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March 14, 2016

Director Brian Salerno
Bureau of Safety and Environmental Enforcement
Department of the Interior
1849 C Street, NW
Washington, DC 20240

Dear Director Salerno,

Thank you for your participation at our semi-annual Center for Offshore Safety External Stakeholders Group meeting in February. Your work with industry demonstrates our shared commitment to the process of continuous and safe operations.

Since our last correspondences, the multi-segment task force has recently concluded its initial review to your QC-FIT report on bolts and fasteners. The report is attached for your reference. Six subcommittees are now tasked to review and consider implementation planning. Overall, we are taking a systematic approach across our signature safety programs to determine if enhancements are required to further strengthen our documented audit and certification programs.

API remains ready to meet with you and your staff at your earliest convenience to continue discussing our shared objective of safe operations.

With warm regards,

Jack N. Gerard
President and CEO

Attachment

API

Multi Segment Task Group on Bolting Failures

TASK GROUP STATUS REPORT

2/29/2016

Contents

1. Scope of Work

As identified in CSEOM action item 15-10: consider issues raised during the January 27, 2015 "QC-FIT Evaluation of Connector and Bolt Failures Summary of Findings – BSEE 2014-01 Report" technical session.

During the initial meetings of the Task Group (TG), the scope was further clarified to take a more holistic approach and look at all types of bolting failures that could occur in the upstream oil and gas industry, determine contributing factors, identify current mitigations, and recommend changes to industry standards.

TG work also included review of the QC-FIT Evaluation of fastener failures-addendum (2016-04) addendum issued February 2016.

2. Membership

TABLE 1: TASK GROUP MEMBERS

TG Roster and Mailing List	
Name – Company	**Name – Company**
Michael Briggs – Cameron	Rob Hilts – Halliburton Energy Services
Rashimi B. Bhavsar – Schlumberger	Jimmy Hood - McMoRan Oil & Gas
Lester Burgess – Texas Screw Products (TSP)	Peter Ireland – Schlumberger
James D. Burk – BP	Satya Meruva – American Bureau of Shipping (ABS)
Bill Carbaugh – GE Oil & Gas	Frederic Oleron – Cameron
Leonard Childers – BP	Harish Patel – American Bureau of Shipping (ABS)
Jason Curtiss – Shell	Jason Price – Fastenal Company
Eric Davidson – Chevron	Rob Turlak – Transocean
Danny Fish – Conoco Phillips	Melvyn F Whitby – Cameron
Austin Freeman – BP	Kim Wiita – BP
Frank B. Gallander – Chevron	Katie Burkle – American Petroleum Institute
Tom Goin - US Bolt Manufacturing Inc.	Roland Goodman – American Petroleum Institute
Kent Grebing – National Oilwell Varco	Holly Hopkins – American Petroleum Institute
Tim Haeberle – GE Oil & Gas	David Miller - American Petroleum Institute

3. Description of Process Used

The Task Group looked at recent failures and developed a summary mapping process contained in Appendix 1. As a part of the failure mapping process the TG determined causes as well as recommended changes in industry standards to mitigate the risk of these failures occurring in the future.

Bolt failure mechanisms were categorized into two basic groups of brittle and ductile failures. Contributing factors, processes, current mitigations, and TG recommendations were then identified for each of the failure mechanisms.

Some mitigation factors applied to multiple failure mechanisms and consequently some TG recommendations are stated in multiple sections. Section 7 summarizes all of the TG recommendations provided in this bolting failure report.

4. Brittle Failure Mechanisms

Bolts that undergo a brittle failure mechanism experience little or no plastic deformation prior to failure. These failures can occur at lower stresses than expected and may result in potentially catastrophic effects.

Four factors that can contribute to brittle failure were considered.

- Environmental assisted cracking
- Large cross section
- Low temperature
- Liquid metal embrittlement

Each of these factors are described below.

4.1. Environmentally Assisted Cracking (See Page 2 and 3 in Appendix 1)

Environmental assisted cracking is a type of failure that occurs under the influence of tensile stresses and harmful environments. Two types of environmental assisted cracking mechanisms are Hydrogen Embrittlement and Stress Corrosion Cracking.

4.1.1. Hydrogen Embrittlement (See Page 2 of Appendix 1)

Hydrogen embrittlement is due to the introduction and subsequent diffusion of hydrogen into the metal. Three contributing factors of hydrogen embrittlement were identified; Internal Environment, External Environment, and Hydrogen Embrittlement Sensitive material.

4.1.1.1. Internal Environment

Internal Environment is the environment generated during the manufacturing process. This can be a result of the process of electroplating metals. The usual sources of hydrogen during plating are acid cleaning and the plating deposition itself. The current mitigations against failures due to the internal environment are requirements within plating specifications such as ASTM B633 and ASTM F1941. Three mitigations were identified in ASTM B633 and ASTM F1941; limiting hardness and tensile strength of plated bolts, stress-relief prior to plating (B633 only reference ASTM B849), and post plating bake (B633 reference ASTM B850). The TG identified four possible additional mitigations as follows:

TGR-1: TG notes that there is conflict between B633 and F1941 related to requirements for hydrogen embrittlement mitigation. B633 requires stress-relief and bake for product greater than 31 HRC. F1941 does not require stress-relief and requires bake for product greater than 39 HRC. API should contact ASTM to request resolution of this conflict. If this cannot be achieved through ASTM, then API needs to issue an equivalent document under API through SC21. In either case, the revised or new document will then need to be adopted by product SCs. This work should also include requirements for maximum hardness on bolting material.

TGR-2: TG recommends that API expand 20E to more adequately cover the requirements of plating and coating as well as move the supplemental requirements for plating and coating into the body of the document, making them standard requirements.

TGR-18: Product subcommittees should review and consider incorporating 20E and 20F requirements (resolve existing conflicting properties specified in product specifications such as hardness).

TGR-3: TG recommends prohibiting Zinc electroplating for Subsea/Marine application. TG further recommends that an investigation be conducted under the direction of SC21 to determine a better short term (storage) corrosion protection system that would not create hydrogen in service. The results of this study would then need to be adopted into product standards.

4.1.1.2. External Environment

The External Environment is the environment bolting is exposed to during service. The external environment considered by the TG that contributed to hydrogen embrittlement was a marine environment in conjunction with zinc plating or cathodic protection or both. Mitigations for cathodic protection and monitoring of excessive charging are contained in NACE SP0176, NORSOK M001, NORSOK M503, ISO 13173 and DNV – RP B401.

Bolting is typically zinc plated for general corrosion protection during storage and shipping. When zinc plating is exposed to seawater it becomes a potential source for excessive hydrogen and can result in hydrogen embrittlement. TG recommendation to mitigate this type of failure is as follows:

TGR-3: TG recommends prohibiting Zinc electroplating for Subsea/Marine application. TG further recommends that an investigation be conducted under the direction of SC21 to determine a better short term (storage) corrosion protection system that would not create hydrogen in service. The results of this study would then need to be adopted into product standards.

4.1.1.3. Hydrogen Embrittlement Sensitive Material

Mitigations to prevent material sensitivity to hydrogen embrittlement are contained in NORSOK M001, API 17D, and API 20E. TG recommends the following as additional mitigations:

TGR-4: TG recommends consideration of an overarching document issued by API through SC21 in cooperation with product SCs covering selection of proper bolting materials for different environments (including subsea) would be helpful.

TGR-18: Product subcommittees should review and consider incorporating 20E and 20F requirements (resolve existing conflicting properties specified in product specifications such as hardness).

4.1.2. Stress Corrosion Cracking (See page 3 of Appendix 1)

Stress corrosion cracking is a general type of failure and can be subdivided into both chloride stress corrosion cracking (Cl-SCC) and sulfide stress cracking (SSC). Although these are two different failure mechanisms, the contributing factors are the same for both mechanisms.

The three contributing factors identified in stress corrosion cracking were:

- Material
- Environment
- Stress

Each of these is discussed in more detail below.

4.1.2.1. Material

Material factors that influence the susceptibility to stress corrosion cracking were divided into two groups (material quality issues and incorrect material selection). Since material quality is related to several of the failure mechanisms, it has been separated out as a specific topic and it is discussed in more detail in Section 6. Incorrect material selection is mitigated by requirements contained in API 6A, NACE MR-01-75 for H2S, and NORSOK M001, API 17A, and ISO 21457. In addition to the mitigations contained in these documents, the TG recommends:

TGR-4: TG recommends consideration of an overarching document issued by API through SC21 in cooperation with product SCs covering selection of proper bolting materials for different environments (including subsea) would be helpful.

4.1.2.2. Environment

Although environmental factors do influence bolting performance, these are difficult to control. Rather than attempting to control the environmental conditions, the risks which are associated with these factors are typically mitigated by material selection and design.

4.1.2.3. Stress

Three factors were identified by the task group when looking at the stress aspect of stress corrosion cracking.

- Dimensions
- Load
- Thread rolling

The dimensional factor is somewhat mitigated by API 6A for API connections but the TG felt that further mitigation was needed as follows:

TGR-4: TG recommends consideration of an overarching document issued by API through SC21 in cooperation with product SCs covering selection of proper bolting materials for different environments (including subsea) would be helpful.

The load factor has several mitigations already in place such as 6A, 6AF, 6AF1, 6AF2, 17D, as well as manufacturer's ratings. However, the TG felt additional mitigation is needed as follows:

TGR-5: TG recommends product specifications to require equipment manufacturers to specify acceptable thread compounds for bolting applications based on material, plating and service.

TGR-6: Torqueing requirements should be reviewed to determine if standardization among product specifications is needed.

Residual stresses are mitigated by the stress relieving requirement after thread rolling in API 20E. However due to the fact that 20E has not been imposed in many of the product specs the TG felt the following additional action was needed:

TGR-18: Product subcommittees should review and consider incorporating 20E and 20F requirements (resolve existing conflicting properties specified in product specifications such as hardness).

4.2. Large Cross Section (See page 4 of Appendix 1)

For Large Cross sections (>2.5" in diameter), the Improper Material Selection and Poor Material Properties contributing factors were identified.

4.2.1. Improper Material Selection

In the case of Improper Material Selection for Large Cross Sections, TG felt additional mitigation is needed as follows:

TGR-8: Do not allow use of B7 or L7 grades above 2.5" in diameter. TG recommends that this be included as part of the overarching document under SC21.

Although API 6A does define criteria for bolting, the TG felt additional mitigation is needed as follows:

TGR-7: TG recommends modification of 6A to require impact testing at or below design temperature w/ acceptance criteria for larger cross section bolting (over 2.5").

4.2.2. Poor Material Properties

The Poor Material Properties contributing factor is related to the API 6A and API 16A 4th Ed mitigation factors. The mitigation factors branch out to mitigation factors API 20E, API 20F, and ASTM A320. In addition to the mitigations contained in these documents the TG recommends:

TGR-9: TG recommends that volumetric examination where bolt diameter exceeds 2.5" should be added as a requirement to 20E, 20F, BSL-2, and BSL-3.

4.3. Low Temperature (See page 5 of Appendix 1)

Low temperature is a condition where the environmental temperature is below the ductile-brittle transition temperature of the alloy being used. Two contributing factors were identified; Improper Material Selection and material not meeting required properties (See section 6).

4.3.1. Improper Material Selection

As stated in section 4.2.1, for Improper Material Selection of large bolts, TG recommends mitigation TGR-8. Two additional mitigation factors were determined for Improper Material

Selection. These are API 6A and API 2C. For API 6A, TG felt additional mitigation is needed as follows:

TGR-4: TG recommends consideration of an overarching document issued by API through SC21 in cooperation with product SCs covering selection of proper bolting materials for different environments (including subsea) would be helpful.

TGR-10: TG recommends modification of 6A to require impact testing at or below design temperature w/ acceptance criteria for larger cross section bolting (over 2.5").

4.4. Liquid Metal Embrittlement (See page 6 of Appendix 1)

The Liquid Metal Embrittlement failure mechanism has been divided into two categories. One for stainless and CRA materials, when the temperature is above 400°F, and the second for high strength low alloy steels in service with temperatures in excess of 150°F.

4.4.1. Temperatures above 400°F

A contributing factor from temperatures above 400°F is the cross contamination of stainless and CRA materials with contaminants such as sulfur during the manufacturing process. The processes for cross contamination is machining or forging with sulfur based oil/lubricants.

TGR-11: Revise 20F to restrict use of sulfur based lubricants during manufacture of bolting.

4.4.2. Temperature in excess of 150°F

The second situation where liquid metal embrittlement can occur is in service where the temperatures are in excess 150°F and the thread compounds containing low melting point alloys (lead, tin, antimony, bismuth) are used with high strength low allow steels. Although it is common knowledge that these elements should not be used in thread compounds the TG felt additional mitigations should be added as follows.

TGR-12: TG recommends adding requirements to API product specifications to restrict combining these elements in thread compounds.

5. Ductile Failure Mechanisms

5.1. Fatigue (See page 7 of Appendix 1)

Three contributing factors were derived from the fatigue failure mechanisms: Materials, Stress, and Environment. In addition to this, it was identified that there has not been an assessment done by API on when fatigue conditions may exist.

TGR-13: Guidance should be issued by API on when and how to perform fatigue sensitivity analysis on bolting.

5.1.1. Material

Fatigue failures related to material are covered in two different sections. The first section being that the incorrect material has been selected and the other being that the material has inadequate material properties. API 2C (cranes) and API 6A both have guidance on the proper material to be used for bolting and mitigate against the incorrect material being selected.

However, since these requirements are limited in nature the TG felt addition mitigations were needed.

TGR-4: TG recommends consideration of an overarching document issued by API through SC21 in cooperation with product SCs covering selection of proper bolting materials for different environments (including subsea) would be helpful.

Although inadequate material properties are covered in Section 6, the TG felt there were also additional steps needed specifically related to fatigue situations.

TGR-14: Involved API SC's should address guidance issued in the product specs to require use of BSL-3 in fatigue sensitive applications and define what is a considered a fatigue sensitive application.

5.1.2. Stress

Within the scope of stress, cyclic loading in excess of design capacity can also be a contributing factor to bolt failure. However, this may be mitigated by using proper preload, provided the design is adequate to support the required preload. Proper preload is covered by two existing API standards: API 6A Annex D for API end connections (preload is required to maintain seal integrity in many cases) and API 17D.

TGR-6: Torqueing requirements should be reviewed to determine if standardization among product specifications is needed.

5.1.3. Environment

Although environmental conditions are a contributing factor to bolting failures, the environment is something that typically cannot be controlled. Instead of trying to control the environment, the risk of failure due to environmental conditions is mitigated through material selection and control of the design.

5.2. Overload (See page 9 of Appendix 1)

Six contribution factors were identified related to overload of bolting: Pressure, Bending load on connector, torque on connector, tensile load on connector, over-torque of bolting, and elevated temperature causing a reduction in yield strength. While these types of stresses are stated individually they can also function as combined stresses and those combined stresses must also be considered.

5.2.1. Pressure

Pressure is affected by the equipment ratings, Company standards on actual loads vs. rated loads, and Hydrostatic Testing requirements (API 6A, 16A, 17D, etc.). The TG did not feel any additional mitigation was needed in this area.

5.2.2. Bending, tensile and torsional loads on connector

External bending, tensile and torsional loads on connectors can create an overload situation in bolting and could lead to failure. In order to mitigate against this type of failure, there are currently company and manufacturer standards for external loading. The requirements in S53 for a watch circle mitigate our potential to overload due to bending loads. However, noting variations in how watch circles are developed, the TG had the following recommendation related to bending loads:

TGR-15: TG recommends revision to API S53 to define a standard method for calculating watch circle.

5.2.3. Over-torqueing of bolts

Excessive torque can generate an overload situation in bolts and cause a failure. To mitigate this failure mechanism the TG has the following recommendations:

TGR-6: TG recommends torqueing requirements be reviewed to determine if standardization among product specifications is needed.

TGR-5: TG recommends that the product specifications require equipment manufacturers to specify acceptable thread compounds for bolting applications based on material, plating and service.

5.2.4. Elevated temperature causes reduction in yield strength

Situations where bolting is exposed to elevated temperatures can reduce the yield strength of the material and create an overload situation. In order to mitigate this type of failure the TG has the following recommendation:

TGR-16: TG recommends API issue a document to provide guidance on derating of bolting. There are several specifications on material derating due to elevated temperature.

6. Material Quality issues (See page 8 of Appendix 1)

Several of the failure mechanisms that were identified by the TG had a common contributing factor of material quality issues. The material quality issues identified by TG were a function of the processes and practices used during bolting and raw material manufacture. The specific processes and practices identified were melting, hardness testing, heat treating, chemistry testing, mechanical property testing, and forming. In general the TG recommends a better alignment with 20E and 20F by the product standards (6A, 16A, 16AR, 17D, etc.).

TG recommends TGR-18 for API product specifications with bolting requirements (e.g. 6A, 16A, 16AR, 17D, etc.). For API 20E and 20F, in addition to TGR-18, TG also recommends TGR-17 and TGR-20. The three mentioned recommendations are listed below:

TGR-18: Product subcommittees should review and consider incorporating 20E and 20F requirements (resolve existing conflicting properties specified in product specifications such as hardness).

TGR-17: Strengthen heat treating and furnace loading requirements in 20E and 20F (more prescriptive requirements related to: spacing, QTC location, and thermocouple placement). Include requirements for oven calibration for pre and post bake operations.

TGR-20: SC20 review the supplier controls in 20E and 20F to ensure these adequately cover required controls for subcontracted processes. SC20 should also monitor the API Q1 revisions.

API Q1 was identified as an additional mitigating factor in the case that the supplied material does not meet specification. TG recommends the following:

TGR-19: SC18 to form a TG to review the BSEE FIT-QC Report on connector bolt failures to determine if the current requirements of API Spec Q1 has the provisions needed to ensure that system control features are in place, and clearly stated, to eliminate these type of failures in the future.

7. Summary of TG recommendations

This section restates the TG recommendations for the mitigation and contributing factors.

TGR-1: TG notes that there is conflict between B633 and F1941 related to requirements for hydrogen embrittlement mitigation. B633 requires stress-relief and bake for product greater than 31 HRC. F1941 does not require stress-relief and requires bake for product greater than 39 HRC. API should contact ASTM to request resolution of this conflict. If this cannot be achieved through ASTM, then API needs to issue an equivalent document under API through SC21. In either case, the revised or new document will then need to be adopted by product SCs. This work should also include requirements for maximum hardness on bolting material.

TGR-2: TG recommends that API expand 20E to more adequately cover the requirements of plating and coating as well as move the supplemental requirements for plating and coating into the body of the document, making them standard requirements.

TGR-3: TG recommends prohibiting Zinc electroplating for Subsea/Marine application. TG further recommends that an investigation be conducted under the direction of SC21 to determine a better short term (storage) corrosion protection system that would not create hydrogen in service. The results of this study would then need to be adopted into product standards.

TGR-4: TG recommends consideration of an overarching document issued by API through SC21 in cooperation with product SCs covering selection of proper bolting materials for different environments (including subsea) would be helpful.

TGR-5: TG recommends that the product specifications require equipment manufacturers to specify acceptable thread compounds for bolting applications based on material, plating and service.

TGR-6: Torqueing requirements should be reviewed to determine if standardization among product specifications is needed.

TGR-7 TG recommends modification of 6A to require impact testing at or below design temperature w/ acceptance criteria for larger cross section bolting (over 2.5").

TGR-8: Do not allow use of B7 or L7 grades above 2.5" in diameter.TG recommends that this be included as part of the overarching document under SC21.

TGR-9: TG recommends that volumetric examination where bolt diameter exceeds 2.5" should be added as a requirement to 20E, 20F, BSL-2, and BSL-3.

TGR-10: TG recommends modification of 6A to require impact testing at or below design temperature w/ acceptance criteria for larger cross section bolting (over 2.5").

TGR-11: Revise 20F to restrict use of sulfur based lubricants during manufacture of bolting.

TGR-12: TG recommends adding requirements to API product specifications to restrict combining these elements in thread compounds.

TGR-13: Guidance should be issued by API on when and how to perform fatigue sensitivity analysis on bolting.

TGR-14: Involved API SC's should address guidance issued in the product specs to require use of BSL-3 in fatigue sensitive applications.

TGR-15: TG recommends revision to API S53 to define a standard method for calculating watch circle.

TGR-16: TG recommends API issue a document to provide guidance on derating of bolting. There are several specifications on material derating due to elevated temperature.

TGR-17: Strengthen heat treating and furnace loading requirements in 20E and 20F (more prescriptive requirements related to: spacing, QTC location, and thermocouple placement). Include requirements for oven calibration for pre and post bake operations.

TGR-18: Product subcommittees should review and consider incorporating 20E and 20F requirements (resolve existing conflicting properties specified in product specifications such as hardness).

TGR-19: SC18 to form a TG to review the BSEE FIT-QC Report on connector bolt failures to determine if the current requirements of API Spec Q1 has the provisions needed to ensure that system control features are in place, and clearly stated, to eliminate these type of failures in the future.

TGR-20: SC20 review the supplier controls in 20E and 20F to ensure these adequately cover required controls for subcontracted processes. SC 20 should also monitor the API Q1 revisions.

The table below lists how the TG recommendations should be assigned to API SCs.

API SC21	API SC20	API SC18	API SC17	API SC16	API SC6	Joint/Other
TGR-1	TGR-2	TGR-19	TGR-3	TGR-3	TGR-3	
Consult on TGR-3	TGR-9		TGR-5, -12	TGR-5, -12	TGR-5, -12	TGR-5, -12
Consult on TGR-4	TGR-11		TGR-6	TGR-6	TGR-6	
Consult on TGR-8	TGR-17		TGR-13	TGR-13	TGR-13	
Consult on TGR-18	TGR-20		TGR-14	TGR-14	TGR-14	
			TGR-16	TGR-15	TGR-16	
			TGR-18	TGR-16	TGR-18	
				TGR-18	TGR-7, -10	

8. References

[1] ASTM B633, *Standard Specification for Electrodeposited Coatings of Zinc on Iron and Steel*

[2] ASTM F1941, Standard Specification for Electrodeposited Coatings on Mechanical Fasteners, Inch and Metric

[3] ASTM B850, Standard Guide for Post-Coating Treatments of Steel for Reducing the Risk of Hydrogen Embrittlement

[4] ASTM B849, Standard Specification for Pre-Treatments of Iron or Steel for Reducing Risk of Hydrogen Embrittlement

[5] API Spec 20E, Alloy and Carbon Steel Bolting for Use in the Petroleum and Natural Gas Industries

[6] NACE SP0176, Corrosion Control of Submerged Areas

[7] NORSOK M001, Materials selection

[8] NORSOK M503, Cathodic protection

[9] DNV-RP-B401, Cathodic protection design

[10] API Spec 17D, Design and Operation of Subsea Production Systems-Subsea Wellhead and Tree Equipment

[11] API Spec 6A, Specification for Wellhead and Christmas Tree Equipment

[12] NACE MR0175, Petroleum and natural gas industries — Materials for use in H2S-containing environments in oil and gas production

[13] API RP17A, Design and Operation of Subsea Production Systems - General Requirements and Recommendations

[14] ISO 21457, Petroleum, petrochemical and natural gas industries -- Materials selection and corrosion control for oil and gas production systems

[15] API TR 6AF, Technical Report on Capabilities of API Flanges Under Combinations of Load

[16] API TR 6AF1, Technical Report on Temperature Derating on API Flanges under Combination of Loading

[17] API TR 6AF2, Technical Report on Capabilities of API Flanges Under Combinations of Loading - Phase II

[18] API Spec 2C, Offshore Pedestal-mounted Cranes

[19] API Spec 16A, Specification for Drill-Through Equipment

[20] API Spec 20F, Corrosion Resistant Bolting for Use in the Petroleum and Natural Gas Industries

[21] ASTM A320, Standard Specification for Alloy-Steel and Stainless Steel Bolting for Low-Temperature Service

[22] API Std. 53, Blowout Prevention Equipment Systems for Drilling Wells

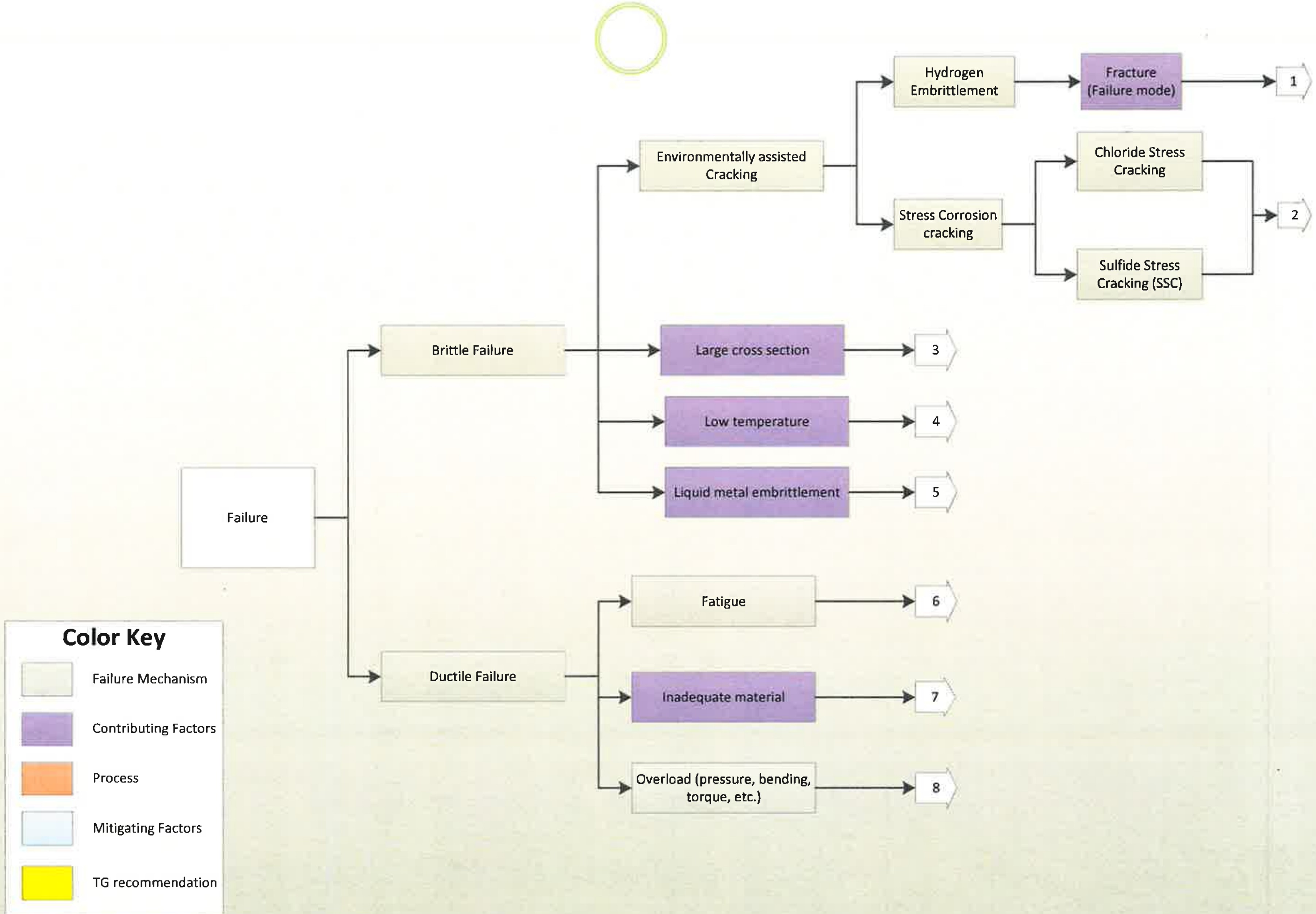
[23] API 16AR, Specification for Drill-through Equipment Repair and Remanufacturing

[24] ISO 13173, Cathodic Protection for Steel Offshore Floating Structures

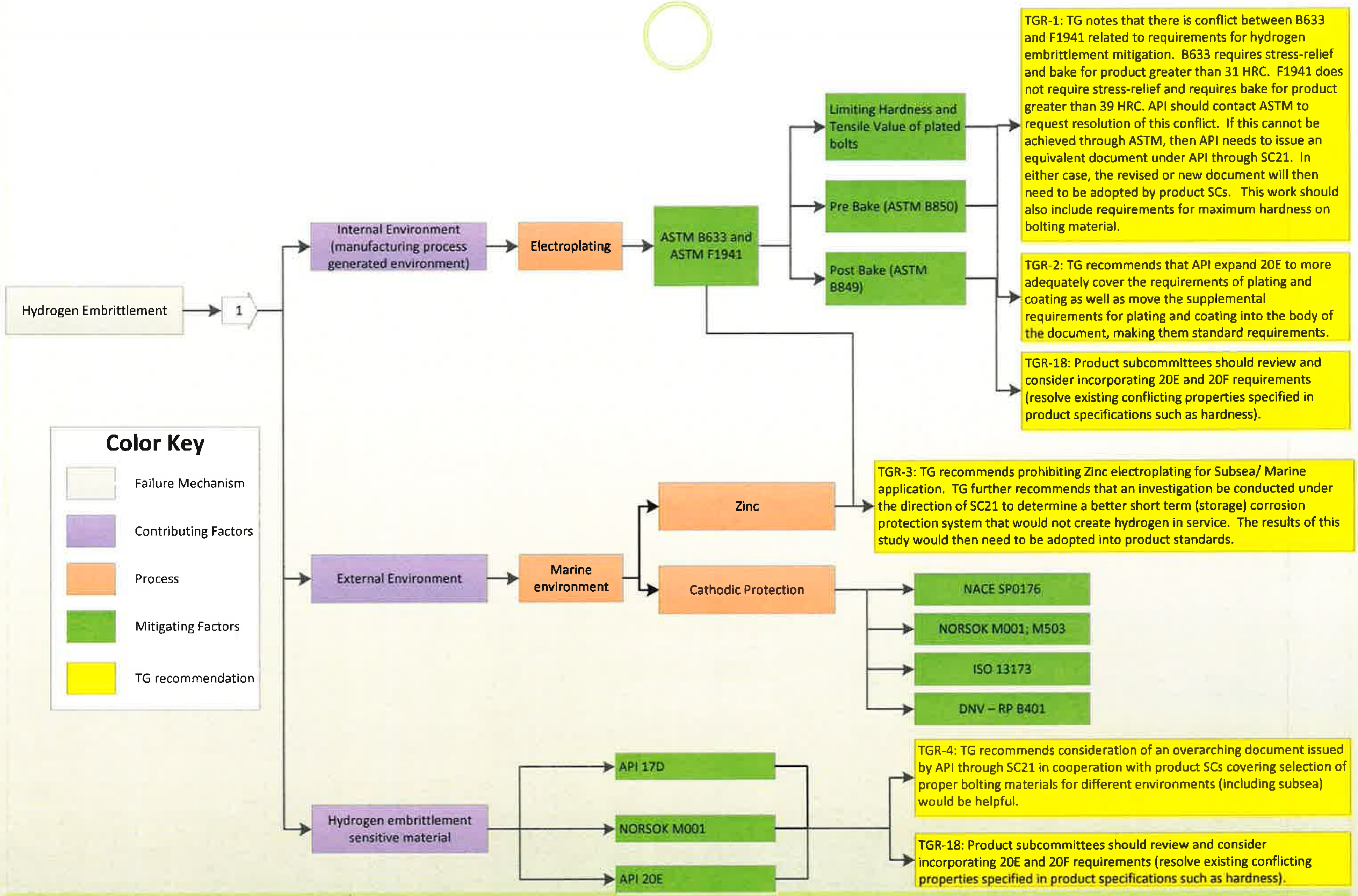
Appendix 1

Failure Mapping for Bolts in the Oil and Gas Industry

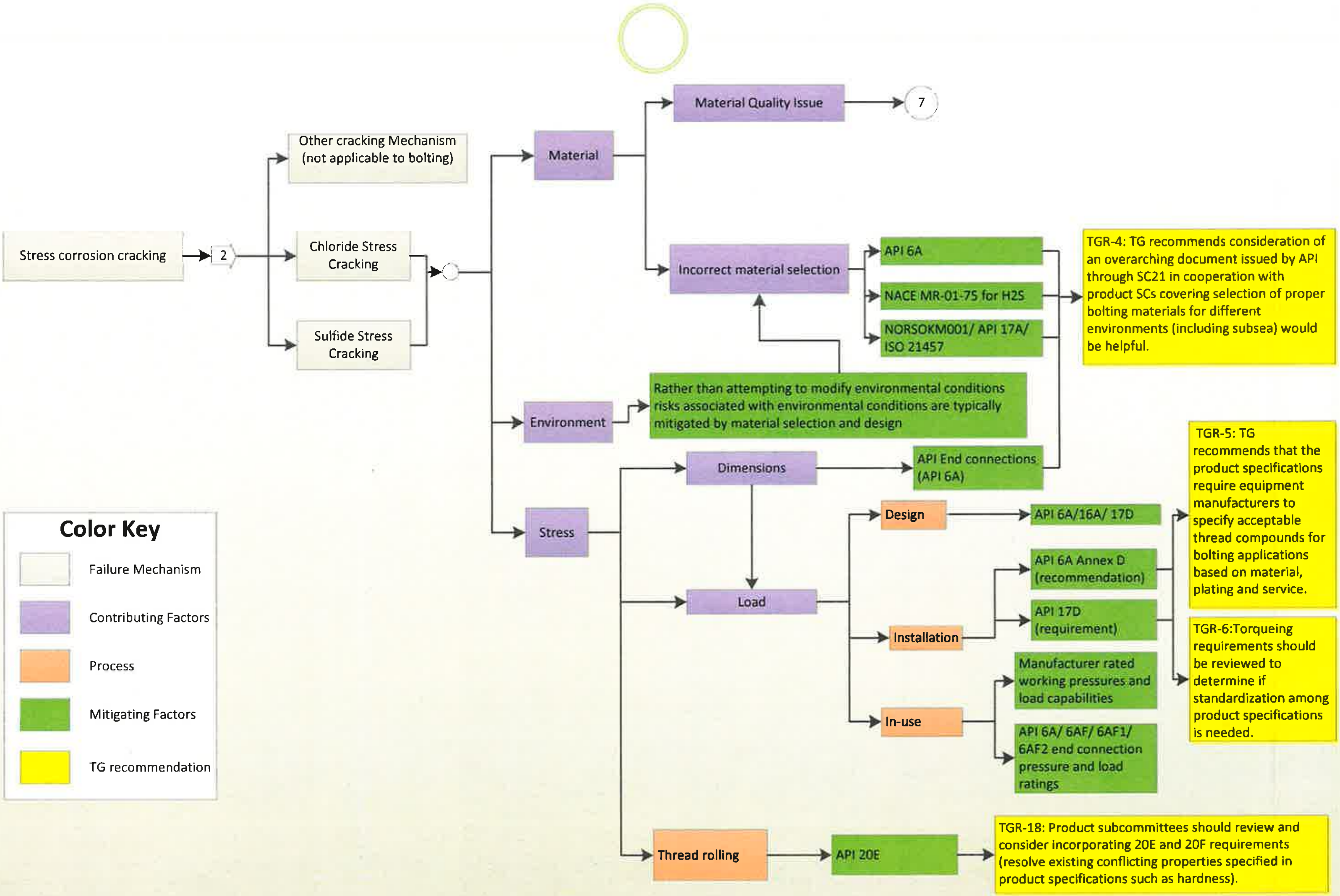
Failure Mapping for Bolts in the Oil and Gas Industry



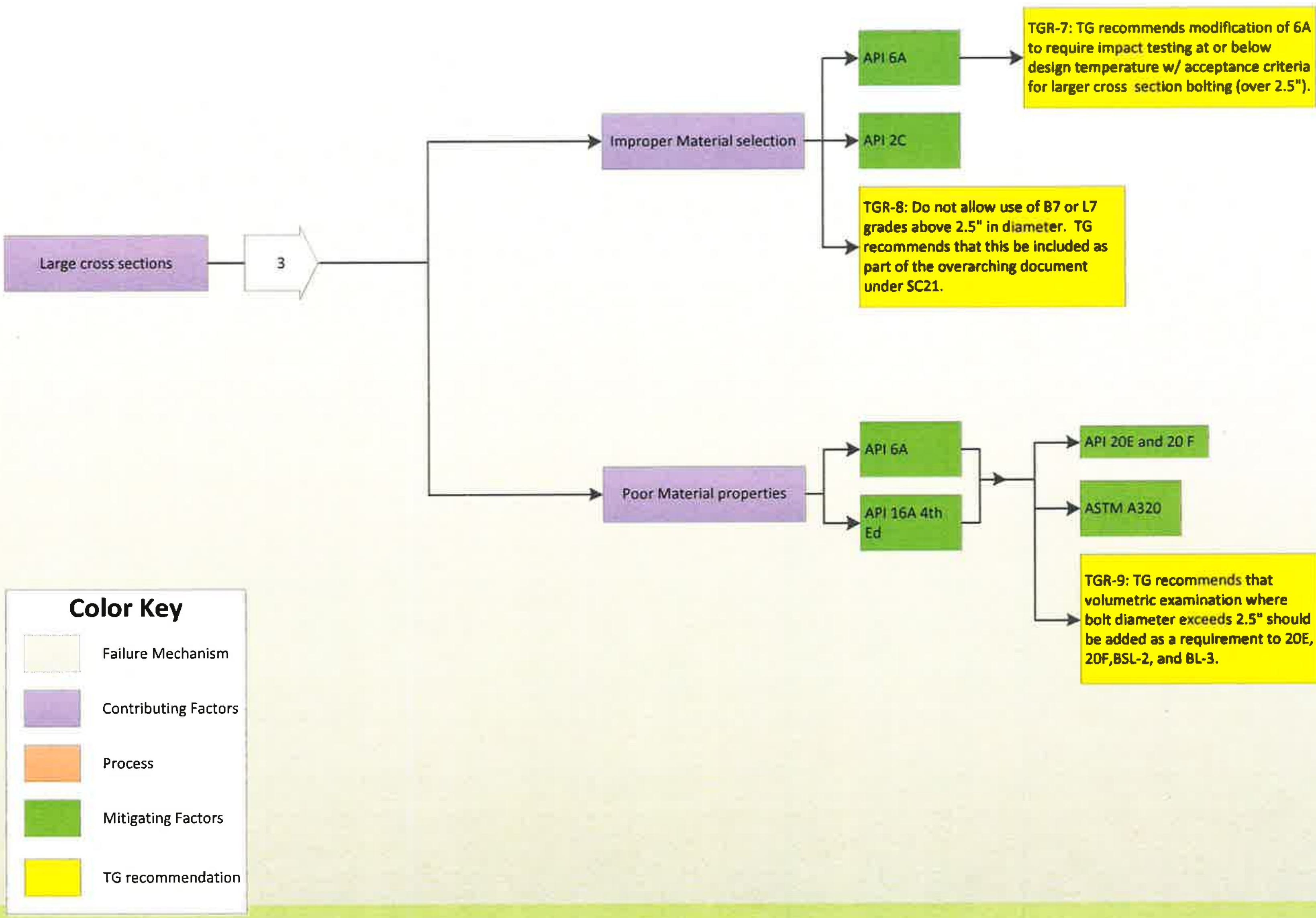
Failure Mapping for Bolts in the Oil and Gas Industry



Failure Mapping for Bolts in the Oil and Gas Industry



Failure mapping for bolts in the Oil and Gas industry



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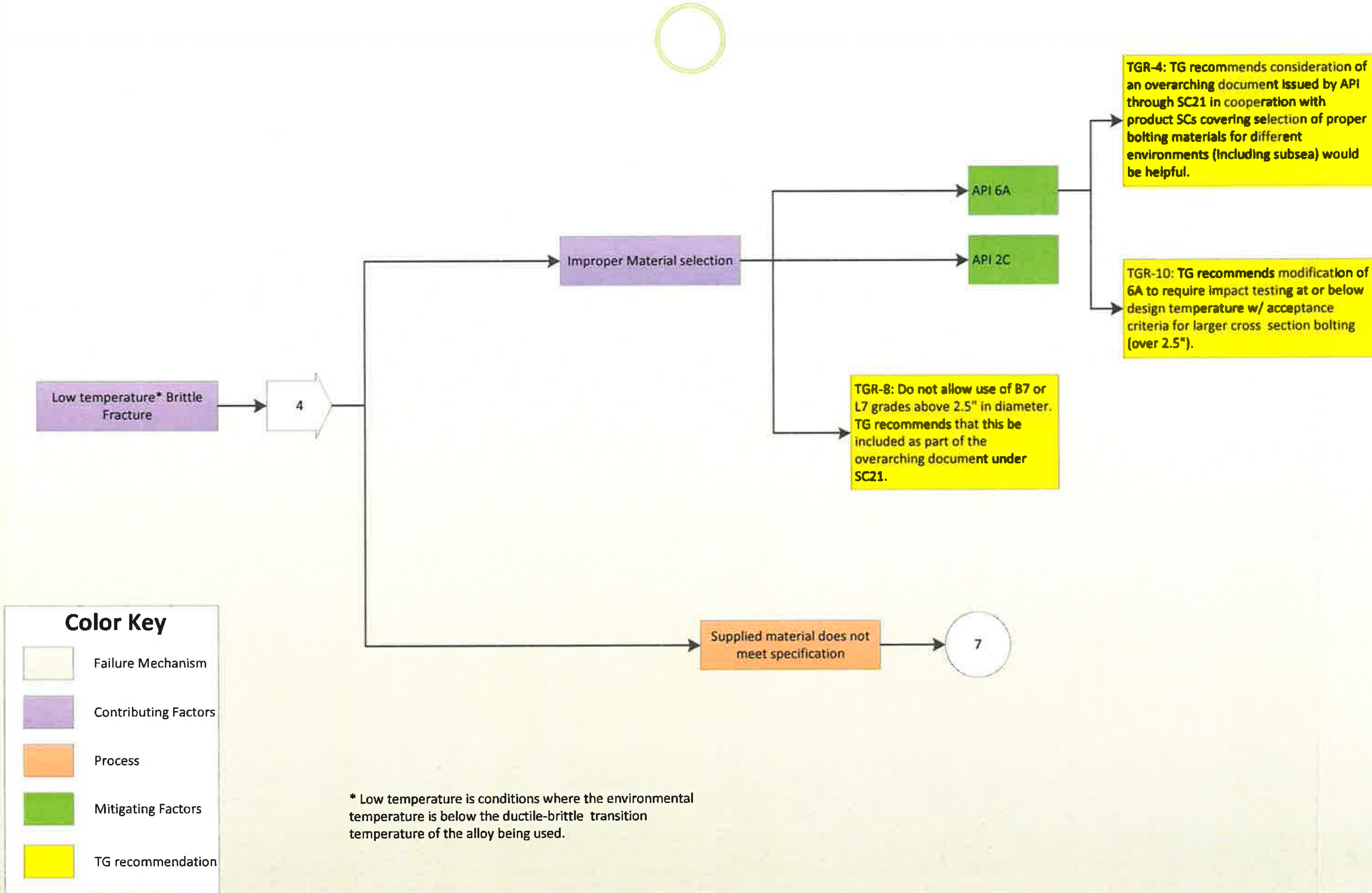
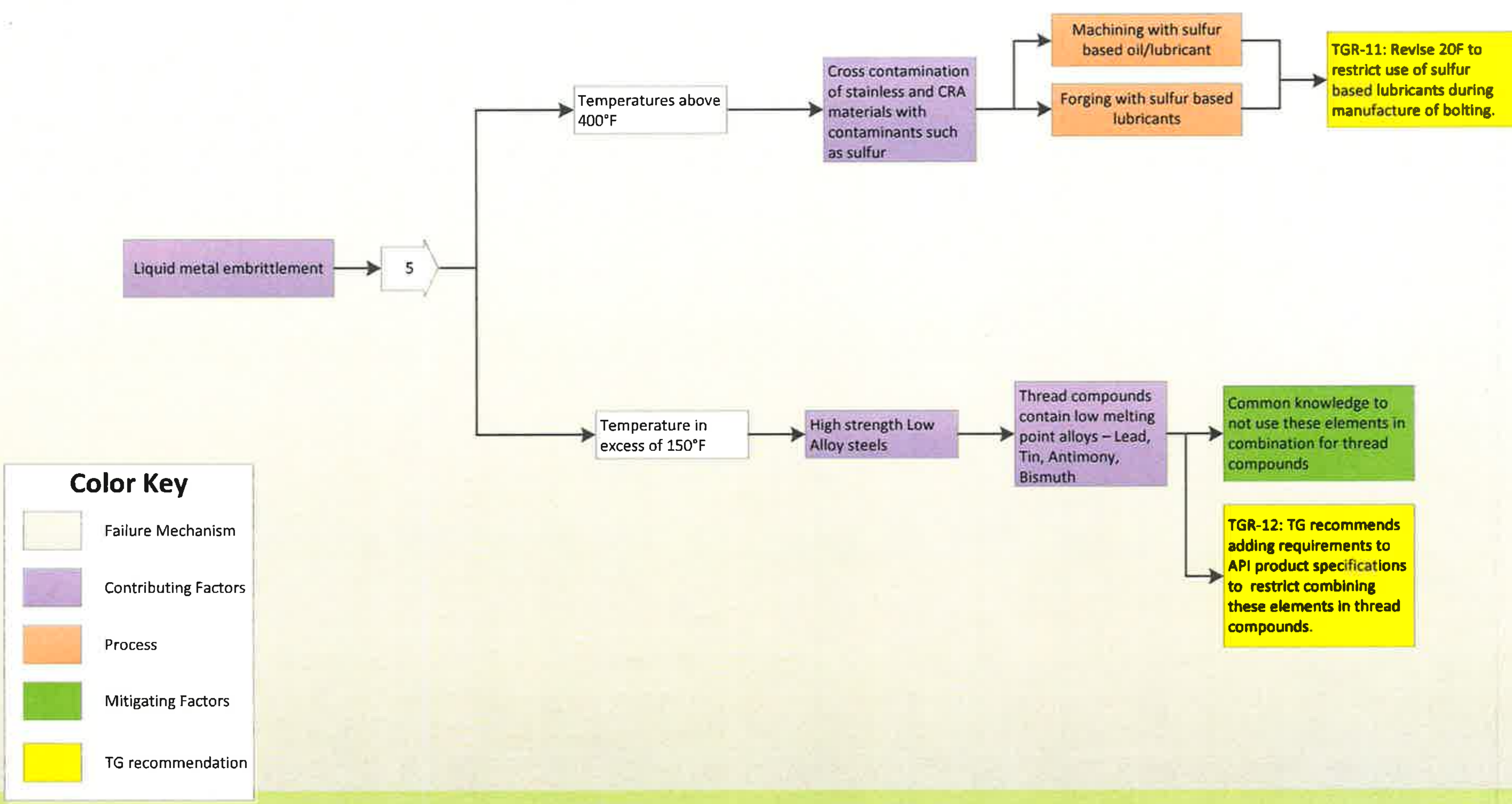


* Low temperature is conditions where the environmental temperature is below the ductile-brittle transition temperature of the alloy being used.

Failure Mapping for Bolts in the Oil and Gas Industry



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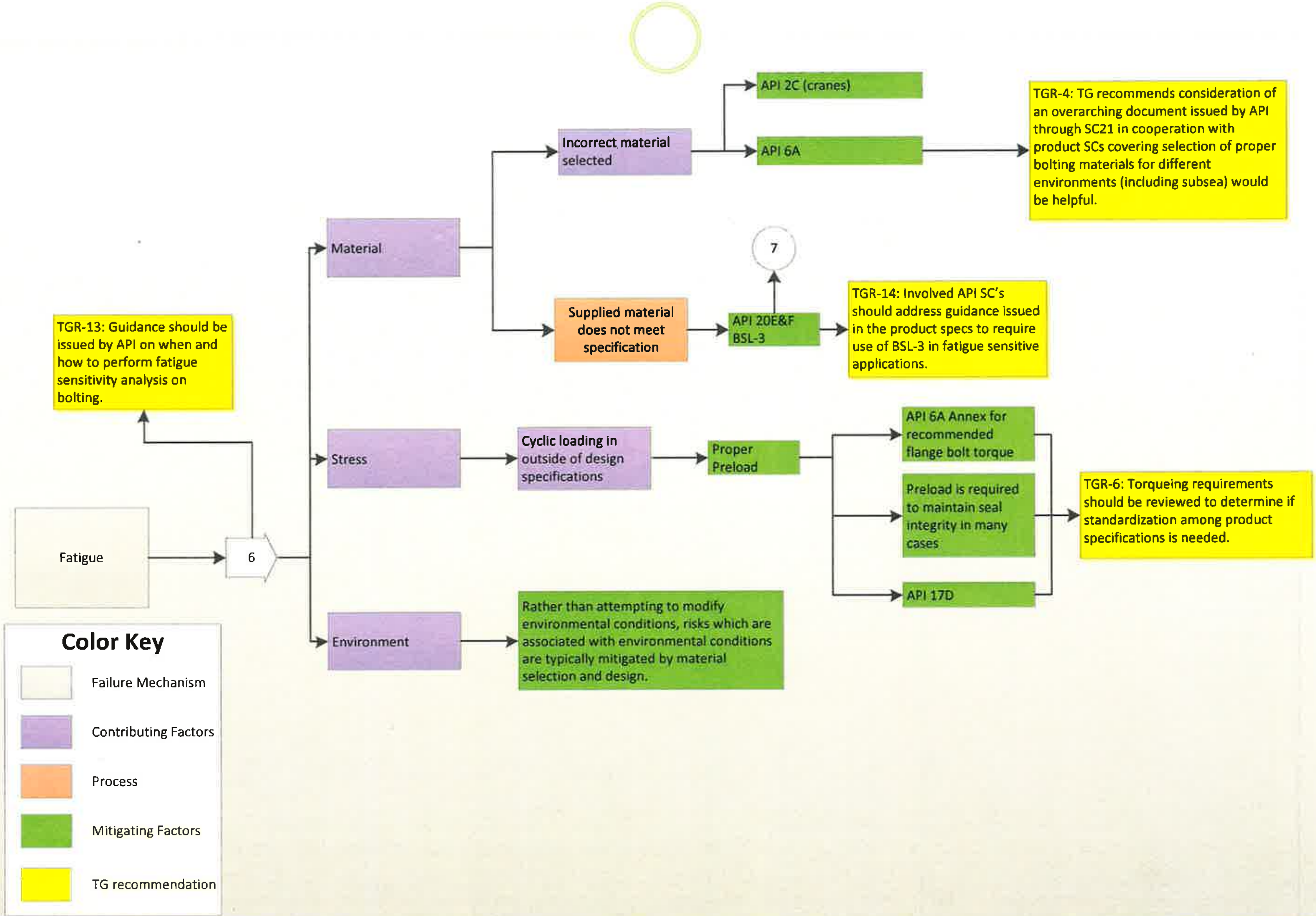

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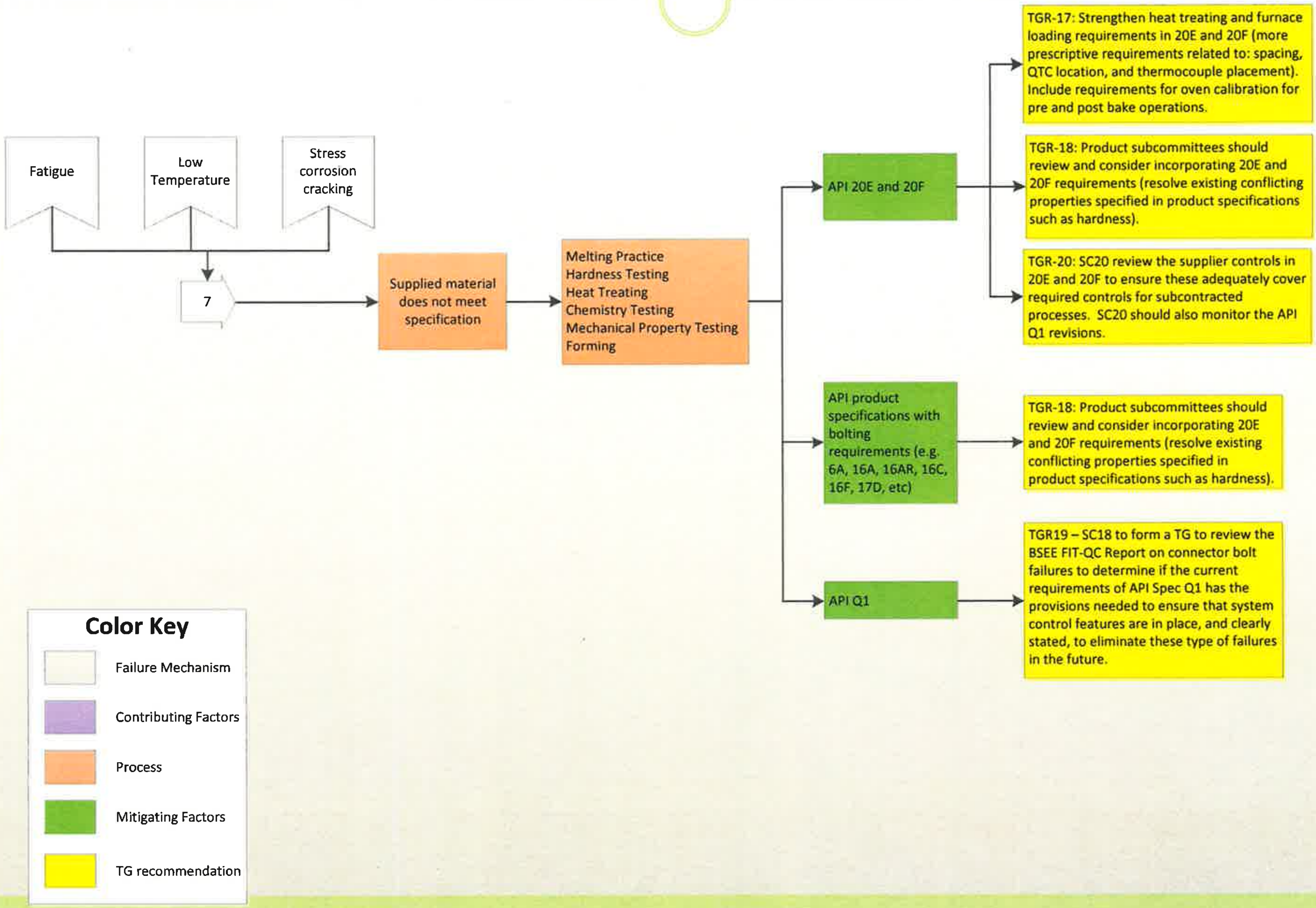

Failure Mapping for Bolts in the Oil and Gas Industry