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Scott Angelle Director Bureau of Safety and Environmental Enforcement U.S. Department of the Interior 1849 C Street, NW Washington, DC 20240

Re: National Academies Report on High-Performance Bolting Technology

Dear Director Angelle:

The American Petroleum Institute (API) and its members are committed to safety as well as continually improving training, operating procedures, technology and industry standards. As such, we appreciate the interest of BSEE and the National Academies in standards development activities related to safety. However, we have some concerns regarding a recently published National Academies report entitled "High-Performance Bolting Technology for Offshore Oil and Natural Gas Operations." As part of this commitment API and Industry have formed a multi-segment workgroup comprised of Operators, Drilling Contractors, and Equipment Manufactures (including bolt manufacturers) and steel mills to address issues related to subsea bolts and fasteners. These experts have reviewed the report and provide the following supplemental information for consideration. Each finding in the report is followed by an industry response. They are numbered for ease of reference.

1. Pages 54-55

Finding: "Oil and gas industry specifications and practice use torque as the value to be measured in tightening flange bolts. Torqueing, as currently specified in the oil and gas industry, is an inaccurate method of preloading flange bolts."

"As operations have moved deeper offshore and bolts experience more demanding service, the use of torque as a bolt/stud/nut tightening criteria to establish a connector tensile preload has outlived its usefulness. There is sufficient evidence that the practice of demanding increasingly accurate bolt torqueing equipment is non-optimal. Furthermore, it carries the risk of believing that the accuracy of torqueing reflects the accuracy of the desired design parameter-bolt preloading."

Industry Response:

Torque methods have been used for decades to reliably preload bolted connections. However, Industry is actively using or investigating newer and more accurate methods of determining preload, such as measuring bolts elongation after torqueing. Original Equipment Manufacturers (OEMs) have performed many empirical tests to accurately determine the friction factors associated with recommend torque values for a given lubricant. These friction factors are then reliably used to calculate the required torque to achieve the desired preload in bolted connections. Original Equipment Manufacturers and equipment owners have detailed procedures and calibrated equipment to ensure the correct torque (and therefore preload) is applied during makeup.

2. Page 55

Option 2.1: "BSEE could convene an industry study group to investigate flange bolt design and installation standards. Options which could be considered include:

- Put a hold on requirements for industry to use more accurate torqueing equipment.
- API Spec 17D could be revised to "require" rather than "recommend" that bolts be accurately preloaded.
- Eliminate the term "torque" as torque has been determined to be inherently inaccurate. Suggest the use of a more accurate bolt pretensioning method for critical flange bolt preloading on all new equipment fabrication and at five yearly inspections. (Appendix J lists some alternative bolt pre-tensioning methods.)
- Consider commissioning engineering design studies to determine realistic tension loading safety margins for flange bolts. Such a study could initially concentrate on the preload variability that results from torqueing, however assessments of operational loading uncertainty and in-service material degradation could also be considered.
- Consider commissioning a study to evaluate the impact of a single bolt failure on overall connector reliability. This study could cover a range of flange sizes (i.e., number of flange bolts).
- Consider new and revised specifications, standards and recommended practices to be incorporated into Code of Federal Regulations (CFR) 30 section 250 based on proactive assessment of risk areas."

Industry Response:

Industry is willing to work with BSEE to further investigate flange bolt design and installation standards. API flange bolt preload specifications of 50% of specified minimum yield strength (SMYS) are lower than other industry codes that allow higher percentages of SMYS. In addition, designs are made to set target pretensions at 10% or more below the maximum allowed stress for the material SMYS. Also, the pre-tension is set to statically load the fastener in excess of environmental forces (pressure and bending fluctuations) while not exceeding the maximum allowed 83% of SMYS.

3. Page 55

Finding: "Current specifications for offshore fastener steels prohibit the use of continuous cast products, primarily because the existence of banding has been observed in steels which also failed in service by hydrogen embrittlement. However, as a result of recent advances in steel making casting technologies, significant advances in product quality have been realized."

Industry Response:

The industry standard prohibiting use of continuous cast steels is limited to products produced in accordance with grade BSL-3 of API Spec 20E - *Alloy and Carbon Steel Bolting for Use in the Petroleum and Natural Gas Industries.* The prohibition is not based solely on banding concerns. Additionally, although hydrogen embrittlement failure is a major concern, it is not the only cause of failure addressed by the continuous cast steel restriction. Continuous cast steel was determined by the API 20E Task Group to be more susceptible to macrostructural and microstructural deficiencies in addition to hydrogen embrittlement. It is recognized that the greater reduction ratios common to ingot cast steel can result in superior properties, with impact properties being the prime example. The API 20E Task Group is currently considering permitting use of continuous cast steel with added process requirements and size limitations.

4. Page 56

Option 2.2: "BSEE could request an industry-led consortium with academic participants to initiate systematic studies to investigate and evaluate the environmentally assisted cracking/hydrogen embrittlement susceptibility of continuous cast and ingot cast steels. The results on continuous cast steels could also include "modern" product produced in newer facilities and characterized with non-destructive testing techniques to assess soundness. The consortium could also evaluate alternate steel alloys and processing histories leading to improved in-service performance. The prohibition of banding to maintain product quality for subsea bolting could also be reviewed."

Industry Response:

API Subcommittee on Materials (SC21) currently has a task group with a charge that includes the basic points of this option. Research is underway to determine the effect of material strength and material quality on the susceptibility to hydrogen embrittlement in seawater service. The initial testing now in progress is on ingot cast steel. Subsequent testing will be on continuous cast steel.

5. Page 56

Option 2.3: "Under the oversight of BSEE, the industry could collect data on the service conditions and performance of bolting in all critical riser/BOP applications for every deepwater drilling operation. This would include subjecting all fasteners, failed and un-failed, in these critical applications to a thorough post-operational inspection—requiring a full dimensional check and metallurgic post-mortem, with root-cause analysis being performed when the equipment did not perform according to design."

Industry Response:

Industry agrees that a root cause analysis (RCA) should be performed on any failed critical BOP/riser fasteners. Several RCAs have been completed with the involvement of BSEE over the past several years. Unfortunately, all of these case studies could not be shared with the NAS committee due to the confidentiality agreement in place with BSEE.

6. Page 57

Option 2.4: "The oil and gas industry could pursue technologies that offer more effective NDT inspection of bolts in-situ, on the deck, and in the shop. Employment of these technologies could be made mandatory by BSEE as they have been qualified in other industries."

Industry Response:

There are various methods of NDT currently being used by equipment users based on API and internal company periodic maintenance requirements. Some of the recognized methods being used are: Visual inspections, Ultrasonic Testing, including Phased Array Ultrasonic Testing (PAUT), Dye Penetrant Inspection, Magnetic Particle inspection, torque checks, and bolt elongation measurements. Industry is utilizing a number of new nondestructive testing (NDT) technologies to evaluate in-service critical BOP bolts. Phased array ultrasonic evaluation has been completed on a number of bolts, and the procedures are being updated with lessons learned to maximize the value of phased array inspection.

7. Page 57

Option 2.5: "BSEE could establish inspection requirements for un-failed bolts during the five-year shop inspection or could require that all critical bolts be replaced during this inspection. BSEE should also establish / require serial numbers on all critical bolts so that inspections of any specific bolt could be documented and catalogued. The results from inspections should be reported as determined by mutual agreement between BSEE and the organization performing the five-year shop inspection."

Industry Response:

The current industry standard (API 53 *Blowout Prevention Equipment Systems for Drilling Wells*) requires an inspection every 3-5 years, regardless of location (e.g., offshore or onshore). As this standard provides for inspections more frequently than every 5 years, industry can know the condition of the bolts and replace them if warranted. Therefore, arbitrary replacement of un-failed bolts every 5 years is overly burdensome. Also, bolts that have been in service and have undergone periodic inspections such as PAUT are generally considered proven for continued use.

Industry will further discuss the recommendation for serial numbers on critical bolts.

Currently bolts that have completely failed are reported through the RAPID-S53 database and internal company equipment failure reporting systems. Failures from the RAPID-S53 database are also reported directly to the Bureau of Transportation Statistics (BTS).

8. Page 58

Recommendation 2.7: "The oil and gas industry should establish a comprehensive methodology and or program to optimize the cathodic protection (CP) practice for critical assets containing fastener metallic materials. For current structures, CP monitoring and assessment practice should be instituted. As new structures are designed, the industry should establish CP design requirements optimized for materials in use, based on electrochemical fundamentals. This project should evaluate the use of "low voltage" aluminum anodes currently being used by the U.S. Navy and the French Navy to reduce the risk of hydrogen assisted cracking of their high-strength alloys."

Industry Response:

Industry agrees with the recommendation of evaluating the use of "low voltage" aluminum anodes. Industry requests that specific details (chemical composition, supplier information) be passed on from the U.S. Navy to share lessons learned. The evaluation of "low voltage" aluminum anodes should consider, as a minimum, the complex geometries of the subsea structures, the wide water temperature and oxygen concentration range in which these structures operate, and the long design life for some of the structures.

Industry is also performing cathodic protection surveys on those in-service BOPs and riser-utilizing ROV probes. Industry will determine how to share the lessons learned from these studies.

As mentioned in number 4 above, API SC21 is conducting research that includes the effect of cathodic protection on bolting of different hardness and quality to determine susceptibility to hydrogen embrittlement in seawater service.

9. Page 59

Recommendation 2.8: "The industry should review the usage of materials (e.g., lubricants containing sulfides) in contact with fasteners that are known to poison the chemical reaction of atomic hydrogen converting to molecular hydrogen (hydrogen gas) and identify substitute materials so that the concentration of atomic hydrogen at the metal surface is reduced.

BSEE could consider immediately prohibiting the use of sulfide-containing lubricants until such a study indicated that they can be used without enabling hydrogen uptake."

Industry Response:

Industry recognizes that there have been fastener failures potentially attributed to the presence of sulfides. Notably, in the 1993 to 1994 timeframe there were several failures of fasteners manufactured from Cu-Ni-Mn-Al-Nb alloy, which is a high strength alloy, with low Charpy values. At that time, these failures were allegedly attributed to environmentally assisted cracking potentially associated with the presence of sulfides. It should be noted that the nature of the Cu-Ni-Mn-Al-Nb alloy makes it susceptible to hydrogen embrittlement even without sulfide presence. Industry research¹ suggests that sulfide-containing lubricants are one risk factor in a complex combination of design, mechanical and environmental factors, which led to the Cu-Ni-Mn-Al-Nb bolt material failures. Therefore, sulfide-containing lubricants may erroneously be blamed for some bolting failures.

For many years industry has used molybdenum-disulfide (MoS₂) lubricants with a heavy paraffin base for lubricating fasteners. In an oil/gas production system, the absolute amount of friction-reducing MoS₂ is limited. Further, additional scavenging and dilution effects by the surrounding metals and fluids occurs. This means that H₂S formation from MoS₂ hydrolysis reaction below 250°F will most likely be lower than NACE-defined sour limit (0.05 psi partial pressure H₂S). Additionally, fasteners used on offshore drilling rigs are typically operating in

¹ Paper No 78 of the NACE International Annual Conference and Exposition CORROSION 96, EVALUATION OF HIGH-STRENGTH Cu-Ni-Mn-Al BOLTING USED IN OIL AND GAS SERVICE

temperatures less than 170°F. Therefore, such temperatures limit the formation of hydrogen sulfide, from MoS₂, that may lead to sulfide stress corrosion cracking or hydrogen embrittlement. Lastly, fasteners used on offshore drilling rigs are typically manufactured from carbon steels or corrosion resistant alloys, excluding the Cu-Ni-Mn-Al-Nb alloy. There are no recorded bolting failures of these materials that can be attributed to sulfide-containing lubricants. Therefore, we believe that sulfide-containing lubricants are not adding additional risk for use on carbon steel, low alloy steel, stainless steel, and corrosion resistant alloy fasteners, excluding fasteners made from Cu-Ni-Mn-Al-Nb alloys and potentially other materials highly susceptible to hydrogen embrittlement.

10. Page 59

Option 2.9: "The committee suggests that cluster failures be investigated by BSEE in large-scale fully instrumented flange test rig that simulates subsea conditions on fasteners in bolted joints including structural loads, environmental conditions, and cathodic polarization. These investigations are necessary to definitively establish the origins of these cluster failures and to prove the effectiveness of mitigation strategies."

Industry Response:

Industry has investigated the "unzipping" characteristic of previous bolt failures. Typically, failure occurs on a bolt with a manufacturing defect. The bolts that are then in close proximity to the failed bolt experience a higher stress which can then cause any material defects to initiate failure at that bolt and expand from there.

11. Page 60

Finding: "There is not an accepted laboratory standard test method within the industry to assess the susceptibility HAC for bolting materials used in offshore applications."

Recommendation 2.10: "The oil and gas industry should establish through adequate research an accepted laboratory standard test method to assess the susceptibility to hydrogen assisted cracking of bolting materials and their coatings used in offshore applications."

Industry Response:

There are laboratory test methods available to determine the susceptibility of hydrogen assisted cracking in offshore applications. Research is being conducted in API SC21 on coatings for short term protection and maximum material strength. Industry standards ASTM F2660 - *Standard Test Method for Qualifying Coatings for Use on A490 Structural Bolts Relative to Environmental Hydrogen Embrittlement* and F1624 - *Standard Test Method for Measurement of Hydrogen Embrittlement Threshold in Steel by the Incremental Step Loading Technique* are being used for this purpose.

12. Page 60

Finding: "Bolt designs, as currently specified in the oil and gas industry, utilize standard well-accepted thread designs. These thread designs can result in extremely high stress concentrations at the thread roots—especially on the first thread root. Other industries have utilized innovative designs to alleviate this problem."

Industry Response:

Industry disagrees that stress concentrations at thread roots is extreme. API 20E - Alloy and Carbon Steel Bolting for Use in the Petroleum and Natural Gas Industries and API 20F - Corrosion-resistant Bolting for Use in the Petroleum and Natural Gas Industries both require external Unified National Threads with "R" (UNR controlled radius root) series on the male threads where the highest stress concentration exists.

13. Page 60

Finding: "Threads are generated by either machining or rolling. To date, assessment of the selected thread design and method of manufacture used for offshore applications to ensure that the design exhibits the maximum resistance to environmentally assisted fracture has not been undertaken."

Industry Response:

Research is planned in API SC21 to quantify the hardness increase in precipitation-hardened nickel alloys of coldrolled threads versus a machining/thread cutting operation and to recommend a method for testing. The project is scheduled to begin in calendar year 2019.

14. Page 60

Recommendation 2.11: "The oil and gas industry should:

- Assess various thread designs and manufacturing methods for maximum resistance to environmentally assisted fracture.
- Conduct systematic studies to assess effect of bolt designs (including the tread geometry) on hydrogen assisted cracking susceptibility.
- Pursue research into thread designs which could reduce the stress concentration in bolt threads."

Industry Response:

Industry requests that specific details of "better thread designs" cited from US Navy (report page 120) be shared so industry can evaluate their performance in our applications.

See additional information in number thirteen above.

15. Page 60

Recommendation 2.12: "The oil and gas industry should review the standards relating to bolt tensioning, both in terms of loading as a percent of yield strength and in terms of preloading technique, to minimize the probability for under- or over-tensioning bolts operating in subsea environments."

Industry Response:

The role of excessive preload with respect to industry bolt failures is inconclusive at this point. Therefore, studies that focus on other areas of identified failure such as bolt coatings would be more beneficial. Analysis methods for rig and equipment operations are more accurate now than in previous years. This ensures that equipment limits are not exceeded when operating the rig and equipment. See additional information in number one above.

16. Page 88

Finding: "There is insufficient attention to individual worker and skill development through selection, training, and work process design."

Industry Response:

The Code of Federal Regulations currently requires a Safety and Environmental Management System (SEMS) for performing work in the Gulf of Mexico. SEMS is a competency management tool that helps identify required training, auditing and assessing of skilled workers. Companies performing operations in the Gulf of Mexico have training requirements and on the job assessments.

Industry has multiple work fronts investigating human factors and how individuals contribute to the success/failure of equipment. Industry agrees competency is a critical piece in the equation for project success. Quality management system specifications such as API Q1 - *Specification for Quality Management System Requirements for Manufacturing Organizations for the Petroleum and Natural Gas Industry* and API Q2 - *Specification for Quality Management System Requirements for Service Supply Organizations for the*

Petroleum and Natural Gas Industries have placed an increasing emphasis on the need for training. In response, industry training requirements and levels have increased significantly and are continuing to improve.

17. Page 89

Finding: "Multiple organizations often have conflicting work processes and share minimal information (rigs, operators, OEMs)"

Industry Response:

While multiple organizations that occupy different functions (suppliers, owners, operators, service providers, etc.) within a single sector will understandably focus on different aspects of the same concern, this should not be interpreted to be that they are conflicting.

Below are a few examples of shared processes and communication channels between typical organization types within the drilling industry:

Contractor and Operator:

- Non-conformance and performance tracking
- Internal and external audits (contractor, operator, manufacturer)
- Shared failure investigations (contractor-operator)

Equipment Owners (contractors and operators) and manufactures:

- Equipment bulletins manufacturers send equipment owners bulletins with solutions to witnessed conditions or performance problems
- Equipment advisories- manufacturers send advisories for events that occurred as a result of inadequate procedure
- Safety alerts can stem from manufacturer, operator, or contractor experiences
- Failure reports equipment owners report failures to manufacturers for resolution
- Product improvements advisories manufacturers communicate product news to equipment owners
- Equipment issue communications equipment owners report equipment issues to both operators and manufacturers
- Equipment modifications and MOC process all have elements of communication as one leg of change management.

All:

- RAPID-S53 [owner, operators and manufacturers]
- JIPs [owner, operators and manufacturers]
- API involvement in standards development [owner, operators, third parties, government representatives, and manufacturers]

18. Page 89

Recommendation 4.1: "The oil and gas industry should promote an enhanced safety culture across organizations and disciplines that is reflected in work rules and that involves encouragement at all levels of the organization to improve the reliability of subsea bolts. This would include the following:

- The creation of a dedicated organizational human systems stakeholder;
- Attention to the individual worker and skill development through training, selection and work process sign;
- Company and industry-wide sharing of best practices for collecting and disseminating information about fastener performance, failures, and near misses; and
- Assessing gaps that could be mitigated by technology developments."

Industry Response:

There are many examples of how, on many levels, the industry's organizations are involved in the improvement to both materials and work standards that improve the reliability of subsea bolts:

- SEMS requirements from subpart S 250.1916 (b) requires employee training for those involved in maintaining equipment and systems as part of the mechanical integrity program.
- The International Association of Drilling Contractors (IADC) has a Key Skills and Ability competencies list which mirrors the content of most contractor's competency programs and includes the subjects of torqueing and friction coefficient's effect on preload.
- Rig personnel receive OEM product bulletins including alerts which carry actions [equipment inspection, procedure reviews, etc.] for all equipment, not just fasteners. There have been nearly a dozen product advisories issued by the OEMs of BOP equipment in the last 3 years that address materials, procedures and measurement which demonstrates active engagement of the subject.
- OEM and equipment owners provide specific torqueing instructions to their crews which complements the OEM issued procedures. [Examples GE x-1018450, Cameron EB962, NOV AX050091, etc.] All of these procedures have common themes of specific lubricants, application of lubrication, use of calibrated tools, torque patterns and staged torque rounds and are easily evidenced when visiting work sites.
- Rig personnel are kept up to date with any revisions to fastener procedures received from the OEMs that result from testing or design changes.
- Both OEMs and equipment owners record the torqueing values and process used, including torqueing pattern and sequence as a part of assembly and maintenance records.
- OEMs, equipment owners, and operators have collaborated within the various API specifications, from supply chain management standards to manufacturing and integration standards, to improve BOP equipment critical fastener quality control and design specification standards. Examples include:
 - o API 20E and API 20F for the manufacture of fasteners,
 - API 16A Specification for Drill-through Equipment, API 16F Specification for Marine Drilling Riser Equipment, API 16C - Choke and Kill Equipment (in ballot), API 6A - Specification for Wellhead and Christmas Tree Equipment (in comment resolution), and API 6DSS - Specification for Subsea Pipeline Valves for design and manufacture of well control equipment, and
 - API S53 *Blowout Prevention Equipment Systems for Drilling Wells* (in comment resolution) for system management.

API appreciates the opportunity to work with BSEE to continue to advance our shared objective of safe offshore operations. If you have any questions, please contact me by phone at (202)682-8439, or by e-mail at https://www.hopkinsh@api.org.

Sincerely,

In J. Atople

Holly A. Hopkins

cc: Doug Morris, Chief, Office of Offshore Regulatory Programs, BSEE Lars Herbst, GOM Regional Director, BSEE