USE OF LOW SMOKE AND HALOGEN FREE CABLES FOR MARINE FIRE SAFETY DESIGN

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Summary

Safety of shipping is a growing concern. The causes of shipping casualties are various. A fire on a ship is one of the most hazardous incidents which can happen on board and a common cause of damages and accidents in ships. However, this knowledge decreases where electrical installations, whose effects are less well-understood, are involved. Because of these effects and risks, the regulations related to cables for a vessel's electrical installations anticipate the use of special low fire propagation and fire-resistant cables made with low smoke emission and halogen-free materials. Despite these criteria, the regulations permit the use of materials such as PVC. The main purpose of this research is to identify the risks associated of the use of PVC versus Low Smoke Zero Halogen (LSOH) cables that could be present for equipment safety and people in case of fire. As a result of the implementation of the regulatory framework, test results from PVC and LSOH cables used in ships have been obtained. Finally, the use of LSOH cables is implemented to assess the effect of fire risk reduction measure for the enhancement of safety of shipping in coastal waters, efficiency and protection of the environment.

Key words: Fire retardant and resistant cables, safety, LSOH material, marine environment.

1. INTRODUCTION

According to (Faulkner 2002), there are two main sources causing vessel loss: about 60% are due to operational causes (i.e. fire, collision, machinery damage); while the remaining 40% are characterized by design and maintenance causes (i.e. water ingress, hull breaking in two, and capsizing). Safe navigation is required to prevent accidents leading to increased risk to life, property and environment.

A review of available accident data (Lloyds List 2013; DNV 2013; EMSA 2015; MAIB 2013 and Kuehmayer 2008) shows that shipping accidents by types are quite many and their impacts on marine environment differ from one another (Akten 2006). In 2014, 3399 vessels were involved in 3025 marine casualties and incidents in and around European Union (EU) waters. The largest number of vessels involved in very serious casualty events (2011-2014) was concerned in flooding/foundering (24%), collision (22%) and around 14% in fires and explosions (European Maritime Safety Agency).

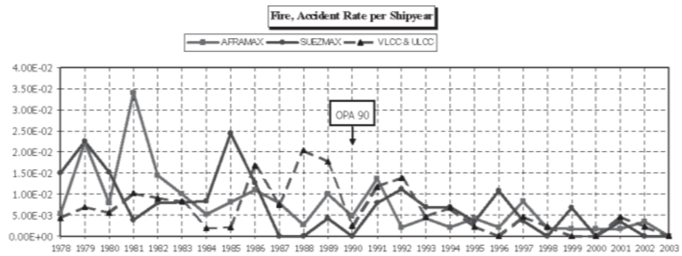
Fires or explosions are quite rare but are very dangerous. A fire on a vessel is one of the most hazardous incidents which can happen on board. If the fire is detected in good time, the crew can prevent larger damages by taking immediate measures. If the fire has already spread, professional aid is needed. The most significant finding was that the numbers of fires/explosions for some ship types (see Table 1) shows great variations between 2010 and other years. In particular, the number that occurred on ferries was up almost 170% from the relatively low number in 2009. Fires on tankers were also substantially higher than the number reported in 2009. Conversely, the number of fires reported on cargo ships was substantially down in comparison to the previous three years.

Table 1. Fire/Explosions by merchant ships type (2007-2010* / 2011-2014**)

Fire/Explosion by ship type	2007	2008	2009	2010	2014
Cargo ships	29	26	30	17	n/a
Tankers	11	11	2	7	n/a
Container ships	3	4	2	4	n/a
Passenger ships	17	17	11	30	n/a
Fishing ships	16	14	9	15	n/a
Other vessels types	15	17	13	10	n/a
Total	91	89	67	83	152

Source: European Maritime Safety Agency (EMSA 2010)* / (EMSA 2015)**. n/a: not available

Figure 1 presents the accident frequencies for fire accidents rates considering only large oil tankers occurring between 1978 and 2003 (Eliopoulou and Papanikolaou 2007). A slight decreasing tendency can be observed in the yearly rates of fire accidents throughout the studied period.

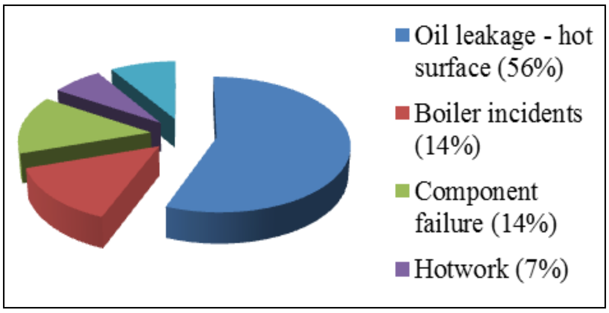


Source: E. Eliopoulou and A. Papanikolaou, 2007

Figure 1. Fire accident rates of large tankers (1978-2003)

The most common fire on a vessel is in the engine room. Recent incidents have demonstrated that engine room fires could threaten the safety of the entire vessel. According to Det Norske Veritas (DNV) statistics (Det Norske Veritas 2001) a ship-owner operating 20 vessels can expect one major engine room fire every 10 years. A research project on 165 fires on board the DNV fleet from 1992 to 1997 resulted in some interesting findings; for instance, engine room fires represent almost two thirds of all fires, second fire source is cargo spaces and finally accommodation.

Related on fires in living and service accommodation due to outfitting materials introduce serious thermal, smokiness and toxic risk (Dobrzynska 2009). Engine room fires also represent a hazard for crew members working in that area and fire fighters. The main causes of engine room fires are given in Figure 2, they are usually caused by fuel spills, overheating components or careless use of electric welding or gas brazing gear.



Source: DNV

Figure 2. Common causes of the engine room fires

Related on recreational crafts, the Boat U.S. (United States Costguard 2012) did some research to determine the most common causes of boat fires: more than half of the fires investigated (55%) were found to have been caused by wiring and electrical problems, with wire chafing found as the most common problem. Electrical systems on board are subject to considerably more additional hazards and exposures than typically experienced ashore in a standard fixed installation: significant exposures to hot and cold temperature extremes, vibration, constant motion, high humidity, sea water, wetting, oils, fuels. The main causes of electrical fires onboard ships are due of short circuits or heating (overloads, poor contacts) or unapproved or modified equipments. Wire size, circuit protection placement, and insulation ratings just begin to scratch the surface of all the preventative measures that are called for. All electrical appliances should be firmly secured and served by permanent connections whenever possible to ensure durability and safe operations over a long period of time.

Application of new techniques and enhanced technologies for the early detection of fires on ships and its prevention have a major impact on the development of new sophisticated systems for fire detection (Bistrović and Tomas 2014). Moreover, ship management should therefore include a clear policy of how to avoid such incidents. Fire safety is just one part of overall safety concern, but one that is not well understood with regard to how cables materials behave under fire conditions.

2. REGULATION

Accidents such as the 1934 fire on the passenger ship, the Morro Castle, which had 134 casualties caused changes in the Safety of Life At Sea (SOLAS) convention (IMO 1974). This incident caused major changes in relation to fire safety on passenger ships. However, it was not until the 1996 amendments to SOLAS which introduced the mandatory Fire Test Procedures code (IMO 2010). It was made mandatory on 1st July 1998 and provides international regulations on testing of the ship. These amendments were introduced to aid companies with knowledge on the safety of products installed in ships sailing under their flag.

Statutory regulations currently in force with respect to the construction of passenger ships, and of cargo ships of 500 tons and over, require compliance with The Institution of Electrical Engineers: “Regulations for the Electrical and Electronic Equipment of Ships with Recommended Practice for their Implementation” (IEE Regulations, 1993) and (IEC Regulations 2004, 2008), except in so far as they may be inconsistent with the statutory regulations. As a matter of good practice, cargo ships less than 500 tons and other small vessels should also comply. The applicable edition of the IEE Regulations depends on the date of build of the ship. Even with these safeguards and procedures fires still occur. SOLAS Maritime Rules and some of the main Classification Societies for ships (Lloyd’s Register 2013; Bureau Veritas 2013; DNV 2013 and Germanischer Lloyd 2013) establish requirement for electrical installation aboard ship, as well type and materials of cables to be used. In particular, IEC 60092-350 (IEC 2014) specifies the general construction requirements and general test recommendations for shipboard cables and includes materials for insulation, inner covering, fillers binders and outer sheat.

The main used for Insulation are:

- Thermoplastic: Polyvinyl Chloride (PVC), Poly ethylene (PE) and LSOH thermoplastic material (SHF1)
- Thermosetting: Cross Linked Poly Ethylene (XLPE), Etylene Propylene (EPR) and Hard grade etylene propylene (HEPR).

For Inner and Outer sheath (protective coverings):

- Thermoplastic: PVC, PE and LSOH (SHF1)
- Thermosetting: Polychloroprene rubber (PCP), Chlorosulfonated polyethylene (CSPE), Chlorinated Polyethylene (CPE) and LSOH thermoset material (SHF2).

In general terms, IEC regulation requires electrical cables used in ships must be flame retardant type (IEC, 2009) and must be fire retardant (Finlayson 1990), when cables are laid in bunches. Additional feature of fire resistance (IEEE, 2002) emergency installations is required in accordance with IEC. Nevertheless, these requirements are not accompanied explicitly with the exigency in the use of cables with materials Low smoke zero halogen (LSOH and also LSF, LSZH, LSHF) during their combustion in the fire presence.

3. MATERIALS AND METHODS

Even if a cable can be made with flame retardant behaviour, some of the fire effects are smoke opacity, toxic hazard and corrosion damage. The main purpose of the research is to show the risks of the use of conventional materials (PVC, PCP, CSPE and CPE) compared with LSOH material, in confined spaces with large amounts of cables, in close proximity to humans or sensitive equipments. Furthermore, this paper will discuss the main benefits of LSOH cables versus conventional (especially with PVC) considering worker safety and protecting the environment.

A technology based on hydrate filled polyolefins (LSOH), an alternative material to PVC, has been utilized to develop improved technology and new materials which will not emit dense smoke that rapidly obscures visibility, and already shows a reduced flame propagation, lower toxic gas concentration and corrosion.

Ships in operation, especially cruise ships, are subject to a vast array of regulations and standards covering every aspect of ship construction and operation. A number of incidents over the years have led to improvements in safety requirements, including those relating to fire safety measures, such as escape routes and fire protections systems.

A principal advantage of LSOH cable products is reduced hazard in terms of smoke density and combustion fume toxicity. In case of reduced spaces of ships, the use of LSOH products will reduce the exposure and inhalation of smoke, toxic gases. Moreover, more time for evacuations is the vital importance, having greater visibility and therefore helps reduce disorientation and panic, allowing the visualization of signals and find emergency escape routes to ensure easy evacuation routes for crew and passengers. The smoke diffusion and the evacuee movements on three deck spaces of a passenger ship and for three different escape scenarios have been studied determining evacuation times from 7’ to 10’ (Fukuchi and Imamura 2005), when the percentage of light transmittance may be less than 20% and Carbon Monoxide (CO) emission more than 300 ppm. In evaluating the risk of fire of ceiling materials, after 10’, a substantial increase in the temperature and heat release occurs (Chung et al 2014). Since it is very important to prevent fires, if a fire still starts it is necessary to take the appropriate action to tackle it an early stage. Hlaváčová and Vondra (2016) deal with the problem of extinguishing fire on ships.

Considering protection of electrical switchgear equipment and electronic systems (for instance, control, informatics and communication), very common in any plant, (see Figure 3), damage from corrosive gases are minimized (corrosion of components, printed circuits, oxidation), due to hydrogen chloride gas, which releases the PVC when burn and combined with the moisture of water, used in extinguishing the fire, just formed vapour of hydrochloric acid (HCl) to be deposited on units and corrode over time, reaching cause much more damage than the fire itself.

Source: own

Figure 3. Switchboard and control systems in ships

Comparatively, for the same heat flux (kW/m^2), PVC reaches its ignition point (burns) in less time than low emission polyethylene and, in fire conditions, for the same period, PVC has a higher loss of mass than the polyethylene, causing a higher concentration of suspended particles, with a corresponding high level of smoke, opacity and toxicity.

Other hazards associated with cables is the cable layout, both horizontal and vertical (see Figure 4), especially vertical positioned cable, a chimney effect. If a cable has a content of PVC higher than 1 kg/m PVC material, once it has ignited at 450°C, measurements of the fire spread, show speeds over 20m/min speed (Alarie 2002). At temperatures of 250°C, emits black smoke.

Source: own

Figure 4. Electrical distribution layout in a 1047 GT tug vessel

The materials such as PVC or rubber, used as insulation or cable sheaths, can improve their properties against fire, by means of flame retardants or special fire retardant compounds. In these cases, the PVC reduces its acid emissions and improves its fire behaviour, improved PVC or PVC reduced propagation and low emission of HCl (RPLHCL), but reduces its mechanical properties. Fire retardant sheaths of both materials (PVC and rubber), contains perfluorooctane sulfonate acid (PFOS), considered hazardous materials for the EMSA (EMSA 2017).

On the other hand, main disadvantage of LSOH materials is high loading levels. LSOH jacket compounds usually have very high filler content to provide the required flame and smoke performance; as a result, most have poorer mechanical, chemical resistance, water absorption and electrical properties than non-LSOH compounds.

4. TEST AND RESULTS

Fire tests are consequently designed to provide information related to the “reaction-to-fire” properties of materials. Noticing the necessity of establishing suitable fire test methods, many national and local governments have developed different apparatuses in which specimens with various sizes and orientations are exposed to different fire scenarios.

The different tests, and standards, which describe the fire behavior of insulations, inner covering, and outer sheath, such as LSOH material, are:

- Halogen content IEC 60754-1
- Equivalent Acid content, IEC 60754-2: Smoke minimum pH and Maxim Smoke Conductivity

- Smoke generation, standard IEC 61034-2: Transmittance
- Determination of the Toxicity Index, standard NES 713

These tests are applied to samples of the materials. Halogen content is checked along with smoke generation and its properties (see Table 2). The fire behaviour of the whole cable is checked through the vertical-tray fire-propagation test.

In Table 3, the most significant values of the cable materials permitted by the regulations governing cables and electrical installations are shown.

Table 2. Typical requirements and results of smoke and halogen emission.

Test	Standard	Requirement	Material PVC	Material PVC (RPLHCl)	Material Polyrethane	Material LSOH
Emission of Halogen Bromine and chlorine content (expressed as HCl), maximum	IEC 60754 -1	0.5%	25 - 30%	12 - 15%	> 5%	<0.5%
Corrosivity. Degree of acidity of gases evolved during combustion:	IEC 60754 -2					
- Minimum pH of smoke		> 4.3	≈ 1	≈ 1	≈ 5.6	≈ 7
- Maximum conductivity of smoke (μS/mm)		< 10	≈ 15	≈ 15	≈ 8	≈ 1.6
Smoke generation - Minimum transmittance %	IEC 61034 -2	> 60	≈ 20	≈ 40	≈ 60	> 80
Toxicity index is a parameter representing the total toxicity of various gases	NES 713, MIL-DTL-24643C (4.8.27)	-	15	-	-	0
- Contents of gas carbon monoxide CO (ppm)			5.5			1.4
- Contents of gas hydrogen chloride HCl (ppm)			6.2			0

Source: own based on Standard Requirements (IEC 60754, IEC 61034 and Naval Engineering Standard)

As a result of the implementation of the regulatory framework and the tests mentioned previously regarding cables with reduced emissions of dense, toxic and corrosive smoke, the following data has been obtained about the fire behaviour of different materials used in cables (PVC and LSOH).

Figure 5 shows the behaviour of these different cables concerning the emission of toxic and corrosive gases like HCl and CO, which can cause intoxication and poisoning as well as damage to equipment.

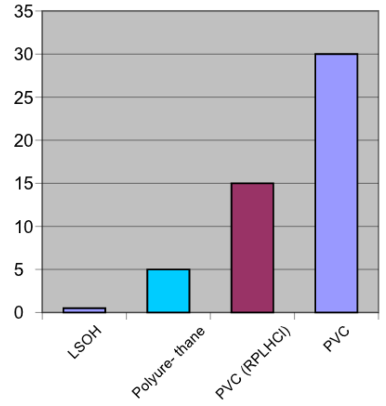


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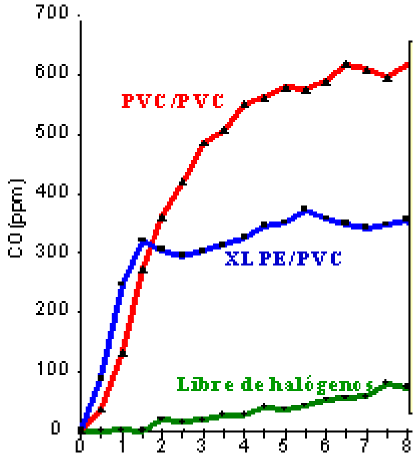
Figure 5. Comparison of HCl emissions according to material

Figure 6 shows the level of accumulated CO gas (ppm) when a complete cable, with different combinations of insulation and outer sheath, burns for 8 minutes.



Source: FACEL, 2003

Figure 6. Comparison of CO emissions according to material (insulation/inner covering).

Figures 7 and 8 show the percentage of light transmittance permitted by these cables over time with respect to the emission of dense smoke.

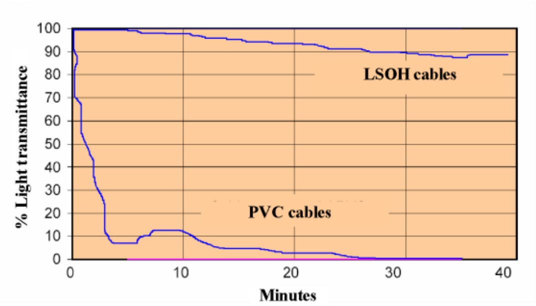


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Figure 7. Comparison of the emission of dense smoke in cables

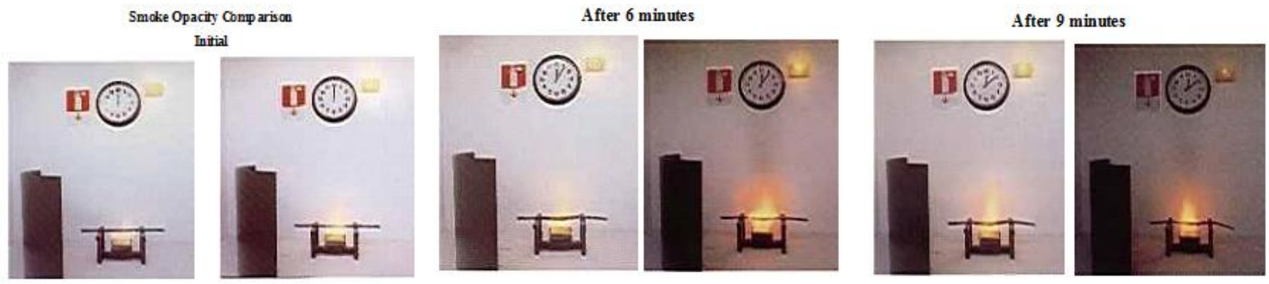

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Figure 8. Comparison of the emission of dense smoke in cables, LSOH (left) and Conventional PVC (right)

5. CONCLUSION

The above results show the low emission of toxic gases, such as CO and HCl, generated during the combustion of LSOH material in comparison with PVC, reducing the risk of intoxication or poisoning of persons due to fire in cable materials. It is also important to note the lack of Hydrochloric Acid and corresponding lack of corrosivity. This minimizes damage to electric, electronic and computer equipment.

It is seen clearly that for PVC the greatest yield of toxic gases occurs during the initial stages of fire growth. This is also when the smoke release is the greatest. Any PVC fire will always be hazardous due to the early release of hazardous combustion.

The property of low fire propagation is not in itself a guarantee of low smoke and halogen-free emission it depends on the materials which the product is made (LSOH or not). In the case of a LSOH product, the fire growth is more gradual and the toxicity of the fire gas increases as the available oxygen reduces.

Required by law or regulation to use of LSOH cables in electrical installations where the risk of fire to people and installations is significant, such as in the public spaces on a cruise ship, will greatly improve human and equipment safety in case of fire emergency.

In the market there is a wide variety of these types of cable, approved and certified by the classification societies. For this reason their general or specific use is technically possible.

The IEC 60092 cable standards for vessels should remove the materials with halogens and indicate the specific advantages of using LSOH material. Moreover, the classification societies should define those installations in which the use of this material, in both insulation and covers (inner and outer sheath), should be a priority, thereby increasing the safety of both passengers and installations on board.

REFERENCES

[1] Akten, N.: Shipping accidents: a serious threat for marine environment, 269 J. Black Sea/Mediterranean Environment, 2006, Vol.12, pp. 269-304.

[2] Alarie, Y.: Toxicity of Fire Smoke. Critical Reviews in Toxicology, 2002, Vol.32, No 4, pp. 259 - 289.

[3] Bistrović, M and Tomas, V: Application of New Techniques and Information Technology for Early Fire Detection on Ships, Nase More, 2014, Vol.61, No 5, pp. 87-95

[4] Bureau Veritas: Rules for the Classification of Steel Ships, 2013.

[5] Chung, W., Lei, M. and Tsai K.: Evaluating current fire test methods for determining flammability performance of ceiling materials, Journal of Marine Science and Technology, 2014, Vol. 22, No 2, pp. 196-203.

[6] Det Norske Veritas: Engine room fires can be avoided, 2001.

[7] Det Norske Veritas: Rules for Classification of Ships, 2013.

[8] DNV CADA casualty database: website: www.dnv.com [accessed 03/07/2015]

[9] Dobrzynska, R.: Selection of outfitting and decorative materials for ship living accommodations from the point of view of toxic hazard in the initial phase of fire progress, Polish Maritime Research, 2009, Vol.16, pp. 72-74.

[10] Eliopoulou, E. and Papanikolaou, A.: Casualty analysis of large tankers. Journal of Marine Science and Technology, 2007, Vol. 12, No 4, pp 240-250.

[11] European Maritime Safety Agency (EMSA): Annual overview of marine casualties and incidents 2015.

[12] European Maritime Safety Agency (EMSA): Maritime Accident Review 2010, 2013.

[13] European Maritime Safety Agency (EMSA): Guidance on the inventory of hazardous materials, 2017.

[14] FACEL (Asociación Española de fabricantes de conductores eléctricos aislados y de fibra óptica): Los cables libres de halógenos. Cables de Alta Seguridad, Revisión: 2, Ref.: PF-7-LH, 2003 (In Spanish).

[15] Faulkner, D.: Shipping safety: A Matter of Concern. Quarterly of the Royal Academy of Engineering, Marine Matters, 2002, pp. 13-20.

[16] Finlayson, A. J.: Low smoke and fume type cables for BNFL Sellafield Works, Power Engineering Journal, 1990, Vol. 4, No 6, pp 301 307.

[17] Fukuchi, N. and Imamura, T.: Risk assessment for fire safety considering characteristic evacuees and smoke movement in marine fires, Journal of Marine Science and Technology, 2005, Vol. 10, No 3, pp. 147-157.

[18] Germanischer Lloyd: Rules for Classification and Construction Ship Technology, 2013.

[19] Hlaváčová, I. M. and Vondra, A.: Future in Marine Fire-Fighting: High Pressure Water Mist Extinguisher with Abrasive Water Jet Cutting. Naše more, Special Issue, 2016, Vol. 63, No 3, pp. 102-107

[20] IEC 60754-2 ed2.0 - 2011-11-17: Title Test on gases evolved during combustion of materials from cables - Part 2: Determination of acidity (by pH measurement) and conductivity, 2011.

[21] IEC 61034-2 ed3.1 - 2005: Measurement of smoke density of cables burning under defined conditions - Part 2: Test procedure and requirements, 2005, A1-2013.

[22] IEEE Std 45-2002: Recommended Practice for Electrical Installations on Shipboard, 2002.

[23] Institution of Electrical Engineers: Regulations for the Electrical and Electronic Equipment of Ships with Recommended Practice for their Implementation (IEE Regulations), 1993.

[24] International Electrotechnical Commission: Standard IEC 60092-350: 2014: Electrical installations in ships - Part 350: General construction and test methods of power, control and instrumentation cables for shipboard and offshore applications, 2014.

[25] International Electrotechnical Commission: Standard IEC 60331-11 ed1.1 - 2009-07-08. Tests for electric cables under fire conditions - Circuit integrity - Part 11: Apparatus - Fire alone at a flame temperature of at least 750 °C, 2009.

[26] International Electrotechnical Commission: Standard IEC 60332-1-2 ed1.0 - 2004-07. Tests on electric and optical fibre cables under fire conditions - Part 1-2: Test for vertical flame propagation for a single insulated wire or cable - Procedure for 1 kW pre-mixed flame, 2004.

[27] International Electrotechnical Commission: Standard IEC 60332-3-22 ed1.1 - 2009-02. Tests on electric and optical fibre cables under fire conditions - Part 3-22: Test for vertical flame spread of vertically-mounted bunched wires or cables - Category A, 2009.

[28] International Maritime Organization (IMO): International Code for Application of Fire Test Procedures. Maritime Safety Committee (MSC), 88th session: 24 November - 3 December 2010.

[29] International Maritime Organization: International Convention for the Safety of Life at Sea (SOLAS), 1974.

[30] Kuehmayer, J. R.: Marine Accident and Casualty Investigation Boards. Austrian Marine Equipment Manufacturers, 2008.

[31] Lloyd's Register: Rules and Regulations for the Classification of Naval Ships, 2013.

[32] Lloyds Casualty data base. Website: http://www.lloydslist.com [accessed 02/07/2013]

[33] Marine Accident Investigation Branch (MAIB), 2013, Website: http://www.maib.gov.uk [accessed 02/04/2015]

[34] Naval Engineering Standard, NES 713, Issue 3, March 1985.NES: Determination of the Toxicity Index of the Products of Combustion from Small Specimens of Material, Issue 3.

[35] US Costguard: Recreational Boating Statistics, 2012. http://www.uscgboating.org [Accessed 07/2015]