THE UNGOVERNED SPACE OF MARINE FIRE SAFETY ENGINEERING™ IN SHIPS & OFFSHORE PLATFORMS AT SEA

In this article Dr Carl Stephen Patrick Hunter explores the essential nature of shipping to the UK, global trade and transportation, the physical dynamics of ships movement at sea and the disturbance and effect this can have on the fire system and its protected spaces, and considers it the "ungoverned space" of marine fire extinguishing systems. Dr Hunter describes the unique demands of the Marine Engineer to manage these highly effective and pressurised marine gaseous extinguishing system at sea as one in which few Marine Engineers are always qualified to fully undertake. A ship is a sophisticated, thinly-crewed and isolated marine asset transporting essential wet and dry cargoes at sea globally. Sailing alone and at sea for 365 days a year but without the ability to call upon Fire Rescue Services as a land-based asset might. This means that its extinguishing systems are its essential defence against the risk of fire at sea. If its contents escape due to their pressurisation from vessel movement or leakage under pressure the ship has no other means to control the fire event. Technology exists to constantly monitor these and the protected spaces into which the extinguishant gas will discharge at the point of fire detection. As ships and their crews are the critical means to transport the needs of todays "just in time" global trade Dr Hunter makes the case for their constant monitoring and the integration of the monitoring data into the existing connectivity of today's smart Safeship™ .

SET IN A SILVER SEA – OUR MARITIME NATION

We sometimes forget we are an Island nation and a glorious archipelago of them too. 95% of goods arriving to the UK by sea because of it. Exported by the same proportion too. We think of aircraft carrying cargo, but their maximum limit is approximately 100 tons. Ships at sea are vast. 200,000 – 300,000 dwt. A Gas Carrier is at sea every 300 nautical miles every moment of every day between Milford Haven and Doha in Qatar. Carrying 17% of the UK's gas needs. We are a G5 economic power and our routes of the internet today reflect remarkably the same maritime trade routes and undersea cable routes developed in the 18th and 19th centuries. Think of that. There are 55,000 vessels in the world's fleet and the UK remains the global centre of the marine industry in ship design, marine power propulsion, Naval Architecture, marine & oceanographic research, marine insurance, Admiralty law, maritime technology, marine surveying, ship broking, marine classification societies and cargo broking. The headquarters of the International Maritime Organisation is in London and we are the world's 3rd largest contributor to it. The North Sea contains some of the most advanced offshore oil and gas technology and the UK leads the world in advanced engineering techniques of decommissioning offshore platforms. The Royal Navy remains a global lead in Safeship™ operations and one of only 5 world powers operating, designing and building nuclear attack and strategic nuclear ballistic submarines. The Royal Navy's approach to Naval Damage Control is rivalled only by the US Navy's in Safety & Survivability. The Royal Navy are soon to commission two of the world's largest Aircraft Carriers and we will be of only 4 nations with the capability to deliver 5th generation maritime strike capabilities once they are. They are our nation's strategic assets fit to serve the global nation we are.

Alongside the USA the UK is the most respected fire engineering country globally. Combined these make the UK uniquely positioned to contribute to global maritime fire safety. This paper explores the continuous monitoring on modern "smart ships" of marine CO2 and NOVEC™ 1230 fire extinguishing systems and Protected Space integrity. Aiming to increase safety, this is the "Ungoverned Space" of marine fire engineering. Going above and beyond regulatory compliance is vital to increasingly high value and safety critical vessels. However, with the impact of marine fires being more widely understood, new research and development explores ultrasonic technology to monitor the extinguishing systems through inspection and integrated, continuous monitoring. The latter gives eyes to shore-based operators at a time of fewer crew and hopes for autonomous shipping. New smart ship technology counters the environment in which a “safety first” culture remains un-pursued and unrewarded. Ultrasound is now being put to more advanced, innovative uses in shipping for fire safety solutions to deliver the Safeship™ of tomorrow. And the UK is at the forefront of this capability. For if we recognise that a gaseous system is a pressurised one, then we accept that it exists in a dynamic state. And if we accept that engineering and scientific fact, to neglect its constant monitoring would be a risk that becomes a neglect. For a ship sails at sea, and it is alone, and its fire system is its protection.

1. MARINE & OFFSHORE GASEOUS EXTINGUISHING SYSTEMS EXIST TO SERVE … BUT WE NEED TO UNDERSTAND THEM SO THEY CAN

Marine Gaseous extinguishing systems are installed to protect against special hazards in critical infrastructure at sea. They deliver the resilience our advanced maritime society requires in its efforts to deliver the “just in time” supply chain the world depends on. If the hazard is special and the vessel is critical, then this is the case for the constant monitoring of the fire systems that aim to deliver their protection. In fire safety engineering, there are four key areas which must be considered to best analyse the efficacy of the system: contents of agent in the cylinders, weight of agent in the cylinders, the cylinder pressure, and the protected space integrity. This paper explores these areas, demonstrating that there exists an “Ungoverned Space” in marine fire safety engineering in the marine sector which must be addressed, so that the industry can work together to improve safety of life, asset and vessel at sea.

1.1 WHAT IS THE “UNGOVERNED SPACE” IN SHIPS AT SEA ?

Who would build a ship or offshore platform and install a power generating or auxiliary machinery without installing emergency power systems or monitoring their condition states? Who today would consider installing an alarm system without monitoring its overall status, not only its actuation, and integrating the whole system into the ship safety management system, with central monitoring being an essential part of it? These are basic engineering principles: building in redundancy and constantly monitoring critical systems.

Yet when it comes to marine fire maintenance, never mind constantly monitoring, of gaseous fire extinguishing systems, there is a lack of knowledge among the majority of the industry, around the potential risks. Awareness should exist about the huge expenses incurred by fire, both in terms of costs upfront from the damage and long-term due to reputation and unknown losses or damage to seafarers, vessel integrity, and cost of downtime and recovery. Above all is the risk to human life presented by fire. Poor maintenance of extinguishing systems risk accidental fatalities due to lack of training about the lethal properties of CO_2: when released it reduces oxygen levels to extinguish fire. Limited appreciation of the need for room integrity testing of protected spaces leads to minimal regulation compliance which could mean a failure of the fire system extinguishing a fire because the room is unable to hold the discharged gas due to leaks of the space into which it actuates. And leaks will occur in any engineering structure as it ages on land. But at sea a ship “turns and bends” as it travels through changing seas adding an additional dynamic of physical stresses which affect it even more.

1.2 ARE STAKEHOLDERS WORKING TOGETHER TO IMPROVE FIRE SAFETY?

Following a fire, 40% of facilities experiencing business dis-continuity do not survive another 12-18 months afterwards. FM Global say that a third of businesses affected by fire go out of business within 3 years [1]. The damage of fire cannot be over-stated. It is necessary for stakeholders to work together to improve fire safety. The stakeholders comprise the ship owners and its leadership team. Critically it also involves the mariners who occupy its spaces, the insurers who safeguard their lives, their consequential loss or injury and the damage to their families, the asset value itself and the fire company who design, install, commission and maintain the marine clean agent system. An engineered marine fire system typically lasts 20 years, longer than some vessels! More automatic fire protection systems mean fewer fires which must be contained by the ship in its isolation. But we understand the FRS far more than the fire engineering solutions embedded in the vessels themselves even though a ship rarely have access to the FRS at sea. And ships are at sea 365 days a year. Ship operators expect 100% availability of the asset and when using it reasonably, they expect 100% safety in it. Is it not time that assets such as vessels and the fire systems that enable that asset availability and protection should be monitored 100% of the time ?

1.3 ADDRESSING THE UNGOVERNED SPACE: EXPERIENCE & EDUCATION

There exists much “ungoverned space” in the marine industry. Few Engineers in the industry fully understand the design, installation, testing, maintenance and safety of gaseous firefighting systems in vessels or offshore marine structures. There is a lack of knowledge of the characteristics of the various extinguishants and the types of fire for which they are suitable. For too many years the industry has been left to too few brilliant – largely British and American - experts to determine safe outcomes. But as the world changes, so must the industry integrate technological solutions to provide a bulwark against wider industry misinterpretation, minimal, occasional and even flagrant disregard of the application of standards and good global engineering practise. Education is key to creating standards which all can understand and apply.

1.4 FIRE SAFETY AT SEA

Shipping, Naval and Offshore Oil and Gas sectors are all safety critical, with possible catastrophic and expensive results in the event of fire. Incidences of fire on ships have been increasingly reported in the press. For example, the International Maritime Risk Rating Agency (IMRRA) have declared fire safety to be the most common deficiency on tankers in October 2016, with 126 incidences [2]. A white paper has been published by the International Union of Marine Insurance (IUMI) suggesting methods for improving fire safety standards on container ships. IUMI’s Loss Prevention Committee Vice Chairman Uwe-Peter Schieder advocated in *IHS Safety at Sea* that “Major fires on container vessels count among the worst hazards in global shipping”. This was published in article arguing “Fire risk grows as ships get bigger” which also highlighted the United States Coast Guard’s awareness of the need for improved fire safety [3].

1.5 GASEOUS ACCIDENTS: REPORTED & UNKNOWN

In aerospace, if a fault occurs on an aircraft that information is quickly and openly shared with Airline Operators, Civil Aviation Authorities and Engineering Organisations. In contrast in shipping, unless a fatality occurs, it is often left un-reported. This does not seem correct considering the aforementioned assumption that pressurised systems leak and protected space integrity changes, How many ships sailing with partially-filled, over-filled or empty cylinders, how many accidental discharges or slow seepages are occurring and whether protect space integrity is tested and maintained after every significant change to the space, are left un-shared and unknown. Here are some high-profile accidents related to fire to emphasise the need for improved fire systems monitoring:

- September 2004 – Hong Kong - A Routine Inspection of the Fixed CO_2 Fire Extinguishing System that led to the Death of Four Officers [4]
- November 2008 - Akula II K-152 Nerpa- At least 20 people have died in an accident on a Russian nuclear submarine when a fire extinguishing system (Halon) was activated by mistake [5]
- May 2010 - Marsol Pride, uncontrolled release of fire-extinguishing gas into engine room, Tui oil and gas field [6]
- August 2011 - Accidental discharge of carbon dioxide on board SD Nimble resulting in serious injury to a shore-based service engineer at Her Majesty's Naval Base Faslane [7]
- July 2014 - Port Hedland, Western Australia -A fire started in the engine room of the bulk carrier Marigold, while it was loading a cargo of iron. Firefighting by the ship's crew included activating the Halon gas fixed fire suppression system for the engine room. However, a full release of Halon gas did not occur, nor was the engine room effectively sealed [8]
- February 2015 – Twentynine Palms, California - 22 US Marines Injured when a halon-containing fire extinguisher went off [9]

1.6 ANECDOTAL SERVICE EXPERIENCE OF GASEOUS SYSTEMS

Industry experience and anecdotes, whilst not independently reviewed, lend themselves to the argument that the industry is not appropriately educated about the issues of fire safety in terms of the extinguishing systems and protected space integrity.

- Systems portrayed and installed by contractors as NOVEC™ 1230 but filled with sand or water.
- High pressure gas systems without the means to actuate them.
- Cylinder pressure gauges sticking in position under humidity or mechanical fatigue.
- Safety pins being retained in position in the cylinder valves after installation.
- Marine CO_2 systems with 20% of the CO_2 cylinders installed on commercial shipping being empty or partially-filled.
- Over-filled and under-filled cylinders.
- Pipework and cylinders freshly painted but with severe internal corrosion leading to particulates of rust which block the discharge nozzle mechanism.
- Room integrity testing with questionable results and with the room integrity remaining un-monitored after testing.
- Liquefied Gas Extinguishants being confused by installers and customers with non-liquefied Inert gas systems.
- There exists a lack of understanding of the organic compounds of some liquid extinguishants and their corrosive effect on the cylinder in the event of condensate ingress.
- Shipping companies not implementing the FSS code of the IMO SOLAS regulations.
- Bathroom weighing scales being chained to the CO_2 cylinders in an effort to comply with IMO SOLAS FSS Code regulations. But no un-qualified Officers or Crew are qualified to shut-down, dis-mantle, weigh and re-install a CO_2 cylinder

2. A TYPICAL SHIP OR OFFSHORE GASEOUS EXTINGUISHING SYSTEM .. THEY ARE UNDER PRESSURE

In terms of ship's extinguishing systems there exist two broad categories: sprinkler systems and pressurised gas systems (typically CO_2 but also NOVEC™1230). While the former can suffer leakage, the latter can cause catastrophic effect given their high pressures. An average ship's CO_2 system comprises between 200 and 600 cylinders each containing 45KG of CO_2 under high pressure, typically 50 Bar or 720 psi. One of the highest probabilities of discharge occurs during their annual certification and maintenance. Clean agents are designed to operate in limited spaces where there is a need for speed of suppression given the asset risk and where the space is occupied by people. They must extinguish a fire without damaging the asset they protect and enable operational continuity of the vessel whilst power is maintained. They must be easily maintained in-situ by qualified teams. They must comply with NFPA 2001 standards demanding fast discharge in 10 seconds and fire extinguishing within 30 seconds. Protecting humans and equipment alike whilst doing so in an environmental manner regarding ozone depletion and governed by the Montreal Protocol. They must be non-flammable and non-toxic. Contained in a design parameter which is "state of the art" and deliver confidence to the operator that it delivers "best fire safety practice".

- International Maritime Organisation (IMO) Safety of Life at Sea (SOLAS) International Fire Safety Systems (FSS) Code Chapter 5, 2.1.1.3 Means shall be provided for the crew to safely check the quantity of the fire-extinguishing medium in the containers. *Inbetween the annual maintenance check ie at sea*
- IMO MSC Circular 1120
  - 7.3.2.6 CO2 cylinders are normally filled up to two-thirds of the height of the cylinder, however, the level will change according to the ambient temperature. Means should be provided to verify the liquid level in all the cylinders, either by weighing the cylinders or by using a suitable liquid level detector.
  - 7.3.7.3 CO2 even makes allowance for crew to undertake this work if suitably qualified IMO MSC/Circular 1318 the MCA adopts the following policy for this Circular: iv) MSC/Circular 1318 paragraph 4) Monthly inspections may be performed by competent crew members, e.g. crew who have undertaken an STCW Advanced Fire Fighting course. *But this is rare. Most crews are not qualified in this.*

2.1 COST THE CRITERIA FOR SAFETY ?

Traditionally, the maritime industry treats fire protection systems as a necessary expenditure, rather than a means to safeguard valuable crew and cargo and maintain business continuity of the vessel. The competitiveness of the free market places great pressure on cost cutting: to deliver systems which often only minimally comply with regulations, and deliver asset protection at the most economical budget. With the value of assets, vessels and importance of business continuity growing, insurers are asked to underwrite almost incalculably high risk. Yet we accept minimally compliant fire systems. Given both the crew lives and cargo at stake, it seems unfathomable that regulations do not mandate fire systems should be permanently monitored rather than certified typically just once a year, particularly since it is a regulatory obligation to ensure that crew can check these themselves. The definition of a free market is an idealised form of a market economy in which buyers and sellers are allowed to transact freely based on a mutual agreement on price without state intervention in the form of taxes, subsidies or regulation. Unable to operate in an idealised economy but one that is regulated, the only reason why price dominates the environment is either because Government and Regulators are standing aside from the creation of an environment in which safe engineering goes rewarded rather than prejudiced, or because the industry itself is unaware of new technology that will help them meet both the spirit and letter of the regulation. This Ungoverned Space of Marine Fire Engineering can be addressed today, with minimal education and cost, to create a "safety first" culture where owners and operates are rewarded for pursuing above and beyond regulation compliance.

2.2 BEST PRACTICE: ULTRASONIC TECHNOLOGY & THE OPPORTUNITY FOR RESOLUTION

The most critical point of a pressurised cylinder is the meeting of the cylinder neck with its valve. For over 100 years the industry has monitored and permanently weighs (even suspends) cylinder pressure and weight of contents at that critical point. The assumption is that the cylinder pressure gauge is of high, almost MIL-SPEC quality, but they are often not and commercial pressures under a bidding process can incline some to select low-end budget, minimally compliant gauge mechanisms. Technologies will soon exist to monitor both liquefied gaseous content and non-liquefied gaseous pressure safely - from the *external sides* of the cylinder *rather than within it* – in both fixed and portable forms. Currently, there are fast, accurate and reliable methods using ultrasonic technology. For example, for checking contents by liquid level indication. Once able to monitor the contents, the mass/weight of the liquefied extinguishant can be calculated. If one can monitor the pressure of the gas on top of the liquefied extinguishant then one can also monitor the pressure of an Inert gas which is in an entirely vaporous form. Today ultrasonic technology can be utilised not only for handheld inspection tools used by marine surveyors, chief engineers and crew, but also for both constant monitoring, delivering remote diagnostics and data to a shore-based operator. These technologies offer great opportunity to the industry. These methods enable the vessel owner, manager and operator to go above and beyond minimal regulation compliance to achieve best standards of safety at sea in terms of fire safety. They enable customers to have confidence that a fire company has installed a gaseous extinguishing system with a semi-autonomous monitoring capability to safeguard it. The customer-supplier relationship becomes an embedded one, with additional value, creating revenue reward. It is in the public interest. What CEO of a shipping company today wants to be shown to have installed a fire system that is left standing and unsupervised over thousands of miles of open seas and often in extreme weather states for 364 days of the year until the return of the marine servicing company for its annual certification check ?

3. COMPARTMENT ROOM INTEGRITY MONITORING – THERE IS A PROBLEM THERE TOO; SHIPS CHANGE SHAPE …

This is essential under ISO 14520 where gaseous extinguishing systems have to be designed in relation to the discharging agent hold-time (if the room cannot hold the agent because of leaks the agent will disperse and not extinguish the fire) and discharging agent peak pressure (if the pressure is too high for partition walls or suspended ceilings they will be blown apart or damaged and possibly destroying the room integrity). At the design stage of a fire extinguishing system protected spaces are tested for room integrity by positively pressurising a room and detecting escaping pressure, to verify that the room itself into which the gaseous extinguishant discharges on actuation, can both hold the agent after its discharge and hold its pressure on actuation. The fire system is then installed and commissioned. A building ages like a ship does at sea at sea. But a ship also “turns and bends” as it travels through the sea, and the extent of it is determined by its load-state, sea state and wind state. It ages and as its structure changes leak sites develop. Regulations may require the protected space to be tested every year, but it should be tested after every major change to the room.

3.1 REGULATIONS FOR MAINTAINING PROTECTED SPACE ROOM INTEGRITY

IMO SOLAS Chapter II-2 Regulation 10, G23.3 states, “The Regulations require that 85% of the required concentrations for machinery spaces and cargo pump rooms is achieved in such spaces within two minutes.” If the room contains leakages, slowing down the process to achieve the required flooding concentration, the CO_2 extinguishing system is able to achieve the desired concentration in the time limit proposed? If room integrity is not secure, wrong arrangements may be made to increase the rate of CO_2 discharge when in fact the problem is related to the room integrity itself.

ISO 14520

- 9.2.4.1 At least every 12 months it shall be determined whether boundary penetration or other changes to the protected enclosure have occurred that could affect leakage and extinguishant performance. If this cannot be visually determined, it shall be positively established by repeating the test for enclosure integrity in accordance with Annex E.
- 9.2.4.2 Where the integrity test reveals increased leakage that would result in an inability to retain the extinguishant for the required period, remedial action shall be carried out.
- 9.2.4.3 Where it is established that changes to the volume of the enclosure or to the type of hazard within the enclosure, or both, have occurred, the system shall be redesigned to provide the original degree of protection. It is recommended that the type of hazard within the enclosure, and the volume it occupies, be regularly checked to ensure that the required concentration of extinguishant can be achieved and maintained.

These regulations recognise the risks to a vessel or building structure ageing and generating leak sites. The case is clear that the industry should support constantly monitoring, above and beyond full regulation compliance, as the risks are so clearly described in the core standards.

3.2 A SHIP CHANGES SHAPE AT SEA

A vessel generates leak sites due to dynamic movement and severity of structural movement amplified within a vessel structure constantly changing by varying sea, wind, load states, cargo types and dynamic stresses. There is a great deal of bending and deformation that naturally occurs in ships during travel. The dynamic movement of a vessel is illustrated through analysis of stills from a video [10] Tuxen, 2016 showing the stress and effect on a vessel during passage from Suez Canal to Singapore in severe weather conditions) as shown by the analysis in the inset figures 4, 5 and 6 below [11]. Considering the importance of maintaining room integrity in order for the gas to suppress a fire within 2 minutes, protected spaces on-board vessels should be tested far more regularly and frequently than currently. They can be right now ultrasonically both to do that and can be dual-use to protect crew when entering spaces protected by CO_2. But the industry does not access them.

Figure 4: This still (1m:20s) shows wire frames highlighting rectangular sections along the vessel which will be used for comparison with Figure 5 (below)

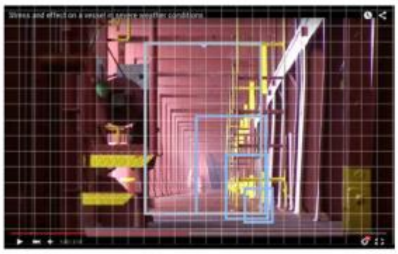


Figure 5: Still from (1m:30s) with rectangular boxes, combined with grids to highlight the movement.

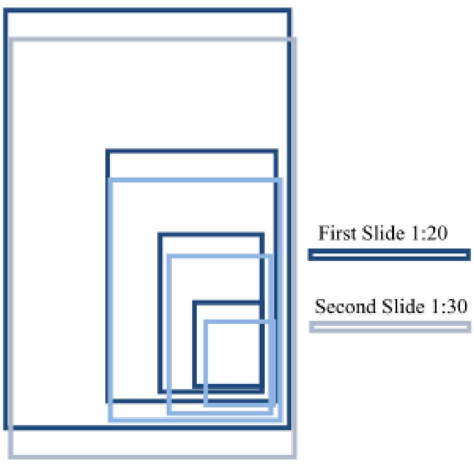


Figure 6: This image overlays the rectangular sections from Figures 4 and 5 to show the difference between 1m:20s and 1m:30s.

Figure 2. Vessel bending in severe weather

4. BRITISH ULTRASONICS SAFESHIP™ TECHNOLOGY AND HOW THEY WORK TOGETHER. TIME FOR SOME MATHEMATICS …

One of the sciences being harnessed by innovators in fire safety is that of ultrasound: i.e. acoustic (sound) energy. Sound is vibrations that propagate as a mechanical wave or pressure and transmit through solid, liquid or gaseous mediums. Dolphins and whales can communicate at sea over long ranges, as sound travels more efficiently through liquids than air. In the air bats navigate by airborne ultrasound. In physiology sound is the reception of such waves and in psychology their perception by the brain. This is why a human being listening with one ear angled from the other (and therefore at a different distance from the sound source to the other) “hears” sound as “one sound”. Ultrasound waves are a high frequency above the human audible range of approximately 20 to 20,000Hz. [10]. Ultrasonic methods can range from 40,000 Hz used in watertight integrity testing [12], 1 MHz used in liquid level detection [12], to diagnostic ultrasound devices employing frequencies of 2 – 15 MHz [13]. Although the shipping world more uses it as a tool to gauge thickness, it is in far more varied use across military, medical and industrial fields. With science at the company’s core, Coltraco Ultrasonics is an example of a company aiming to replicate nature and use these fundamental physical principles to design and manufacture products and systems that can be used by the Royal Navy, Engineers, Crew and customers alike. E.g. to identify that difference in a cylinder containing liquefied agent and in room integrity testing. New Safeship® technology utilizes ultrasonics to enable operators to implement a “safety first” culture, through constant monitoring.

4.1 ULTRASONICS AND ATTENUATION

Attenuation is the loss of intensity of sound as it passes through a medium and is a combination of absorption and scattering [14]. For ultrasonic waves, absorption is the dominant cause of attenuation. Absorption can occur because of friction between air molecules which generates heat and through relaxational processes where sound energy is transferred to the air molecules and the molecules dissipate the energy through rotation and vibration. The attenuation over a distance is quantified by the attenuation coefficient, α. See in the equation below:

$$A = \alpha \times l \times f$$

where A is the attenuation, α is the attenuation coefficient, l is the length it travels into the medium and f is the frequency of the incident ultrasound beam. Attenuation coefficients vary widely between materials, for example, air has an attenuation coefficient (at a frequency of 1MHz) of α = 164MHz · m (for 20°C) [15]. while water is α = 0.22MHz·m [16]. The attenuation is dependent on many other factors including the frequency of the wave and the medium in which the wave is propagating. As can be seen from the equation above, the attenuation is linearly dependent on the frequency of the incident ultrasound beam. This explains why ultrasound, with a high frequency of 1MHz is attenuated so greatly. It is also known that ultrasound intensity decays exponentially due to attenuation:

$$I = I_0 e^{-\alpha x}$$

where I is the intensity, I_0 is the initial intensity, α is the attenuation coefficient and x is the distance travelled by the wave.

As higher frequency results in higher attenuation, the equation shows that ultrasound intensity will decrease exponentially. This will occur much faster compared to audible sound of lower frequency due to the greater attenuation in ultrasound. To address the "Ungoverned Space", the attenuation of ultrasound waves is discussed with relevance to three main applications: liquid level detection, pressure monitoring and protected space integrity / leak detection.

4.2 HOW IT WORKS TO IDENTIFY LIQUID LEVEL AND MONITOR PRESSURE IN SHIPS EXTINGUISHING SYSTEMS

As explained above, higher frequency ultrasound has a greater attenuation. To measure the liquid level, the attenuation should be greater, to differentiate the different liquid/gas phases within the cylinder being measured. This technology utilises the attenuation of the ultrasound as it travels through different materials. It is the extent of this attenuation (most importantly its energy dissipation) that differentiates between different materials. Instrumentation which relies on the attenuation of ultrasound is the Portalevel™ MAX handheld liquid level indicator by Coltraco Ultrasonics and their Permalevel™ Multiplex constant monitoring system. These convert electrical energy into ultrasonic waves through the reverse piezoelectric effect. Piezoelectricity is the appearance of an electrical potential across a crystal when it is subjected to mechanical stress, and is a reversible effect. A crystal which exhibits this effect by becoming charged when it is compressed, twisted or distorted is a piezoelectric crystal. Similarly, passing electricity through a piezoelectric crystal causes the crystal to vibrate back and forth; this is the reverse piezoelectric effect [17].

The liquid level of a cylinder can be found because the ultrasonic signal received from the vapour section of the cylinder is different to the liquid section. (The exact location of the liquid level is then pinpointed by finding the point at which the readings change). The difference is the response of liquids and gases due to their physical properties. In a liquid, the molecules are all free to move but still are mostly in contact with each other. In a gas, none of the molecules are touching each other – there are large gaps between then – i.e. gases are much less dense than liquids. The large difference in density suggests that the liquid and gas sections disperse ultrasound very differently (the ultrasonic waves travel very differently through the two media). These different media possess different attenuation coefficients which then affects the overall attenuation of the ultrasonic signal resulting in distinct values that can be used to interpret the liquid levels. At sea whether liquefied or non-liquefied systems are used they are pressurised and the gas pressure affects the ultrasound travelling in it. So, whether liquid level or pressure monitoring the capability to monitor marine fire systems at sea now exist.

4.3 HOW IT WORKS TO MONITOR PROTECTED SPACES INTEGRITY AND IDENTIFY LEAKS

It has already been established that ultrasound is highly effective in detecting leaks relating to watertight integrity in ships. Research which Coltraco carried out showed that "a linear relationship was found between signal leakage out of a certain sized hole (in a watertight box) and the quantity of water able to enter that hole' [18]. "The theory relating the area of a leak site to volume flow rate through said leak is well understood. The volume flow rate, Q, through a hole is given by:

$$Q = A\sqrt{2gh}$$

Where A is the area of the hole, g is the acceleration due to gravity on Earth and h is the height of the head of water above the leak. Therefore, we are to expect a linear relationship between flow rate and hole area."

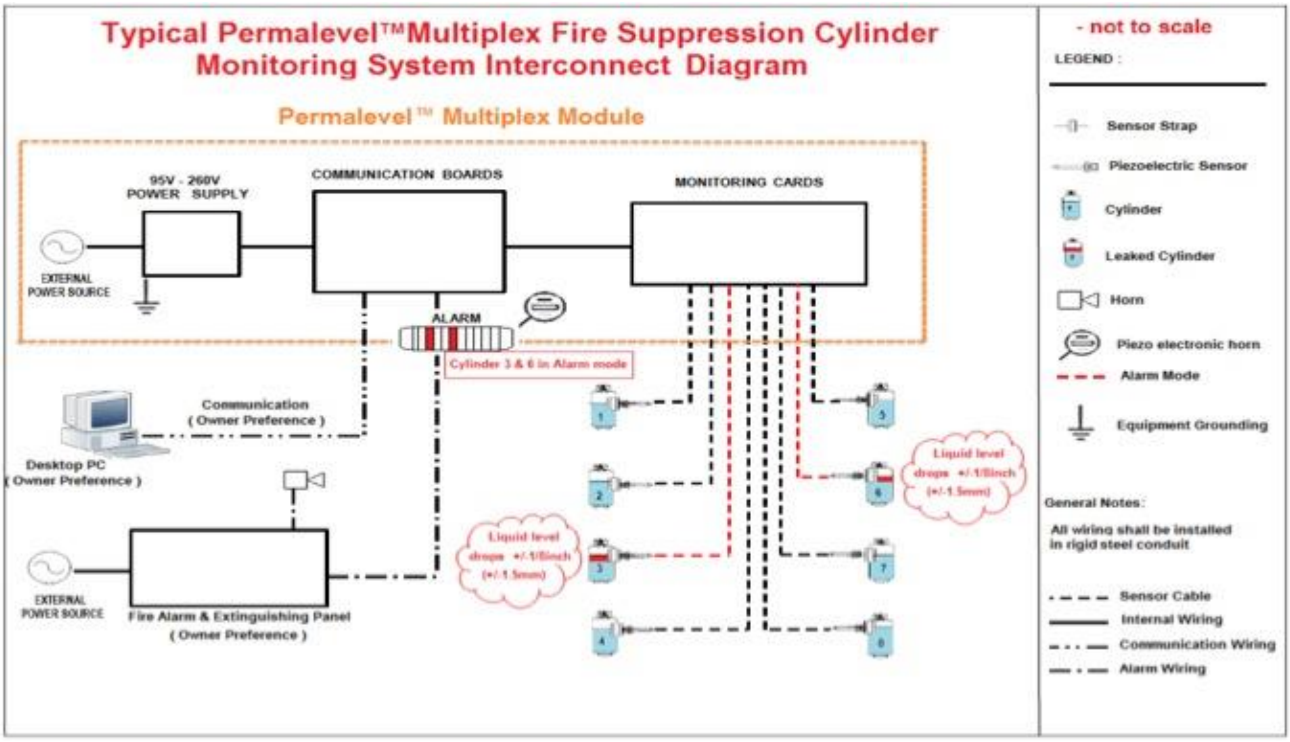
"There is a linear relationship between the flow rate of water through a leak and ultrasound pressure measured through the leak. An increase in signal received is proportional to the quantity of water which could enter through the leak. This has important implications as it allows the user of the

Portascanner™ to operate the equipment in confidence that a spike in the signal does indeed imply that there is a leak.” Just as how the flow rate of water through a leak has a good fit linear relationship to the ultrasound pressure measured through the leak, we would expect the behaviour of gas leaking through the aperture to be similar as well. This would allow effective leak detection in an enclosure needed to contain the clean agent to extinguish fire. Any spike in the ultrasound signal would suggest a leak beginning to form in the enclosure. Ultrasonic Technology is highly advantageous because it accurately and rapidly detects the exact leak locations and size. Although models vary, generally the equipment is comprised of two main components: a generator and a receiver. The ultrasound generator emits a modulated signal of a specific frequency of ultrasound. By utilizing a lower frequency ultrasound, attenuation in air is reduced to allow effective wave propagation through any leaks in seals. The receiver then picks up the signal leaking through the seal and converts it into a result indicating room integrity.

5. SAFESHIP® CONSTANT MONITORING TECHNOLOGY … TO CLOSE THE GAP OF THE UNGOVERNED MARINE FIRE ENGINEERING SPACE

Uwe-Peter Schieder, IUMI Loss Prevention Committee vice says, “[improving fire safety] is an issue of improving the technology” [19]. The “white heat” of British ultrasonic technology shines as a beacon of hope and justifies customers actively engaging in constant monitoring of fire systems and protected spaces as an integrated and essential element to their business activity. The UK shipping industry is accepted as a world leader in its understanding of good engineering practice. The UK is the 5th largest contributor to the IMO by Gross Tonnage and the 3rd largest contributor to the IMO overall. Technologies exist right now that can mathematically and far more efficiently test fire systems contents and room/protected space integrity. Technology exists to quickly and accurately identify pipework corrosion. Gases under pressure can be monitored and liquefied gases can be constantly monitored. Contents and pressure can be simultaneously monitored offering remote diagnostics and remote monitoring capabilities and can extend to the delivery of autonomous systems in relation to them and achieve the Safeship™ we all desire in regard to marine fire system engineering.

[illegible]



5.1 MATHEMATICS MUST BE AT THE CORE of MARINE FIRE ENGINEERING

Customers depend on the fire industry to deliver the best fire engineering to minimise the risk to life, vessel and cargo at sea. Marine Insurance companies and P&I Clubs underwrite shipping risk. But the mathematics of fire engineering failure are high: whether in the application and understanding of the formulas they use to calculate design concentrations of gases or flow rates, or in the deployment of fundamental engineering principles to protect dynamic pressurised systems and the structures they are working so hard to protect against the risk of fire. It is important that the fire protection of a vessel be considered as a whole. These problems can be solved by applying fundamental scientific and engineering principles. The whole drive of civilisation is to continually strive to understand and apply the fundamental Laws of Science and application of Physical Principles. Mathematics explains them and is the language to explain the physical principles of the universe and is required to ensure safe and accurate standards are put in place and implemented. British Standards are some of the most rigorous in the world. The British Standards Institute suggest the UK generates over 50% of all European Standards. BS EN ISO 14520 -1:2015(E) reasonably assumes that the execution of its provisions is entrusted to people qualified and experienced. Furthermore, the regulatory bodies and influencers should reflect on past standards to check they are relevant and correct. Where the mathematics is wrong or where there are gaps – as proven by the ungoverned spaces explored in this paper – the regulators must accept the need for amendments and updates. Influencing the owners, operators and crew, the regulators need to show a fuller understanding of new innovative systems and methods available. And they are. Right now in the Permalevel™ Multiplex gaseous constant monitoring system.

5.2 TECHNOLOGICAL ANSWERS AT SEA

Coltraco Ultrasonics is a leading example of a manufacturer operating in 108 countries, with equipment on-board over 10,000 vessels worldwide, who is innovating to improve safety at sea. Constant monitoring of fire extinguishing systems by Permalevel® Multiplex. This is a fixed system to monitor the fire system cylinders 24/7 with data-logging and autonomous monitoring. Signals from these fixed monitoring sites can be monitored centrally on the bridge and in the ship's shore-side technical office concurrently. Please see the rough schematic of the Permalevel® Multiplex network above for a simplified outline of the potential connectivity. Handheld inspection of the cylinders to comply with the IMO SOLAS FSS regulation above, and many others from ISO, NFPA, and so on, is available via UL, ABS & RINA approved liquid level indicator Portalevel™ MAX. Converting the known liquid level into the weight/mass of agent is achieved through Portasteele™ Calculator – another of the world's first ever such technology, all in a simple 7" tablet format. Coltraco's technology will monitor both liquid content and gas pressure safely from the external sides of the cylinder rather than within it.

5.3 CONSTANT MONITORING of MARINE FIRE SYSTEMS IS REQUIRED

Marine gaseous fire systems deliver the very self-contained resilience a ship needs at sea. But resilience means the permanence of capability and functionality. That permanence can only be delivered by constant monitoring of the systems that enable it. It is essential that marine gaseous extinguishing systems be carefully maintained to ensure instant readiness when required. Routine maintenance is liable to be overlooked or given insufficient attention by the owner of the system. It is neglected to the peril of the lives of seafarers and at the risk of crippling financial loss to the vessel or critical offshore infrastructure. It is usually the case of systems like these that they are out of sight and out of mind, as they are in awkward, rarely-visited spaces. Add to this the priceless nature of data and whether the special hazard is a container ship, offshore platform or submarine, the critical need for constant monitoring is evident.

The importance of maintenance of such systems cannot be emphasised enough. Installation and maintenance should only be done by qualified personnel. Inspection by a fully certified third party, should include an evaluation that the extinguishing system continues to provide adequate protection for the risk (protected zones, as well compartments built for room integrity, can change over time as they age or are modified). But as importantly the marine gaseous system should be maintained not just in relation to itself but regarding the "Protected Space" into which its extinguishing agents discharge on actuation. If that space cannot "hold" the agent on discharge, or its walls and bulkheads or indeed its distributing pipework, cannot sustain the pressures of the gaseous agent on discharge, then the agent will disperse and the fire grow unimpeded. So constantly monitoring the Compartment Room Integrity too is now possible too with Portascanner™ CO2 Room and NOVEC™ 1230 on those Gas Carriers through Coltraco's ATEX Approved Zone 1 Portalevel™ Intrinsically Safe.

6. CONCLUSION

Having systems that operate transparently will work not just to convince a vessel owner that his asset is in good hands, but also to reassure the crew that their safety is taken seriously by both their employer and the marine servicing company. The science of a marine gaseous extinguishing system is a complex one. The mathematics that underpin its science are demanding ones. But in simple terms gaseous systems are pressurised and in that they are dynamic not passive ones. They are there to protect critical marine structures in a safe and expeditious manner in the only way that a gaseous system can, complemented by the integrity of the protected space. One would not imagine an alarm system exists without monitoring it 24/7, but why is the industry still leaving unattended the very automatic gaseous clean agent extinguishing systems that protect us at sea when even the core regulations of its installation and maintenance specifically allude to its potential to accidentally discharge or leak its contents? Fortunately lead elements of the critical infrastructure community are asking the same question. So are the world's insurance companies. But should our own industry not answer the question by implementing constant monitoring 24/7/365 before it is asked of them by the very people it is helping protect ? We can do it now we have the technology. And it is British.

Biography of the Author

Dr Carl Stephen Patrick Hunter BA(Dunelm) Hon DSc FRINA FIMarEST MRAeS is CEO and Managing Director of Coltraco Ultrasonics, a British designer and manufacturer of portable and fixed monitoring systems for the naval, shipping, offshore, energy and fire sectors. He is a former Greenjacket Officer in the British Army and a Graduate and Honorary Doctor of Science from the University of Durham, a Fellow of the Royal Institution of Naval Architects, a Fellow of the Institute of Marine Engineers and Member of the Royal Aeronautical Society, Royal Institute for International Affairs, Royal Society of Asian Affairs and Royal United Services Institute. Dr. Hunter is a Council Member of the British Naval Equipment Association, a member of the Export Council of the Fire Industry Association(FIA) and the FIA's Working Group Gases which is the Lead UK Fire delegate organisation to British Standards and BSI the lead fire delegate to the International Standards Organisation in Gaseous Extinguishing Systems and an active member of the Society of Maritime Industries the lead British marine organisation and voice of the marine industry in the UK. His interests are in Physics, International Business, the Constitution, South Asia, International & Strategic Affairs, Defence, the British Commonwealth and bringing UK Scientists into business. Dr Carl lives in London and Somerset in England, travels extensively in Asia, Europe and the Middle East, has been married for 27 years to Dorothy and a proud Father of four Children.

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My kindest regards,
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