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Technical Note

Proper Use of Technical Standards in Offshore Petroleum Industry

Dejan Brkić * and Pavel Praks *

IT4Innovations National Supercomputing Centre, VŠB—Technical University of Ostrava, 70800 Ostrava, Czech Republic

* Correspondence: dejanbrkic0611@gmail.com or dejan.brkic@vsb.cz (D.B.); pavel.praks@vsb.cz (P.P.)

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Abstract: Ships for drilling need to operate in the territorial waters of many different countries which can have different technical standards and procedures. For example, the European Union and European Economic Area EU/EEA product safety directives exclude from their scope drilling ships and related equipment onboard. On the other hand, the EU/EEA offshore safety directive requires the application of all the best technical standards that are used worldwide in the oil and gas industry. Consequently, it is not easy to select the most appropriate technical standards that increase the overall level of safety and environmental protection whilst avoiding the costs of additional certifications. We will show how some technical standards and procedures, which are recognized worldwide by the petroleum industry, can be accepted by various standardization bodies, and how they can fulfil the essential health and safety requirements of certain directives. Emphasis will be placed on the prevention of fire and explosion, on the safe use of equipment under pressure, and on the protection of personnel who work with machinery. Additionally considered is how the proper use of adequate procedures available at the time would have prevented three large scale offshore petroleum accidents: the Macondo Deepwater Horizon in the Gulf of Mexico in 2010; the Montara in the Timor Sea in 2009; the Piper Alpha in the North Sea in 1988.

Keywords: equipment certification; maritime safety; offshore accidents; oil and gas; technical standards; petroleum engineering

1. Introduction

Today, when the protection of the environment is a top priority, it is also imperative to protect oceans from pollution. Oceans know no national borders, and hence one oil and gas accident can have a large impact on many states. In the current world, we witness huge amounts of gas being burnt, unused on the flares of offshore oil fields or on distant onshore oil fields [1,2]. On the other hand, even the trade of quotas for the gasses with greenhouse effects exists, and some unused sources of natural gas are being investigated by energy companies for possible future exploration. In such a controversial world, it is important to re-evaluate current practices in the application of legislation for oil and gas drilling that are used worldwide [3,4]. For example, every region has its own characteristics, where, for example, drilling in cold regions [5–8] has additional requirements compared with drilling in moderate climatic regions. Similar to nuclear accidents, the probability that a major offshore oil and gas accident will occur is relatively low, but if it happens the consequences can be catastrophic. The offshore petroleum industry is complex, with different hazards, such as from leakage [9], pressure [10], moving objects, fatigue [11], fire, explosions, and in different various shocking events [12–15].

Devices and equipment which are used in the offshore petroleum industry are highly sophisticated, complex and they are developed, designed, and manufactured using certain technical standards. Some technical standards are developed on the national level, but in practice, if they are widely accepted as a good example of the best practice by the worldwide offshore petroleum industry, informally they are treated as international. Obviously, the recommended best procedures ought to be accepted and used around the world, but this should be done carefully to avoid damages to the domestic industry of a host country [16–18].

Offshore petroleum industries are based on a variety of overlapping philosophies with very different approaches to achieving high levels of safety. A very short overview of three offshore accidents to describe the complexity of this industry follows (two accidents from drilling mobile units and one from a production permanent platform): (1) the Macondo Deepwater Horizon oil spill in the Gulf of Mexico; (2) the Montara in the Timor Sea; (3) the Piper Alpha accident in the North Sea:

(1) The Macondo Deepwater Horizon oil spill occurred in the Gulf of Mexico on 20 April 2010 on the Macondo prospect, around 60 km seaward from the Louisiana coast, where British Petroleum (BP) was the oil company operator while Transocean was the rig contractor. It is to date the largest offshore petroleum accident ever in terms of hydrocarbon release [19–24]. It should be noted that the mentioned spill was caused by the Macondo Deepwater Horizon semi-submersible rig, operated by Transocean Ltd., the world's second largest offshore drilling contractor who is based in Switzerland but also with offices in many other countries. The rig was registered by the American Bureau of Shipping (ABS) and operated under a Marshall Islands flag of convenience and was built by South Korean company Hyundai Heavy Industries. The rig was chartered to British Petroleum, headquartered in London, the United Kingdom, which was the developer of the Macondo prospect with 65% stake, while the United States-based now defunct Anadarko Petroleum Corporation had 25% stake. Last but not least, United States-based MOEX Offshore 2007, a subsidiary of large company, Japanese Mitsui had 10% stake. The cause of the accident was a failure of the cement to form a proper shield of concrete at the base of the Macondo well at the level at which it was supposed to contain oil and gas.

(2) The Montara oil spill occurred on 21 August 2009 in the Montara offshore oil field northwest of the Australian coast in the Timor Sea. Although much smaller in terms of hydrocarbon release compared with the Macondo Deepwater Horizon accident, the Montara oil spill was the first such accident in this part of the world for 25 years [25]. The West Atlas jack-up drilling rig at the Montara prospect was built by Keppel Fels at the Keppel Shipyard in Singapore in 2007 and was one of the largest in the world. The West Atlas rig was owned by the Norwegian–Bermudan Seadrill and operated by PTTEP Australasia (PTTEPAA), a subsidiary of PTT Exploration and Production (PTTEP), an oil and gas exploration company from Thailand. The cause of the accident was a failure of the cement to form a barrier of concrete (failure to install a pressure containment cap on the well).

(3) The Piper Alpha accident occurred on 6 July 1988, offshore in the North Sea about 190 km northeast of Aberdeen, Scotland [26]. It is, to date, the deadliest offshore petroleum accident. The Piper Alpha was a large fixed production platform located at the offshore Piper oilfield, which was operated by Occidental Petroleum (Caledonia) Limited-OXY, a US company. The platform, which had four modules separated by firewalls, was constructed partly by McDermott Engineering in Scotland and partly by the Union Industrielle d'Entreprise in France. The cause of the accident has been unclear to date, but most probably it was due to bad maintenance management—the release of as little as 30 kg of condensate (mainly propane) over thirty seconds through an unsecured blind flange, where a pressure safety relief valve had been removed as part of maintenance on the standby condensate pump [27].

From these three examples, it is obvious that devices and equipment for the offshore petroleum industry are manufactured in different countries and most probably using many different technical standards. Besides, it can be foreseen that such equipment and devices installed and used on drilling units will, by default, often be transferred during their lifetime from one country to another (sometimes possibly avoiding custom duties and related technical controls). This can cause problems if the technical standards in the different host countries are incompatible. Therefore, selecting the appropriate and the best technical standards is complex, as some countries prescribe exactly which standards should be used, while in others the best worldwide available appropriate technical standards are expected to be used (sometimes without going into too much detail about how to choose such standards).

Here we will describe the specific situation in the European Union and European Economic Area (EU/EEA), where the product safety directives explicitly exclude from their scope offshore mobile units for drilling, and in some cases, related equipment on board (with some extensions to the well-control equipment under pressure, which is used onshore). Details about these exclusions will be explained especially in the spotlight of the EU/EEA offshore safety directive, which explicitly requires the use of the best worldwide available technical standards. Some notes about the prevention of major or other types of accidents in the offshore petroleum industry will be examined, mostly in respect to the safe use of equipment under pressure, protection against fire and explosions, the protection of staff who work with machinery, etc.

2. Legislation and Technical Standards

European Union directives are legally binding pieces of legislation in the European Union (EU) and also in the European Economic Area (EEA), which includes Norway, Iceland, and Lichtenstein (and in the UK, after leaving the EU during the transitional period, at least until the end of 2020, and in some other countries through bilateral agreements, such as Switzerland, which is out of both the EU and the EEA). All EU/EEA directives are principally designed to protect the single market of the EU/EEA [28].

The directives relevant for the offshore petroleum industry are (i) Directive 2013/30/EU on safety of offshore oil and gas operations (used as an umbrella Directive for offshore safety) and (ii) the product safety directives (these directives are relevant but, as explained in Section 2.1, they explicitly exclude from their scope drilling ships and related equipment)—(ii-1) the ATEX directive 2014/34/EU, for prevention against explosions; (ii-2) the pressure equipment directive 2014/68/EU; (ii-3) the machinery directive 2006/42/EC. Some others, such as the EU/EEA marine equipment directive 2014/90/EU, apply to equipment installed and used on-board ships that are registered in the EU and the EEA, but does not interfere with oil and gas drilling (therefore the "Wheelmark" sign, i.e., certification according to this directive does not apply to oil and gas equipment intended for drilling).

Conformity with the EU/EEA directives can be achieved through the harmonized technical standards, which are nonbinding pieces of regulation. To prevent technical barriers and to assure freedom of trade in the EU/EEA where various standards existed or still exist, even the use of harmonized technical standards are sometimes not sufficient to assure full compliance with the essential health and safety requirements prescribed by the directives (some directives refer only to the essential safety requirements). In general, all other available technical standards can be used in addition to the harmonized standards if they can assure full conformity with the prescribed essential requirements. In Section 2.2. we will analyze the role of harmonized and other technical standards in the EU/EEA offshore petroleum industry and interactions among different standardization bodies. Technical standards should be used in the EU/EEA to provide easier compliance with the provisions of the essential health and safety requirements of the relevant directives (consequently, the Conformité Européenne "CE" sign could be affixed to a product. Certifications should be done in general by the notified bodies listed in the EU/EEA NANDO database (the New Approach Notified and Designated Organizations).

2.1. Explicit Exclusions from EU/EEA Product Safety Directives

In general, all equipment and machinery in the EU/EEA need to fulfil the essential health and safety requirements of the relevant directives, or only safety requirements in the case of directives which primarily protect equipment and only secondarily humans (e.g., the machinery directive 2006/42/EC deals with essential health and safety requirements, but the pressure equipment directive 2014/68/EU only deals with essential safety requirements). Additionally, as a rule in the EU/EEA, required by the "New Legislative Framework" [29] from 2008, which is an EU/EEA package of measures that aim to improve market surveillance and boost the quality of conformity assessments, the mandatory Conformité Européenne "CE" mark must be affixed on equipment and machinery that complies with the directives. This ensures fair competition by holding all companies accountable to the same rules (combining equipment manufactured using technical standards of different countries in an assembly is strongly discouraged—it is also not permitted to then affix the CE marking to components).

The importance of offshore environmental protection [30,31] and safety is noted in the European Parliament resolution, "Facing the challenge of the safety of offshore oil and gas activities". EU/EEA oil and gas offshore safety is based on the 2013/30/EU Directive, which deals with major accidents, while in general the product safety directives should be used for protection against all other types of accidents. However, the three mentioned product safety directives that are relevant for offshore safety in the EU/EEA—(1) the ATEX directive 2014/34/EU for prevention against explosions; (2) the pressure equipment directive 2014/68/EU; (3) the machinery directive 2006/42/EC—explicitly do not cover mobile offshore drilling units and, under certain conditions, related equipment on board. The exclusions are as follows:

(1) From the ATEX directive 2014/34/EU: In article 1, section 2(e) "seagoing vessels and mobile offshore units together with equipment on board such vessels or units";
(2) From the pressure equipment directive 2014/68/EU (essential safety requirements are designed to protect the equipment against hazards caused by pressure): in article 1, section 2(a): "pipelines comprising piping or a system of piping designed for the conveyance of any fluid or substance to or from an installation (onshore or offshore) . . . "; section 2(i): "well-control equipment used in the petroleum, gas or geothermal exploration and extraction industry and in underground storage which is intended to contain and/or control well pressure; this shall comprise the wellhead (Christmas tree), the blow out preventers (BOP), the piping manifolds and all their equipment upstream"; section 2(j–ii) " . . . compressors, pumps . . . "; section 2(n): "ships, rockets, aircraft and mobile off-shore units, as well as equipment specifically intended for installation onboard or the propulsion thereof";

(3) From the machinery directive 2006/42/EC (the essential health and safety requirements of this directive protect workers and personnel primarily): in article 1, section 2(f): "seagoing vessels and mobile offshore units and machinery installed onboard such vessels and/or units".

In general, so-called other types of accidents that should be covered by the product safety directives, in the worst-case scenario, can lead to major accidents with catastrophic consequences through a chain of unpredicted events. In addition to climatic changes or significant damage to the environment, the term "major accident" is defined in the directive 2013/30/EU as an incident with an explosion, fire, loss of well control, release of dangerous fluids or any other cause that has significant potential to cause fatalities or severe injuries to five or more people, and can lead to significant damage to an installation. Instead, through the product safety directives, drilling ships and oil and gas equipment onboard has been covered through the International Convention for the Safety of Life at Sea (SOLAS) and more specifically through the Code for the construction and equipment of Mobile Offshore Drilling Units of the International Maritime Organization (the MODU code). The MODU code has been developed to protect any ship as a vessel, and its integrity and stability in the first place in terms of navigation [32–35], emphasizing the additional requirements caused by drilling activities [36], but does not include requirements for the drilling of subsea wells or the procedures for their control (such drilling operations are subject to control by the coastal state). The MODU code is used in relation to the EU/EEA product safety directives as follows: (1) Protection against explosions; (2) Protection of pressure equipment; (3) Protection of personnel who works with machinery:

(1) Protection against explosions: The ATEX directive 2014/34/EU protects equipment onshore and on offshore fixed platforms and the ATEX directive 1999/92/EC protects personnel [37].

However, as prescribed by the MODU code, protection against explosions onboard mobile drilling units in the EU/EEA waters goes through the International Electrotechnical Commission System for Certification to Standards Relating to Equipment for Use in Explosive Atmospheres (IECEx). The IECEx was developed mostly for electrical devices [38] and hence explosions caused by mechanical equipment is not extensively covered through this scheme. For the many decades during which mechanical equipment has been used in hazardous areas without causing damage, some accidents have undoubtedly occurred, mostly due to friction and overheating [39]. Following that reasoning, the EU/EEA also included anti-explosive protection for machinery through the ATEX scheme [40]. On the other hand, the main shortcoming under the ATEX scheme is that it allows self-certification in some zones (manufacturer can demonstrate the safety), which is not allowed in the IECEx scheme [41–46]. Additionally, the ATEX scheme refers only to equipment and protective systems and does not make any distinction between machinery and electrical equipment [47–50]. Some other requirements are prescribed in other countries, such as in Russia [51,52].

(2) Protection of pressure equipment: Some equipment under pressure used offshore in the EU/EEA which is not specifically modified by adding, for example, moving compensators [53] (to annul the effect of waves at sea) are under the scope of the pressure equipment directive 2014/68/EU. The pressure equipment directive 2014/68/EU also excludes from its scope almost all equipment under pressure for drilling, exploitation or transport used in petroleum industries, including well-control equipment [54–57], both offshore on fixed or mobile units, or onshore. Besides, pumps are in the scope of the pressure equipment directive 2014/68/EU only if technical analyses show that the hazard, due to pressure, is the dominant and main factor of risk. Additionally, all assemblies under pressure need to be certified through the notified bodies listed in the EU/EEA NANDO database (the New Approach Notified and Designated Organizations), even when all parts of such assemblies have already been individually attested.

(3) Protection of personnel who works with machinery: Machinery which is used in the EU/EEA onshore or on fixed offshore platforms are under the scope of the machinery directive 2006/42/EC. The transfer of such machinery from mobile units to fixed platforms or onshore without the proper EU/EEA certification, or avoiding payments of custom duties is problematic.

2.2. Certification Using Technical Standards

Technical standards are not legally binding documents, but they are widely accepted in engineering practice. In the EU/EEA, they should be used to support the application of the relevant directives. In the EU, conformity with the appropriate directives can be achieved by using the appropriate harmonized standards. With the "New approach" of the Council of the European Union from 1985, there is an obligation of results (i.e., to meet the essential health and safety requirements, and not of means). For the application of imposed standards, any standard may be used, provided that it meets the essential health and safety requirements [38,58].

The most relevant standards for the offshore petroleum industry are by the Norwegian NORSOK (Norsk Sokkels Konkurranseposisjon—the Norwegian shelf's competitive position), by the United States' American Petroleum Institute (API), and by the International Organization for Standardization (ISO) Technical Committee TC 67. On the other hand, standards developed by classification societies and private institutions can be used in the offshore petroleum industry, but only in addition to the abovementioned technical standards. The role of classification societies in the shipping industry is to establish and maintain technical standards for the construction, operation, and classification of ships and offshore structures.

Harmonized standards are developed by the recognized European Standards Organizations, the Comité Européen de Normalisation (CEN), and the Comité Européen de Normalisation Électrotechnique (CENELEC). Although adherence to the standards is ultimately voluntary, these standards are created to support manufacturers, other economic operators, and conformity assessment bodies to demonstrate that products, services, and processes comply with the relevant directives. These two European Standardization Organizations—CEN and CENELEC—are officially recognized as competent in the area of voluntary technical standardization in Regulation 1025/2012. Besides, in the EU/EEA, ultimately any standard may be used provided that it meets the essential health and safety requirements of the relevant directives. For certain directives, only essential safety requirements are required, where the application of the harmonized CEN/CENELEC standards gives only a presumption of conformity to these directives.

The use of all the best worldwide available technical standards is also prescribed by the umbrella directive for offshore oil and gas safety in the EU/EEA: Directive 2013/30/EU (harmonized standards with this directive are not available). Here it should be noted that harmonized standards, which can support the product safety directives exist; they are extensively developed for the machinery directive 2006/42/EC and for the pressure equipment directive 2014/68/EU, but only partially for the ATEX directive 2014/34/EU. Due to the lack of harmonized standards, all other available technical standards should be used if they can assure full compliance with the essential health and safety requirements of the ATEX directive 2014/34/EU.

The International Organization for Standardization (ISO) develops technical standards for the offshore petroleum industry through its Technical Committee TC 67 "Materials, equipment and offshore structures for petroleum, petrochemical and natural gas industries". Some of the ISO standards are developed jointly with the American Petroleum Institute (API) [59]. Sometimes, the API standards are recognized by the ISO through TC 67, where they can be harmonized with appropriate EU/EEA directives through the Vienna agreement. The Vienna Agreement on technical co-operation between ISO and CEN, signed in 1991, was drawn up to prevent duplication of efforts of CEN and ISO, and reducing time spent preparing standards (a similar agreement exists between IEC and CENELEC—the Frankfurt agreement). The path for the harmonization of API standards with the relevant EU/EEA directives through these two agreements is depicted with a red arrow in Figure 1.

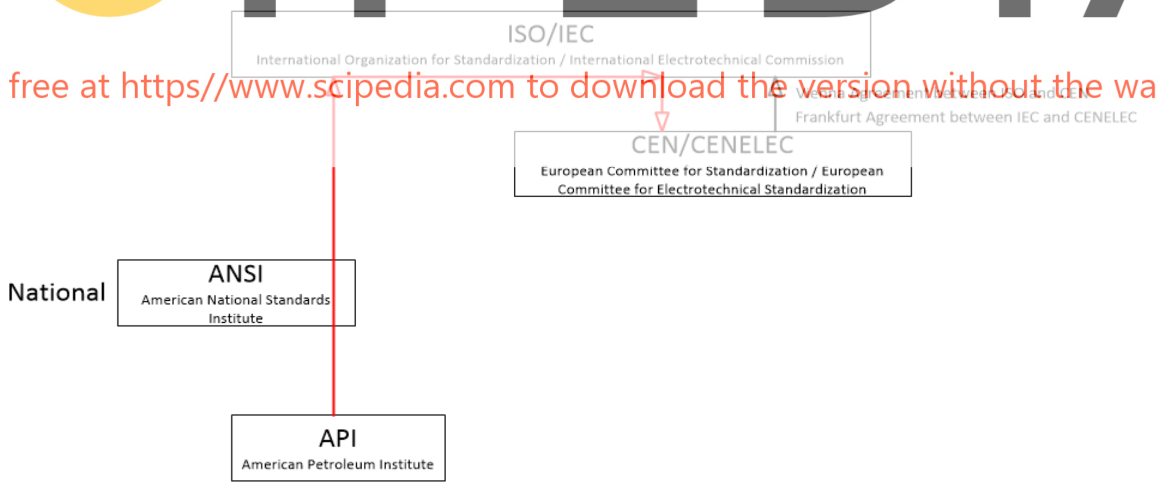

Figure 1. CEN/CENELEC harmonization of API standards with the appropriate EU/EEA directives through ISO/IEC following the Vienna and Frankfurt Agreements.

Some concerns exist regarding the combination of devices to form an assembly where some of the devices in the assembly are certified using different technical standards. Prior to being used, such assemblies must again be certified, but this time as a whole.

Even the best standards, such as ISO and API, can have shortcomings, and therefore additional re-evaluations or additional checks can be useful.

3. Conclusions

The technical standards used in the offshore petroleum industry are high level, but sometimes they are inadequately applied. For example, the three accidents mentioned in this technical note could have been prevented: (1) The Macondo Deepwater Horizon accident—that the concrete at the bottom of the Macondo borehole did not create a seal would easily be detected by performing a cement bond log; a measurement to verify the presence and quality of the cement used to seal the oil and gas-bearing rock formations; (2) The Montara accident:—there is no doubt that the Montara oil spill in Australia would not have happened in other countries, such as the UK and Norway, where the regulatory framework requires the mandatory inspection of wells during and at the completion of construction; (3) The Piper Alpha accident—proper maintenance management would most probably have been sufficient to prevent the disaster at the Piper Alpha platform.

Offshore drilling ships, including equipment onboard, which by definition operate in various countries, are very modern and therefore can usually be certified easily following many different legislative and technical norms. However, these parallel certifications are costly and should be simplified through international collaboration to avoid overlapping by signing agreements for mutual recognition among various countries (e.g., such as through Mutual Recognition Agreements (MRAs) and the designated Conformity Assessment Bodies (CABs)).

In the current situation, most drilling ships and equipment onboard are certified through various certification rules, which assure high levels of safety. These certifications are recognized or tolerated worldwide and they are complementarily used with domestic standards (in some countries, such domestic standards for offshore oil and gas drilling are not fully developed). All re-evaluations should be done carefully, and only if the additional cost would increase the overall level of safety and environmental protection significantly.

Related to the offshore petroleum activities in the EU/EEA waters, special care should be taken to the following:

- In the past, harmonized standards developed by CEN or CENELEC assured full conformity, while today to remove barriers for trade in the EU/EEA, any other available technical standards can be used if they can assure compliance to the health and safety requirements of the relevant directives. The umbrella directive 2013/30/EU for oil and gas offshore safety in the EU/EEA allows, and even requires, the use of the best available standards, which are recognized internationally.
- Due to exemption from the scope of the product safety directives, the machinery directive 2006/42/EC, the pressure equipment directive 2014/68/EU, and the ATEX directive 2014/34/EU, drilling ships and, in certain cases, oil and gas equipment used offshore are out of their scope (therefore are not required to fulfil the essential health and safety requirements of these directives and to be certified according to them). However, the use of some of their harmonized standards can be recommended if such practice can increase the overall level of safety. Additionally, it should be double-checked if the observed equipment is really excluded from the scope in every observed particular case (in case of exclusion, the international MODU code applies).
- Well-control equipment is also out of the scope of the pressure equipment directive 2014/68/EU onshore, and it is not required to follow its essential safety requirements (this directive does not refer to essential health requirements). Besides, well-control equipment onshore and offshore on fixed platforms is under the scope of the machinery directive 2006/42/EC and the relevant essential health and safety requirements of this directive should be satisfied.
- Protection against explosions on fixed offshore platforms goes through the European ATEX scheme, while on mobile offshore units through the IECEx scheme.

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Notations: The following are used in this paper:

European Union directives:

– Offshore safety directive 2013/30/EU-Directive on safety of offshore oil and gas operations (used as umbrella Directive for offshore oil and gas safety)
– Product safety directives: (1) ATEX directive 2014/34/EU; (2) pressure equipment directive 2014/68/EU; (3) machinery directive 2006/42/EC
– Marine equipment directive 2014/90/EU
– ATEX directive 1999/92/EC for protection of personnel

Documents, Regulations, and Databases:

– New Legislative Framework package, that reinforces the application and enforcement of internal market legislation in the EU/EEA
– Facing the challenge of the safety of offshore oil and gas activities: 2011/2072(INI), Motion for a European parliament resolution from 26 July 2011
– IECEx: International Electrotechnical Commission System for Certification to Standards Relating to Equipment for Use in Explosive Atmospheres
– International Convention for the Safety of Life at Sea (SOLAS) from 1974 and in force since 25 May 1980
– MODU code: "Code for the construction and equipment of Mobile Offshore Drilling Units of the International Maritime Organization" from 2009
– NANDO: New Approach Notified and Designated Organizations Information System (Conformity Assessment and Acceptance of Industrial Products Notification Bodies)
– Regulation (EU) No 1025/2012, related to European standardization
– "New approach": Council Resolution of 7 May 1985 on a new approach to technical harmonization and standards

Standardization and other bodies:

– NORSOK: Norwegian Technical standards
– API: American Petroleum Institute
– ISO: International Organization for Standardization
– TC 67: Technical committee of the ISO "Materials, equipment and offshore structures for petroleum, petrochemical and natural gas industries"
– CEN: Comité Européen de Normalisation
– CENELEC: Comité Européen de Normalisation Électrotechnique
– IEC: International Electrotechnical Commission
– ANSI: American National Standardization Institute
– CABs: Conformity Assessment Bodies

Agreements:

– Vienna agreement—technical cooperation between ISO and CEN
– Frankfurt agreement—technical cooperation between IEC and CENELEC
– MRAs—Mutual Recognition Agreements promote trade in goods between the EU and third countries and facilitate market access

Offshore accidents:

– Macondo Deepwater Horizon: the Gulf of Mexico in 2010 (offshore drilling rig, to date the biggest in terms of hydrocarbon release)
– Montara: the Timor Sea in 2009 (offshore drilling rig)
– Piper Alpha: the North Sea in 1988 (fixed production platform, to date the deadliest offshore petroleum accident)

Companies:

– British Petroleum (BP)
– MOEX Offshore-subsidiary of Mitsui

- Occidental Petroleum (Caledonia) Limited-OXY
- Anadarko Petroleum Corporation—Now defuncted
- PTTEP Australasia (PTTEPAA)—Subsidiary of PTT Exploration and Production (PTTEP)
- Transocean: rig contractor
- Norwegian–Bermudan Seadrill: rig contractor
- Keppel Fels: rig manufacturer
- Hyundai Heavy Industries: rig manufacturer
- McDermott Engineering: platform manufacturer
- Union Industrielle d'Entreprise: platform manufacturer

Oil fields and Wells:

- Macondo (the Gulf of Mexico)
- Montara (the Timor Sea)
- Piper (the North Sea)

Rigs and platforms:

- Deepwater Horizon: semi-submersible rig
- West Atlas: jack-up drilling rig
- Piper Alpha: fixed production platform

Ship registers:

- American Bureau of Shipping (ABS)

Product marking:

- Conformité Européenne "CE" sign: general conformity with the relevant EU/EEA Directives
- "Wheelmark" sign: conformity with marine equipment Directive 2014/90/EU

Equipment:

- BOP—Blow out preventers
- "Christmas tree"—Wellhead

References

1. Elvidge, C.D.; Ziskin, D.; Baugh, K.E.; Tuttle, B.T.; Ghosh, T.; Pack, D.W.; Erwin, E.H.; Zhizhin, M. A fifteen-year record of global natural gas flaring derived from satellite data. *Energies* **2009**, *2*, 595–622. [CrossRef]
2. Rabe, B.; Kaliban, C.; Englehart, I. Taxing flaring and the politics of state methane release policy. *Rev. Policy Res.* **2020**, *37*, 6–38. [CrossRef]
3. Baalisampang, T.; Abbassi, R.; Khan, F. Overview of marine and offshore safety. *Met. Chem. Proc. Saf.* **2018**, *2*, 1–97. [CrossRef]
4. Fattakhova, E.Z.; Barakhnina, V. Accident rate analysis on the offshore oil and gas production installations and platforms. *Int. J. Appl. Fund. Res.* **2015**, *1*. Available online: http://www.science-sd.com/460-24767 (accessed on 14 July 2020).
5. Zolotukhin, A.; Gavrilov, V. Russian Arctic petroleum resources. *Oil Gas Sci. Technol.* **2011**, *66*, 899–910. [CrossRef]
6. Aalto, P. Modernisation of the Russian energy sector: Constraints on utilizing Arctic offshore oil resources. *Eur. Asia Stud.* **2016**, *68*, 38–63. [CrossRef]
7. Helle, I.; Mäkinen, J.; Nevalainen, M.; Afenyo, M.; Vanhatalo, J. Impacts of oil spills on Arctic marine ecosystems: A quantitative and probabilistic risk assessment perspective. *Environ. Sci. Technol.* **2020**, *54*, 2112–2121. [CrossRef]
8. Lindholt, L.; Glomsrød, S. The Arctic: No big bonanza for the global petroleum industry. *Energy Econ.* **2012**, *34*, 1465–1474. [CrossRef]
9. Torres, L.; Jiménez-Cabas, J.; González, O.; Molina, L.; López-Estrada, F.-R. Kalman Filters for leak diagnosis in pipelines: Brief history and future research. *J. Mar. Sci. Eng.* **2020**, *8*, 173. [CrossRef]
10. McBain, G. A user's view of the pressure equipment directive. *Meas. Control* **2003**, *36*, 300–304. [CrossRef]
11. Ciavarella, M.; Carbone, G.; Vinogradov, V. A critical assessment of Kassapoglou's statistical model for composites fatigue. *Facta Univ. Mech. Eng.* **2018**, *16*, 115–126. [CrossRef]

12. Zhao, X.; Wang, S.; Wang, X.; Fan, Y. Multi-state balanced systems in a shock environment. *Reliab. Eng. Syst. Saf.* **2020**, *193*, 106592. [CrossRef]
13. Wang, X.; Zhao, X.; Wang, S.; Sun, L. Reliability and maintenance for performance-balanced systems operating in a shock environment. *Reliab. Eng. Syst. Saf.* **2020**, *195*, 106705. [CrossRef]
14. Zhao, X.; Wu, C.; Wang, X.; Sun, J. Reliability analysis of k-out-of-n: F balanced systems with multiple functional sectors. *Appl. Math. Model.* **2020**, *82*, 108–124. [CrossRef]
15. Luo, F.; Zhang, S.; Yang, D. Anti-explosion performance of composite blast wall with an auxetic re-entrant honeycomb core for offshore platforms. *J. Mar. Sci. Eng.* **2020**, *8*, 182. [CrossRef]
16. Lindøe, P.H.; Baram, M.; Renn, O. *Risk Governance of Offshore Oil and Gas Operations*; Cambridge University Press: Cambridge, UK, 2013. [CrossRef]
17. Lindøe, P.H.; Baram, M.S. The role of standards in hard and soft approaches to safety regulation. In *Standardization and Risk Governance*; Olsen, O.E., Juhl, K.V., Lindøe, P.H., Engen, O.A., Eds.; Routledge: Abingdon, UK, 2020; pp. 235–254. [CrossRef]
18. Yang, Y. Reforming health, safety, and environmental regulation for offshore operations in China: Risk and resilience approaches? *Sustainability* **2019**, *11*, 2608. [CrossRef]
19. Crone, T.J.; Tolstoy, M. Magnitude of the 2010 Gulf of Mexico oil leak. *Science* **2010**, *330*, 634. [CrossRef]
20. Croisant, S.A.; Lin, Y.L.; Shearer, J.J.; Prochaska, J.; Phillips-Savoy, A.; Gee, J.; Jackson, D.; Panettieri, R.A.; Howarth, M.; Sullivan, J.; et al. The Gulf coast health alliance: Health risks related to the Macondo spill (GC-HARMS) study: Self-reported health effects. *Int. J. Environ. Res. Public Health* **2017**, *14*, 1328. [CrossRef]
21. Zilversmit, L.; Wickliffe, J.; Shankar, A.; Taylor, R.J.; Harville, E.W. Correlations of biomarkers and self-reported seafood consumption among pregnant and non-pregnant women in southeastern Louisiana after the Gulf oil spill: The GROWH study. *Int. J. Environ. Res. Public Health* **2017**, *14*, 784. [CrossRef]
22. Nunziata, F.; Buono, A.; Migliaccio, M. COSMO–SkyMed Synthetic aperture radar data to observe the deep-water horizon oil spill. *Sustainability* **2018**, *10*, 3599. [CrossRef]
23. Zhang, Y.; Li, S.; Guo, Z. The Evolution of the coastal economy: The role of working waterfronts in the Alabama Gulf Coast. *Sustainability* **2015**, *7*, 4310–4322. [CrossRef]
24. Moerschbaecher, M.; Day, J.W., Jr. Ultra-deep water Gulf of Mexico oil and gas: Energy return on financial investment and a preliminary assessment of energy return on energy investment. *Sustainability* **2011**, *3*, 2009–2026. [CrossRef]
25. Hayes, J. Operator competence and capacity–Lessons from the Montara blowout. *Saf. Sci.* **2012**, *50*, 563–574. [CrossRef]

26. Paté-Cornell, M.E. Learning from the piper alpha accident: A postmortem analysis of technical and organizational factors. *Risk Anal.* **1993**, *13*, 215–232. [CrossRef]
27. Cullen, L.W. The public inquiry into the Piper Alpha disaster. *Drilling Contractor* **1993**, *49*. Available online: https://www.osti.gov/biblio/6208554 (accessed on 27 June 2020).
28. Messerlin, P.A. The European Union single market in goods: Between mutual recognition and harmonisation. *Aust. J. Int. Aff.* **2011**, *65*, 410–435. [CrossRef]
29. Pollack, M.A. Theorizing the European Union: International organization, domestic polity, or experiment in new governance? *Annu. Rev. Polit. Sci.* **2005**, *8*, 357–398. [CrossRef]
30. Fiorino, D.J. *The New Environmental Regulation*; MIT Press: Cambridge, MA, USA, 2006.
31. Manheim, F.T. *The Conflict Over Environmental Regulation in the United States: Origins, Outcomes, and Comparisons with the EU and Other Regions*; Springer Science and Business Media: Berlin/Heidelberg, Germany, 2008. [CrossRef]
32. Xu, P.; Du, Z.; Gong, S. Numerical investigation into freak wave effects on deep water pipeline installation. *J. Mar. Sci. Eng.* **2020**, *8*, 119. [CrossRef]
33. Zan, Y.; Guo, R.; Yuan, L.; Wu, Z. Experimental and numerical model investigations of the underwater towing of a subsea module. *J. Mar. Sci. Eng.* **2019**, *7*, 384. [CrossRef]
34. Yu, G.; Zhang, L.; Jia, S.; Geng, Y.; Liu, J. Numerical study on the natural convection of air in a cubic cavity subjected to a yawing motion. *J. Mar. Sci. Eng.* **2019**, *7*, 204. [CrossRef]
35. Yu, G.; Jia, S.; Geng, Y. Numerical investigation into the two-phase convective heat transfer within the hold of an oil tanker subjected to a rolling motion. *J. Mar. Sci. Eng.* **2019**, *7*, 94. [CrossRef]
36. Kaiser, M.J.; Snyder, B. The five offshore drilling rig markets. *Mar. Policy* **2013**, *39*, 201–214. [CrossRef]
37. Marx, I. Combining the best of both worlds. *IEEE Ind. Appl. Mag.* **2010**, *16*, 30–34. [CrossRef]

38. Petitfrere, C.; Proust, C. Analysis of ignition risk on mechanical equipment in ATEX. Proceeding of the 4th IEEE European Conference on Electrical and Instrumentation Applications in the Petroleum and Chemical Industry, Paris, France, 13–15 June 2007; pp. 1–9. [CrossRef]
39. Leroux, P. New regulations and rules for ATEX directives. *IEEE Ind. Appl. Mag.* **2006**, *13*, 43–51. [CrossRef]
40. Parise, G.; Sutherland, P.E.; Moylan, W.J. Electrical safety for employee workplaces in Europe and in the USA. *IEEE Trans. Ind. Appl.* **2005**, *41*, 1091–1098. [CrossRef]
41. Campbell, J.D.; Chudleigh, J.P. Problems encountered in designing electrical systems for hazardous areas. In *IEEE Transactions on Industry and General Applications*; IEEE: Piscataway, NJ, USA, 1970; Volume IGA-6, pp. 326–329. [CrossRef]
42. Rodrigues, A.M.T.G. A Software Application to Define and Rank ATEX Zones. Ph. D. Thesis, Faculdade de Engenharia da Universidade do Porto, Porto, Portugal, 2016. Available online: https://repositorio-aberto.up.pt/bitstream/10216/88507/2/156964.pdf (accessed on 11 June 2020).
43. Riikonen, J. ATEX certification for hazardous areas. *World Pumps* **2010**, *2010*, 22–24. [CrossRef]
44. Pommé, R.; Sijrier, H.J. IECEX certification schemes versus ATEX directives. Proceeding of the Petroleum and Chemical Industry Conference Europe—Electrical and Instrumentation Applications (PCIC Europe), Oslo, Norway, 15–17 June 2010; pp. 1–8. Available online: https://ieeexplore.ieee.org/xpl/conhome/5512515/proceeding (accessed on 29 June 2020).
45. Nicols, R. ATEX directives for the UK sector. *Meas. Control* **2003**, *36*, 147–155. [CrossRef]
46. Propst, J.E.; Barrios, L.A.; Lobitz, B. Applying the API alternate method for area classification. *IEEE Trans. Ind. Appl.* **2007**, *43*, 162–171. [CrossRef]
47. Khaymedinova, Z. Explosion-Proof Requirements for Electrical Machines in Chemical, Oil and Gas Industry in Russia and CIS Countries. Ph.D. Thesis, Lappeenranta University of Technology, Lappeenranta, Finland, 2009. Available online: https://lutpub.lut.fi/bitstream/handle/10024/46840/nbnfi-fe200908031986.pdf (accessed on 11 June 2020).
48. Sinclair, R. ATEX good and bad/A notified body's perspective. *Meas. Control* **2003**, *36*, 140–141. [CrossRef]
49. Dearden, H.T. Who's afraid of ATEX? *Meas. Control* **2006**, *39*, 17–18. [CrossRef]
50. Towle, C. ATEX directives/A manufacturer's viewpoint. *Meas. Control* **2003**, *36*, 152–154. [CrossRef]
51. Hitchen, I.R. Vibration monitoring for rotating machinery. *Meas. Control* **1980**, *13*, 97–102. [CrossRef]
52. Shu-Chao, L. The main differences of general requirements and intrinsic safety between IEC and Russian standards. electric explosion protection. *China Nat. Knowl. Infrastruct. J.* **2004**, *3*. Available online: http://en.cnki.com.cn/Article_en/CJFDTotal-DQFB200403001.htm (accessed on 11 June 2020).
53. Stefanowicz, D. ATEX for installers and maintainers. *Meas. Control* **2003**, *36*, 144–158. [CrossRef]
54. Harvey, S.; Elashvili, I.; Valdes, J.J.; Kamely, D.; Chakrabarty, A.M. Enhanced removal of Exxon Valdez spilled oil from Alaskan gravel by a microbial surfactant. *Biotechnology* **1990**, *8*, 228–230. [CrossRef] [PubMed]
55. Khan, F.I.; Sadiq, R.; Husain, T. Risk-based process safety assessment and control measures design for offshore process facilities. *J. Hazard. Mater.* **2002**, *94*, 1–36. [CrossRef]
56. Mutlu, M.; Tang, Y.; Franchek, M.A.; Turlak, R.; Gutierrez, J.A. Dynamic performance of annular blowout preventer hydraulic seals in deepwater environments. *J. Offshore Mech. Arct. Eng.* **2018**, *140*, 061301. [CrossRef]
57. Crumpton, H. *Well Control for Completions and Interventions*; Gulf Professional Publishing: Houston, TX, USA, 2018. [CrossRef]
58. Marangon, A.; Carcassi, M. ATEX Directives: The New Approach. Valutazione e Gestione del Rischio negli Insediamenti Civili ed Industriali, 2006. Available online: http://conference.ing.unipi.it/vgr2006/archivio/Archivio/2006/Articoli/700213.pdf (accessed on 29 June 2020).
59. Weightman, R.T.; Warnack, M.F. API and ISO standards can be combined. *Oil Gas J.* **1992**, *90*, 50–52. Available online: https://www.ogj.com/home/article/17218930/api-and-iso-standards-can-be-combined (accessed on 10 March 2020).