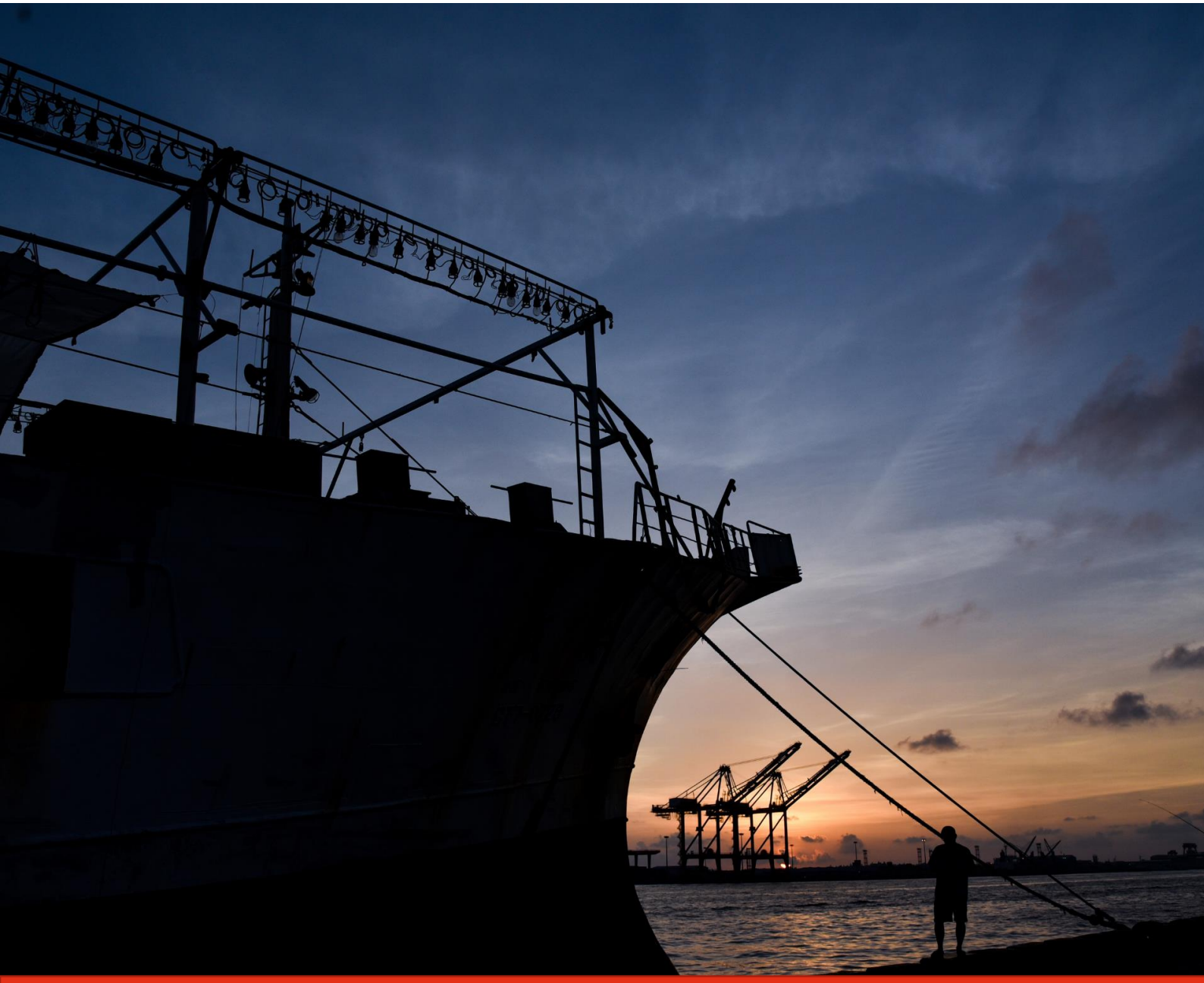
iima
International
Iron Metallics Association

Direct Reduced Iron (DRI): Guide to Shipping, Handling and Storage

April 2022



Contents

Copyright® International Iron Metallics Association

List of figures

This guide has been prepared on the basis of existing regulations, industry experience and best practice. This guide does not specifically address the Health & Safety aspects of shipping, handling and storage of DRI and should not be considered as a replacement for a Material Safety Data Sheet (MSDS). Persons working with DRI should obtain a MSDS from the Shipper or other concerned party and follow the applicable safety procedures such as use of personal protective equipment (hardhats, reflective vests, steel-toed boots and eye/ear protection) at all points from production plant to end use facility.

Readers should note that production and handling of Direct Reduced Iron (DRI) is a process that has evolved over the years and will doubtless continue to do so, meaning that the information, precautions and measures given in this guide may be need to be updated from time to time. Please therefore check on our website to ensure that you have the most up-to-date version. This is version 1.0.

Copyright® International Iron Metallics Association

Chapter 1 - Introduction to Direct Reduced Iron (DRI)

Figure 1: Direct Reduced Iron
Image courtesy of Midrex Technologies

DRI, also known as Sponge Iron, is the product of the direct reduction of iron ore (mainly pellets) or other iron-bearing materials while in the solid state, i.e. without melting, using "reducing agents" carbon monoxide and hydrogen, derived from reformed natural gas, syngas or coal (and in the future, hydrogen derived from electrolysis). The two principal global technologies for direct reduction of iron are Midrex and Energiron, both gas-based shaft furnace processes where a descending column of iron ore is reduced by an ascending column of gas - see Figures 2 and 3. These technologies accounted for 72.4% of global DRI production in 2020. The principal feedstock is iron oxide pellets which are coated (with a material such as bauxite, lime or cement) to inhibit the formation of clusters due to sintering together of individual pellets (sticking) at higher operating temperatures.

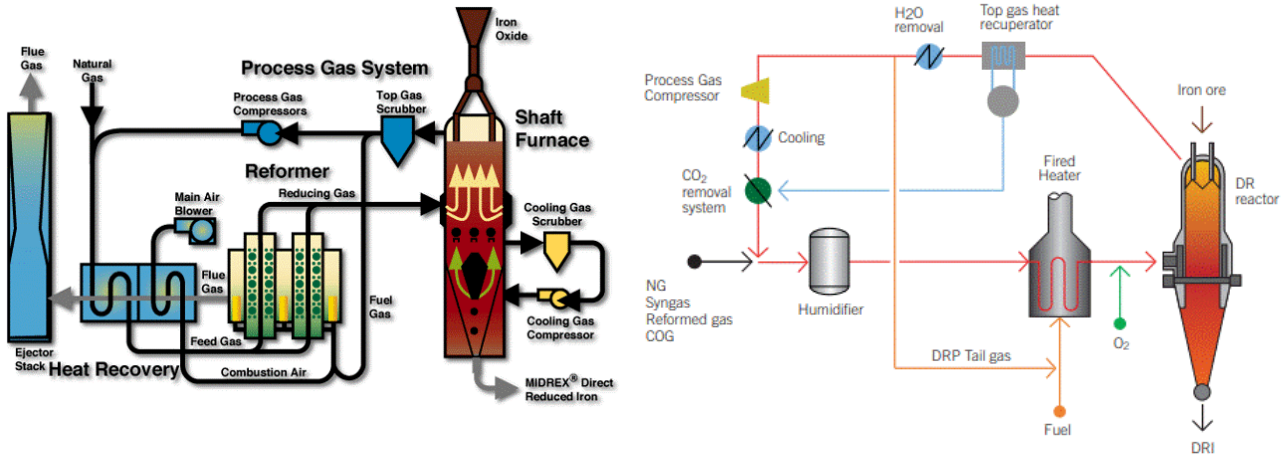


Figure 2: Flowsheets for Midrex (left) and Energiron (right) processes
Diagrams courtesy of Midrex Technologies and Energiron

Figure 3: Modern direct reduction plants
Images courtesy of Midrex Technologies, Energiron

DRI is produced in three basic forms: cold DRI (CDRI), hot DRI (HDRI) and Hot Briquetted Iron (HBI[1]). **This guide deals with CDRI.** HDRI is used in integrated mini-mills where HDRI is transferred "in-house" from the direct reduction plant directly to the electric arc furnace. HBI is a form of DRI which is briquetted at high temperature (≥650°C) and pressing force. The compaction of DRI into a dense briquette reduces its porosity and thus the surface area available to oxygen and water, meaning that HBI has a much lower reactivity and tendency to reoxidise and self-heat, and therefore does not require the rigorous safety precautions required for safe shipment of DRI

1.1 Reactivity of DRI

It has been observed that there is a relationship between DRI porosity and reactivity. Ore source and minerology and reduction temperature are the main influencing factors, as well as carbon content (in the form of iron carbide/cementite/Fe_3C) which decreases reactivity.

As its alternate name, sponge iron, suggests, DRI is highly porous. Over 50% of the pellet is internal void. This connected internal porosity results in the material having a very large surface area to weight ratio. The internal surface area of a DRI pellet can be 2000 times greater than the surface area of the feedstock pellet. Like all iron and steel metallics, DRI is subject to corrosion and oxidation when exposed to air and/or water. However, with its high porosity, low density, large surface area and low thermal conductivity due to the interstices or voids between the metallic surfaces, DRI has a propensity to undergo very rapid corrosion and reoxidation reactions. Many of these reactions are exothermic, leading to self-heating and eventually self-ignition and fires if not controlled. Corrosion and oxidation reactions of DRI (especially when exposed to saltwater) can also produce hydrogen, an explosive gas which is lighter than air, and carbon monoxide, a highly toxic gas that can also be combustible in high concentration. Some important reactions that occur are:

[1] See IIMA's Guide to Shipping, Handling & Storage of Hot Briquetted Iron

Copyright® International Iron Metallics Association

(1) $4Fe + 3O_2 \rightarrow 2Fe_2O_3$ (re-oxidation of DRI)
(2) $2Fe + 3H_2O \rightarrow Fe_2O_3 + 3H_2$ (re-oxidation of DRI)
(3) $2Fe + 2H_2O + O_2 \rightarrow 2Fe(OH)_2$ (corrosion/rusting of DRI)
(4) $2C + O_2 \rightarrow 2CO$ (Oxidation/combustion of contained carbon)
(5) $Fe3C + O_2 \rightarrow 3FeO + CO$ (Oxidation of contained iron carbide)

Low temperature reactions involving liquid water are likely to proceed as aqueous galvanic reactions, which are beyond the scope of this publication. Although reaction (2) with liquid water is endothermic (heat absorbing), it will be exothermic (heat producing) if the water is in the vapour phase. As many reactions can occur simultaneously and, as many other reactions of reactive and hot DRI are possible with water and air, it is possible that reaction (2) occurs with steam after it has been formed by, say, the evaporation of water caused by the heat generated from reaction (1) and/or reaction (3). In short, both heat and hydrogen and carbon monoxide can be generated by the rapid reoxidation of DRI, provided that the conditions are right - the quantum will depend on the amount of reactive DRI present. It is also important to note that hydrogen can be produced in the absence of air or oxygen, such as in an inerted hold or silo.

DRI has low thermal conductivity in comparison with other types of iron, due to its greater porosity and lower bulk density relative to other forms of iron. Depending on the environment as well as feedstock iron oxide pellet characteristics, the heat generated by reoxidation/rusting inside the DRI pile can build up and cause ignition of a pile of DRI.

DRI is relatively weak in comparison with iron oxide pellets and many other common bulk materials and tends to break down during handling to produce dust and fines. Dust and fines are generated in several ways: (1) on impact (e.g., freefall drops from handling equipment in yards and into vessel holds, transfer points on conveyor belts, bins or other hard surfaces; (2) crushing of pellets under load in piles and when traversed by heavy mobile equipment; (3) by abrasion (rubbing against sliding surfaces and other pellets; (4) general deterioration of pellet strength when held in storage over an extended period of time. The dust that is produced during handling is initially generated primarily as metallic iron, and is a combustible metal dust. Accumulations of DRI dust tend to be even more reactive than the bulk DRI and have a high propensity to self-heat and and cause fires. DRI dust that is dispersed in air can ignite in a flash fire. Ignition of DRI dust within a container, such as a silo, enclosed conveyor, or de-dusting device can lead to a dust explosion potentially causing the rupture, mechanical failure and collapse of the enclosure. Accumulations of DRI dust within buildings can lead to fires, flash fires or explosions that can cause significant structural damage to the building and represent a serous risk to workers in the area. This hazard is separate from the hazard associated with the generation of hydrogen gas. A dispersed cloud of DRI dust can ignite and/or explode with no combustible gases being present.

In summary, the main hazards in shipping, handling and storage of DRI include:

1. Its tendency to self-heat when exposed to an ignition source or when in sustained contact with air (oxygen) and water;
2. generation of hydrogen when in sustained contact with water, especially saltwater;
3. generation of carbon monoxide when reacting with air and/or water (not in the case of hydrogen-based DRI which contains no carbon);
4. generation of combustible metal dust during handling

Copyright® International Iron Metallics Association

These and other hazards in shipment of DRI are dealt with in subsequent chapters.

1.2 Passivation of DRI

Once produced, DRI for shipment should be aged for at least 72 hours to allow passivation to occur. DRI is most reactive immediately after it is produced, and the rate of reaction with oxygen (air) will decrease by roughly 3 orders of magnitude or 1000x in the first 72 hours. In a storage silo, controlled passivation can be achieved by introducing a flowing supply of gas containing 3% oxygen or an equivalent oxygen partial pressure. The oxygen reacts with the exposed metallic iron surface of the DRI and forms a thin, inert layer of oxide on the internal and external exposed metallic iron surfaces of the DRI. This thin oxide layer reduces the reoxidation tendency (reactivity) and stabilises (passivates) the DRI. The impacts of reduction temperature and reducing gas chemistry tend to be smaller than the impact of passivation; however, if the source iron ore or the reducing conditions are less than ideal, it can be difficult to achieve passivation as the re-oxidation reaction can run away and lead to self-heating and ignition of the DRI.

DRI can also be aged when stored in warehouses in ambient air. In this case a good natural draft of ventilation should be provided, but both Shipper and carrier should be aware that passivation may not be as consistent as is achieved in a silo under a controlled atmosphere.

1.3 Maritime transport of DRI

For the purposes of maritime transportation, the IMO's International Maritime Solid Bulk Cargoes Code (IMSBC Code) uses the following bulk cargo shipping name (BCSN) for DRI: "Direct Reduced Iron (B) Lumps, pellets, cold-moulded briquettes." The IMSBC Code schedule for DRI (B) is quoted in full in Annex 1 to this guide.

For further information about both DRI please visit www.metallics.org.

Copyright® International Iron Metallics Association

Chapter 2 - Handling & storage at production plants, port terminals and stockyards

2.1 Equipment for handling DRI at plants, ports & yards

All types of conventional bulk material handling equipment can be used with DRI for yard storage, reclaiming, loading and/or unloading):

- bucket-wheel stacker-reclaimers
- cranes equipped with magnets or clamshell-type buckets
- front-end loaders, backhoes
- fixed or mobile conveyors and conveyor belt systems, including pipe conveyor systems
- fixed or mobile bins and hoppers
- if at port terminal or at anchor for mid-streaming operations to barges, ship travelling bridge cranes, fixed cranes, floating cranes and belt systems
- self-release skips
- railcar straddle carriers and rotary dumpers

Figure 4: DRI storage silos
Image courtesy of Nu-Iron

Figure 5: Photo collage of stacking, reclaiming and handling equipment
Images courtesy of IIMA

Whether at the production plant, the port, intermediate terminal or the end-user's stockyard, handling of DRI is similar in that industry utilises standard bulk material handling equipment of various types, sizes and capacities. Although many types of material handling equipment can do the job of moving

Copyright® International Iron Metallics Association

DRI, some types of equipment are better suited for handling DRI and accommodating its unique and challenging properties. Because DRI can burn, special attention should be paid to potential heat or ignition sources. Because DRI is water reactive, equipment that accumulates moisture while in use or at rest should be avoided, or at least properly cleared of any standing water before being put into service. Due to the highly reactive and combustible nature of DRI dust and fines, equipment that leads to excessive spillage or accumulation of dust should be avoided. When DRI will be handled by equipment that also moves other types of material, careful attention should be paid to avoiding incompatible materials, as well as the potential for residual moisture. As an example, although aggregate is not incompatible with DRI, handling wet aggregate before DRI can bring DRI dust into contact with water, leading to equipment fires. A risk assessment involving careful evaluation of handling and storage equipment should be carried out in order to assess the specific hazards associated with combustible DRI dust, the potential for hydrogen and carbon monoxide generation and fires.

At the point of production, DRI for external delivery is transferred from the shaft furnace to storage and, after sufficient cooling, reclaimed for loadout (to vessel, barge, rail or truck). Discharge of DRI can be by geared vessels' onboard cranes or by shore-based cranes for vessels not equipped with their own cranes.

At port terminals, various types of handling systems may either transport the DRI to temporary ground storage, or convey it to hoppers for controlled re-loading to barges, railcars, or trucks. Many terminals offer flexible combinations.

DRI is susceptible to breaking into chips and producing iron-laden dust during handling from production site to end user. Therefore a key focus with DRI handling is the need to minimise generation of chips, fines and dust - and spillage. Material losses during handling and storage arise from the a variety of sources:

- spillage from conveyor belts and mobile equipment handling
- breakage and degradation at transfer points and through handling by mobile equipment
- degradation during storage and reclaim
- dust collection losses

A frequently quoted estimate for DRI handling breakage is 0.25% loss for each 2 metre drop experienced. The loss can be much greater for weaker material, longer drops or poorly designed transitions. The amount of breakage also can be much lower for well-designed transitions, almost regardless of drop height.

Material losses can be kept to a minimum by optimising the material handling system, for example by minimising the number of transfer points along the entire chain, and by limiting the height and number of free fall drops. However, metering and control of feed to conveyor systems should not be compromised through elimination of transfer points as spillage from an overloaded conveyor could be greater than breakage at an additional transfer point. While the number of transfer points may not be controllable, the choice of equipment and operator-controlled drop heights usually are. Use of gentle lay down practice or "soft-loading" is recommended. All operators of material handling and transport equipment should be alerted to use soft handling techniques to minimise breakage and fines generation. When using front-end loaders and other mobile equipment with DRI, care should be taken to minimise running them on top of piles so as to avoid breakage and fines generation.

Copyright® International Iron Metallics Association

Figure 6: Railcar loaders having "soft-loading" capability (to minimise drop height)
Images sourced from: left - Hub-4.com; right - PiercePacific.com

In order to optimise the material handling system, the extent of breakage along the system should be quantified by taking samples at each transfer point or transition and performing a screen test. These data should be used to prioritise and correct problem transitions.

DRI should ideally be completely screened to remove "fine material" before any handling or storage as the fines are highly reactive and susceptible to reoxidation in contact with oxygen and/or water, especially saltwater (see Figure 7). The definition of "fine material" varies from plant to plant, <3 mm and <6.3 mm being typical examples. It should be noted that screening is a very dusty process and concentrating the undersized material can correspondingly increase the risk associated with such dust and fines. The storage and handling of the undersized material should therefore be carried out with extreme care. Because the fraction of material under 3mm can represent hundreds or thousands of tons from an ocean-going vessel, any screening plan should include safe recycling or disposal of the undersized material.

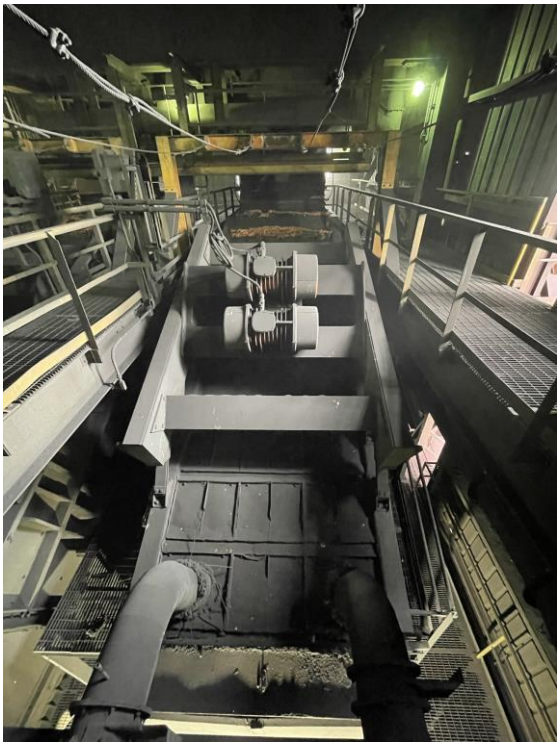


Figure 7: Screening DRI prior to shipment
Image courtesy of Nu-Iron

2.2 Storage of DRI

DRI can be stored in the following areas or containers:

- Stockyards and warehouses
- Silos, bins, hoppers or other confined spaces

General guidelines for all forms of storage are:

- keep clean and dry (with proper drainage)
- keep free of combustible materials: wood, coal, coke, etc.
- keep free of chlorides or past cargoes: avoid cement, lye, borax, fertilisers
- store DRI at sufficient distance from other stored materials
- ensure ability to monitor the storage space for temperature, hydrogen, carbon monoxide, and oxygen

2.2.1 Stockyards and warehouses

Whilst covered storage is recommended for DRI, it can be stored in the open air, provided that proper precautions are taken to prevent wetting of the material during precipitation, **although as a general rule, open air storage of DRI is not recommended**. Open air piles of DRI should always be covered when there is a risk of precipitation. Quality loss, specifically loss of metallisation is likely to be much faster in open air storage. The risk of a major material loss due to self-heating is much higher for outside stockyards and open air piles should be covered with breathable tarpaulins (to prevent condensation) or equivalent. DRI should never be stored on damp ground or where the base of the pile is close to the water table. DRI will draw moisture through a layer of dry aggregate or even concrete when within 1-2 meters of damp ground or the water table. Dry DRI should never be placed on top of wet DRI.

2.2.1.1 Conveying systems for DRI

In addition to the general comments about materials handling systems for DRI in section 2.1, the following precautions should be observed:

1. conveyor systems should ideally be covered in order to protect the local environment from dust and accumulation of rainwater;
2. all conveyor belts carrying DRI should be dry and special attention should be paid to the belt cleaning systems, such as the driving drum scraper, to ensure that they are functioning efficiently;
3. if there are two parallel conveyors for carrying DRI, it is recommended that both belts be in operation, one loaded, one empty – this to avoid accumulation of fines and DRI spillage on a stopped belt and thereby to minimise the risk of fires;
4. transfer points should be engineered to minimise the generation of fines and/or dust and/or breakage of DRI pellets;
5. if there are automatic fire-extinguishing water sprays on the belts or inside chutes, ensure that they are firmly closed in order to avoid water leakage. A “dry pipe” system can reduce the risk of accidental water leaks from the fire protection system;
6. during DRI handling, all chutes should be cleaned periodically, using pressurized nitrogen or water. If using water, any accumulation of water or moisture inside chutes or on connected conveyor equipment should be removed and allowed to thoroughly dry before handling DRI. When using compressed nitrogen or air to clean chutes, be aware that dispersed clouds of DRI dust can be ignited into a flash fire or an explosion in a confined space. The hazards associated with asphyxiation should be carefully evaluated before nitrogen is used for cleaning. Dust and fines

Copyright® International Iron Metallics Association

removed during cleaning should be carefully handled and disposed of, with special attention to the potential generation of hydrogen from wet fines;

7. conveying systems carrying DRI should be equipped with temperature monitoring devices:
   a. if elevated temperature or fire is detected, the flow of DRI onto the affected belt(s) should where practical be stopped and the belt discharge diverted to an emergency pile; in such situation, regardless of temperature, loaded belts should not be stopped until empty of all DRI;
   b. the affected area should be flooded with water and the entire belts and chutes cleaned;
   c. care should be taken in handling/using hot DRI in transfer to an emergency pile – usage of such material should be in small batches as they may increase fire risk and, in any case, will have lower metallic Fe content;
   d. care should be taken in handling/using wet DRI in transfer to an emergency pile – usage of such material should be in small batches as they may increase fire risk and, in any case, will have lower Fe content. Saturated DRI can hold as much as 12% moisture by weight. Introduction of wet DRI into the steelmaking process can result in steam explosions;
8. hot or wet DRI should not be transferred to a silo. If hot or wet DRI has been placed in a silo accidentally, the material should be carefully monitored for further temperature increases and silo atmosphere should be monitored for the accumulation of hydrogen and/or carbon monoxide. Such material should be used as soon as possible or removed from the silo. In case of increasing temperature inside the silo, the procedures given in section 2.2.2 on storage in silos should be followed;
9. general area alarm-equipped gas monitoring devices for oxygen, hydrogen (or total combustibles) and carbon monoxide should be installed in poorly ventilated areas where gases could accumulate. Wearable, personal gas monitors should be available to involved personnel, for personnel safety and/or to detect any abnormal conditions;
   a. the O_2 alarm should be set below 19% O_2 concentration (exposure to atmospheres containing 10-13% O_2 can cause unconsciousness too quickly for the individual to take evasive action;
   b. the H_2 alarm should be set at 1% concentration;
   c. the carbon monoxide (CO) alarm could be set at 50 ppm, the TLV (threshold limit value) – the LEL (lower explosive limit) for CO in air is 12.5% by volume;
10. all material spills that occur either as the result of normal operation or equipment malfunction should be cleaned promptly and not allowed to accumulate on, under, or near equipment

In comparison with a series of troughed belts, pipe conveyors offer a good solution for DRI handling. A pipe belt starts as a conventional troughed belt in the material loading zone, then wraps the conveyor belt into a tube completely surrounding the material. The belt unwraps at the discharge end, then wraps back up for the return path.

Figure 8: Pipe conveyor schematic and example system

Diagram courtesy of Midrex Technologies, Image courtesy of Energiron

By wrapping the belt into a tube, it is possible for a pipe belt to make both vertical and horizontal turns, whereas a conventional troughed belt can only make vertical plane bends (see Figure 8). Pipe belt conveyors are not a new technology, but they are very effective for moving dusty, granular or pelletised material like both DRI and oxide pellets. Because pipe belt conveyors make horizontal turns, they can eliminate transfer points. In addition, pipe belts have much less spillage in comparison with conventional belts. Dribble from carry back material on the return side is contained to just the head and tail. Because the material being carried is wrapped up in the conveyor belt, even in a belt over-fill condition material spillage is limited to head and tail.

2.2.1.2 Stacking DRI

The storage area should be kept clean and free of any combustible and non-compatible materials. Interaction with materials such as coal, wood or plastics can lead to self-heating and ignition. It is good practice to avoid standing water anywhere near the storage area by providing an even surface with moderate slope with adequate drainage. DRI piles should not be located in areas subject to condensation, for example downwind from cooling towers. In addition, the piles should not be located close to heat sources such as steam lines or hot process gas ducts. All storage areas should have clear signage explaining the potential hazards of DRI.

A very common source of DRI heating and material loss is when dry DRI is placed on top of wet DRI or a stockpile absorbs water from the ground below. Use of a storage pad with a concrete base is preferable to one with a base of compacted dirt, fill, crushed rock or other materials, as front-end loader operators may accidentally dig into the base when loading the DRI, pick up unwanted base materials and intermix them with the DRI. Tramp materials or residues in the cargo may negatively impact the steelmaking process and thus the value of the DRI. Ideally a sealant layer of tar, bitumen or some other material impervious to water should be laid down before the concrete base is poured in order to avoid ground water seeping into the DRI pile from the ground below.

Stockyards and warehouses for bulk storage vary from plant to plant and the method of piling DRI will therefore be dictated accordingly. In any case, it is recommended that piles are not stacked more than 5 metres in height. Conical piles with overlapping bases can mean difficult access for mobile plant, for example in dealing with hot spots and thereby mitigating increased pile temperature. One school of thought is that flat-topped, tent shaped piles are preferred. However, in any stockpile arrangement, it can be very difficult to remove hot material that initiates near the bottom of the pile due to the low angle of repose formed by DRI, and the propensity of the pile to slide down into and intermingle with the problematic hot material. Good housekeeping is an essential element of stockpile management. Personnel working in the vicinity of DRI stockpiles should wear or carry a portable gas monitor to check oxygen and carbon monoxide levels.

DRI piles should be accessible to personnel and mobile plant for inspection purposes and for moving material in case of need. Personnel operating around DRI stock piles should be aware that reacting DRI can produce carbon monoxide in dangerous concentrations, even in well ventilated areas.

In stacking DRI, inclusion of excessive amounts and concentrations of chips and fines should be avoided – fines and chips will tend to re-oxidise more quickly than whole DRI and can create heat in the pile. DRI chips and fines will always tend to concentrate at the point of loading of any pile, due to the fact that clean whole pellets roll out toward the perimeter and the chips and fines tend to be less

Copyright® International Iron Metallics Association

mobile. This natural tendancy of DRI to size segregate presents challenges for many aspects of storage and handling.

Material that has become wetted for whatever reason should be separated from the pile and allowed to dry before being re-introduced back to the pile.

The temperature of the piles should be monitored on a daily basis, using thermocouples 30 cm (±1 ft) in length at several locations in the pile. The surface temperature of the pile can also be monitored with a non-contact IR pyrometer or thermal camera. DRI with temperature in excess of 65°C (149°F) should be separated from the pile and allowed to cool.

2.2.1.3 Self-heating and auto-ignition of DRI

After material handling in bulk, DRI can be expected to experience a temporary increase in temperature of about 30°C (86°F) due to self-heating. Under normal circumstances the temperature should gradually fall to ambient. Due to its dark color, DRI that is left in the sunshine may also increase in temperature, but the temperature increase should be limited to the surface layer of material and should not get hot enough to reach the auto-ignition temperature.

As was explained in section 1.1, DRI in bulk has very low thermal conductivity. DRI can sustain a temperature gradient of several hundred degrees over as little as 30 cm. As a result, it can be very difficult to detect hot spots. Self-heating can sometimes be detected by measuring temperatures at the top of the pile. Temperatures in excess of 100°C (212°F) that cannot be explained by exposure to sun can be a serious indication of material overheating, and it is likely that higher temperature material may be present within the pile. At this stage, no flame will be present. If wet or reacting material is present in the centre of a stockpile, the heat cannot readily escape and the temperature may rise, leading to ignition. Auto-ignition is the temperature at which DRI will react directly with oxygen in the air in a sustained combustion reaction. In this case, the combustion reaction is the reoxidation of metallic iron. Conditions indicative of self-heating and auto-ignition are:

- sustained re-oxidation;
- elevated temperatures (approaching/exceeding 100°C (212°F));
- presence of water in the centre of a pile (particularly saltwater);
- excessive fines in the pile (greater than 5% by volume), particularly when segregated in the centre

If hot-spots develop in the pile (i.e. localised temperatures exceeding 100°C (212°F)), the affected material should be removed from the pile and spread out on dry ground in a layer of about 0.5 metres using a track-equipped bulldozer or front-end loader, as illustrated in Figure 9. Use of rubber-tyred front-end loaders may cause tyre damage, depending on the temperature, size and location of the hot spot. Whenever hot material is disturbed, there is a risk of ignition of dust clouds resulting in flash fires. It is also likely that CO will be present and personnel should be protected from exposure.

Copyright® International Iron Metallics Association

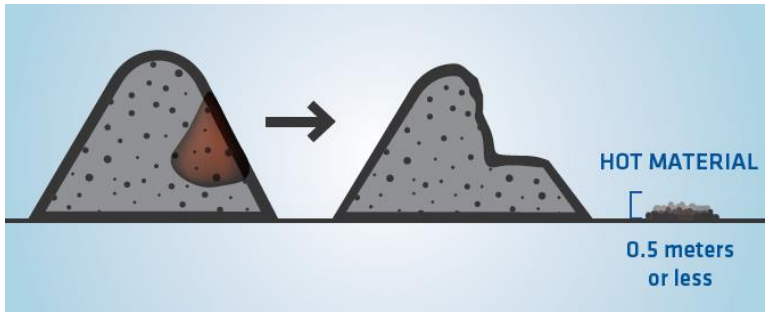


Figure 9: Method for controlling hot material in a storage pile
Diagram courtesy of Midrex Technologies

Another method is to bury the pile under sand or other suitable material to cut off the oxygen supply. With this method, safety is the primary objective, but the trade-off is that when reclaimed, the DRI will have to be screened to remove the added material if the latter is not to end up in the steel furnace. Screening operations can be very dusty and should only be attempted if no hot material is present.

In case these measures or other alternatives are not practical or effective, the material can be flooded with water. However, this should be a last resort because it will result in a significant loss of metallisation and expert advice should if possible be sought prior to such action.

Important note: water should not be sprayed on an overheated DRI pile under normal conditions. However, as a last resort in case of a runaway fire, the pile should be inundated with a strong water stream. Firefighters should be prepared for violent steaming and hydrogen flashing resulting from such action. Violent reaction between water and hot DRI can disturb accumulations of dust and create a significant risk of a DRI dust flash fire or dust explosion.

2.2.1.4 Dissipation of water from precipitation (steaming)

DRI will release water vapor in the form of a visible plume after being heavily wetted by precipitation (see Figures 10 and 11). This so-called "steaming" is often misinterpreted by materials handling personnel as overheating of the DRI, but is in reality a normal reaction which does not usually pose a hazard to the personnel, material, or surroundings. DRI that has been heavily wetted by precipation will undergo significant loss of metallisation and value over a time span of days and should be used promptly. A DRI pile that has been wetted by precipitation should never be moved and restocked in a different area, as this is likely to cause some of the wet DRI to be relocated to the center of the new pile. A DRI pile that has been wetted should only be reclaimed for final consumption or disposal. The DRI can warm up to around 60°C (140°F) as the steaming occurs, but should normally cool down again to ambient temperature once the free water is driven off. It is not necessary to take any preventive action if the pile is steaming and the temperature in isolated pockets does not exceed 100°C (212°F). If properly stored on a dry base, DRI will not necessarily overheat as a result of being wetted by precipitation. The risk of significant material loss is much higher when DRI is not protected from precipitation. Material that has been wetted by precipitation should not be placed into silos, day bins, or enclosed spaces where hydrogen can accumulate. Covering the stockpiles with tarpaulins and spraying the stockpiles with liquid latex also helps to minimise re-oxidation and wetting.

Copyright® International Iron Metallics Association

Figure 10: Minor vapour plume as hot material meets atmospheric moisture
Image courtesy of Energiron

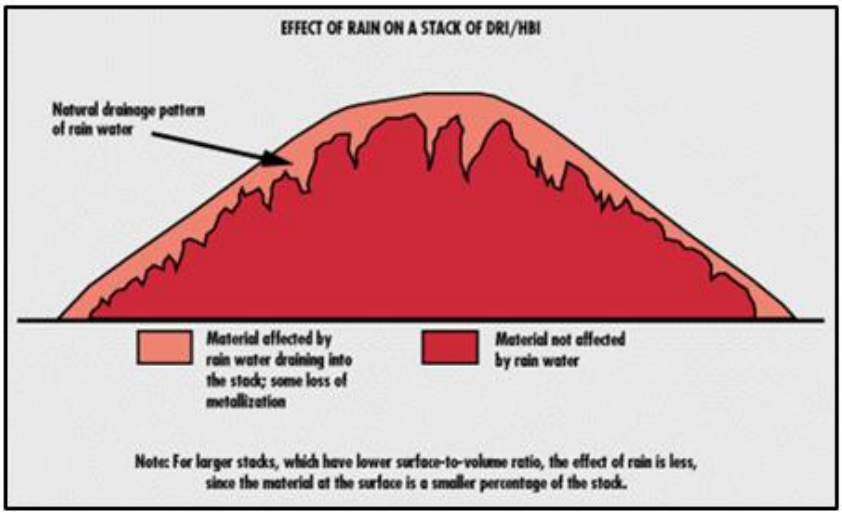


Figure 11: Effect of precipitation on surface of DRI stockpile
Image courtesy of Midrex Technologies

2.2.1.5 Dust suppression

DRI dust is generated more or less constantly during handling of DRI and is composed primarily of metallic iron, which if inhaled or in contact with the eye can cause irritation or eye damage. Therefore, eye protection should always be worn when working in the vicinity of DRI handling operations. A face mask should also be used to avoid inhalation in dusty conditions.

DRI dust is a combustible metal dust. This means that it can be ignited in a pile, or if dispersed in air and ignited it can create a flash fire. If a flash fire occurs inside of a rigid container, like a silo, conveyor enclosure, de-dusting device, or even a building, the rapid pressure rise can result in a deflagration or explosion. This can lead to mechanical failure of the "container," significant damage to property and harm to people. DRI dust must be carefully controlled, managed and disposed of. Excellent resources are available for guidance specifically related to combustible dusts from the National Fire Protection Association (NFPA) and other governmental and non-governmental bodies in Europe and North America.

DRI dust remaining on metal surfaces for an extended time will eventually convert to an extremely adherant and hard layer of rust - in order to minimise damage to such surfaces, washing with high pressure water as soon as practicable is recommended.

Dust collection is necessary for the safe and reliable operation of DRI material handling systems. In some areas, it may also be a regulatory requirement. Fugitive DRI dust represents a flash fire hazard and can lead to equipment fires, damage to bearings, damaged electrical equipment, etc. DRI dust is combustible and a careful dust hazard analysis should be performed to ensure hazards associated with fugitive dust and dust collection equipment are properly addressed. By their design, de-dusting devices typically concentrate dust from multiple areas or pieces of process equipment. As a result, if the hazards are not properly understood and controlled, de-dusting equipment can pose the highest

Copyright® International Iron Metallics Association

risk of fire or explosion in a material handling system. Some recommendations for dust collection systems for DRI handling are as follows:

1. in the design of the dust collection system the ducting should have the minimum number of bends and elevation changes so as to maintain suction velocity and minimise accumulation of dust;
2. the system should have sufficient conveying velocity through all branches of the system to prevent dust deposits within the duct, and to ensure that dust will be re-entrained by the airstream in the event of power loss or equipment failure;
3. when there is not sufficient air flow inside all parts of the dedusting system including the duct and air-material separation device, the mixture of DRI dust and air can reach the MEC (minimum explosible concentration) where combustion or explosion can be sustained. This is equivalent to the LEL for a combustible gas. If there is a risk of reaching the MEC at any point in the system, it may be necessary to have some so-called "explosive doors" in the ducting or de-dusting device in order to release pressure caused by a dust explosion. These pressure relief devices should be engineered and installed in accordance with applicable codes;
4. long material drops, such as down a long chute, can generate a significant amount of induced air. Induced air is produced when DRI pellets move away from each other in free fall, then collapse together when the material stream reaches the landing zone. Multiple dedusting points and increased collection volumes may be required for long chutes;
5. specific recommendations for design of dedusting systems for typical material handling systems can be found in resources such as the ACGIH publication: *Industrial Ventilation – a Manual of Recommended Design;*
6. dry and wet dedusting systems are recommended – the dedusting duct, dry cyclone and wet venturi should be checked and cleaned periodically, depending on system design;
7. dry media type collectors, such as filter bag dedusting systems require special hazard assessment and safety systems, such as explosion and fire protection. Dry media collectors may not be appropriate in all applications. Dust and fines captured by all types of de-dusting systems must be handled carefully. Wet fines have the potential to generate hydrogen gas. Dry fines have the potential to catch on fire or cause a dust explosion;
8. Water sprays to control dust are not recommended.

2.2.2 Silos, bins and hoppers

DRI is also stored in silos, bins or hoppers, for example in steel plant feedstock charging systems or at terminals prior to shipment (see Figure 4 above). As a general observation, the design of silos, bins or hoppers should be determined on the basis of the material flow properties of the bulk solid(s) to be stored. The costs for silo design and testing are small compared to the costs of lost production, quality problems, and retrofits that may be needed because of irregular flow patterns. Some general design guidelines:

1. silos, bins or hoppers should be under cover and protected from precipitation or flooding;
2. silos should be designed for complete discharge in order to avoid product stagnation;
3. dropping heights should be limited to ≤ 2 metres in order to minimise breakage of pellets, by using fall damping devices, e.g. a rock ladder, or in the absence thereof by keeping the silos close to full;
4. silos should be equipped with dedusting equipment, as significant quantities of dust can be generated during both filling and discharge operations;
5. temperature sensors, connected to and monitored by the control room, should be installed at minimum three levels within the silo in order to monitor the temperature of the DRI;

Copyright® International Iron Metallics Association

6. hydrogen probes, connected to and monitored by the control room, should be installed at the highest level inside the silos;
7. oxygen probes, connected to and monitored by the control room, should be installed at the top of the silo interior;
8. personnel working in the vicinity of silos, bins and hoppers containing DRI should wear or carry personal gas monitors in order to check oxygen and carbon monoxide (CO) levels. CO should also be monitored within the silos;
9. any silo, day bin, or closed top hopper will require special considerations for the prevention of a DRI dust explosion. This may include explosion venting, suppression, or continuous inerting of the silo.

The following precautions are recommended when storing DRI products in bins and silos:

1. any DRI exhibiting a temperature in excess of 65°C should not be charged to a storage bin or silo, and should be separated from all other material and spread out on dry ground in a layer of about 0.5 metres depth in order to cool;
2. care should be taken not to mix any incompatible materials such as wet lime, coal, etc. with DRI in storage silos or bins, as this may instigate heating of the DRI to a hazardous level;
3. bins and silos should be purged with an inert gas from the bottom;
4. top slide gates should be closed except when DRI is being delivered;
5. bottom slide gates should be closed except when DRI is being discharged;
6. inert gas, e.g. nitrogen, should be introduced into the top of the bin or silo during extended storage periods to insure a slight positive pressure while the top and bottom slide gates are closed - however there should always be an open vent at the top of the silo in order to avoid excessive pressure build-up inside the silo;
7. the temperature within the silo should be monitored regularly;
8. periodic gas analyses should be performed to ensure the oxygen, hydrogen, and carbon monoxide levels are within an acceptable range. Abnormal increase in hydrogen or carbon monoxide concentration should be investigated and dealt with without delay (Note: the LEL of hydrogen in air is 4% by volume);
9. reoxidation activity within the silo may be first reflected by a temperature increase or an increase in hydrogen and/or carbon monoxide or all three;
    a. if the temperature exceeds 65°C, increasing the flow of nitrogen should normally bring down the temperature - temperature stabilisation could take hours or even days with high nitrogen flow;
    b. if the temperature exceeds 70°C, consideration should be given to emptying 5-10% of the contents in order to improve nitrogen flow through the material; if the temperature continues to climb rapidly or does not fall below 70°C after say two hours, consider removing a further 5-10% of the material;
    c. if the temperature reaches or exceeds 80°C, the silo should be emptied onto the ground or to an emergency pile (Note: when emptying a silo of material exhibiting a temperature >100°C, incoming air (oxygen) could cause further exothermic reoxidation and thus temperature increase);
    d. in the event of an emergency discharge of hot material, personnel should be prepared for hot material, ignition of fines, and dust flash fires;
    e. if an elevated hydrogen concentration is observed, the nitrogen flow should be increased to the maximum available. If the increased nitrogen flow is not sufficient to dilute the hydrogen

Copyright® International Iron Metallics Association

and the hydrogen concentration continues to increase, emergency discharge of the silo should be started immediately, and stopped only when the silo is empty or the hydrogen concentration begins to decrease. The reactions which generate hydrogen from water and DRI do not require oxygen to be present and can continue rapidly even in a fully inerted silo;

f. if a silo is exhibiting high temperature, elevated hydrogen or carbon monoxide levels, no additional material should be loaded to that silo until the problem is resolved.

If the DRI is to be continuously charged to the electric arc furnace, DRI should be screened prior to the EAF feed system, e.g. with a grizzly, in order to remove large pieces of tramp material or occasional clusters of pellets. While clusters of pellets do not pose any problem within the furnace, they may impede steady flow rates from a bin to a belt or launder that charges the furnace.

2.2.3 Inventory control and storage

DRI should ideally be used or dispatched on a "first-in, first-out" basis. As pointed out in the reactivity section of Chapter 1, the content of metallic iron decreases over time as a consequence of re-oxidation in the presence of oxygen and moisture, so that material used on a "first-in, last-out" basis will have variable metallic iron content which in turn will affect steel plant yield as well as furnace operation.

2.2.4 Quality loss in storage

Quality loss while in storge varies greatly, depending on the type of storage. DRI that is stored in an inerted silo will lose very little metallisation over the course of weeks or months. Properly passivated DRI that is stored in a covered, dry, but open air stock house, may lose 0.25% metallisation per month or less. Material that is stored in open stock piles and exposed to preciptation may lose several precent metallisation per month, with significantly higher rates of loss from the outer layers of the pile. A DRI stockpile that is stored on damp ground or is allowed to self-heat for some other reason can lose 80% of its metallisation in a matter of days or a couple weeks. Loss of metallisation has a significant impact on value to the melting operation. Typical EAF steelmaking furnaces are primarily melting, not smelting furnaces and are not equipped to reduce iron oxide back to metallic iron in a cost effective way. The other aspect of quality loss, is material breakage. Chips and fines will re-oxidise more quickly than whole DRI pellets. Depending on the method of charging the DRI to the melting furnace, chips and fines may not be recovered and will be lost to the slag, or melting furnace dedusting sytem. A storage system that minimises handling steps and material breakage can improve the observed quality of the DRI by several percent.

Copyright® International Iron Metallics Association

Chapter 3 - Handling and shipment by ocean-going vessel

3.1 IMSBC Code schedule for DRI (B)

For the purposes of international maritime transportation and the IMSBC Code, DRI is designated as Direct Reduced Iron (B), hereinafter referred to as DRI or DRI (B). The description, characterisation and hazard classification of DRI (B) contained in the IMSBC Code schedule for DRI (B) is as follows:

Description

Direct reduced iron (DRI) (B) is a highly porous, black/grey metallic material formed by the reduction (removal of oxygen) of iron oxide at temperatures below the fusion point of iron. Cold-moulded briquettes are defined as those which have been moulded at a temperature less than 650°C or which have a density of less than 5,000 kg/m^3. Fines and small particles under 6.35 mm in size shall not exceed 5% by weight.

Characteristics

Physical properties			
Size	**Angle of repose**	**Bulk density (kg/m^3)**	**Stowage factor (m^3/t)**
Lumps and pellets: average particle size 6.35mm to 25mm. Cold moulded briquettes: approximate maximum dimensions 35mm to 40mm. Fines and small particles: under 6.35mm uo to 5% by weight.	Not applicable	1,750 to 2,000	0.50 to 0.57
Hazard classification			
Class	**Subsidiary hazard(s)**	**MHB**	**Group**
Not applicable	Not applicable	SH and/or WF	B

Hazard

Temporary increase in temperature of about 30 °C due to self-heating may be expected after material handling in bulk.

There is a risk of overheating, fire and explosion during transport. This cargo reacts with air and with fresh water or seawater to produce heat and hydrogen. Hydrogen is a flammable gas that can form an explosive mixture when mixed with air in concentrations above 4% by volume. The reactivity of this cargo depends upon the origin of the ore, the process and temperature of reduction, and the subsequent ageing procedures. Cargo heating may generate very high temperatures that are sufficient to ignite the cargo. Build-up of fines may also lead to self-heating, auto-ignition and explosion. Oxygen in cargo spaces and enclosed spaces may be depleted.

Copyright® International Iron Metallics Association

In addition, there is a requirement for loading that the moisture content must be ≤0.3% by weight. The complete schedule is reproduced in Annex 1 to this guide.

3.2 Preparations for loading

3.2.1 Vessel type

The following types of vessel have been used for ocean transport of DRI:

- dry bulk carriers: single-deck, Handy-size, Handy-max, Supra-max, or Panamax with hydraulically or mechanically operated type or twin-fold type hatch covers of watertight construction;
- double-deck (tween deck) vessels are not recommended for shipment of DRI.

3.2.2 Steps to be taken prior to loading DRI - Shipper

1. Prior to shipment, the cargo shall be aged for at least three days, or treated with an air-passivation technique or another equivalent method, that reduces the reactivity to the same level as the aged product. Such ageing process shall be approved by the applicable competent authority which shall provide a certificate to that effect.
2. Due consideration shall be given to the possibility of moisture inside the cargo pile so as to avoid wet cargo or a wet portion of the cargo, recognising that the bottom of the pile can be wet even though the surface of the pile appears to be dry.
3. The Carrier's nominated technical persons or other representatives shall have reasonable access to stockpiles and loading installations for inspection.
4. In accordance with section 4.2 of the IMSBC Code, "the Shipper shall provide the Master or his representative with appropriate information on the cargo sufficiently in advance of loading to enable the precautions which may be necessary for proper stowage and safe carriage of the cargo to be put into effect." In particular, the Shipper or his appointed representative shall provide to the Master of the carrying vessel with information about the nature of DRI and the potential hazards associated with shipping it, together with the relevant safety precautions and emergency procedures. Such hazards include (a) the potential for DRI to self-heat and generate hydrogen gas after contact with water, especially saltwater and (b) the risk of entering enclosed spaces adjacent to or in the vicinity of cargo holds without prior testing for safe atmosphere. The Master should be requested to convey such information to crew members. Proof that such instructions were so provided, such as a signed receipt from the Master, should be obtained by the Shipper. Such information may be an amplification of the IMSBC Code, but shall not be contradictory thereto with respect to safety. Such information may include:
   a) copy of this guide;
   b) material safety data sheet;
   c) copy of the IMSBC Code schedule for DRI (B).
5. Following sampling and testing of the DRI to be loaded, and prior to loading the cargo, the Shipper shall provide the Master with a certificate issued by a competent person recognised by the competent authority of the port of loading stating that the cargo, at the time of loading, is suitable for shipment, and that it conforms with the requirements of the IMSBC Code; that the quantity of fines and small particles is no more than 5% by weight; that the moisture content does not exceed 0.3%; and that the temperature does not exceed 65°C (149ºF). This certificate shall state the date of manufacture for each lot of cargo to be loaded in order to meet the loading criteria with regard to ageing and material temperature.

Copyright® International Iron Metallics Association

6. Prior to loading, the terminal shall ensure that the conveyor belts and equipment used for loading DRI contain no accumulation of water or other substances. Each time cargo operations are commenced or restarted, particularly after precipitation or washing down, any loading belt shall be operated empty and not over a ship's cargo space.
7. Prior to loading, provision shall be made to introduce a dry, inert gas at tank top level so that the inert gas purges the air from the cargo and fills the head space above. Nitrogen is preferred for this purpose. All vents, accesses and other openings, such as coaming drains, that could allow the inert atmosphere to be lost from cargo holds carrying DRI shall be closed and sealed.
8. The ship shall be provided with the means to ensure that the requirement of the IMSBC Code to maintain the oxygen concentration below 5% can be achieved throughout the voyage. The ship's fixed CO2 fire-fighting system shall not be used for this purpose. Consideration shall be given to providing the vessel with the means to top up the cargo spaces with additional supplies of inert gas, taking into account the duration of the voyage. In practice it is advisable to inert holds on completion of loading to an oxygen concentration of 2-3% in order to account for leakage of inert gas.
9. The ship shall be provided with the means for reliably measuring the temperatures at several points within the stow, and determining the concentrations of hydrogen and oxygen in the cargo hold atmosphere during the voyage whilst minimising as far as practicable loss of the inert atmosphere.
10. Equipment for quantitative monitoring of hydrogen concentration shall be suitable for use in an oxygen depleted atmosphere and of a type certified safe for use in an explosive atmosphere. The instruments should be of durable field use design which prevents moisture ingress (which might affect readings). Gas monitors using catalytic bead or electrochemical (diffusion type) sensors should be fitted for reliable hydrogen detection. Sensors based on infrared technology do not warn against hydrogen explosion dangers and should therefore not be used. A minimum of two (three preferred) gas monitors equipped with the approved type of gas sensors should be on board the ship prior to loading DRI. The ship’s hatch covers should be fitted with appropriate sampling points (minimum one, preferably two) for the measurement of gases in each cargo hold to contain DRI.
11. All monitoring equipment should be operational and properly calibrated at the commencement of loading, in accordance with manufacturer’s instructions, calibration to be valid for the duration of the voyage. The vessel’s crew should be properly trained in the use of this equipment.
12. Any pre-loading inspections or procedures required by or on behalf of applicable competent authorities shall have been carried out.

Copyright® International Iron Metallics Association

3.2.3 Steps to be taken prior to loading DRI - vessel

Figure 12: Protecting vessel equipment from DRI dust

Images courtesy of Köppern

1. Due consideration shall be given to protecting equipment, machinery and accommodation spaces from the dust of the cargo. Radars and exposed radiocommunication equipment of ships which carry DRI shall be protected from DRI dust (see Figure 12 above). Persons who may be exposed to DRI dust shall wear protective clothing, goggles or other equivalent dust eye-protection and dust filter masks, as necessary.
2. Prior to loading, an ultrasonic test or another equivalent method with a suitable instrument shall be conducted to ensure integrity and weathertightness of hatch covers and closing arrangements, and all readings shall confirm weathertightness. Such integrity and weathertightness shall be maintained throughout the voyage.
3. Hold inspection shall be carried out on each hold to carry DRI. Holds to carry DRI shall be clean, dry and free from salt and residues of previous cargoes. Prior to loading, wooden fixtures such as battens, loose dunnage, debris and combustible materials shall be removed.
4. Wash down deck surfaces, etc. to remove any salt present.
5. Ensure that bilge wells of the holds shall be clean, dry and protected from ingress of the cargo, using non-combustible material. The bilge system of a hold to which DRI is to be loaded shall be tested to ensure that it is working properly and such tests documented.
6. The Master shall be in possession of all applicable permits, etc. from competent authorities.

3.3 Weather and other general precautions

1. DRI shall be kept dry at all times during storage, before and during loading and during transportation. The cargo shall not be loaded onto ships, or transferred between ships or barges during precipitation. During loading of this cargo, all non-working hatches of cargo holds into which DRI is loaded, or to be loaded, shall be kept closed.

Copyright® International Iron Metallics Association

2. During any handling of DRI, "NO SMOKING" signs shall be posted on decks and in areas adjacent to cargo spaces, and no naked lights shall be permitted in these areas. Smoking, burning, cutting, chipping, grinding or other sources of ignition shall not be allowed in the vicinity of cargo spaces containing this cargo at any time.
3. Cargo holds containing DRI and adjacent spaces may become oxygen-depleted. Flammable gas may also build up in these spaces. All precautions shall be taken when entering the cargo spaces.[2] It is recommended that personnal working in and around such spaces wear or carry a personal gas monitor.
4. Persons who may be exposed to DRI dust shall wear protective clothing, goggles or other equivalent eye-protection and dust filter masks, as necessary.

3.4 Vessel loading procedures

3.4.1 BLU Code

Loading of bulk cargoes, including DRI, is governed by the BLU Code i.e. the Code of Practice for the Safe Loading and Unloading of Bulk Cargoes, issued by the International Maritime Organisation[3]. Section 2 of the BLU Code addresses the suitability of ships and terminals: section 2.2 deals with ships and section 2.3 deals with terminals.

3.4.2 Loading and pre-voyage procedures and precautions

1. "Hot work" permits should be required on both the jetty and the ship when DRI is being loaded. Masters are advised to ensure a hot work permit is in place for any relevant maintenance or other work on deck while the ship is being loaded, unloaded, or underway.
2. DRI shall not be loaded if its temperature is in excess of 65°C (149°F), if its moisture content is in excess of 0.3% or if the quantity of fines and small particles (up to 6.35 mm in size) exceeds 5% by weight. Any DRI that has been wetted, or is known to have been wetted, shall not be loaded into any hold. Any DRI that has already been loaded into a cargo space and which subsequently becomes wetted, or in which oxidation/corrosion reactions have started, shall be discharged without delay.
3. In the event that pockets of material with temperature in excess of 65°C (149°F) (hot spots) are found in a hold following loading and before sailing, if such material does not cool down naturally within a reasonable period of time, it should be dug out and turned over in the hold to facilitate cooling or if necessary discharged and cooled before reloading. What constitutes "a reasonable time" depends upon the circumstances on the spot: Is the temperature stable or continuing to rise? What equipment and resources are available on the vessel/at the port? If in doubt, seek expert advice.
4. DRI shall not be loaded during precipitation. During loading of DRI all non-working hatches of the cargo holds into which this cargo has been loaded or are to be loaded shall be kept closed. Only when weather permits may non-working hatch covers be left open for a minimum of one hour after completion of each pour to allow cooling after cargo handling in bulk.

[2] Refer to Revised recommendations for entering enclosed spaces aboard ships (resolution A.1050(27))
[3] Latest (2010) edition published in 2011 by the International Maritime Organisation

Copyright® International Iron Metallics Association

5. The cargo shall be loaded in such a way so as to minimise breakage of the DRI, additional generation of fines and small particles and concentration of fines in any area of the cargo. The crucial factor in managing DRI size degradation during handling is the drop height which should be kept to a minimum. Once the initial DRI has begun to create a pile in the hold, the impact of subsequent material is cushioned (and drop heights diminish) as the pile builds in the hold. Consideration should be given to use of "soft loading" devices, for example as illustrated in Figure 13.

Figure 13: Photos of "soft-loading" devices

Left: skip used for loading scrap, pig iron, DRI, HBI, here with ship's gear (load capacity 25 tonnes)
Centre: adjustable, rotatable slide chutes minimise drop height to 10m during vessel loading
Right: telescopic spout used for loading DRI
Images courtesy of Oldendorff Carriers, IIMA and Nu-Iron

6. DRI loaded shall be homogeneous with no added waste. The deliberate addition of fines and particles less than 6.35 mm or dust to DRI cargoes shall be prohibited.
7. Due consideration shall be given to spreading the cargo evenly across the tank top so as to minimise concentrations of fine material.
8. The cargo temperature shall be monitored during loading and recorded in a log detailing the temperature and moisture content for each lot of cargo loaded, a copy of which shall be provided to the Master and the Shipper. Infrared thermal guns are typically used to measure the temperatures via the hatch coaming.
9. Stowage and segregation:
   - "separated from" goods of classes 1 (division 1.4S), 2, 3, 4 and 5, and class 8 acids in packaged form (See IMDG Code);
   - "separated from" solid bulk materials of classes 4 and 5;
   - goods of class 1, other than division 1.4S, shall not be carried in the same ship;
   - boundaries of compartments where DRI is carried shall be resistant to fire and passage of liquid.
10. Trim in accordance with the relevant provisions required under sections 4 and 5 of the IMSBC Code (see Figure 14).

Copyright® International Iron Metallics Association

Figure 14: DRI in vessel hold after trimming
Image courtesy of Nu-Iron

11. Loading of DRI against sources of heat should be avoided unless such heat sources can be isolated (for example in the case of bunker fuel tanks if the heating coils can be isolated when tanks are empty).
12. On completion of loading of a hold containing DRI, it shall be immediately closed and sealed. Sufficient inert gas shall then be introduced to achieve an oxygen concentration less than 5% throughout the hold, as required by the IMSBC Code. Given the scope for leakage of inert gas during the voyage, as mentioned in section 3.2.2 point 8, it is recommended to go further and introduce sufficient inert gas to reduce oxygen concentration to 3% or even 2% throughout the hold in order to maintain as good a reserve of inert gas as practicable on board.
13. On completion of loading and at all times when closing hatch covers, hatch coamings and gaskets should be thoroughly cleaned and inspected to ensure that coamings are free of cargo debris and that an adequate hatch to coaming seal is made.
14. After loading, a certificate, confirming that throughout the whole consignment the fines and small particles (under 6.35 mm in size) are less than 5% by weight, that the moisture content does not exceed 0.3% and that the temperature does not exceed 65°C (149°F) shall be issued by a competent person recognised by the National Administration of the port of loading.
15. The ship shall not sail until the Master and a competent person recognised by the competent authority of the port of loading are satisfied:
    - that all loaded cargo spaces are correctly sealed and inerted;
    - that the temperature of the cargo has stabilised at all measuring points and that the temperature does not exceed 65°C; and
    - that, at the end of the inerting process, the concentration of hydrogen in the free space of the holds has stabilised and does not exceed 0.2% by volume.

Copyright® International Iron Metallics Association

3.4.3 Effects of loading on ship with DRI

The IMSBC Code has standard language for loading of heavy cargoes, such as DRI:
"The tank top may be overstressed unless the cargo is evenly spread across the tank top to equalise the weight distribution. Due consideration shall be paid to ensure that the tank top is not overstressed during voyage and during loading by a pile of the cargo."

3.4.4 Dust

Dust evolved during handling/unloading of DRI can accumulate over the ship's surface. In a marine environment, the dust rapidly rusts to form iron hydroxide, which has a reddish-brown colour. Laboratory testing has shown that such dust does not damage the integrity of the ship's paint system.

Remove the dust periodically during and immediately on completion of loading by sweeping/ vacuuming. On completion of loading emphasis should be on 'dry-cleaning' of cargo holds, by brush or air, to remove as much dust as possible, and to remove dust accumulation on flat surfaces and pipes. Then thoroughly wash down other affected surfaces of the ship. Specialised barrier coats may help minimise the extent of dust-related cleaning, especially on horizontal surfaces. Dry-cleaning by crew during loading and discharge helps reduce dust. Use of air to knock down dust from pipes and hatch channels helps final cleaning.

Sensitive equipment, such as radars should be protected against dust. Wrapping sensitive hatch fittings, such as exposed hydraulic cylinders, with plastic-stretch food wrap and/or aluminium foil provides a fast and economic means to secure equipment and is easily and quickly removed as needed.

Top-coat type paint coatings on main deck and accommodation (cosmetic - urethane based paints) may fail when using muriatic acid (hydrochloric acid) during cleaning. Not all ships have a top-coat. Friendlier acids may reduce coatings damage albeit at a cost increase. Preference should be given to 500 bar high pressure wash when in doubt. Most epoxy type coatings used in cargo holds are rated to 60°C (140°F) and resist chemical damage from common acids used for cleaning DRI dust.

Sometimes misconceptions by owners and industry attribute the rust-coloured residues (that remain hardened if not fully cleaned) as being due to corrosion of the hull. In fact, this is generally only the oxidation of the DRI residues and has no ill-effect upon the ship's steel structure.

DRI dust is a combustible dust and special considerations should be taken to reduce the risk of dust fires, flash fires or explosions.

3.5 During the voyage

1. Although not required by the IMSBC Code, it is strongly recommended that a suitably qualified[4] Cargo Technician shall board the vessel at the loading port and remain on board the vessel for the duration of voyage. The Cargo Technician should be appointed by the Shipper and have the following duties on board the vessel:
   a) to monitor the loading operations;

[4] This means qualified/trained in: basic maritime safety; understanding of direct reduced iron and its behaviour; ocean transport and storage of direct reduced iron; use of portable instruments for temperature and gas monitoring.

Copyright® International Iron Metallics Association

b) to advise on and supervise the installation of thermocouples in the cargo holds for temperature monitoring, to monitor the performance of the thermocouples and to keep the Master informed accordingly;
c) to monitor and report on the cargo/hold parameters, namely temperature and hydrogen and oxygen concentrations, as well as other data or information relating directly to cargo behaviour, such duty to include taking readings in conjunction with designated crew members and ensuring that readings are communicated on a regular and frequent basis to the Master (who shall forward them to the Shipper and/or applicable competent authority which should respond with appropriate advice in case of need);
d) to advise and coordinate with the Master and crew as appropriate in connection with the operation of the inert gas systems; and
e) to provide advice and assistance to and cooperate with the Master and crew in case of an emergency pertaining to the cargo.

2. The cargo shall be kept dry during the voyage. The hydrogen concentration can rise rapidly once the cargo becomes wetted – a rise to the LEL of 4% by volume within 24 hours of first detection has been observed.
3. Bilge wells shall be checked regularly for the presence of water. If water is found, it shall be removed by pumping or draining the bilge wells.
4. Hatches should remain closed while at sea in order to prevent the entry of water into the holds. Under no circumstances should saltwater be allowed to enter the holds.
5. Consideration should be given to use of hatch-tape for centre hatch joints as a precautionary measure. Use of hatch tape should be confirmed to the ship's Master by the Shipper or vessel operator as the case may be. Note: some types of hatch-tape are more suitable than others.
6. The cargo holds carrying DRI shall remain tightly sealed and the inert atmosphere maintained during the voyage.
7. The concentrations of hydrogen and oxygen in the cargo spaces carrying this cargo shall be measured at regular intervals during voyage and the results of the measurements recorded and kept on board for a minimum of two years.
8. The oxygen concentration in the cargo spaces carrying this cargo shall be maintained below 5% by volume throughout the duration of the voyage.
9. If the monitored hydrogen concentration exceeds 1% by volume (>25% LEL), immediately seek and follow expert advice and take action in accordance with the emergency procedures given in Chapter 5, section 5.4 of this guide.
10. Cargo temperature readings shall be taken at regular intervals during the voyage and the results of the measurements recorded and kept on board for a minimum of two years.
11. A cargo temperature of 65°C (149°F) in a cargo hold is an indicator of a potential approaching emergency contingency and is therefore a trigger for increased monitoring (every two to three hours and not less than every four hours, provided always and to the extent that prevailing conditions permit) and vigilance, as well as preparation for dealing with an emergency, should it eventuate. If in doubt, expert advice shall be sought. **NOTE:** A temporary increase of up to about 30°C (86°F) in the cargo temperature due to self-heating may be expected after material handling in bulk, e.g. immediately after loading. A gradual temperature decline towards ambient should follow. In warm latitudes, the ambient temperature in the cargo holds above the stow may rise during the day due to solar warming, accompanied by condensation. This should not significantly affect the temperature within the cargo.
12. Other precautionary measures that should be taken:

Copyright® International Iron Metallics Association

a) if possible, check for bulkhead heating in adjacent cargo holds; if significant bulkhead heating is detected from within an empty cargo space, spray with water from the empty cargo space side, provided the bulkheads are mechanically sound;
b) check for signs of abnormal heat in affected sounding pipes and air pipes.

13. If the temperature continues to increase, establish with the Shipper or the assigned expert the best course of action, taking into account the prevailing circumstances and history of the cargo in question, for example the rate of temperature increase, the remaining sailing time to the scheduled discharge port, etc. If the temperature in a hold shows signs of approaching, reaches or exceeds 100°C (212°F), appropriate safety measures shall be taken in accordance with the emergency procedures given in Chapter 5, section 5.2. of this guide.
14. Consideration shall be given to increasing the frequency of cargo monitoring following periods of bad weather. All measurements shall be taken such as to minimise the loss of inert gas from the cargo holds.
15. Personnel should not be permitted to enter cargo holds containing DRI under any circumstances during the voyage. Appropriate signs should be displayed at all access points, and where possible, access points to cargo holds should be locked.
16. No person shall enter an enclosed space adjacent to a cargo hold containing DRI unless such adjacent space has been found to be gas-free and have sufficient oxygen to support life.
17. Notwithstanding the provisions of point 16, **emergency entry** to an enclosed space adjacent to a cargo hold containing DRI may be permitted provided that:
    a) the entry into the space is undertaken only by trained personnel wearing self-contained breathing apparatus;
    b) the entry to the space is under the supervision of a responsible officer;
    c) no source of ignition is introduced into the space;
    d) the crew should be familiar with confined space rescue safety.

3.6 Water intrusion into holds

The effects of water, especially seawater ingress into a cargo hold containing DRI can be the following

- generation of hydrogen (hydrogen concentration can rise rapidly once the cargo becomes wetted – a rise to the LEL of 4% by volume within 24 hours of first detection has been observed);
- increase in temperature;
- steaming.

In the event of water ingress into a cargo hold containing DRI, the following guidelines and procedures should be followed:

- first eliminate the source of water ingress to the extent possible;
- maintain temperature and gas monitoring in affected cargo holds and increase the frequency of measurements to hourly;
- in case of temperature >65°C (149°F), implement the safety measures given in section 3.5 above, points 11, 12 and 13 and, if necessary or in doubt, seek and follow expert advice;
- in the case that the hydrogen concentration exceeds 1% by volume (25% LEL), seek expert advice and take action in accordance with the emergency procedures given in Chapter 5, section 5.4 of this guide.

Copyright® International Iron Metallics Association

3.7 Vessel unloading procedures

3.7.1 Actions prior to unloading

The following actions should be taken prior to unloading a vessel carrying DRI - if necessary seek expert advice:

1. check the hydrogen concentration before opening hatches of cargo holds containing DRI and if the hydrogen concentration in a cargo hold is 1% or more by volume (25% LEL), take all appropriate safety precautions before opening hatch covers (for example no smoking, burning, welding, cutting, chipping and/or other source of ignition to be allowed in the proximity of a cargo hold loaded with DRI, including mast houses and areas common to the cargo holds), continue ventilation and monitoring of the hydrogen concentration and do not open the hatches until the hydrogen concentration is less than 1% by volume;
2. check the carbon monoxide (CO) concentration before opening hatches of cargo holds containing DRI as elevated CO concentrations represent a hazard to the crew or shore personnel on board the ship. In case CO is detected, ensure that all personnel take refuge away from or up-wind of the affected hold;
3. measure the cargo temperature in holds containing DRI and if the temperature readings are stable and ≤65°C (149°F), it is safe to unload in the normal manner - if the temperature exceeds 65°C (149°F), refer to the emergency procedures given in Chapter 5 (section 5.3);
4. before any personnel enter a cargo hold containing DRI, measure the oxygen concentration (which should be at least 21% by volume), the hydrogen concentration (which should be below 1% by volume) and the carbon monoxide concentration (which should be below 50 ppm) before entry; otherwise entry shall be permitted only by trained personnel wearing self-contained breathing apparatus and under the supervision of a responsible officer and provided that no source of ignition is introduced into the space;
5. where possible, provide electrical grounding/earthing in the cargo holds in order to reduce sparking potential from any electrical sources;
6. protect radar, RDF scanners and other sensitive equipment from dust and fines;
7. when it is safe to do so, open the hatches and inspect the condition of the cargo. Such inspection should include the following:
   a) the presence of wetted DRI on top of the cargo, indicating that water has seeped in via the hatch covers;
   b) entry of water through the double bottom of the hull, indicated by wetted DRI at the edges of the bottom of the pile;
   c) the presence of hot spots - defined as areas where the temperature exceeds 100°C (212°F).

Because of the relatively high bulk density of DRI (1,750-2,000 kg/m^3), care must be taken not to overload materials handling equipment. To optimise handling, drop heights should be minimised to reduce size degradation and the evolution of dust.

3.7.2 Vessel unloading

Ships carrying DRI are normally discharged:

- at shore-based terminals with unloading by shore-based or on-board cranes directly to stockyard or silos via the terminal conveyor system or to barges or smaller vessels (see Figure 15 below);

Copyright® International Iron Metallics Association

- in midstream to barge or smaller ship with unloading by on-board or floating cranes, e.g. as practised in the US Gulf area (see Figure 16 below).

DRI can be handled using conventional bulk materials handling techniques, so most equipment used for discharge of bulk materials can be used for DRI, including on-board handling systems designed for iron ore, scrap, or pig iron. For example:

- magnets (DRI is magnetic);
- overhead bridge crane with grab buckets, clamshells or magnets, or independent mobile or fixed-position cranes with grabs;
- small front-end loader in hold discharging into buckets or skips (normally used for small piles and final clean-up of the ship's cargo holds);
- systems to transfer DRI onto belts, trucks, railcars or barges.

Some midstreaming operations may use a floating terminal, just offshore, equipped with conveyor systems, in which case barges are moved beneath hoppers which directly load to barge holds.

DRI should not be discharged during precipitation. During precipitation, all discharging and cargo handling operations shall be suspended, hatches of holds containing DRI closed and monitoring for hydrogen in such holds resumed.

Ships crew should avoid 'pressing-up' ballast tanks during discharge and hold off on ballasting operations as far as practical.

Figure 15: Simultaneous transfer to barges and port storage using vessel floating cranes
Image courtesy of Marine Inspection, LLC

Figure 16: Midstreaming: discharging cargo to barges using floating cranes on both sides of the vessel
Image courtesy of CBG

3.7.3 Dust suppression during unloading

Generation of dust and fines during handling of DRI was described in section 3.4.4 above. Measures to protect equipment and deal with dust during unloading and transfer to the stockyard of a shipment of DRI are essentially the same as those applicable during loading:

- minimise the number and height of drops between vessel and stockyard;
- use of a water spray to supress dust is not recommended;
- eye protection should always be worn when working in the vicinity of DRI handling operations and a face mask should also be used to avoid inhalation in dusty conditions;

Copyright® International Iron Metallics Association

- to deal with dust accumulations on the ship, remove the dust periodically during and immediately on completion of unloading by sweeping/vacuuming and on completion of unloading thoroughly wash down the affected surfaces of the ship with fresh water. If practicable, use of seawater should be avoided;
- protect sensitive fittings and equipment, such as exposed hydraulic cylinders, radars, etc. (see examples in Figure 12 in section 3.2.3.).

Chapter 4 - Transportation of DRI by barge, rail and truck

4.1 Barge transportation

4.1.1 Barge condition

Covered barges are recommended for transport of DRI, but open barges are also acceptable provided that the appropriate precautionary measures are taken (see Figure 17).

Figure 17: Open and covered barge operations
Images sources: left Creative Commons-Tim Kiser; right Nu-Iron

Barges must comply with the following conditions:

- clean and dry, with no accumulations of water, e.g. in bottom indentations;
- free of chlorides and previous cargoes;
- free of combustible materials;
- bilge pumps must be operable (where applicable);
- access to portable stripping pumps for removal of standing water;
- covered barges should be fitted with inspection ports adequate to provide natural ventilation if needed.

Prior to loading, the barges should be inspected to ensure that the cargo hold is dry and free of rags, wood or other contaminants and free from salt or residues from previous cargoes, particularly those that might increase oxidation, such as cement, lye, and borax, which in turn could cause self-heating. In the case of covered barges, the covers should be inspected for water-tightness prior to loading.

4.1.2 Barge loading

The precautions and procedures for loading barges are essentially the same as for loading ocean-going vessels (see Chapter 3 above). Barge loading operations should be supervised by personnel familiar with the safety precautions and emergency procedures associated with handling DRI. The

Copyright® International Iron Metallics Association

loading operators should be trained in the appropriate safety precautions and emergency procedures for handling DRI:

1. DRI should not be loaded if its temperature exceeds 65°C (149°F);
2. DRI should not be loaded during precipitation; covered barges should be closed during precipitation; use of open barges is not recommended if precipitation is expected during the expected period for loading and during the voyage to the destination;
3. barges should be visually checked for water prior to loading, especially aft where water may accumulate from wash water and/or precipitation;
4. drop height should be minimised, to reduce breakage and the generation of fines;
5. loading operations should be carried out in a manner such as to reduce stress on the barge - typically, loading should start at one end and continue along the length of the barge hopper;
6. DRI should be loaded leaving room at the bow and stern for access to drain and pump standing water as deemed necessary;
7. DRI should be evenly distributed in the barge, making the stow in small heaps (see Figure 18);
8. barges should be loaded in a manner so as to have a slight "trim by the stern" to enable easier water extraction;
9. covered barges should be closed as soon as possible after completion of loading.

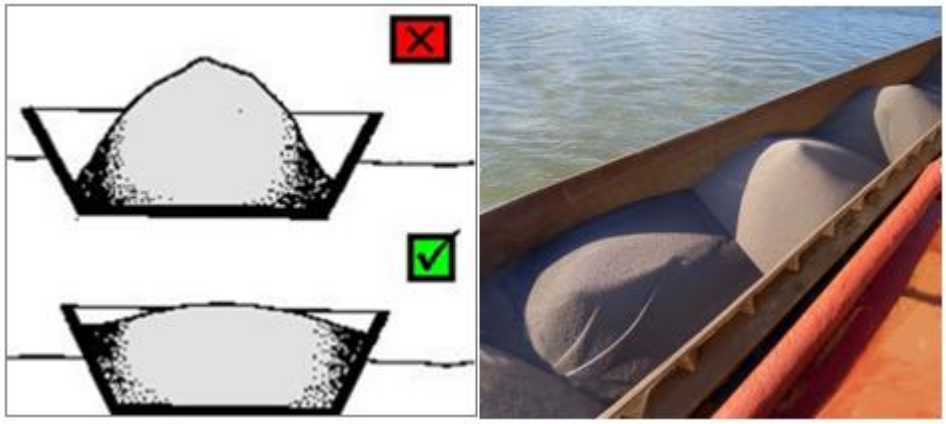


Figure 10: Correct loading of DRI to barges
Diagram courtesy of BHP, image courtesy of Nu-Iron

4.1.3 Barge shipment

During shipment, the following precautions should be taken:

1. if the transport is by sea, watertight hatch covers must be used to prevent ingress of seawater into the barge;
2. water from precipitation should not be allowed to accumulate in the bottom as this may lead to oxidation of the DRI and associated hazards;
3. covered barges should remain closed until unloading;
4. if at any time the cargo compartment of a loaded covered barge must be entered, the compartment must be checked for adequate oxygen concentration (minimum 21%) - before any personnel enter a cargo compartment containing DRI, the cover must be opened for a sufficient length of time to dissipate any accumulated gases;
5. when DRI is transported by barge, a copy of any applicable permits should be on board the tug or towing vessel - when the barge is moored, the shipping documents and a copy of such permit should remain on the barge in a suitably protected location.

Copyright® International Iron Metallics Association

4.2 Transportation by truck and rail

Truck and railcar beds should be clean to prevent contamination, the containers should not have any large gapped openings that would allow spillage, and truck tailgates should be properly sealed. DRI should be loaded uniformly along the length of the railcar or truck.

In some situations, trucks and/or railcars may be loaded directly from a ship or barge using a variety of equipment combinations, but because time for discharging is intended to be as short as possible (to avoid demurrage charges), it is common practice to send the product to a temporary storage, and later reclaim product from the storage pile. Reclaiming is performed by whatever equipment is in place to effect the loading, e.g. conveyor belt system that discharges to large capacity hoppers, which then allow for controlled loading to rail or truck (see Figure 19 for discharge of barges).

Figure 11: Left railcar loading Right discharge from barges

Images courtesy of IIMA (left) Nu-Iron (right)

To avoid loss during transport, trucks should not be overloaded (see Figure 20 below). The bulk density of DRI is relatively high (1,750-2,000 kg/m^3) and has to be taken into account during loading. It is strongly recommended that tarpaulins be used to suppress dust emission and to limit moisture pick-up en-route to the customer's yard, especially in an area where precipitation can occur or is predicted. Adhere to local regulations regarding use of tarpaulins.

Copyright® International Iron Metallics Association

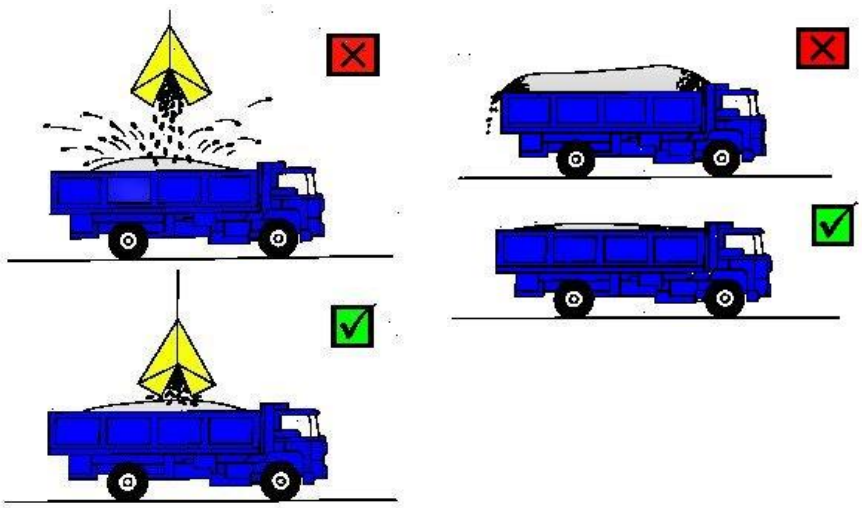


Figure 20: Keep drop heights low and avoid overloading railcars and trucks
Diagrams courtesy of BHP

Chapter 5 - Emergency procedures

This section provides information about emergency procedures commonly used in shipping, handling and storage of DRI. There are two principal potentially dangerous situations (contingencies) with DRI cargoes and piles which can arise:

- self-heating to elevated temperatures in excess of 100°C (212°F) and as high as the ignition temperature (above 312°C to >750°C (594°F to >1,382°F);
- sustained hydrogen concentration in excess of 1% by volume (25% LEL) in confined spaces, e.g. cargo holds, covered storage sheds and adjacent spaces.

5.1 Action plan for DRI at elevated temperatures during truck and railcar unloading

Unloading of DRI from trucks and railcars is not recommended during precipitation.

At the general level:

1. the Operations Supervisor and the Material Handling Operators are responsible for properly executing the action plan if a train or truck arrives at the point of reception carrying DRI at the temperature levels shown in sections 5.1.1 and 5.1.2 below - unloading operations must be supervised by personnel familiar with the safety precautions and emergency procedures for handling DRI;
2. in all cases, before unloading railcars or trucks, measure the DRI temperature in each railcar or truck, and record the measurements in the temperature log book - this should be done every two hours while the contingency is in effect;
3. the zone of the storage area designated for hot DRI should be clean and free of debris and flammable material, such as coal, coke and wood;
4. while transferring hot DRI by conveyor, inspect the belt transfer system regularly for any sign of overheating - in case of overheating, stop the DRI transfer, but keep the transfer belts in motion until they cool and take special care to avoid ingress of water into hoppers and other equipment;

Copyright® International Iron Metallics Association

5. in the designated zone of the storage area, hot DRI should be spread out on the ground for cooling (separately from the main stockpile) in a layer of about 0.5 m depth (maximum 1.0 m), using a track-equipped bulldozer - mix cooler DRI with hotter material to lower the average temperature (do not use water);
6. in essence, the hottest material should be unloaded first.

5.1.1 Material at temperature above 150°C (302°F)

Position the railcars/trucks containing DRI with temperatures above 150°C (302°F) in a designated location in the reception area and spray with pressurised water (in this case, there is no option other than to cool down the DRI before discharge and transfer to a designated zone in the storage area for cooling, as conveyor belts will burn at temperatures above 150°C (302°F).

5.1.2 Material at temperature up to 150°C (302°F)

1. First unload any railcars/trucks with DRI at temperature above 100°C (212°F) in a designated location and immediately transfer to a designated zone in the storage area for cooling.
2. Then unload DRI with temperatures between 65°C and 100°C (149°F and 212°F) in the designated location and immediately transfer to the designated zone in the storage area for cooling.

5.2 Action plan for DRI at elevated temperatures during the ocean voyage

During the voyage, if the temperature of any cargo hold shows signs of approaching or exceeding 100°C (212°F), taking into account the prevailing circumstances and history of the cargo in question, for example the rate of temperature increase, the remaining sailing time to the scheduled discharge port, etc., the first step is to seek expert advice from the Shipper, Owner, Charter, P&I Club or other appointed surveyor or expert. Depending on the advice of the appointed surveyor or expert, the following solutions may be considered:

1. deviation to a port of refuge to discharge the affected cargo if the cargo temperature exceeds 120°C (248°F) in which case preparations should be made for grab discharge;
2. **as a last resort and if safe,** flooding the affected cargo holds with water, always taking into account the stability and strength of the ship.

The temperatures mentioned in this section 5.2 are indicative and the advice of the appointed surveyor or expert should be followed.

5.3 Action plan for DRI at elevated temperatures during unloading of ships/barges

At the general level:

1. the Master of the ship must notify the competent port authorities if elevated temperatures are exhibited in holds containing DRI;
2. the Operations Supervisor and the Material Handling Operators are responsible for properly executing the action plan if a ship or barge arrives at the discharge port carrying DRI at the temperature levels in sections 5.3.1 and 5.3.2 below - discharging operations must be supervised by personnel familiar with the safety precautions and emergency procedures for handling DRI;
3. the zone of the storage area designated for hot DRI should be clean and free of debris and flammable material, such as coal, coke and wood;

Copyright® International Iron Metallics Association

4. in all cases, before unloading the ship or barge, measure the DRI temperature in each hold and record the measurements in the temperature log book - this should be done every two hours while the contingency is in effect;
5. while transferring hot DRI by conveyor, inspect the belt transfer system regularly for any sign of overheating, in case of which, stop the DRI loading and transfer, but keep the transfer belts in motion until they cool and take special care to avoid ingress of water into hoppers and other equipment;
6. hot DRI should be spread out on the ground in the designated zone of the storage area for cooling in a layer of about 0.5 m depth (maximum 1 metre), using a track-equipped bulldozer - mix cooler DRI with hotter material to lower the average temperature (do not use water);
7. elevated temperature in this context means in excess of 65°C (149°F) - in essence, the hottest material should be unloaded first (hot DRI may be localised within the hold of a ship or barge (so-called hot spots) and should be unloaded first).

5.3.1 Temperatures above 150°C (302°F)

Starting with any hot spots, discharge DRI with temperatures above 150°C (302°F), position it in a designated location and spray with pressurised water (in this case, there is no option other than to cool down the material before transfer to the designated zone of the storage area, as conveyor belts will burn at temperatures above 150°C (302°F)). When the temperature has fallen to 150°C (302°F) or below proceed immediately with transfer to the designated zone in the storage areas for cooling.

5.3.2 Temperatures at or below 150°C (302°F)

1. Starting with any hot spots, first unload the holds containing DRI with temperature between 100°C and 150°C (212°F and 302°F) in the designated area, immediately transfer the hot material to the designated zone in the storage area for cooling.
2. Then, starting with any hot spots, unload the holds containing DRI with temperature between 65°C and 100°C (149°F and 212°F) in the designated area and immediately transfer the hot material to the designated zone in the storage area for cooling.

Caution: Do not spray water on hot DRI that is steaming (i.e. emitting water vapour).

5.4 Hydrogen gas contingency

If the hydrogen concentration remains persistently above 1% by volume (25% LEL) inform the Shipper and other interested parties such as Owners, Charters and P&I Clubs immediately and seek and follow expert advice.

Measures to be followed (only on and in accordance with the advice of the appointed expert or surveyor) may include consideration of judicious use of natural ventilation to lower hazardous levels of hydrogen: hydrogen vents relatively quickly from the cargo holds depending upon the 'drafting effect' (the effect of the wind velocity and direction relative to the ship's speed and heading). Hydrogen, being lighter than air, initially vents relatively faster than the restoration of oxygen levels back into the cargo hold. By opening leeward vents only for short periods of time (15-20minutes), hydrogen may be vented from the head space, while keeping oxygen levels depleted and the nitrogen blanket intact. However, indiscriminate periods of natural ventilation should be avoided so as to safeguard against excess oxygen levels and disturbance or depletion of the nitrogen blanket. During ventilation, the hydrogen concentration should be closely monitored.

Copyright® International Iron Metallics Association

Other than in the case of a last resort, lifting of the hatch covers for the purpose of additional ventilation should be undertaken only following receipt of expert advice.

In any case:

- ensure there are no possible sources of ignition near the cargo holds, adjacent spaces or open decks and take great care to prevent any spark generation;
- at sea, do not open the affected hold(s) without explicit instructions to do so from the appointed expert or surveyor;
- increase monitoring of the hydrogen concentration in the affected holds to at least hourly or as frequently as is practicable (with careful documentation of both the hydrogen concentration and the time of measurement) until it drops to 1% by volume (25% LEL) or below, then proceed as normal.

Copyright® International Iron Metallics Association

Annex 1: Direct Reduced Iron (B) Schedule of the IMSBC Code[5]

Direct Reduced Iron (B)

Lumps, pellets, cold-moulded briquettes

Description

Direct reduced iron (DRI) (B) is a highly porous, black/grey metallic material formed by the reduction (removal of oxygen) of iron oxide at temperatures below the fusion point of iron. Cold-moulded briquettes are defined as those which have been moulded at a temperature less than 650oC or which have a density of less than 5,000 kg/m3. Fines and small particles under 6.35 mm in size shall not exceed 5% by weight.

Characteristics

Physical properties			
Size	**Angle of repose**	**Bulk density (kg/m^3)**	**Stowage factor (m^3/t)**
Lumps and pellets: average particle size 6.35mm to 25mm. Cold moulded briquettes: approximate maximum dimensions 35mm to 40mm. Fines and small particles: under 6.35mm uo to 5% by weight.	Not applicable	1,750 to 2,000	0.50 to 0.57
Hazard classification			
Class	**Subsidiary hazard(s)**	**MHB**	**Group**
Not applicable	Not applicable	SH and/or WF	B

Hazard

Temporary increase in temperature of about 30°C due to self-heating may be expected after material handling in bulk.

There is a risk of overheating, fire and explosion during transport. This cargo reacts with air and with fresh water or seawater to produce heat and hydrogen. Hydrogen is a flammable gas that can form an explosive mixture when mixed with air in concentrations above 4% by volume. The reactivity of this cargo depends upon the origin of the ore, the process and temperature of reduction, and the subsequent ageing procedures. Cargo heating may generate very high temperatures that are sufficient

[5] While this publication contains excerpts from the IMO document, MSC 101/24/Add.3 Annex 7, it has not been approved by IMO and these excerpts may therefore differ from the authentic texts. In cases of doubt the authentic text should be consulted and will prevail in the event of conflict. International Maritime Organization, 4 Albert Embankment, London, SE1 7SR, United Kingdom

Copyright® International Maritime Organisation 2020

to ignite the cargo. Build-up of fines may also lead to self-heating, auto-ignition and explosion. Oxygen in cargo spaces and enclosed spaces may be depleted.

Stowage and segregation
"Separated from" goods of classes 1 (division 1.4S), 2, 3, 4 and 5, and class 8 acids in packaged form (See IMDG Code).
"Separated from" solid bulk materials of classes 4 and 5.
Goods of class 1, other than division 1.4S, shall not be carried in the same ship.
Boundaries of compartments where this cargo is carried shall be resistant to fire and passage of liquid.

Hold cleanliness
The cargo spaces shall be clean, dry and free from salt and residues of previous cargoes. Prior to loading, wooden fixtures such as battens, loose dunnage, debris and combustible materials shall be removed.

Weather precautions
The cargo shall be kept dry at all times during storage, before and during loading, and during transportation. The cargo shall not be loaded onto ships, or transferred between ships or barges, during precipitation. During loading of this cargo, all non-working hatches of cargo spaces into which this cargo is loaded, or to be loaded, shall be kept closed.

Loading
Prior to loading, the terminal shall ensure that the conveyor belts used for loading this cargo contain no accumulation of water or other substances. Each time cargo operations are commenced or restarted, particularly after rain or washing down, any loading belt shall be operated empty and not over a ship's cargo space.

Prior to loading, an ultrasonic test or another equivalent method with a suitable instrument shall be conducted to ensure weathertightness of the hatch covers and closing arrangements and all readings shall confirm weathertightness.

Prior to loading this cargo, the Shipper shall provide the Master with a certificate issued by a competent person recognized by the competent authority of the port of loading stating that the cargo, at the time of loading, is suitable for shipment, and that it conforms with the requirements of this Code; that the quantity of fines and small particles is no more than 5% by weight; that the moisture content is less than 0.3%; and that the temperature does not exceed 65°C. This certificate shall state the date of manufacture for each lot of cargo to be loaded in order to meet the loading criteria with regard to ageing and material temperature.

The cargo shall not be accepted for loading when its temperature is in excess of 65°C or if its moisture content is in excess of 0.3% or if the quantity of fines and small particles exceeds 5% by weight. Any cargo that has been wetted, or is known to have been wetted, shall not be loaded into any cargo space.

Prior to loading, provision shall be made to introduce a dry, inert gas at tank top level so that the inert gas purges the air from the cargo and fills the free volume above. Nitrogen is preferred for this

Copyright® International Maritime Organisation 2020

purpose. All vents, accesses and other openings, such as coaming drains, that could allow the inert atmosphere to be lost from cargo spaces carrying this cargo shall be closed and sealed.

The cargo shall be loaded in such a way as to minimize both the breakage of the cold-moulded briquettes, pellets, lumps and the additional generation of fines and the concentrating of fines in any area of the cargo. This cargo shall be homogenous, with no added waste. The addition of DRI particles, fines or dust in this cargo shall be prohibited.

Due consideration shall be given to evenly spreading the cargo across the tank top to minimize the concentration of fines. Trim in accordance with the relevant provisions required under sections 4 and 5 of this Code.

When the stowage factor of this cargo is equal to or less than 0.56 m3/t, the tank top may be overstressed unless the cargo is evenly spread across the tank top to equalize the weight distribution. Due consideration shall be given to ensure that the tank top is not overstressed during the voyage and during loading by a pile of the cargo.

The cargo temperature and moisture shall be monitored during loading and recorded in a log detailing the temperature and moisture for each lot of cargo loaded, a copy of which shall be provided to the Master. After loading, a certificate shall be issued by a competent person recognized by the competent authority of the port of loading, confirming that, throughout the whole consignment, fines and small particles (under 6.35 mm size) are less than 5% by weight, that the moisture content has not exceeded 0.3% and the temperature does not exceed 65°C.

On completion of loading of a cargo space, it shall be immediately closed and sealed. Sufficient inert gas shall then be introduced to achieve an oxygen concentration less than 5% throughout the cargo space.

Precautions

Due consideration shall be given to the possibility of moisture inside the cargo pile in order to avoid loading of wet cargo or a wet part of the cargo, recognizing that the bottom of the pile can be wet even though the surface of cargo pile looks dry. The carrier's nominated technical persons or other representatives shall have reasonable access to stockpiles and loading installations for inspection. Prior to shipment, the cargo shall be aged for at least 3 days, or treated with an air-passivation technique, or another equivalent method, that reduces the reactivity to the same level as the aged product. Such ageing process shall be approved by the competent authority that shall also provide a certificate to that effect.

Shippers shall provide comprehensive information on the cargo and safety procedures to be followed in the event of emergency. This advice may be an amplification of this Code, but shall not be contrary thereto in respect of safety.

Where practicable, ballast tanks adjacent to the cargo spaces containing this cargo, other than double-bottom tanks, shall be kept empty. Weathertightness shall be maintained throughout the voyage. Bilge wells of the cargo spaces shall be clean, dry and protected from ingress of the cargo, using non-combustible material.

Copyright® International Maritime Organisation 2020

Due consideration shall be given to protecting equipment, machinery and accommodation spaces from the dust of the cargo. Radars and exposed radiocommunication equipment of ships which carry this cargo shall be protected from the dust of this cargo. Persons who may be exposed to the dust of the cargo shall wear protective clothing, goggles or other equivalent dust eye-protection and dust filter masks, as necessary.

During any handling of this cargo, "NO SMOKING" signs shall be posted on decks and in areas adjacent to cargo spaces, and no naked lights shall be permitted in these areas. Smoking, burning, cutting, chipping, grinding or other sources of ignition shall not be allowed in the vicinity of cargo spaces containing this cargo at any time.

Cargo spaces containing this cargo and adjacent spaces may become oxygen-depleted. Flammable gas may also build up in these spaces. All precautions shall be taken when entering the cargo spaces.[6]

The ship shall be provided with the means to ensure that the requirement of this Code to maintain the oxygen concentration below 5% can be achieved throughout the voyage. The ship's fixed CO2 fire-fighting system shall not be used for this purpose. Consideration shall be given to providing the vessel with the means to top up the cargo spaces with additional supplies of inert gas, taking into account the duration of the voyage.

The ship shall be provided with the means for reliably measuring the temperatures at several points within the stow, and determining the concentrations of hydrogen and oxygen in the cargo space atmosphere on voyage whilst minimizing as far as practicable the loss of the inert atmosphere.

Any cargo that has already been loaded into a cargo space and which subsequently becomes wetted, or in which reactions have started, shall be discharged without delay.

The ship shall not sail until the Master and a competent person recognized by the competent authority of the port of loading are satisfied:
1. that all loaded cargo spaces are correctly sealed and inerted;
2. that the temperature of the cargo has stabilized at all measuring points and that the temperature does not exceed 65°C; and
3. that, at the end of the inerting process, the concentration of hydrogen in the free space of the holds has stabilized and does not exceed 0.2% by volume.

Ventilation
The cargo spaces carrying this cargo shall remain tightly sealed and the inert condition maintained during the voyage.

Carriage
For quantitative measurements of hydrogen and oxygen, suitable detectors shall be on board while this cargo is carried. The detectors shall be suitable for use in an oxygen-depleted atmosphere and of a type certified safe for use in explosive atmospheres. The concentrations of hydrogen and oxygen in the

[6] Refer to Revised recommendations for entering enclosed spaces aboard ships (resolution A.1050(27))

Copyright® International Maritime Organisation 2020

cargo spaces carrying this cargo shall be measured at regular intervals during voyage, and the results of the measurements shall be recorded and kept on board for a minimum of two years.

The oxygen concentration in the cargo spaces carrying this cargo shall be maintained at less than 5% throughout the duration of the voyage. When the monitored hydrogen concentration is higher than 1% (> 25% lower explosive limit (LEL)) by volume, appropriate safety precautions shall be taken in accordance with those procedures provided by the Shipper in the event of emergency. If in doubt, expert advice shall be sought.

Cargo temperatures shall be taken at regular intervals during voyage and the results of the measurements shall be recorded and kept on board for a minimum of two years. If the temperature in the cargo space exceeds 65°C, appropriate safety precautions shall be taken in accordance with the procedures provided by the Shipper in the event of emergency. If in doubt, expert advice shall be sought.

Bilge wells shall be checked regularly for the presence of water. If water is found, it shall be removed by pumping or draining the bilge wells. Consideration shall be given to increasing the frequency of cargo monitoring following periods of bad weather. All measurements shall be taken so as to minimize as far as practicable the loss of inert gas from the cargo spaces.

Discharge
The hydrogen concentration in the cargo space shall be measured immediately before any opening action of the hatch covers. If the hydrogen concentration is greater than 1% (> 25% lower explosive limit (LEL)) by volume, all appropriate safety precautions in conformity with the procedures provided by the Shipper or the recommendations of the competent authority shall be taken. If in doubt, expert advice shall be sought.

During precipitation, all cargo operations shall be suspended and holds containing cargo shall be closed. Monitoring for hydrogen in those holds containing cargo shall be resumed.

Clean-up
Accumulations of dust from this cargo on deck or in proximity to cargo spaces shall be removed as quickly as possible. Hosing with seawater shall be avoided. Consideration shall be given to carefully cleaning exposed radiocommunication equipment to which dust from the cargo might adhere, such as radar, radio aerials, VHF installations, AIS and GPS.

Copyright® International Maritime Organisation 2020

Emergency Procedures

Special emergency equipment to be carried
Nil

Emergency procedures
Nil

Emergency action in the event of fire
In the event of emergency, the specific procedures provided by the shipper should be consulted and followed, as appropriate.

Do not use CO_2. Do not use water. Do not use steam.

Batten down and reinstate the inert atmosphere using supplies or equipment if available on board. Increase the frequency of monitoring. If temperature and/or hydrogen concentration steadily rise, seek expert advice as quickly as possible.

If the temperature in the cargo space exceeds 120°C, the ship should make for the nearest appropriate port to discharge the cargo affected. Preparations should be made for grab discharge.

If additional nitrogen gas is available, the use of this gas will assist in keeping the oxygen concentration down and may contain the fire and prevent an explosive atmosphere if hydrogen is produced.

Flooding with water of the affected cargo hold should only be contemplated as a last resort, always taking the stability and strength of the ship into account.

Medical first aid
Refer to the *Medical First Aid Guide* (MFAG), as amended.

Copyright® International Maritime Organisation 2020