SHIPPING OF DRI
"The Nu-Iron Experience"

By Nigel Noel & Curtis Moore, ***Nu-Iron***

Editor's Note: *The following paper was adapted from a presentation given by Nu-Iron at the 2014 AIST Conference held in Indianapolis, Indiana. This paper describes the Nu-Iron experience in developing the safe transport of direct reduced iron (DRI). It is a detailed look at the precautions and measures that are necessary for safe transport of cold DRI (CDRI) and how Nu-Iron's dedication and attention to proper procedures has allowed the company to transport millions of tons of products via safe ocean transport.*

INTRODUCTION

The shipping of cold direct reduced iron (CDRI) is a complicated, detailed and potentially hazardous process. Nu-Iron has successfully tackled the challenges of storing and transporting CDRI over long distances following the extensive regulations laid out by the International Maritime Organization (IMO).

Nu-Iron is a MIDREX® CDRI facility with a nameplate capacity of 1.6 million metric tons (MT) per year located in Trinidad and Tobago and is a full subsidiary of Nucor Steel. Nucor is the most diversified steelmaker and the largest recycler of steel and steel products in the United States. The company also has facilities located in Canada and Italy.

Nu-Iron uses high quality DR grade pellets to produce what is referred to by the IMO as DRI (B), as defined on the right. Production began on December 31st, 2006, and the first cargo was shipped to Mobile, Alabama on January 21st, 2007. With no steelmaking capability at its site in Trinidad, Nu-Iron ships all DRI produced to four ports in the USA: Charleston, South Carolina; Mobile, Alabama; New Orleans, Louisiana and Morehead City, North Carolina. After discharge, the product is transported via barges to receiving mills based in: Berkeley County, South Carolina; Tuscaloosa, Alabama; Decatur, Alabama; Memphis, Tennessee; Hickman, Arkansas and Hertford County, North Carolina.

THE IMO'S CLASSIFICATIONS

The IMO carefully describes and categorizes different bulk materials for shipping, leaving as little room for misunderstanding as possible.

DRI (A) – Hot-molded Briquette Iron

DRI (B) – Cold Direct Reduced Iron, Cold-molded Briquette Iron

DRI (C) – By-product Fines

Nu-Iron has successfully shipped their DRI product without any major incidents over the past seven years. This has been achieved by putting the right procedures in place for the storage, handling, passivation and loading of DRI, as well as using a shipping company (GBSMT) that has had experience in the carriage of DRI and whose vessels are configured in such a way that the cargo can remain safe during the vessel's voyage. The integrity of the cargo is always maintained.

THE REGULATORY ENVIRONMENT IN 2007: THE BC CODE

When Nu-Iron started producing and shipping CDRI in 2007, the shipping of DRI was regulated by the 2004 International Maritime Organization Code of Safe Practice for Solid Bulk Cargoes, otherwise known as the BC Code. The BC Code made suggestions for the shipping of two forms of DRI: DRI (A) (generally known as HBI) and DRI (B) (generally known as CDRI). Nu-Iron's product, of course, fell under the category of DRI (B). The main suggestions and definitions of the BC Code pertaining to Nu-Iron's product were as follows:

- **Material description:**
  DRI (B) is a metallic material of a manufacturing process formed by the reduction of iron oxide at temperatures below the fusion point of iron.
- **Material Characteristics:**
  Lumps and pellets; average particle size, 6 mm to 25 mm; no more than 5% fines (particles smaller than 4 mm).
- **Hazard:**
  DRI may react with water and air to produce hydrogen and heat. The heat produced may cause ignition. Oxygen in an enclosed space may be depleted.
- **Hold Cleanliness:**
  All cargo spaces should be clean and dry. Bilges should be sift-proof and kept dry during the voyage. Wooden fixtures such as battens should be removed.
- **Weather Precautions:**
  Do not load cargo during precipitation. Keep the cargo dry and close hatches that are not being worked.
- **Loading:**
  DRI should not be loaded if the material temperature is in excess of 65° C (150° F).
- **Precautions:**
  A competent authority recognized by the national administration of the country of shipment should certify to the ship's master that the DRI, at the time of loading, is suitable for shipment.

  Prior to shipment, DRI should be aged for at least 72 hours, treated with an air passivation technique, or some other equivalent method that reduces the reactivity of the material to at least the same level of the aged product.

  Hatches should be sealed. All ventilators and other openings should be closed to maintain an inert atmosphere.

  Prior to loading, provision should be made to introduce an inert gas at tank top level in order to maintain the cargo spaces under an inert atmosphere containing less than 5% oxygen.

  The hydrogen content of the atmosphere should be maintained at less than 1% by volume.

  Suitable detectors for quantitative measurement of oxygen and hydrogen should be on board. The detectors should be suitable for use in an inert atmosphere.

Nu-Iron was also required to obtain a United States Coast Guard Special Permit I-07 for the shipping of DRI (B). This permit covered the special transportation requirements for the shipping of DRI (B) into the United States and for the movement of DRI (B) in unmanned barges within the United States.

DEVELOPMENT OF NU-IRON'S EARLY SHIPPING PROCEDURES

Prior to shipping its product, Nu-Iron developed procedures that surpassed the requirements of the concurrent BC Code, utilizing the input of relevant stakeholders. The prospective shipping company, the United States Coast Guard, various Protection & Indemnity Clubs (international maritime insurance providers) and cargo incident investigators all contributed to ensuring that personnel and cargo on board the vessels would remain safe during every voyage.

The procedures developed by Nu-Iron sought to manage the key areas impacting cargo transport. The main requirements were:

- **Vessel Suitability:**
  Once a vessel has been nominated by the ship owner, the ship owner is required to communicate to Nu-Iron prior to the vessel's arrival that a pre-loading risk assessment has been performed by a representative of the ship owner, and this representative certifies that the vessel is suitable for the loading and carriage of DRI.

  On arrival at Nu-Iron, a surveyor performs ultrasonic testing to verify hatch and hold water tightness. Any abnormality is corrected and retested prior to berthing of the vessel.

- **Crew Readiness:**
  Prior to the berthing of a vessel, a vessel representative communicates to Nu-Iron that the vessel's crew has reviewed all ship procedures related to the carriage of DRI.

- **Cargo Handling and Passivation:**
  Cargo is to be stored in enclosed silos. Once the silo is filled, the top slide gate is closed and seal gas (inert gas with between 0.7 and 3% oxygen by volume) is introduced at the top and bottom cone of the silo for a minimum of 72 hours. Once the passivation process is completed, the material is kept under a nitrogen blanket.

  If for any reason material has to be added to a partially filled silo with passivated material, the entire passivation process has to be repeated before that cargo can be loaded into a ship.

  Any un-passivated material that goes into the product warehouse must be aged in the warehouse for at least 120 hours before it can be loaded into a ship.

  All silos have analyzers that continuously monitor the oxygen and hydrogen atmospheres within the silo and three thermocouples that continuously monitor the temperature of the cargo.

- **Cargo Readiness:**
  Prior to vessel loading, Nu-Iron provides data to the competent authority and the ship's master showing the quality (metallization and carbon); temperature; fines content; and start and end times for passivation of all cargo to be loaded.

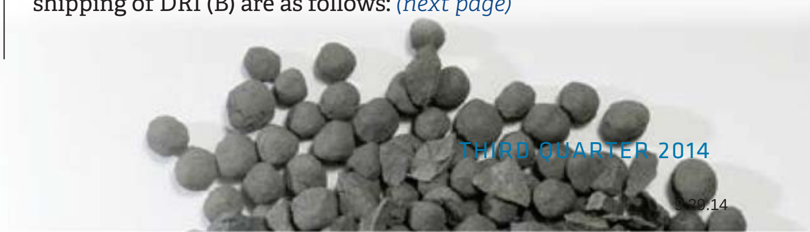
- **Cargo Loading:**
  During loading, the temperature of the cargo is continuously monitored via a temperature monitoring device placed over the conveyor. If the temperature reaches 50° C, an alarm sounds in the control room informing the operator that some action needs to be taken. If the temperature reaches 58° C, the system will shut down to prevent the possibility of high temperature material going on to the vessel.

- **Vessel Inerting:**
  After loading, the cargo holds are sealed and nitrogen is injected into the hold until the oxygen content drops below 2%.

- **Cargo Monitoring:**
  During loading, sailing, and discharge, the cargo temperature and the vessel hold conditions (oxygen, carbon monoxide, and hydrogen content) are monitored three times a day (06:00, 12:00, and 18:00) and reported to the vessel and Nu-Iron. The gas monitors must be calibrated annually, and calibration records are shared with the ship owner representatives.

THE NEW REGULATIONS: THE IMSBC CODE

In 2008, the IMO published a new shipping code: the International Maritime Solid Bulk Cargo Code, or IMSBC Code. As opposed to the BC Code it replaced, which phrased its requirements as suggestions ("should"), the new IMSBC Code uses strictly requisite language ("shall"). It also provides significantly more detail concerning the shipping of many bulk cargoes, including DRI (B). This new code went into effect on January 1st, 2011. Many of the regulations are essentially the same. The main differences between the BC Code and the IMSBC Code for the shipping of DRI (B) are as follows: *(next page)*



- **Material Description:**
  The IMSBC Code gives a more detailed and descriptive definition for DRI: DRI (B) is a highly porous, black/grey metallic material formed by the reduction of iron oxide at temperatures below the fusion point of iron.

- **Material Characteristics:**
  The IMSBC Code uses larger particle size for fines and adds information on bulk density:
  Lump and pellets: Average particle size 6.35 mm to 25 mm with no more than 5% fines (smaller than 6.35 mm) by weight.

  Bulk density of DRI (B) is between 1750 and 2000 kg/m^3.

- **Hazard:**
  These are more detailed as to the specifics of the potential hazards of DRI (B):
  Increase in temperature of about 30° C due to self-heating may be expected after material-handling in bulk.

  Hydrogen has the potential to form an explosive mixture when mixed with air in concentrations above 4% by volume.

  Reactivity of the cargo depends on the origin of the ore, the process and temperature at which reduction is achieved, and the subsequent ageing procedures.

- **Loading:**
  The IMSBC Code provides checks that should be carried out on the system used to load the DRI on the vessel as well as vessel checks. It also describes the conditions that the cargo must conform to before, during, and after loading:
  Prior to loading, the terminal shall ensure that the conveyor belts used for loading the cargo contain no accumulation of water or other substances.

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

  Prior to loading, the shipper shall provide the ship's master with a certificate issued by a competent authority recognized by the national administration of the port of loading, stating that the cargo, at the time of loading, is suitable for shipment and conforms to the requirements of the code. The certificate shall state the date of manufacture of each lot of cargo to be loaded in order to meet the requirements of ageing and temperature.

  Prior to loading, the vessel should have provisions to provide an inert gas (preferably nitrogen) to purge air from the hold and airtight cargo spaces.

  The cargo temperature and moisture for each lot of cargo shall be monitored during loading, recorded in a log, and copied for the ship's master.

  After loading, a certificate shall be issued by the competent authority confirming that throughout the whole consignment, fines are less than 5% by weight, the moisture has not exceeded 0.3% and the temperature does not exceed 65° C.

  On completion of loading of a cargo space, it should be immediately closed, sealed, and inerted to less than 5% oxygen.

- **Precautions:**
  More detailed and specific about the rights of the vessel to confirm safety of the cargo and precautions to be taken by the vessel:
  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 that shall be approved by the competent authority which shall also provide a certificate to that effect.

  Shippers shall provide comprehensive procedures to be followed in the event of an emergency. This advice may be an amplification of this Code but shall not be contrary thereto.

During any handling of the cargo, "NO SMOKING" signs shall be posted on decks and in areas adjacent to cargo spaces.

The ship shall be provided with the means to ensure that the cargo holds remains below 5% oxygen throughout the voyage.

The vessel shall be provided with the means for reliably measuring the temperature at several points within the stow and determining the concentration of hydrogen and oxygen within the cargo spaces.

The ship shall not sail until the ship's master and the competent authority are satisfied that:
- All loaded cargo spaces are correctly sealed and inerted;
- The temperature of the cargo has stabilized and does not exceed 65° C;
- The concentration of hydrogen in the free spaces does not exceed 0.2% by volume.

- **Carriage:**
  More detailed and specific about the equipment to be used for monitoring cargo spaces and the frequency of the same:
  Suitable detectors must be used for the quantitative measurement of hydrogen and oxygen during the voyage. The detectors shall be suitable for use in an oxygen-depleted atmosphere and of a type safe for use in an explosive atmosphere.

  The temperature of the cargo and concentrations of hydrogen and oxygen in the cargo spaces carrying this cargo shall be measured at regular intervals during the voyage and the results recorded and kept on board for at least two years.

  If the temperature in the cargo space exceeds 65° C or if the hydrogen concentration is higher than 1%, appropriate safety precautions shall be taken in accordance with the emergency procedures provided by the shipper. If in doubt, expert advice shall be sought.

- **Discharge:**
  Previously there were no discharge regulations:
  The hydrogen in the cargo space shall be monitored immediately before opening of the hatch covers. If the hydrogen concentration is greater than 1% by volume, all appropriate safety precautions must be taken before the hatch cover can be opened.

"AT ALL TIMES, NU-IRON'S OWN STANDARDS HAVE EXCEEDED THE REGULATIONS OF THE IMO."

MODIFICATION OF NU-IRON'S PROCEDURES

On January 1st, 2011, with the changing of the shipping code, Nu-Iron had to make some minor updates to their procedures. Nu-Iron also chose to make some changes based on their experiences with shipping DRI over the years. The changes to Nu-Iron's shipping procedures are as follows:

- **Cargo Loading:**
  During the loading of the vessel, Nu-Iron has samples taken from every lot of cargo being loaded. Each sample is tested for its moisture and screened to determine the fines content. The temperature of the material being loaded at the time the sample is taken is also recorded.

  After loading is completed, the full lab analysis of temperature, moisture, and fines content is communicated to the competent authority, who issues a certificate confirming that the entire cargo loaded conforms to the IMSBC code.

- **Vessel Inerting:**
  After loading, the cargo holds are sealed and nitrogen is injected into the hold until the oxygen content drops below 3% oxygen.

At all times, Nu-Iron's own standards have exceeded the regulations of the IMO. The development of thorough and stringent procedures has facilitated the safe shipping of over 9.0 million MT of CDRI over the last seven years. However, it wasn't a journey without setbacks.

CHALLENGES FACED BY NU-IRON

The safe handling of DRI (B) involves unique hindrances, granted by the material's tendency to react with moisture very readily. As a result, the IMSBC Code requires as little contact with water as possible, or else flammable and poison gases will be produced. Unfortunately, moisture is prevalent in Nu-Iron's area. Cargo cannot be loaded during precipitation; the reduced iron must be aged for three days or passivated to an equivalent degree. The dry cargo is therefore very dusty and messy. If passivation procedures are breached, shipment is immediately delayed until aging is complete. Any setback means more money lost, both in lack of sales and production, as well as compensatory payments to the shippers.

Yet, Nu-Iron has confronted and minimized each of these barriers with great success and safety.

Hydrogen & Carbon Monoxide Generation

In late 2007, Nu-Iron experienced instances during vessel sailings where small amounts of hydrogen (less than 20% LEL) and larger amounts of carbon monoxide (up to 800 ppm) were being detected in some of the vessel holds. Hydrogen generation typically occurs when DRI comes into contact with moisture. Carbon monoxide generation can come from either contact with moisture or interaction with air.

> **THE REACTIONS**
>
> $Fe + H_2O = FeO + H_2$
> $Fe + C + 2H_2O = FeO + 2H_2 + CO$
> $Fe + C + O_2 = FeO + CO$

The generation of hydrogen and carbon monoxide meant that the DRI was being exposed to moisture somewhere within the storage, loading, or handling process. After extensive investigation, it was determined that hydrogen was only generated in vessel holds loaded with cargo that had been stored in Nu-Iron's DRI warehouse.

Nu-Iron stores the majority of its DRI in enclosed silos (twelve silos with a total capacity of 72,000 MT) whereas the warehouse was used as back-up storage in the event of conveyor maintenance or DRI vessel scheduling delays. The warehouse only has a capacity of 6,000 MT.

At this time, Nu-Iron's warehouse had an earthen floor. They realized that during the rainy season in Trinidad (which is typically from June to November) moisture would seep up through the ground due to the water table being close to the surface, exposing the cargo to moisture.

Once this was determined, material storage in the warehouse ceased, and a concrete floor was laid in early 2008. Once this floor was laid, there were no more instances of cargo exposed to moisture and no more issues with hydrogen or carbon monoxide generation.

Graph of CO Generation by Vessel Hold

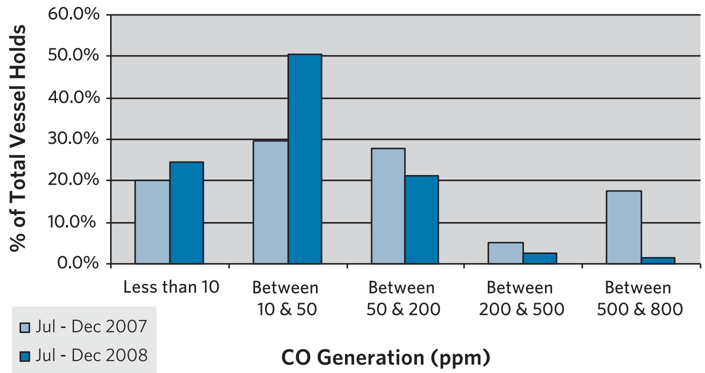
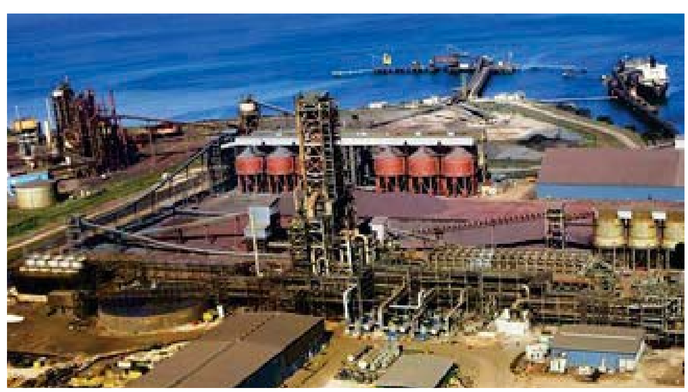


FIGURE 1 *Graph of Carbon Monoxide generation by vessel hold for July – December 2007 & 2008*

Figure 1 displays the prevalence and subsequent rectification of the problem. Between July and December 2007, approximately 80% of vessel holds loaded evolved less than 200 ppm carbon monoxide, while 20% evolved between 200 ppm and 800 ppm carbon monoxide. For the same period in 2008, approximately 95% of vessel holds loaded evolved less than 200 ppm carbon monoxide and 5% evolved between 200 ppm and 800 ppm carbon monoxide, a significant improvement.



Graph of H_2 Generation by Vessel Hold

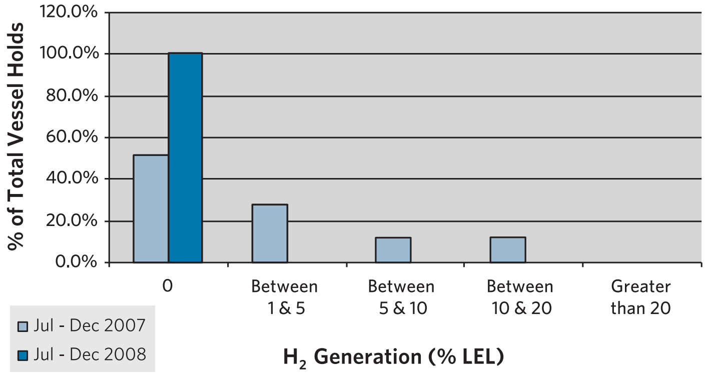


FIGURE 2 *Graph of Hydrogen generation by vessel hold for July – December 2007 & 2008*

The improvement was even more significant for hydrogen levels. Between July and December 2007, approximately 88% of the vessel holds loaded evolved less than 10 % LEL hydrogen, and 12% evolved between 10 and 20 % LEL hydrogen. For the same period in 2008, 100% of the vessel holds loaded evolved 0 % LEL.

Dust Mitigation

DRI is a cargo with a moisture content of less than 0.3% and can have up to 5% by weight of particles less than 6.35 mm in size. In sum, it is a very dry, dusty product.

Therefore during handling and loading of vessels, dust handling and the mitigation of its dispersion is a major concern. Ship owners were hesitant to transport DRI because of the additional cleaning and maintenance costs associated with handling a dry material that can contain up to 5% of fine particles.

To alleviate this problem, Nu-Iron worked with the vessel provider (GBSMT) to modify the vessel hatch covers that are used to load DRI, allowing Nu-Iron to load the vessel with the hatch covers closed. This alleviates the concern of airborne dust from loading activities and thus minimizes any additional maintenance and cleaning costs associated with handling the DRI.

Weather Delays

DRI must always remain dry, and thus, loading operations cannot be performed during precipitation. Nu-Iron is based in the Caribbean, where the rainy season lasts for about half of the year, June to November. During the rainy season, time was lost due to rain and "threat of rain". "Threat of rain" occurs when there is no rainfall, but loading stops because of the possibility of imminent rainfall.

Since loading through closed hatch covers began, time lost due to "threat of rain" was reduced by approximately 80%, reducing the time a vessel spends alongside and reducing the demurrage incurred.

Failure of the Seal Gas Compressor

In late 2007, Nu-Iron experienced the failure of their seal gas compressor, which provides the seal gas used to passivate the DRI in the silos. The repairs were expected to take several days, and there was sufficient material to load a vessel but no means to complete the passivation. This would have resulted in significant demurrage.

Nu-Iron put this problem to their teammates, and, "in true Nu-Iron style," a teammate made the following suggestion: "Why not blend instrument air [which is very dry] with nitrogen in order to create a dry, inert gas?"

This was an excellent suggestion, as Nu-Iron was able to supply a dry inert gas with controlled oxygen content to the silos and thus continue the passivation process.

Given the success of this solution, Nu-Iron has installed an automated system whereby whenever there is no seal gas, they can blend instrument air with nitrogen to provide inert gas at a controlled oxygen content to continue the passivation process.

CONCLUSION

The shipping of cold direct-reduced iron (CDRI) is a complicated, detailed and potentially hazardous process if the proper procedures and precautions are not followed. CDRI may react with water and air to produce hydrogen and heat. The resulting heat produced may cause ignition leading to a risk of overheating, fire and explosion during transport. Due to the reactive nature of CDRI in bulk scenarios, special care is taken especially in wet environments such as Nu-Iron's location in Trinidad and Tobago and for ocean transportation. Nu-Iron has followed and improved upon IMO procedures and practices to safely transport via ocean more than 9.0 million tons of CDRI since 2007. Their experience is a textbook case study for how to store and successfully ship CDRI. ■