TO WHAT EXTENT CAN EXISTING INERT GAS TECHNOLOGY BE USED TO PROVIDE FIRE PROTECTION ON RN SURFACE SHIPS

BY

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ABSTRACT

In the Royal Navy (RN) there were over 1500 peacetime fires onboard ships during the last sixteen years and current trends show an increase in the average duration of fires leading to concerns over fire fighting issues in future lean manned vessels. New systems and operating procedures are continually being investigated in both the commercial and naval sectors in order to reduce the risk of fire. One system that has been developed over the last 50 years is the use of inert gas as a fire suppressant. Since specific requirements were introduced into the 1974 Safety of Life at Sea Convention (SOLAS), inert gas systems (IGS) have become an integral part of the tanker industry leading to a reduction in the number of fires and explosions occurring within this sector. This technology has not yet been adapted for use onboard warships although inert gas is used for fire extinguishing on some submarines. This paper investigates the extent to which existing inert gas technology can be utilised onboard RN surface warships for fire prevention or extinguishing in order to reduce the overall fire risk.

Introduction

Background

The most effective method to prevent flammable gas atmospheres occurring in a compartment or tank is to maintain the oxygen content below that required for combustion [1,2]. The first inert gas systems to achieve this were introduced into tankers by an oil company in 1925[1]. Other vessels followed and in the 1960's a large number of companies were operating inert gas systems. A series of tanker explosions between 1969 and 1972 led to specific requirements for cargo ships being incorporated into the 1974 SOLAS convention, including the need for some vessels to inert their cargo tanks. Since then, legislation has increased and IGS are now an integral part of the tanker industry, which has in turn been reflected by a reduction in the number of fires and explosions within the industry. Common specifications for inert gas for crude oil tankers are shown in Table 1[3] and it is expected that similar levels should be applied to RN ships should they adopt such a system.

Table 1 Common specifications for inert gas in crude oil tankers [3]

Gas	Requirement
Oxygen	5% or less
Carbon dioxide	14% or less
Sulphur dioxide	100ppm or less
Nitrogen	Up to 100%
Particulate contamination	Negligible

In addition to using an IGS to create a controlled atmosphere (CA) within a compartment, they can also be used as a drench system for fire fighting. It is in this role that IGS have seen some use in the RN with nitrogen drench systems fitted onboard some submarines as a secondary method of fire fighting.

Aim

The aim of this paper is to outline an assessment strategy that was developed to give an evaluation of the benefits of utilising current inert gas technology to reduce fire risk on current and future RN surface ships. It also describes the potential drawbacks and additional benefits of inert gas systems with relation to their use in this role. It does not cover a cost/benefit analysis as the cost savings associated with a reduction in fire risk (including a possible saving of life and fire damage to equipment) is a difficult and contentious issue which was deemed to fall outside the bounds of this paper.

Inert gas systems

A controlled atmosphere, or low oxygen atmosphere, runs on the principle of purging the viable gas with an inert gas and they are not only used within the tanker industry but also used for food preservation, corrosion protection, and within the electrical industry for production of certain components as well as many other areas. Generally speaking, four different types of inert gas system are commercially available: Fuel oil burning inert gas generators [3,4], Flue inert gas systems [1,3,5], Pressure swing absorption (PSA) nitrogen generators [4,6,7] and Membrane nitrogen generators [4,6,8].

The first of these burns LPS or Kerosene at sub-stoichiometric levels so that the exhaust gas is almost free of oxygen. They have high unit production costs and through life costs and require vast quantities of cooling water, fuel and electrical power. The standard fuel is not used within the RN and this, coupled with the plant's large size and corrosion problems with the gas, make this type of plant unsuitable for use on RN warships. Secondly the flue inert gas system takes gas from a main or auxiliary boiler and passes it through a scrubber which cools and cleans the gas. The RN has moved away from boilers as both a main or auxiliary system and hence the flue gas system is not suitable for use on warships. Finally the nitrogen generator systems use two different methods to produce high purity nitrogen (95% or better) and can either be portable plants housed within containers or permanent plants fitted within machinery spaces. This makes them extremely versatile and their size and low maintenance requirement would make them ideal for use on RN warships if an IGS were to be used.

Fire prevention in the Royal Navy

In peacetime and at war fires are a very real threat onboard RN warships and therefore when designing new vessels considerable thought is given to reducing the fire risk and in providing systems and routines to aid the rapid extinction of any fire. Despite this, there were over 1500 peacetime fires onboard naval surface vessels at sea and alongside in the period from Jan 88 to Jan 04 [9]. On existing RN vessels fire prevention relies on good maintenance, rounds routines and vigilance of the personnel onboard. This has worked well to date with nearly 90% of fires being discovered quickly and being extinguished by first aid fire fighting measures. That said, a recent report commissioned by the Warship Support Agency (WSA) [10] highlighted a possible requirement for greater fire protection on future ships, particularly if further reductions in man-power were to be made. Whilst this belief is not supported in all areas of the MoD, the links between fire risk/fire fighting and man power levels are always considered in the design of a ship.

Viewing this from another perspective, fire risk was identified as an area of concern during the early concept design phase of the Future Surface Combatant (FSC) due to man power levels and the possible use of a trimaran hull form. This led to the question of the possible use of low oxygen compartments for fire prevention and it was felt that the proposed modularity of the design might additionally facilitate this approach.

THE ASSESSMENT PROCESS

Methodology

From the research, it was evident that there would be several key issues that would need to be addressed, such as the required levels of access to equipment and compartment, the location of compartments within the ship, normal access routes through the ship etc. It was thus necessary to devise a progressive assessment strategy that would start by considering general criteria such as remaining life of a vessel and generic compartment fire risk before moving on to ship specific operating procedures, compartment design, and emergency scenarios. In order to aid the development of such a process the aim of a potential IGS had to be defined. After consultation with operators, designers and other key staff within the MoD and RN the following requirement was defined.

> "The inert gas system must be capable of maximising the fire protection capability of future warships and should negate the additional fire risk caused by low manpower levels. Fire prevention should be achieved by creating a controlled atmosphere in unmanned or high risk compartments without having any effect on the operational capability of the ship"

With this in mind the following 5-stage assessment strategy was compiled:

- Ship Identification. This was designed to identify classes of ship that would be suitable for an IGS based on relative complement size and remaining life of the vessels.
- Generic Compartment Identification. This identifies generic types of compartment that could be suitable for inerting based on current fire data and access requirements.
- Ship Specific Compartment Identification. This assesses each of the suitable generic compartments against current or intended operating procedures for that compartment in a particular ship.
- The effects of an Emergency of Damage Scenario. This assesses the impact of having those compartments already assessed as suitable inerted during a damage or emergency situation e.g. collision.
- Benefit assessment. This uses a simplistic calculation in order to give a rough estimate of the potential reduction in fire risk for each class of ship and is defined later.

For new and future ships, where there is limited or no fire data, the historical data was used and correlated to new vessels by assuming that a similar relative percentage of fires would occur across each compartment type irrespective of age of vessel. (i.e. 50% of fires would occur in machinery spaces on both current and future ships.) As the aim was to identify the possible reduction in fire risk and not the overall cost benefit of fitting an IGS, cost was not considered

Ship identification

There are essentially three sizes of vessel within the RN; small ships such as minesweepers and fishery protection ships, large ships such as destroyers and frigates, and capital ships such as aircraft and helicopter carriers.

Table 2 Current and future surface ships and their suitability for an IGS

	Class of Ship	Approx Complement	Approx disp per crew member (T/crew)	In service date or remaining life	Suitable for IGS
Small Ships	Hunt	45	17	Newest ship launched 1988	No. T/crew ratio too small
	Sandown	34	18	Newest ship launches 2001	No. T/crew ratio too small
	Castle	42	35	In service in 1980/81 due to be replaced soon.	No. Limited life would not make this cost effective
Large Ships	Type 42 Destroyer	280	17	Due to be replaced by T45 commencing 2006	No. T/crew ratio too small and limited life left.
	Type 22 Frigate	250	16	Latest in service 1988 and only 4 now remaining	No. T/crew ratio too small and limited life left
	Type 23 Frigate	180	23	Latest in service 2000	No. T/crew ratio to small
	Type 45 Destroyer	200	39	In service date 2006	Yes. Large T/crew ratio and long life remaining.
	FSC (Future Surface Combatant)	150	33	In service date beyond 2016	Yes. Although T/crew ratio is not that large the immaturity of this design makes it ideal for further consideration
Capital Ships	CVS (current aircraft carrier)	700 (1100 when aircrew embarked)	19-30	Currently in service but due to be replaced by the CVF (2012)	No. T/crew ratio too small and limited life left
	LPH (HMS OCEAN)	300 or 1200 when fully embarked	18-75	In service in 1995 and sole unit of this type	Yes. Operates predominately with crew of 300 therefore large T/crew ratio
	LPD(R) (landing platform dock)	325	59	In service 2001	Yes. New vessel with suitable T/crew ratio
	CVF (future aircraft carrier)	600 (plus aircrew)	100	In service date 2012	Yes. Future vessel with large T/crew ratio

When assessing a vessel's suitability for an IGS the size of ship compared with the crew size is a useful indicator as reduced manning levels are one of the main reasons for investigating the use of inert gas. Using the fire data for individual classes of ship and the conclusions from the WSA report a ship size to crew ratio of 30, measured in displacement tonnes/crew (T/crew), was used as an initial indicator of a manning level that may lead to an increased fire risk. This value is not an absolute criterion and it has to be considered on an individual basis along with remaining ship life and current perceived acceptable levels of fire risk. Another possible index would be volume to crew size however data on relative volumes of vessels is not as readily available as displacement. As can be seen from Table 2 small vessels, having a relatively small T/crew ratio, would have little benefit from such a system. Of the large ships, the future Type 45 and FSC classes are suitable considering the T/crew ratio and the expected life. Likewise, the capital ships that are suitable are the LPH, LPD(R) and CVF.

Generic compartment identification

There are several different types of compartments and spaces onboard warships and these were assessed using the broad categories from the Fire Data Base [9] to assess their risk before considering their likely access requirements and hence suitability for inerting.

- Machinery Spaces: These account for nearly 50% of al fires and are therefore an important group of compartments for further consideration. Unfortunately the majority of machinery spaces on current vessels require regular rounds to be conducted and may therefore prove unsuitable for inerting without a serious change to operating practices. On future vessels there will be a greater use of automation and hence this may support the move to unmanned machinery spaces (UMS), as is currently the case in the Merchant Navy, and hence they could be suitable for inerting.
- Electrical Compartments: These compartments account for the second largest proportion of fires onboard and, with the move to electrical propulsion, will increase in number on future vessels. Electrical compartments are also generally unmanned and hence are ideal for further consideration.
- Stores: These account for approximately 3% of fires and often require daily access in order to obtain items. On future vessels the intention is to automate these stores hence negating the access requirement and although it may prove difficult to maintain the inert atmosphere when the system is running they could still be considered at this stage.
- Galleys, accommodation spaces and passageways: Whilst a number of fires have occurred in these areas they require permanent access and are therefore unsuitable for inerting.
- High risk compartments: certain compartments are classed as high risk as a fire in them could be catastrophic. These include weapon magazines and fuel pump rooms and due to their classification they will be considered further for inerting.
- Other compartments: There are a number of compartments that have not been covered in the above groups however the level of fire risk in them is either so minimal (i.e. void spaces) or the access

requirement too great (i.e. operations room) that they can not be considered for inerting.

Although some of the above compartments are currently designed to use forced ventilation for cooling purposes, this should not be seen as prohibitive when considering inerting the space and this is discussed later in the paper.

Ship specific compartment identification

Table 3 Examples of Ship Specific Compartment Identification for Type 45

Compartment	Fire Risk	Operational Importance	Frequency of Access	Importance of Access	Benefit from Inerting	Suitable for Inerting
Machinery Rooms	High	High	Hourly Rounds	Medium	Medium – increases fire protection in a high risk space and could also reduce rounds requirement	Yes
Low Voltage (LV) Switchboard Rooms	Medium	High	Daily rounds and drills	High	Low – requirement for access too great to justify medium fire protection increase.	No

This stage of the process considered those generic compartments that were identified as suitable for inerting in the previous stage and assessed them for specific ships. This was based on the following criteria (Table 3) and the results for two different compartments in a Type 45 Destroyer (T45) are shown as an example. It should be noted that this is a subjective assessment and ideally this would take place early in the design phase of the ship and involve all relevant subject matter experts in order to ensure the optimum solution.

- Fire Risk. Historical data was used to assess the likelihood of a fire occurring in a compartment (i.e. 50% of fires occur in machinery spaces) coupled with the presence of an ignition source, and the affect of a fire was assessed based on the contents of the compartment (i.e. fuel would give a high assessment due to its flammability). This meant that the risk could be calculated using likelihood multiplied by affect and the results were simplified to give low, medium or high risk.
- Operational Importance. This was based on a standard RN assessment for effect on Operational Capability (OC). It rates the effect of losing the compartment on the vessel's OC as low, medium or high. The rating for the machinery room is high as losing this compartment would result in a significant reduction in propulsion capability. Similarly, the rating for the LV switchboard is high as

this would result in a loss of electrical supplies to various items of important equipment.

- Frequency of Access. This simply gives the current intended access requirements for each compartment.
- Importance of Access. This was a comparison of the operational importance of the compartment and the reason for access. It was incorporated because the level of automation on future ships could reduce the intended frequency of access particularly if the fire risk was also reduced. The main machinery rooms have a high operational importance and although they are expected to be visited hourly the level of automation actually supports UMS. The importance of access was therefore assessed as medium. This section also allowed for any legislation that defines if compartments must be manned at certain times i.e. an emergency steering position.
- Benefit from Inerting. This was assessed as low, medium or high by comparing the fire risk with the importance of access. With the machinery room the fire risk is high and the importance of access is medium giving a medium benefit assessment. The LV switchboard has a medium fire risk but the importance of access is high therefore the benefit of inerting is assessed as low. This is because the requirement to access the compartment outweighs the fire risk.
- Suitable for Inerting. This was based on the benefit assessment and the practicality of entering the compartment should it be inerted. The machinery room is assessed as suitable as there is a medium benefit and access would be feasible in breathing apparatus (BA) if required. Conversely the LV switchboard is assessed as unsuitable as there is a low benefit and regular access in BA would be prohibitive.

Of the five classes of ship that had been brought forward to this stage all had a number of compartments that were deemed to be suitable following the assessment. These vessels (Type 45, FSC, LPH, LPD(R), and CVF) therefore continued on to the next stage of the process.

The effects of an emergency or damage scenario

An important consideration, particularly when dealing with warships, is the possible effect of having inerted compartments onboard should an emergency or damage scenario arise. The following emergency and damage scenarios were therefore considered: fire in an adjacent compartment, flood, collision, grounding and breach of the gas tight boundary.

The overall affect on the ship of various compartments being inerted during each of these scenarios would depend on a number of criteria:

- Location of the compartment.
- Types of adjacent compartment.

- The importance of equipment in the compartment
- The importance of accessing the compartment during the scenario.

From these criteria, assessments could be made for each compartment on the likelihood of damage, the access requirements, the overall impact should it be inerted and hence a compartments overall suitability for inerting.

Table 4 illustrates, as an example, the assessment for the Avcat Pump Space on a CVF and explains the reason behind each decision. This led to the results shown in Tables 5-9 for each class of vessel.

Table 4 CVF Avcat Pump Space Assessment

Criteria	Response for Avcat Pump Space	Explanation
Location	8 Deck Aft	
Adjacent accommodation or regularly manned spaces	Possible accommodation directly above	If this gas tight boundary was breached the accommodation area would have to be evacuated.
Other adjacent compartments	Stores and other machinery spaces	No major impact would be expected if these boundaries were breached as they are not permanently manned spaces.
Importance of equipment in compartment	High	The equipment is vital to maintaining the operation of all aircraft.
Affect on fire fighting capability in an adjacent compartment	Low	The only likely requirement to aid fire fighting in an adjacent compartment would be boundary cooling. This is not an alternative access point of emergency escape route.
Affect of a flood in the compartment	Medium	A flood could disable the compartment however inerting will have little impact on the prevention or control of a flood.
Risk of damage in a collision	Medium	Below the waterline however it is not positioned in an area of the ship where collision damage is most likely to occur.
Risk of damage in a grounding	High	The compartment is very low in the vessel and therefore could easily be damaged in a grounding incident.
Importance of access in an emergency or damage scenario	Medium	The compartment provides fuel for all of the aircraft and whilst in peacetime this may not be important, in war it is far more important.
Suitable for inerting	Yes	In an action scenario it would be feasible to gain access using BA in order to continue fuelling the aircraft. In peacetime access would not be a priority.

Table 5 CVF Results

Compartment	Suitable for Inerting
Main Machinery Rooms	Yes
Conversion Machinery Room	Yes
Boiler Space	Yes
Avcat Pump Space	Yes
HV Switchboard	Yes
Magazines	Yes

Table 6 FSC Results

Compartment	Suitable for Inerting
Engine Rooms	Yes
Water jet Room	Yes
Centrally automated store	No
Switchboard Room	Yes
Air Weapons Magazine	Yes
Main Gun Magazine	Yes

Table 7 LPH Results

Compartment	Suitable for Inerting
Stern Gate Operating Machinery Compartment	Yes
Emergency Generator Room	Yes
Emergency Switchboard Room	Yes
Magazines	Yes

Table 8 LPD(R) Results

Compartment	Suitable for Inerting
Stern Gate Operating Machinery Compartment	Yes
Emergency Generator Room	Yes
Emergency Switchboard Room	Yes
Magazines	Yes

Table 9 Type 45 Results

Compartment	Suitable for Inerting
Machinery Rooms	Yes
Gas Turbine Rooms	No
Avcat Pump Space	Yes
HV Switchboard Rooms	Yes
Magazines	Yes

As can be seen from the results, the LPH no longer had any compartments deemed to be suitable for inerting. Thus was primarily due to the location of the compartments within the ship and their susceptibility to damage during collision or grounding and also the proximity of accommodation spaces. The four other classes of ship all had a number of compartments that were deemed to be suitable for inerting.

Benefit assessment

The final stage of the assessment process was aimed at trying to identify the possible benefit of inerting compartments based on historical fire data. Unfortunately, as Type 45, CVF and FSC are all future vessels and LPD(R) has only been in service for a limited period, estimates had to be made as to the applicability of historical data for each ship. The percentage of total fires occurring in a general type of compartment was used and compared with the percentage of that type of compartment being inerted to give an overall reduction in fires should an IGS be used.

For instance, nearly 50% of all fires occur in machinery spaces. If 25% of all of the machinery spaces onboard a class of ship are inerted then this will give approximately 12.5% reduction in the potential number of fires onboard. Correspondingly the reduction in the potential number of fires onboard plus increase in fire protection due to inerting of the magazines for Type 45, CVF, FSC and LPD(R) are 20%, 35%, 25% and 20% respectively.

DISCUSSION

Other considerations

The assessment process highlighted that increased fire protection could be achieved by the use of IGS on specific classes of new generation warships. There are however some issues with using an IGS that have not been covered thus far and that arose from discussions with ship staff and designers during the course of research.

- Lack of access to machinery and electrical equipment may require a change to maintenance routines and monitoring systems.
- The effect of inerted compartments on personnel and the interaction between the two will need careful managing to ensure it does not inhibit normal working practices or cause any increase in health and safety issues or accidents.
- Additional training and safety procedures will be required for the IGS.
- Alternative cooling arrangements will be required for those compartments that are normally force ventilated and are now required to be inerted.
- Ventilation system design will need to be redesigned to facilitate inerting and de-gassing which may result in additional or larger fans and vent trunking.
- A cost benefit analysis will need to be conducted to assess if the benefits of reduced fire risk and associated cost savings outweigh the installation and through life costs.

The majority of these issues could be addressed by considering the fitting of an IGS very early on in a ships design cycle. In doing this location of accommodation areas, access routes and design of the ventilation system could be chosen to maximise the benefit of an IGS whilst mitigating the risks. The issue of cost would need careful consideration as the savings are extremely difficult to quantify however if a reduction in manpower could be identified in the design phase this would undoubtedly make it a beneficial proposal.

Also to be considered should be the secondary benefits of using inert gas in compartments, particularly in machinery spaces and electrical compartments. These include:

- Decrease in corrosion levels possible leading to reduced through life costs.
- Possible reduction in required Ingress Protection (IP) ratings for electrical equipment leading to cost reductions. This could prove significant when considering full electric propulsion.
- Possible further reductions in required manpower levels as increased fire protection could support a case for fewer or smaller fire fighting teams.
- The possible use of the IGS to provide a gas drench fire fighting system and thus maximise the use of the system whilst removing the requirement for some of the other fixed fire fighting equipment.

Outline of IGS requirements

As previously mentioned, current inert gas technology is available and could be fitted to a warship; however it is important to consider how such equipment should be installed to provide an effective system for fire protection. Ideally the compartments should be inerted so that the oxygen level is reduced to 5% to allow for a safety margin. A ready supply of inert gas should be stored in a pressure reservoir to allow for 'topping up' of compartments if necessary and the inert gas generator will maintain this reservoir at a set pressure. The compartments must be air tight and access when the compartment is inerted should be in breathing apparatus (BA). As a safety precaution, adjacent compartments should be fitted with emergency life support apparatus (ELSA) in case of a breach of the gas tight boundary.

The number of plants fitted will be dependent on the number, size and location of compartments. For instance, in the case of FSC, the compartments can be grouped into a forward/midships section and an aft section. This makes it ideal for two separate plants, each covering its own zone with a cross connection fitted for use if one plant is defective.

Various sensors and monitoring systems and alarms should be fitted. For example, oxygen sensors should be placed at strategic locations to monitor oxygen levels both within the inerted compartment and adjacent compartments; portable instruments should also be provided as an alternative method of measuring the gas concentration via sampling tubes. Pressure sensors should be fitted within the inerted compartment which will shut down the gas supply if the pressure within the compartment exceeds a pre-set level and will give a warning in the control room thus preventing over pressurisation of the compartment.

Conclusion

With the exception of LPD(R), none of the RN's current warships are suitable for an IGS as the access requirements for the compartments with fire records that would support a fire protection system are too great.

Future warships are being designed to have a much higher level of automation in their machinery and electrical compartments and it is these compartments that currently account for the majority of fires onboard. This paper has shown that these vessels could have between 20% and 35% reduction in the potential number of fires onboard if an IGS is fitted. Although this was a simplistic calculation it does demonstrate a benefit that should be considered particularly if manpower levels are going to continue to decrease on future platforms. This benefit could further be increase by considering the use of an IGS at the start of a vessels design phase in order to maximise the system's potential both for low oxygen compartments and as a drenching system.

Whilst current safety is deemed to be acceptable within the RN the trends are showing that there could be a potential increase in duration and hence seriousness of fires onboard. It is this potential risk that an IGS is expected to combat and this paper has discussed that for future ships it is a feasible option which should be considered further in the design of these ships.

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