FINAL

Summary Report for the External Peer Review of
Evaluation of Pressure Rating Methods Recommended by API RP 17TR8

May 12, 2017

Prepared by:

ENDYNA

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1. INTRODUCTION

The EnDyna Team was tasked with selecting three scientific experts to evaluate the *Evaluation of Pressure Rating Methods Recommended by API RP 17TR8* which was which was prepared by Aiken Engineering Company for Argonne National Laboratory (ANL).

The research was funded by BSEE. The evaluation report consisted of the 38-page report, the *Evaluation of Pressure Rating Methods Recommended by API RP 17TR8 223,* and Appendices, which consisted of 223 pages of formulas, charts, graphs, illustrations, and explanations.

In recruiting peer reviewers and coordinating the peer review, the EnDyna Team evaluated the qualifications of peer review candidates, conducted a thorough conflict of interest (COI) screening process, and independently selected the peer reviewers. The EnDyna Team then provided coordination and oversight of the peer review process, and produced this report that summarizes and synthesizes peer reviewer responses to charge questions.

The sections below describe the EnDyna Team's process for selecting external peer reviewers.

1.1 Identification of Experts

The EnDyna Team was tasked with selecting three scientific experts to evaluate BSEE's report. The experts needed to collectively have the following areas of expertise: 1) practical experience with design of offshore equipment in high pressure and high temperature environments, and 2) practical experience in applying API RP 17TR8 and ASME Pressure Vessel Codes Section VII, Division 2 and Division 3, and API Specification 6A in the design, modeling, and/or testing of high pressure and high temperature equipment.

The EnDyna Team contacted six (6) potential reviewers and received five (5) positive responses from qualified candidates expressing interest and availability to participate in this peer review. The other candidate did not feel qualified to perform the review. Four candidates provided their name, contact information, and curriculum vitae (CV) and/or biographical sketch containing their education, employment history, area(s) of expertise, research activities, recent service on advisory committees, publications, and awards.

1.2 Conflict of Interest Screening Process

The EnDyna Team initiated COI screening on the four interested individuals to ensure that the experts had no COI or appearance of the lack of impartiality. The screening was conducted in accordance with the BSEE Peer Review Process Manual (dated August 2014) and involved each expert completing a COI questionnaire to determine if they were involved with any other work and/or organizations that might create a real or perceived COI for this peer review.

The EnDyna Team received completed COI questionnaires for four (4) candidates and evaluated each expert's professional and financial information. Conflict of interest screening was completed on the four individuals. No real COI issues were identified.

A signed Non-Disclosure Agreement (NDA) was also collected from each reviewer.

1.3 Selection of Candidates

In selecting the peer reviewers, the EnDyna Team evaluated each candidate's credentials to select the experts that collectively covered the areas of expertise needed for this peer review, had no real or apparent COI or appearance of the lack of impartiality, and were available to complete the peer review within the desired timeframe. After review and consideration of the available information described above the EnDyna Team selected three (3) peer reviewers that met those criteria. The names, affiliations, education, and expertise of the three peer reviewers are provided below.

The three peer reviewers selected to review *Evaluation of Pressure Rating Methods Recommended by API RP 17TR8* were:

1. **Paul Bunch**
   Bunch Technical Services, Inc.

2. **Daniel T. Peters**
   Structural Integrity Associates

3. **Richard C. Biel**
   Lord & Biel, LLC

Peer Reviewers Selected by the EnDyna Team:

Paul Bunch
Current Employer: Bunch Technical Services Inc., Consultant for Cameron, OneSubsea Sr Technical Consultant, Surface Systems, OSS and Drilling Systems Responsible for design analysis and testing procedures and consulting of Cameron HPHT equipment. **Previous Employers:** Cameron International Corporation ▪ Director, Global Technical Systems, Subsea Systems (2008-2010) ▪ Manager, Metallurgy, Welding and Analysis Departments (2006-2008) ▪ Engineering Analysis Department Manager Responsible for structural, thermal, functional, fatigue, failure, and erosion analyses. (1988-2008) Cameron Iron Works, Inc. ▪ Group Leader, Design and development of high pressure (30,000 psi) production wellhead system. (1980-1987) ▪ Engineering Design and Analysis. Performed numerous stress analyses utilizing finite element techniques initially using ANSYS, and ABAQUS. Applications of stress analysis included elastic, elastic-plastic, two and three dimensional models, and thermal analysis. (1975 – 1980)

API and ASME Task Group Work:

- API TGR13/14 Task Group Chairman –Design Analysis and Material Requirements for Fatigue Sensitive Bolting (2016- Present)
- ASME Sec VIII, Div 3, Subsea Task Group Member (2015 – Present)
- API 17TR8 Task Group member – High-pressure High-temperature Design Guidelines (2013-Present)
- API 6X Task Group Member – API Std 6X Design Calculations for Pressure Containing Equipment. (2013-2014)
- API PER15K Task Group member – Protocol for Verification and Validation of High-pressure High-temperature Equipment (2008-2013)
- API 6A Task Group Member and Chairman (1999) – API 6A Design Analysis (1994-2000)

Education:

- B. S. Mechanical Engineering, University of Tennessee, 1972
- Graduate Work in Fracture Mechanics and Mechanical Metallurgy, University of Houston, 1978-1982

Bio/Expertise:

Mr. Bunch has more than 40 years' experience doing design analysis, design, and testing of high-pressure, high temperature metal components, working primarily for and with Cameron International Corporation and Cameron Iron Works, and currently working as a consultant for Cameron, responsible for the design analysis and testing procedures of high pressure, high temperature (HPHT) equipment. He has conducted stress analyses using finite elements techniques as well as empirical formulas. He has used applications of stress analysis included elastic, elastic-plastic, two and three-dimensional models, and thermal analysis. He has also conducted frequency domain riser analysis and erosion/corrosion analysis. He designed and developed a high pressure (30,000 psi) production well head system, and supervised the design structural analysis performed on individual components, determined design stress allowable, and set requirements for material specifications. He has been responsible for structural, thermal, functional, fatigue, failure, and erosion analyses. He has also served as Cameron's Director for Global Technical System, and Subsea Systems, Including Management of Design Analysis, Metallurgy, Welding Engineering, CAD Systems and Reliability Departments.

Mr. Bunch is also one of the leaders of the oil and gas HPHT subsea industry, serving on ASME and API task forces. He currently serves as an ASME Sec VIII, Div 3, Subsea Task Group Member, an API 17TR8 Task Group member, and has served as an API 6X Task Group Member, dealing with API Std 6X Design Calculations for Pressure Containing Equipment, and API PER15K Task Group member dealing with the Protocol for Verification and Validation of HPHT Equipment, and an API 6A Task Group Member and Chairman for API 6A Design Analysis.

Daniel T. Peters, PE

Current Employer:

Associate, Structural Integrity Associates (2006 to present)

Previous Employers:

FMC Technologies, Manager, Mechanical Engineering (2005 – 2006)
Autoclave Engineers, Division of Snap-tite, Inc., Senior Engineer (1995 – 2005)

Saegertown Manufacturing, Project/Process Engineer (1992-1995)
The Timken Company, Tooling Engineer (1991-1992)

API and ASME Participation:

- API PER15K and 17TR8 Participant, 2008-Present
- ASME Pressure Vessels and Piping Division, Past Division Chair, Past Chair of the High-Pressure Technology Committee Codes & Standards
- ASME Codes and Standards Development
- Chair ASME Subgroup on High Pressure Vessels – Member 10 years
- Member of the ASME Committee on Pressure Vessels (Section VIII) – 12 years
- Past Chair, ASME Ad Hoc Committee on High Pressure Systems

Education:

- B.S. Mechanical Engineering, Pennsylvania State University, 1991
- M.S. Mechanical Engineering, Gannon University, 1999

Bio/Expertise:

Mr. Peter's activities over the last twenty years have focused on the design and analysis of high-pressure equipment, including the application of fracture mechanics to the design and analysis of pressure vessels for evaluation of the life of the equipment. Prior to joining Structural Integrity (SI), Mr. Peters spent 10 years at Autoclave Engineers focusing on the design and analysis of high pressure vessels. This included both industrial and experimental custom designed equipment with pressures from 500 psi to 150 ksi. He was also responsible for the mentoring of younger engineers in the design philosophy of Autoclave, the application of finite element analysis (FEA) and the application of the ASME Boiler and Pressure Vessel Code. He has worked extensively with ASME Sections II and VIII Divisions 1, 2, and 3.

The last several years while at Autoclave, one area of work focused on application of engineering principles to the in-service inspection of equipment and fitness for service evaluations including applications of API 579-1 / ASME FFS-1 Fitness for Service Standard. This included remaining life assessment utilizing fracture mechanics and fatigue, flaw evaluation and practical application of NDE techniques. Beginning with his work at Autoclave, Mr. Peters became active in the American Society of Mechanical Engineers both in the area of Codes and Standards and technology development through the Pressure Vessel and Piping Division. He has held several offices and positions in this capacity, largely supporting the development of high pressure technology. Mr. Peters has authored or coauthored several papers in this area with subject matter including cycle life of pressure vessels and high pressure components and stress concentration factors at cross-bores of cylinders. Mr. Peters received awards for two of his papers and is currently the Chairman of the ASME Pressure Vessel and Piping Division. Mr. Peters is an ASME Fellow and has received the ASME Dedicated Service Award.

Richard C. Biel

Current Employer:
Lord & Biel, LLC, Staff Engineer

Previous Employers:
Stress Engineering Services

- Senior Staff Consultant, (2011 – 2016)
- Senior Associate/Staff Consultant, (1998 – 2011)
- Staff Consultant, (1994 – 1998)

Enpro Systems, Inc., Manager, Research and Development (1990 – 1994)

API and ASME Participation:

- Member, ASME Boiler and Pressure Vessel Code, Sub Group High Pressure Vessels (Section VIII, Division 3, Alternative Rules for Construction of High Pressure Vessels)
- Task Group on Design "TGD", 1994, Appointment "Commission" expires June 2016. His contributions to this Task Group have aided the preparation of the new and revised Code rules for these vessels.
- He formerly chaired a Task Group, within the Sub Group, that reviewed new construction techniques for inclusion into the Code and was instrumental in the passage of Section VIII, Division 3, Code Case 2390 Composite Reinforced Pressure Vessels.
- Former Member, ASME-HPS High Pressure Systems Standard (Main) Committee, 2007
- Member, API Steering Committee, Recommended Practice for >15 ksi Equipment, Liaison to ASME, 2005 - 2009
- Member, ASME Boiler and Pressure Vessel Code, Task Group on Impulsively Loaded Vessels (SCVIII), 2003-2010

Education:

- M.E., Mechanical Engineering, University of Houston, 1979
- B.S., Mechanical Engineering, New Mexico State University, 1968

Bio/Expertise:

In addition to providing expert consulting services, Mr. Biel's current work is focused on design of high pressure vessels and fitness for service evaluations of pressure vessels and piping components and systems. His evaluation work emphasizes high pressure (greater than 10,000 psi) equipment. This international practice has served a variety of clients including fabricators, petroleum refineries, power and chemical plants, and paper mills. Before joining Stress Engineering Services, Inc. in 1994, he was the manager of R&D for a fabricator of pressure vessels and specialty high temperature refinery equipment and associated valves. His design work has included ASME Code pressure vessels for Division 1, 2, and 3 compliance as well as general machine designs. In addition, Mr. Biel has over 14 years of industrial experience in the design of API land well heads and gate valves, including designs for Arctic service and critical sour, corrosive service. As a consultant from 1980 to 1985, he had assignments with numerous clients involving well heads, gate valves, pressure vessels, oil tools, general machine design, and forensic engineering. Mr. Biel currently serves as a member of the Sub Group on High Pressure Vessels (SGHPV SC VIII). This ASME Code committee authors the Boiler and Pressure Vessel Code, Section VIII, Division 3, Alternate Rules for Construction of High Pressure Vessels. This Code committee appointment was offered in 1994 and he continues to serve as a major contributor. He also serves on various other ASME Code committees and is the liaison between ASME and API for High Pressure High Temperature (HPHT) design verification methodologies. Mr. Biel has tested prototype valves and well heads under extreme environmental conditions, including low temperature and high temperature and high pressure gas. He has qualified many well head components to meet API Specifications by classical calculations and physical tests. He designed modifications to a flowing test facility where he physically life-cycle tested gate valves to 10,000 psi for hundreds of cycles to evaluate wear and performance. He has published many articles on analysis, design, development and testing of HPHT vessels and equipment.

This peer review report is comprised of Sections 2, 3, 4, 5, 6, and 7. ***Section 2*** provides the charge questions sent to each of the peer reviewers for comments, ***Section 3*** provides the synthesis of their peer review comments, and ***Section 4*** provides the peer review comments of each reviewer organized by charge question. In addition, ***Section 5*** (Appendix A) consists of the individual peer reviewers' comments. The peer review materials package is found in ***Section 6*** (Appendix B). References are provided in ***Section 7***.

2. CHARGE QUESTIONS

The purpose of this review was to obtain written comments from individual experts on the report entitled, *Evaluation of Pressure Rating Methods Recommended by API RP 17TR8 223*. Each reviewer was charged with evaluating the report, providing their overall impressions of the scientific merit of the report, and responding to eight major charge questions with some sub-questions. The eight charge questions and sub-questions provided to the reviewers are presented below.

I. General Impressions	Provide overall impressions (approximately 1/2 page in length) addressing the accuracy of information presented, clarity of presentation, and soundness of conclusions.
II. Response to Charge Questions	Provide narrative responses to each of the eight Charge Questions below.
1.	***Evaluation of Test Methods***
1.1	Were the test objects selected for analysis valid test objects to evaluate the standard as applied? Consider true stresses and strains in the context of valid discussion.
1.2	Are the assessments of engineering safety factors for the cited standards and their divisions valid for the expected applications?
1.3	Were comparisons of the computational methods and design methods adequate?
1.4	Are the assumptions of the modeling and tests clearly defined and appropriate?
1.5	Did the report identify and adequately address the strengths or weaknesses of the analytical methods used for the modeling and testing methods used?
1.6	Were the actual materials within specification for F22 material properties adequate?
1.7	Determine the degree of certainty that each test object did not have a latent defect, was forged properly, and manufactured properly; for example, should there have been a post manufacturing stress reduction heat treatment?

1.8	The report documents a failure of the tested object for the 17 TR8 Division 3 method to show a failure of the test object at a threshold below the design standard. Do the conclusions and recommendation based upon this stand alone? Are there other considerations, such as the fact that the material chosen is a non-Division 3 material, or any other alternate logical explanation for failure event below the Division 3 design standard?
1.9	Are there other obvious conclusions that the report should have addressed identified by the peer review?
2.	***Evaluation of Modeling Results: Do the modeling results describe with reasonable accuracy the basis for decisions in the applied methods:***
2.1	Are the limitations and uncertainties clearly identified and adequately characterized for the methods of modeling selected?
2.2	Are the assumptions of the modeling appropriate for the methods of modeling selected? Assumptions evaluated should include, but are not limited to: ▪ Material Thickness ▪ Mesh chosen ▪ The correspondence of the modeling to the design basis specified in the standard
3.	***Are there strengths or weaknesses of the analytical methods used for the empirical calculations chosen in the report?***
4.	***Are the conclusions drawn by the report appropriate based on the modeling results and empirical analysis?***
5.	***Are the conclusions related to the test appropriate?***
6.	***Are the other conclusions appropriate?***
7.	***Are the recommendations logical, appropriate, and supported by the conclusions of the test results, empirical analysis, and modeling results? The scope of the recommendations pertains to all recommendations, not just those derived from the modeling results.***
8.	***Are there any obvious technical considerations the report should have covered that are missing?***

3. SUMMARY OF PEER REVIEWERS COMMENTS

The section below provides the synthesis of peer reviewers' comments, including general impressions and responses to charge questions.

It is noted that a number of standards, normative references, and recommended practices for HPHT design and evaluation have been updated since ANL began their project and published their draft report; these standards could have additional bearing on the application of final conclusions and recommendations.

3.1 General Impressions

<table>
<tr><th colspan="2">GENERAL IMPRESSIONS</th></tr>
<tr><td colspan="2">Provide overall impressions (approximately 1/2 page in length) addressing the accuracy of information presented, clarity of presentation, and soundness of conclusions.</td></tr>
<tr><td>Tests Limited but Appear Valid</td><td>One reviewer accepted "…the validity and accuracy of the burst test results. Also, the use of classical equations and finite element analyses appear to be done accurately. However, the finite element analyses can only be checked for accuracy by a detailed examination of the input files. Presuming that the analytical work was done by someone skilled in the method, there is no reason to doubt its accuracy." -RB

He added, "Whatever design methodology was used, it appears that both large and small neck designs were adequate for the intended pressure rating of 20,000 psi. The report fully justifies that pressure rating. Even the calculation of the pressure rating from the results of the burst test in Appendix E… of the report shows the adequacy of the design." -RB</td></tr>
<tr><td>Limited Sample</td><td>A reviewer noted that the sample size of two test pieces was insufficient for the conclusions that were made.

The two component evaluations conducted are insufficient in number to demonstrate the analytically predicted collapse pressure vs the proof test provide a statistical distribution range of data. It is stated that the error may be greater for more complex geometries which may be true, but that only means there would be a wider distribution of data points, which could result in higher or lower predicted collapse loads vs. burst pressure. Additionally, more complex shapes may result in burst pressures initiating from local failure due to strain limit damage as opposed to tensile overload of the cross-section. -PB

He also remarked,

The recommendation of comparing collapse pressure from FEA with burst pressures from hydrotests for a variety of subsea equipment is impractical and the failure mode could change depending on the component. More research into existing and possibly additional test specimens should be conducted to obtain a more complete statistical</td></tr>
</table>

GENERAL IMPRESSIONS	
Provide overall impressions (approximately 1/2 page in length) addressing the accuracy of information presented, clarity of presentation, and soundness of conclusions.	
	distribution of results. It should not be based on a data set of two tests to establish a lower bound for all test data. -PB
No Reference to HPHT Published Research	A reviewer was concerned that no literature review was done. The report does not appear to make any reference to the published research which has been done previously on this subject, nor the basis for the standards, nor technical reports which are available in industry today to support the technical approaches put forth in the standards. -DP
No Reference to Non-Subsea HPHT Industry	The same reviewer was concerned about lack of reference to the non-subsea HPHT industry. Most of the conclusions appear to ask for the subsea industry to consider what they are doing as unique and completely different from other equipment which operates with internal pressure in corrosive environments in cyclic service with similar temperature, pressures and materials. The idea that this equipment, together with it environment and operation, is unique from other pressure equipment in other industries is a misconception. The subsea industry would greatly benefit from looking at the past experience of other industries and using that as a basis for the work going forward. -DP
Preconceived Hypothesis	Reviewers expressed concern that the report seemed to have pre-conceived hypotheses, and extended the interpretation of test results to support them. The report appears to have been written with pre-conceived hypotheses, and the report attempts to use data from the testing and analysis to support these hypotheses and the conclusions of the report. There are data in the analysis section of the report which were not addressed as they do not support the final conclusions of the report. -DP …when the report takes the added steps to generate pressure ratings based on plastic collapse by analysis, and further applies a load factor to the burst test results, it seems the intent is to stretch the validity of Division 3 beyond its normal assessment uses. -RB

GENERAL IMPRESSIONS	
Provide overall impressions (approximately 1/2 page in length) addressing the accuracy of information presented, clarity of presentation, and soundness of conclusions.	
Design Margin and Design Load Issues	A reviewer questioned the conclusion that design margins for subsea equipment should equal historic margins, which are based upon outdated stress analysis methods. The conclusions all center on some belief that the design margin required for successful operation in subsea equipment must equal the same margin that has been used since the 1960s and designs are best determined by using stress analysis methods which are becoming outdated. -DP The reviewer continues, "None of the standards referenced by API for this purpose have the same margins for that period of time." -DP. According to the reviewer's opinion, this is "largely due to advancements in material production, fabrication, and more sophisticated design approaches." -DP Another reviewer suggested the process for developing the ASME Sec VIII, Div 3 load factor of 1.8 be reviewed before determining that it is unacceptable. The ASME Sec VIII, Div 3 load factor of 1.8 was developed over time. There is historical information, technical justification and testing by ASME that should be reviewed before a decision is made that the design load factor of 1.8 is not acceptable for API subsea equipment. -PB Another reviewer questioned whether the writer was familiar with Division 3 and the history of the design margin, and the difference between the design margin and load factor. Refer to the Figures 9.1a and 9.1b. It seems the writer is not sufficiently familiar with Division 3 to know how to accurately portray the historical design margin. Division 3 did not come into existence until 1997 and in the early editions used the design margin of 2.0. In the 2007 edition with the 2009 addenda the current design margin of 1.732 was introduced along with the LRFD methodology that included the load factor of 1.8. -RB The difference between the design margin and load factor as used in Section VIII, Division 3. The basic design margin in Division 3 is 1.732 (the square root of three) for materials that have a ratio of material yield strength to ultimate strength that is greater than approximately 0.72. The difference is small, approximately 2% when evaluated for thick-wall cylinders. Use of the value of 1.8 as a "design factor" points to a basic misunderstanding of the use of LRFD load factors used to assess adequacy of the design according to the Code. -RB

GENERAL IMPRESSIONS	
Provide overall impressions (approximately 1/2 page in length) addressing the accuracy of information presented, clarity of presentation, and soundness of conclusions.	
Design Margin and Design Load Issues (cont.)	He also mentioned that the writer used the term "design factor" instead of the correct term, "design margin." In addition, he wondered why the writer referred to the 2013 edition of the code when the 2015 edition was available. The ASME code writers currently use the term "design margin" that was formerly known as the "safety factor" to describe the level of uncertainty with respect to failure of a component or pressure vessel. The term used extensively in the report as "design factor" is not consistent with terminology in current use within the ASME Code. Also, it is not clear why the report occasionally uses the 2013 edition of the Code when the 2015 edition of the Code was available during the time this report was written. -RB
Conclusions Based on Limited Assumptions	A reviewer remarked that the conclusions were made based on historical approaches for defining pressure ratings, rather than considering newer information. The conclusions made were based on comparisons of historical pressure rating allowable stresses and procedures for defining pressure ratings which have changed. API 6A/6X/17D were referenced as one of the current design methodologies of equipment rated for working pressure up to and including 15 ksi. The current design methodology is defined in API 6X, which allows the use of von Mises stresses to calculate the design allowable. API 6X is referenced in 17TR8. ASME Div 2 linear-elastic design stress allowable was defined to be based on yield strength and it is not. Div 2 refers to ASME Sec II Part D for allowables which are based on ultimate strength. ASME Sec VIII, Div 3, KD-12 is referenced as an acceptable procedure for proof testing to failure to define equipment pressure ratings. KD-1254 does not allow pressure ratings to be determined using proof testing. -PB
No Testing of Other Types of Failure	The same reviewer stated that the report did not provide a complete evaluation of 17TR8, and failed to evaluate other common types of failure. This review is limited in scope in that the report does not address the complete evaluation of 17TR8 for pressure rating. The focus of the report was based on collapse pressure and does not address local failure, ratcheting, fatigue, serviceability, etc. As such, the peer review responses are evaluating this limited scope of work. Other failure modes are addressed in this review only in context of references made in the text or how they would influence the collapse pressure predictions. -PB

<table>
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<tr><td>API 17TR8 Not a Standard</td><td>The same reviewer pointed out that the report erroneously refers to API 17R8 as a standard, although it is a technical report.

Additionally, API 17TR8 is referred to as a standard in the charge questions of this review and it is not, it is a technical report. API 17TR8 is not a standalone document (as stated in the Introduction section of the document), it is a guideline for HPHT development, and must be used in conjunction with all applicable industry standards to assure completeness and accuracy of the design requirements. HPHT guidelines from BSEE Standards Workshop: HPHT Session, May 8, 2015, provided the following statement; 'BSEE also recognizes that API 17 TR8 is a general guidance document, is not complete in its scope, is not the only HPHT guidance document, and does not address all issues associated with the construction of all HPHT oil field equipment. Technical Reports are not Engineering Standards.' There are additional specifications referenced in the peer review that are pertinent and applicable to HPHT designs. -PB</td></tr>
<tr><td>Code is Not a Design Handbook</td><td>Another reviewer remarked that the ASME Boiler and Pressure Vessel Code is treated as a design methodology document, while it is only intended for an assessment of design.

This writer has a fundamental philosophical difficulty with the use of the ASME Boiler and Pressure Vessel Code as a design methodology document. The intent of the Code is that the methodology and processes in the Code be used only for an assessment of a design. The Code explicitly states that it is not a design handbook. For many decades however, the designers of API equipment have misused the Code as a design handbook. -RB</td></tr>
<tr><td>Additional Analysis of Report</td><td>One of the reviewers provided additional analysis of the evaluation report.

Factors that Threatened Validity of Test Results

He mentioned that:

There are topics in this report which are difficult to determine the accuracy due to the limited amount of information. This includes:

▪ Completeness of the material properties. It cannot be definitively stated that the material properties used in the analysis were representative of the properties at the location of the burst.
▪ The FEA models did not include all components of the assembly which was subjected to burst, such as the flange bolting, ring</td></tr>
</table>

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<tr><td>Additional Analysis of Report (cont.)</td><td>gasket and blind flanges. These may not influence the results, but not including them raises the question of accuracy in the modeling.
▪ The data provided for the strain gage testing was incomplete. Data was not provided for the high strain regions on the ID and the data from external gages were only for principal strains up to hydrostatic test pressure and does not provide the elastic-plastic strains up to burst pressure. The results of the strain gage testing did not provide an acceptable validation of the accuracy of the FEA. Nor were they used to define collapse pressure. -PB
▪ The material properties used for the FEA were defined to be obtained from true stress-true strain data. There are three different sets of material tensile properties, it is unclear if the properties used for the FEA were the lowest of the three measurements.

He also commented that more information is needed about the quenching process.

The material process did not provide non-proprietary material processing procedures from the forgemaster, such as information on the quenching of the forging defining orientation and circulation of quench fluids in the quench tanks. It wasn’t clear if the prolongation was attached during the heat treat cycle and it wasn’t clear if both test samples had prolongations or if just one prolongation was used for both test samples. -PB

In addition, he said additional strain gage measurements were needed during the burst test for validation of the FEA for predicting burst.

Regarding the burst testing the strain gage measurements were only obtained for the hydrostatic test, but should have provided the readings during the burst test for validation of the FEA for predicting burst. Not all strain gage data was reported, the internal gages were determined to be inaccurate. -PB</td></tr>
<tr><td>Clarity of Presentation</td><td>He did acknowledge that:

Overall the procedures for proof test analysis were very well defined and understood. The FEA Models were clear, all reference standards used for determining design margins were well referenced. Equations which defined how allowable design pressures were calculated and clearly defined. -PB</td></tr>
</table>

3.2 Responses to Charge Questions

The section below provides the synthesis of the peer reviewers' comments, concerns, and suggestions regarding the charge questions.

RESPONSES TO CHARGE QUESTIONS	
1. *Evaluation of Test Methods*	
1.1	*Were the test objects selected for analysis valid test objects to evaluate the standard as applied? Consider true stresses and strains in the context of valid discussion.*
	Reviewers agreed that the test objects were valid, with some reservations. One stated that the objects were in compliance for internal and external pressure only. > In my opinion, the configuration of the test articles that were chosen were adequate to demonstrate compliance with the technical report 17TR8 for internal and external pressure only. Obviously missing are loads due to external tension and bending. External tension and bending loads have been identified as significant loads, possibly defining loads, for subsea equipment. -RB Another reviewer acknowledged that while there can be a lot of variation in pieces of equipment, the general configuration is similar in size to equipment in the industry. > The test bodies shown in Figure 5.1 and 5.2 of the report are very similar geometrically to other types of valves, tees, connectors, and equipment used in the subsea HPHT industry. Fillet radii, ring joint geometry, and other details vary greatly between manufacturers, so it is difficult to say if it is specifically applicable relative to a specific design. The general configuration is similar in size to other such equipment in the industry. -DP The same reviewer recognized that the flanges met requirements, but the size and number of bolts might not meet requirements. > The flanges used in this situation are standard size 20 ksi flanges based on Table B.43 of API 6A for 20 ksi rated working pressures. The analysis does show that the flanges meet the requirement of global collapse at these pressures. However, it is likely that the size and number of bolts used, might not meet the requirements of ASME Section VIII-2. -DP He also noted that some of the fillet radii were larger than in typical equipment. > Additionally, based on experience with other HPHT equipment in industry, some of the fillet radii were larger than in typical equipment.

RESPONSES TO CHARGE QUESTIONS	
1. *Evaluation of Test Methods*	
1.1	*Were the test objects selected for analysis valid test objects to evaluate the standard as applied? Consider true stresses and strains in the context of valid discussion.*
	This could lead to under predicting local plastic strain in these areas which could lead to localized failure in typical equipment. This is not the focus of the current study. -DP Another reviewer stated that the test objects were valid except for tensile test location and CVN values, and provided details on the standards that need to be met. The test objects were valid based on referenced standard of API 6A and technical report 17TR8 as they were defined in the report, except for tensile test location and CVN values. There are additional industry published specifications for material processing and testing requirements above those defined in API 6A, which were released prior to the development of this project. The use of API 6A material requirements is not adequate for development of HPHT equipment. As an example, API 6A material Charpy V-notch impact requirements require an avg of 20 ft-lbf, where ASME Div 3 requires 50 ft-lbf, and the material specification for this test object required an avg of 40 ft-lb. Applying design criteria for global collapse using ASME Div 3 for HPHT designs, should meet the toughness requirements of this document. Additionally, API 20B and DNVGL-RP-0034 'Steel Forgings for subsea applications' provide guidelines for material processing, testing and Charpy values (RP-0034). API 20B is currently being applied in the industry and RP-0034 is being reviewed for HPHT equipment applications. As defined in 17TR8, API 6A/17D/6X are specifications for equipment rated for working pressures up to and including 15 ksi equipment. -PB He provided analysis of the two sets of material tensile tests and their results. There were two sets of material tensile tests reported which were obtained from the prolongation material. A true stress-true strain curve was defined as the material input in FEA (supplied by ANL) and it is assumed this test was in addition to the reported tensile tests results, and provides a third set of tensile properties. There are variations in the results of the tensile properties for the two tests provided. The two engineering yield strengths values were 92.2 ksi and 91.6 ksi and the ultimate strength values were 111.1 ksi and 108.7 ksi. It is unclear if the true stress-true strain curve input for the FEA represents the lowest yield and ultimate stress data obtained from the material tensile testing. -PB

RESPONSES TO CHARGE QUESTIONS	
1. *Evaluation of Test Methods*	
1.1	*Were the test objects selected for analysis valid test objects to evaluate the standard as applied? Consider true stresses and strains in the context of valid discussion.*
	He further described specifications for material testing. The material specification references API 6A PSL 3 as the criteria for material testing. Mechanical properties were taken from 1/4T location on the prolongation. API 6A requires test coupons to be taken at '3mm (1/8 in) from the mid-thickness of the thickness section of a hollow QTC.' Additionally, 20B and DNVGL-RP-0034 require mechanicals at 1/2T location in both the longitudinal and transverse directions. -PB He also explained that a qualification forging cutup should have been performed when comparing FEA collapse pressure to test specimen burst pressure. To obtain the most accurate results when comparing FEA collapse pressure to test specimen burst pressure, mechanical properties in the flange neck in the transverse direction using a qualification forging (first article) cutup to obtain the properties should have been performed, reference API 20B. -PB

RESPONSE TO CHARGE QUESTIONS	
1. *Evaluation of Test Methods*	
1.2	*Are the assessments of engineering safety factors for the cited standards and their divisions valid for the expected applications?*
	Reviewers acknowledged, with reservations, that the assessments and conclusions from the test results were adequate. One reviewer noted that the report does not address important loads such as external tension and bending. As stated earlier, the report does not address important loads such as external tension and bending. In this respect, the underlying design margin in Division 3 cannot be fully assessed. That said, the assessments and conclusions from the test results and analytical work for pressure only using Division 3 are not thought to be adequate for pressures above 20,000 psi. -RB Another reviewer noted that API 6X should have been referenced instead of 6A for linear-elastic design allowables. API 6A was referenced for design allowables. API 6X is referenced in TR8 as applicable for equipment rate for 15 ksi or less pressure. API 6X, which will be the referenced design methodology for API 6A, 16A

RESPONSE TO CHARGE QUESTIONS	
1. *Evaluation of Test Methods*	
1.2	*Are the assessments of engineering safety factors for the cited standards and their divisions valid for the expected applications?*
	and 17D in the next releases, is based on von Mises stress criteria for defining stress allowables. This document should have been used instead of API 6A for the linear-elastic analysis design allowables. The maximum allowable stress at hydrotest defined in 6A and 6X (5/6*Sy) is more limiting than the working pressure allowable stress (2/3*Sy) where hydrotest pressure is 1.5*WP. ASME Div 2 linear-elastic design stress allowable was defined to be based on yield strength and it is not. It refers to ASME Sec II Part D for allowables which are based on ultimate strength (Sult/2.4). ASME Sec VIII, Div 3, KD-12 does not allow testing to failure to determine collapse pressure. The design load factors for ASME Div2 and Div 3 elastic-plastic analysis were correct and applied properly to the analyses. -PB A third reviewer commented that the term "design margins" should have been used instead of "safety factor." API 17 TR8 and ASME VIII-2 and VIII-3 do not use the term "safety factor" for their designs. The term used is "design margins". It is assumed that each of these terms are being used interchangeably here. Some in the industry would call this interchange of words a dangerous precedence which could have consequences if the understanding of the difference in the terms is not well understood. -DP **Design Margins** He described the different design margins specified by the various standards. Each of these standards have many design margins and not one specific margin. ASME VIII-2 and VIII-3 use the Load Resistance Factor Design (LRFD) methodology which uses multiple factors for the various combinations of loads which are to be considered. The basic design margins on pressure for a piece of equipment, for use with an elastic-plastic analysis, are 2.4 and 1.8 in VIII-2 and VIII-3, respectively. However, these are lowered to 2.1 and 1.58 for VIII-2 and VIII-3, respectively, for other combinations of applied loading including seismic, wind and other load combinations, and 1.7 and 1.28, respectively for evaluation of the local criteria looking at local strain. ASME fatigue assessments also have their own margins and they vary based on the methodology used (VIII-2 fatigue, VIII-3 fatigue, and VIII-3 fracture mechanics). -DP

RESPONSE TO CHARGE QUESTIONS	
1. *Evaluation of Test Methods*	
1.2	*Are the assessments of engineering safety factors for the cited standards and their divisions valid for the expected applications?*

Limitation of Linear-Elastic Methods

The same reviewer expressed his concern about the use of API 6A and linear-elastic analysis for design of subsea equipment.

> It is further noted that the current report endorses the use of API 6A and linear-elastic stress analysis for design of subsea equipment based on past industry practice. The report cites significant successful industry experience using these methods. Based on my experience, the industry typically uses linear-elastic methods at these pressure ratings, but its application is limited, particularly as the pressure ratings increase and stresses in components exceed the yield stress. Several linear-elastic designs have been reviewed that are acceptable relative to the requirements of a linear-elastic methodology, which have excessive plastic strain or localized stress concentrations which may not be acceptable using elastic-plastic finite element analysis or have very limited fatigue life. Comparative studies have been done to evaluate the use of linear-elastic methods to elastic-plastic methods. Dixon, et al[1] have shown that for equipment with required wall ratios (OD/ID) in excess of ~1.25, the linear-elastic method may be non-conservative. The equipment being designed here at 20 ksi and using the material properties cited in the report would have a required wall ratio of 1.25. Therefore, it could be argued that either of the methods for the area of the failure could be appropriate. -DP

Support for 1.8 Margin and Elastic-Plastic Evaluation

He described Terada's work to establish the use of 1.8 as the margin in ASME VIII-3 for elastic-plastic evaluation. Terada also reported on a series of burst tests, which have been statistically evaluated.

> It is also noted that Terada's work[2] was used to help establish the margin of 1.8 currently used in ASME VIII-3. This is important to note as the work did effectively two things. First, it established the basis for using 1.8 as the margin in ASME VIII-3 for elastic-plastic evaluation. Secondly, the paper has a series of burst tests in it, which have been statistically evaluated. The standard deviation in this work was shown to be 7-9% based on the methods used in today's codes and standards. This work shows that the margins using elastic-plastic analysis are not meant to be lower bound pressure ratings. It shows that it is expected that using this type of analysis, it is expected for the margin to be nominally 1.8, if specified minimum material properties such as yield and tensile strength are actually achieved in manufacture, in lieu of

RESPONSE TO CHARGE QUESTIONS	
1. *Evaluation of Test Methods*	
1.2	*Are the assessments of engineering safety factors for the cited standards and their divisions valid for the expected applications?*
	higher strengths. It also shows that in practice the actual margin for a piece of equipment based on actual properties if they are near specification minimum, may be slightly less than 1.8 or 2.4 specified for analytical comparison. API and ASME have both accepted this potential variation as the case when adopting these margins. Section 6.0 of the report states that "it is crucial that the theoretical collapse pressure closely agrees with the actual burst pressure". This appears to not be in complete alignment with the work that is the basis of the margins in ASME VIII-3. The report further states in Section 6.1 that "it is imperative that the theoretical collapse pressures from FEA be accurate or at least conservative." The methods used have inherent variability in them relative to the actual material properties and are based on a mean rating, not a minimum value. This is the basis which again has been adopted by both API by reference and ASME in the development of their standards. -DP The same reviewer remarked that it is gross simplification to say that the elastic-plastic analysis is solely based on tensile strength. It is noted in the report Section 2.0 that the margins are based on either yield strength for linear-elastic analysis or tensile strength for elastic-plastic analysis. While it is true that the allowable stress in a material for linear-elastic analysis methods is based on 2/3 of the yield strength, it is a gross simplification to say that the elastic-plastic analysis is solely based on tensile strength. -DP He also commented that: The report only considers the margins on global collapse in the analytical assessment and it does use the proper margins in those cases. HPHT equipment has not been shown to be any different from any other pressure equipment, whether manufactured to ASME, API, or any other standards around the world. The margins referenced by API 17 TR8 are appropriate for high pressure equipment. -DP

RESPONSE TO CHARGE QUESTIONS	
1. ***Evaluation of Test Methods***	
1.3	*Were comparisons of the computational methods and design methods adequate?*

Methods Adequate with Reservations

Reviewers felt that the design and computational methods were adequate within the limited scope of the tests, but questioned conclusions that were beyond the scope of the tests.

A reviewer acknowledged the methods for determining global collapse were acceptable.

> The methods used for determination of global collapse appear to be used appropriately for each of the methods chosen. I have not investigated this fully through modeling or other calculations, but the methods used in the modeling appear to follow generally accepted practice for global collapse. -DP

A reviewer expressed consent about the attempt to extend the pressure ratings above the design requirements.

> In my opinion, the design and computational methods are considered adequate and correspond to current practice in the engineering of API equipment. However, the assessments and conclusions attempting to extend the pressure ratings above the design requirements are considered to be inconsistent with the scope of Division 3 rules. RB

Many Design Methods Not Evaluated

A reviewer felt the methods were not adequate because they didn't evaluate other design methods.

> No, see question 1.2 above. This evaluation is only for burst pressure and doesn't evaluate other design methods, such as strain limit damage, bolting, gasket leakage or ratcheting and the respective allowables for each. -PB

Another reviewer agreed that:

> There are many different criteria that need to be evaluated, as stated earlier such as local strain limits, ratcheting assessment, life assessment, and other specified serviceability criteria. None of these were evaluated with this component. It is recognized in the high-pressure industry that the fatigue life or design of areas of local strain may control the pressure rating of a component in lieu of the global collapse rating. -DP

RESPONSE TO CHARGE QUESTIONS	
1. ***Evaluation of Test Methods***	
1.3	*Were comparisons of the computational methods and design methods adequate?*
	Limitations of Linear-Elastic Analysis A reviewer pointed out that the report does not acknowledge the limits of linear-elastic analysis. > The report does not identify the limits of linear-elastic analysis as defined in Div 2/3 and 17TR8. This method is only recommended for wall thicknesses where R/t>4 and Do/Di<1.25 or the von Mises stress does not exceed the yield strength more than 5% of the wall thickness. It is stated that ‘nonlinear stress distributions associated with heavy wall sections are not accurately represented by the implicit linear stress distribution utilized in the stress categorization and classification procedure. The misrepresentation of the stress distribution is enhanced if yielding occurs.’ -PB **Determining Design Pressure** A reviewer corrected a statement about using elastic-plastic evaluation to determine maximum pressure rating, and applying the design margin to it. > The report indicates that it is a requirement, when using elastic-plastic evaluation, to determine the maximum pressure rating for a component and then apply the design margin to it. This is an incorrect statement. ASME VIII-2 and VIII-3 require demonstration of a component to withstand loading that has been factored above the design rating. This is a subtle difference, but can result in huge design costs if it were mandated to determine the maximum load that each piece of equipment can withstand in every combination. -DP > Appendix E determines the collapse pressure by proof test. The “Pressure Ratings of the Test Bodies by Rules of ASME Section VIII Division 3” section shows the calculation of the rated pressure using the equations from KD-1254. The key input to this process is the collapse pressure (CP). The method for determination of CP is found in KD-1253, which requires that the strain be determined at the OD of the cylinder while under test. There were strain gages shown in the photo of the burst tube in the area of interest, but no data was included from them in the report. The CP values used in the evaluation were based on the actual failure of the components. KD-1253(b) states that if the vessel fails, that the component should be redesigned and retested. It is likely that the 2% strain on the OD was exceeded during the testing performed to determine the CP values. In other words, it is suspected that the CP values would be lower than the reported values if the CP values were

RESPONSE TO CHARGE QUESTIONS	
1. *Evaluation of Test Methods*	
1.3	*Were comparisons of the computational methods and design methods adequate?*
	determined in accordance with the 2% strain on the OD. This would have greatly lowered the design pressure allowed by proof testing using this method. This however is a different criteria for the determination of the rated working pressure than used in the finite element analysis and should not be directly comparable. -DP

RESPONSE TO CHARGE QUESTIONS	
1. *Evaluation of Test Methods*	
1.4	*Are the assumptions of the modeling and tests clearly defined and appropriate?*
	Reviewers acknowledged that the modeling assumptions are fairly well listed, but all reviewers had concerns about the modeling assumptions. The modeling assumptions made are fairly well listed in the report. There are potential subtle nuances. -DP The plots of the results for von Mises stresses, total strain and displacements are defined and clear in the report. -PB A reviewer remarked that all properties except axial constraint were defined. The boundary conditions, loadings, material properties of the finite element models were clearly defined with the exception of axial constraint. The ¼ section model is restrained in the Y-X plane for X direction constraint and Y-Z plane for the Z direction constraint, but there is not a clear plot or description of how the model is restrained in the Y direction. -PB He also commented that: The assumption in the modeling that the true stress - true strain curves defined from tests conducted on the prolongation material are appropriate for a predicted failure mode that is hoop stress dominant has not been verified. The analysis and the component failure clearly indicated the mechanical properties input into the model should have been transverse tensile properties in order to assure accuracy. -PB Another reviewer had questions about dimensions and model tolerance. The report is not clear on whether dimensions used in the modeling result in a minimum material condition or if the nominal listed

RESPONSE TO CHARGE QUESTIONS	
1. *Evaluation of Test Methods*	
1.4	*Are the assumptions of the modeling and tests clearly defined and appropriate?*
	dimensions from the drawing. The model tolerances shouldn't greatly affect the results, but this should be clarified in the report. -DP Another reviewer remarked that the geometries of the gaskets and blind flanges were not modeled. The geometries of the gaskets and blind flanges were not modeled which changes the reaction loads going into the flanges, and it was not verified in the report the contributing effects of these components on the results. -PB He also commended that there was no indication of the how tolerance of dimensions was addressed. There was no indication in the modeling of how the tolerance of dimensions were addressed, i.e. was the model generated using nominal, minimum/maximum material conditions or as tested dimensions. The same is true for alignment tolerances. -PB Another reviewer commented that samples should have been taken to determine properties as a minimum in the tangential direction relative to the forged body. It is noted that the material properties are from test locations from prolongations on the ends of the forgings and were taken in the longitudinal direction. Large thick section forgings can have significant variations in the material properties of the components, including variation based on test location and direction of the testing done. The majority of the conclusions of this report center around the burst pressure of the cylindrical tube sections with an axial rupture of the cylinders. The samples should have been taken to determine properties as a minimum in the tangential direction relative to the forged body. They also should have been taken at a location at mid thickness of the wall that failed, and not at ¼ T of the prolongation. The report in Appendix A2 also states that a drawing illustrating the testing locations would be provided. This was not located in the report but would be helpful in understanding the exact location of the testing. -DP Another reviewer remarked that the modeling and tests do not address external tension and bending. As stated earlier, the modeling and tests do not address external tension and bending that are considered to be significant loads for subsea

RESPONSE TO CHARGE QUESTIONS	
1. *Evaluation of Test Methods*	
1.4	*Are the assumptions of the modeling and tests clearly defined and appropriate?*
	equipment. In particular, the finite element analysis techniques and methodology for the pressure tests are in general accord with accepted practice for those activities. -RB A reviewer discussed whether bolt and blow-off loads should have been considered. It is stated in the report that loads simulating the blow off loading was applied at the locations of the screws on the flanges of the components. Typically, the preloading (bolt loads) for a seal would be higher than that required for the blow off loading. Utilizing the actual bolt tension may result in added stress on flanges due to this loading for the analyses. Traditional modern finite element codes would commonly include all of the components in the analysis including the bolts and apply contact between them. However, it is noted that only the burst of the tube in each body was evaluated and relevant to the analysis, and hence, the method of application of the bolt loads versus the blow off loads, likely have no relevance. -DP The same reviewer explained how limit load analysis is conducted. The report states that a limit load analysis is required for determination of the pressure rating of these components. This is not specifically true. It needs to be demonstrated that a component can withstand the rated loads when factored by the design margins for specific combinations of loads. However, for this particular exercise, which appears to be solely focused on the evaluation of the margin on global collapse, it is appropriate to attempt to determine the highest pressure (in this case) that the component can withstand. It is recognized that in the report that there is a certain amount of error in this technique. The report indicates that multiple iterations of each finite element analyses were performed to determine the collapse load for each component. -DP

RESPONSE TO CHARGE QUESTIONS	
1. *Evaluation of Test Methods*	
1.5	*Did the report identify and adequately address the strengths or weaknesses of the analytical methods used for the modeling and testing methods used?*
	Reviewers agreed the report did not identify the strengths and weaknesses of the assessment methods. The report does not explicitly identify the strengths and weaknesses of the assessment methods that were used. The analysis techniques and

RESPONSE TO CHARGE QUESTIONS	
1. *Evaluation of Test Methods*	
1.5	*Did the report identify and adequately address the strengths or weaknesses of the analytical methods used for the modeling and testing methods used?*
	pressure test methodology are consistent with accepted practice for those activities. -RB One reviewer discussed the appropriate use of von Mises criteria for linear-elastic evaluation. The report also points to the difference between Tresca criteria and von Mises or equivalent stress criteria for linear-elastic evaluation. The report indicates about a 15% difference between the API 6A and Division 2 linear-elastic methods. This is as expected based on the fundamental concept of the two criteria. Most modern approaches, including almost all modern finite element programs utilize the concept of equivalent or von Mises stress for a failure criteria in yielding. There are many variations in material hardening models to model actual plasticity behavior, but the concept of using von Mises to predict the onset of yielding is well proven, as is the source of the potential 15% difference. -DP A reviewer acknowledged the use of strain gage testing. The report did some strain gage testing during the hydrostatic testing of each body. No plastic strain was experienced in the cylindrical sections during these tests, either at the gage, or at the ID of the tubes. This can be verified using the methods of ASME VIII-3 KD-5 for determination of the extent of plastic yield in the wall of a cylinder. -DP The same reviewer recommended that the strain gage data should have been provided for the collapse pressure loading. Part of the study was to perform strain gage testing to validate the accuracy of the FEA. Considering this was an analysis to define collapse pressure the strain gage data should have been provided for the collapse pressure loading. This would have been very relevant data to compare yield point of the test objects to the predicted yield point of the FEA. ASME Sec VIII, Div 3, KD-1212 allows the use of strain gage testing to be used to determine the collapse pressure. -PB A reviewer suggested that research into the background of the standards referenced would be appropriate. The report did not reference the basis for the methods used nor the background explaining where the design margins came from. It appears

RESPONSE TO CHARGE QUESTIONS	
1. *Evaluation of Test Methods*	
1.5	*Did the report identify and adequately address the strengths or weaknesses of the analytical methods used for the modeling and testing methods used?*

> that some research into the background of the standards referenced might be appropriate for this work and add to the understanding of the margins. -DP

Another reviewer suggested that the procedure should have been used to identify all other failure modes and assure all issues of those failure modes were being addressed.

> The report does not indicate a detailed FMECA was conducted, but indicates that the internal pressure will rupture the neck based on the elastic-plastic analysis to collapse pressure. Although there is no reference to a formal FMECA being conducted, this procedure should have been used to identify all other failure modes and assure all issues of those failure modes were being addressed in the test, such as gasket leakage, and bolting failure. Additionally, it should have identified that the material properties in the transverse direction were controlling the defined failure mode and are necessary to predict the collapse pressure and thus driven the material testing for these tensile properties. -PB

The same reviewer noted that the analyses did not include the bolt holes in the flange, bolting, or the ring gaskets and mating blind flanges.

> The additional FEA studies of the 13-5/8” 20 ksi and 16-3/4” 10 ksi flanges were evaluated for collapse pressure using axisymmetric models. These analyses did not include the bolt holes in the flange, bolting or the ring gaskets and mating blind flanges. Removing the bolt holes will change the stiffness of the flange and may result in higher predicted burst pressures than a full 3-d model with all components included. The results assume the flanges would fail due to a collapse pressure of the flange neck. The 16-3/4” 10 ksi flange analysis predicted collapse pressure is well above the tensile failure of the bolting. Thus, the failure mode should have been identified as bolting failure. The 13-5/8” 20 ksi flange analysis predicted a burst pressure was lower than the tensile failure of the bolting. If the bolting stresses included both tensile and bending loads due to flange rotation, it is possible the bolts will fail before the flange reaches collapse pressure, for this flange as well.

RESPONSE TO CHARGE QUESTIONS	
1. *Evaluation of Test Methods*	
1.6	*Were the actual materials within specification for F22 material properties adequate?*
	One reviewer acknowledged that the materials met some F22 requirements, while not meeting others. The material properties met the requirements of allowable materials per API17D/6A and NACE MR0175/ISO 15156, in regard to chemistries and mechanical properties (error on reported chemistry was corrected by ANL). There were no transverse material properties tested, thus it is not possible to determine if these were equivalent to the longitudinal properties used in the analysis. There were no mechanical properties tests to verify the prolongation properties were representative of the neck region of the test object. -PB A reviewer commented that the material properties used appear to be higher than those specified in most ASTM materials. The material properties used appear to be higher than specified in most ASTM materials. The reduction in area and elongation is slightly lower than the next lower strength materials of lower strength from a comparable material specification (ASME SA-336). Table KM-234.2(a) of ASME VIII-3 would require Charpy impact toughness of 50 ft-lb average for a set of three and 40 ft-lb minimum for a single specimen when testing in the longitudinal direction. Longitudinal toughness testing is also only permitted when the component shape or size does not permit removal in the transverse direction. It is believed that when taking samples from the prolongation, it should have been possible to take full size specimens in the transverse direction from these components. -DP Another reviewer explained that the material properties were obtained from specimens taken at locations not consistent with Division 3 requirements. The actual material properties were obtained from specimens taken at locations that are not consistent with Division 3 requirements. According to the material specification for test body included in Appendix A2, paragraph 11, the specified location of material sample specimens is not consistent with Division 3 paragraph KM-211.2(c). Paragraph KM-211.2(c) requires that the minimum distances from quenched surfaces be greater than the minimum distances given in the material specification. Also, the minimum required impact values required by Table KM-234.2(a) are greater than the impact values given in paragraph 12 of the material specification. [The reported values were higher.] Still not verified is the exact location where the material

RESPONSE TO CHARGE QUESTIONS	
1. *Evaluation of Test Methods*	
1.6	*Were the actual materials within specification for F22 material properties adequate?*
	samples for testing were taken since drawings or sketches were not provided in the documentation. If the location where the material samples were taken is not in strict accordance with the Division 3 requirements the use of the values determined by these material tests would not be valid for assessments using the methods of Division 3. -RB Hence, the use of material property results from the specimens taken according to the material specification in the report are questionable for assessments according to Division 3 due to being taken from a location that does not conform to Division 3 requirements. -RB A reviewer pointed out that though the report referred to PSL5 requirements, no effort was made to evaluate these for the test objects. The report makes the statement in reference to 17TR8 that; 'Product Specification Level 5 (PSL5) was added. PSL5 includes fracture toughness requirements, higher Charpy toughness values, and improved QA/QC.' The report acknowledges there are requirements above those of API 6A, PSL 3, but no effort is made to evaluate these for the test objects. -PB He also challenged the statement that 'materials that have been used in subsea equipment for many years already meet the additional requirements in TR8.' Additionally, the report states 'Consider the additional material requirements in TR8. Materials that have been used in subsea equipment for many years already meet the additional requirements in TR8.' This cannot be verified due to the fact that previous API criteria did not require fracture toughness values, higher Charpy values or increased QA/QC requirements. -PB Another reviewer noted that the effectiveness of the quenching in the bore of the component is not determined. The heat treatment drawing in Appendix F also shows the prebore in the forging for heat treatment. Based on the description of the test locations, the effectiveness of the quenching in the bore of the component is not determined. -DP

RESPONSE TO CHARGE QUESTIONS	
1. *Evaluation of Test Methods*	
1.7	*Determine the degree of certainty that each test object did not have a latent defect, was forged properly, and manufactured properly; for example, should there have been a posted manufacturing stress reduction heat treatment?*
	Material Quality Seems Adequate Two reviewers agreed that the material quality was adequate as forged. The material specification in Appendix 2 seems to cover the typical aspects of specifying material properties required from this material. It is typical for the material to have both a surface examination and a volumetric examination. -DP From the NDE documentation that was provided, it seems as though the material quality, as-forged, was adequate. There is documentation to verify that the forging reduction required by the specification was achieved. -RB However, a reviewer pointed out that: A review of the forgemaster MPS and a microstructural evaluation is necessary to determine if the component was properly forged and has a wrought structure throughout. Hardness testing should have been conducted to assure uniform hardness throughout the test objects. -PB He added that to determine a failure as either initiation from a defect or tensile overload require post-test fractography. The test objects can only be assumed to have defects equal to or smaller than the NDE acceptance criteria, which was defined to be API 6A, PSL 3. Determining the failure as either initiation from a defect or tensile overload requires post-test fractography, which should be performed to assure the test was due to the assumed structural instability with tensile overload as defined by the analysis. This evaluation will determine if there were defects which were initiation sights for crack growth. -PB **Heat Treatment Not Typical** Two reviewers pointed out that heat treatment is not typical or appropriate part of manufacturing for a quenched and tempered alloy. This is a quenched and tempered alloy, so it would not be typical for a non-welded component such as the one involved in this testing to have a post weld heat treatment. -DP

RESPONSE TO CHARGE QUESTIONS	
1. *Evaluation of Test Methods*	
1.7	*Determine the degree of certainty that each test object did not have a latent defect, was forged properly, and manufactured properly; for example, should there have been a posted manufacturing stress reduction heat treatment?*
	Post manufacturing heat treatment is not a practice used in the industry and would have been beyond the requirements of either the Technical Report TR8 or API specifications of 6A, 17D or 20B. Any heat treatment after manufacturing has the risk of distortion and dimensions not meeting tolerance. -PB

RESPONSE TO CHARGE QUESTIONS	
1. *Evaluation of Test Methods*	
1.8	*The report documents a failure of the tested object for the 17 TR8 Division 3 method to show a failure of the test object at a threshold below the design standard. Do the conclusions and recommendation based upon this stand alone? Are there other considerations, such as the fact that the material chosen is a non-Division 3 material, or any other alternate logical explanation for failure event below the Division 3 design standard?*
	The three reviewers agreed that the failure conclusions and recommendations were extended beyond the evidence provided by the failure of one piece of equipment and the tests of the two pieces of equipment. A reviewer explained that the 1.8 load factor was developed through many years of study, research, testing and development. All the years of research and development should be considered before accepting the recommendation that the 1.8 load factor be dismissed because of the failure of one of the proof tests, and subsequent deductions made by the evaluator. The Div 3 Code was first developed starting in 1980 and the first edition was published in 1997. The 2007 edition applied the design load factor for collapse pressure of 1.732 (√3) using an elastic-perfectly plastic analysis. The 2010 Edition changed to elastic-plastic analysis and a load factor of 1.8. Thus, the application of the design load factors has 10 years of experience using the Div 3 criteria. All relevant information of research, service applications and testing that was done by ASME defining the 1.732 and 1.8 load factors should be reviewed before concluding it is unacceptable for API HPHT equipment. -PB Another reviewer described the work done by Terada to establish 1.8 as the design margin. …Terada's work[2] was used to help establish the margin of 1.8 currently used in ASME VIII-3. This is important to note as the work does effectively two things. The first is that it established the basis for using 1.8 as the margin in ASME VIII-3 for elastic-plastic evaluation.

RESPONSE TO CHARGE QUESTIONS	
1. *Evaluation of Test Methods*	
1.8	*The report documents a failure of the tested object for the 17 TR8 Division 3 method to show a failure of the test object at a threshold below the design standard. Do the conclusions and recommendation based upon this stand alone? Are there other considerations, such as the fact that the material chosen is a non-Division 3 material, or any other alternate logical explanation for failure event below the Division 3 design standard?*
	Secondly, the paper has a series of burst tests in it, which have been statistically evaluated. The standard deviation in this work was shown to be 7-9% based on the methods used in today's codes and standards. This work shows that the margins using elastic-plastic analysis are not meant to be lower bound pressure ratings. It shows that it is expected that using this type of analysis, it is expected for the margin to be nominally 1.8, if specified minimum material properties such as yield and tensile strength are actually achieved in manufacture, in lieu of higher strengths. It also shows that in practice the actual margin for a piece of equipment based on actual properties if they are near specification minimum, may be slightly less than 1.8 or 2.4 specified for analytical comparison. API and ASME have both accepted this potential variation as the case when adopting these margins. Section 6.0 of the report states that "it is crucial that the theoretical collapse pressure closely agrees with the actual burst pressure". This appears to not be in complete alignment with the work that is the basis of the margins in ASME VIII-3. The report further states in Section 6.1 that "it is imperative that the theoretical collapse pressures from FEA be accurate or at least conservative". The methods used have inherent variability in them relative to the actual material properties and are based on a mean rating, not a minimum value. This is the basis which again has been adopted by both API by reference and ASME in the development of their standards. -DP While the evaluation expressed great concern about the failure of the test object at a threshold below the design standard, a reviewer points out that the numerical analysis doesn't need to exactly match the results of the physical test. The report draws a false conclusion from Table 6.1 - that the numerical analysis should exactly match the results of the physical test. The numerical analysis uses an idealized material that is rarely achieved in actual practice. In fact, noting the deficiencies in the location of the material test specimens noted above, the actual deep section properties of the material could account for the difference. In addition, the analytical work has some unanswered questions that could affect the results. Refer to the comments on the analysis using numerical methods [in other sections]. As a practical consideration, the burst test results and

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> the analytical results both show that the plastic collapse results exceeded the design requirements. -RB

A reviewer added that the conclusions and recommendations do not consider the variability of the data.

> The conclusions and recommendations do not take into consideration the variability of the data. The statement that the failure of the test object is at a threshold below the design standard cannot be made based on the limited number of two tests. Two test samples are not a sufficient number of tests to obtain a statistical distribution of data points defining the range of values for predicted vs actual burst pressure. Assuming all tests are skewed to have a difference of burst vs predicted of -7% and that the two burst tests represent and lower bound of all data is not accurate. Assuming all additional tests are predicted to be equal to or higher burst pressures, based on a set of two data points is not accurate. A review should be conducted for the results defined in the paper by Susumu Tada, ICPVT-12, 2009, "*Proposal of New Equations for Cylindrical and Spherical Shell of ASME Section VIII Division 3 for High Pressure Vessels".* An additional study was performed in the API industry to evaluate burst pressures of API materials, reference Grohmann, A., Selvey, J. and Ellisor, S., 'Design Margins for Normal, Extreme and Survival HPHT Applications, OTC paper no. 27605, 2017. -PB

Note that OTC paper no. 27605, 2017 was published after the draft ANL report; it was not available to the writer(s) of the report.

Discussion About Material Used

One reviewer explained that while the material used was not currently a listed material in ASME VIII-2 or VIII-3, it is similar to materials used in the production of HPHT equipment.

> The design methods in ASME VIII-2 and VIII-3 are identical from an elastic-plastic standpoint, with the exception being the design margin. The material used, while not currently a listed material in ASME VIII-2 or VIII-3 is similar in properties and composition to other materials

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	commonly used in the production of high pressure equipment in this pressure range. -DP It can be noted that ASME B31.3 references ASME VIII-2 and VIII-3 in a similar manner to API 17TR8 and has the allowance for the use of "unlisted materials" (ASME B31.3 K302.3.2(c)). In reality, the material doesn't know which "standard" it is being used in. If the material is specified properly, has adequate material properties including strength characteristics, toughness, etc. and is designed such that the critical failure modes are avoided or their potential is minimized, the standard doesn't matter. -DP ASME VIII-3 uses a lower margin than VIII-2 due to many factors such as additional material testing, higher toughness requirements, additional NDE requirements, etc., and more stringent design specification requirements for the end user of the equipment. -DP This reviewer also noted that if quenching was not done properly, the tube walls could vary from what was reported in the testing. It is noted that large thick section forgings may experience significant through thickness material property variation. It is recognized due to failures in industry that this is the case. The 2015 edition of ASME VIII-3 KM-211.2 states "*In addition to the following, for quenched and tempered materials, the location of the datum point shall be equal to or farther from the nearest quenched surface than any pressurized surface or area of significant loading is from the quenched surface.*" This is recognition of this material property variation and that the test location of the test location should represent the "worst case" material properties for the areas of high stress in the vessels. If the quenching due to a small pre-bore was ineffective to get good material properties at the ID, the material strength properties in the tube walls could vary from what were reported in the testing. The strain gage data in the report do not go far enough to evaluate any plasticity that may occur in the test piece. -DP

RESPONSE TO CHARGE QUESTIONS	
1. ***Evaluation of Test Methods***	
1.9	*Are there other obvious conclusions that the report should have addressed [that can be identified] by the peer review?*

Designs Seemingly Met Requirements

One reviewer stated, with some reservations, that the evaluation report should have concluded the designs met all requirements for the intended pressure rating of 20,000 psi.

> With the deficiencies noted in this writing [about the report], the report should have concluded the designs met all requirements for the intended pressure rating of 20,000 psi. This conclusion would require a stipulation that the specimens for material property tests were taken from a location that was not consistent with Division 3 requirements. The report does not show that the requirements of KD-1254(c) were met for a design pressure determined by collapse pressure (burst pressure). -RB

Discrepancies in Strain Gage Readings

Another reviewer claimed the report should have addressed the discrepancies and inaccuracies in the strain gage reading when compared to the FEA results.

> The conclusions should have addressed the discrepancies and inaccuracies in the strain gage readings when compared to the FEA results. The statement that the flange preload strains are included in the hydrotest strains, but not included in the FEA strains, indicate a discrepancy in the model and actual test objects assemblies. It is also stated that 'The reason the preload strains are not included in the FEA is that Division 2 and 3 do not include preload for global plastic collapse.' This statement is incorrect, particularly when a proof test is being compared to the FEA results to evaluate the design load factor of 1.8. Without analyzing these components, it is not possible to accurately determine the 'weakest link' for the failure mode (i.e. bolting failure, gasket leakage, or structural overload). The test should have obtained strain gage readings for the bolting and the test should have had strain gage measurement recordings for the burst testing. It was not explained why this procedure was not used to define the burst pressure. -PB

Equipment Designed for API 17TR8 Not Unique

A third reviewer emphasized that the report should have concluded that there is nothing unique about equipment designed to API 17TR8 as compared with equipment designed to ASME VIII-2 or VIII-3.

RESPONSE TO CHARGE QUESTIONS	
1. *Evaluation of Test Methods*	
1.9	*Are there other obvious conclusions that the report should have addressed [that can be identified] by the peer review?*

> One conclusion that should be emphasized is that there is nothing more unique about equipment designed to API 17 TR8 than other designed to ASME VIII-2 or VIII-3, other than accessibility of the API 17 TR8 equipment is limited in all cases once it is in service. There is a fleet of down hole test equipment used today for testing drilling tools which uses similar materials at equal or greater pressures and temperatures as HPHT subsea equipment, in the same or more severe environments designed to ASME VIII-2 and VIII-3 for regular pressure vessel applications. -DP

Metallurgical Evaluation of Failed Components

Another overlooked conclusion is that a metallurgical evaluation of the failed components should have been conducted and reported.

> ...a metallurgical evaluation of the failed components should be conducted. This would include, but may not be limited to, examination of the fracture surface to determine the initiation site of the failure and the mode of failure, investigate any contaminates which may have influenced or initiated the failure, investigate for potential mechanical damage on the surface of the components, and look for potential material inclusions or other issues which could have affected the integrity of the component. -DP

Recommendation for Change in Standard

The reviewer also stated that because the report suggests that the margin of 1.8 is incorrect, it should recommend that the standard be changed.

> Section 10.0 on page 28 implies that the margin of 1.8 in ASME VIII-3 is somehow incorrect and that it should be considered as 2.1. The basis for this is that the margins used in the elastic-plastic analysis should be lower bound and absolute margins, with all potential manufacturing scenarios showing that these margins are conservative. If this is the case, one conclusion of the report should be that it should be recommended to ASME to consider that their margins should be adjusted in both VIII-2 and VIII-3 to result in absolute lower bound ratings relative to collapse of the equipment. Further to that end, the standard deviation by Terada[2] shows that a single standard deviation is approximately 7% and a +/- 3 standard deviations might be considered to account for the total population of distribution. I disagree with this recommendation, but if the report stands as is, the authors of the report should recommend ASME and API 17 TR8 through its reference of ASME should correct

RESPONSE TO CHARGE QUESTIONS	
1. *Evaluation of Test Methods*	
1.9	*Are there other obvious conclusions that the report should have addressed [that can be identified] by the peer review?*
	its standards. This is implied on page 29, but stops short on making recommendations regarding what should change in ASME. -DP **Confusing, Contradictory, and Misleading Information** According to same reviewer, "Several of the conclusions and statements in the report are either confusing, contradictory or potentially misleading or incorrect." -DP These included misleading statements about the use of elastic-plastic FEA. Section 1.0 of the report states "the use of Division 2 and Division 3 elastic-plastic methods are new to the industry." However, the report goes on in Section 9.0 on page 24 to state that "Currently, standard practice for most major subsea equipment manufacturers is to perform only elastic-plastic FEA". This should be clarified if the elastic-plastic methods are truly "new to the industry" or if they are truly "standard practice", which is my experience. -DP Page 26 states that elastic-plastic FEA was "not allowed prior to 2015". This statement is misleading, as BSEE was reviewing analyses using this approach prior to 2015 and had no rules stating that it was unacceptable. This was prior to the formal publication of API 17 TR8. -DP Section 2.0 page 9 indicates that "API has not approved verification by elastic-plastic FEA". This is confusing as the use of elastic-plastic FEA is recommended in API 17TR8. -DP Section 2.0 on page 10 implies that there are two elastic-plastic methods. There is actually only one method which is used in both Division 2 and Division 3 with two margins. This should be cleaned up in this report to avoid causing confusion in the industry. -DP One statement in Section 9.1 on page 24 states that "the least conservative pressure ratings were determined by ASME VIII-3 elastic-plastic analysis". This is not correct. Table 9.2 shows that the least conservative margin calculated is 1.74 based on linear-elastic analysis by ASME Section VIII Division 2 using the API 17 TR8 / 6A / 17D allowable stresses. -DP He questions a statement that ratings by proof test should be higher than pressure ratings by theoretical method.

RESPONSE TO CHARGE QUESTIONS	
1. ***Evaluation of Test Methods***	
1.9	*Are there other obvious conclusions that the report should have addressed [that can be identified] by the peer review?*
	Section 7.0 page 18 states that "…pressure ratings by actual proof test would be higher than pressure ratings by theoretical methods." This statement is confusing and is contrary to an actual statistical data set from Terada[2] which shows actual distribution of the burst data. -DP He questions the report's recommendation that further testing should be done to confirm that lower margins are safe from failure without acknowledging the literature that is full of evidence and data to support the margins. It is possible to produce high strength low alloy steels, as used in this example with low toughness. The enhanced material requirements in API 17 TR8 are one aspect of the requirements, which also include additional NDE requirements for the material, additional requirements for welding and fabrication testing, and more rigorous analysis of the components. Page 25 of the report goes on to state that testing should be done to confirm that the lower margin designs are safe from failure. The margins are experienced based and have been adopted by ASME and recommended by API 17 TR8 based on that experience. The literature is full of this information and data which can be shown to support this position. -DP In addition, he notes that the report has a statement that a load histogram with proper sequence cannot be developed for subsea equipment, while many manufacturers postulate loading histograms for equipment in service based on past operation experience. On page 29 it states that "a load histogram with loads in the proper sequence cannot be developed for subsea equipment". This is incorrect. Many manufacturers are able to postulate plausible loading histograms for equipment in service based on past operational experience. This was demonstrated in work done on Deepstar project 12302 which is expected to be released to API for publication this summer. In that work, a postulated loading histogram was generated and compared to actual well head data to look at operational trends in wells. The histogram was conservative in the number of cycles, the sequence of operational cycles and the loading degradation over time for the example cited. Operators have this type of information from their typical operations available and it can be utilized for developing plausible operational histograms. -DP

RESPONSE TO CHARGE QUESTIONS	
2. Evaluation of Modeling Results: Do the modeling results describe with reasonable accuracy the basis for decisions in the applied methods:	
2.1	*Are the limitations and uncertainties clearly identified and adequately characterized for the methods of modeling selected?*
	Reviewers agreed that the limitation and uncertainties of the method and modeling were not clearly identified. For example, one reviewer stated: > The report attempts to present some perceived limitations of the methods. However, some appear to be overlooked. Such as the design margin on burst of 1.74 using linear-elastic analysis using ASME VIII-2. There is an entire discussion about the use of linear-elastic analysis and its applicability in high pressure design. The reference cited earlier by Dixon and Perez[1] discusses that in some detail. The basic premise is that steels do yield in service. Linear-elastic analysis does not account for that and instead assumes that the amount of load it can take will continue to linearly increase past the yield point. There should be some discussion about the potential for over predicting the load capacity of a structure using this evaluation technique compared to actual material response. -DP A reviewer commented that the report did not acknowledge "that the only failure criteria which is evaluated in this report is global plastic collapse due to internal pressure in the cylinder section." -DP Another reviewer pointed out that "There are statements that multiple models with finer meshes and more load steps were evaluated but no documentation is provided for these sensitivity studies." -PB Another reviewer explained that the report did not discuss the analytical assumptions that underlie the final element method. > The report does not comment on the analytical assumptions that underlie the final element method. While it is generally accepted that the final element work represents sound engineering practice, some input data has limited precision. For example, Young's modulus is an important input parameter that has limited precision and yet the results of the analysis represent or suggest much higher precision. -RB Another reviewer commented that no justification was provided for the elimination of blind flanges, bolting and gaskets for end connections. > The elimination of the blind flanges, bolting and gaskets for end connections was not clearly justified. There were no evaluations for bolting criteria or gasket sealing criteria which are additional failure modes that can occur before the burst pressure is reached. If the flange had been designed to API 6A requirements for the wall thickness of the

RESPONSE TO CHARGE QUESTIONS	
2. Evaluation of Modeling Results: Do the modeling results describe with reasonable accuracy the basis for decisions in the applied methods:	
2.1	*Are the limitations and uncertainties clearly identified and adequately characterized for the methods of modeling selected?*
	neck, the failure mode may have been bolting tensile overload or gasket leakage. Most API components are designed with a straight neck flange connections making the burst pressure much higher than the test objects for the given end flange size, which could result in other failure modes before burst pressure of the neck is reached. -PB Another reviewer identified multiple material models which can be employed in elastic-plastic analysis. There are also multiple material models which can be employed in the elastic-plastic analysis method. This includes the model used which was a true stress-true strain model as found in ASME VIII-2 or VIII-3. There is an elastic-perfectly plastic model as found in ASME VIII-3 KD-236. Each of these may be used for evaluation of global plastic collapse. The elastic-perfectly plastic material model is more conservative than the true stress-true strain model which incorporates the concept of strain hardening into the model. API 17 TR8 also allows the use of actual stress strain curves in analysis when testing has been performed. The analysis uses actual data for input to the curves generated using ASME VIII-2/VIII-3 methodology. The variation between these techniques could be useful to discuss. -DP

RESPONSE TO CHARGE QUESTIONS	
2. Evaluation of Modeling Results: Do the modeling results describe with reasonable accuracy the basis for decisions in the applied methods:	
2.2	*Are the assumptions of the modeling appropriate for the methods of modeling selected? Assumptions evaluated should include, but are not limited to:* ▪ *Material Thickness* ▪ *Mesh Chosen* ▪ *The correspondence of the modeling to the design basis specified in the standard*
	One reviewer noted that assumptions of the modeling were appropriate for the methods of determining the collapse pressure, but the collapse of the tube in the component was the only item considered in the evaluation. The mesh plots shown indicate that there are ample elements, based on experience, to accurately determine the collapse pressure of the component. The time stepping also appears to be sufficiently small to allow for capture of the final collapse pressure of the equipment when using elastic-plastic analysis. -DP

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	The finite element modeling appears to be sufficient relative to the prediction of global collapse of the tube in the bodies, provided the proper dimensional information was utilized to reflect the actual tests, when the comparisons are being made. -DP It is noted that the collapse of the tube in the component was the only item considered in the linear-elastic evaluation of the components. -DP Two reviewers noted that minimum material conditions should have been used instead of the nominal dimensions, which were used in the test. The design calculations provided in Appendix B1 Figure B1.13 indicate that nominal dimensions were used as opposed to minimum material conditions. Analysis should be based on minimum material conditions. -PB It is not clear what the dimensional assumption was for the modeling of the finite element model used in the report versus the actual test piece. The design standards require the use of minimum thickness models based on the manufacturing tolerances of the components. This could account for a 2-3% variation in burst pressure based on reported manufacturing tolerances. -DP A reviewer commented that the bolting allowable limits and the gasket sealing limits were not addressed in the report. The design basis according to 17TR8 requires the evaluation of collapse pressure for the pressure containing body, the allowable bolt limits based on linear-elastic criteria and a service criteria evaluation for gasket sealing. The bolting allowable limits and the gasket sealing limits were not addressed in this report. -PB He also commented that the thick body section did not contribute any useful information because the design assured the failure would occur in the neck region.

RESPONSE TO CHARGE QUESTIONS	
2. Evaluation of Modeling Results: Do the modeling results describe with reasonable accuracy the basis for decisions in the applied methods:	
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	The thick body section with intersecting bores did not contribute any useful information regarding the proof test in that the design was adjusted to assure the failure would occur in the neck region. It is possible that the intersecting bores could have resulted in strain limit damage at the burst pressure, but this failure mode was not evaluated. Additionally, the strain gage measurements in this region were not valid. -PB A reviewer repeated the observation that "the location which the material testing was performed may not truly be representative of the failure location within the tube." -DP He also commented that: A component's operational loading variation should be considered in conjunction with the design margin selected. The loading histogram should reflect the worst case loading a component will experience in service, while accounting for total variation in load over time. -DP Another reviewer discussed several issues regarding the modeling assumptions. As previously mentioned, the only way to adequately review a detailed numerical analysis is a close inspection of the input data. A review of the input data will show whether the annotations on the plots concerning boundary conditions are consistent with good practice for this type of analysis. Also, it is not clear what the material model was used to describe the strain hardening behavior of this material, if any. Most analysts use the Ramberg–Osgood equation or a similar formulation such as given in both Division 2 and Division 3 of the code. The investigators missed an opportunity to obtain an actual stress-strain curve during the mechanical property tests. This is not commonly done for construction of new equipment but would give important information for a technical study as was done to determine pressure ratings. -RB He also pointed out that the analyst did not provide load-displacement curves.

<table>
<tr><th colspan="2">RESPONSE TO CHARGE QUESTIONS</th></tr>
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<tr><td>2.2</td><td>Are the assumptions of the modeling appropriate for the methods of modeling selected? Assumptions evaluated should include, but are not limited to:
▪ Material Thickness
▪ Mesh Chosen
▪ The correspondence of the modeling to the design basis specified in the standard</td></tr>
<tr><td></td><td>The analyst did not provide load-displacement curves in the report. This would give insight to the development of plastic hinges. The load-displacement curves could also be used for an alternative determination of the calculated plastic collapse pressure using the double elastic slope method. -RB

He added that a design pressure determination should include a ratcheting check.

Also, a design pressure determination should include a ratcheting check by the method prescribed by Division 3. It does not seem that the ratcheting check was attempted but is an important part of assignment of a pressure rating. -RB</td></tr>
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<table>
<tr><th colspan="2">RESPONSE TO CHARGE QUESTIONS</th></tr>
<tr><td colspan="2">3. Are there strengths or weaknesses of the analytical methods used for the empirical calculations chosen in the report?</td></tr>
<tr><td></td><td>The reviewers acknowledged the appropriate use of ABAQUS FEA. A reviewer described the process used as well as the results.

An Independent FEA of the large neck flange using ABAQUS FEA was conducted (using nominal dimensions). The calculated collapse pressure results for the large neck flange were very close to the values in the report, 72,251 psi vs 72,850 psi of the report. This was evaluated for collapse pressure using ¼, ½ and a full model with close to the same results obtained for each analysis. A 6% drop in the yield through ultimate true stress true strain data will result in the FEA matching the test results for collapse pressure vs burst, using the report model for the large neck flange. This indicates the criticality of accurate material properties. -PB

Another reviewer described the ABAQUS FEA process and results in similar fashion.

An independent review of the analysis which included these components was conducted using ABAQUS FEA. The analysis used a</td></tr>
</table>

RESPONSE TO CHARGE QUESTIONS

3. Are there strengths or weaknesses of the analytical methods used for the empirical calculations chosen in the report?

> 3-D geometry of a ½ section model. The calculated burst pressure for the large neck flange was 72,900 psi vs. the report value of 72,850 psi. This confirms that eliminating the bolting, gasket and blind flange does not affect the results for predicting the collapse pressure of the vessel itself. -PB

He further explained that either ANSYS or ABAQUS finite element programs are appropriate for the design analysis of API HPHT equipment.

> Both ANSYS and ABAQUS finite element programs are used in design analysis of API HPHT equipment. Either program is considered acceptable when applied properly. Each is based on the von Mises flow rule. As stated in the report, large displacement theory was used for the analysis. -PB

He noted, however, that "The report model did not include the bolting, gasket or mating blind flange." -PB

Another reviewer explained that:

> Empirical or classical calculations using equations from strength of materials derivations, are valid so long as the stresses do not approach the yield strength of the material being used and the stresses change in a linear fashion. For thick-walled components, the linear-elastic methods have been shown to be non-conservative since the stress fields are typically nonlinear. -RB

Another reviewer repeated the need to acknowledge the potential variation in the burst pressure of steel components.

> The variation in the burst testing of components needs to be repeated here. The data set presented by Terada[2] demonstrates the potential variation in the burst pressure of steel components. The analytical methods are highly repeatable and reproducible from one analyst to another, provided identical geometry, material and boundary conditions are used in the evaluations. The test data used in the empirical evaluation of the results and the evaluation of the margin has inherent variability due to variations in material processing, etc. Terada's paper[2] also points out the variations on empirical burst pressure equations which are in the literature. In short, comparison to burst test results will have variation and the authors of this report should be commended that their results are completely within the expected scatter band. -DP

RESPONSE TO CHARGE QUESTIONS	
3. Are there strengths or weaknesses of the analytical methods used for the empirical calculations chosen in the report?	
	He also stated, "The potential issues with the application to linear-elastic analysis have been considered earlier in this line of questions and won't be repeated here." -DP

RESPONSE TO CHARGE QUESTIONS	
4. Are the conclusions drawn by the report appropriate based on the modeling results and empirical analysis?	
	One reviewer suggested that this question dealt primarily with section 10 Conclusions. "As pointed out in question 1.9 of this survey, there are conclusions drawn throughout this report and not limited to the conclusions section in 10.0. However, it is assumed that this question refers directly to section 10.0. -DP A reviewer acknowledged that "…the conclusions drawn regarding the prediction of collapse pressure based on elastic-plastic FEA were verified to be accurate through an independent analysis." -PB However, he stated that: > There are discrepancies in the defined allowable limits where API 6A/6X are referenced. The TR8 report references both documents but the current practice is to use API6X. The allowables stated for ASME Sec VIII, Div 2 are incorrect, they assume the allowable =2/3*σ_y where ASME is σ_{uts}/2.4. The elastic-plastic analysis and design load factors for ASME Div 2 and Div 3 are correct as stated in the report. -PB Another reviewer questioned the validity of extending conclusions beyond verification of the design pressure. > The conclusions in the report that extend the application of the assessment methods beyond verification of the basic design pressure are not considered valid. Therefore, this writer does not agree with any conclusion for pressure beyond the design pressure. It is thought that a competent designer would generate a design independent of the assessment means using experience, knowledge, and sound engineering judgment then subject the design to the appropriate assessment means. -RB Another expressed the same concern, that the report was recommending reverting to linear-elastic methods as a gold standard, while they have been shown to be non-conservative as pressure ratings increase.

RESPONSE TO CHARGE QUESTIONS	
4. Are the conclusions drawn by the report appropriate based on the modeling results and empirical analysis?	
	…the elastic-plastic methods used in both ASME VIII-2 and VIII-3 are the same for global plastic collapse with different design margins used for each division. If a recommendation is made to change the margin in ASME VIII-3, it is unclear why that would be valid and not make a similar change in VIII-2. It would seem that the linear-elastic methods are being used as a "gold standard" which the newer more rigorous modern methods are being held to. This linear-elastic method has been shown to be non-conservative as pressure ratings increase in the work by Dixon[1]. As technology improves, industry must be able to use the advancements in order to stay competitive. -DP

RESPONSE TO CHARGE QUESTIONS	
5. Are the conclusions related to the test appropriate?	
	One reviewer acknowledged that the burst test supported the original design pressure of 20,000 psi using assessment methods from both API 6A and Division 3. The test was an instrumented pressure test at various pressures both internal and external and lastly an internal pressure test to failure. The burst test results support the original design pressure of 20,000 psi using assessment methods from both API Standard 6A and Division 3. Not repeated here are the objections to extending the validity of the Division 3 assessment methodology. -RB Just as the reviewer mentioned his objections to extending the validity of the Division 3 assessment methodology, the other reviewers also expressed concerns about the report extending its recommendations beyond what was learned from the burst tests. **Concerns about Reverting to Previous Methods and Standards** Reviewers were concerned about recommendations to use historical methods to determine load factors. One reviewer explained that a recommended design load factor of 2.1 is not based on test results. The conclusion that 'The Division 2 elastic-plastic method with a design load factor of 2.1 would be more in line with historically successful equipment…' is not based on test results. The test results if taken as the lower bound of test data would suggest a design load factor of 1.93. The purpose of the study was to validate the pressure rating methods in API 17TR8. The conclusions in the report go beyond that, suggesting the

RESPONSE TO CHARGE QUESTIONS	
5. Are the conclusions related to the test appropriate?	
	load factors be based on historical methods instead, using linear-elastic analysis. -PB A reviewer explained that the recommended linear-elastic analysis isn't always going to yield conservative results. … the conclusions that are related to the test are based on a flawed premise that the methods used are going to be conservative in all cases with no variation in the burst pressure in components. The test data also proved that linear-elastic analysis can, in certain situations also yield non-conservative results as shown in Table 9.2 (1.74 margin VIII-2). -DP The same reviewer pointed out that HPHT equipment is designed with appropriate margins while considering loading variation, material properties, manufacturing tolerances, etc., which have been accounted for in ASME and API standards. HPHT equipment is designed with these margins with the expectation that it won't experience loading above design while in service. The point of a design margin is to allow for a margin due to the unknowns in the design condition. The industry has considered the variation in things such as loading variation, material properties, manufacturing tolerances, etc., and have accounted for them in the factors which are used in ASME and API standards today. -DP **Burst Testing Limitations** A reviewer explained that burst tests are prohibited for defining collapse pressure and subsequent pressure rating of the equipment. The statement that the "load factor of 1.8 would be more justifiable if the factor is applied to the rupture pressure" is not appropriate according to ASME Div 3. KD-1212 prohibits the use of tests to destruction to define collapse pressure and subsequent pressure rating of the equipment. -PB He also explained that burst tests are impractical and unsafe. The statement "It is recommended that the subsea industry consider comparing collapse pressures from FEA with burst pressures from hydrotest for a variety of subsea equipment is impractical and unsafe. These test for standard API components are impractical in that bolting failure or gasket leakage would have a higher potential for failure prior to actual burst pressure. As an example, the current proposed design of an 18-3/4" 20 ksi flange neck has a wall thickness of 9.86 inches and

RESPONSE TO CHARGE QUESTIONS	
5. Are the conclusions related to the test appropriate?	
	would have a calculated burst pressure according to flow stress equations of 70,536 psi, using API 6A minimum yield and ultimate strengths. Failure of the bolting or gasket leakage of this flange would occur prior to the burst pressure limit. -PB Another reviewer claimed that proof or burst testing is dated, expensive, and potential dangerous. The conclusion that components should be rated based on proof testing or burst testing is, in my opinion, dated, expensive and potentially dangerous. Modern design methods are used to reduce costs for the industry, and allow them to be competitive, without the need to perform excessive burst testing of components. Finite element technology is well known and the methods are proven and widely used in many other pressure equipment industries, and other industries such as aircraft, automotive, bridge design and many others. Complex shaped components are designed every day to ASME B31, VIII-2, and VIII-3 standards. ASME VIII-3 does have KD-12 in its document as an option, but it is rarely used. When it is used, my experience [has been that] it is typically for very small components. -DP **Strain Measurement** A reviewer recommended that strain testing would be a better method for determining collapse pressure. KD-1212 specifically states that strain measurement test may be used to determine the collapse pressure. If the test had been conducted to be in compliance with ASME Div 3, the strain gage measurements should have been used in the burst pressure test to define the collapse pressure. Reference is made to API 6A, 19th ed. proof test. The requirements of this document for proof test pressure limits are based on strain gage readings. -PB

RESPONSE TO CHARGE QUESTIONS	
6. Are the conclusions appropriate?	
	One reviewer suggested that the hypothesis of the study was to provide evidence to justify methods used in API 17TR8, while justification has already been provided through more than 40 years of study. Many of the conclusions appear to be based on a desire for additional information to justify the methods used in API 17 TR8. This type of information was discussed and was considered during the adoption of the rules in the ASME standards over the course of the last forty years.

RESPONSE TO CHARGE QUESTIONS	
6. Are the conclusions appropriate?	
	API SC 17 considered the standards of ASME and adopted that experience base and other bases as their own, through the recommendations in 17 TR8. -DP The reviewers all agreed that the other conclusions were not appropriate nor justified. For example, one reviewer clarified that API 6A and NACE MR0175 complaint material requirement is not sufficient for TR8 requirements. It is stated that 'TR8 requires that all pressure containing components meet the material requirements of API 6A and NACE MR0175. Materials that meet the requirements of these two codes will be ductile, have high impact strengths and have high facture toughness. Materials with these properties are not susceptible to brittle failures.' API17TR8 does not state that these two codes are sufficient for defining material requirements or that they are acceptable for defining required fracture toughness. ASME Sec VIII, Div 3 toughness requirements are much higher than those stated in API 6A. API Does not provide guidelines on fracture mechanics evaluation and thus Div 3 CVN requirements should be applied when defining failure due to a critical crack size. Heavy wall components, such as BOP bodies, have constraints where a crack growing to a critical crack depth can occur in a plane strain condition, which could result in brittle fracture, for the defined material fracture toughness. API alloy steels exposed to hydrogen charged environments can have significant loss in fracture toughness which can result in a brittle failure mode. -PB The same reviewer described how a fracture mechanics analysis would need to be conducted, which would justify a design load factor of 1.8. It is stated in the conclusions that 'The subsea industry should confirm that performing a fracture mechanics analysis required by Division 3 justifies a reduction of the design load factor to 1.8.' It is unclear how the fracture mechanics analysis would justify the design load factor of 1.8. The fracture mechanics is part of the fatigue evaluation of TR8 and there is a defined critical crack depth, with a design margin, based on all design loads. These are required for Category 1 equipment. These evaluations are not based on benign environment at room temperature, but are defined for maximum operating loads and worst operating environments. The maximum operating pressure is verified for collapse by applying a 1.8 factor, where the thermal and external loads are verified applying a 1.58 factor. The loads that satisfy the collapse load using the 1.58 factor for collapse are the loads (non-factored) that are evaluated for cyclic fatigue crack growth and an allowable critical crack depth using fracture mechanics analysis. Additionally, there is a design

RESPONSE TO CHARGE QUESTIONS	
6. Are the conclusions appropriate?	
	factor for the allowable number of cycles to be 50% of the total fatigue cycles to critical crack depth. -PB The same reviewer explained how it is possible to create a fracture mechanics analysis load history for subsea equipment, contrary to a claim of the report. It is stated in the report that 'fracture mechanics analysis requires an explicit, time-based load history. This history is not possible for subsea equipment.' It is possible to review the load histogram and evaluate a worst-case loading sequence for fatigue analysis. There can also be multiple load sequences run to verify a worst case. -PB Additionally, there are verification analyses for local failure due to strain limit damage, ratcheting evaluation and service criteria evaluations, such as gasket leakage, and bolting stress allowables. Any of these verifications can define the limits of the design. -PB Another reviewer questioned why 20,000 psi components from the non-subsea had not been used to help substantiate the conclusions of the report. It is unclear in the report what is fundamentally different between the 20,000 psi components in the subsea industry and a 20,000-psi component which is not in the subsea industry which would substantiate the conclusions in the report. -DP He also suggested that if author of the report feels strongly about his conclusions, he should submit a recommendation to ASME to consider increasing the margins in both VIII-2 and VIII-3. If the author feels strongly that the conclusions in the report are valid, another conclusion should be a recommendation, likely to ASME, to consider increasing the margins in both VIII-2 and VIII-3 by some factor to ensure that the ratings are always lower bound. -DP

RESPONSE TO CHARGE QUESTIONS	
7. Are the recommendations logical, appropriate, and supported by the conclusions of the test results, empirical analysis, and modeling results? The scope of the recommendations pertains to all recommendations, not just those derived from the modeling results.	
	The reviewers all agreed that the recommendations were not adequately supported by the conclusions of the test results. Two reviewers agreed that the basing the report's conclusions on a single series of tests was invalid.

RESPONSE TO CHARGE QUESTIONS	
7. Are the recommendations logical, appropriate, and supported by the conclusions of the test results, empirical analysis, and modeling results? The scope of the recommendations pertains to all recommendations, not just those derived from the modeling results.	
	The determination that there are some problems using the Division 3 assessment methodology from a single series of tests from one material and by one investigator is not considered valid. Typical verification and validation means are done using round-robin techniques that attain data from several different sources and the results are independently assessed. -RB The results appear to be based on a single test with no ability to review the statistics of that test. Typically, testing is performed based on a set of tests with some statistical relevance and not one or two data points. -DP While the report recommended the use of stress intensities instead of von Mises stresses for linear-elastic analysis, a reviewer pointed out that von Mises stresses, rather than stress intensities, are approved for linear-elastic analysis. It is recommended that stress intensities be used instead of von Mises stresses for linear-elastic analysis. API 17T8 references API 6X which allows the use of von Mises stresses for linear-elastic analysis. The use of linear-elastic analysis for pressure ratings above 15 ksi is not considered accurate as defined by ASME Div2/3 where the analysis is only allowed for designs with $R/t \leq 4$. -PB This reviewer also felt the report provided insufficient data for its recommendation that the Division 3 elastic-plastic method not be used for HPHT subsea equipment with a 1.8 design-load factor. The statement that; 'The Division 3 elastic-plastic method is not recommended for HPHT subsea equipment published with a 1.8 design-load factor' is not based on sufficient technical review and test data to assure validity of the recommendation. -PB In addition, he repeated that the recommendation to compare subsea collapse pressures from FEA with burst pressures is impractical, and does not follow ASME or API guidelines. See responses to question 5. It is 'recommended that the subsea industry compare collapse pressures from FEA with burst pressures from hydrotests for a variety of subsea equipment' which is impractical and does not follow ASME or API guidelines. -PB Another reviewer questioned the conclusion that the industry needs to verify the additional fracture mechanics analysis and more rigorous material

RESPONSE TO CHARGE QUESTIONS	
7. Are the recommendations logical, appropriate, and supported by the conclusions of the test results, empirical analysis, and modeling results? The scope of the recommendations pertains to all recommendations, not just those derived from the modeling results.	
	requirements in to justify Division 3's 33% reduction of the design load factor as compared to Division 2. The one conclusion states that "For subsea equipment the industry should verify that the additional fracture mechanics analysis and more rigorous material requirements in Division 3 justify a 33-percent reduction of the design load factor as compared to Division 2." This conclusion is confusing at best. The conclusion draws on the premise that there is something special about pressure equipment in the subsea industry that is different that the technological challenges present in other industries. This is not the case. The bases for the use of ASME VIII-3 has been considered and has been accepted by the ASME Committees and by API by reference. The conclusion appears to be based on the premise that it is impossible to develop a loading histogram to represent the annual cycles expected for a piece of subsea equipment over the life of the piece of equipment. This is currently done in the industry and has been shown that it can be done conservatively, as was done in the Deepstar 12302 project which was recently completed. -DP The same reviewer reminded us that "There are also many conflicting statements throughout the report, which have been cited previously." -DP

RESPONSE TO CHARGE QUESTIONS

8. Are there any obvious technical considerations the report should have covered that are missing?

Important Technical Considerations

Reviewers identified several important technical considerations that were missing from the study. One of these is, "The report should have reviewed the technical background and testing used by ASME to establish the 1.8 load factor defined in Div 3." -PB

Another reviewer questioned the investigator's use of the load factor as a design factor.

> Is not clear if the investigator understands the underlying principles of assessments using LRFD since he uses the load factor intended for the LRFD method as a "design factor." [This same misapplication of terminology also exists in API TR8.] -RB

The same reviewer stated that "… the report attempted to cover a scope of work that was overly broad. As a result, some items lacked rigor by failing to properly define material sample locations with reference to Division 3 requirements and obtain actual material stress-strain data." -RB

Another reviewer pointed out that the report neglected other failure modes, many of which are far more common.

> The report only focused on global collapse of a cylindrical tube. None of the other failure modes, many of which are far more common, were investigated. This includes the concept of local strain accumulation and damage in areas of high stress concentration, the concept of shakedown, the evaluation of the hydrostatic testing criteria for the components. There are many technical discussions in the area of bolting and flange design which also are not covered in any detail in the report. -DP

Burst Test Results

One of the reviewers acknowledged that the burst test was in line with anticipated scatter in burst test results.

> One conclusion that appears to be appropriate, in lieu of the conclusions in the report, is that the burst testing is exactly in line with the anticipated scatter in test data which may occur in a burst test, and that the pressure rating of ASME is not lower bound, but mean. The report should also have considered if "extreme" or "survival" type loads come into play and to be sure that the potential scatter doesn't result in failure of a component under loads beyond the design basis. -DP

RESPONSE TO CHARGE QUESTIONS	
8. Are there any obvious technical considerations the report should have covered that are missing?	
	Another reviewer said that the burst test results should have been compared with existing ASME data. > The report should have compared the burst test results of the two components with existing ASME data to establish a statistical distribution of data points to determine if the results fall within an acceptable range of scatter. -PB This reviewer also stated that: > The report should have addressed the probability of occurrence for calculated collapse pressure vs burst before concluding that the Division 3 elastic-plastic method is not recommended for HPHT subsea equipment as published with a 1.8 design load factor. -PB **API 17TR8, PSL 5** The same reviewer claimed that: > The report should have addressed the requirements of API 17TR8, PSL 5, when using ASME Div 3 design verification. The document does not state specific requirements for meeting the PSL 5, but makes reference to being above and beyond API 6A PSL3/4 in regard to Charpy toughness, fracture toughness and NDE. A reasonable interpretation would be to evaluate these material parameters as they apply to Div 3 elastic-plastic analysis. -PB

4. PEER REVIEWER COMMENTS BY CHARGE QUESTIONS

4.1 General Impressions

GENERAL IMPRESSIONS	
Provide overall impressions (approximately 1/2 page in length) addressing the accuracy of information presented, clarity of presentation, and soundness of conclusions.	
Daniel T. Peters	The information presented is organized and fairly simple to follow. Some items do need to be clarified, and have been noted in the comments to follow. The report appears to have been written with pre-conceived hypothesis, and the report attempts to use data from the testing and analysis to support these hypotheses and the conclusions of the report. There are data in the analysis section of the report which were not addressed as they do not support the final conclusions of the report. The report does not appear to make any reference to the published research which has been done previously on this subject, nor the basis for the standards, nor technical reports which are available in industry today to support the technical approaches put forth in the standards. Most of the conclusions appear to ask for the subsea industry to consider what they are doing as unique and completely different from other equipment which operates with internal pressure in corrosive environments in cyclic service with similar temperature, pressures and materials. The idea that this equipment, together with it environment and operation, is unique from other pressure equipment in other industries is a misconception. The subsea industry would greatly benefit from looking at the past experience of other industries and using that as a basis for the work going forward. The conclusions all center on some belief that the design margin required for successful operation in subsea equipment must equal the same margin that has been used since the 1960s and designs are best determined by using stress analysis methods which are becoming outdated. None of the standards referenced by API for this purpose have the same margins for that period of time, largely due to advancements in material production, fabrication, and more sophisticated design approaches.
Paul Bunch	First, it must be clarified that this review is limited in scope in that the report does not address the complete evaluation of 17TR8 for pressure rating. The focus of the report was based on collapse pressure and does not address local failure, ratcheting, fatigue, serviceability, etc. As such, the peer review responses are evaluating this limited scope of work. Other failure modes are addressed in this review only in context of references made in the text or how they would influence the collapse pressure predictions. Additionally, API 17TR8 is referred to as a standard in the charge questions of this review and it is not, it is a technical report. API 17TR8 is not a standalone

GENERAL IMPRESSIONS	
Provide overall impressions (approximately 1/2 page in length) addressing the accuracy of information presented, clarity of presentation, and soundness of conclusions.	
Paul Bunch (cont.)	document (as stated in the Introduction section of the document), it is a guideline for HPHT development, and must be used in conjunction with all applicable industry standards to assure completeness and accuracy of the design requirements. HPHT guidelines from BSEE Standards Workshop: HPHT Session, May 8, 2015, provided the following statement; 'BSEE also recognizes that API 17 TR8 is a general guidance document, is not complete in its scope, is not the only HPHT guidance document, and does not address all issues associated with the construction of all HPHT oil field equipment. Technical Reports are not Engineering Standards.' There are additional specifications referenced in the peer review that are pertinent and applicable to HPHT designs. **Accuracy of Information** There are topics in this report which are difficult to determine the accuracy due to the limited amount of information. This includes: ▪ Completeness of the material properties. It cannot be definitively stated that the material properties used in the analysis were representative of the properties at the location of the burst. ▪ The FEA models did not include all components of the assembly which was subjected to burst, such as the flange bolting, ring gasket and blind flanges. These may not influence the results but not including them raises the question of accuracy in the modeling. ▪ The data provided for the strain gage testing was incomplete. Data was not provided for the high strain regions on the ID and the data from external gages were only for principal strains up to hydrostatic test pressure and does not provide the elastic-plastic strains up to burst pressure. The results of the strain gage testing did not provide an acceptable validation of the accuracy of the FEA. Nor were they used to define collapse pressure. ▪ The material properties used for the FEA were defined to be obtained from true stress-true strain data. There are three different sets of material tensile properties, it is unclear if the properties used for the FEA were the lowest of the three measurements. **Clarity of Presentation** Overall the procedures for proof test analysis were very well defined and understood. The FEA Models were clear, all reference standards used for determining design margins were well reference. Equations which defined how allowable design pressures were calculated and clearly defined. The material process did not provide non-proprietary material processing procedures from the forgemaster, such as information on the quenching of the forging defining orientation and circulation of quench fluids in the quench

GENERAL IMPRESSIONS	
Provide overall impressions (approximately 1/2 page in length) addressing the accuracy of information presented, clarity of presentation, and soundness of conclusions.	
Paul Bunch (cont.)	tanks. It wasn't clear if the prolongation was attached during the heat treat cycle and it wasn't clear if both test samples had prolongations or if just one prolongation was used for both test samples. Regarding the burst testing the strain gage measurements were only obtained for the hydrostatic test but should have provided the readings during the burst test for validation of the FEA for predicting burst. Not all strain gage data was reported, the internal gages were determined to be inaccurate. **Soundness of Conclusions** The conclusions made were based on comparisons of historical pressure rating allowable stresses and procedures for defining pressure ratings which have changed. API 6A/6X/17D were referenced as one of the current design methodologies of equipment rated for working pressure up to and including 15 ksi. The current design methodology is defined in API 6X, which allows the use of von Mises stresses to calculate the design allowable. API 6X is referenced in 17TR8. ASME Div 2 linear-elastic design stress allowable was defined to be based on yield strength and it is not. Div 2 refers to ASME Sec II Part D for allowables which are based on ultimate strength. ASME Sec VIII, Div 3, KD-12 is referenced as an acceptable procedure for proof testing to failure to define equipment pressure ratings. KD-1254 does not allow pressure ratings to be determined using proof testing. The two component evaluations conducted are insufficient in number to demonstrate the analytically predicted collapse pressure vs the proof test provide a statistical distribution range of data. It is stated that the error may be greater for more complex geometries which may be true, but that only means there would be a wider distribution of data points, which could result in higher or lower predicted collapse loads vs. burst pressure. Additionally, more complex shapes may result in burst pressures initiating from local failure due to strain limit damage as opposed to tensile overload of the cross-section. The recommendation of comparing collapse pressure from FEA with burst pressures from hydrotests for a variety of subsea equipment is impractical and the failure mode could change depending on the component. More research into existing and possibly additional test specimens should be conducted to obtain a more complete statistical distribution of results. It should not be based on a data set of two tests to establish a lower bound for all test data. The ASME Sec VIII, Div 3 load factor of 1.8 was developed over time. There is historical information, technical justification and testing by ASME that

<table>
<tr><th colspan="2">GENERAL IMPRESSIONS</th></tr>
<tr><td colspan="2">Provide overall impressions (approximately 1/2 page in length) addressing the accuracy of information presented, clarity of presentation, and soundness of conclusions.</td></tr>
<tr><td></td><td>should be reviewed before a decision is made that the design load factor of 1.8 is not acceptable for API subsea equipment.</td></tr>
<tr><td>Richard C. Biel</td><td>This writer has a fundamental philosophical difficulty with the use of the ASME Boiler and Pressure Vessel Code as a design methodology document. The intent of the Code is that the methodology and processes in the Code be used only for an assessment of a design. The Code explicitly states that it is not a design handbook. For many decades however, the designers of API equipment have misused the Code as a design handbook.

The ASME code writers currently use the term "design margin" that was formerly known as the "safety factor" to describe the level of uncertainty with respect to failure of a component or pressure vessel. The term used extensively in the report as "design factor" is not consistent with terminology in current use within the ASME Code. Also, it is not clear why the report occasionally uses the 2013 edition of the Code when the 2015 edition of the Code was available during the time this report was written.

The reader should also be aware of the difference between the design margin and load factor as used in Section VIII, Division 3. The basic design margin in Division 3 is 1.732 (the square root of three) for materials that have a ratio of material yield strength to ultimate strength that is greater than approximately 0.72. The difference is small, approximately 2% when evaluated for thick-wall cylinders. Use of the value of 1.8 as a “design factor” points to a basic misunderstanding of the use of LRFD load factors used to assess adequacy of the design according to the Code.

This author does not question the validity and accuracy of the burst test results. Also, the use of classical equations and finite element analyses appear to be done accurately. However, the finite element analyses can only be checked for accuracy by a detailed examination of the input files. Presuming that the analytical work was done by someone skilled in the method, there is no reason to doubt its accuracy.

Whatever design methodology was used, it appears that both large and small neck designs were adequate for the intended pressure rating of 20,000 psi. The report fully justifies that pressure rating. Even the calculation of the pressure rating from the results of the burst test in Appendix E (more details below) of the report shows the adequacy of the design. However, when the report takes the added steps to generate pressure ratings based on plastic collapse by analysis, and further applies a load factor to the burst test results, it seems the intent is to stretch the validity of Division 3 beyond its normal assessment uses.</td></tr>
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GENERAL IMPRESSIONS	
Provide overall impressions (approximately 1/2 page in length) addressing the accuracy of information presented, clarity of presentation, and soundness of conclusions.	
Richard C. Biel (cont.)	Lastly, refer to the Figures 9.1a and 9.1b. It seems the writer is not sufficiently familiar with Division 3 to know how to accurately portray the historical design margin. Division 3 did not come into existence until 1997 and in the early editions use the design margin of 2.0. In the 2007 edition with the 2009 addenda the current design margin of 1.732 was introduced along with the LRFD methodology that included the load factor of 1.8.

4.2 Responses to Charge Questions

RESPONSE TO CHARGE QUESTIONS	
1. Evaluation of Test Methods	
1.1	*Were the test objects selected for analysis valid test objects to evaluate the standard as applied? Consider true stresses and strains in the context of valid discussion.*
Daniel Peters	The test bodies shown in Figure 5.1 and 5.2 of the report are very similar geometrically to other types of valves, tees, connectors, and equipment used in the subsea HPHT industry. Fillet radii, ring joint geometry, and other details vary greatly between manufacturers, so it is difficult to say if it is specifically applicable relative to a specific design. The general configuration is similar in size to other such equipment in the industry. The flanges used in this situation are standard size 20 ksi flanges based on Table B.43 of API 6A for 20 ksi rated working pressures. The analysis does show that the flanges meet the requirement of global collapse at these pressures. However, it is likely that the size and number of bolts used, might not meet the requirements of ASME Section VIII-2. Additionally, based on experience with other HPHT equipment in industry, some of the fillet radii were larger than in typical equipment. This could lead to under predicting local plastic strain in these areas which could lead to localized failure in typical equipment. This is not the focus of the current study.
Paul Bunch	The test objects were valid based on referenced standard of API 6A and technical report 17TR8 as they were defined in the report, with the exception of tensile test location and CVN values. There were additional industry published specifications for material processing and testing requirements above those defined in API 6A, which were released prior to the development of this project. The use of API 6A material requirements is not adequate for development of HPHT equipment. As an example, API 6A material Charpy V-notch impact requirements require an avg of 20 ft-lbf, where ASME Div 3 requires 50 ft-lbf, and the material specification for this test object required an avg of 40 ft-lb. Applying design criteria for global collapse using ASME Div 3 for HPHT designs, should meet the toughness requirements of this document.

RESPONSE TO CHARGE QUESTIONS	
1. Evaluation of Test Methods	
1.1	*Were the test objects selected for analysis valid test objects to evaluate the standard as applied? Consider true stresses and strains in the context of valid discussion.*
Paul Bunch (cont.)	Additionally, API 20B and DNVGL-RP-0034 'Steel Forgings for subsea applications' provide guidelines for material processing, testing and Charpy values (RP-0034). API 20B is currently being applied in the industry and RP-0034 is being reviewed for HPHT equipment applications. As defined in 17TR8, API 6A/17D/6X are specifications for equipment rated for working pressures up to and including 15 ksi equipment. There were two sets of material tensile tests reported which were obtained from the prolongation material. A true stress-true strain curve was defined as the material input in FEA (supplied by ANL) and it is assumed this test was in addition to the reported tensile tests results, and provides a third set of tensile properties. There are variations in the results of the tensile properties for the two tests provided. The two engineering yield strengths values were 92.2 ksi and 91.6 ksi and the ultimate strength values were 111.1 ksi and 108.7 ksi. It is unclear if the true stress-true strain curve input for the FEA represents the lowest yield and ultimate stress data obtained from the material tensile testing. The material specification references API 6A PSL 3 as the criteria for material testing. Mechanical properties were taken from 1/4T location on the prolongation. API 6A requires test coupons to be taken at '3mm (1/8 in) from the mid-thickness of the thickness section of a hollow QTC.' Additionally, 20B and DNVGL-RP-0034 require mechanicals at 1/2T location in both the longitudinal and transverse directions. To obtain the most accurate results when comparing FEA collapse pressure to test specimen burst pressure, mechanical properties in the flange neck in the transverse direction using a qualification forging (first article) cutup to obtain the properties should have been performed, reference API 20B.
Richard C. Biel	In my opinion, the configuration of the test articles that were chosen were adequate to demonstrate compliance with the technical report 17TR8 for internal and external pressure only. Obviously missing are loads due to external tension and bending. External tension and bending loads have been identified as significant loads, possibly defining loads, for subsea equipment.

RESPONSE TO CHARGE QUESTIONS	
1. ***Evaluation of Test Methods***	
1.2	*Are the assessments of engineering safety factors for the cited standards and their divisions valid for the expected applications?*
Daniel Peters	API 17 TR8 and ASME VIII-2 and VIII-3 do not use the term "safety factor" for their designs. The term used is "design margins". It is assumed that each of these terms are being used interchangeably here. Some in the industry would call this interchange of words a dangerous precedence which could have consequences if the understanding of the difference in the terms is not well understood. Each of these standards have many design margins and not one specific margin. ASME VIII-2 and VIII-3 use the Load Resistance Factor Design (LRFD) methodology which uses multiple factors for the various combinations of loads which are to be considered. The basic design margins on pressure for a piece of equipment, for use with an elastic-plastic analysis, are 2.4 and 1.8 in VIII-2 and VIII-3, respectively. However, these are lowered to 2.1 and 1.58 for VIII-2 and VIII-3, respectively, for other combinations of applied loading including seismic, wind and other load combinations, and 1.7 and 1.28, respectively for evaluation of the local criteria looking at local strain. ASME fatigue assessments also have their own margins and they vary based on the methodology used (VIII-2 fatigue, VIII-3 fatigue, and VIII-3 fracture mechanics). It is further noted that the current report endorses the use of API 6A and linear-elastic stress analysis for design of subsea equipment based on past industry practice. The report cites significant successful industry experience using these methods. Based on my experience, the industry typically uses linear-elastic methods at these pressure ratings, but its application is limited, particularly as the pressure ratings increase and stresses in components exceed the yield stress. Several linear-elastic designs have been reviewed that are acceptable relative to the requirements of a linear-elastic methodology, which have excessive plastic strain or localized stress concentrations which may not be acceptable using elastic-plastic finite element analysis or have very limited fatigue life. Comparative studies have been done to evaluate the use of linear-elastic methods to elastic-plastic methods. Dixon, et al[1] have shown that for equipment with required wall ratios (OD/ID) in excess of ~1.25, the linear-elastic method may be non-conservative. The equipment being designed here at 20 ksi and using the material properties cited in the report would have a required wall ratio of 1.25. Therefore, it could be argued that either of the methods for the area of the failure could be appropriate. It is also noted that Terada's work[2] was used to help establish the margin of 1.8 currently used in ASME VIII-3. This is important to note as the work did effectively two things. First, it established the basis for using 1.8 as the margin in ASME VIII-3 for elastic-plastic evaluation. Secondly, the paper has a series

RESPONSE TO CHARGE QUESTIONS	
1. *Evaluation of Test Methods*	
1.2	*Are the assessments of engineering safety factors for the cited standards and their divisions valid for the expected applications?*
Daniel Peters (cont.)	of burst tests in it, which have been statistically evaluated. The standard deviation in this work was shown to be 7-9% based on the methods used in today's codes and standards. This work shows that the margins using elastic-plastic analysis are not meant to be lower bound pressure ratings. It shows that it is expected that using this type of analysis, it is expected for the margin to be nominally 1.8, if specified minimum material properties such as yield and tensile strength are actually achieved in manufacture, in lieu of higher strengths. It also shows that in practice the actual margin for a piece of equipment based on actual properties if they are near specification minimum, may be slightly less than 1.8 or 2.4 specified for analytical comparison. API and ASME have both accepted this potential variation as the case when adopting these margins. Section 6.0 of the report states that "it is crucial that the theoretical collapse pressure closely agrees with the actual burst pressure". This appears to not be in complete alignment with the work that is the basis of the margins in ASME VIII-3. The report further states in Section 6.1 that "it is imperative that the theoretical collapse pressures from FEA be accurate or at least conservative". The methods used have inherent variability in them relative to the actual material properties and are based on a mean rating, not a minimum value. This is the basis which again has been adopted by both API by reference and ASME in the development of their standards. It is noted in the report Section 2.0 that the margins are based on either yield strength for linear-elastic analysis or tensile strength for elastic-plastic analysis. While it is true that the allowable stress in a material for linear-elastic analysis methods is based on 2/3 of the yield strength, it is a gross simplification to say that the elastic-plastic analysis is solely based on tensile strength. The report only considers the margins on global collapse in the analytical assessment and it does use the proper margins in those cases. HPHT equipment has not been shown to be any different from any other pressure equipment, whether manufactured to ASME, API, or any other standards around the world. The margins referenced by API 17 TR8 are appropriate for high pressure equipment.
Paul Bunch	API 6A was referenced for design allowables. API 6X is referenced in TR8 as applicable for equipment rate for 15 ksi or less pressure. API 6X, which will be the referenced design methodology for API 6A, 16A and 17D in the next releases, is based on von Mises stress criteria for defining stress allowables. This document should have been used instead of API 6A for the linear-elastic analysis design allowables. The maximum allowable stress at hydrotest defined in 6A and 6X (5/6*Sy) is more limiting than the working pressure allowable stress (2/3*Sy) where hydrotest pressure is 1.5*WP. ASME Div 2 linear-elastic

RESPONSE TO CHARGE QUESTIONS	
1. *Evaluation of Test Methods*	
1.2	*Are the assessments of engineering safety factors for the cited standards and their divisions valid for the expected applications?*
Paul Bunch (cont.)	design stress allowable was defined to be based on yield strength and it is not. It refers to ASME Sec II Part D for allowables which are based on ultimate strength (Sult/2.4). ASME Sec VIII, Div 3, KD-12 does not allow testing to failure to determine collapse pressure. The design load factors for ASME Div2 and Div 3 elastic-plastic analysis were correct and applied properly to the analyses.
Richard C. Biel	As stated earlier, the report does not address important loads such as external tension and bending. In this respect, the underlying design margin in Division 3 cannot be fully assessed. That said, the assessments and conclusions from the test results and analytical work for pressure only using Division 3are not thought to be adequate for pressures above 20,000 psi.

RESPONSE TO CHARGE QUESTIONS	
1. *Evaluation of Test Methods*	
1.3	*Were comparisons of the computational methods and design methods adequate?*
Daniel Peters	The methods used for determination of global collapse appear to be used appropriately for each of the methods chosen. I have not investigated this fully through modeling or other calculations, but the methods used in the modeling appear to follow generally accepted practice for global collapse. The report indicates that it is a requirement, when using elastic-plastic evaluation, to determine the maximum pressure rating for a component and then apply the design margin to it. This is an incorrect statement. ASME VIII-2 and VIII-3 require demonstration of a component to withstand loading that has been factored above the design rating. This is a subtle difference, but can result in huge design costs if it were mandated to determine the maximum load that each piece of equipment can withstand in every combination. There are many different criteria that need to be evaluated, as stated earlier such as local strain limits, ratcheting assessment, life assessment, and other specified serviceability criteria. None of these were evaluated with this component. It is recognized in the high-pressure industry that the fatigue life or design of areas of local strain may control the pressure rating of a component in lieu of the global collapse rating. Appendix E determines the collapse pressure by proof test. The "Pressure Ratings of the Test Bodies by Rules of ASME Section VIII Division 3" section shows the calculation of the rated pressure using the equations from KD-1254. The key input to this process is the collapse pressure (CP). The method for

RESPONSE TO CHARGE QUESTIONS	
1. *Evaluation of Test Methods*	
1.3	*Were comparisons of the computational methods and design methods adequate?*
Daniel Peters (cont.)	determination of CP is found in KD-1253, which requires that the strain be determined at the OD of the cylinder while under test. There were strain gages shown in the photo of the burst tube in the area of interest, but no data was included from them in the report. The CP values used in the evaluation were based on the actual failure of the components. KD-1253(b) states that if the vessel fails, that the component should be redesigned and retested. It is likely that the 2% strain on the OD was exceeded during the testing performed to determine the CP values. In other words, it is suspected that the CP values would be lower than the reported values if the CP values were determined in accordance with the 2% strain on the OD. This would have greatly lowered the design pressure allowed by proof testing using this method. This however is a different criteria for the determination of the rated working pressure than used in the finite element analysis and should not be directly comparable.
Paul Bunch	No, see question 1.2 above. This evaluation is only for burst pressure and doesn't evaluate other design methods, such as strain limit damage, bolting, gasket leakage or ratcheting and the respective allowables for each. The report does not identify the limits of linear-elastic analysis as defined in Div 2/3 and 17TR8. This method is only recommended for wall thicknesses where R/t>4 and Do/Di<1.25 or the von Mises stress does not exceed the yield strength more than 5% of the wall thickness. It is stated that 'nonlinear stress distributions associated with heavy wall sections are not accurately represented by the implicit linear stress distribution utilized in the stress categorization and classification procedure. The misrepresentation of the stress distribution is enhanced if yielding occurs.'
Richard C. Biel	In my opinion, the design and computational methods are considered adequate and correspond to current practice in the engineering of API equipment. However, the assessments and conclusions attempting to extend the pressure ratings above the design requirements are considered to be inconsistent with the scope of Division 3 rules.

RESPONSE TO CHARGE QUESTIONS	
1. *Evaluation of Test Methods*	
1.4	*Are the assumptions of the modeling and tests clearly defined and appropriate?*
Daniel Peters	The modeling assumptions made are fairly well listed in the report. There are potential subtle nuances The report is not clear on whether dimensions used in the modeling result in a minimum material condition or if the nominal listed dimensions from the drawing. The model tolerances and shouldn't greatly affect the results, but this should be clarified in the report. It is noted that the material properties are from test locations from prolongations on the ends of the forgings and were taken in the longitudinal direction. Large thick section forgings can have significant variations in the material properties of the components, including variation based on test location and direction of the testing done. The majority of the conclusions of this report center around the burst pressure of the cylindrical tube sections with an axial rupture of the cylinders. The samples should have been taken to determine properties as a minimum in the tangential direction relative to the forged body. They also should have been taken at a location at mid thickness of the wall that failed, and not at ¼ T of the prolongation. The report in Appendix A2 also states that a drawing illustrating the testing locations would be provided. This was not located in the report but would be helpful in understanding the exact location of the testing. It is stated in the report that loads simulating the blow off loading was applied at the locations of the screws on the flanges of the components. Typically, the preloading (bolt loads) for a seal would be higher than that required for the blow off loading. Utilizing the actual bolt tension may result in added stress on flanges due to this loading for the analyses. Traditional modern finite element codes would commonly include all of the components in the analysis including the bolts and apply contact between them. However, it is noted that only the burst of the tube in each body was evaluated and relevant to the analysis, and hence, the method of application of the bolt loads versus the blow off loads, likely have no relevance. The report states that a limit load analysis is required for determination of the pressure rating of these components. This is not specifically true. It needs to be demonstrated that a component can withstand the rated loads when factored by the design margins for specific combinations of loads. However, for this particular exercise, which appears to be solely focused on the evaluation of the margin on global collapse, it is appropriate to attempt to determine the highest pressure (in this case) that the component can withstand. It is recognized that in the report that there is a certain amount of error in this technique. The report

RESPONSE TO CHARGE QUESTIONS	
1. *Evaluation of Test Methods*	
1.4	*Are the assumptions of the modeling and tests clearly defined and appropriate?*
	indicates that multiple iterations of each finite element analyses were performed to determine the collapse load for each component.
Paul Bunch	The boundary conditions, loadings, material properties of the finite element models were clearly defined with the exception of axial constraint. The ¼ section model is restrained in the Y-X plane for X direction constraint and Y-Z plane for the Z direction constraint, but there is not a clear plot or description of how the model is restrained in the Y direction. The plots of the results for von Mises stresses, total strain and displacements are defined and clear in the report. The assumption in the modeling that the true stress - true strain curves defined from tests conducted on the prolongation material are appropriate for a predicted failure mode that is hoop stress dominant has not been verified. The analysis and the component failure clearly indicated the mechanical properties input into the model should have been transverse tensile properties in order to assure accuracy. The geometries of the gaskets and blind flanges were not modeled which changes the reaction loads going into the flanges, and it was not verified in the report the contributing effects of these components on the results. There was no indication in the modeling of how the tolerance of dimensions were addressed, i.e. was the model generated using nominal, minimum/maximum material conditions or as tested dimensions. The same is true for alignment tolerances.
Richard C. Biel	As stated earlier, the modeling and tests do not address external tension and bending that are considered to be significant loads for subsea equipment. In particular, the finite element analysis techniques and methodology for the pressure tests are in general accord with accepted practice for those activities.

RESPONSE TO CHARGE QUESTIONS	
1. *Evaluation of Test Methods*	
1.5	*Did the report identify and adequately address the strengths or weaknesses of the analytical methods used for the modeling and testing methods used?*
Daniel Peters	The report did not reference the basis for the methods used nor the background explaining where the design margins came from. It appears that some research into the background of the standards referenced might be appropriate for this work and add to the understanding of the margins.

RESPONSE TO CHARGE QUESTIONS	
1. *Evaluation of Test Methods*	
1.5	*Did the report identify and adequately address the strengths or weaknesses of the analytical methods used for the modeling and testing methods used?*
Daniel Peters (cont.)	The report did some strain gage testing during the hydrostatic testing of each body. No plastic strain was experienced in the cylindrical sections during these tests, either at the gage, or at the ID of the tubes. This can be verified using the methods of ASME VIII-3 KD-5 for determination of the extent of plastic yield in the wall of a cylinder. The report also points to the difference between Tresca criteria and von Mises or equivalent stress criteria for linear-elastic evaluation. The report indicates about a 15% difference between the API 6A and Division 2 linear-elastic methods. This is as expected based on the fundamental concept of the two criteria. Most modern approaches, including almost all modern finite element programs utilize the concept of equivalent or von Mises stress for a failure criteria in yielding. There are many variations in material hardening models to model actual plasticity behavior, but the concept of using von Mises to predict the onset of yielding is well proven, as is the source of the potential 15% difference.
Paul Bunch	The report does not indicate a detailed FMECA was conducted, but indicates that the internal pressure will rupture the neck based on the elastic-plastic analysis to collapse pressure. Although there is no reference to a formal FMECA being conducted, this procedure should have been used to identify all other failure modes and assure all issues of those failure modes were being address in the test, such as gasket leakage, and bolting failure. Additionally, it should have identified that the material properties in the transverse direction were controlling the defined failure mode and are necessary to predict the collapse pressure and thus driven the material testing for these tensile properties. Part of the study was to perform strain gage testing to validate the accuracy of the FEA. Considering this was an analysis to define collapse pressure the strain gage data should have been provided for the collapse pressure loading. This would have been very relevant data to compare yield point of the test objects to the predicted yield point of the FEA. ASME Sec VIII, Div 3, KD-1212 allows the use of strain gage testing to be used to determine the collapse pressure. The additional FEA studies of the 13-5/8” 20 ksi and 16-3/4” 10 ksi flanges were evaluated for collapse pressure using axisymmetric models. These analyses did not include the bolt holes in the flange, bolting or the ring gaskets and mating blind flanges. Removing the bolt holes will change the stiffness of the flange and may result in higher predicted burst pressures than a full 3-d model with all components included. The results assume the flanges would fail due to a collapse pressure of the flange neck. The 16-3/4” 10 ksi flange analysis

RESPONSE TO CHARGE QUESTIONS	
1. *Evaluation of Test Methods*	
1.5	*Did the report identify and adequately address the strengths or weaknesses of the analytical methods used for the modeling and testing methods used?*
Paul Bunch (cont.)	predicted collapse pressure is well above the tensile failure of the bolting. Thus, the failure mode should have been identified as bolting failure. The 13-5/8” 20 ksi flange analysis predicted a burst pressure was lower than the tensile failure of the bolting. If the bolting stresses included both tensile and bending loads due to flange rotation, it is possible the bolts will fail before the flange reaches collapse pressure, for this flange as well.
Richard C. Biel	The report does not explicitly identify the strengths and weaknesses of the assessment methods that were used. The analysis techniques and pressure test methodology are consistent with accepted practice for those activities.

RESPONSE TO CHARGE QUESTIONS	
1. Evaluation of Test Methods	
1.6	*Were the actual materials within specification for F22 material properties adequate?*
Daniel Peters	I am not a metallurgist so I will limit my comments on the metallurgical aspects of this question. I also find this question somewhat ambiguous. The material properties used appear to be higher than specified in most ASTM materials. The reduction in area and elongation is slightly lower than the next lower strength materials of lower strength from a comparable material specification (ASME SA-336). Table KM-234.2(a) of ASME VIII-3 would require Charpy impact toughness of 50 ft-lb average for a set of three and 40 ft-lb minimum for a single specimen when testing in the longitudinal direction. Longitudinal toughness testing is also only permitted when the component shape or size does not permit removal in the transverse direction. It is believed that when taking samples from the prolongation, it should have been possible to take full size specimens in the transverse direction from these components. The heat treatment drawing in Appendix F also shows the prebore in the forging for heat treatment. Based on the description of the test locations, the effectiveness of the quenching in the bore of the component is not determined.
Paul Bunch	The material properties met the requirements of allowable materials per API17D/6A and NACE MR0175/ISO 15156, in regard to chemistries and mechanical properties (error on reported chemistry was corrected by ANL). There were no transverse material properties tested, thus it is not possible to determine if these were equivalent to the longitudinal properties used in the analysis. There were no mechanical properties tests to verify the prolongation properties were representative of the neck region of the test object.

RESPONSE TO CHARGE QUESTIONS	
1. Evaluation of Test Methods	
1.6	*Were the actual materials within specification for F22 material properties adequate?*
Paul Bunch (cont.)	The report makes the statement in reference to 17TR8 that; 'Product Specification Level 5 (PSL5) was added. PSL5 includes fracture toughness requirements, higher Charpy toughness values, and improved QA/QC.' The report acknowledges there are requirements above those of API 6A, PSL 3, but no effort is made to evaluate these for the test objects. Additionally, the report states 'Consider the additional material requirements in TR8. Materials that have been used in subsea equipment for many years already meet the additional requirements in TR8.' This cannot be verified due to the fact that previous API criteria did not require fracture toughness values, higher Charpy values or increased QA/QC requirements.
Richard C. Biel	The actual material properties were obtained from specimens taken at locations that are not consistent with Division 3 requirements. According to the material specification for test body included in Appendix A2, paragraph 11, the specified location of material sample specimens is not consistent with Division 3 paragraph KM-211.2(c). Paragraph KM-211.2(c) requires that the minimum distances from quenched surfaces be greater than the minimum distances given in the material specification. Also, the minimum required impact values required by Table KM-234.2(a) are greater than the impact values given in paragraph 12 of the material specification. [The reported values were higher.] Still not verified is the exact location where the material samples for testing were taken since drawings or sketches were not provided in the documentation. If the location where the material samples were taken is not in strict accordance with the Division 3 requirements the use of the values determined by these material tests would not be valid for assessments using the methods of Division 3. Hence, the use of material property results from the specimens taken according to the material specification in the report are questionable for assessments according to Division 3 due to being taken from a location that does not conform to Division 3 requirements.

RESPONSE TO CHARGE QUESTIONS	
1. *Evaluation of Test Methods*	
1.7	*Determine the degree of certainty that each test object did not have a latent defect, was forged properly, and manufactured properly; for example, should there have been a posted manufacturing stress reduction heat treatment?*
Daniel Peters	I am not a metallurgist so I will limit my comments on the metallurgical aspects of this question.

RESPONSE TO CHARGE QUESTIONS	
1. *Evaluation of Test Methods*	
1.7	*Determine the degree of certainty that each test object did not have a latent defect, was forged properly, and manufactured properly; for example, should there have been a posted manufacturing stress reduction heat treatment?*
Daniel Peters (cont.)	The material specification in Appendix 2 seems to cover the typical aspects of specifying material properties required from this material. It is typical for the material to have both a surface examination and a volumetric examination. This is a quenched and tempered alloy, so it would not be typical for a non-welded component such as the one involved in this testing to have a post weld heat treatment.
Paul Bunch	A review of the forgemaster MPS and a microstructural evaluation is necessary to determine if the component was properly forged and has a wrought structure throughout. Hardness testing should have been conducted to assure uniform hardness throughout the test objects. The test objects can only be assumed to have defects equal to or smaller than the NDE acceptance criteria, which was defined to be API 6A, PSL 3. Determining the failure as either initiation from a defect or tensile overload requires post test fractography, which should be performed to assure the test was due to the assumed structural instability with tensile overload as defined by the analysis. This evaluation will determine if there were defects which were initiation sights for crack growth. Post manufacturing heat treatment is not a practice used in the industry and would have been beyond the requirements of either the Technical Report TR8 or API specifications of 6A, 17D or 20B. Any heat treatment after manufacturing has the risk of distortion and dimensions not meeting tolerance.
Richard C. Biel	From the NDE documentation that was provided, it seems as though the material quality, as-forged, was adequate. There is documentation to verify that the forging reduction required by the specification was achieved.

RESPONSE TO CHARGE QUESTIONS	
1. *Evaluation of Test Methods*	
1.8	*The report documents a failure of the tested object for the 17 TR8 Division 3 method to show a failure of the test object at a threshold below the design standard. Do the conclusions and recommendation based upon this stand alone? Are there other considerations, such as the fact that the material chosen is a non-Division 3 material, or any other alternate logical explanation for failure event below the Division 3 design standard?*
Daniel Peters	The design methods in ASME VIII-2 and VIII-3 are identical from an elastic-plastic standpoint, with the exception being the design margin. The material used, while not currently a listed material in ASME VIII-2 or VIII-3 is similar

RESPONSE TO CHARGE QUESTIONS	
1. *Evaluation of Test Methods*	
1.8	*The report documents a failure of the tested object for the 17 TR8 Division 3 method to show a failure of the test object at a threshold below the design standard. Do the conclusions and recommendation based upon this stand alone? Are there other considerations, such as the fact that the material chosen is a non-Division 3 material, or any other alternate logical explanation for failure event below the Division 3 design standard?*
Daniel Peters (cont.)	in properties and composition to other materials commonly used in the production of high pressure equipment in this pressure range. It can be noted that ASME B31.3 references ASME VIII-2 and VIII-3 in a similar manner to API 17TR8 and has the allowance for the use of "unlisted materials" (ASME B31.3 K302.3.2(c)). In reality, the material doesn't know which "standard" it is being used in. If the material is specified properly, has adequate material properties including strength characteristics, toughness, etc. and is designed such that the critical failure modes are avoided or their potential is minimized, the standard doesn't matter. ASME VIII-3 uses a lower margin than VIII-2 due to many factors such as additional material testing, higher toughness requirements, additional NDE requirements, etc., and more stringent design specification requirements for the end user of the equipment. It is also noted that Terada's work[2] was used to help establish the margin of 1.8 currently used in ASME VIII-3. This is important to note as the work does effectively two things. The first is that it established the basis for using 1.8 as the margin in ASME VIII-3 for elastic-plastic evaluation. Secondly, the paper has a series of burst tests in it, which have been statistically evaluated. The standard deviation in this work was shown to be 7-9% based on the methods used in today's codes and standards. This work shows that the margins using elastic-plastic analysis are not meant to be lower bound pressure ratings. It shows that it is expected that using this type of analysis, it is expected for the margin to be nominally 1.8, if specified minimum material properties such as yield and tensile strength are actually achieved in manufacture, in lieu of higher strengths. It also shows that in practice the actual margin for a piece of equipment based on actual properties if they are near specification minimum, may be slightly less than 1.8 or 2.4 specified for analytical comparison. API and ASME have both accepted this potential variation as the case when adopting these margins. Section 6.0 of the report states that "it is crucial that the theoretical collapse pressure closely agrees with the actual burst pressure". This appears to not be in complete alignment with the work that is the basis of the margins in ASME VIII-3. The report further states in Section 6.1 that "it is imperative that the theoretical collapse pressures from FEA be accurate or at least conservative". The methods used have inherent variability in them relative to the actual material properties and are based on a mean rating, not a minimum

RESPONSE TO CHARGE QUESTIONS	
1. *Evaluation of Test Methods*	
1.8	*The report documents a failure of the tested object for the 17 TR8 Division 3 method to show a failure of the test object at a threshold below the design standard. Do the conclusions and recommendation based upon this stand alone? Are there other considerations, such as the fact that the material chosen is a non-Division 3 material, or any other alternate logical explanation for failure event below the Division 3 design standard?*
Daniel Peters (cont.)	value. This is the basis which again has been adopted by both API by reference and ASME in the development of their standards. It is noted that large thick section forgings may experience significant through thickness material property variation. It is recognized due to failures in industry that this is the case. The 2015 edition of ASME VIII-3 KM-211.2 states “In addition to the following, for quenched and tempered materials, the location of the datum point shall be equal to or farther from the nearest quenched surface than any pressurized surface or area of significant loading is from the quenched surface.” This is recognition of this material property variation and that the test location of the test location should represent the “worst case” material properties for the areas of high stress in the vessels. If the quenching due to a small pre-bore was ineffective to get good material properties at the ID, the material strength properties in the tube walls could vary from what were reported in the testing. The strain gage data in the report do not go far enough to evaluate any plasticity that may occur in the test piece.
Paul Bunch	The conclusions and recommendations do not take into consideration the variability of the data. The statement that the failure of the test object is at a threshold below the design standard cannot be made based on the limited number of two tests. Two test samples are not a sufficient number of tests to obtain a statistical distribution of data points defining the range of values for predicted vs actual burst pressure. Assuming all tests are skewed to have a difference of burst vs predicted of -7% and that the two burst tests represent and lower bound of all data is not accurate. Assuming all additional tests are predicted to be equal to or higher burst pressures, based on a set of two data points is not accurate. A review should be conducted for the results defined in the paper by Susumu Tada, ICPVT-12, 2009, “Proposal of New Equations for Cylindrical and Spherical Shell of ASME Section VIII Division 3 for High Pressure Vessels”. An additional study was performed in the API industry to evaluate burst pressures of API materials, reference Grohmann, A., Selvey, J. and Ellisor, S., ‘Design Margins for Normal, Extreme and Survival HPHT Applications, OTC paper no. 27605, 2017. The Div 3 Code was first developed starting in 1980 and the first edition was published in 1997. The 2007 edition applied the design load factor for collapse pressure of 1.732 (√3) using an elastic-perfectly plastic analysis. The 2010 Edition changed to elastic-plastic analysis and a load factor of 1.8. Thus, the

RESPONSE TO CHARGE QUESTIONS	
1. ***Evaluation of Test Methods***	
1.8	*The report documents a failure of the tested object for the 17 TR8 Division 3 method to show a failure of the test object at a threshold below the design standard. Do the conclusions and recommendation based upon this stand alone? Are there other considerations, such as the fact that the material chosen is a non-Division 3 material, or any other alternate logical explanation for failure event below the Division 3 design standard?*
Paul Bunch (cont.)	application of the design load factors have 10 years of experience using the Div 3 criteria. All relevant information of research, service applications and testing that was done by ASME defining the 1.732 and 1.8 load factors should be reviewed before concluding it is unacceptable for API HPHT equipment.
Richard C. Biel	The report draws a false conclusion from Table 6.1 - that the numerical analysis should exactly match the results of the physical test. The numerical analysis uses an idealized material that is rarely achieved in actual practice. In fact, noting the deficiencies in the location of the material test specimens noted above, the actual deep section properties of the material could account for the difference. In addition, the analytical work has some unanswered questions that could affect the results. Refer to the comments on the analysis using numerical methods in the sections below. As a practical consideration, the burst test results and the analytical results both show that the plastic collapse results exceeded the design requirements.

RESPONSE TO CHARGE QUESTIONS	
1. ***Evaluation of Test Methods***	
1.9	*Are there other obvious conclusions that the report should have addressed identified by the peer review?*
Daniel Peters	Several of the conclusions and statements in the report are either confusing, contradictory or potentially misleading or incorrect. Section 1.0 of the report states "the use of Division 2 and Division 3 elastic-plastic methods are new to the industry." However, the report goes on in Section 9.0 on page 24 to state that "Currently, standard practice for most major subsea equipment manufacturers is to perform only elastic-plastic FEA". This should be clarified if the elastic-plastic methods are truly "new to the industry" or if they are truly "standard practice", which is my experience. Section 2.0 page 9 indicates that "API has not approved verification by elastic-plastic FEA". This is confusing as the use of elastic-plastic FEA is recommended in API 17TR8. Section 2.0 on page 10 implies that there are two elastic-plastic methods. There is actually only one method which is used in both Division 2 and Division 3

RESPONSE TO CHARGE QUESTIONS	
1. *Evaluation of Test Methods*	
1.9	*Are there other obvious conclusions that the report should have addressed identified by the peer review?*
Daniel Peters (cont.)	with two margins. This should be cleaned up in this report to avoid causing confusion in the industry. Section 7.0 page 18 states that "…pressure ratings by actual proof test would be higher than pressure ratings by theoretical methods." This statement is confusing and is contrary to an actual statistical data set from Terada[2] which shows actual distribution of the burst data. One statement in Section 9.1 on page 24 states that "the least conservative pressure ratings were determined by ASME VIII-3 elastic-plastic analysis". This is not correct. Table 9.2 shows that the least conservative margin calculated is 1.74 based on linear-elastic analysis by ASME Section VIII Division 2 using the API 17 TR8 / 6A / 17D allowable stresses. It is possible to produce high strength low alloy steels, as used in this example with low toughness. The enhanced material requirements in API 17 TR8 are one aspect of the requirements, which also include additional NDE requirements for the material, additional requirements for welding and fabrication testing, and more rigorous analysis of the components. Page 25 the report goes on to state that testing should be done to confirm that the lower margin designs are safe from failure. The margins are experienced based and have been adopted by ASME and recommended by API 17 TR8 based on that experience. The literature is full of this information and data which can be shown to support this position. Page 26 states that elastic-plastic FEA was "not allowed prior to 2015". This statement is misleading, as BSEE was reviewing analyses using this approach prior to 2015 and had no rules stating that it was unacceptable. This was prior to the formal publication of API 17 TR8. Section 10.0 on page 28 implies that the margin of 1.8 in ASME VIII-3 is somehow incorrect and that it should be considered as 2.1. The basis for this is that the margins used in the elastic-plastic analysis should be lower bound and absolute margins, with all potential manufacturing scenarios showing that these margins are conservative. If this is the case, one conclusion of the report should be that it should be recommended to ASME to consider that their margins should be adjusted in both VIII-2 and VIII-3 to result in absolute lower bound ratings relative to collapse of the equipment. Further to that end, the standard deviation by Terada[2] shows that a single standard deviation is approximately 7% and a +/- 3 standard deviations might be considered to account for the total population of distribution. I disagree with this recommendation, but if the report stands as is, the authors of the report should recommend ASME and API 17 TR8 through its reference of ASME should correct its standards. This is implied

RESPONSE TO CHARGE QUESTIONS	
1. *Evaluation of Test Methods*	
1.9	*Are there other obvious conclusions that the report should have addressed identified by the peer review?*
Daniel Peters (cont.)	on page 29, but stops short on making recommendations regarding what should change in ASME. On page 29 it states that "a load histogram with loads in the proper sequence cannot be developed for subsea equipment". This is incorrect. Many manufacturers are able to postulate plausible loading histograms for equipment in service based on past operational experience. This was demonstrated in work done on Deepstar project 12302 which is expected to be released to API for publication this summer. In that work, a postulated loading histogram was generated and compared to actual well head data to look at operational trends in wells. The histogram was conservative in the number of cycles, the sequence of operational cycles and the loading degradation over time for the example cited. Operators have this type of information from their typical operations available and it can be utilized for developing plausible operational histograms. One conclusion that should be emphasized is that there is nothing more unique about equipment designed to API 17 TR8 than other designed to ASME VIII-2 or VIII-3, other than accessibility of the API 17 TR8 equipment is limited in all cases with the once it is in service. There is a fleet of down hole test equipment used today for testing drilling tools which uses similar materials at equal or greater pressures and temperatures as HPHT subsea equipment, in the same or more severe environments designed to ASME VIII-2 and VIII-3 for regular pressure vessel applications. The one conclusion that is overlooked is that a metallurgical evaluation of the failed components should be conducted. This would include but may not be limited to examination of the fracture surface to determine the initiation site of the failure and the mode of failure, investigate any contaminates which may have influenced or initiated the failure, investigate for potential mechanical damage on the surface of the components, and look for potential material inclusions or other issues which could have affected the integrity of the component.
Paul Bunch	The conclusions should have addressed the discrepancies and inaccuracies in the strain gage readings when compared to the FEA results. The statement that the flange preload strains are included in the hydrotest strains, but not included in the FEA strains, indicate a discrepancy in the model and actual test objects assemblies. It is also stated that 'The reason the preload strains are not included in the FEA is that Division 2 and 3 do not include preload for global plastic collapse.' This statement is incorrect, particularly when a proof test is being compared to the FEA results to evaluate the design load factor of 1.8. Without analyzing these components, it is not possible to accurately determine the

RESPONSE TO CHARGE QUESTIONS	
1. *Evaluation of Test Methods*	
1.9	*Are there other obvious conclusions that the report should have addressed identified by the peer review?*
Paul Bunch (cont.)	'weakest link' for the failure mode (i.e. bolting failure, gasket leakage, or structural overload). The test should have obtained strain gage readings for the bolting and the test should have had strain gage measurement recordings for the burst testing. It was not explained why this procedure was not used to define the burst pressure.
Richard C. Biel	With the deficiencies noted in this writing, the report should have concluded the designs met all requirements for the intended pressure rating of 20,000 psi. This conclusion would require a stipulation that the specimens for material property tests were taken from a location that was not consistent Division 3 requirements. The report does not show that the requirements of KD-1254(c) were met for a design pressure determined by collapse pressure (burst pressure).

RESPONSE TO CHARGE QUESTIONS	
2. Evaluation of Modeling Results: Do the modeling results describe with reasonable accuracy the basis for decisions in the applied methods:	
2.1	*Are the limitations and uncertainties clearly identified and adequately characterized for the methods of modeling selected?*
Daniel Peters	It is noted that the only failure criteria which is evaluated in this report is global plastic collapse due to internal pressure in the cylinder section. The report attempts to present some perceived limitations of the methods. However, some appear to be overlooked. Such as the design margin on burst of 1.74 using linear-elastic analysis using ASME VIII-2. There is an entire discussion about the use of linear-elastic analysis and its applicability in high pressure design. The reference cited earlier by Dixon and Perez[1] discusses that in some detail. The basic premise is that steels do yield in service. Linear-elastic analysis does not account for that and instead assumes that the amount of load it can take will continue to linearly increase past the yield point. There should be some discussion about the potential for over predicting the load capacity of a structure using this evaluation technique compared to actual material response. There are also multiple material models which can be employed in the elastic-plastic analysis method. This includes the model used which was a true stress-true strain model as found in ASME VIII-2 or VIII-3. There is an elastic-perfectly plastic model as found in ASME VIII-3 KD-236. Each of these may be used for evaluation of global plastic collapse. The elastic-perfectly plastic material model is more conservative than the true stress-true strain model which incorporates the concept of strain hardening into the model. API 17 TR8 also allows the use of actual stress strain curves in analysis when testing has been

RESPONSE TO CHARGE QUESTIONS	
2. Evaluation of Modeling Results: Do the modeling results describe with reasonable accuracy the basis for decisions in the applied methods:	
2.1	*Are the limitations and uncertainties clearly identified and adequately characterized for the methods of modeling selected?*
Daniel Peters (cont.)	performed. The analysis uses actual data for input to the curves generated using ASME VIII-2/VIII-3 methodology. The variation between these techniques could be useful to discuss.
Paul Bunch	There are statements that multiple models with finer meshes and more load steps were evaluated but no documentation is provided for these sensitivity studies. The elimination of the blind flanges, bolting and gaskets for end connections was not clearly justified. There were no evaluations for bolting criteria or gasket sealing criteria which are additional failure modes that can occur before the burst pressure is reached. If the flange had been designed to API 6A requirements for the wall thickness of the neck, the failure mode may have been bolting tensile overload or gasket leakage. Most API components are designed with a straight neck flange connections making the burst pressure much higher than the test objects for the given end flange size, which could result in other failure modes before burst pressure of the neck is reached.
Richard C. Biel	The report does not comment on the analytical assumptions that underlie the final element method. While it is generally accepted that the final element work represents sound engineering practice, some input data has limited precision. For example, Young's modulus is an important input parameter that has limited precision and yet the results of the analysis represent or suggest much higher precision.

RESPONSE TO CHARGE QUESTIONS	
2. Evaluation of Modeling Results: Do the modeling results describe with reasonable accuracy the basis for decisions in the applied methods:	
2.2	*Are the assumptions of the modeling appropriate for the methods of modeling selected? Assumptions evaluated should include, but are not limited to:* ▪ *Material Thickness* ▪ *Mesh chosen* ▪ *The correspondence of the modeling to the design basis specified in the standard*
Daniel Peters	It is not clear what the dimensional assumption was for the modeling of the finite element model used in the report versus the actual test piece. The design standards require the use of minimum thickness models based on the manufacturing tolerances of the components. This could account for a 2-3% variation in burst pressure based on reported manufacturing tolerances.

<table>
<tr><th colspan="2">RESPONSE TO CHARGE QUESTIONS</th></tr>
<tr><td colspan="2">2. Evaluation of Modeling Results: Do the modeling results describe with reasonable accuracy the basis for decisions in the applied methods:</td></tr>
<tr><td>2.2</td><td>Are the assumptions of the modeling appropriate for the methods of modeling selected? Assumptions evaluated should include, but are not limited to:
Material Thickness
Mesh chosen
The correspondence of the modeling to the design basis specified in the standard</td></tr>
<tr><td>Daniel Peters (cont.)</td><td> The mesh plots shown indicate that there are ample elements, based on experience, to accurately determine the collapse pressure of the component. The time stepping also appears to be sufficiently small to allow for capture of the final collapse pressure of the equipment when using elastic-plastic analysis. It was previously pointed out that the location which the material testing was performed may not truly be representative of the failure location within the tube. It is noted that the collapse of the tube in the component was the only item considered in the linear-elastic evaluation of the components. The finite element modeling appears to be sufficient relative to the prediction of global collapse of the tube in the bodies, provided the proper dimensional information was utilized to reflect the actual tests, when the comparisons are being made. A component’s operational loading variation should be considered in conjunction with the design margin selected. The loading histogram should reflect the worst case loading a component will experience in service, while accounting for total variation in load over time. </td></tr>
<tr><td>Paul Bunch</td><td> The thick body section with intersecting bores did not contribute any useful information regarding the proof test in that the design was adjusted to assure the failure would occur in the neck region. It is possible that the intersecting bores could have resulted in strain limit damage at the burst pressure, but this failure mode was not evaluated. Additionally, the strain gage measurements in this region were not valid. The design calculations provided in Appendix B1 Figure B1.13 indicate that nominal dimensions were used as opposed to minimum material conditions. Analysis should be based on minimum material conditions. The design basis according to 17TR8 requires the evaluation of collapse pressure for the pressure containing body, the allowable bolt limits based on linear-elastic criteria and a service criteria evaluation for gasket sealing. The </td></tr>
</table>

RESPONSE TO CHARGE QUESTIONS	
2. Evaluation of Modeling Results: Do the modeling results describe with reasonable accuracy the basis for decisions in the applied methods:	
2.2	*Are the assumptions of the modeling appropriate for the methods of modeling selected? Assumptions evaluated should include, but are not limited to:* ▪ *Material Thickness* ▪ *Mesh chosen* ▪ *The correspondence of the modeling to the design basis specified in the standard*
	bolting allowable limits and the gasket sealing limits were not addressed in this report.
Richard C. Biel	As previously mentioned, the only way to adequately review a detailed numerical analysis is a close inspection of the input data. A review of the input data will show whether the annotations on the plots concerning boundary conditions are consistent with good practice for this type of analysis. Also, it is not clear what the material model was used to describe the strain hardening behavior of this material, if any. Most analysts use the Ramberg–Osgood equation or a similar formulation such as given in both Division 2 and Division 3 of the code. The investigators missed an opportunity to obtain an actual stress-strain curve during the mechanical property tests. This is not commonly done for construction of new equipment but would give important information for a technical study as was done to determine pressure ratings. The analyst did not provide load-displacement curves in the report. This would give insight to the development of plastic hinges. The load-displacement curves could also be used for an alternative determination of the calculated plastic collapse pressure using the double elastic slope method. Also, a design pressure determination should include a ratcheting check by the method prescribed by Division 3. It does not seem that the ratcheting check was attempted but is an important part of assignment of a pressure rating.

RESPONSE TO CHARGE QUESTIONS	
3. Are there strengths or weaknesses of the analytical methods used for the empirical calculations chosen in the report?	
Daniel Peters	The potential issues with the application to linear-elastic analysis has been considered earlier in this line of questions and won't be repeated here. The variation in the burst testing of components needs to be repeated here. The data set presented by Terada[2] demonstrates the potential variation in the burst pressure of steel components. The analytical methods are highly repeatable and reproducible from one analyst to another, provided identical geometry, material and boundary conditions are used in the evaluations. The test data used in the empirical evaluation of the results and the evaluation of the margin has inherent

RESPONSE TO CHARGE QUESTIONS	
3. Are there strengths or weaknesses of the analytical methods used for the empirical calculations chosen in the report?	
Daniel Peters (cont.)	variability due to variations in material processing, etc. Terada's paper[2] also points out the variations on empirical burst pressure equations which are in the literature. In short, comparison to burst test results will have variation and the authors of this report should be commended that their results are completely within the expected scatter band.
Paul Bunch	Both ANSYS and ABAQUS finite element programs are used in design analysis of API HPHT equipment. Either program is considered acceptable when applied properly. Each is based on the von Mises flow rule. As stated in the report, large displacement theory was used for the analysis. An Independent FEA of the large neck flange using ABAQUS FEA was conducted (using nominal dimensions). The calculated collapse pressure results for the large neck flange were very close to the values in the report, 72,251 psi vs 72,850psi of the report. This was evaluated for collapse pressure using ¼, ½ and a full model with close to the same results obtained for each analysis. A 6% drop in the yield through ultimate true stress true strain data will result in the FEA matching the test results for collapse pressure vs burst, using the report model for the large neck flange. This indicates the criticality of accurate material properties. The report model did not include the bolting, gasket or mating blind flange. An independent review of the analysis which included these components was conducted using ABAQUS FEA. The analysis used a 3-D geometry of a ½ section model. The calculated burst pressure for the large neck flange was 72,900 psi vs. the report value of 72,850 psi. This confirms that eliminating the bolting, gasket and blind flange does not affect the results for predicting the collapse pressure of the vessel itself.
Richard C. Biel	Empirical or classical calculations using equations from strength of materials derivations, are valid so long as the stresses do not approach the yield strength of the material being used and the stresses change in a linear fashion. For thick-walled components, the linear-elastic methods have been shown to be nonconservative since the stress fields are typically nonlinear.

RESPONSE TO CHARGE QUESTIONS	
4. Are the conclusions drawn by the report appropriate based on the modeling results and empirical analysis?	
Daniel Peters	As pointed out in question 1.9 of this survey, there are conclusions drawn throughout this report and not limited to the conclusions section in 10.0. However, it is assumed that this question refers directly to section 10.0. It should be noted that the elastic-plastic methods used in both ASME VIII-2 and VIII-3 are the same for global plastic collapse with different design margins used for each division. If a recommendation is made to change the margin in ASME VIII-3, it is unclear why that would be valid and not make a similar change in VIII-2. It would seem that the linear-elastic methods are being used as a “gold standard” which the newer more rigorous modern methods are being held to. This linear-elastic method has been shown to be non-conservative as pressure ratings increase in the work by Dixon[1]. As technology improves, industry must be able to use the advancements in order to stay competitive.
Paul Bunch	There are discrepancies in the defined allowable limits where API 6A/6X are referenced. The TR8 report references both documents but the current practice is to use API6X. The allowables stated for ASME Sec VIII, Div 2 are incorrect, they assume the allowable =2/3*σy where ASME is σuts/2.4. The elastic-plastic analysis and design load factors for ASME Div 2 and Div 3 are correct as stated in the report. The conclusions drawn in regard to the prediction of collapse pressure based on elastic-plastic FEA were verified to be accurate through an independent analysis.
Richard C. Biel	No. The conclusions in the report that extend the application of the assessment methods beyond verification of the basic design pressure are not considered valid. Therefore, this writer does not agree with any conclusion for pressure beyond the design pressure. It is thought that a competent designer would generate a design independent of the assessment means using experience, knowledge, and sound engineering judgment then subject the design to the appropriate assessment means.

RESPONSE TO CHARGE QUESTIONS	
5. Are the conclusions related to the test appropriate?	
Daniel Peters	No, the conclusions that are related to the test are based on a flawed premise that the methods used are going to be conservative in all cases with no variation in the burst pressure in components. The test data also proved that linear-elastic analysis can, in certain situations also yield non-conservative results as shown in Table 9.2 (1.74 margin VIII-2). HPHT equipment is designed with these margins with the expectation that it won't experience loading above design while in service. The point of a design margin is to allow for a margin due to the unknowns in the design condition. The industry has considered the variation in things such as loading variation, material properties, manufacturing tolerances, etc., and have accounted for them in the factors which are used in ASME and API standards today. The conclusion that components should be rated based on proof testing or burst testing is, in my opinion, dated, expensive and potentially dangerous. Modern design methods are used to reduce costs for the industry, and allow them to be competitive, without the need to perform excessive burst testing of components. Finite element technology is well known and the methods are proven and widely used in many other pressure equipment industries, and other industries such as aircraft, automotive, bridge design and many others. Complex shaped components are designed every day to ASME B31, VIII-2, and VIII-3 standards. ASME VIII-3 does have KD-12 in its document as an option, but it is rarely used. When it is used, my experience it is typically for very small components.
Paul Bunch	The statement that the "load factor of 1.8 would be more justifiable if the factor is applied to the rupture pressure" is not appropriate according to ASME Div 3. KD-1212 prohibits the use of tests to destruction to define collapse pressure and subsequent pressure rating of the equipment. The statement "It is recommended that the subsea industry consider comparing collapse pressures from FEA with burst pressures from hydrotest for a variety of subsea equipment is impractical and unsafe. These test for standard API components are impractical in that bolting failure or gasket leakage would have a higher potential for failure prior to actual burst pressure. As an example, the current proposed design of an 18-3/4" 20ksi flange neck has a wall thickness of 9.86 inches and would have a calculated burst pressure according to flow stress equations of 70,536 psi, using API 6A minimum yield and ultimate strengths. Failure of the bolting or gasket leakage of this flange would occur prior to the burst pressure limit. KD-1212 specifically states that strain measurement test may be used to determine the collapse pressure. If the test had been conducted to be in compliance with ASME Div 3, the strain gage measurements should have been used in the burst pressure test to define the collapse pressure. Reference is made

RESPONSE TO CHARGE QUESTIONS	
5. Are the conclusions related to the test appropriate?	
Paul Bunch (cont.)	to API 6A, 19th ed proof test. The requirements of this document for proof test pressure limits are based on strain gage readings. The conclusion that 'The Division 2 elastic-plastic method with a design load factor of 2.1 would be more in line with historically successful equipment…' is not based on test results. The test results if taken as the lower bound of test data would suggest a design load factor of 1.93. The purpose of the study was to validate the pressure rating methods in API 17TR8. The conclusions in the report go beyond that suggesting the load factors be based on historical methods instead, using linear-elastic analysis.
Richard C. Biel	The test was an instrumented pressure test at various pressures both internal and external and lastly an internal pressure test to failure. The burst test results support the original design pressure of 20,000 psi using assessment methods from both API Standard 6A and Division 3. Not repeated here are the objections to extending the validity of the Division 3 assessment methodology.

RESPONSE TO CHARGE QUESTIONS	
6. Are the other conclusions appropriate?	
Daniel Peters	Many of the conclusions appear to be based on a desire for additional information to justify the methods used in API 17 TR8. This type of information was discussed and was considered during the adoption of the rules in the ASME standards over the course of the last forty years. API SC 17 considered the standards of ASME and adopted that experience base and other bases as their own, through the recommendations in 17 TR8. It is unclear in the report what is fundamentally different between the 20,000 psi components in the subsea industry and a 20,000-psi component which is not in the subsea industry which would substantiate the conclusions in the report. If the author feels strongly that the conclusions in the report are valid, another conclusion should be a recommendation, likely to ASME, to consider increasing the margins in both VIII-2 and VIII-3 by some factor to ensure that the ratings are always lower bound.
Paul Bunch	It is stated in the conclusions that 'The subsea industry should confirm that performing a fracture mechanics analysis required by Division 3 justifies a reduction of the design load factor to 1.8.' It is unclear how the fracture mechanics analysis would justify the design load factor of 1.8. The fracture mechanics is part of the fatigue evaluation of TR8 and there is a defined critical crack depth, with a design margin, based on all design loads. These are required for Category 1 equipment. These evaluations are not based on benign environment at room temperature, but are defined for maximum operating loads and worst operating environments. The maximum operating pressure is verified

RESPONSE TO CHARGE QUESTIONS	
6. Are the other conclusions appropriate?	
Paul Bunch (cont.)	for collapse by applying a 1.8 factor, where the thermal and external loads are verified applying a 1.58 factor. The loads that satisfy the collapse load using the 1.58 factor for collapse are the loads (non-factored) that are evaluated for cyclic fatigue crack growth and an allowable critical crack depth using fracture mechanics analysis. Additionally, there is a design factor for the allowable number of cycles to be 50% of the total fatigue cycles to critical crack depth. It is stated in the report that 'fracture mechanics analysis requires an explicit, time-based load history. This history is not possible for subsea equipment.' It is possible to review the load histogram and evaluate a worst-case loading sequence for fatigue analysis. There can also be multiple load sequences run to verify a worst case. It is stated that 'TR8 requires that all pressure containing components meet the material requirements of API 6A and NACE MR0175. Materials that meet the requirements of these two codes will be ductile, have high impact strengths and have high facture toughness. Materials with these properties are not susceptible to brittle failures.' API17TR8 does not state that these two codes are sufficient for defining material requirements or that they are acceptable for defining required fracture toughness. ASME Sec VIII, Div 3 toughness requirements are much higher than those stated in API 6A. API Does not provide guidelines on fracture mechanics evaluation and thus Div 3 CVN requirements should be applied when defining failure due to a critical crack size. Heavy wall components, such as BOP bodies, have constraints where a crack growing to a critical crack depth can occur in a plane strain condition, which could result in brittle fracture, for the defined material fracture toughness. API alloy steels exposed to hydrogen charged environments can have significant loss in fracture toughness which can result in a brittle failure mode. Additionally, there are verification analyses for local failure due to strain limit damage, ratcheting evaluation and service criteria evaluations, such as gasket leakage, and bolting stress allowables. Any of these verifications can define the limits of the design.
Richard C. Biel	No.

RESPONSE TO CHARGE QUESTIONS	
7. Are the recommendations logical, appropriate, and supported by the conclusions of the test results, empirical analysis, and modeling results? The scope of the recommendations pertains to all recommendations, not just those derived from the modeling results.	
Daniel Peters	The results appear to be based on a single test with no ability to review the statistics of that test. Typically, testing is performed based on a set of tests with some statistical relevance and not one or two data points. There are also many conflicting statements throughout the report, which have been cited previously. The one conclusion states that "For subsea equipment the industry should verify that the additional fracture mechanics analysis and more rigorous material requirements in Division 3 justify a 33-percent reduction of the design load factor as compared to Division 2." This conclusion is confusing at best. The conclusion draws on the premise that there is something special about pressure equipment in the subsea industry that is different that the technological challenges present in other industries. This is not the case. The bases for the use of ASME VIII-3 has been considered and has been accepted by the ASME Committees and by API by reference. The conclusion appears to be based on the premise that it is impossible to develop a loading histogram to represent the annual cycles expected for a piece of subsea equipment over the life of the piece of equipment. This is currently done in the industry and has been shown that it can be done conservatively, as was done in the Deepstar 12302 project which was recently completed.
Paul Bunch	It is recommended that stress intensities be used instead of von Mises stresses for linear-elastic analysis. API 17T8 references API 6X which allows the use of von Mises stresses for linear-elastic analysis. The use of linear-elastic analysis for pressure ratings above 15ksi is not considered accurate as defined by ASME Div2/3 where the analysis is only allowed for designs with R/t≤4. The statement that; 'The Division 3 elastic-plastic method is not recommended for HPHT subsea equipment published with a 1.8 design-load factor' is not based on sufficient technical review and test data to assure validity of the recommendation. It is 'recommended that the subsea industry compare collapse pressures from FEA with burst pressures from hydrotests for a variety of subsea equipment' which is impractical and does not follow ASME or API guidelines.
Richard C. Biel	Lastly, the determination that there are some problems using the Division 3 assessment methodology from a single series of tests from one material and buy one investigator is not considered valid. Typical verification and validation means are done using round-robin techniques that attain data from several different sources and the results are independently assessed.

RESPONSE TO CHARGE QUESTIONS	
8. Are there any obvious technical considerations the report should have covered that are missing?	
Daniel Peters	The report only focused on global collapse of a cylindrical tube. None of the other failure modes, many of which are far more common, were investigated. This includes the concept of local strain accumulation and damage in areas of high stress concentration, the concept of shakedown, the evaluation of the hydrostatic testing criteria for the components. There are many technical discussions in the area of bolting and flange design which also are not covered in any detail in the report. One conclusion that appears to be appropriate, in lieu of the conclusions in the report, is that the burst testing is exactly in line with the anticipated scatter in test data which may occur in a burst test, and that the pressure rating of ASME is not lower bound, but mean. The report should also have considered if “extreme” or “survival” type loads come into play and to be sure that the potential scatter doesn’t result in failure of a component under loads beyond the design basis.
Paul Bunch	The report should have addressed the probability of occurrence for calculated collapse pressure vs burst before concluding that the Division 3 elastic-plastic method is not recommended for HPHT subsea equipment as published with a 1.8 design load factor. The report should have reviewed the technical background and testing used by ASME to establish the 1.8 load factor defined in Div 3. The report should have compared the burst test results of the two components with existing ASME data to establish a statistical distribution of data points to determine if the results fall within an acceptable range of scatter. The report should have addressed the requirements of API 17TR8, PSL 5, when using ASME Div 3 design verification. The document does not state specific requirements for meeting the PSL 5, but makes reference to being above and beyond API 6A PSL3/4 in regard to Charpy toughness, fracture toughness and NDE. A reasonable interpretation would be to evaluate these material parameters as they apply to Div 3 elastic-plastic analysis.
Richard C. Biel	It seems to this writer, that the report attempted to cover a scope of work that was overly broad. As a result, some items lacked rigor by failing to properly define material sample locations with reference to Division 3 requirements and obtain actual material stress-strain data. Is not clear if the investigator understands the underlying principles of assessments using LRFD since he uses the load factor intended for the LRFD method as a "design factor." [This same misapplication of terminology also exists in API TR8.]

5. APPENDIX A: INDIVIDUAL REVIEWER COMMENTS

5.1 Daniel T. Peters, PE

PEER REVIEW COMMENT TEMPLATE
Evaluation of Pressure Rating Methods Recommended by API RP 17TR8
NAME: Daniel T. Peters
DATE: April 11, 2016
AFFILIATION: Structural Integrity Associates
BACKGROUND. Briefly describe how your background, experience, and involvement with HPHT subsea equipment qualify you to evaluate the *Evaluation of Pressure Rating Methods Recommended by API RP 17TR8API RP 17TR8*:
I have worked for 18 years with ASME in the Subgroup on High Pressure Vessels (Chair of the Committee for nine years), which is primarily responsible for ASME Section VIII Division 3, and as a member of ASME Committee on Pressure Vessels, which also oversees ASME Section VIII Division 2. I have also worked with the ASME PER15K and API 17 TR8 Committee for the last eight years. I spearheaded the initiation of the ASME Task Group on Subsea Applications to help to enhance the ability to reference ASME Codes and Standards in the construction of subsea equipment. I have also worked with ASME Pressure Vessels and Piping Division where I developed the plenary session in 2014 regarding the challenges of referencing ASME Codes and Standards and their use in the design and construction of High Pressure / High Temperature (HPHT) subsea equipment. I have over 20 years' experience in the design, manufacture, and life management of high pressure equipment in many different industries. This includes the last ten years with Structural Integrity Associates, working as a consultant for various companies in the design and analytical assessment of high pressure equipment. Many of these companies, for whom I have consulted, are involved in the manufacture of HPHT equipment utilizing API 17 TR8 and its concepts for the last five years. I was the lead investigator on a recently completed project for DeepStar which provided an example of a verification analysis using all of the methods listed in API 17 TR8, which may be considered relevant to this review (DeepStar report 12302).
I. GENERAL IMPRESSIONS
Provide overall impressions (approximately 1/2 page in length) addressing the accuracy of information presented, clarity of presentation, and soundness of conclusions.
The information presented is organized and fairly simple to follow. Some items do need to be clarified, and have been noted in the comments to follow. The report appears to have been written with pre-conceived hypothesis, and the report attempts to use data from the testing and analysis to support these hypotheses and the conclusions of the report. There are data in the analysis section of the report which were not addressed as they do not support the final conclusions of the report.

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The report does not appear to make any reference to the published research which has been done previously on this subject, nor the basis for the standards, nor technical reports which are available in industry today to support the technical approaches put forth in the standards.

Most of the conclusions appear to ask for the subsea industry to consider what they are doing as unique and completely different from other equipment which operates with internal pressure in corrosive environments in cyclic service with similar temperature, pressures and materials. The idea that this equipment, together with it environment and operation, is unique from other pressure equipment in other industries is a misconception. The subsea industry would greatly benefit from looking at the past experience of other industries and using that as a basis for the work going forward.

The conclusions all center on some belief that the design margin required for successful operation in subsea equipment must equal the same margin that has been used since the 1960's and designs are best determined by using stress analysis methods which are becoming outdated. None of the standards referenced by API for this purpose have the same margins for that period of time, largely due to advancements in material production, fabrication, and more sophisticated design approaches.

II. RESPONSE TO CHARGE QUESTIONS

1. *Evaluation of Test Methods*

1.1–*Were the test objects selected for analysis valid test objects to evaluate the standard as applied? Consider true stresses and strains in the context of valid discussion.*

The test bodies shown in Figure 5.1 and 5.2 of the report are very similar geometrically to other types of valves, tees, connectors, and equipment used in the subsea HPHT industry. Fillet radii, ring joint geometry, and other details vary greatly between manufacturers, so it is difficult to say if it is specifically applicable relative to a specific design. The general configuration is similar in size to other such equipment in the industry.

The flanges used in this situation are standard size 20 ksi flanges based on Table B.43 of API 6A for 20 ksi rated working pressures. The analysis does show that the flanges meet the requirement of global collapse at these pressures. However, it is likely that the size and number of bolts used, might not meet the requirements of ASME Section VIII-2.

Additionally, based on experience with other HPHT equipment in industry, some of the fillet radii were larger than in typical equipment. This could lead to under predicting local plastic strain in these areas which could lead to localized failure in typical equipment. This is not the focus of the current study.

1.2–*Are the assessments of engineering safety factors for the cited standards and their divisions valid for the expected applications?*

API 17 TR8 and ASME VIII-2 and VIII-3 do not use the term "safety factor" for their designs. The term used is "design margins". It is assumed that each of these terms are being used interchangeably here. Some in the industry would call this interchange of words a dangerous

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precedence which could have consequences if the understanding of the difference in the terms is not well understood.

Each of these standards have many design margins and not one specific margin. ASME VIII-2 and VIII-3 use the Load Resistance Factor Design (LRFD) methodology which uses multiple factors for the various combinations of loads which are to be considered. The basic design margins on pressure for a piece of equipment, for use with an elastic-plastic analysis, are 2.4 and 1.8 in VIII-2 and VIII-3, respectively. However, these are lowered to 2.1 and 1.58 for VIII-2 and VIII-3, respectively, for other combinations of applied loading including seismic, wind and other load combinations, and 1.7 and 1.28, respectively for evaluation of the local criteria looking at local strain. ASME fatigue assessments also have their own margins and they vary based on the methodology used (VIII-2 fatigue, VIII-3 fatigue, and VIII-3 fracture mechanics).

It is further noted that the current report endorses the use of API 6A and linear-elastic stress analysis for design of subsea equipment based on past industry practice. The report cites significant successful industry experience using these methods. Based on my experience, the industry typically uses linear-elastic methods at these pressure ratings, but its application is limited, particularly as the pressure ratings increase and stresses in components exceed the yield stress. Several linear-elastic designs have been reviewed that are acceptable relative to the requirements of a linear-elastic methodology, which have excessive plastic strain or localized stress concentrations which may not be acceptable using elastic-plastic finite element analysis or have very limited fatigue life. Comparative studies have been done to evaluate the use of linear-elastic methods to elastic-plastic methods. Dixon, et al[1] have shown that for equipment with required wall ratios (OD/ID) in excess of ~1.25, the linear-elastic method may be non-conservative. The equipment being designed here at 20ksi and using the material properties cited in the report would have a required wall ratio of 1.25. Therefore, it could be argued that either of the methods for the area of the failure could be appropriate.

It is also noted that Terada's work[2] was used to help establish the margin of 1.8 currently used in ASME VIII-3. This is important to note as the work did effectively two things. First, it established the basis for using 1.8 as the margin in ASME VIII-3 for elastic-plastic evaluation. Secondly, the paper has a series of burst tests in it, which have been statistically evaluated. The standard deviation in this work was shown to be 7-9% based on the methods used in today's codes and standards. This work shows that the margins using elastic-plastic analysis are not meant to be lower bound pressure ratings. It shows that it is expected that using this type of analysis, it is expected for the margin to be nominally 1.8, if specified minimum material properties such as yield and tensile strength are actually achieved in manufacture, in lieu of higher strengths. It also shows that in practice the actual margin for a piece of equipment based on actual properties if they are near specification minimum, may be slightly less than 1.8 or 2.4 specified for analytical comparison. API and ASME have both accepted this potential variation as the case when adopting these margins. Section 6.0 of the report states that "it is crucial that the theoretical collapse pressure closely agrees with the actual burst pressure". This appears to not be in complete alignment with the work that is the basis of the margins in ASME VIII-3.

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The report further states in Section 6.1 that "it is imperative that the theoretical collapse pressures from FEA be accurate or at least conservative". The methods used have inherent variability in them relative to the actual material properties and are based on a mean rating, not a minimum value. This is the basis which again has been adopted by both API by reference and ASME in the development of their standards.

It is noted in the report Section 2.0 that the margins are based on either yield strength for linear-elastic analysis or tensile strength for elastic-plastic analysis. While it is true that the allowable stress in a material for linear-elastic analysis methods is based on 2/3 of the yield strength, it is a gross simplification to say that the elastic-plastic analysis is solely based on tensile strength.

The report only considers the margins on global collapse in the analytical assessment and it does use the proper margins in those cases. HPHT equipment has not been shown to be any different from any other pressure equipment, whether manufactured to ASME, API, or any other standards around the world. The margins referenced by API 17 TR8 are appropriate for high pressure equipment.

1.3–*Were comparisons of the computational methods and design methods adequate?*

The methods used for determination of global collapse appear to be used appropriately for each of the methods chosen. I have not investigated this fully through modeling or other calculations, but the methods used in the modeling appear to follow generally accepted practice for global collapse.

The report indicates that it is a requirement, when using elastic-plastic evaluation, to determine the maximum pressure rating for a component and then apply the design margin to it. This is an incorrect statement. ASME VIII-2 and VIII-3 require demonstration of a component to withstand loading that has been factored above the design rating. This is a subtle difference, but can result in huge design costs if it were mandated to determine the maximum load that each piece of equipment can withstand in every combination.

There are many different criteria that need to be evaluated, as stated earlier such as local strain limits, ratcheting assessment, life assessment, and other specified serviceability criteria. None of these were evaluated with this component. It is recognized in the high-pressure industry that the fatigue life or design of areas of local strain may control the pressure rating of a component in lieu of the global collapse rating.

Appendix E determines the collapse pressure by proof test. The "Pressure Ratings of the Test Bodies by Rules of ASME Section VIII Division 3" section shows the calculation of the rated pressure using the equations from KD-1254. The key input to this process is the collapse pressure (CP). The method for determination of CP is found in KD-1253, which requires that the strain be determined at the OD of the cylinder while under test. There were strain gages shown in the photo of the burst tube in the area of interest, but no data was included from them in the report. The CP values used in the evaluation were based on the actual failure of the components. KD-1253(b) states that if the vessel fails, that the component should be redesigned

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and retested. It is likely that the 2% strain on the OD was exceeded during the testing performed to determine the CP values. In other words, it is suspected that the CP values would be lower than the reported values if the CP values were determined in accordance with the 2% strain on the OD. This would have greatly lowered the design pressure allowed by proof testing using this method. This however is a different criteria for the determination of the rated working pressure than used in the finite element analysis and should not be directly comparable.
1.4–*Are the assumptions of the modeling and tests clearly defined and appropriate?*
The modeling assumptions made are fairly well listed in the report. There are potential subtle nuances. The report is not clear on whether dimensions used in the modeling result in a minimum material condition or if the nominal listed dimensions from the drawing. The model tolerances and shouldn't greatly affect the results, but this should be clarified in the report. It is noted that the material properties are from test locations from prolongations on the ends of the forgings and were taken in the longitudinal direction. Large thick section forgings can have significant variations in the material properties of the components, including variation based on test location and direction of the testing done. The majority of the conclusions of this report center around the burst pressure of the cylindrical tube sections with an axial rupture of the cylinders. The samples should have been taken to determine properties as a minimum in the tangential direction relative to the forged body. They also should have been taken at a location at mid thickness of the wall that failed, and not at ¼ T of the prolongation. The report in Appendix A2 also states that a drawing illustrating the testing locations would be provided. This was not located in the report but would be helpful in understanding the exact location of the testing. It is stated in the report that loads simulating the blow off loading was applied at the locations of the screws on the flanges of the components. Typically, the preloading (bolt loads) for a seal would be higher than that required for the blow off loading. Utilizing the actual bolt tension may result in added stress on flanges due to this loading for the analyses. Traditional modern finite element codes would commonly include all of the components in the analysis including the bolts and apply contact between them. However, it is noted that only the burst of the tube in each body was evaluated and relevant to the analysis, and hence, the method of application of the bolt loads versus the blow off loads, likely have no relevance. The report states that a limit load analysis is required for determination of the pressure rating of these components. This is not specifically true. It needs to be demonstrated that a component can withstand the rated loads when factored by the design margins for specific combinations of loads. However, for this particular exercise, which appears to be solely focused on the evaluation of the margin on global collapse, it is appropriate to attempt to determine the highest pressure (in this case) that the component can withstand. It is recognized that in the report that there is a

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certain amount of error in this technique. The report indicates that multiple iterations of each finite element analyses were performed to determine the collapse load for each component.

1.5–*Did the report identify and adequately address the strengths or weaknesses of the analytical methods used for the modeling and testing methods used?*

The report did not reference the basis for the methods used nor the background explaining where the design margins came from. It appears that some research into the background of the standards referenced might be appropriate for this work and add to the understanding of the margins.

The report did some strain gage testing during the hydrostatic testing of each body. No plastic strain was experienced in the cylindrical sections during these tests, either at the gage, or at the ID of the tubes. This can be verified using the methods of ASME VIII-3 KD-5 for determination of the extent of plastic yield in the wall of a cylinder.

The report also points to the difference between Tresca criteria and von Mises or equivalent stress criteria for linear-elastic evaluation. The report indicates about a 15% difference between the API 6A and Division 2 linear-elastic methods. This is as expected based on the fundamental concept of the two criteria. Most modern approaches, including almost all modern finite element programs utilize the concept of equivalent or von Mises stress for a failure criteria in yielding. There are many variations in material hardening models to model actual plasticity behavior, but the concept of using von Mises to predict the onset of yielding is well proven, as is the source of the potential 15% difference.

1.6–*Were the actual materials within specification for F22 material properties adequate?*

I am not a metallurgist so I will limit my comments on the metallurgical aspects of this question. I also find this question somewhat ambiguous.

The material properties used appear to be higher than specified in most ASTM materials. The reduction in area and elongation is slightly lower than the next lower strength materials of lower strength from a comparable material specification (ASME SA-336). Table KM-234.2(a) of ASME VIII-3 would require Charpy impact toughness of 50 ft-lb average for a set of three and 40 ft-lb minimum for a single specimen when testing in the longitudinal direction. Longitudinal toughness testing is also only permitted when the component shape or size does not permit removal in the transverse direction. It is believed that when taking samples from the prolongation, it should have been possible to take full size specimens in the transverse direction from these components.

The heat treatment drawing in Appendix F also shows the prebore in the forging for heat treatment. Based on the description of the test locations, the effectiveness of the quenching in the bore of the component is not determined.

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1.7–*Determine the degree of certainty that each test object did not have a latent defect, was forged properly, and manufactured properly; for example, should there have been a posted manufacturing stress reduction heat treatment?*
I am not a metallurgist so I will limit my comments on the metallurgical aspects of this question. The material specification in Appendix 2 seems to cover the typical aspects of specifying material properties required from this material. It is typical for the material to have both a surface examination and a volumetric examination. This is a quenched and tempered alloy, so it would not be typical for a non-welded component such as the one involved in this testing to have a post weld heat treatment.
1.8–*The report documents a failure of the tested object for the 17 TR8 Division 3 method to show a failure of the test object at a threshold below the design standard. Do the conclusions and recommendation based upon this stand alone? Are there other considerations, such as the fact that the material chosen is a non-Division 3 material, or any other alternate logical explanation for failure event below the Division 3 design standard?*
The design methods in ASME VIII-2 and VIII-3 are identical from an elastic-plastic standpoint, with the exception being the design margin. The material used, while not currently a listed material in ASME VIII-2 or VIII-3 is similar in properties and composition to other materials commonly used in the production of high pressure equipment in this pressure range. It can be noted that ASME B31.3 references ASME VIII-2 and VIII-3 in a similar manner to API 17TR8 and has the allowance for the use of “unlisted materials” (ASME B31.3 K302.3.2(c)). In reality, the material doesn’t know which “standard” it is being used in. If the material is specified properly, has adequate material properties including strength characteristics, toughness, etc. and is designed such that the critical failure modes are avoided or their potential is minimized, the standard doesn’t matter. ASME VIII-3 uses a lower margin than VIII-2 due to many factors such as additional material testing, higher toughness requirements, additional NDE requirements, etc., and more stringent design specification requirements for the end user of the equipment. It is also noted that Terada’s work[2] was used to help establish the margin of 1.8 currently used in ASME VIII-3. This is important to note as the work does effectively two things. The first is that it established the basis for using 1.8 as the margin in ASME VIII-3 for elastic-plastic evaluation. Secondly, the paper has a series of burst tests in it, which have been statistically evaluated. The standard deviation in this work was shown to be 7-9% based on the methods used in today’s codes and standards. This work shows that the margins using elastic-plastic analysis are not meant to be lower bound pressure ratings. It shows that it is expected that using this type of analysis, it is expected for the margin to be nominally 1.8, if specified minimum material properties such as yield and tensile strength are actually achieved in manufacture, in lieu of higher strengths. It also shows that in practice the actual margin for a piece of equipment based on actual properties if they are near specification minimum, may be slightly less than 1.8

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or 2.4 specified for analytical comparison. API and ASME have both accepted this potential variation as the case when adopting these margins. Section 6.0 of the report states that "it is crucial that the theoretical collapse pressure closely agrees with the actual burst pressure". This appears to not be in complete alignment with the work that is the basis of the margins in ASME VIII-3. The report further states in Section 6.1 that "it is imperative that the theoretical collapse pressures from FEA be accurate or at least conservative". The methods used have inherent variability in them relative to the actual material properties and are based on a mean rating, not a minimum value. This is the basis which again has been adopted by both API by reference and ASME in the development of their standards. It is noted that large thick section forgings may experience significant through thickness material property variation. It is recognized due to failures in industry that this is the case. The 2015 edition of ASME VIII-3 KM-211.2 states "*In addition to the following, for quenched and tempered materials, the location of the datum point shall be equal to or farther from the nearest quenched surface than any pressurized surface or area of significant loading is from the quenched surface.*" This is recognition of this material property variation and that the test location of the test location should represent the "worst case" material properties for the areas of high stress in the vessels. If the quenching due to a small pre-bore was ineffective to get good material properties at the ID, the material strength properties in the tube walls could vary from what were reported in the testing. The strain gage data in the report do not go far enough to evaluate any plasticity that may occur in the test piece.
1.9–*Are there other obvious conclusions that the report should have addressed identified by the peer review?*
Several of the conclusions and statements in the report are either confusing, contradictory or potentially misleading or incorrect. Section 1.0 of the report states "the use of Division 2 and Division 3 elastic-plastic methods are new to the industry." However, the report goes on in Section 9.0 on page 24 to state that "Currently, standard practice for most major subsea equipment manufacturers is to perform only elastic-plastic FEA". This should be clarified if the elastic-plastic methods are truly "new to the industry" or if they are truly "standard practice", which is my experience. Section 2.0 page 9 indicates that "API has not approved verification by elastic-plastic FEA". This is confusing as the use of elastic-plastic FEA is recommended in API 17TR8. Section 2.0 on page 10 implies that there are two elastic-plastic methods. There is actually only one method which is used in both Division 2 and Division 3 with two margins. This should be cleaned up in this report to avoid causing confusion in the industry. Section 7.0 page 18 states that "…pressure ratings by actual proof test would be higher than pressure ratings by theoretical methods." This statement is confusing and is contrary to an actual statistical data set from Terada[2] which shows actual distribution of the burst data.

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One statement in Section 9.1 on page 24 states that "the least conservative pressure ratings were determined by ASME VIII-3 elastic-plastic analysis". This is not correct. Table 9.2 shows that the least conservative margin calculated is 1.74 based on linear-elastic analysis by ASME Section VIII Division 2 using the API 17 TR8 / 6A / 17D allowable stresses. It is possible to produce high strength low alloy steels, as used in this example with low toughness. The enhanced material requirements in API 17 TR8 are one aspect of the requirements, which also include additional NDE requirements for the material, additional requirements for welding and fabrication testing, and more rigorous analysis of the components. Page 25 the report goes on to state that testing should be done to confirm that the lower margin designs are safe from failure. The margins are experienced based and have been adopted by ASME and recommended by API 17 TR8 based on that experience. The literature is full of this information and data which can be shown to support this position. Page 26 states that elastic-plastic FEA was "not allowed prior to 2015". This statement is misleading, as BSEE was reviewing analyses using this approach prior to 2015 and had no rules stating that it was unacceptable. This was prior to the formal publication of API 17 TR8. Section 10.0 on page 28 implies that the margin of 1.8 in ASME VIII-3 is somehow incorrect and that it should be considered as 2.1. The basis for this is that the margins used in the elastic-plastic analysis should be lower bound and absolute margins, with all potential manufacturing scenarios showing that these margins are conservative. If this is the case, one conclusion of the report should be that it should be recommended to ASME to consider that their margins should be adjusted in both VIII-2 and VIII-3 to result in absolute lower bound ratings relative to collapse of the equipment. Further to that end, the standard deviation by Terada[2] shows that a single standard deviation is approximately 7% and a +/- 3 standard deviations might be considered to account for the total population of distribution. I disagree with this recommendation, but if the report stands as is, the authors of the report should recommend ASME and API 17 TR8 through its reference of ASME should correct its standards. This is implied on page 29, but stops short on making recommendations regarding what should change in ASME. On page 29 it states that "a load histogram with loads in the proper sequence cannot be developed for subsea equipment". This is incorrect. Many manufacturers are able to postulate plausible loading histograms for equipment in service based on past operational experience. This was demonstrated in work done on Deepstar project 12302 which is expected to be released to API for publication this summer. In that work, a postulated loading histogram was generated and compared to actual well head data to look at operational trends in wells. The histogram was conservative in the number of cycles, the sequence of operational cycles and the loading degradation over time for the example cited. Operators have this type of information from their typical operations available and it can be utilized for developing plausible operational histograms. One conclusion that should be emphasized is that there is nothing more unique about equipment designed to API 17 TR8 than other designed to ASME VIII-2 or VIII-3, other than accessibility

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of the API 17 TR8 equipment is limited in all cases with the once it is in service. There is a fleet of down hole test equipment used today for testing drilling tools which uses similar materials at equal or greater pressures and temperatures as HPHT subsea equipment, in the same or more severe environments designed to ASME VIII-2 and VIII-3 for regular pressure vessel applications.

The one conclusion that is overlooked is that a metallurgical evaluation of the failed components should be conducted. This would include but may not be limited to examination of the fracture surface to determine the initiation site of the failure and the mode of failure, investigate any contaminates which may have influenced or initiated the failure, investigate for potential mechanical damage on the surface of the components, and look for potential material inclusions or other issues which could have affected the integrity of the component.

2. *Evaluation of Modeling Results: Do the modeling results describe with reasonable accuracy the basis for decisions in the applied methods:*

2.1–*Are the limitations and uncertainties clearly identified and adequately characterized for the methods of modeling selected?*

It is noted that the only failure criteria which is evaluated in this report is global plastic collapse due to internal pressure in the cylinder section.

The report attempts to present some perceived limitations of the methods. However, some appear to be overlooked. Such as the design margin on burst of 1.74 using linear-elastic analysis using ASME VIII-2. There is an entire discussion about the use of linear-elastic analysis and its applicability in high pressure design. The reference cited earlier by Dixon and Perez[1] discusses that in some detail. The basic premise is that steels do yield in service. Linear-elastic analysis does not account for that and instead assumes that the amount of load it can take will continue to linearly increase past the yield point. There should be some discussion about the potential for over predicting the load capacity of a structure using this evaluation technique compared to actual material response.

There are also multiple material models which can be employed in the elastic-plastic analysis method. This includes the model used which was a true stress-true strain model as found in ASME VIII-2 or VIII-3. There is an elastic-perfectly plastic model as found in ASME VIII-3 KD-236. Each of these may be used for evaluation of global plastic collapse. The elastic-perfectly plastic material model is more conservative than the true stress-true strain model which incorporates the concept of strain hardening into the model. API 17 TR8 also allows the use of actual stress strain curves in analysis when testing has been performed. The analysis uses actual data for input to the curves generated using ASME VIII-2/VIII-3 methodology. The variation between these techniques could be useful to discuss.

2.2–*Are the assumptions of the modeling appropriate for the methods of modeling selected? Assumptions evaluated should include, but are not limited to:*

- *Material Thickness*

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- *Mesh chosen*
- *The correspondence of the modeling to the design basis specified in the standard*

It is not clear what the dimensional assumption was for the modeling of the finite element model used in the report versus the actual test piece. The design standards require the use of minimum thickness models based on the manufacturing tolerances of the components. This could account for a 2-3% variation in burst pressure based on reported manufacturing tolerances.

The mesh plots shown indicate that there are ample elements, based on experience, to accurately determine the collapse pressure of the component. The time stepping also appears to be sufficiently small to allow for capture of the final collapse pressure of the equipment when using elastic-plastic analysis.

It was previously pointed out that the location which the material testing was performed may not truly be representative of the failure location within the tube.

It is noted that the collapse of the tube in the component was the only item considered in the linear-elastic evaluation of the components.

The finite element modeling appears to be sufficient relative to the prediction of global collapse of the tube in the bodies, provided the proper dimensional information was utilized to reflect the actual tests, when the comparisons are being made.

A component's operational loading variation should be considered in conjunction with the design margin selected. The loading histogram should reflect the worst case loading a component will experience in service, while accounting for total variation in load over time.

3. ***Are there strengths or weaknesses of the analytical methods used for the empirical calculations chosen in the report?***

The potential issues with the application to linear-elastic analysis has been considered earlier in this line of questions and won't be repeated here.

The variation in the burst testing of components needs to be repeated here. The data set presented by Terada[2] demonstrates the potential variation in the burst pressure of steel components. The analytical methods are highly repeatable and reproducible from one analyst to another, provided identical geometry, material and boundary conditions are used in the evaluations. The test data used in the empirical evaluation of the results and the evaluation of the margin has inherent variability due to variations in material processing, etc. Terada's paper[2] also points out the variations on empirical burst pressure equations which are in the literature. In short, comparison to burst test results will have variation and the authors of this report should be commended that their results are completely within the expected scatter band.

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4. *Are the conclusions drawn by the report appropriate based on the modeling results and empirical analysis?*

As pointed out in question 1.9 of this survey, there are conclusions drawn throughout this report and not limited to the conclusions section in 10.0. However, it is assumed that this question refers directly to Section 10.0.

It should be noted that the elastic-plastic methods used in both ASME VIII-2 and VIII-3 are the same for global plastic collapse with different design margins used for each division. If a recommendation is made to change the margin in ASME VIII-3, it is unclear why that would be valid and not make a similar change in VIII-2. It would seem that the linear-elastic methods are being used as a "gold standard" which the newer more rigorous modern methods are being held to. This linear-elastic method has been shown to be non-conservative as pressure ratings increase in the work by Dixon[1]. As technology improves, industry must be able to use the advancements in order to stay competitive.

5. *Are the conclusions related to the test appropriate?*

No, the conclusions that are related to the test are based on a flawed premise that the methods used are going to be conservative in all cases with no variation in the burst pressure in components. The test data also proved that linear-elastic analysis can, in certain situations also yield non-conservative results as shown in Table 9.2 (1.74 margin VIII-2).

HPHT equipment is designed with these margins with the expectation that it won't experience loading above design while in service. The point of a design margin is to allow for a margin due to the unknowns in the design condition. The industry has considered the variation in things such as loading variation, material properties, manufacturing tolerances, etc., and have accounted for them in the factors which are used in ASME and API standards today.

The conclusion that components should be rated based on proof testing or burst testing is, in my opinion, dated, expensive and potentially dangerous. Modern design methods are used to reduce costs for the industry, and allow them to be competitive, without the need to perform excessive burst testing of components. Finite element technology is well known and the methods are proven and widely used in many other pressure equipment industries, and other industries such as aircraft, automotive, bridge design and many others. Complex shaped components are designed every day to ASME B31, VIII-2, and VIII-3 standards. ASME VIII-3 does have KD-12 in its document as an option, but it is rarely used. When it is used, my experience it is typically for very small components.

6. *Are the other conclusions appropriate?*

Many of the conclusions appear to be based on a desire for additional information to justify the methods used in API 17 TR8. This type of information was discussed and was considered during the adoption of the rules in the ASME standards over the course of the last forty years. API SC 17 considered the standards of ASME and adopted that experience base and other bases as their own, through the recommendations in 17 TR8.

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It is unclear in the report what is fundamentally different between the 20,000 psi components in the subsea industry and a 20,000-psi component which is not in the subsea industry which would substantiate the conclusions in the report. If the author feels strongly that the conclusions in the report are valid, another conclusion should be a recommendation, likely to ASME, to consider increasing the margins in both VIII-2 and VIII-3 by some factor to ensure that the ratings are always lower bound.
7. *Are the recommendations logical, appropriate, and supported by the conclusions of the test results, empirical analysis, and modeling results? The scope of the recommendations pertains to all recommendations, not just those derived from the modeling results.*
The results appear to be based on a single test with no ability to review the statistics of that test. Typically, testing is performed based on a set of tests with some statistical relevance and not one or two data points. There are also many conflicting statements throughout the report, which have been cited previously. The one conclusion states that "For subsea equipment the industry should verify that the additional fracture mechanics analysis and more rigorous material requirements in Division 3 justify a 33-percent reduction of the design load factor as compared to Division 2." This conclusion is confusing at best. The conclusion draws on the premise that there is something special about pressure equipment in the subsea industry that is different that the technological challenges present in other industries. This is not the case. The bases for the use of ASME VIII-3 has been considered and has been accepted by the ASME Committees and by API by reference. The conclusion appears to be based on the premise that it is impossible to develop a loading histogram to represent the annual cycles expected for a piece of subsea equipment over the life of the piece of equipment. This is currently done in the industry and has been shown that it can be done conservatively, as was done in the Deepstar 12302 project which was recently completed.
8. Are there any obvious technical considerations the report should have covered that are missing?
The report only focused on global collapse of a cylindrical tube. None of the other failure modes, many of which are far more common, were investigated. This includes the concept of local strain accumulation and damage in areas of high stress concentration, the concept of shakedown, the evaluation of the hydrostatic testing criteria for the components. There are many technical discussions in the area of bolting and flange design which also are not covered in any detail in the report. One conclusion that appears to be appropriate, in lieu of the conclusions in the report, is that the burst testing is exactly in line with the anticipated scatter in test data which may occur in a burst test, and that the pressure rating of ASME is not lower bound, but mean. The report should also

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have considered if "extreme" or "survival" type loads come into play and to be sure that the potential scatter doesn't result in failure of a component under loads beyond the design basis.

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DATE:03/22/2017
AFFILIATION: Bunch Technical Services Inc
BACKGROUND. Briefly describe how your background, experience, and involvement with HPHT subsea equipment qualify you to evaluate the *Evaluation of Pressure Rating Methods Recommended by API RP 17TR8API RP 17TR8*:
42 years' experience in the design, analysis and testing of API equipment. Previously, Director of Cameron International Worldwide Technical Services Department which included departments of: Metallurgy, Welding Engineering, Design Analysis, CAD Systems and Reliability. I have previously managed the engineering technical oversight of Cameron's 25 ksi drilling and production equipment development for design, analysis and testing. API 6A task group member that developed API 6A, 15th edition, Design Methods, API 6AB, 6AF, 6AF1 and 6AF2. A member of API Task Groups of API 6RPHP, PER 15K, 17TR8, API 6X and currently on the task group for the development of API 16A HPHT. Member of ASME Sec VIII, Div 3, Task Group for Subsea Applications.
III. GENERAL IMPRESSIONS
Provide overall impressions (approximately 1/2 page in length) addressing the accuracy of information presented, clarity of presentation, and soundness of conclusions.
First, it must be clarified that this review is limited in scope in that the report does not address the complete evaluation of 17TR8 for pressure rating. The focus of the report was based on collapse pressure and does not address local failure, ratcheting, fatigue, serviceability, etc. As such, the peer review responses are evaluating this limited scope of work. Other failure modes are addressed in this review only in context of references made in the text or how they would influence the collapse pressure predictions. Additionally, API 17TR8 is referred to as a standard in the charge questions of this review and it is not, it is a technical report. API 17TR8 is not a standalone document (as stated in the Introduction section of the document), it is a guideline for HPHT development, and must be used in conjunction with all applicable industry standards to assure completeness and accuracy of the design requirements. HPHT guidelines from BSEE Standards Workshop: HPHT Session, May 8, 2015, provided the following statement; 'BSEE also recognizes that API 17 TR8 is a general guidance document, is not complete in its scope, is not the only HPHT guidance document, and does not address all issues associated with the construction of all HPHT oil field equipment. Technical Reports are not Engineering Standards.' There are additional specifications referenced in the peer review that are pertinent and applicable to HPHT designs. **Accuracy of Information** There are topics in this report which are difficult to determine the accuracy due to the limited amount of information. This includes:

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- Completeness of the material properties. It cannot be definitively stated that the material properties used in the analysis were representative of the properties at the location of the burst.
- The FEA models did not include all components of the assembly which was subjected to burst, such as the flange bolting, ring gasket and blind flanges. These may not influence the results but not including them raises the question of accuracy in the modeling.
- The data provided for the strain gage testing was incomplete. Data was not provided for the high strain regions on the ID and the data from external gages were only for principal strains up to hydrostatic test pressure and does not provide the elastic-plastic strains up to burst pressure. The results of the strain gage testing did not provide an acceptable validation of the accuracy of the FEA. Nor were they used to define collapse pressure.
- The material properties used for the FEA were defined to be obtained from true stress-true strain data. There are three different sets of material tensile properties, it is unclear if the properties used for the FEA were the lowest of the three measurements.

Clarity of Presentation

Overall the procedures for proof test analysis were very well defined and understood. The FEA Models were clear, all reference standards used for determining design margins were well reference. Equations which defined how allowable design pressures were calculated and clearly defined.

The material process did not provide non-proprietary material processing procedures from the forgemaster, such as information on the quenching of the forging defining orientation and circulation of quench fluids in the quench tanks. It wasn’t clear if the prolongation was attached during the heat treat cycle and it wasn’t clear if both test samples had prolongations or if just one prolongation was used for both test samples.

Regarding the burst testing the strain gage measurements were only obtained for the hydrostatic test but should have provided the readings during the burst test for validation of the FEA for predicting burst. Not all strain gage data was reported, the internal gages were determined to be inaccurate.

Soundness of Conclusions

The conclusions made were based on comparisons of historical pressure rating allowable stresses and procedures for defining pressure ratings which have changed. API 6A/6X/17D were referenced as one of the current design methodologies of equipment rated for working pressure up to and including 15ksi. The current design methodology is defined in API 6X, which allows the use of von Mises stresses to calculate the design allowable. API 6X is referenced in 17TR8. ASME Div 2 linear-elastic design stress allowable was defined to be based on yield strength and it is not. Div 2 refers to ASME Sec II Part D for allowables which are based on ultimate strength. ASME Sec VIII, Div 3, KD-12 is referenced as an acceptable procedure for proof testing to

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failure to define equipment pressure ratings. KD-1254 does not allow pressure ratings to be determined using proof testing.

The two component evaluations conducted are insufficient in number to demonstrate the analytically predicted collapse pressure vs the proof test provide a statistical distribution range of data. It is stated that the error may be greater for more complex geometries which may be true, but that only means there would be a wider distribution of data points, which could result in higher or lower predicted collapse loads vs. burst pressure. Additionally, more complex shapes may result in burst pressures initiating from local failure due to strain limit damage as opposed to tensile overload of the cross-section.

The recommendation of comparing collapse pressure from FEA with burst pressures from hydrotests for a variety of subsea equipment is impractical and the failure mode could change depending on the component. More research into existing and possibly additional test specimens should be conducted to obtain a more complete statistical distribution of results. It should not be based on a data set of two tests to establish a lower bound for all test data.

The ASME Sec VIII, Div 3 load factor of 1.8 was developed over time. There is historical information, technical justification and testing by ASME that should be reviewed before a decision is made that the design load factor of 1.8 is not acceptable for API subsea equipment.

IV. RESPONSE TO CHARGE QUESTIONS

1. *Evaluation of Test Methods*

1.1–*Were the test objects selected for analysis valid test objects to evaluate the standard as applied? Consider true stresses and strains in the context of valid discussion.*

The test objects were valid based on referenced standard of API 6A and technical report 17TR8 as they were defined in the report, with the exception of tensile test location and CVN values. There were additional industry published specifications for material processing and testing requirements above those defined in API 6A, which were released prior to the development of this project. The use of API 6A material requirements is not adequate for development of HPHT equipment. As an example, API 6A material Charpy V-notch impact requirements require an avg of 20 ft-lbf, where ASME Div 3 requires 50 ft-lbf, and the material specification for this test object required an avg of 40 ft-lb. Applying design criteria for global collapse using ASME Div 3 for HPHT designs, should meet the toughness requirements of this document. Additionally, API 20B and DNVGL-RP-0034 'Steel Forgings for subsea applications' provide guidelines for material processing, testing and Charpy values (RP-0034). API 20B is currently being applied in the industry and RP-0034 is being reviewed for HPHT equipment applications. As defined in 17TR8, API 6A/17D/6X are specifications for equipment rated for working pressures up to and including 15 ksi equipment.

There were two sets of material tensile tests reported which were obtained from the prolongation material. A true stress-true strain curve was defined as the material input in FEA (supplied by ANL) and it is assumed this test was in addition to the reported tensile tests results, and provides

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a third set of tensile properties. There are variations in the results of the tensile properties for the two tests provided. The two engineering yield strengths values were 92.2 ksi and 91.6 ksi and the ultimate strength values were 111.1 ksi and 108.7 ksi. It is unclear if the true stress-true strain curve input for the FEA represents the lowest yield and ultimate stress data obtained from the material tensile testing. The material specification references API 6A PSL 3 as the criteria for material testing. Mechanical properties were taken from 1/4T location on the prolongation. API 6A requires test coupons to be taken at '3mm (1/8 in) from the mid-thickness of the thickness section of a hollow QTC.' Additionally, 20B and DNVGL-RP-0034 require mechanicals at 1/2T location in both the longitudinal and transverse directions. To obtain the most accurate results when comparing FEA collapse pressure to test specimen burst pressure, mechanical properties in the flange neck in the transverse direction using a qualification forging (first article) cutup to obtain the properties should have been performed, reference API 20B.
1.2–*Are the assessments of engineering safety factors for the cited standards and their divisions valid for the expected applications?*
API 6A was referenced for design allowables. API 6X is referenced in TR8 as applicable for equipment rate for 15 ksi or less pressure. API 6X, which will be the referenced design methodology for API 6A, 16A and 17D in the next releases, is based on von Mises stress criteria for defining stress allowables. This document should have been used instead of API 6A for the linear-elastic analysis design allowables. The maximum allowable stress at hydrotest defined in 6A and 6X (5/6*Sy) is more limiting than the working pressure allowable stress (2/3*Sy) where hydrotest pressure is 1.5*WP. ASME Div 2 linear-elastic design stress allowable was defined to be based on yield strength and it is not. It refers to ASME Sec II Part D for allowables which are based on ultimate strength (Sult/2.4). ASME Sec VIII, Div 3, KD-12 does not allow testing to failure to determine collapse pressure. The design load factors for ASME Div2 and Div 3 elastic-plastic analysis were correct and applied properly to the analyses.
1.3–*Were comparisons of the computational methods and design methods adequate?*
No, see question 1.2 above. This evaluation is only for burst pressure and doesn't evaluate other design methods, such as strain limit damage, bolting, gasket leakage or ratcheting and the respective allowables for each. The report does not identify the limits of linear-elastic analysis as defined in Div 2/3 and 17TR8. This method is only recommended for wall thicknesses where R/t>4 and Do/Di<1.25 or the von Mises stress does not exceed the yield strength more than 5% of the wall thickness. It is stated that 'nonlinear stress distributions associated with heavy wall sections are not accurately represented by the implicit linear stress distribution utilized in the stress categorization and

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classification procedure. The misrepresentation of the stress distribution is enhanced if yielding occurs.'

1.4–*Are the assumptions of the modeling and tests clearly defined and appropriate?*

The boundary conditions, loadings, material properties of the finite element models were clearly defined with the exception of axial constraint. The ¼ section model is restrained in the Y-X plane for X direction constraint and Y-Z plane for the Z direction constraint, but there is not a clear plot or description of how the model is restrained in the Y direction.

The plots of the results for von Mises stresses, total strain and displacements are defined and clear in the report.

The assumption in the modeling that the true stress - true strain curves defined from tests conducted on the prolongation material are appropriate for a predicted failure mode that is hoop stress dominant has not been verified. The analysis and the component failure clearly indicated the mechanical properties input into the model should have been transverse tensile properties in order to assure accuracy.

The geometries of the gaskets and blind flanges were not modeled which changes the reaction loads going into the flanges, and it was not verified in the report the contributing effects of these components on the results.

There was no indication in the modeling of how the tolerance of dimensions were addressed, i.e. was the model generated using nominal, minimum/maximum material conditions or as tested dimensions. The same is true for alignment tolerances.

1.5–*Did the report identify and adequately address the strengths or weaknesses of the analytical methods used for the modeling and testing methods used?*

The report does not indicate a detailed FMECA was conducted, but indicates that the internal pressure will rupture the neck based on the elastic-plastic analysis to collapse pressure. Although there is no reference to a formal FMECA being conducted, this procedure should have been used to identify all other failure modes and assure all issues of those failure modes were being address in the test, such as gasket leakage, and bolting failure. Additionally, it should have identified that the material properties in the transverse direction were controlling the defined failure mode and are necessary to predict the collapse pressure and thus driven the material testing for these tensile properties.

Part of the study was to perform strain gage testing to validate the accuracy of the FEA. Considering this was an analysis to define collapse pressure the strain gage data should have been provided for the collapse pressure loading. This would have been very relevant data to compare yield point of the test objects to the predicted yield point of the FEA. ASME Sec VIII, Div 3, KD-1212 allows the use of strain gage testing to be used to determine the collapse pressure.

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The additional FEA studies of the 13-5/8" 20 ksi and 16-3/4" 10 ksi flanges were evaluated for collapse pressure using axisymmetric models. These analyses did not include the bolt holes in the flange, bolting or the ring gaskets and mating blind flanges. Removing the bolt holes will change the stiffness of the flange and may result in higher predicted burst pressures than a full 3-d model with all components included. The results assume the flanges would fail due to a collapse pressure of the flange neck. The 16-3/4" 10 ksi flange analysis predicted collapse pressure is well above the tensile failure of the bolting. Thus, the failure mode should have been identified as bolting failure. The 13-5/8" 20 ksi flange analysis predicted a burst pressure was lower than the tensile failure of the bolting. If the bolting stresses included both tensile and bending loads due to flange rotation, it is possible the bolts will fail before the flange reaches collapse pressure, for this flange as well.
1.6–*Were the actual materials within specification for F22 material properties adequate?*
The material properties met the requirements of allowable materials per API17D/6A and NACE MR0175/ISO 15156, in regard to chemistries and mechanical properties (error on reported chemistry was corrected by ANL). There were no transverse material properties tested, thus it is not possible to determine if these were equivalent to the longitudinal properties used in the analysis. There were no mechanical properties tests to verify the prolongation properties were representative of the neck region of the test object. The report makes the statement in reference to 17TR8 that; 'Product Specification Level 5 (PSL5) was added. PSL5 includes fracture toughness requirements, higher Charpy toughness values, and improved QA/QC.' The report acknowledges there are requirements above those of API 6A, PSL 3, but no effort is made to evaluate these for the test objects. Additionally, the report states 'Consider the additional material requirements in TR8. Materials that have been used in subsea equipment for many years already meet the additional requirements in TR8.' This cannot be verified due to the fact that previous API criteria did not require fracture toughness values, higher Charpy values or increased QA/QC requirements.
1.7–*Determine the degree of certainty that each test object did not have a latent defect, was forged properly, and manufactured properly; for example, should there have been a posted manufacturing stress reduction heat treatment?*
A review of the forgemaster MPS and a microstructural evaluation is necessary to determine if the component was properly forged and has a wrought structure throughout. Hardness testing should have been conducted to assure uniform hardness throughout the test objects. The test objects can only be assumed to have defects equal to or smaller than the NDE acceptance criteria, which was defined to be API 6A, PSL 3. Determining the failure as either initiation from a defect or tensile overload requires post test fractography, which should be performed to assure the test was due to the assumed structural instability with tensile overload as defined by the analysis. This evaluation will determine if there were defects which were initiation sights for crack growth.

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Post manufacturing heat treatment is not a practice used in the industry and would have been beyond the requirements of either the Technical Report TR8 or API specifications of 6A, 17D or 20B. Any heat treatment after manufacturing has the risk of distortion and dimensions not meeting tolerance.
1.8–*The report documents a failure of the tested object for the 17 TR8 Division 3 method to show a failure of the test object at a threshold below the design standard. Do the conclusions and recommendation based upon this stand alone? Are there other considerations, such as the fact that the material chosen is a non-Division 3 material, or any other alternate logical explanation for failure event below the Division 3 design standard?*
The conclusions and recommendations do not take into consideration the variability of the data. The statement that the failure of the test object is at a threshold below the design standard cannot be made based on the limited number of two tests. Two test samples are not a sufficient number of tests to obtain a statistical distribution of data points defining the range of values for predicted vs actual burst pressure. Assuming all tests are skewed to have a difference of burst vs predicted of -7% and that the two burst tests represent and lower bound of all data is not accurate. Assuming all additional tests are predicted to be equal to or higher burst pressures, based on a set of two data points is not accurate. A review should be conducted for the results defined in the paper by Susumu Tada, ICPVT-12, 2009, "*Proposal of New Equations for Cylindrical and Spherical Shell of ASME Section VIII Division 3 for High Pressure Vessels"*. An additional study was performed in the API industry to evaluate burst pressures of API materials, reference Grohmann, A., Selvey, J. and Ellisor, S., 'Design Margins for Normal, Extreme and Survival HPHT Applications, OTC paper no. 27605, 2017. The Div 3 Code was first developed starting in 1980 and the first edition was published in 1997. The 2007 edition applied the design load factor for collapse pressure of 1.732 (√3) using an elastic-perfectly plastic analysis. The 2010 Edition changed to elastic-plastic analysis and a load factor of 1.8. Thus, the application of the design load factors have 10 years of experience using the Div 3 criteria. All relevant information of research, service applications and testing that was done by ASME defining the 1.732 and 1.8 load factors should be reviewed before concluding it is unacceptable for API HPHT equipment.
1.9–*Are there other obvious conclusions that the report should have addressed identified by the peer review?*
The conclusions should have addressed the discrepancies and inaccuracies in the strain gage readings when compared to the FEA results. The statement that the flange preload strains are included in the hydrotest strains, but not included in the FEA strains, indicate a discrepancy in the model and actual test objects assemblies. It is also stated that 'The reason the preload strains are not included in the FEA is that Division 2 and 3 do not include preload for global plastic collapse.' This statement is incorrect, particularly when a proof test is being compared to the FEA results to evaluate the design load factor of 1.8. Without analyzing these components, it is not possible to accurately determine the 'weakest link' for the failure mode (i.e. bolting failure,

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gasket leakage, or structural overload). The test should have obtained strain gage readings for the bolting and the test should have had strain gage measurement recordings for the burst testing. It was not explained why this procedure was not used to define the burst pressure.

2. *Evaluation of Modeling Results: Do the modeling results describe with reasonable accuracy the basis for decisions in the applied methods:*

2.1–*Are the limitations and uncertainties clearly identified and adequately characterized for the methods of modeling selected?*

There are statements that multiple models with finer meshes and more load steps were evaluated but no documentation is provided for these sensitivity studies.

The elimination of the blind flanges, bolting and gaskets for end connections was not clearly justified. There were no evaluations for bolting criteria or gasket sealing criteria which are additional failure modes that can occur before the burst pressure is reached. If the flange had been designed to API 6A requirements for the wall thickness of the neck, the failure mode may have been bolting tensile overload or gasket leakage. Most API components are designed with a straight neck flange connections making the burst pressure much higher than the test objects for the given end flange size, which could result in other failure modes before burst pressure of the neck is reached.

2.2–*Are the assumptions of the modeling appropriate for the methods of modeling selected? Assumptions evaluated should include, but are not limited to:*

- *Material Thickness*
- *Mesh chosen*
- *The correspondence of the modeling to the design basis specified in the standard*

The thick body section with intersecting bores did not contribute any useful information regarding the proof test in that the design was adjusted to assure the failure would occur in the neck region. It is possible that the intersecting bores could have resulted in strain limit damage at the burst pressure, but this failure mode was not evaluated. Additionally, the strain gage measurements in this region were not valid.

The design calculations provided in Appendix B1 Figure B1.13 indicate that nominal dimensions were used as opposed to minimum material conditions. Analysis should be based on minimum material conditions.

The design basis according to 17TR8 requires the evaluation of collapse pressure for the pressure containing body, the allowable bolt limits based on linear-elastic criteria and a service criteria evaluation for gasket sealing. The bolting allowable limits and the gasket sealing limits were not addressed in this report.

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3. *Are there strengths or weaknesses of the analytical methods used for the empirical calculations chosen in the report?*
Both ANSYS and ABAQUS finite element programs are used in design analysis of API HPHT equipment. Either program is considered acceptable when applied properly. Each is based on the von Mises flow rule. As stated in the report, large displacement theory was used for the analysis. An Independent FEA of the large neck flange using ABAQUS FEA was conducted (using nominal dimensions). The calculated collapse pressure results for the large neck flange were very close to the values in the report, 72,251 psi vs 72,850 psi of the report. This was evaluated for collapse pressure using ¼, ½ and a full model with close to the same results obtained for each analysis. A 6% drop in the yield through ultimate true stress true strain data will result in the FEA matching the test results for collapse pressure vs burst, using the report model for the large neck flange. This indicates the criticality of accurate material properties. The report model did not include the bolting, gasket or mating blind flange. An independent review of the analysis which included these components was conducted using ABAQUS FEA. The analysis used a 3-D geometry of a ½ section model. The calculated burst pressure for the large neck flange was 72,900 psi vs. the report value of 72,850 psi. This confirms that eliminating the bolting, gasket and blind flange does not affect the results for predicting the collapse pressure of the vessel itself.
4. *Are the conclusions drawn by the report appropriate based on the modeling results and empirical analysis?*
There are discrepancies in the defined allowable limits where API 6A/6X are referenced. The TR8 report references both documents but the current practice is to use API6X. The allowables stated for ASME Sec VIII, Div 2 are incorrect, they assume the allowable $=2/3*\sigma_y$ where ASME is $\sigma_{uts}/2.4$. The elastic-plastic analysis and design load factors for ASME Div 2 and Div 3 are correct as stated in the report. The conclusions drawn in regard to the prediction of collapse pressure based on elastic-plastic FEA were verified to be accurate through an independent analysis.
5. *Are the conclusions related to the test appropriate?*
The statement that the "load factor of 1.8 would be more justifiable if the factor is applied to the rupture pressure" is not appropriate according to ASME Div 3. KD-1212 prohibits the use of tests to destruction to define collapse pressure and subsequent pressure rating of the equipment. The statement "It is recommended that the subsea industry consider comparing collapse pressures from FEA with burst pressures from hydrotest for a variety of subsea equipment is impractical and unsafe. These test for standard API components are impractical in that bolting failure or gasket leakage would have a higher potential for failure prior to actual burst pressure. As an example, the current proposed design of an 18-3/4" 20 ksi flange neck has a wall thickness of 9.86 inches and would have a calculated burst pressure according to flow stress equations of

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70,536 psi, using API 6A minimum yield and ultimate strengths. Failure of the bolting or gasket leakage of this flange would occur prior to the burst pressure limit.

KD-1212 specifically states that strain measurement test may be used to determine the collapse pressure. If the test had been conducted to be in compliance with ASME Div 3, the strain gage measurements should have been used in the burst pressure test to define the collapse pressure. Reference is made to API 6A, 19th ed proof test. The requirements of this document for proof test pressure limits are based on strain gage readings.

The conclusion that 'The Division 2 elastic-plastic method with a design load factor of 2.1 would be more in line with historically successful equipment…' is not based on test results. The test results if taken as the lower bound of test data would suggest a design load factor of 1.93. The purpose of the study was to validate the pressure rating methods in API 17TR8. The conclusions in the report go beyond that suggesting the load factors be based on historical methods instead, using linear-elastic analysis.

6. ***Are the other conclusions appropriate?***

It is stated in the conclusions that 'The subsea industry should confirm that performing a fracture mechanics analysis required by Division 3 justifies a reduction of the design load factor to 1.8.' It is unclear how the fracture mechanics analysis would justify the design load factor of 1.8. The fracture mechanics is part of the fatigue evaluation of TR8 and there is a defined critical crack depth, with a design margin, based on all design loads. These are required for Category 1 equipment. These evaluations are not based on benign environment at room temperature, but are defined for maximum operating loads and worst operating environments. The maximum operating pressure is verified for collapse by applying a 1.8 factor, where the thermal and external loads are verified applying a 1.58 factor. The loads that satisfy the collapse load using the 1.58 factor for collapse are the loads (non-factored) that are evaluated for cyclic fatigue crack growth and an allowable critical crack depth using fracture mechanics analysis. Additionally, there is a design factor for the allowable number of cycles to be 50% of the total fatigue cycles to critical crack depth.

It is stated in the report that 'fracture mechanics analysis requires an explicit, time-based load history. This history is not possible for subsea equipment.' It is possible to review the load histogram and evaluate a worst-case loading sequence for fatigue analysis. There can also be multiple load sequences run to verify a worst case.

It is stated that 'TR8 requires that all pressure containing components meet the material requirements of API 6A and NACE MR0175. Materials that meet the requirements of these two codes will be ductile, have high impact strengths and have high facture toughness. Materials with these properties are not susceptible to brittle failures.' API17TR8 does not state that these two codes are sufficient for defining material requirements or that they are acceptable for defining required fracture toughness. ASME Sec VIII, Div 3 toughness requirements are much higher than those stated in API 6A. API Does not provide guidelines on fracture mechanics evaluation and thus Div 3 CVN requirements should be applied when defining failure due to a

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critical crack size. Heavy wall components, such as BOP bodies, have constraints where a crack growing to a critical crack depth can occur in a plane strain condition, which could result in brittle fracture, for the defined material fracture toughness. API alloy steels exposed to hydrogen charged environments can have significant loss in fracture toughness which can result in a brittle failure mode. Additionally, there are verification analyses for local failure due to strain limit damage, ratcheting evaluation and service criteria evaluations, such as gasket leakage, and bolting stress allowables. Any of these verifications can define the limits of the design.
7. *Are the recommendations logical, appropriate, and supported by the conclusions of the test results, empirical analysis, and modeling results? The scope of the recommendations pertains to all recommendations, not just those derived from the modeling results.*
It is recommended that stress intensities be used instead of von Mises stresses for linear-elastic analysis. API 17T8 references API 6X which allows the use of von Mises stresses for linear-elastic analysis. The use of linear-elastic analysis for pressure ratings above 15 ksi is not considered accurate as defined by ASME Div2/3 where the analysis is only allowed for designs with R/t≤4. The statement that; 'The Division 3 elastic-plastic method is not recommended for HPHT subsea equipment published with a 1.8 design-load factor' is not based on sufficient technical review and test data to assure validity of the recommendation. It is 'recommended that the subsea industry compare collapse pressures from FEA with burst pressures from hydrotests for a variety of subsea equipment' which is impractical and does not follow ASME or API guidelines.
8. Are there any obvious technical considerations the report should have covered that are missing?
The report should have addressed the probability of occurrence for calculated collapse pressure vs burst before concluding that the Division 3 elastic-plastic method is not recommended for HPHT subsea equipment as published with a 1.8 design load factor. The report should have reviewed the technical background and testing used by ASME to establish the 1.8 load factor defined in Div 3. The report should have compared the burst test results of the two components with existing ASME data to establish a statistical distribution of data points to determine if the results fall within an acceptable range of scatter. The report should have addressed the requirements of API 17TR8, PSL 5, when using ASME Div 3 design verification. The document does not state specific requirements for meeting the PSL 5, but makes reference to being above and beyond API 6A PSL3/4 in regard to Charpy

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toughness, fracture toughness and NDE. A reasonable interpretation would be to evaluate these material parameters as they apply to Div 3 elastic-plastic analysis.

5.3 Richard C. Biel

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NAME: Richard C. Biel, P.E.(TX)
DATE: April 3, 2017
AFFILIATION: Lord & Biel, LLC
BACKGROUND. Briefly describe how your background, experience, and involvement with HPHT subsea equipment qualify you to evaluate the *Evaluation of Pressure Rating Methods Recommended by API RP 17TR8API RP 17TR8*:
My experience in oilfield equipment began in 1975 when working for Gray Tool Company, now GE Oil and Gas. I currently serve as a member of the Subgroup on High Pressure vessels. This ASME Code committee writes Division 3. I have served on this committee since 1994 and continue to serve as a major contributor. During 2007 and 2008, I was the ASME technical project manager that updated the elastic-plastic rules and the basic design margins that are currently used in Division 3. I also have 14 years' experience designing API 6A equipment and have been a consultant for manufacturers of oilfield equipment over 20 years. I have recently served as a major contributor to the philosophy and design parts of the HPHT annex being written for API Standard 16A for drilling through equipment. With my background, my comments are mostly focused on the features of Division 3 that are used in this report.
V. GENERAL IMPRESSIONS
Provide overall impressions (approximately 1/2 page in length) addressing the accuracy of information presented, clarity of presentation, and soundness of conclusions.
This writer has a fundamental philosophical difficulty with the use of the ASME Boiler and Pressure Vessel Code as a design methodology document. The intent of the Code is that the methodology and processes in the Code be used only for an assessment of a design. The Code explicitly states that it is not a design handbook. For many decades however, the designers of API equipment have misused the Code as a design handbook. The ASME code writers currently use the term "design margin" that was formerly known as the "safety factor" to describe the level of uncertainty with respect to failure of a component or pressure vessel. The term used extensively in the report as "design factor" is not consistent with terminology in current use within the ASME Code. Also, it is not clear why the report occasionally uses the 2013 edition of the Code when the 2015 edition of the Code was available during the time this report was written. The reader should also be aware of the difference between the design margin and load factor as used in Section VIII, Division 3. The basic design margin in Division 3 is 1.732 (the square root of three) for materials that have a ratio of material yield strength to ultimate strength that is greater than approximately 0.72. The difference is small, approximately 2% when evaluated for thick-wall cylinders. Use of the value of 1.8 as a "design factor" points to a basic misunderstanding of the use of LRFD load factors used to assess adequacy of the design according to the Code.

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NAME: Richard C. Biel, P.E.(TX)
This author does not question the validity and accuracy of the burst test results. Also, the use of classical equations and finite element analyses appear to be done accurately. However, the finite element analyses can only be checked for accuracy by a detailed examination of the input files. Presuming that the analytical work was done by someone skilled in the method, there is no reason to doubt its accuracy. Whatever design methodology was used, it appears that both large and small neck designs were adequate for the intended pressure rating of 20,000 psi. The report fully justifies that pressure rating. Even the calculation of the pressure rating from the results of the burst test in Appendix E (more details below) of the report shows the adequacy of the design. However, when the report takes the added steps to generate pressure ratings based on plastic collapse by analysis, and further applies a load factor to the burst test results, it seems the intent is to stretch the validity of Division 3 beyond its normal assessment uses. Lastly, refer to the Figures 9.1a and 9.1b. It seems the writer is not sufficiently familiar with Division 3 to know how to accurately portray the historical design margin. Division 3 did not come into existence until 1997 and in the early editions use the design margin of 2.0. In the 2007 edition with the 2009 addenda the current design margin of 1.732 was introduced along with the LRFD methodology that included the load factor of 1.8.
VI. RESPONSE TO CHARGE QUESTIONS
1. *Evaluation of Test Methods*
1.1–*Were the test objects selected for analysis valid test objects to evaluate the standard as applied? Consider true stresses and strains in the context of valid discussion.*
In my opinion, the configuration of the test articles that were chosen were adequate to demonstrate compliance with the technical report 17TR8 for internal and external pressure only. Obviously missing are loads due to external tension and bending. External tension and bending loads have been identified as significant loads, possibly defining loads, for subsea equipment.
1.2–*Are the assessments of engineering safety factors for the cited standards and their divisions valid for the expected applications?*
As stated earlier, the report does not address important loads such as external tension and bending. In this respect, the underlying design margin in Division 3 cannot be fully assessed. That said, the assessments and conclusions from the test results and analytical work for pressure only using Division 3are not thought to be adequate for pressures above 20,000 psi.
1.3–*Were comparisons of the computational methods and design methods adequate?*
In my opinion, the design and computational methods are considered adequate and correspond to current practice in the engineering of API equipment. However, the assessments and conclusions attempting to extend the pressure ratings above the design requirements are considered to be inconsistent with the scope of Division 3 rules.

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1.4–*Are the assumptions of the modeling and tests clearly defined and appropriate?*

As stated earlier, the modeling and tests do not address external tension and bending that are considered to be significant loads for subsea equipment. In particular, the finite element analysis techniques and methodology for the pressure tests are in general accord with accepted practice for those activities.

1.5–*Did the report identify and adequately address the strengths or weaknesses of the analytical methods used for the modeling and testing methods used?*

The report does not explicitly identify the strengths and weaknesses of the assessment methods that were used. The analysis techniques and pressure test methodology are consistent with accepted practice for those activities.

1.6–*Were the actual materials within specification for F22 material properties adequate?*

The actual material properties were obtained from specimens taken at locations that are not consistent with Division 3 requirements. According to the material specification for test body included in Appendix A2, paragraph 11, the specified location of material sample specimens is not consistent with Division 3 paragraph KM-211.2(c). Paragraph KM-211.2(c) requires that the minimum distances from quenched surfaces be greater than the minimum distances given in the material specification. Also, the minimum required impact values required by Table KM-234.2(a) are greater than the impact values given in paragraph 12 of the material specification. [The reported values were higher.] Still not verified is the exact location where the material samples for testing were taken since drawings or sketches were not provided in the documentation. If the location where the material samples were taken is not in strict accordance with the Division 3 requirements the use of the values determined by these material tests would not be valid for assessments using the methods of Division 3.

Hence, the use of material property results from the specimens taken according to the material specification in the report are questionable for assessments according to Division 3 due to being taken from a location that does not conform to Division 3 requirements.

1.7–*Determine the degree of certainty that each test object did not have a latent defect, was forged properly, and manufactured properly; for example, should there have been a posted manufacturing stress reduction heat treatment?*

From the NDE documentation that was provided, it seems as though the material quality, as-forged, was adequate. There is documentation to verify that the forging reduction required by the specification was achieved.

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1.8–*The report documents a failure of the tested object for the 17 TR8 Division 3 method to show a failure of the test object at a threshold below the design standard. Do the conclusions and recommendation based upon this stand alone? Are there other considerations, such as the fact that the material chosen is a non-Division 3 material, or any other alternate logical explanation for failure event below the Division 3 design standard?*
The report draws a false conclusion from Table 6.1 - that the numerical analysis should exactly match the results of the physical test. The numerical analysis uses an idealized material that is rarely achieved in actual practice. In fact, noting the deficiencies in the location of the material test specimens noted above, the actual deep section properties of the material could account for the difference. In addition, the analytical work has some unanswered questions that could affect the results. Refer to the comments on the analysis using numerical methods in the sections below. As a practical consideration, the burst test results and the analytical results both show that the plastic collapse results exceeded the design requirements.
1.9–*Are there other obvious conclusions that the report should have addressed identified by the peer review?*
With the deficiencies noted in this writing, the report should have concluded the designs met all requirements for the intended pressure rating of 20,000 psi. This conclusion would require a stipulation that the specimens for material property tests were taken from a location that was not consistent Division 3 requirements. The report does not show that the requirements of KD-1254(c) were met for a design pressure determined by collapse pressure (burst pressure).
2. ***Evaluation of Modeling Results: Do the modeling results describe with reasonable accuracy the basis for decisions in the applied methods:***
2.1–*Are the limitations and uncertainties clearly identified and adequately characterized for the methods of modeling selected?*
The report does not comment on the analytical assumptions that underlie the final element method. While it is generally accepted that the final element work represents sound engineering practice, some input data has limited precision. For example, Young's modulus is an important input parameter that has limited precision and yet the results of the analysis represent or suggest much higher precision.
2.2–*Are the assumptions of the modeling appropriate for the methods of modeling selected? Assumptions evaluated should include, but are not limited to:* ▪ *Material Thickness* ▪ *Mesh chosen* ▪ *The correspondence of the modeling to the design basis specified in the standard*
As previously mentioned, the only way to adequately review a detailed numerical analysis is a close inspection of the input data. A review of the input data will show whether the annotations on the plots concerning boundary conditions are consistent with good practice for this type of analysis. Also, it is not clear what the material model was used to describe the strain hardening behavior of this material, if any. Most analysts use the Ramberg–Osgood equation or a similar formulation such as given in both Division 2 and Division 3 of the code. The investigators

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missed an opportunity to obtain an actual stress-strain curve during the mechanical property tests. This is not commonly done for construction of new equipment but would give important information for a technical study as was done to determine pressure ratings.

The analyst did not provide load-displacement curves in the report. This would give insight to the development of plastic hinges. The load-displacement curves could also be used for an alternative determination of the calculated plastic collapse pressure using the double elastic slope method.

Also, a design pressure determination should include a ratcheting check by the method prescribed by Division 3. It does not seem that the ratcheting check was attempted but is an important part of assignment of a pressure rating.

3. ***Are there strengths or weaknesses of the analytical methods used for the empirical calculations chosen in the report?***

Empirical or classical calculations using equations from strength of materials derivations, are valid so long as the stresses do not approach the yield strength of the material being used and the stresses change in a linear fashion. For thick-walled components, the linear-elastic methods have been shown to be nonconservative since the stress fields are typically nonlinear.

4. ***Are the conclusions drawn by the report appropriate based on the modeling results and empirical analysis?***

No. The conclusions in the report that extend the application of the assessment methods beyond verification of the basic design pressure are not considered valid. Therefore, this writer does not agree with any conclusion for pressure beyond the design pressure. It is thought that a competent designer would generate a design independent of the assessment means using experience, knowledge, and sound engineering judgment then subject the design to the appropriate assessment means.

5. ***Are the conclusions related to the test appropriate?***

The test was an instrumented pressure test at various pressures both internal and external and lastly an internal pressure test to failure. The burst test results support the original design pressure of 20,000 psi using assessment methods from both API Standard 6A and Division 3. Not repeated here are the objections to extending the validity of the Division 3 assessment methodology.

6. ***Are the other conclusions appropriate?***

No.

7. ***Are the recommendations logical, appropriate, and supported by the conclusions of the test results, empirical analysis, and modeling results? The scope of the recommendations pertains to all recommendations, not just those derived from the modeling results.***

Lastly, the determination that there are some problems using the Division 3 assessment methodology from a single series of tests from one material and buy one investigator is not

PEER REVIEW COMMENT TEMPLATE
Evaluation of Pressure Rating Methods Recommended by API RP 17TR8
NAME: Richard C. Biel, P.E.(TX)
considered valid. Typical verification and validation means are done using round-robin techniques that attain data from several different sources and the results are independently assessed.
8. Are there any obvious technical considerations the report should have covered that are missing?
It seems to this writer, that the report attempted to cover a scope of work that was overly broad. As a result, some items lacked rigor by failing to properly define material sample locations with reference to Division 3 requirements and obtain actual material stress-strain data. Is not clear if the investigator understands the underlying principles of assessments using LRFD since he uses the load factor intended for the LRFD method as a "design factor." [This same misapplication of terminology also exists in API TR8.]

6. APPENDIX B: PEER REVIEW MATERIALS PACKAGE

Name
Address 1
Address 2
City, State Zip Code
Email Address

March 13, 2017

Dear TBD:

Thank you for accepting our invitation to review the report entitled, *Evaluation of Pressure Rating Methods Recommended by API RP 17TR8.* We are conducting this external letter-style peer review for the **U.S. Department of the Interior (DOI), Bureau of Safety and Environmental Enforcement (BSEE)**. Please find attached the Peer Review Materials Package, which is the official document that authorizes you to perform this work. In this package, we have included the following items:

- Peer Review Charge Document, which includes:
  - Project History and Objectives
  - Work Scope and Schedule
  - Deliverables Schedule
  - Location
  - Confidentiality Requirements
  - Disclaimer
  - BSEE Charge for the Scope of this Peer Review
  - Instructions for Preparing Written Comments and Logistics
  - Charge Questions
- Peer Review Comment Template
- Report: Attachment, *Evaluation of Pressure Rating Methods Recommended by API RP 17TR8.*

We request that you complete your written review of the report on or before 04/10//2017 and appreciate your sensitivity towards the deadline. Please email your comments in an MS Word attachment, using the template provided, to Max Cropper at mcropper@endyna.com.

After the reviewers have completed and submitted their written comments to the EnDyna Team, the comments will be provided directly to BSEE. Following completion and acceptance of your review, we will ask you to send us an invoice for your services.

As noted in the confidentiality requirements below, your comments and the report should not be distributed or discussed with any outside party.

Thank you again for participating in this peer review. Please do not hesitate to contact Max Cropper (mcropper@endyna.com) if you have questions.

Sincerely,

Smita Siddhanti, PhD
Program Manager

PEER REVIEW CHARGE DOCUMENT	
ENDYNA PROJECT NUMBER:	DINP-009
TITLE:	Peer Review of the report entitled, Evaluation of Pressure Rating Methods Recommended by API RP 17TR8
PEER REVIEWER NAME:	TBD
PERIOD OF PERFORMANCE:	Complete written review on or before 04/10/2017
HONORARIUM:	$1,000.00

Project History and Objectives

The Bureau of Safety and Environmental Enforcement (BSEE) has requested an external peer review of the report: *Evaluation of Pressure Rating Methods Recommended by API RP 17TR8*, which was prepared by Aiken Engineering Company for Argonne National Laboratory. BSEE, within the U.S. Department of the Interior (DOl), is charged with the responsibility to permit, oversee, and enforce the laws and regulations associated with the development of energy (oil and natural gas) resources on the Outer Continental Shelf (OCS). BSEE's Office of Offshore Regulatory Programs is the responsible program manager for permit policy oversight and for regulations and standards development for offshore oil and gas facilities. Current regulations require that operators of these offshore oil and gas facilities submit detailed information that demonstrates equipment are able to perform in the applicable High Pressure and High Temperature (HPHT) environment in their permits for applications to drill, and applications for a permit to modify and deepwater operations plans (30 CFR 250.804).

Whereas more submissions to BSEE show the need for HPHT applications, BSEE has a need to determine whether or not operators' submissions are acceptable based upon proper modeling, safety factors, correct application of standards, and application of an appropriate design basis.

BSEE awarded a contract in 2014 to fill this information need, which generated a large technical report with appendices. The report is *Evaluation of Pressure Rating Methods Recommended by API RP 17TR8*. The conclusions of this report are anticipated to have a significant impact on selection of methods and factors chosen by industry and subsequently evaluated by BSEE. This report may be ·used to support the criteria for determination of acceptance and approval for the submissions and permits indicated above, and meet the criteria for "influential scientific information" under the Office of Management and Budget's Memorandum on Peer Review (OMB M-05-03). Therefore, BSEE has determined that selected sections of the report containing new scientific information shall be subjected to peer review.

The objective of this letter-style peer review is for BSEE to receive comments from individual experts on the selected sections of the report, *Evaluation of Pressure Rating Methods Recommended by API RP 17TR8*. This letter-style peer review is technical in nature, reviewing the methods, assumptions, data quality, the strengths of any inferences made, and the overall strengths and limitations of the study. Refer to the **BSEE Charge for the Scope of this Peer Review** provided below for an explanation of the sections of the report that are within the scope of this peer review.

Work Scope and Schedule

Your primary function as a peer reviewer is to review and provide written comments on the report. Specifically, you shall evaluate the report, provide general comments and overall impressions of the scientific merit of the report, and respond to the Charge Questions provided below. You are not requested to and should not provide input or advice on BSEE's policies and decisions. Your review is not page-limited, and you should take as much space as you feel is necessary to complete your review.

The EnDyna Team has selected you as part of a panel of three experts with: 1) practical experience with design of offshore equipment in high pressure and high temperature environments, and 2) practical experience in applying API RP 17TR8 and ASME Pressure Vessel Codes Section VIII, Division 2 and Division 3, and API Specification 6A in the design, modeling, and/or testing of high pressure and high temperature equipment.

You have more than three weeks to complete your written review of the report. After all three reviewers have completed and submitted their written comments to the EnDyna Team, the comments will be compiled into a comprehensive peer review report for distribution to BSEE. Your name and affiliation will be disclosed in the report, and the peer review report may be posted on BSEE's research webpage alongside the report. The peer review and the report may be openly discussed in industry forums and workshops. BSEE will likely publish a formal response to the peer review comments in a Comment Response Document.

KEY PEER REVIEW DATES	
Receive Peer Review Materials Package	March 14, 2017
Complete and Submit Written Comments	April 10, 2017

Location

No travel is required as this is a letter-style peer review.

Confidentiality Requirements

As noted in the confidentiality agreement, your comments should not be distributed or discussed with any outside party, including members of the public, state government, DOI, or other Federal agencies. If you are contacted in person or in writing regarding the report under review by anyone other than EnDyna Team, you should immediately inform EnDyna.

Disclaimer

In accordance with the Office of Management and Budget's (OMB) *Final Information Quality Bulletin for Peer Review*, "this information is distributed solely for the purpose of pre-dissemination peer review under applicable information quality guidelines. It has not been formally disseminated by the Agency. It does not represent and should not be construed to represent any agency determination or policy."

In addition, the reviewers shall conduct their review of the report in a manner that complies with the guidelines and policies included in OMB's *Final Information Quality Bulletin for Peer Review*, Executive Order 12866, and DOI's Information Quality Standards, Department Manual, and Peer Review Process Manual.

BSEE Charge for the Scope of this Peer Review

BSEE has carefully defined the scope of this peer review in order to focus the peer review process effectively on BSEE's Charge Questions. Your written comments should stay within the BSEE scope defined below. It is important to remember that this letter-style peer review is technical in nature, reviewing the methods, assumptions, data quality, the strengths of any inferences made, and the overall strengths and limitations of the study.

The scope of the peer review is focused on the material, fabrication, computations, testing, engineering factors, modeling, and their basis, and final recommendations components of the report generated by this study. The review is technical in nature and does not focus on editorial style. The peer review must consider the appendices as pertains to the peer review questions. The peer reviewers may refer to out-of-scope sections when providing comments on the conclusion and recommendations, which draw from out-of-scope sections and the computations, engineering factors, modeling and final recommendations components contained in the report. The document for review is located at:

https://anl.app.box.com/v/pressure-rating-methods.

Instructions for Preparing Written Comments and Logistics

In order to ensure that all Charge Questions are answered completely and each reviewer submits their comments in a consistent format, a peer review comment template containing the two major sections below is attached. Please use this template to prepare your written comments. Once you have completed the template, please email your comments in MS Word to Max Cropper at mcropper@endyna.com. **Comments are due on or before April 10, 2017.**

When completing each section in the peer review comment template, refer to the **BSEE Charge for the Scope of this Peer Review** provided above. Please remember that the scope of this peer review is focused on the material, fabrication, computations, testing, engineering factors, modeling, and their basis, and final recommendations components of the report generated by this study.

I. **General Impressions –** Provide overall impressions (approximately 1/2 page in length) addressing the accuracy of information presented, clarity of presentation, and soundness of conclusions.

II. **Response to Charge Questions –** Provide narrative responses to the Charge Questions. The Charge Questions are listed below.

PEER REVIEW COMMENT TEMPLATE
Evaluation of Pressure Rating Methods Recommended by API RP 17TR8
NAME:
DATE:
AFFILIATION:
BACKGROUND. Briefly describe how your background, experience, and involvement with HPHT subsea equipment qualify you to evaluate the *Evaluation of Pressure Rating Methods Recommended by API RP 17TR8API RP 17TR8*:
VII. GENERAL IMPRESSIONS
Provide overall impressions (approximately 1/2 page in length) addressing the accuracy of information presented, clarity of presentation, and soundness of conclusions.
VIII. RESPONSE TO CHARGE QUESTIONS
Provide narrative responses to each of the eight Charge Questions below.
1. *Evaluation of Test Methods*
1.1–*Were the test objects selected for analysis valid test objects to evaluate the standard as applied? Consider true stresses and strains in the context of valid discussion.*
1.2–*Are the assessments of engineering safety factors for the cited standards and their divisions valid for the expected applications?*
1.3–*Were comparisons of the computational methods and design methods adequate?*
1.4–*Are the assumptions of the modeling and tests clearly defined and appropriate?*
1.5–*Did the report identify and adequately address the strengths or weaknesses of the analytical methods used for the modeling and testing methods used?*
1.6–*Were the actual materials within specification for F22 material properties adequate?*

PEER REVIEW COMMENT TEMPLATE
Evaluation of Pressure Rating Methods Recommended by API RP 17TR8
1.7–*Determine the degree of certainty that each test object did not have a latent defect, was forged properly, and manufactured properly; for example, should there have been a posted manufacturing stress reduction heat treatment?*
1.8–*The report documents a failure of the tested object for the 17 TR8 Division 3 method to show a failure of the test object at a threshold below the design standard. Do the conclusions and recommendation based upon this stand alone? Are there other considerations, such as the fact that the material chosen is a non-Division 3 material, or any other alternate logical explanation for failure event below the Division 3 design standard?*
1.9–*Are there other obvious conclusions that the report should have addressed identified by the peer review?*
2. *Evaluation of Modeling Results: Do the modeling results describe with reasonable accuracy the basis for decisions in the applied methods:*
2.1–*Are the limitations and uncertainties clearly identified and adequately characterized for the methods of modeling selected?*
2.2–*Are the assumptions of the modeling appropriate for the methods of modeling selected? Assumptions evaluated should include, but are not limited to:* ▪ *Material Thickness* ▪ *Mesh chosen* ▪ *The correspondence of the modeling to the design basis specified in the standard*
3. *Are there strengths or weaknesses of the analytical methods used for the empirical calculations chosen in the report?*

PEER REVIEW COMMENT TEMPLATE
Evaluation of Pressure Rating Methods Recommended by API RP 17TR8
4. ***Are the conclusions drawn by the report appropriate based on the modeling results and empirical analysis?***
5. ***Are the conclusions related to the test appropriate?***
6. ***Are the other conclusions appropriate?***
7. ***Are the recommendations logical, appropriate, and supported by the conclusions of the test results, empirical analysis, and modeling results? The scope of the recommendations pertains to all recommendations, not just those derived from the modeling results.***
8. Are there any obvious technical considerations the report should have covered that are missing?

7. REFERENCES

1 *Dixon, R. D., E. H. Perez, "Comparison Between Linear-Elastic and Limit Analysis Methods for the Design of High Pressure Vessels", ASME PVP-Vol 344, High Pressure Technology, New York, NY, 1997.*

2 *Terada, Susumu, "Development of Alternate Methods for Establishing Design Margins for ASME Section VIII Division 3", ASME PVP2008-61146, New York, NY, 2008.*