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Agenda item 2.1

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MEASURES TO IMPROVE SAFE TRANSPORT OF SOLID BULK CARGOES

Provisions and identification of hazard for materials hazardous only in bulk (MHB)

Additional information on the amendment to the existing schedule for METAL SULPHIDE CONCENTRATES in relation to MHB hazards

Submitted by Belgium

SUMMARY

Executive summary:	This document provides additional information to document CCC 2/5/15 on the amendments to the existing schedule for carriage of METAL SULPHIDE CONCENTRATES in the IMSBC Code
Strategic direction:	5.2
High-level action:	5.2.3
Output:	5.2.3.3
Action to be taken:	Paragraph 3
Related documents:	CCC 2/5/15 and CCC 2/15

General

1 This document provides additional information to support the proposal in document CCC 2/5/15 regarding the amendments to the existing schedule for carriage of METAL SULPHIDE CONCENTRATES in the IMSBC Code.

2 The Guidance on Classification of Copper Concentrates for MHB, Classification of Pb Ores & Concentrates for Materials Hazardous in Bulk, Guidance on Classification of Zinc Concentrates for MHB and Guidance on Classification of Nickel Concentrates for Materials Hazardous in Bulk are provided, as set out in annexes 1 to 4.

Action requested of the Group

3 The group is invited to note the information provided.

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ANNEX 1

GUIDANCE ON CLASSIFICATION OF COPPER CONCENTRATES FOR MHB

International Copper Association
Copper Alliance

8 December 2014

The aim of the International Maritime Solid Bulk Cargoes (IMSBC) Code is to ensure safe maritime transport of solid bulk materials. Specific criteria to identify Materials Hazardous only in Bulk (MHB) were adopted in the 2013 amendment to the International Maritime Solid Bulk Cargoes code (IMSBC 02-2013) through resolution MSC.354(92).

The assessed hazard classes, relevant to MHB are:

- Combustible solids
- Self-heating solids
- Solids that evolve into flammable gas when wet
- Solids that evolve toxic gas when wet
- Toxic solids
- Corrosive solids

To support the global copper industry in meeting its obligations, the International Copper Association has completed an initial assessment of the hazard characteristics of copper concentrates relevant to MHB. Information on chemical identity (mineral and elemental composition) and particle size distribution was combined with the results from solubility tests and UN tests, assessed for representative concentrates. The assessment, compliant with MSC.354(92), includes methodologies and data that have been used to assess copper concentrates under the UN's Global Harmonized System and IMO HME. This information can be used by companies as a guidance for future MHB classifications. The assessment of the specific concentrates is to be done on a case by case basis.

The baseline assessment, summarized below (Annex[1]), indicates that 30% of the copper concentrates may meet the requirements to be classified as toxic solids and therefore MHB, due to the presence of minor elements (especially lead but in some cases also cadmium, arsenic and/or nickel). For such concentrates, information on the solubility/bio-accessibility of these metals present may refine the classification outcome. Further work related to assessment of some of the MHB endpoints (corrosive solids, solids that evolve into flammable gases when wet and solids that evolve toxic gas when wet) is needed.

Dr. Katrien Delbeke, Director Health, Environment & Sustainable

Development in Co-operation with
Dr. P. Rodriguez, Universidad Adolfo Ibanez. Faculty of Engineering and Science, Santiago, Chile
Dr. C. Oates, Apllied Geochemistry Solutions, UK

[1] The assessment made is focused on the metal/minerals and does not take into account chemicals used to produce the concentrates. The influence of these chemicals on the classification of the concentrate should be assessed by the companies.

Annex 1: Summary of the guidance relevant for the classification and assessment of substances as Materials Hazardous in Bulk (MHB).

The classification assessment procedure was carried out following the guidelines and criteria laid out in United Nations Recommendations on the Transport of Dangerous Goods, and the amendment to the International Maritime Solid Bulk Cargoes Code (IMSBC 02-2013), adopted through resolution MSC.354(92). To account for the specificities related to the testing of ore and metal concentrates, the methodology is consistent with the 2014 ICMM guidelines "Hazard assessment of ores and concentrates for marine transport"[2]. The assessment made is focused on the metal/minerals and does not take into account chemicals used to produce the concentrates. The influence of these chemicals on the classification of the concentrate should be assessed by the companies.

1. Copper concentrates manufacturing process

Copper concentrates are mainly produced by flotation. The ore is crushed and milled to a particle size of less than 100 µm. This produces a mix of particles containing pure phases of primary or secondary copper sulfides. The ground ore is mixed with water and reagents, to form a slurry, where the copper sulfide mineral particles bind to the reagent, rendering a hydrophobic complex. Submitted to aeration, this complex binds preferentially to the air bubbles and floats to the surface producing a highly enriched, copper sulfide froth that can be skimmed off the top. This then passes through a cleaning process to remove unwanted impurities. In some cases, the concentrate is submitted to an additional processing step to extract a by-product (e.g. molybdenum sulfide). Finally, the copper concentrate is dried ready for transportation to the next step (smelting). The copper concentrate production process does not involve any chemical modification of the original ore body.

2. Chemical Identity – information on ingredients

The composition of copper concentrates was assessed for 122 samples, covering the world-wide copper concentrates production (tables 1 and 2). Copper concentrates are dominated by copper, iron and sulphur. These elements are incorporated in sulphidic minerals such as chalcopyrite ($CuFeS_2$), bornite (Cu_5FeS_4), diginite (Cu_9S_5), covellite (CuS), chalcocite (Cu_2S).

Other major elemental constituents (Al, Ca, Mg, K, Si, Mn) are incorporated in minerals, usually defined as "gangue", such as calcite, dolomite, hornblende, quartz, chlinochlore, feldspar, kaolinite, biotite, etc.

Copper concentrates may also contain small amounts of zinc, lead, arsenic, nickel, cobalt, silver. These metals are incorporated in distinct minerals such as sphalerite (ZnS), galena (PbS), enargite (Cu_3AsS_4), arsenopyrite (FeAsS).

The reported water content of the final concentrate, transported, typically varies between 7 and 10% water.

2 http://www.icmm.com/publication/hazard-assessment-ores-and-concentrates.

Mineral	Min	50thP	60thP	70thP	80thP	90thP	Max
Tennantite	0.00	0.00	0.00	0.00	0.08	0.71	5.80
Tetrahedrite	0.00	0.00	0.00	0.00	0.00	0.27	5.50
Copper (II) oxide	0.00	0.00	0.00	0.00	0.00	0.00	0.15
Enargite	0.00	0.00	0.00	0.00	0.00	0.08	25.00
Arsenopyrite	0.00	0.00	0.00	0.00	0.00	0.02	2.50
Galena	0.00	0.10	0.30	0.70	1.50	3.90	15.00
Quartz	0.00	2.10	3.00	4.27	7.00	9.95	30.00
Chalcocite	0.00	0.00	0.43	1.13	3.05	7.97	44.32
Sphalerite	0.00	0.80	1.20	4.40	5.96	8.00	18.84
Bornite	0.00	0.13	1.08	3.73	6.10	15.06	42.10
Digenite	0.00	0.00	0.00	0.00	0.00	0.00	4.70
Chalcopyrite	0.00	63.00	67.50	73.00	77.50	81.20	85.00
Covellite	0.00	0.00	0.42	0.84	1.72	3.77	25.00
Anglesite	0.00	0.00	0.00	0.00	0.00	0.00	6.00
Pyrite	0.09	12.73	16.14	18.82	20.37	30.05	55.30

Table 1: Mineralogical composition of 110 copper concentrates. Only minerals present in more than 5 samples are reported.

	Cu	**Sb**	**As**	**Zn**	**Pb**	**Ni**	**Ag**	**Cd**	**Co**
Min	14	0	0	0	0	0	0	0	0
50thp	26.7	0.01	0.12	0.65	0.14	0.003	0.007	0.005	0.01
60thp	27.6	0.02	0.15	1.4	0.27	0.005	0.01	0.007	0.013
70thp	28.5	0.024	0.19	2.9	0.57	0.01	0.013	0.01	0.02
80thp	30	0.05	0.3	3.67	1.49	0.011	0.021	0.015	0.03
90thp	34	0.12	0.52	5.63	3.01	0.032	0.072	0.026	0.04
Max	51	7.25	7.5	9.28	12.71	0.83	1.91	0.07	0.25

Table 2: Elemental composition of world-wide copper concentrates (n= 120)

3. Physical and chemical properties

The physico-chemical properties are summarized below

Appearance	Solid, grey powder (particle sizes : see below)
Odour	Odourless
Odour threshold	Not applicable because odourless
pH	Some concentrates are slightly acidic with recorded pHs between 4 and 8
melting point	900-1170°C
Initial boiling point and boiling range	Not applicable because solid melting above 1000°C
Flash point	Not applicable to inorganic solid
Evaporation rate	Not applicable (solid)

Vapour pressure	Not applicable (inorganic solid melting above 300°C)
Vapour density	Not applicable (inorganic solid melting above 300°C)
Relative density	Range from 3.5-4.7 g/cm3 at 20°C (from 18 copper concentrates)
Solubility(ies)	Sparingly soluble in water
Partition coefficient n- octanol/water	Not applicable to inorganic substances. Decomposition and/or melting starts above 900°C.
Oxidizing properties	Not classified under UN O.1, based on chemistry (inorganic solid) and some company data in accordance to the UN test

4. Particle size

Copper concentrates have particles sizes <100 µm. Table 3 summarizes the particle size distributions of 23 copper concentrates and concludes on a typical median particle diameter of 27 µm. The respirable fraction (<10µm) is typically less than 33%.

Particle size distribution	Range	10th P	50th P	90th P
D50 - µm	6-80	16	27	55
<10 µm – volume based %	5-71	18	24	33

Table 3: Summary of the particle size distribution measured (usually by laser diffraction) in 23 copper concentrates (D50 = median diameter; P = percentile).

5. MHB physico-chemical hazards assessment

Combustible solid:
5 copper concentrates, with varying physico-chemical characteristics (chalcopyrite as well as Bornite/chalcocite dominated concentrates), were subjected to a test in accordance to the United Nations Recommendations on the Transport of Dangerous Goods, Manual of Tests and Criteria – United Nations Manual of Tests and Criteria, part III, 33.2.1.4.3.1 (Test N.1).

From the tests it was concluded that these copper concentrates are not readily combustible substances of Division 4.1 and are not a Material Hazardous only in Bulk (MHB) of the IMSBC Code.

Solid – self-heating:
5 copper concentrates were subjected to a test in accordance to the United Nations Recommendations on the Transport of Dangerous Goods According to United Nations Manual of Tests and Criteria, part III, 33.4.1.4.3.5 (Test N.4).

From the tests, it was concluded that none of the tested copper concentrate show signs of exothermic activity during the first trial, and therefore they are not subject to transportation restrictions of UN Class 4 Division 4.2 nor does it meet the criteria to be classed as a Material Hazardous only in Bulk (MHB) of the IMSBC Code.

Solids that evolve into flammable gases when wet:
No test was carried out. The substance is manufactured with water and the final product contains 7-10% water whereby long-term experience may or may not indicate the production of flammable gases. The outcome is therefore not considered as conclusive.

Solids that evolve toxic gas when wet:
No test was carried out. Copper concentrates contains up to 43% sulphides. These may slowly react with water and generate H2S, being toxic by inhalation – acute 2. This depends amongst others of the pH of the concentrate. The outcome is therefore not considered as conclusive.

6. MHB Human Health hazards assessment:

The amendment to the International Maritime Solid Bulk Cargoes code (IMSBC 02-2013) adopted through resolution MSC.354(92) identifies that materials that have toxic hazards to humans if inhaled or when in contact with skin when loaded, unloaded, or transported in bulk shall be classified as MHB.

A material shall be classified as MHB – toxic solid, in accordance with the criteria laid down in GHS:

- GHS Acute Toxicity Dusts Category 4[3]
- GHS Specific Target Organ Toxicity Single Exposure Inhalation Dust Category 1.
- GHS Specific Target Organ Toxicity Repeated Dose Inhalation Dust Category 1.
- GHS Acute Toxicity Dermal Category 4[3].
- GHS Specific Target Organ Toxicity Single Exposure Dermal Category 1.
- GHS Specific Target Organ Toxicity Repeated Dose Dermal Category 1.
- GHS CMR Category 1A and 1B.

A hazard evaluation was carried out considering the hazardous properties of the constituents.

The dominant minerals (median values above >1%) in copper concentrates are copper sulphides (chalcopyrite (63%), pyrite (11%), quartz (2%) and "gange". Their hazard profiles are summarized as:

- The hazard profile of copper and copper compounds, available from the OECD SIDs Initial assessment Report summary (SIAP on copper and copper compounds, 2014) and the REACH dossiers, concludes:

  - No acute oral, dermal nor acute inhalation toxicity of copper sulphides.

  - No concern for repeated dose toxicity (STOT), genotoxicity, reprotoxicity and carcinogenicity for copper containing materials.

- Pyrite is a benign iron containing mineral with no known hazards.

- Quartz, a crystalline silica, is present at a median concentration of 2% with a 90th percentile of 10% (table 1). Respirable quartz is classified as STOT-RE – cat 1 at 10%. The small probability of copper concentrates particles being respirable (3-11%), calculated based on detailed laser diffraction particle size analysis for

[3] Concentrates classified as categories 1 to 3 are considered as dangerous goods (IMDG)

10 concentrates and SWERF[4], indicates that the presence of "respirable quartz" is usually expected to be below 1%. STOT-RE-cat 1 is therefore unlikely.

- Other major elemental constituents (Al, Ca, Mg, K, Si, Mn) are major elements of terrestrial environments and incorporated in other minerals called "gangue": calcite, dolomite, hornblende, chlinochlore, feldspar, kaolinite, biotite. No hazards are attributed to these elements.

As indicated in tables 1 and 2, copper concentrate contain minor amounts of As, Cd, Co, Ni, Pb. The occurrence/concentration of these elements depends on the particular geochemistry of the originator ore body. Therefore the toxicity profiles of the copper concentrates were further assessed, considering the hazard profiles of the relevant metals/metal compounds (obtained from REACH dossiers), the potential release of the relevant metal ions in body fluids[5] and the GHS mixtures rules. This assessment was done using the MECLAS tool (http://www.meclas.eu) for 122 concentrates with known elemental/mineral composition.

From the assessment, the following conclusions are drawn for dry concentrates":

- GHS Acute Toxicity Category 1-4: only 1/122 classified as Cat 4 inhalation toxicity.

- GHS Specific Target Organ Toxicity Single Exposure Inhalation Dust Category 1: none classified.

- GHS Specific Target Organ Toxicity Repeated Dose Inhalation Dust Category 1: based on the worst case bio-accessibility (in gastric fluid), reported above, concentrates with lead content > 1.8 % Pb have the potential to be classified as Cat 1[5].

- GHS Acute Toxicity Dermal Category 1-4: none classified.

- GHS Specific Target Organ Toxicity Single Exposure Dermal Category 1: since metals are poorly absorbed through the skin (REACH dossiers), the potential for dermal toxicity is expected to be limited.

- GHS Specific Target Organ Toxicity Repeated Dose Dermal Category 1: since metals are poorly absorbed through the skin (REACH dossiers), the potential for dermal toxicity is expected to be limited.

- GHS CMR Category 1A and 1B:

  - Mutagenicity Cat 1 are not expected (none of the concentrates assessed demonstrated a potential for mutagenicity cat 1).

  - Carcinogenicity Cat 1: the assessment showed that even when considering the worst case bio-accessibility factors, the potential for a carcinogenicity cat 1 classification is very limited (4% of the samples had a marginal exceedance due to Cd, Ni or As).

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4 http://www.ima-europe.eu/content/swerf-method-quantify-fine-fraction-of-cs-bulk-material.

5 The worst case bio- accessibility factors measured from 10 concentrates, in the worst case body fluid (gastric fluids, pH 1.5) were used for the initial assessment : As (2%), Cd (14%), Co (4%), Ni (11%), Pb (57%).

- Reproductive toxicity Cat 1: based on the worst case bio-accessibility (in gastric fluid), reported above, concentrates with lead content > 0.53% Pb have the potential to be classified for reproductive toxicity Cat 1.

- Based on the information of the mineral constituents, additional hazard classes, relevant to the MHB category (corrosive solids-see below) were assessed:

  - Based on the information of the mineral constituents, and using the MECLAS tool (http://www.meclas.eu) in accordance to the GHS guidance (2011), respiratory sensitization cat1, skin corrosion/irritation cat 1 or cat 2 or eye damage/irritation cat 1 or 2 is not expected.

Lead is therefore a main driver for the CMR property of copper concentrates and thus a potential main driver for its MHB property. For lead, reproductive toxicity is a consequence of systemic toxicity induced by oral or inhalation exposures.

7. Corrosive solids – corrosive to metals:

5 copper concentrates, with varying physico-chemical characteristics (chalcopyrite as well as Bornite/chalcocite dominated concentrates), were subjected to a test in accordance to the United Nations Recommendations on the Transport of Dangerous Goods, Manual of Tests and Criteria (Test C.1).

This test is described as a "Test for determining the corrosive properties of liquids and solids that may become liquid during transport as dangerous goods of Class 8, packing group III". Some evidence of corrosivity has been found and it is under research.

From the currently available information it can be concluded that some copper concentrates may be classified as MHB due to the presence of minor constituents classified as toxic solids (STOT-RE, carcinogenicity or reproductive toxicity). The potential of copper concentrates to be corrosive or to be classified as solids that evolve into flammable gases when wet and solids that evolve toxic gas needs further investigation.

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ANNEX 2

CLASSIFICATION OF PB ORES & CONCENTRATES FOR MATERIALS HAZARDOUS IN BULK

International Lead Association

December 2015

The aim of the International Maritime Solid Bulk Cargoes (IMSBC) Code is to ensure safe maritime transport of solid bulk materials. Specific criteria to identify Materials Hazardous only in Bulk (MHB) were adopted in the 2013 amendment to the International Maritime Solid Bulk Cargoes code (IMSBC 02-2013) through resolution MSC.354(92).

The assessed hazard classes, relevant to MHB are:

- Combustible solids
- Self-heating solids
- Solids that evolve into flammable gas when wet
- Solids that evolve toxic gas when wet
- Toxic solids
- Corrosive solids

The International Lead Association has completed an initial assessment of the hazard characteristics of metal sulphide lead ores and concentrates (Galena) relevant to MHB. Information on chemical identity (elemental composition) combined with data from UN tests and available hazard information on constituents was assessed for a limited number representative concentrates of lead sulphide based ores. The assessment, compliant with MSC.354(92), includes methodologies and data that have been used to assess lead concentrates under the UN's Global Harmonized System and IMO HME. The assessment of the specific concentrates is to be done on a case by case basis and remains the responsibility of shippers.

Assessment of MHB

The classification assessment procedure was carried out following the guidelines and criteria laid out in United Nations Recommendations on the Transport of Dangerous Goods, and the amendment to the International Maritime Solid Bulk Cargoes code (IMSBC 02-2013), adopted through resolution MSC.354(92). To account for the specificities related to the testing of ore and metal concentrates, the methodology is consistent with the 2014 ICMM guidelines "Hazard assessment of ores and concentrates for marine transport". The assessment made is focused on the metal/minerals and does not take into account chemicals used to produce the concentrates. The influence of these chemicals on the classification of the concentrate should be assessed by the companies.

1. Chemical Composition

Table 1. Composition of Ores/Concentrates Evaluated *

Pb Ore and Concentrate samples				
Elements		**X01-093 (%)**	**X01-094 (%)**	**X01-095 (%)**
Lead	**Pb**	56.3	54.3	77.52
Copper	**Cu**	2.1	0.14	1.06
Antimony	**Sb**	0.59	0.12	0.0024
Arsenic	**As**	0.19	0.03	0.028
Zinc	**Zn**	10	15.2	0.83
Nickel	**Ni**			0.08
Gold	**Au**	0.00005	0.0038	<0.01
Sulfur	**S**	21.5	20.7	15.12
Mercury	**Hg**		0.0035	0.84
Selenium	**Se**		0.008	<0.0001
Tellurium	**Te**		0.0001	<0.0001
Tin	**Sn**			<0.0001
Thallium	**Tl**			0.0006
Bismuth	**Bi**	0.21	<0.01	<0.0001
Silver	**Ag**	0.63	0.05	<0.01
Cadmium	**Cd**	0.1	0.1	0.011
Molybdenum	**Mo**			
Magnesium	**Mg**			
Magnesium Oxide	**MgO**	0.02	0.014	0.75
Manganese Oxide	**MnO**	0.014		
Calcium	**Ca**			
Calcium oxide	**CaO**	0.001	0.187	0.187
Iron	**Fe**	6	5.9	2.51
Silicon dioxide	**SiO2**	0.67	2.82	1
Aluminium oxide	**Al2O3**	0.24	0.18	0.37
Fluoride	**F**	0.008	0.0264	0.007
Chloride	**Cl**		0.003	0.022
Germanium	**Ge**			3
Sulphide				10.17
Berylinium				<0.0001
Cobalt	**Co**		0.016	0.06

* These ores were sampled from a variety of mines and were considered representative of Galena ores and concentrates that will be shipped by sea.

The concentrate is obtained from naturally lead ores, without chemical modifications. The lead concentrate consists of sulphide minerals, mostly Galena (PbS). The concentrate may also contains small quantities of other minerals such as Pyrite (FeS_2), Chalcopyrite ($CuFeS_2$), Sphalerite (ZnS), arsenic and cadmium sulphides.

2. Physico-Chemical Properties

Appearance	Dark grey, fine powder
Odour	May have weak organic odour from entrained flotation reagents
pH	6.3-6.5 (1:10 suspension in water
Melting Point	Lead has a melting point of 327 °C (621 °F)
Boiling Point	Not applicable
Flash Point	Not applicable
Solubility	Essentially insoluble
Oxidizing Properties	Not classified based on chemistry (inorganic solid) and some company data in accordance to the UN test

3. MHB Physico-Chemical Hazards Assessment

Combustible Solid
Lead concentrate were subjected to a test in accordance to the United Nations Recommendations on the Transport of Dangerous Goods According to United Nations Manual of Tests and Criteria. From the tests, it was concluded that lead concentrate is not subject to transportation restrictions of UN Class 4 Division 4.1 nor does it meet the criteria to be classed as a Material Hazardous only in Bulk (MHB) of the IMSBC Code.

Self-Heating Solid
Lead concentrates were subjected to a test in accordance to the United Nations Recommendations on the Transport of Dangerous Goods According to United Nations Manual of Tests and Criteria.
From the tests, it was concluded that none of the tested concentrate are subject to transportation restrictions of UN Class 4 Division 4.2 nor does it meet the criteria to be classed as a Material Hazardous only in Bulk (MHB) of the IMSBC Code.

Solid that Evolves Flammable Gas When Wet
No test data available but not expected from physical chemical properties to meet the criteria for classification.

Solid that Evolves Toxic Gas When Wet
No tests carried out. Lead concentrates contain sulphides that may react slowly with water releasing H2S gas but not expected to meet classification criteria.

Corrosive to Solids
Two lead concentrates have been subjected to a test in accordance to the United Nations Recommendations on the Transport of Dangerous Goods, Manual of Tests and Criteria (Test C.1). Some evidence of corrosivity (exhibited as localized corrosion) has been found and it is currently under research. However the corrosion rate on either steel or aluminum did not meet the classification criteria of between 4 mm/year and 6.25 mm/year.

4. MHB Human Health Hazard Assessment

A material shall be classified as MHB – toxic solid, in accordance with the criteria laid down in GHS:

- GHS Acute Toxicity Dusts Category 4
- GHS Acute Toxicity Dermal Category 4
- GHS Specific Target Organ Toxicity Single Exposure Inhalation Dust Category 1
- GHS Specific Target Organ Toxicity Repeated Dose Inhalation Dust Category 1
- GHS Specific Target Organ Toxicity Single Exposure Dermal Category 1
- GHS Specific Target Organ Toxicity Repeated Dose Dermal Category 1
- GHS Respiratory sensitizer Category 1
- GHS Serious Eye Damage/Eye Irritation Cat 1, 2A
- GHS Skin corrosion/irritation Cat 2
- GHS CMR Category 1A and 1B

A hazard evaluation was carried out considering the hazardous properties of the constituents.

As indicated in table 1, lead concentrate contain minor amounts of other metals including zinc, copper, silver, cadmium, antimony and arsenic The occurrence/concentration of these elements depends on the particular geochemistry of the originator ore body. Therefore the toxicity profiles of the lead concentrates were further assessed, considering the hazard profiles of the relevant metals/metal compounds (obtained from EU REACH dossiers), using the GHS mixtures rules. This assessment was done using the MECLAS tool (http://www.meclas.eu) for 5 concentrates with known elemental/mineral composition. No account for bio-accessibility was taken and classifications were derived using the nominal metal concentration ranges likely to be present in the concentrate.

Given the observation that minor impurities such as cadmium or arsenic compounds can have an effect on classification, it is not possible to give a generic classification for ALL lead ores and concentrates and companies will need to do this with knowledge of their material composition. However, based upon typical Pb compound levels the human GHS classification would be:

Acute Tox. 4 (oral); H302: Harmful if swallowed.
Acute Tox. 4 (inhalation); H332: Harmful if inhaled.
Repro. 1A; H360Df: May damage the unborn child. Suspected of damaging fertility.
Carc. 1A; H350: May cause cancer.
STOT RE1; H372: Causes damage to organs through prolonged or repeated exposure.

This classification may vary dependent upon regional GHS implementation approaches but on this basis lead concentrates would be determined as a "Material Hazardous in Bulk" (MHB) in that several of the human health criteria are met.

References:
1. Ores and Concentrates. An industry approach to EU Hazard Classification. ICMM
2. Dagobert Heijerick. Tier 2 Classification of Lead Ores and Concentrates. ARCHE February 2012

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ANNEX 3

GUIDANCE ON CLASSIFICATION OF ZINC CONCENTRATES FOR MHB

10 December 2015

The aim of the International Maritime Solid Bulk Cargoes (IMSBC) Code is to ensure safe maritime transport of solid bulk materials. Specific criteria to identify Materials Hazardous only in Bulk (MHB) were adopted in the 2013 amendment to the International Maritime Solid Bulk Cargoes code (IMSBC 02-2013) through resolution MSC.354(92).

The assessed hazard classes, relevant to MHB are:

- Combustible solids
- Self-heating solids
- Solids that evolve into flammable gas when wet
- Solids that evolve toxic gas when wet
- Toxic solids
- Corrosive solids

To support the global zinc industry in meeting its obligations, the International Zinc Association has completed an initial assessment of the hazard characteristics of zinc concentrates relevant to MHB. Information on chemical identity (mineral and elemental composition) was combined with the results from solubility tests and UN tests, assessed for representative concentrates. The assessment, compliant with MSC.354(92), includes methodologies and data that have been used to assess zinc concentrates under the UN's Global Harmonized System and IMO HME. Companies can use this information as guidance for future MHB classifications. The assessment of the specific concentrates is to be done on a case-by-case basis.

The baseline assessment, summarized below (Annex[1]), indicates that most the zinc concentrates may meet the requirements to be classified as toxic solids and therefore MHB, due to the presence of minor elements (especially lead but in some cases also cadmium or arsenic). For such concentrates, information on the solubility/bio-accessibility of these metals present may refine the classification outcome. Further work related to assessment of some of the MHB endpoints (solids that evolve into flammable gases when wet and solids that evolve toxic gas when wet) is needed.

Ir Mik Gilles, International Zinc Association

[1] The assessment made is focused on the metal/minerals and does not take into account chemicals used to produce the concentrates. The companies should assess the influence of these chemicals on the classification of the concentrate.

Annex 1: Summary of the guidance relevant for the classification and assessment of substances as Materials Hazardous in Bulk (MHB)

The classification assessment procedure was carried out following the guidelines and criteria laid out in United Nations Recommendations on the Transport of Dangerous Goods, and the amendment to the International Maritime Solid Bulk Cargoes code (IMSBC 02-2013), adopted through resolution MSC.354(92). To account for the specificities related to the testing of ore and metal concentrates, the methodology is consistent with the 2014 ICMM guidelines "Hazard assessment of ores and concentrates for marine transport"[2]. The assessment made is focused on the metal/minerals and does not take into account chemicals used to produce the concentrates. The influence of these chemicals on the classification of the concentrate should be assessed by the companies.

1. Zinc concentrates manufacturing process

Zinc concentrates are mainly produced by flotation. The ore is crushed and milled to a particle size of less than 100 µm. This produces a mix of particles containing pure phases of primary or secondary zinc sulfides. The ground ore is mixed with water and reagents, to form a slurry, where the zinc sulfide mineral particles bind to the reagent, rendering a hydrophobic complex. Submitted to aeration, this complex binds preferentially to the air bubbles and floats to the surface producing a highly enriched, zinc sulfide froth that can be skimmed off the top. This then passes through a cleaning process to remove unwanted impurities. Finally, the zinc concentrate is dried ready for transportation to the next step (smelting). The zinc concentrate production process does not involve any chemical modification of the original ore body.

2. Chemical Identity – information on ingredients

Zinc sulphide concentrate is a concentrate of the zinc sulphide mineral, sphalerite (ZnS), containing mostly zinc and sulphur.

Zinc concentrates may also contain small amounts of iron, lead, copper, arsenic, cadmium, nickel, cobalt and silver. These metals are incorporated in distinct minerals such as pyrites (FeS_2), arsenopyrite (FeAsS), chalcopyrite (CuFeS), galena (PbS), etc.

Other major elemental constituents (Al, Ca, Mg, K, Si, Mn) are incorporated in minerals, usually defined as "gangue", such as dolomite ($CaCO_3.MgCO_3$), calcite, quartz, barite, feldspar, kaolinite, etc.

The water content of the final concentrate, transported, typically varies between 7 and 10% water.

	Zn	Fe	Pb	Cu	Cd	As	Ag	Ni	SiO2
Minimum	33,5	0,4	0,09	0,03	0,06	0,001	0,0004	0,00005	0,12
50% percentile	52,6	6,8	1,25	0,45	0,19	0,063	0,0137	0,00160	1,83
60% percentile	53,3	7,8	1,59	0,65	0,23	0,100	0,0171	0,00200	2,11
70% percentile	54,3	9,0	1,91	0,86	0,28	0,136	0,0214	0,00254	2,47
80% percentile	56,1	10,1	2,29	1,17	0,36	0,214	0,0324	0,00410	2,86

[2] http://www.icmm.com/publication/hazard-assessment-ores-and-concentrates.

90% percentile	58,2	11,8	3,21	1,58	0,42	0,404	0,0521	0,00825	4,16
95% percentile	60,0	12,9	3,57	2,07	0,48	0,543	0,0797	0,01626	4,88
Maximum	64,6	17,4	6,58	3,15	0,81	1,092	0,4395	0,05833	6,10
Average	52,2	7,0	1,56	0,67	0,24	0,139	0,0244	0,00386	1,99

Table 1: Elemental composition [in wt%] of world-wide zinc concentrates (n= 107)

3. Physical and chemical properties

The physico-chemical properties are summarized below

Appearance	Solid, grey or brown powder (particle sizes : see below)
Odour	Odourless
Odour threshold	Not applicable because odourless
pH	pH between 7.5 and 8.5
melting point	Not applicable. Will burn before melting unless in an inert atmosphere
Initial boiling point and boiling range	Not applicable
Flash point	Not applicable to inorganic solid
Evaporation rate	Not applicable (solid)
Vapour pressure	Not applicable (inorganic solid melting above 300°C)
Vapour density	Not applicable (inorganic solid melting above 300°C)
Relative density	Range from 4.0 to 4.3 g/cm³ at 20°C, bulk density 2.0-2.3 g/cm³
Solubility	Sparingly soluble in water
Partition coefficient n-octanol/water	Not applicable to inorganic substances. Decomposition and/or melting starts above 900°C.
Oxidising properties	Not classified under UN O.1, based on chemistry (inorganic solid) and some company data in accordance to the UN test
Auto-ignition temperature	450-550°C
Decomposition temperature	450-550°C
Flammability	Non-flammable

4. Particle size

Zinc concentrates have particles sizes <100 µm. The respirable fraction (<10µm) is typically less than 50%.

5. MHB physico-chemical hazards assessment Combustible solid:

3 zinc concentrates, with varying chemical composition, were subjected to a test in accordance to the United Nations Recommendations on the Transport of Dangerous Goods, Manual of Tests and Criteria – United Nations Manual of Tests and Criteria, part III, 33.2.1.4.3.1 (Test N.1).
From the tests, it was concluded that these zinc concentrates are not readily combustible substances according Division 4.1 and are not a Material Hazardous only in Bulk (MHB) of the IMSBC Code

Solid – self-heating:
There are no shipping incidents reported regarding self-heating of sulphidic zinc ore concentrates. Therefore, it is reasonable to assume that sulphidic zinc ore concentrates are not self-heating. To obtain further confirmation, 3 zinc concentrates were subjected to a test in accordance to United Nations document, "Recommendations of the Transport of Dangerous Goods Manual of Tests and Criteria, part III" (Test N4). In the tests, none of the tested zinc concentrates classified as self-heating substance.
Considering the above, sulphidic zinc ore concentrates are not subject to transportation restrictions of UN Class 4 Division 4.2 nor does it meet the criteria to be classed as a Material Hazardous only in Bulk (MHB) of the IMSBC Code.

Solids that evolve into flammable gases when wet:
No test was carried out. The substance is manufactured with water and the final product contains 7-10% water whereby long term experience may or may not indicate the production of flammable gases. The outcome is therefore not considered as conclusive.

Solids that evolve toxic gas when wet:
No test was carried out. Zinc sulphide concentrates contains up to 95% sulphides. These may slowly react with water and generate H2S, being toxic by inhalation – acute 2. The outcome is therefore not considered as conclusive.

Corrosive:
Sulphidic zinc ore concentrates do not corrode plain steel railroad lorries that are used on a daily basis to transport concentrates between mining and smelting plants. In addition, carbon steel storage silos for sulphidic zinc ore concentrates with service live of more than 40 years do not show signs of corrosion.
Therefore, it is reasonable to assume that sulphidic zinc ore concentrates are not corrosive. To obtain further confirmation, 3 zinc concentrates were subjected to a test in accordance to United Nations document, "Recommendations of the Transport of Dangerous Goods Manual of Tests and Criteria, part III" (Test C1). In the tests, none of the tested zinc concentrates classified as corrosive towards steel or aluminum.

Considering the above, sulphidic zinc ore concentrates are not subject to transportation restrictions of UN Class 8, nor does it meet the criteria to be classified as a Material Hazardous only in Bulk (MHB) of the IMSBC Code.

6. MHB Human Health hazards assessment:

The amendment to the International Maritime Solid Bulk Cargoes code (IMSBC 02-2013) adopted through resolution MSC.354(92) identifies that those materials that have toxic hazards to humans if inhaled or when in contact with skin when loaded, unloaded, or transported in bulk shall be classified as MHB.

A material shall be classified as MHB – toxic solid, in accordance with the criteria laid down in GHS:

- GHS Acute Toxicity Dusts Category 4[3]
- GHS Specific Target Organ Toxicity Single Exposure Inhalation Dust Category 1
- GHS Specific Target Organ Toxicity Repeated Dose Inhalation Dust Category 1
- GHS Acute Toxicity Dermal Category 4[3]
- GHS Specific Target Organ Toxicity Single Exposure Dermal Category 1
- GHS Specific Target Organ Toxicity Repeated Dose Dermal Category 1
- GHS CMR Category 1A and 1B

A hazard evaluation was carried out considering the hazardous properties of the constituents. The dominant minerals (median values above >1%) in zinc concentrates are zinc sulphides (sphalerite) (up to 90%), pyrite (up to 20%), galena (up to 4%), quartz (2%) and "gangue". Their hazard profiles are summarized as:

- The hazard profile of zinc and zinc compounds, available from the OECD SIDs Initial assessment Report summary (SIAP on zinc and zinc compounds, 2014) and the REACH dossiers, concludes:

  - No acute oral, dermal nor acute inhalation toxicity of zinc sulphides.

  - No concern for repeated dose toxicity (STOT), genotoxicity, reprotoxicity and carcinogenicity for zinc containing materials.

- Pyrite is a benign iron-containing mineral with no known hazards.

- Quartz, crystalline silica, is present at a median concentration of 1.8% with a 95th percentile of 4.9% (table 1). Respirable quartz is classified as STOT-RE – cat 1 at 10%. With 50% particles in a zinc concentrate being respirable (<10µm), the presence of "respirable quartz" is usually expected to be below 2.5%. STOT-RE-cat 1 is therefore unlikely.

- Other major elemental constituents (Al, Ca, Mg, K, Si, Mn) are major elements of terrestrial environments and incorporated in other minerals called "gangue" like calcite, dolomite, feldspar, kaolinite, biotite. No hazards are attributed to these elements.

As indicated in table 1, zinc concentrates contain minor amounts of Pb, Cd, As, Cu, Ni. The occurrence/concentration of these elements depends on the particular geochemistry of the originator ore body. Therefore, the toxicity profiles of the zinc concentrates were further assessed, considering the hazard profiles of the relevant metals/metal compounds (obtained

[3] Concentrates classified as categories 1 to 3 are considered as dangerous goods (IMDG).

from REACH dossiers), the potential release of the relevant metal ions in body fluids[4] and the GHS mixtures rules. This assessment was done using the MECLAS tool (http://www.meclas.eu) for 107 concentrates with known elemental/mineral composition.

From the assessment, the following conclusions are drawn for dry concentrates:

- GHS Acute Toxicity Category 1-4: none classified

- GHS Specific Target Organ Toxicity Single Exposure Inhalation Dust Category 1: none classified

- GHS Specific Target Organ Toxicity Repeated Dose Inhalation Dust Category 1: based on the worst case bio-accessibility (in gastric fluid), reported above, concentrates with lead content > 10% Pb have the potential to be classified as Cat 1. Such high Pb concentrations only occur in mixed zinc lead concentrates, often referred to as "zinc bulk concentrates".

- GHS Acute Toxicity Dermal Category 1-4: none classified

- GHS Specific Target Organ Toxicity Single Exposure Dermal Category 1: since metals are poorly absorbed through the skin (REACH dossiers), the potential for dermal toxicity is expected to be limited.

- GHS Specific Target Organ Toxicity Repeated Dose Dermal Category 1: since metals are poorly absorbed through the skin (REACH dossiers), the potential for dermal toxicity is expected to be limited.

- GHS CMR Category 1A and 1B:

  - Mutagenicity Cat 1 are not expected (none of the concentrates assessed demonstrated a potential for mutagenicity cat 1).

  - Carcinogenicity Cat 1: the assessment showed that when considering the worst case bio- accessibility factors, the potential for a carcinogenicity cat 1 classification can occur for concentrates with Cd > 1.45%, As > 0.5% or Ni > 1%. Such high concentrations of Cd or Ni are not observed. Concentrations of As>0.5% rarely occur (93 percentile <0.48% As) and can trigger a classification Carcinogenic Cat 1.

  - Reproductive toxicity Cat 1: based on the worst case bio-accessibility (in gastric fluid), reported above, concentrates with lead content > 0.48 % Pb have the potential to be classified for reproductive toxicity Cat 1. Since most zinc concentrates contain more than 0.5% Pb, **Many zinc concentrates will likely classify for Reproductive toxicity Cat 1 due to presence of Pb.**

- Based on the information of the mineral constituents, additional hazard classes, relevant to the MHB were assessed:

  - Based on the information of the mineral constituents, and using the MECLAS tool (http://www.meclas.eu) in accordance to the GHS guidance (2011), respiratory sensitization cat1, skin corrosion/irritation cat 1 or cat 2 or eye damage/irritation cat 1 or 2 is not expected.

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[4] The worst case bio- accessibility factors measured from 10 concentrates, in the worst case body fluid (gastric fluids, pH 1.5) were used for the initial assessment : As (15.7%), Cd (7.1%), Zn (3.1%), Cu (15.9%), Pb (62.9%).

Lead is therefore a main driver for the CMR property of zinc concentrates and thus a potential main driver for its MHB property. For lead, reproductive toxicity is a consequence of systemic toxicity induced by oral or inhalation exposures.

From the currently available information it can be concluded that some zinc concentrates may be classified as MHB due to the presence of minor constituents classified as toxic solids (STOT-RE, carcinogenicity or reproductive toxicity). The potential of zinc concentrates to be classified as solids that evolve into flammable gases when wet and solids that evolve toxic gas needs further investigation.

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ANNEX 4

GUIDANCE ON CLASSIFICATION OF NICKEL CONCENTRATES FOR MATERIALS HAZARDOUS IN BULK

January 6, 2016

The aim of the International Maritime Solid Bulk Cargoes (IMSBC) Code is to ensure safe maritime transport of solid bulk materials. Specific criteria to identify Materials Hazardous only in Bulk (MHB) were adopted in the 2013 amendment to the International Maritime Solid Bulk Cargoes code (IMSBC 02-2013) through resolution MSC.354(92).

The assessed hazard classes, relevant to MHB are:

- Combustible solids
- Self-heating solids
- Solids that evolve into flammable gas when wet
- Solids that evolve toxic gas when wet
- Toxic solids
- Corrosive solids

To support the global nickel industry in meeting its obligations, the Nickel Institute through the Nickel Producers Environmental Research Association has completed an initial assessment of the hazard characteristics of nickel concentrates relevant to MHB. Information on chemical identity (mineral and elemental composition) and particle size distribution was combined with the results from solubility tests and UN tests, assessed for representative concentrates. The assessment includes methodologies and data that have been used to assess nickel concentrates under the UN's Global Harmonized System and IMO HME. This information can be used by companies as a guidance for future MHB classifications. The assessment of the specific concentrates is to be done on a case by case basis.

The baseline assessment, summarized below (Annex[1]), indicates that nickel concentrates meet some of the criteria to be classified as toxic solids and therefore MHB. For such concentrates, information on the solubility/bio- accessibility of these metals present may refine the criteria used in the classification outcome. Further work related to assessment of some of the MHB endpoints (corrosive solids, solids that evolve toxic gas when wet) is needed.

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[1] The assessment made is focused on the metal/minerals and does not take into account chemicals used to produce the concentrates. The influence of these chemicals on the classification of the concentrate should be assessed by the companies.

Annex 1: Summary of the guidance relevant for the classification and assessment of substances as Materials Hazardous in Bulk (MHB).

The classification assessment procedure was carried out following the guidelines and criteria laid out in United Nations Recommendations on the Transport of Dangerous Goods, and the amendment to the International Maritime Solid Bulk Cargoes code (IMSBC 02-2013), adopted through resolution MSC.354(92). To account for the specificities related to the testing of ore and metal concentrates, the methodology is consistent with the 2014 ICMM guidelines "Hazard assessment of ores and concentrates for marine transport"[2]. The assessment made is focused on the metal/minerals and does not take into account chemicals used to produce the concentrates. The influence of these chemicals on the classification of the concentrate should be assessed by the companies.

1. Nickel concentrates manufacturing process

Nickel concentrates are mainly produced by flotation. The ore is crushed and milled, which produces a mix of particles containing nickel sulfides. The ground ore is mixed with water and reagents, to form a slurry, where the nickel sulfide mineral particles bind to the reagent, rendering a hydrophobic complex. Submitted to aeration, this complex binds preferentially to the air bubbles and floats to the surface producing a highly enriched, nickel sulfide froth that can be skimmed off the top. This then passes through a cleaning process to remove unwanted impurities. Finally, the nickel concentrate is dried ready for transportation to the next step (smelting). The nickel concentrate production process does not involve any chemical modification of the original ore body.

2. Chemical Identity –information on ingredients

The nickel ores and concentrates composition data were collected and information on the classifications of individual ore and concentrate constituents were used to prepare general composition ranges for key mineral constituents that characterize the different nickel ore and concentrate groups. Rather than classifying nickel concentrates on an individual basis, groups of similar nickel concentrates are presented in order to harmonize classification. The main nickel-containing constituents are:

- Heazlewoodite (Ni3S2)
- Millerite (NiS)
- Niccolite/nickeline (NiAs)
- Pentlandite ((Fe, Ni)9S8)
- Violarite (FeNi2S4)

Some nickel ores and concentrates contain other classified constituents that should also be considered during classification:

- Copper in the form of chalcopyrite
- Arsenic
- Lead in the form of galena
- Cobalt
- Respirable Crystalline Silica (RCS)
- Asbestos fibres

Based on the general composition and the type of nickel minerals present, nickel ores and concentrates were categorized into the following different groupings:

– Nickel Sulphidic Ores and Concentrates (3 groups):

- Group 1 Nickel Sulphidic Ores and Concentrates (with ≥ 10% NiS)
- Group 2 Nickel Sulphidic Ores and Concentrates (with ≥ 10% pentlandite and 0.1% ≥ NiS or Ni_3S_2 < 2.5%)
- Group 3 Nickel Sulphidic Ores and Concentrates (with ≥ 10% pentlandite and 2.5% ≥ NiS or Ni_3S_2 < 10%)

– Nickel-Iron-Sulphide Ores and Concentrates (2 groups):

- Group 1 Nickel-Iron-Sulphide Ores and Concentrates with ≥ 4% pentlandite or violarite and < 0.1% NiS, NiAs or Ni_3S_2
- Group 2 Nickel Iron-Sulphide Ores and Concentrates with ≥ 4% pentlandite or violarite and ≥ 0.1% niccolite/nickeline (NiAs) ≤1%

3. Physical and chemical properties

The physico-chemical properties are summarized below:

Appearance	Solid, dark or grey slurry, powder, or grain
Odor	Odorless
Odor threshold	Not applicable because odorless
pH	Variable pH
melting point	Not Available
Initial boiling point and boiling range	Not Available
Flash point	Not Applicable
Evaporation rate	Not Applicable
Vapor pressure	Not Applicable (inorganic solid)
Vapor density	Not Applicable (inorganic solid)
Relative density	Approximately 4-5 g/cm3
Solubility(ies)	Insoluble to sparingly soluble in water
Partition coefficient n-octanol/water	Not Applicable to inorganic substances.
Oxidizing properties	Non-oxidizing

4. Particle size

Nickel concentrates typically have particles sizes <100 µm. Particle size distribution data are unavailable. Nickel concentrates may oxidize during storage and shipping, possibly forming agglomerates.

5. MHB physico-chemical hazards

Combustible solid:
Under normal conditions nickel concentrate is non-combustible.

Solid – self-heating:
No test was carried out.

Solids that evolve into flammable gases when wet:
No test was carried out.

Solids that evolve toxic gas when wet:
No test was carried out. Nickel concentrates contains sulphides. These may slowly react with water and generate H2S, being toxic by inhalation. The outcome is therefore not considered conclusive.

6. MHB Human Health hazards assessment:

The amendment to the International Maritime Solid Bulk Cargoes code (IMSBC 02-2013) adopted through resolution MSC.354(92) identifies that materials that have toxic hazards to humans if inhaled or when in contact with skin when loaded, unloaded, or transported in bulk shall be classified as MHB.

A material shall be classified as MHB – toxic solid, in accordance with the criteria laid down in GHS:

- GHS Acute Toxicity Dusts Category 4
- GHS Specific Target Organ Toxicity Single Exposure Inhalation Dust Category 1
- GHS Specific Target Organ Toxicity Repeated Dose Inhalation Dust Category 1
- GHS Acute Toxicity Dermal Category 4
- GHS Specific Target Organ Toxicity Single Exposure Dermal Category 1
- GHS Specific Target Organ Toxicity Repeated Dose Dermal Category 1
- GHS CMR Category 1A and 1B

A hazard evaluation was carried out considering the hazardous properties of the constituents. The dominant minerals in nickel concentrates are:

- Heazlewoodite (Ni3S2)
- Millerite (NiS)
- Niccolite/nickeline (NiAs)
- Pentlandite ((Fe, Ni)9S8)
- Violarite (FeNi2S4)

Some nickel ores and concentrates contain other classified constituents that should also be considered during classification:

- Copper in the form of chalcopyrite
- Arsenic

- Lead in the form of galena
- Cobalt
- Respirable Crystalline Silica (RCS)
- Asbestos fibres

The occurrence/concentration of these elements depends on the particular geochemistry of the originator ore body.

The following conclusions are drawn for nickel concentrates:

- GHS Acute Toxicity Category 1-4: classified as Cat 4 acute toxicity by inhalation
- GHS Specific Target Organ Toxicity Single Exposure Inhalation Dust Category 1: none classified
- GHS Specific Target Organ Toxicity Repeated Dose Inhalation Dust Category 1: classified as Cat 1
- GHS Acute Toxicity Dermal Category 1-4: none classified
- GHS Specific Target Organ Toxicity Single Exposure Dermal Category 1: since metals are poorly absorbed through the skin (REACH dossiers), the potential for dermal toxicity is expected to be limited.
- GHS Specific Target Organ Toxicity Repeated Dose Dermal Category 1: since metals are poorly absorbed through the skin (REACH dossiers), the potential for dermal toxicity is expected to be limited.
- GHS CMR Category 1A and 1B:
    - Mutagenicity Cat 1 are not expected
    - Carcinogenicity Cat 1: Classified as Cat 1 based on the major constituents.
    - Reproductive toxicity Cat 1: none classified.

7. Corrosive solids – corrosive to metals:

Some evidence of corrosively using "Test for determining the corrosive properties of liquids and solids that may become liquid during transport as dangerous goods of Class 8, packing group III" has been found and further research is underway.

From the currently available information it can been concluded that nickel concentrates should classified as MHB based on Specific Target Organ Toxicity Repeated Dose Inhalation and Carcinogenicity. The potential of nickel concentrates to be corrosive or to be classified as solids that evolve toxic gas needs further investigation.

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