testing Methodology

• If Physical Tests are Impractical
  – Analytical Simulations
  – Scale Model Tests
  – Tests of Less Magnitude - Scale
Design Validation Process

FMECA
(Failure Mode and Effects Criticality Analysis)

Define
- Requirement
- Environment
- Testing

Identify
- Failure modes

Analyze
- Design
- Test for Failure mode

Control
- Implement design
- Maintain design reliability

Validate
- Demonstration test
- Process

Test
- DOE
- ALT
Design Meets Functional Design Specification (FDS)

- Both Legs of Process Flowchart Must be Satisfied
  - The Design Validation Process Confirms the Design Verification Results
- Document All Design, Verification & Validation Data
- Design Specifications and Practices
  - Applicable Industry Standards
  - Customer Specifications
  - Company Proprietary IP
- Material / Welding Specifications
- NDE Criteria
- Design Verification Analysis
- Design Validation Testing
- Quality Plans
Elements Required to Complete The Manufacturing Process

Development Process

- Basis of Design
- Functional Design Specification
- Design Equipment & Documentation

- Design Verification
- Design Validation

Design Meets FDS

Elements Required to Complete The Manufacturing Process

- API RECOMMENDED PRACTICE
- Manufacture
- Functional Specification
- Design Basis

- Purchase Specs
- Design Verification
- Design Validation
- Design / Prototype Elements

- Materials
- QA/QC
- Inspection

- FAT
- Use Documentation
- Repair
- Re-certify

- Production

Product / Manufacturing Elements
More Backups Slides
API 18 LCM - Product Life Cycle and the API Monogram

Monogrammed → Functionally Tested → Serviced → Repaired → Serviced
→ Installed → In use → Inspected → Remanufactured

Life Cycle Management System & Product Standards

Maintenance & Operational Status - Verified Standards Compliance - Verified Design Changes – Implemented Regulatory Compliance - Verified
| API 18 LCM - Lifecycle Management Systems-Walk Across |
|-----------------|-------------------------------------------------|
| API RP 64       | Diverter Systems Equipment and Operations       |
| API RP 53       | Recommended Practices for Blowout Prevention Equipment Systems for Drilling Wells |
| API RP 5C1      | Recommended Practice for Care and Use of Casing and Tubing |
| API RP 7L       | Procedures for Inspection, Maintenance, Repair, and Remanufacture of Drilling Equipment, 1st Edition |
| API 1951        | API-ASME for the Design, Construction, Inspection and Repair of Unfired Pressure Vessels |
| API 653         | Tank Inspection, Repair, Alteration, and Reconstruction, Fourth Edition |
| API 510         | Pressure Vessel Inspection Code: In-Service Inspection, Rating, Repair, and Alteration |
| API TR 939B     | Repair and Remediation Strategies for Equipment Operating in Wet H2S Service |
| API 6A          | Annex J: Repair & Remanufacture |
| API 16A         | Annex B: Repair & Remanufacture |
| API 16D         | Section 6: Inspection & Maintenance |
Risks Analysis, Assessment & Management

Risk models have different levels of detail – but most work in a similar manner.