Fire!

A guide to the causes and prevention of cargo fires

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‘Fire!’ has been written in cooperation with Dr Neil Sanders, a partner with Burgoynes. In his twenty years with the company he has investigated more than 1,200 incidents involving fires and explosions on land and on ships, water escapes, electrical faults, marine cargo problems, process engineering, food manufacture, mechanical failure, product failure and contamination. He has conducted investigations on container ships, bulk carriers, tankers, passenger ships, car carriers, survey vessels, pipelayers, barges and yachts; and has inspected cargo areas, engine rooms, accommodation and shipyards, as well as explosions. He has given advice on live marine incidents and conducted investigations and given advice on cargo problems, cargo contamination and chemical hazards, including DRI, coal and bulk foodstuffs.

Contents

1 Introduction

When a fire breaks out on board a vessel there is no fire service ready to assist in extinguishing it – it is up to the crew themselves. The consequences can be catastrophic, and all those who have worked on board a vessel are aware of the difficulties involved with managing a fire and the crucial importance of fire prevention.

The information in this handbook is designed to assist shipowners and crews in those fire prevention efforts. Fire! explores marine cargo fires and explosions, focusing particularly on self-heating: explaining the principles of self-heating, and investigating several types of cargo fires and explosions including those in bulk cargoes, containers and tankers.

This handbook is not designed as a substitute for the full International Maritime Solid Bulk Cargoes (IMSBC) and International Maritime Dangerous Goods (IMDG) Code entries, which should be understood and followed.

Quick reference guide

Prevention: Important considerations

A. Self-heating

Coal

Coal starting temperature. It is important to check coal temperatures vs. the 55°C limit before and during loading. The International Maritime Solid Bulk Cargoes (IMSBC) Code also limits heating of fuel tanks adjacent to cargo holds.

Coal carbon monoxide production. When evaluating how to deal with high carbon monoxide concentrations in coal it is important to consider all of the relevant gas readings over the period since the coal was loaded.

Coal Lower Explosible Limit (LEL) readings. A high reading, above approx. 20% LEL, needs careful consideration because a risk of explosion may be developing.

Coal fires. If coal self-heating becomes a fire, then fire-fighting is usually carried out with water. The IMSBC Code states that water should not be used but there may be little alternative. Fresh water should be used if possible because seawater often causes problems with the end use of the coal.

Coal methane production. Some coal contains methane gas that is released once the coal is mined. Methane is flammable and so it can present an explosion risk in ships' holds. Note: methane-emitting coal therefore needs ventilation, which is the opposite of self-heating coal.

Direct reduced iron. Direct reduced iron (DRI) is affected by water ingress, and so in heavy weather can start problematic self-heating. Seawater tends to be more reactive than fresh water. Direct reduced iron should be properly cooled and aged before loading in order to reduce its reactivity.

Charcoal

Charcoal is subject to the International Maritime Dangerous Goods (IMDG) Code. Depending on the particular material, there may be requirements such as adequate heat treatment and then cooling before packing. This is to reduce the reactivity of the charcoal by allowing it to oxidise under controlled conditions. Also, hermetically sealed packing may be required.

Reactive solids

Reactive solids include calcium hypochlorite and other oxidising solids. These materials do not react with air but they can be relatively unstable chemicals that decompose slowly over time, evolving oxygen. This self-decomposition can evolve heat which can lead to thermal runaway and an explosion. The IMDG Code, the International Group of P&I Clubs and some shipping lines give requirements for shipping some cargoes of this type, which are intended to reduce the risk of incidents.

B. Other causes of cargo fires and explosions

Cargo lights

Cargo lights in holds need to be properly isolated before cargo is loaded. This is best done by removing fuses or other physical links in the electrical circuits so that the lights cannot be switched on by mistake.

Smoking and hot work

Smoking and hot work need to be properly controlled. Control of smoking can be difficult where stevedores are working on board. Hot work permits need to be properly considered, not just a 'tick box' exercise.

Cars and other vehicles

Cars and other vehicles carried on board ships present some risk of fire. Risks include cargo shifting in heavy weather and used vehicles in poor condition giving rise to electrical faults.

Fumigants

Fumigants can cause fire or explosion, particularly if there is an excessive amount of fumigant in one place; or if the fumigant is in contact with liquid water e.g. from sweating or condensation. In these situations the fumigant can react too quickly, evolving excessive heat or explosive gas/vapour. Fumigants must be correctly applied by qualified personnel.

2 Statistics

When comparing statistics it is important to note that fires on board ships are thankfully rare and cargo fires are even rarer, compared with fires in the engine room or fires originating from an electrical unit. However when a fire starts on board it is often serious and can lead to loss of lives and/or loss of a vessel.

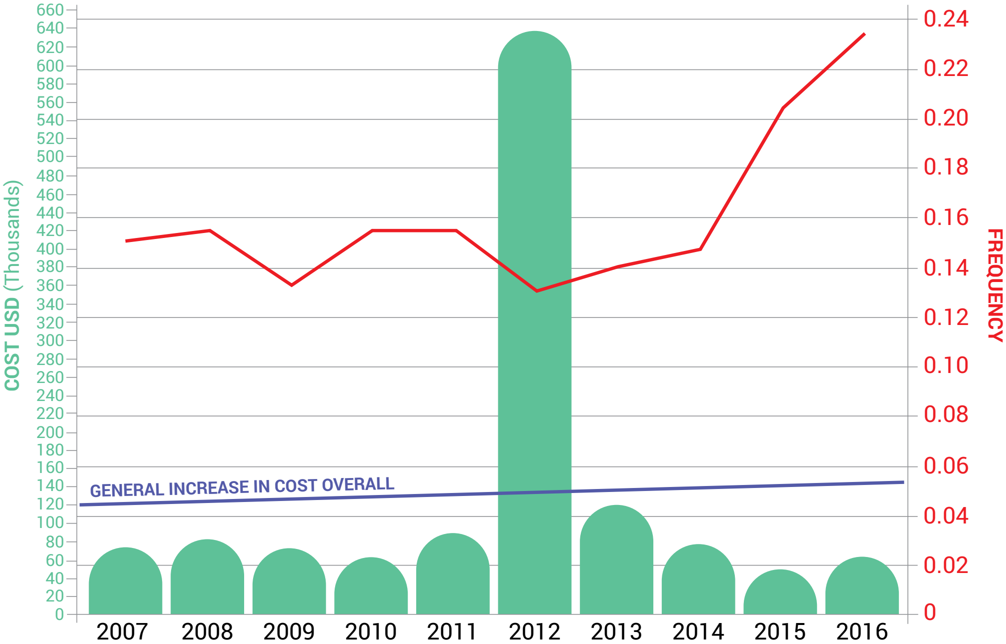
These statistics focus upon cargo damage caused by fires which are covered by P&I insurance, and include incidents on bulk carriers, container vessels, dry cargo and ro-ro vessels.

P&I cargo statistics - all vessel types

Claim cost & frequency

P&I cargo claims 2007-2016

(Claims cost =>USD 5,000 – uncapped)

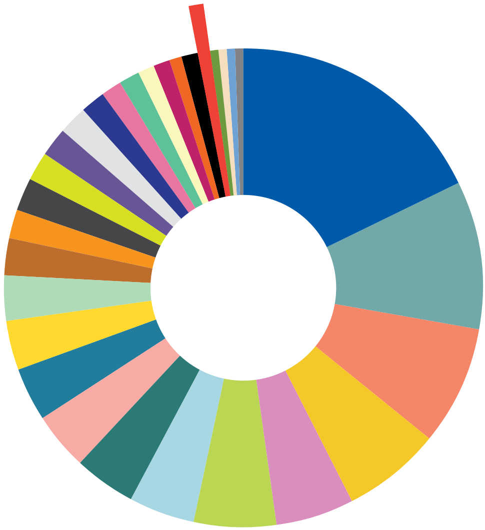


A substantial increase in frequency can be seen between 2014 and 2016, from 14% to 24% of all vessels insured under P&I suffering a cargo claim. This is an increase of almost 70% from 2014, which unfortunately seems to be a continuing trend, which we explore further in our publication ***P&I Claims Analysis***.

The high cost anomaly shown for 2012 is due to a higher number of significant losses than expected.

All claims are after the deductible and have generated a claims cost of USD 5,000 or above.

Total number of cargo claims

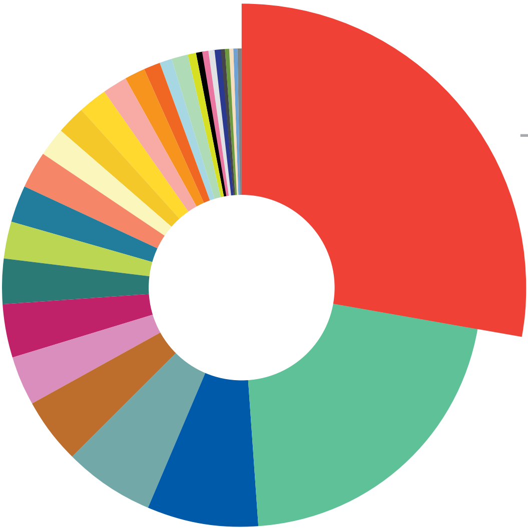


P&I cargo claims 2007-2016

(Claims cost =>USD 5.000 – uncapped, immediate cause)

Improper cargo handling, shore-side	18.13%
Other	10.36%
Improper cargo handling, ship-side	8.15%
Poor tally	6.55%
Heavy weather	5.48%
Damage prior loading	5.48%
Error in calculation	4.65%
Leaking hatch covers	4.34%
Multiple	3.88%
Flooding of hold	3.43%
Insufficient cleaning	3.35%
Not applicable	2.97%
Inherent vice	2.51%
Poor stowage	2.13%
Leaking container	2.13%
Insufficient lashing/securing by shipper	2.06%
Reefer mechanical failure	1.83%
Insufficient lashing/securing by stevedore	1.75%
Poor monitoring/maintenance of reefer unit	1.52%
Damage post discharge	1.45%
Grounding	1.37%
Leaking vents	1.22%
Collision	1.14%
Insufficient lashing/securing, ship-side	1.14%
Leaking pipes	0.84%
Fire	**0.76%**
Leaking cargo	0.46%
Blocked bilges	0.38%
Loading heavy containers on top flight	0.30%
Contact	0.23%

Total cost for all cargo claims



P&I cargo claims 2007-2016

(Claims cost =>USD 5.000 – uncapped, immediate cause)

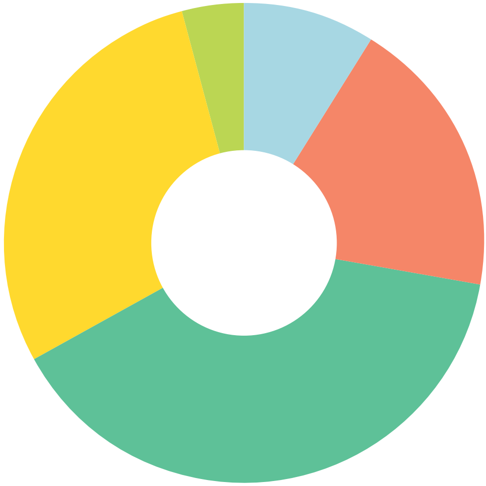
Fire	**28.04%**
Grounding	21.36%
Improper cargo handling, shore-side	7.72%
Other	6.23%
Inherent vice	4.41%
Heavy weather	3.65%
Collision	3.22%
Leaking hatch covers	2.85%
Damage prior loading	2.73%
Flooding of hold	2.60%
Improper cargo handling, ship-side	2.51%
Leaking vents	2.11%
Poor tally	1.90%
Insufficient cleaning	1.80%
Multiple	1.65%
Poor stowage	1.57%
Insufficient lashing/securing, ship-side	0.99%
Error in calculation	0.80%
Not applicable	0.77%
Insufficient lashing/securing by shipper	0.51%
Leaking pipes	0.41%
Damage post discharge	0.39%
Insufficient lashing/securing by stevedore	0.38%
Poor monitoring/maintenance of reefer unit	0.37%
Reefer mechanical failure	0.34%
Leaking container	0.29%
Leaking cargo	0.18%
Blocked bilges	0.14%
Loading heavy containers on top flight	0.07%
Contact	0.01%

Claims cost vs total number of claims

It can be seen in the previous graphs that cargo fires thankfully seldom occur, but when they happen they are very expensive. The average cost of a cargo fire is several million USD and some cargo fires can result in the total loss of the vessel.

This highlights even further the importance of taking preventive measures.

Different vessel types



P&I cargo claims 2007-2016

(Claims cost USD >= 5,000 – uncapped, per vessel type)

Bulker	9%
Container	19%
Dry Cargo	39%
Ro-ro	29%
Tanker	4%

This graph identifies those vessel types which have suffered most cargo fires. The relatively low tanker figures are a testament to the tight regulation and safety culture that exists in this industry. The ro-ro figure is however surprisingly high, and can be explained by the non-homogeneous nature of the cargo these vessels carry. The operator has to rely on a number of shippers correctly declaring the nature and risk of the cargo in the manifest, and is unable to easily check the condition of the goods. Old batteries, unstable equipment, leaks – none of these will necessarily be made obvious. This situation also applies to the container statistics - the shipowner is only aware of what has been declared on the cargo documentation.

3 Self-heating

Self-heating principles

Many marine cargo fires and explosions are due to self-heating in some form. In general, self-heating occurs when an exothermic (heat-producing) chemical or biochemical reaction happens within a body of cargo. Loss of the heat produced by the reaction is restricted by the surrounding cargo, packaging, dunnage, containers etc. Due to restricted heat loss, the temperature within the cargo tends to increase.

The rate of most chemical reactions increases with increasing temperature and it often roughly doubles for each 10°C rise in temperature. Therefore the heating and the temperature rise can worsen, which can ultimately lead to a fire in the cargo and surrounding materials.

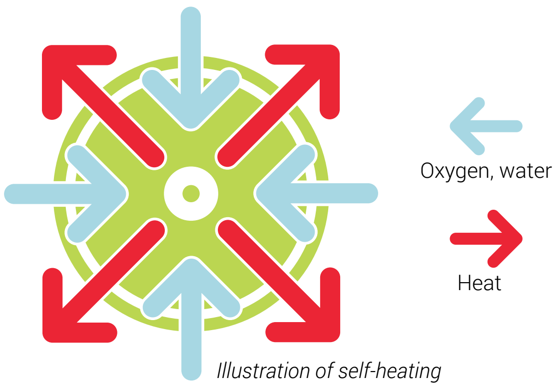


Illustration of self-heating

Two main types of reaction can lead to cargo self-heating:

1

Oxidising reactions in which cargo reacts with oxygen in air and/or water. Common examples are coal, oil seed cake, direct reduced iron (DRI) and metal turnings.

2

Self-reaction or self-decomposition of cargo. A well-known example is calcium hypochlorite.

Immediate causes - factors affecting self-heating

The main principles of self-heating mean that several factors can affect the severity of self-heating and whether it develops to a problematic level:

Availability of oxygen. For example, with many bulk coal cargoes the holds need to be kept closed and sealed. This restricts the access of air (oxygen) to the cargo which restricts the oxidation reactions, so that temperatures do not rise to problematic levels.

Availability of water. For example, DRI needs to be kept dry so that it cannot react with water. If water does enter holds containing DRI it can start a self-heating reaction which can then worsen, leading to oxidation reactions with air and then severe heating.

Reactivity of cargo. Some cargoes need to be 'aged' by exposure to air/oxygen so that the most easily oxidised parts have reacted before loading. This means that the rate of oxidation of the cargo is reduced and so self-heating is less likely. For example, DRI and some charcoal cargoes need to be properly aged before loading.

Ability of air/oxygen to diffuse into the cargo. Self-heating due to oxidation can only progress to a problematic level if enough oxygen can pass into the cargo to produce heat that cannot be dissipated. For example, some cargoes, such as activated carbon, may need to be carried in hermetically sealed bags to stop air/oxygen contacting the cargo. Also, bulk coal cargoes need to be properly trimmed to give a compacted, flat surface that restricts the entry of air/oxygen into the stow.

Temperature of cargo. Reactions are faster at higher temperatures, so the loading temperature of some cargoes needs to be restricted so that oxidation rates are not too fast. For example, bulk coal needs to be at a maximum temperature of 55°C when loading.

Size of the body of cargo. Heat is dissipated less effectively from a larger body, for example, some cargoes have package size restrictions or maximum container load restrictions.

Regulations - IMO requirements relating to self-heating

The IMSBC Code and the IMDG Code address factors affecting self-heating. For some cargoes there may be other relevant requirements or guidance. Some of the main IMO requirements are below, which may vary depending on the type of cargo:

- Closing and sealing holds to exclude air/oxygen and water
- Flushing holds with inert gas to exclude air/oxygen
- Adhering to maximum cargo loading temperature
- 'Away from' sources of heat, out of direct sunlight
- Proper ageing before loading/stuffing
- Packaging/stuffing requirements such as maximum package sizes

***Important note**: In all cases the full relevant IMSBC or IMDG requirements must be understood and followed.*

Cargoes affected by self-heating

1 Bulk coal self-heating

Bulk coal self-heating is primarily caused by oxidation occurring due to the oxygen in air.

In summary, self-heating of coal is affected by:

Reactivity of the particular coal due to its source and other factors such as the way it was mined and stored and how quickly it was loaded after mining. The cargo declaration may indicate possible problems but not always.

Starting temperature of the coal; hence it is important to check coal temperatures vs. the 55°C limit before and during loading. The IMSBC Code also limits heating of fuel tanks adjacent to cargo holds. Hold temperatures measured via sounding pipes or tubes are not often useful because coal is a good thermal insulator, so only the temperature near the sounding tube is indicated.

Availability of oxygen. This is controlled by trimming the coal properly at the end of loading, and by closing and sealing the hatch covers.

Coal that can self-heat produces carbon monoxide gas (CO). Carbon monoxide is also produced by fires, particularly those which are smouldering. Carbon monoxide concentrations in the hold ullage spaces should be checked and the matter reported to shippers and owners/managers if 50 parts per million (50 ppm) is reached, or if there is a steady rise over three consecutive days. In some cases, however, the carbon monoxide concentration can greatly exceed 50 ppm without necessarily leading to problematic self-heating. If the oxygen concentration is kept low by excluding air/oxygen then in due course the carbon monoxide concentration may fall and problematic heating may not occur.

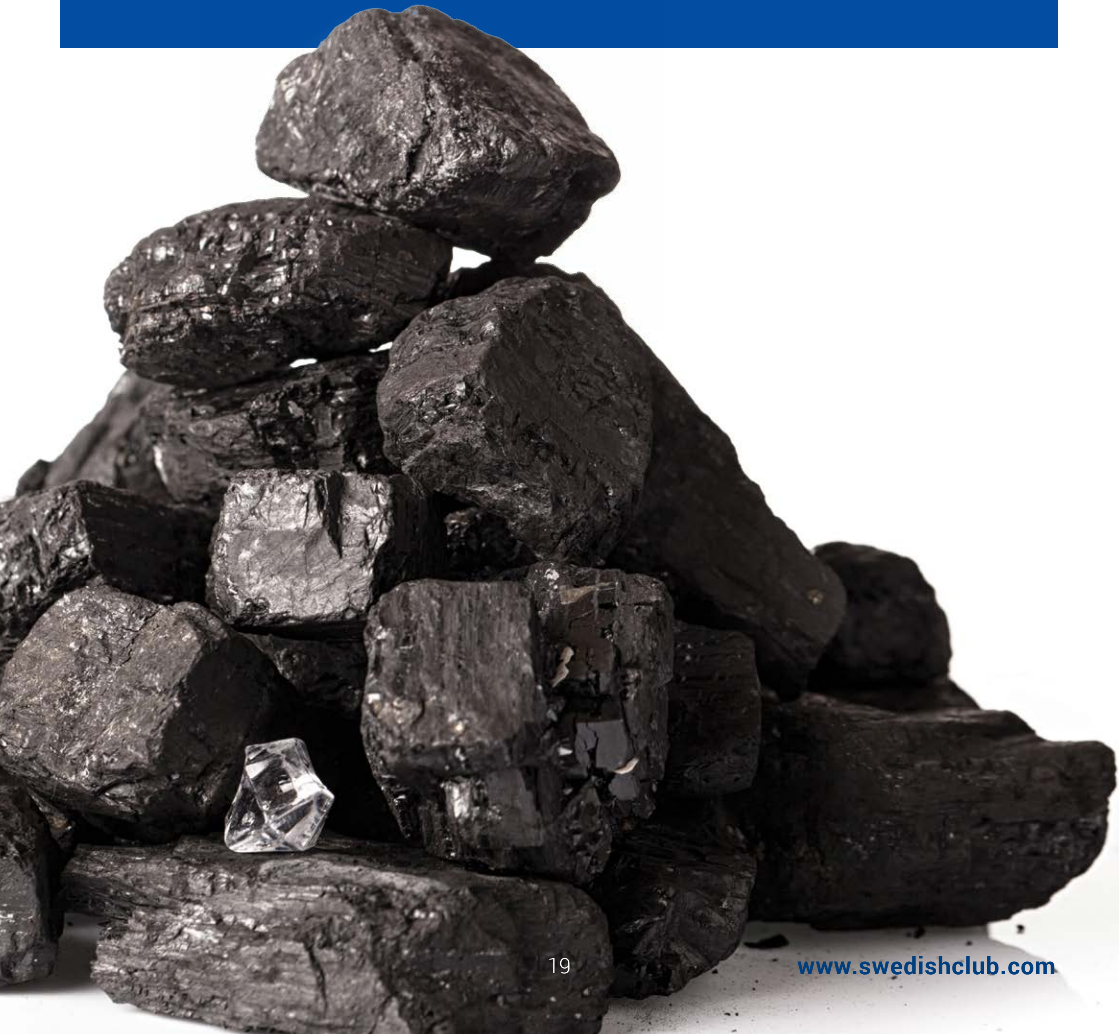
Whether problematic self-heating happens therefore depends on several factors, including what actions are taken on board the ship. When evaluating how to deal with high carbon monoxide concentrations it is important to consider all of the relevant gas readings over the period since loading. These readings will include oxygen concentrations and flammable/explosive gas concentrations (discussed below). It is also important to consider what actions have already been taken, such as any ventilation history.

If coal oxidation develops to the point of problematic self-heating or burning then some of the coal will decompose to produce flammable/explosive gas or vapour. Most gas meters used on board ships respond to most flammable/explosive gases and vapours and produce a single reading, expressed as a percentage of the lower explosive limit, % LEL. (LEL is the lowest concentration of flammables that will burn in air). Often the gas detector is calibrated using methane gas and the meter may even indicate the % LEL reading as methane (CH_4). Therefore it may be mistakenly assumed that the coal is emitting methane, when in fact the % LEL reading may be wholly or partly a result of self-heating or burning.

In any case a high % LEL reading, above approx. 20% LEL, needs careful consideration because a risk of explosion may be developing. If there is any doubt about the situation seek technical advice.

Other factors to consider in coal self-heating cases include:

- The gas meter make and model. Many types are inaccurate when oxygen concentrations are low (i.e. below about 10% by volume).
- Surface treatments for coal are sometimes said to prevent or tackle self-heating, although Burgoynes is not aware of any authenticated 'live' incidents where these treatments have been successful.
- If coal self-heating becomes a fire, then water is often used to knock down flames. The IMSBC Code states that water is not to be used, but there may be little alternative on board.
- Fresh water should be used if possible because seawater can cause problems with the end use of the coal.
- The best course of action is to get the coal off the vessel.



2 Bulk coal self-heating and emitting methane

In rare cases coal cargoes can self-heat and emit methane at the same time – this has been recently observed with cargoes of Indonesian coals.

Background

Some coal contains methane gas that is released once the coal is mined. Methane is a flammable/explosive gas and so it can present an explosion risk in ships' holds. Methane-emitting coal therefore needs ventilation and the IMSBC Code advises adequate surface ventilation of holds if methane exceeds 20% LEL. (As 100% LEL is 5% by volume this corresponds to roughly 1% by volume in air.) Gas concentrations therefore must be monitored and ventilation carried out accordingly.

Generally methane emission reduces with time as the fixed amount of methane trapped in the coal is released and vented out.

Some coal cargoes can self-heat as well as emitting methane, as discussed on the next page, so ventilation should usually be kept to the minimum needed to keep the % LEL readings acceptable.

It is important to consider whether a high % LEL reading is produced by methane-emitting coal, or by self-heating or burning as discussed in the previous example. The carbon monoxide readings may also be informative on this point. If there is any doubt about the situation, seek technical advice.

In some cases methane emission from coal has only been discovered when there is an explosion. Following the IMSBC Code requirements, and seeking advice when indicated by the gas readings, should avoid this situation. The Code indicates that, for coal cargoes generally,

hot work and other sources of ignition must be avoided.

Bulk coal self-heating and emitting methane is problematic because the remedial actions for each occurrence are conflicting (excluding air/oxygen to tackle self-heating, vs. ventilation to deal with methane).

Dealing with the problem

The IMSBC Code does not really cover this situation and therefore it may be necessary to seek technical advice on the points detailed below.

It may be possible to control the situation by ventilating holds only just enough to keep the flammable/explosive gas concentration sufficiently below 100% LEL to avoid an explosion risk, while minimising air/oxygen entry to the coal to minimise self-heating. As methane emission usually decreases over time it may eventually be possible to treat the problem in the same way as self-heating, by closing and sealing the holds. Again, it is important to consider whether a high % LEL reading is produced by methane-emitting coal, or by self-heating or burning.

The question of the oxygen concentration in the hold ullage space should be considered because, if the oxygen concentration is below about 10% by volume, then no explosion can occur because the gas-air mixture is non-flammable. In that case, under carefully controlled conditions, it may be possible to stop ventilation and allow the methane concentration to rise.

Careful consideration of the gas concentration history is needed to determine whether continued minimum ventilation or closing holds is appropriate; or whether other action is needed such as discharging the coal.

❸ Bulk direct reduced iron

Direct reduced iron (DRI) is made from iron ore by direct contact with hot reducing gas. The resulting iron pellets are porous and so they can be highly reactive with water, or oxygen in air, due to the very large surface area present within the pores.

There are three types of direct reduced iron:

A	B	C
Type A DRI Hot moulded briquettes	**Type B DRI** Lumps, pellets, cold moulded briquettes	**Type C DRI** By-products, fines

Water ingress to holds, e.g. in heavy weather, can start problematic self-heating. Seawater tends to be more reactive than fresh water.

Direct reduced iron should be properly cooled and aged before loading in order to reduce its reactivity. The IMSBC Code requires loading at max. 65°C; avoiding water; and (for DRI pellets - Type B) flushing the holds with nitrogen after loading. Nitrogen flushing reduces the possibility of oxidation reactions.

If direct reduced iron does react with water it gives off hydrogen which is a highly flammable/explosive gas that is colourless, odourless, easily ignited and presents a serious explosion risk.

Initial heating due to the reaction with water can lead to elevated temperatures of roughly 150°C, at which point the reaction with oxygen in air becomes significant and results in further heating. Eventually the direct reduced iron can glow red hot or hotter and flames of hydrogen may be produced.

If hydrogen evolution and self-heating starts then the direct reduced iron is likely to need discharging or perhaps blanketing with inert gas or an inert solid such as sand. This is to exclude air/oxygen and so eliminate the oxidation and heating. Blanketing with a heavy solid material such as sand may well require the strength and stability of the ship to be considered.

Type C DRI is made up from iron fines that usually come from broken-down DRI pellets. The fines, if wet, can evolve hydrogen due to the oxidation reaction with water, which produces a serious explosion risk.

DRI fines are sometimes given other, possibly misleading, titles such as 'iron ore fines', which can mean that proper precautions like eliminating ignition sources may not be taken.

DRI fines tend to self-heat somewhat but usually they do not self-heat problematically. This is because the fine material limits the amount of air/oxygen that can diffuse into the stow, which limits the amount of self-heating.

4 Charcoal

Charcoal is shipped for various uses including shisha pipes (water bubble pipes) and for barbecues. Charcoal is porous and so it provides a large surface area for reaction with air/ oxygen. Self-heating is therefore possible in charcoal. In recent years this has mainly been seen happening in containers.

Some charcoal tablets for shisha pipes are not pure charcoal but contain impurities e.g. metal filings and hydrocarbon liquid which may make them more likely to self-heat. As a result packaging requirements may apply such as hermetically sealed, smaller packs.

The IMDG Code for charcoal may require adequate heat treatment and then cooling of the charcoal before packing. This is to reduce the reactivity of the charcoal by allowing it to oxidise under controlled conditions.

Whilst charcoal is covered by IMDG, the correct sampling, testing and certification may in some circumstances be used to show that no special precautions are needed (see Case Study 1 below). It may assist to check the relevant documentation.

Charcoal fire
Case Study 1

A container vessel had just left port when the OOW noticed smoke being emitted from the forward part of the vessel. He informed the Master at once, and the Master requested that the Chief Officer investigate. The Chief Officer identified that it was from a container in the forward part of the vessel. A fire team was assembled and fire hoses were used to spray the container and also for boundary cooling of the containers which were directly adjacent. The container that was alight was at the bottom of the stack. The crew tried to open the container's doors but as they couldn't get them fully open, they sprayed water through the partially opened doors. The cargo in the container was charcoal.

The vessel turned around and sailed back to the departure port. After the vessel had berthed an emergency response team embarked and assisted the crew. The burning container was quickly unloaded.

The charcoal had not been classed as dangerous cargo and had no IMDG signs. It is important to know that IMDG-classed charcoal, whether activated or non-activated, falls under IMDG class 4.2. In this case it could have been disastrous if the container had been loaded under deck in the cargo hold.

Charcoal fire

Case Study 2

A container vessel was sailing in open sea when smoke could be seen coming out from the vent of one of the cargo holds. The Master sounded the general alarm and all crew were mustered and accounted for.

A fire team was assembled and proceeded to shut off the ventilation and close the fire dampers for the cargo hold. An access hatch cover was opened for the fire team to enter the cargo hold, but it was full of smoke and there was no visibility so the fire team turned back and closed the hatch.

The Master made the decision to release CO_2 into the cargo hold and the vessel turned back to its last port of call. After the CO_2 had been released some smoke could still be seen coming from the cargo hold but it was less than before. The crew could not find any hot spots on deck and when they inspected the adjacent cargo hold there were no hotspots or discolouration.

After the vessel berthed the local fire brigade embarked and confirmed that the fire was extinguished.

The cargo manifest did not show any dangerous cargo loaded into the affected cargo hold. However it was found that the container that caught fire was loaded with charcoal and that the shipper had declared the charcoal as not IMDG dangerous cargo.

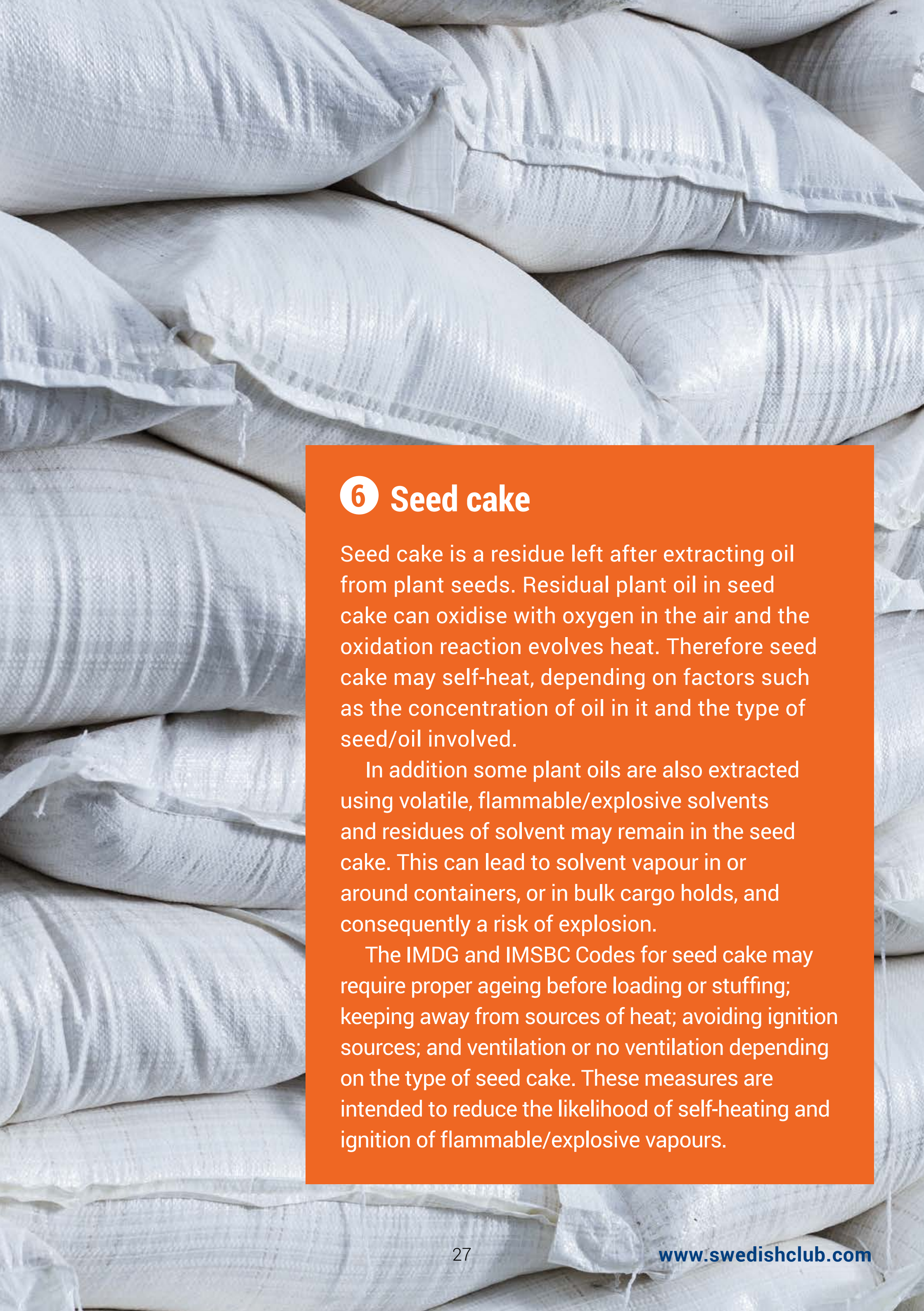
The shipper had misdeclared the cargo. Laboratory tests confirmed that the cargo should have been classed as dangerous cargo as per IMDG Code class 4.2.

5 Metal powder or metal turnings

Finely-divided metals have a large surface area. If the surfaces have not previously oxidised then they may react with oxygen in air or water, in a similar way to direct reduced iron. Oxidation with water can produce hydrogen and consequently a serious explosion risk.

Examples of this problem include wetting of scrap metal or metal powder. Wetting can happen before loading or on board ship, e.g. due to seawater ingress via leaking cargo hatch covers or due to bilge system problems or operational errors.

Other examples of this problem involve oxidation of metal by oxygen in air, which can lead to self-heating and sometimes ignition of the metal.



6 Seed cake

Seed cake is a residue left after extracting oil from plant seeds. Residual plant oil in seed cake can oxidise with oxygen in the air and the oxidation reaction evolves heat. Therefore seed cake may self-heat, depending on factors such as the concentration of oil in it and the type of seed/oil involved.

In addition some plant oils are also extracted using volatile, flammable/explosive solvents and residues of solvent may remain in the seed cake. This can lead to solvent vapour in or around containers, or in bulk cargo holds, and consequently a risk of explosion.

The IMDG and IMSBC Codes for seed cake may require proper ageing before loading or stuffing; keeping away from sources of heat; avoiding ignition sources; and ventilation or no ventilation depending on the type of seed cake. These measures are intended to reduce the likelihood of self-heating and ignition of flammable/explosive vapours.

7 Reactive solids

Cargoes that fall into this category include calcium hypochlorite and other oxidising solids. They are often used for swimming pool sterilisation and fabric treatment (bleaching or washing). These materials do not oxidise but they can be relatively unstable chemicals that decompose slowly over time, evolving oxygen. This self-decomposition can evolve heat. A self-heating process can therefore happen in which the material towards the middle of a body of cargo becomes hotter, so the rate of decomposition and heating increases. This can lead to 'thermal runaway' with very rapid self-decomposition and evolution of heat and gases, sometimes including further oxygen. The effects of this in a hold can be similar to an explosion. The heat and oxygen produced can lead to fire spreading.

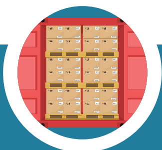
Potential causes of self-decomposition incidents include:

Exposure to heat e.g. solar radiation (before or after loading), cargo lights and heated fuel tanks

Cargo formulation

Contamination of cargo at manufacture

Spillage and thus reaction between cargo and combustibles e.g. timber



Excess quantity of cargo in containers giving insufficient dissipation of heat

Inadequate separation of packages in containers, also giving insufficient dissipation of heat

The IMDG Code, the International Group of P&I Clubs and some shipping lines give requirements for shipping some cargoes of this type, which are intended to reduce the risk of incidents.

We are aware, however, of instances of misdeclaration of such cargoes, presumably to avoid increased shipping costs associated with meeting the proper requirements.

Calcium hypochlorite - special considerations

Calcium hypochlorite is not considered a stable substance as it decomposes under normal circumstances and slowly releases heat and oxygen. If the heat that is released can be dissipated, it will not create any problems. However, it is recognised that when stowed in too great a bulk, the heat generated by the slow decomposition may not be able to escape.

When such a scenario occurs, the internal temperature of the cargo rises, the rate of decomposition increases, and this can lead to a runaway reaction that ultimately results in a fire and/or an explosion.

A similar problem can happen if the surrounding temperature is too high. Impurities within calcium hypochlorite can also increase the rate of decomposition. Such impurities can be introduced during the manufacturing process, or by failure of packaging allowing escape of cargo.

Calcium hypochlorite is an IMDG Class 5.1 oxidising agent. The Code stipulates the following requirements in relation to the stowage and segregation of the common types of high strength calcium hypochlorite: 'Category D [on deck only]. Cargo transport units shall be shaded from direct sunlight and stowed away from sources of heat. Packages in cargo transport units shall be stowed so as to allow for adequate air circulation throughout the cargo. Separated from ammonium compounds, acids, cyanides, hydrogen peroxides and liquid organic substances.'

Additionally, the information below in relation to the properties of calcium hypochlorite is included within the IMDG Code.

'May cause fire in contact with organic materials or ammonium compounds. Substances are liable to exothermic decomposition at elevated temperatures. This condition may lead to fire or explosion. Decomposition can be initiated by heat or by impurities (e.g. powdered metals (iron, manganese, cobalt, magnesium) and their compounds). Liable to heat slowly.'

For more information please refer to IG P&I Guidelines for the Carriage of Calcium Hypochlorite in Containers. ***(http://static.igpandi.org/igpi_website/media/article_attachments/CH_Guidelines_27_April.pdf)***

Reactive solids

Case Study

It was early morning and from the bridge the Master saw a large cloud of smoke issuing from the forward part of the vessel. At the same time the fire detection system for cargo hold 2 sounded on the bridge. The Master described the smoke as being white at first and then greyish. The Chief Officer, however, described the smoke as being "dark grey, almost black".

The ventilation fans for the cargo holds were stopped. The fans for cargo hold 2 were not operating at that time but natural ventilation was being provided for the holds as the covers for the vents were open. Crew members closed the covers of the vents for cargo hold 2 and no crew member entered the cargo hold.

Meanwhile the Master navigated the ship to a nearby anchorage.

After various checks had been performed, the Chief Engineer released the contents of 197 CO_2 cylinders into cargo hold 2. This discharge was the designated full complement of CO_2 required for the hold, and appeared to extinguish the fire. A couple of hours later smoke began to issue from the hold and a further 57 CO_2 cylinders were released into cargo hold 2. About six hours later smoke was observed issuing from cargo hold 2 and the Chief Engineer released a further 57 CO_2 cylinders.

Salvors boarded the vessel the following morning. Shortly before midnight, temperature checks were completed by the vessel's crew indicating that the temperature in cargo hold 2 was rising so five more CO_2 cylinders were released. In the morning another 15 CO_2 cylinders were released.

The salvors entered cargo hold 1 and measured the temperature for the bulkhead to cargo hold 2 - it was 83°C. It was decided that cargo hold 2 should be filled with water from the fire hydrants. The water filled three container tiers up and after a couple of hours the salvors considered the fire to be extinguished.

The container where the fire started was not declared as dangerous cargo but was actually loaded with calcium hypochlorite and had been misdeclared by the shipper.

The charterer had loaded the container as per the rules of the IMDG Code. As per the manifest, the container was allowed to be loaded in the cargo hold, but as the cargo was calcium hypochlorite it should not have been loaded below deck or in the position it was stowed in.

8 Biomass in bulk

Biomass is shipped in bulk to provide fuel for 'green' power stations. Examples of biomass include wood chips and husks of oil seeds. These types of biomass do not contain significant amounts of oil, so there is no self-heating from oxidation of oil. Biomass can, however, naturally evolve carbon monoxide, even if it is not self-heating. This can lead to incorrect assumptions about whether there is a fire or self-heating in the biomass.

Recent experience has shown that biomass can undergo a rotting process in which microbes (bacteria and mould) break it down. This can produce some heating, but the heating is not usually severe enough to cause fire. Microbial action can continue where oxygen concentrations are low, however, and that type of 'anaerobic' rotting can produce dangerous concentrations of methane. We have seen holds in which rotting biomass has produced methane concentrations of about 40% by volume in the ullage space.

The causes of biomass rotting problems are related to the nature of the biomass, its storage time and conditions before loading, and possibly conditions after loading. The IMSBC Code currently covers some types of wood pellets but not necessarily all types of biomass.

Dealing with a biomass rotting problem is likely to involve opening the holds and discharging the cargo. If holds contain high methane concentrations that approach or exceed 100% LEL then explosion risks need to be considered. If oxygen concentrations are below about 10% then there may be no immediate explosion risk due to low oxygen. When opening holds, however, entry of air may cause the resulting gas mixture to enter the flammable/explosive range, when an explosion can theoretically occur. In practice, opening holds and venting them naturally in appropriate conditions is unlikely to lead to ignition. Nonetheless parties have decided to carry out inert gas flushing before opening holds in some cases.

❾ Fertilisers

Fertilisers, which are often shipped in bulk, may have some of the same characteristics as the aforementioned reactive solids. If some fertilisers become hot enough they may be able to decompose rapidly with evolution of heat and, often, toxic gases. Precautions for fertilisers include avoiding sources of heat, eg. cargo lights and heated fuel tanks.

⑩ Batteries

Rechargeable batteries such as nickel-metal-hydride (NiMH) and lithium ion (Li-ion) are often shipped part-charged, which means that a stow of them contains a lot of stored electrical energy. Batteries also incorporate a great deal of combustible material such as plastic casings, plastic internal insulation, combustible electrolyte (in some batteries) and packaging. Consequently the total electrical and chemical energy released in a fire can be substantial, and can result in explosion and/or fire spreading to other containers.

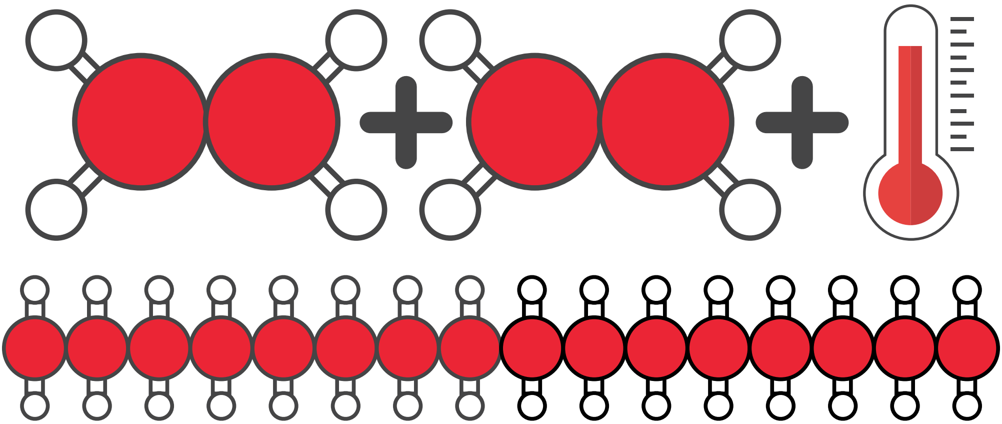
There are several possible causes of rechargeable battery incidents including incorrect packaging allowing short circuits; damage in transit allowing short circuits or puncturing batteries; water ingress allowing short circuits; and manufacturing defects allowing internal short circuits. Also, many rechargeable batteries naturally lose their charge slowly over time ('self-discharge'). This means that self-heating can occur as the natural slow discharge releases electrical energy as heat. If that heat cannot be dissipated fast enough from the stow, then batteries may become so hot that faults occur, such as failure of internal insulation. This can then spread rapidly to other batteries, leading to ignition and fire.

⓫ Reactive liquid cargo

Some chemicals are shipped as liquid monomers that have a tendency to polymerise. Polymerisation means that the individual monomer molecules join together to make larger molecules. Polymerisation often evolves heat.

Inhibitors may be added to monomers, to stop or slow down polymerisation, but the inhibitors are usually used up over time. Inhibitors may also need oxygen to work, but in a closed tank there is a limited supply of oxygen. Therefore there is likely to be a time limit after which the risk of polymerisation is much higher.

The rate of polymerisation is higher at higher temperatures, and in addition, inhibitors and oxygen are also used up more rapidly at a higher temperature. The time for which the monomer is protected is therefore likely to be shorter as temperatures rise.



If the concentration of inhibitor or oxygen falls too far then the rate of polymerisation may increase to a point at which heat is produced very quickly and the temperature becomes very high.

This can cause boiling and release of flammable monomers and polymers via relief valves on a tank or tank container, which gives rise to an explosion risk. Also, the relief valves may not be able to cope with the required rate of release, or they may be blocked by polymer, in which case the tank itself may fail, giving an explosive release of flammable/explosive material.

With monomers that are prone to polymerisation, the inhibitor and oxygen concentrations must be appropriate for the voyage, taking into account the time involved and the expected temperatures before and after loading as well as on board ships.

4 Other causes of cargo fires and explosions

1 Cargo hold lights

Many bulk carrier/general cargo holds have fixed cargo lights. These can easily ignite combustible cargoes such as grain, animal feed, wood chips, pulp and paper if they are too close to the light. Self-decomposition of fertilizer has been initiated in this manner.

Cargo lights in holds need to be properly isolated before cargo is loaded. This is best done by removing fuses or other physical links in the electrical circuits so that the lights cannot be switched on by mistake.

In container ships the lights need to be properly placed so that they do not overheat cargo or other combustibles and thus cause damage or fire. Lights in car carriers and ferries are usually fluorescent, which are unlikely to cause ignition. Nonetheless it makes sense to leave lights switched off when they are not needed, particularly in cargo areas where combustibles are present.

Cargo hold lights

Case Study

A bulker had loaded sugar beet pellets in all three cargo holds with the operation taking 27 hours. When loading was completed the ventilation hatches and all other access points to the cargo holds were secured. In cargo hold 1 there were two metres of space between the cargo and the cargo hatch. In cargo holds 2 and 3 the cargo was almost up to the bottom of the hatch coaming.

Two days into the voyage the crew noticed smoke coming from cargo hold 2. Hot spots were discovered in hold 2 on the transverse hatch coaming, both forward and aft on the portside, and an additional hot spot was also discovered on hold 3 on the transverse hatch coaming, on the portside aft. All hot spots were located adjacent to recesses in the coamings for the cargo holds' floodlights.

The crew isolated the electrical power to the floodlights. Because of the increased temperature of the hot spots in hold 2, the Master released CO_2 into the hold. The CO_2 did not extinguish the fire but reduced its severity for a while.

When the vessel arrived at the discharge port the cargo hatches were opened and flames broke out from hold 2. At the same time a plume of smoke escaped from hold 3.

The top layer of cargo in hold 2 had been burned. About four metres below the cargo surface the cargo was in good condition. It was discovered that the cargo in hold 3 had been damaged by condensation and tainted by smoke. There were clear burn marks around the floodlights and distinct burn marks by the coaming at the same locations where the hot spots had been discovered. The floodlights were situated 1m below the cargo surface in holds 2 and 3 and there was black, burned cargo covering the floodlights.

There were two floodlights fitted in cargo hold 1, port and starboard and four floodlights fitted in both cargo holds 2 and 3. All the floodlights were installed in recesses in the hatch coaming. The floodlights were protected by round bars preventing crane hooks, grabs etc from hitting them, but these bars do not prevent cargo like sugar beet pellets from

covering the lights. The floodlights were controlled from the bridge on a panel with four key-switches. These switches were marked 1, 2, 3 and 4 respectively. No drawings or legends were attached clarifying which areas these key-switches served.

The subsequent investigation revealed that the cargo floodlights were not connected according to the approved 'as built' circuit diagrams delivered with the vessel.

It was not clear on board which lights were controlled by which key-switch. The fire was caused because a number of cargo lights were operating while cargo covered them, so the lights ignited the cargo. There was a lack of information on board about how the light circuits were connected and how the light system should be operated. There was also a lack of records concerning use of the lights.

2 Smoking and hot work

Many cargoes, including a wide range of bulk cargoes and general cargoes can be ignited by cigarettes and/or hot work. Smoking and hot work therefore need to be properly controlled. Control of smoking can be difficult where stevedores are working on board. Hot work permits need to be properly considered, not just a 'tick box' exercise.

Once a fire has started, some bulk cargoes will smoulder for long periods even after closing and sealing holds and using CO_2 to maintain a low oxygen concentration in the ullage space. This extended smouldering is often due to residual oxygen absorbed into the cargo and air/oxygen in voids in the cargo e.g. between pellets. In cases of extended smouldering the only option may be to discharge part or all of the cargo.

Smoking and hot work
Case Study 1

A bulk carrier carrying general cargo was loading additional steel cargo into its cargo holds. In order to secure this cargo, the crew welded D-rings to the tween deck. It was late in the evening and the Bosun noticed smoke from the lower hold.

He informed the Chief Officer at once about the smoke and tried to reach the area where the smoke was coming from with a fire hose but was unsuccesful. The Chief Officer assisted the Bosun with a fire extinguisher but could not access the area as the tween deck was full of cargo.

The Chief Officer informed the Master who sounded the general alarm. All the crew was mustered and accounted for.

A fire team was assembled and boundary cooling started. Fire hoses were also used for spraying water into the cargo hold. This did not extinguish the fire as more smoke was escaping from the cargo hold.

The Master decided that the cargo hold hatch covers should be closed and CO_2 released into the cargo hold.

When the local fire brigade arrived the hatch covers were removed. A great deal of smoke escaped from the cargo hold and so the fire brigade and crew sprayed water through the hatch. After a couple of hours the fire brigade confirmed that the fire had been extinguished.

Smoking and hot work

Case Study 2

A container vessel was awaiting instructions for when to enter the port. During the wait the Chief Officer made the decision to carry out repairs to the cell guides in one of the cargo holds. The engine fitter and an AB began to prepare the welding job for the cell guides.

Before the welding commenced a risk assessment and hot work permit were completed. As per the hot work permit, fire extinguishers were in place and one AB was the designated fire watch. The Chief Officer approved the job and was also present.

Some time into the job, the engine fitter began to smell burned rubber, and on investigation saw that a container had caught fire.

In the vicinity were a couple of oxygen and acetylene bottles which the engine fitter moved to safety. The Chief Officer ordered everyone to evacuate the cargo hold and informed the bridge that a container had caught fire. The general alarm was sounded and a fire team assembled and began boundary cooling.

The heavy smoke and high temperature made it impossible for the fire team to approach the fire so the Master decided to release the CO_2 system into the cargo hold, which extinguished the fire.

The container that had caught fire was an open top container covered by a tarpaulin and containing cloths, tyres, wooden pallets and machinery.

❸ Vehicles and refrigeration units

Cars and other vehicles carried on board ships present some risk of fire, as does the carriage of refrigeration units. There are a number of risks:

Cargo shifting in heavy weather can lead to ignition e.g. by rupturing gasoline tanks, damaging electrical cables and causing friction.

Vehicles being driven can lead to fire, if they are faulty. Working on vehicles to try to start them can lead to ignition e.g. using petrol to top up tanks and using jump leads to start vehicles that have flat batteries. These risks are higher when dealing with used vehicles that may be in poor condition.

Electrical faults. Many vehicles have electrical circuits that remain energised even when the ignition is switched off. Electrical faults do not commonly cause fires in cars that are not being driven, but large numbers of cars are transported by ship and occasionally a fault can develop to cause ignition during shipment. Refrigeration units too are subject to electrical faults

Not all risks of fires in vehicles can be eliminated. Risks of significant fire damage can be reduced by following proper procedures when working on cars, and by ensuring that ships' fire precautions and procedures are correct and are followed properly.

Vehicles and refrigeration units

Case Study 1

A ro-ro vessel was underway and was expected to sail through heavy weather at Beaufort 10 the following day with waves of about 6-8 metres.

The cargo comprised vehicles, containers and jerrycans on flat racks. Before loading commenced the Chief Officer went ashore to inspect the cargo. He inspected the jerrycans which were secured with quick lashings through the handles of each row and secured to bars on the flat racks.

He was concerned that the jerrycans were placed on flat racks and not in containers, as there were no sides around the flat racks to protect them. However, he decided to accept the cargo on board.

The flat racks on the forward part of the weather deck were secured with two lashings (and some with three or four) at each end. Some of the units were secured with lashings along the length of the unit. The containers were secured with a combination of web lashings and chains.

The following morning the Chief Officer and crew inspected the cargo and the Chief Officer found only minor issues to correct, with some slack lashings that needed to be tightened, and some lashings needing to be added to certain units that were a bit loose or did not have ideal angles.

Later in the morning the wind increased, the vessel started to roll and the Master slowed down to about 10 knots. Around lunch time the wind increased even further and the vessel slowed down to about 6 knots. The vessel was now sailing through Beaufort 10 and waves of about 8 metres.

This caused one of the containers to come loose which hit one of the flat racks containing jerrycans.

Due to the heavy rolling, the Master believed it to be unsafe for the crew to go onto the weather deck and re-lash the container. A number of the jerrycans fell onto the deck and spilled fuel. As water was washing over the weather deck the Master assumed that any fuel would have been washed away by the water, but it could be seen that this was not the case.

From the cameras on the bridge, sparks could be seen on the weather

Continued on **page 44**

deck from the moving containers. To prevent a fire from starting the electricity was turned off for the reefer units on the weather deck and the sprinkler system was started. The Master hoped that this would wash away all the fuel on deck, but this too was unsuccessful.

Large flames could then be seen on the weather deck through the vessel's cameras. The Master activated the fire alarm and broadcast a mayday over the VHF. The crew were assembled and all accounted for.

The burning cargo was in the forward part of the weather deck. The fire crew approached the blaze from the side walkways and from the stern on the weather deck. The sprinklers were also running. There were now flames up to 30 metres high.

Several explosions occurred from fuel containers and jerrycans. The crew fought the fire for about five hours until they finally got it under control.

The vessel eventually berthed safely at the next port.

Vehicles and refrigeration units

Case Study 2

While a ro-ro vessel was sailing, an AB was checking the reefer containers during his deck patrol when he saw smoke coming out from one of the trailers on the weather deck.

The AB could not detect the source so he started the fire alarm. The smoke alarm had not yet been triggered on the fire detection system. The OOW started the general alarm after he had been informed by the AB. All the crew were assembled and accounted for.

The sprinkler system was started and a fire team approached the fire. The Master slowed the vessel down and altered course so that there was almost no relative wind on the weather deck.

The fire team managed to extinguish the fire quickly before it spread from the trailer.

It was suspected that the fire had started in the trailer's refrigeration unit.

Vehicles and refrigeration units

Case Study 3

A reefer container on board a container vessel caught fire. The container was loaded with cartons of frozen meat and the container was connected to the vessel's power supply.

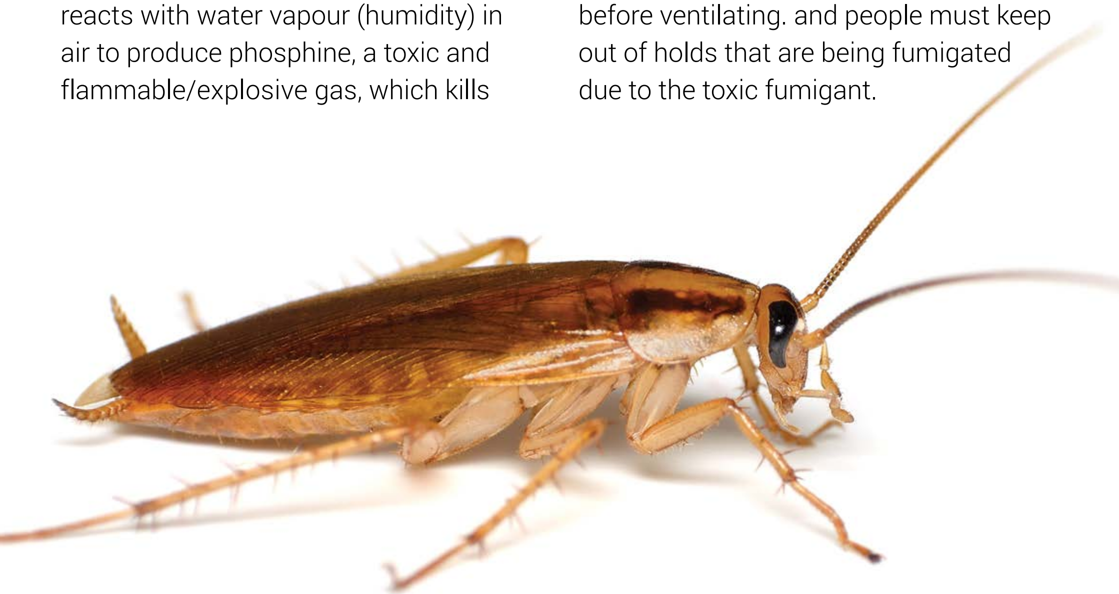
The area of the control panel where the fire started was located close to the stowage zone of the electrical feeding power cable. The 30-metre feeding power cable was found in good condition but aluminium parts from the container were found melted around the control panel. The fire most likely started in the 440V cable that was folded in a basket.

Once the fire took hold, it melted the aluminium coating, foam insulation and other parts of the panel. As the reefer fans were still working, fire and smoke was sucked into the container.

All the meat was considered to be waste.

4 Fumigation

Agricultural products in bulk may be fumigated in ships' holds to prevent insect infestation. Solid aluminium phosphide (or similar) is often used for fumigation. Aluminium phosphide reacts with water vapour (humidity) in air to produce phosphine, a toxic and flammable/explosive gas, which kills insects. Heat is also given off during the reaction. The solid fumigant may be applied in fabric 'socks' or as pellets on the surface, just before closing holds. Holds are then kept closed for a period before ventilating. and people must keep out of holds that are being fumigated due to the toxic fumigant.



If there is an excessive amount of fumigant in one place, or if the fumigant is contacted by liquid water e.g. from sweating or condensation, then the fumigant can react too quickly. This can evolve excessive heat and lead to ignition of cargo and/ or packaging such as bags or paper placed over the top of the cargo. Under certain conditions the fumigant gas itself may ignite, producing an explosion.

It is important that fumigant is applied according to the correct instructions. As holds are always un-ventilated for a time after fumigation, there may be a risk of excessive condensation, which can produce sweating or dripping. This can lead to cargo damage as well as the fire and explosion risks mentioned above. The weather conditions and cargo conditions, such as moisture content, therefore need to be considered properly before fumigation, which is often carried out by specialist companies.

Fumigation

Case Study

A bulk carrier was fully loaded with yellow corn. After loading was completed, fumigation technicians came on board and fumigated the cargo holds with fumigation pellets.

The fumigation pellets should, as per the requirements, be applied subsurface. However the technicians poured the pellets on top of the cargo. This work took a little more than an hour and afterwards all cargo hatches were closed and the vessel sailed.

A couple of hours later an explosion occurred in hold number 3. The crew noted that the hatch covers had moved slightly and blue-grey smoke was seen coming from under the edges of the hatch covers. About an hour later another explosion occurred. This time it was from hold number 4 and a couple of minutes later an explosion in hold number 6 occurred. The remaining holds 1, 2, 5 and 7 had explosions shortly afterwards.

Fumigation pellets and similar fumigants are formulated with some 55% aluminium phosphide, ammonium carbamate and inert materials. The aluminium phosphide reacts with water to produce phosphine, which is extremely toxic and an effective fumigant. Under normal conditions, phosphine is a gas that is slightly denser than air. It is colourless, highly toxic, and has an odour variously described as 'fishy', 'garlic-like' or 'like carbide'. Phosphine gas will form an explosive (or flammable) mixture when mixed with air in a concentration exceeding about 1.8% to 2% by volume - this is its lower explosive limit.

The probability of the phosphine concentration exceeding the lower explosive limit concentration is increased if pellets are allowed to accumulate in a heap, as opposed to being spread out across the surface of a cargo, or buried in the bulk of the cargo. The explosive phosphine/ air mixture mentioned above spontaneously ignited.

The method of application mentioned above had likely permitted the accumulation of the pellets in limited areas and promoted relatively rapid reaction of the fumigation pellets with moisture, thereby generating concentrations of phosphine gas above the lower explosive limit concentration.

5 Flammable liquid cargo

Flammable liquid cargoes present risks of explosions in cargo tanks and other compartments. These explosions are often followed by fire.

Sometimes fire and/or explosions propagate to other tanks. In that case, to investigate the cause it is necessary to work back to the origin tank by plotting the direction of the first displacement of bulkheads between tanks. At the first tank, all of the bulkheads will most probably have been displaced outwards initially.

In many tankers the basis of safety is avoiding flammable/explosive mixtures by using inert gas (IG). In this case it is obviously essential to ensure that the IG system is working properly and is used correctly.

In other tankers, usually smaller ones, there may be no IG facility. There are periods of higher risk such as when

discharging a volatile flammable cargo and air is drawn into the tanks, when the resulting mixture of residual cargo vapour and air may be flammable/ explosive. Instruments, pumps and other relevant items need to be kept in good condition to avoid producing ignition sources. Procedures such as cleaning should be carried out strictly in accordance with the relevant guidance to avoid producing ignition sources. The International Safety Guide for Oil Tankers and Terminals (ISGOTT) provides detailed guidance on how tanker operations should be carried out.

Before maintenance or repair work is started, all relevant spaces need to be properly gas-freed and all applicable safety procedures complied with. Explosions have occurred because residual sludge or other material in tanks has evolved flammable vapour after gas-freeing, so that an explosive mixture has developed later.

5 Glossary of terms

IMDG Code	International Maritime Dangerous Goods
IMSBC Code	International Maritime Solid Bulk Cargoes
UN number	Four-digit numbers that identify hazardous cargo that is transported internationally
IMO	International Maritime Organization
IG	Inert gas
ISGOTT	International Safety Guide for Oil Tankers and Terminals

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