APHC
U.S. ARMY PUBLIC HEALTH CENTER
8252 Blackhawk Road, Aberdeen Proving Ground, Maryland 21010-5403

Toxicology Report No. S.0064909-19, February 2020

Toxicology Assessment for SERDP Project WP19-1105: Development of Pyrophoric Materials for Environmentally Benign Pyrotechnics. January 2019-February 2020

Prepared by William S. Eck, Ph.D.
Health Effects Division, Toxicology Directorate

General Medical 500A, Public Health Data

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
02/28/2020	Technical	January 2019-February 2020

4. TITLE AND SUBTITLE
Toxicology Assessment for SERDP Project WP19-1105: Development of Pyrophoric Materials for Environmentally Benign Pyrotechnics

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
William S. Eck, Ph.D.

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER
WP19-1105

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Health Effects Division, Toxicology Directorate
U.S. Army Public Health Center
8252 Blackhawk Road
Aberdeen Proving Ground, MD 21010

8. PERFORMING ORGANIZATION REPORT NUMBER
S.0064909-19

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Strategic Environmental Research and Development Program (SERDP)
4800 Mark Center Drive, Suite 17D08
Alexandria, VA 22350

10. SPONSOR/MONITOR'S ACRONYM(S)
SERDP

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT
This report is an assessment of the human health and environmental impact for this developmental pyrotechnic formulation. The formulation is based upon the action of ferrous oxalate dihydrate on wheat flour. These components and their combustion products are considered to be relatively non-toxic to humans and the environment.

15. SUBJECT TERMS
pyrophoric materials, flares, environmentally-friendly components.

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			William S. Eck
U	U	U	UU	18	19b. TELEPHONE NUMBER *(Include area code)* 410-390-3980

The author would like to acknowledge the support and encouragement provided to this effort by Dr. Robin Nissan, Strategic Environmental Research and Development Program.

Table of Contents

Toxicology Report No. S.0064909-19
Toxicology Assessment for SERDP Project WP19-1105
Development of Pyrophoric Materials for Environmentally Benign Pyrotechnics
February 2020

1 Summary

1.1 Overview

Research, development, testing, training, and use of substances potentially less hazardous to human health and the environment is vital to the readiness of the US Army. Safeguarding the health of Soldiers, civilians, and the environment requires assessing of alternatives before they are fielded. Continuous assessments begun early in the Research, Development, Testing and Evaluation (RDT&E) process can save significant time and effort during RDT&E, as well as over the life cycle of the items developed. Residues of pyrotechnics, propellants, explosives and incendiaries that were part of mission-essential activities have been found in soil, air, surface and groundwater samples. Remediation of the contaminated areas has cost the DOD millions of dollars and can interfere with training activities.

1.2 Purpose

The purpose of this report is to provide an assessment of the human health and environmental toxicity hazards of the subject formulation.

1.3 Conclusions

The two components of this flare mixture are considered to be relatively non-toxic to humans or the environment in the configuration envisioned.

1.4 Recommendations

No additional testing is recommended at this time.

2 PURPOSE

The goal of this project is to develop a fuze formulation for pyrotechnic devices that has less impact on human health and the environment than current pyrotechnic formulations.

3 AUTHORITY

Funding for this work was provided under Military Interdepartmental Purchase Request No. W74RDV90086070 dated 08 Jan 2019. This Toxicology Assessment addresses, in part, the e\Environment, Safety, and Occupational Health (ESOH) requirements outlined in the following:

- DDoD Directive 4715.1E, *Environment, Safety, and Occupational Health (ESOH)*, March 19, 2005; Change 1, August 31, 2018;

- Army Regulation (AR) 200–1, *Environmental Protection and Enhancement*, 2007;

- AR 40–5, *Preventive Medicine*, 2007;
- AR 70–1, *Army Acquisition Policy*, 2018; and
- Army Environmental Requirement and Technology Assessment (AERTA) Requirement PP-2-02-06, *Toxic Metal Reduction in Surface Finishing of Army Weapons Systems*.

The sponsor is the DOD Strategic Environmental Research and Development Program (SERDP). The principle investigator is Dr. Zhaohua Luan (CCDC-AR), Picatinny Arsenal, New Jersey.

4 BACKGROUND

Current regulations require assessment of human health and environmental effects arising from exposure to substances in soil, surface water and groundwater. Applied after an item has been fielded, these assessments can reveal the existence of adverse environmental and human health effects that must be addressed, often at substantial cost. It is more efficient to begin the assessment of exposure, effects, and environmental transport of military-related compounds/substances early in the RDT&E process in order to avoid unnecessary costs, conserve physical resources, and sustain the health of our Forces and others potentially exposed.

In an effort to support this preventive approach, the U.S. Army Public Health Center (APHC) has been tasked with creating a phased process to identify ESOH effects impacting readiness, training, and development costs. This report represents the status of information available for this work unit as of the date of publication.

5 STATEMENT OF PROBLEM

Pyrophoric iron materials have long been known as the primary pyrotechnic charge in pyrophoric penetrators, ammunition training round markers, and aerial decoy devices against heat-seeking missiles, etc. For example, a known type of decoy flare reported in the literature is constructed with pyrophoric iron coated onto steel foils. The process to produce the materials and fabricate the finished items, however, is extremely corrosive, expensive, and suffers from reproducibility issues. In addition, the residue left on training ranges after steel foils testing is difficult to collect and certify for recycling. This task seeks to continue development of environmentally benign structured pyrophoric foam materials.

6 METHODS

In order to determine the human health and environmental impact of compounds employed in these formulations, it is necessary to correctly identify each compound and to determine its physical, chemical, and toxicological properties. The primary means of identification employed for each compound in this program is its Chemical Abstracts Service Registry Number (CAS RN) (Table 1). While all compounds do not necessarily have a single CAS RN, the CAS RN is an unambiguous way of accessing information for chemical substances. The CAS RN is readily used as a keyword for searching online databases and is often cross-referenced with both

systematic and trivial (i.e., "common" or non-systematic) names for chemical substances. In some cases, synonyms or trade names are also used to identify structures.

The properties necessary to assess fate and transport in the environment include—

- Molecular weight (MW)
- Boiling point (bp)
- Octanol-water partition coefficient (log K_{ow})
- Organic carbon partition coefficient (log K_{oc})
- Water solubility
- Henry's Law constant (K_H)
- Vapor pressure (vp)

Basic physical and chemical properties are usually determined by consulting tertiary sources when such information is available.

Toxicological information needed to estimate potential human health risks includes reported toxicity effects of oral, inhalation, dermal, and ocular exposures; potential for developmental or reproductive toxicity, neurotoxicity, genotoxicity and carcinogenicity; and modes(s) and mechanisms of toxicity. Toxicological information is derived directly from primary sources whenever possible.

Table 1: Formulation Components

Component	CAS RN
Wheat flour	Unknown
Ferrous oxalate dihydrate	6047-25-2

Sources used in this search include the U. S. National Library of Medicine's PubMed® database, the National Center for Biotechnology Information (NCBI) PubChem® database, the U.S. Environmental Protection Agency (EPA) ECOTOXicology Database System (ECOTOX), the Defense Technical Information Center, and the U.S. Department of Health and Human Services' Agency for Toxic Substances and Disease Registry. Additional sources may include *The Merck Index* (O'Neil 2006), the U.S. National Institute for Occupational Safety and Health (NIOSH), the World Health Organization (WHO), the U.S. National Center for Biotechnology Information (NCBI) and the International Agency for Research on Cancer (IARC).

Primary references are identified using PubMed, PubChem and Google Scholar™. Commercial suppliers may provide results of in-house research that do not appear in the open literature (e.g., Safety Data Sheets).

Persistence, bioaccumulation, human health toxicity and ecotoxicity were assigned to general categories of risk (i.e., low, moderate, or high) using criteria modified from Howe et al. (2006). Table 2 describes the criteria used in the categorization, though the relative proportions of each substance were factored into the final assessment. In addition, classification in the Globally Harmonized System (GHS) (OSHA 2012) is also included for many of these compounds (See Appendix B).

Table 2. Categorization Criteria Used in the Development of Environmental Safety and Occupational Health Severity (modified from Howe et al., 2006).

	Low	Moderate	High
PERSISTENCE	Readily biodegrades (<28 days)	Degradation 1/2 life: water <40 days , soil <120 days	Degradation 1/2 life: water >40 days soil > 120 days
TRANSPORT	Water sol. < 10 mg/L log K_{OC} > 2.0	Water sol. 10–1000 mg/L log K_{OC} 2.0-1.0	Water sol. > 1000 mg/L log Koc <1.0
BIOACCUMULATION	log K_{OW} <3.0	log K_{OW} 3.0–4.5	log K_{OW} >4.5
TOXICITY	No evidence of carcinogenicity/ mutagenicity; Subchronic LOAEL > 200 mg/kg-d	Mixed evidence for carcinogenicity/mutagenicity (B2, 2); Subchronic LOAEL 5–200 mg/kg-d	Positive corroborative evidence for carcinogenicity /mutagenicity; LOAEL < 5 mg/kg-d
ECOTOXICITY	Acute LC_{50}/LD_{50} >1 mg/L or 1500 mg/kg; Subchronic EC_{50} >100 µg/L or LOAEL >100 mg/kg-d	Acute LC_{50}/LD_{50} 1-0.1 mg/L or 1500-150 mg/kg; Subchronic EC_{50} 100-10 µg/L or LOAEL 10–100 mg/kg-d	Acute LC_{50}/LD_{50}<100 µg/L or <150 mg/kg; Subchronic LOAEL <10 mg/kg-d

Legend:
mg/L = milligrams per liter
log K_{OC} = organic carbon partition coefficient
log K_{OW} = octanol-water partition coefficient
LOAEL = lowest-observed adverse effect level
LC_{50} = concentration expected to result in 50% lethality to a population of test animals
LD_{50} = Dose resulting in 50% mortality
EC_{50} = Effective concentration to achieve 50% effect
mg/kg-d = milligrams per kilogram per day
µg/L = micrograms per liter

7 RESULTS

7.1 Physical Properties

Table 3 summarizes the physical properties of the alternative compounds. The "ND" indicates no data was found, and "n/a" indicates the property named is not applicable to the substance being described. For example, if the compound is a non-volatile solid or an inorganic salt, the vp, K_{OW}, K_{OC}, and K_H are typically negligible.

Table 3. Physical properties

Compound	Molar Mass (g/mol)	Melting Point (°C)	Boiling Point (°C)	Aqueous solubility (mg/L) @ 25°C	log K_{OW}	log K_{OC}	Henry's Law Constant (atm-m^3/mol) @ 25°C	Vapor Pressure mmHg @ 25°C
Wheat flour	ND	ND	ND	ND	ND	ND	ND	ND
Ferrous oxalate dihydrate	179.89[a]	180[b] (dec)	ND	2.28	n/a	n/a	n/a	n/a

Legend:
g/mol = grams per mole
°C = degrees Celsius
mg/L = milligrams per liter
atm-m^3/mol = cubic meters of atmosphere per mole
n/a = not applicable
mmHg = millimeters of mercury
ND = no data

Notes:
a = PubChem 2020
b = Zboril et al. 2004

7.2 Compound Summaries

Table 4 summarizes the mammalian toxicity data. Tables 5 and 6 present assessments of human health and environmental toxicity, respectively, for each formula component. Each characterization is generally based on the criteria in Table 2. The final risk characterization also incorporates an assessment of the uncertainty associated with available data, the amount of each compound present in the formulation, and the nature of potential exposure associated with use of the end item.

Table 4. Toxicity Data

Compound	Acute Oral (mg/kg)	Chronic Oral LOAEL (mg/kg-d)	Inhalation (g/m^3-h)	Dermal	Ocular	Devel/ Repro	Genotoxicity	Carcinogen-icity
Wheat flour	ND	ND	ND	ND	ND	ND	ND	ND
Ferrous oxalate dihydrate	ND	ND	ND	ND	ND	ND	ND	ND

ND = No data

Table 5. Toxicity Assessment

Compound	Oral	Inhalation	Dermal	Ocular	Carcinogenicity
Wheat flour	Low	Low	Low	Low	Low
Ferrous oxalate dihydrate	Mod	Low	Low	Low	Low

Table 6. Ecotoxicity Assessment

Compound	Aquatic	Terrestrial Invertebrates	Terrestrial Plants	Mammals	Birds
Wheat flour	Low	Low	Low	Low	Low
Ferrous oxalate dihydrate	Low	Unk	Unk	Low	Unk

Legend:
Unk = Unknown

7.3 Wheat flour

7.3.1 General Information

Wheat flour is a complex natural products reported to contain 65% starch, 14% water, 2% lipids with the balance being non-starch polysaccharides (Manley 2000). Wheat flour will function as the fuel in this formulation.

7.3.2 Toxicology Data

While wheat flour is generally considered non-toxic, a peptic-tryptic-cotazyme digest of crude wheat gliadin (alcohol-soluble fraction of gluten proteins) has been found to inhibit *in vitro* development and morphogenesis of small intestine tissue from 17- and 18-day-old rat fetuses, while being harmless to older rats (DeRitis et al. 1979).

7.3.2.1 Oral

As wheat flour is a primary ingredient in bread, it has no associated oral toxicity.

7.3.2.2 Inhalation

Inhalation of wheat proteins in an occupational environment has the potential to result in asthma. In a case report of a baker who developed asthma, initial symptoms included sneezing, itching, hyaline rhinorrhea and nasal obstruction. The following year, symptoms progressed to include mild to moderate dyspnea, chest tightness, cough and wheezing during periods of exposure. The case was qualified as an occupational disease with a permanent partial disability of 25% (Galindo-Pacheco et al. 2013).

The National Institute for Occupational Safety and Health (NIOSH) conducted a study to determine prevalence of sensitization to bakery-associated antigens and work-related respiratory symptoms at a large commercial bakery. Employees in a higher-exposure group had significantly higher prevalence of work-related wheezing, runny nose, stuffy nose and frequent sneezing than in the lower exposure group. The prevalence of IgE specific to wheat was significantly higher among employees who ever had a job in the higher exposure group or in production at another bakery at both the ≥0.10 kU/L and the ≥0.35 kU/L cutoffs, and to flour dust and α-amylase at the ≥0.10 kU/L cutoff, compared to the lower exposure group (Page et al. 2010).

In addition to wheat flour, rye flour has also been implicated in induction of allergic responses (Letran et al. 2008, Ehrlich and Prescott 2005).

7.3.2.3 Dermal

There is no dermal toxicity known to be associated with wheat flour.

7.3.2.4 Ocular

There is no ocular toxicity known to be associated with wheat flour.

7.3.2.5 Development and Reproduction

Other than the *in vitro* circumstance noted above, there is no known developmental or reproductive toxicity associated with wheat flour.

7.3.2.6 Neurotoxicity

There is no neurotoxicity known to be associated with wheat flour.

7.3.2.7 Genotoxicity

There is no genotoxicity known to be associated with wheat flour.

7.3.2.8 Carcinogenicity

Buecher and Gallaher (2014) examined the effect of wheat class and refining on colonic precancerous lesions (aberrant crypt foci, ACF) in rats. Hard red wheat-fed groups had significantly fewer ACF than soft white wheat-fed groups, however state of refinement had no significant effect on ACF number. Hence, wheat class, not state of refinement appears to influence colon cancer risk, with hard red wheat protective relative to soft white wheat.

7.3.2.9 Ecotoxicology

7.3.2.9.1 Fate and transport

Wheat flour is a generally insoluble solid that is subject to biodegradation over time.

7.3.2.9.2 Ecotoxicity

There is no ecotoxicity known to be associated with wheat flour.

7.3.2.9.3 Degradation/Treatment

Wheat flour is subject to biodegradation over time.

7.4 Ferrous oxalate dihydrate

7.4.1 General Information

Ferrous oxalate dihydrate is a pale yellow crystalline powder (PubChem 2020).

7.4.2 Toxicology Data.

Virtually no toxicity data could be found for ferrous oxalate dihydrate as a discrete substance. Since it is a salt, toxicity can be deduced from a comparison of Fe^{2+}, as represented by iron(II) chloride, and sodium oxalate.

7.4.2.1 Oral

Ferrous oxalate dihydrate is categorized in GHS Category 4, and hence is of low toxicity (Sigma 2020).

The TOPKAT modeling predicts an acute oral LD_{50} for oxalate in rats of 300.0 mg/kg at low confidence. The chronic LOAEL is predicted to be 158.8 mg/kg at high confidence. These values correspond to a classification of Moderate in the APHC system, and Category 3 in the GHS.

7.4.2.2 Inhalation

No data was found. The TOPKAT modeling predicts an inhalation LC_{50} for oxalate to be greater than 10 g/m^3-hour at moderate confidence. Dry ferrous oxalate dihydrate is expected to be a respiratory irritant if inhaled. This corresponds to a classification in the APHC system of Low and unclassifiable in the GHS.

7.4.2.3 Dermal

Ferrous oxalate dihydrate is categorized in GHS Category 4, and hence is of low toxicity (Sigma 2020).

7.4.2.4 Ocular

No data was found. The TOPKAT modeling predicts oxalate will be a mild ocular irritant.

7.4.2.5 Development and Reproduction

No data was found. The TOPKAT modeling predicts oxalate will be a developmental or reproductive toxicant at high confidence. This is likely due to oxalate's ability to act as a chelating agent, removing vital cations from the body.

Old World rats (*Rattus spp.*) were found to demonstrate retarded growth when exposed to ferrous chloride at concentrations from 0-150 ppm for a period of 73-74 days (ECOTOX 2020).

7.4.2.6 Neurotoxicity

No data was found.

7.4.2.7 Genotoxicity

No data was found. The TOPKAT modeling predicts oxalate will be mutagenic in the Ames assay at high confidence; again, this is likely due to the ability of oxalate to act as a chelating agent.

7.4.2.8 Carcinogenicity

Ferrous oxalate dihydrate is not considered to be carcinogenic by the International Agency for Research on Cancer, U.S. National Toxicology Program, or the U.S. Occupational Health and Safety Agency (Sigma 2020).

7.4.2.9 Ecotoxicology

7.4.2.9.1 Fate and transport

Due to its high solubility, ferrous oxalate dihydrate is expected to have a high mobility in water, where it will likely dissociate to its two ions. Due to its ionic nature, partition to the atmosphere is not expected.

7.4.2.9.2 Ecotoxicity

No data was found for ferrous oxalate dihydrate as a compound. Ferrous chloride can be used to assess the iron contribution to ferrous oxalate toxicity. The 48-hour LC_{50} of ferrous chloride *Daphnia* is reported to be 0.019 mg/L. The NOEC for green algae (*Chlorella vulgaris*) is more than 10 mg/L. The 96-hour LC_{50} to striped bass (*Morone saxatilis*) is reported to be 6 mg/L (ECOTOX 2020).

Similarly, sodium oxalate can be used to assess the oxalate contribution to ferrous oxalate toxicity. The 48-hour NOEC of sodium oxalate in water flea (*Daphnia magna*) is reported to be 214 mg/L and the 96-hour LC_{50} in zebrafish (*Danio rerio*) is 630 mg/L (ECOTOX 2020).

The values for iron and oxalate qualify for an acute aquatic toxicity classification in Category III (OSHA 2012).

7.1.2.9.3 Degradation/Treatment

Oxalate may be degraded by the action of plants and microorganisms.

8 Discussion

8.1 Compound Summaries

8.1.1 Wheat flour

Wheat flour is considered non-toxic as a food item, but in exposures such as bakeries where there is long-term inhalation exposure, allergic reactions have been found. There are no ecotoxicity hazards known to be associated with wheat flour.

8.1.2 Ferrous oxalate

Although there is a lack of experimental data, ferrous oxalate is assessed to be of low toxicity on the basis of the contributions of the iron(II) and oxalate ions. The dry substance may reasonably be expected to be an irritant to eyes, skin and the respiratory system. However, solutions should be significantly less irritating. There is no indication ferrous oxalate is either mutagenic or carcinogenic. Metal ion chelation may result after oral ingestion, but large exposures would be required for any effect.

8.2 Regulations and Standards

8.2.1 Wheat flour

There are no toxicity regulations or standards associated with wheat flour.

8.2.2 Ferrous oxalate

The EPA has established a Federal Drinking Water Guideline of 300 µg/L measured as iron (PubChem 2020).

Ferrous oxalate dihydrate is listed in Right-to-Know legislation in Pennsylvania (Sigma 2020).

9 Conclusions

The two components of this flare mixture are considered to be non-toxic to humans or the environment in the configuration envisioned.

10 Recommendations

No additional testing is recommended at this time.

11 Point of Contact

The Point of Contact for this report is Dr. William Eck, telephone 410-436-3980, DSN: 584-3980; e-mail: usarmy.apg.medcm-phc.mbx.tox-info@mail.mil.

Army Public Health Center
Toxicology Directorate
Aberdeen Proving Ground, MD 21010

Prepared by:

ECK.WILLIAM.S.1145749839
Digitally signed by ECK.WILLIAM.S.1145749839
Date: 2020.04.02 16:30:45 -04'00'

William S. Eck, Ph.D.
Biologist,
Health Effects Division

Approved by:

QUINN.MICHAEL.J.JR.1282372092
Digitally signed by QUINN.MICHAEL.J.JR.1282372092
Date: 2020.04.03 07:52:33 -04'00'

Michael J. Quinn, Ph.D.
Division Chief
Health Effects Division

JOHNSON.MARK.STEVEN.1229380717
Digitally signed by JOHNSON.MARK.STEVEN.1229380717
Date: 2020.04.02 10:41:06 -04'00'

Mark S. Johnson, Ph.D., D.A.B.T.
Director, Toxicology

REFERENCES

Appendix A

Buescher, MI and DD Gallaher. 2014. Wheat color (class), not refining influences colon cancer risk in rats. *Nutr Cancer* 66:849-856.

DeRitis, G, P Occorsio, S Aurrichio, F Gramenzi, G Morisi and V Silano. 1979. Toxicity of Wheat Flour Proteins and Protein-derived Peptides for In Vitro Developing Intestine from Rat Fetus. *Ped Res* 13:1255-1261.

Ehrlich, R and R Prescott. 2005. Baker's asthma with a predominant clinical response to rye flour. *Am J Ind Med* 48:153-155.

Galindo-Pacheco, LV, R Toral-Villenueva and NH Sequra-Mendez. 2013. Occupational asthma related to wheat. Presentation of one case. *Rev Alerq Mex* 60:82-86.

Letran, A, A Palacin, P Barranco, G Salcedo, C Pascual and S Quirce. 2008. Rye flour allergens: an emerging role in baker's asthma. *Am J Ind Med* 51:324-328.

Manley, D. 2000. Wheat flour and vital wheat glute. In: Technology of Biscuits, Crackers and Cookies, 3d Ed. https://www.sciencedirect.com/topics/biochemistry-genetics-and-molecular-biology/wheat-flour. Accessed 11 Feb 2020

OSHA. 2012. The Globally Harmonized System of Classification and Labeling of Chemicals. Occupational Safety and Health Administration. URL: http://www.osha.gov/dsg/hazcom/ghs.html. Accessed 17 Nov 2012.

Page, EH, CH Dowell, CA Mueller, RE Biagini and D Heederik. 2010. Exposure to flour dust and sensitization among bakery employees. *Am J Ind Med* 53:1225-1232.

PubChem. 2020. *Iron oxalate*. https://pubchem.ncbi.nlm.nih.gov/compound/168963. Accessed 29 Jan 2020.

Sigma. 2020. Iron(II) oxalate dehydrate. Sigma-Aldrich Safety Data Sheet, Version 6.3, dated 15 Jan 20, https://www.sigmaaldrich.com/. Accessed 19 Feb 2020.

Zboril, R,- L Machala, M Mashlan, M Hermanek, M Miglierini and A Fojtik. 2004. Structural, magnetic and size transformations induced by isothermal treatment of ferrous oxalate dehydrate in static air conditions. *Physica status solidi* 1:3583-3588.

Appendix B

Globally Harmonized System

The acronym for the Globally Harmonized System of Classification and Labeling of Chemicals is (GHS). The GHS attempts to establish international consensus for defining health, physical, and environmental hazards of chemicals; creating a classification process for comparison with defined hazard criteria; and communicating hazard information and protective measures on labels and Safety Data Sheets (SDS) formerly known as Material Safety Data Sheets (MSDS). The GHS attempts to reduce differences among levels of protection for workers established by the different countries and reduce regulatory burden and barriers to commerce while establishing consistent standards for classification. The GHS is the result of an international mandate adopted in the 1992 United Conference on Environment and Development, often called the "Earth Summit". The harmonization and classification of chemicals was one of six program areas endorsed by the U.N. General Assembly to strengthen international efforts in the environmentally sound management of chemicals. While there are several aspects of the GHS, the one most important area for our purposes is classification of chemicals into various hazard categories based upon their effects and the route of exposure. Tabular extracts of the criteria for acute toxicity (both oral and inhalation), dermal, and ocular effects are included below. More information can be found in the original source (OSHA 2012).

Table B-1. GHS Acute Toxicity

	Category 1	Category 2	Category 3	Category 4	Category 5
Oral (mg/kg)	≤5	>5 ≤50	>50 ≤300	>300 ≤2000	Criteria: -Anticipated LD50 between 2000 and 5000 mg/kg -Indication of significant effects in humans. -Any mortality in Category 4 -Significant clinical signs in Category 4 -Indications from other studies. *If assignment to a more hazardous class is not warranted.
Dermal (mg/kg)	≤50	>50 ≤200	>200 ≤1000	>1000 ≤2000	
Gases (ppm)	≤100	>100 ≤500	>500 ≤2500	>2500 ≤5000	
Vapors (mg/L)	≤0.5	>0.5 ≤2.0	>2.0 ≤10	>10 ≤20	
Dusts & Mists (mg/L)	≤0.05	>0.05 ≤0.5	>0.5 ≤1.0	>1.0 ≤5	

Table B-2. GHS Skin Corrosion/Irritation

Skin Corrosion Category 1			Skin Irritation Category 2	Mild Skin Irritation Category 3
Destruction of dermal tissue; visible necrosis in at least one animal.			Reversible adverse effects in dermal tissue Draize score: ≥ 2.3, <4.0, or persistent inflammation	Reversible adverse effects in dermal tissue Draize score: ≥ 1.5, <2.3
Subcategory 1A Exposure < 3 minutes Observation < 1 hour	Subcategory 1B Exposure < 1 hour Observation < 14 days	Subcategory 1C Exposure < 4 hours Observation < 14 days		

Table B-3: GHS Eye Effects

<table>
<tr><td>Category 1
Serious Eye Damage</td><td colspan="2">Category 2
Eye Irritation</td></tr>
<tr><td rowspan="2">Irreversible damage 21 days after exposure

Draize score:
Corneal opacity ≥ 3
Iritis ≥ 1.5</td><td colspan="2">Reversible adverse effects on cornea, iris, conjunctiva

Draize score:
Corneal opacity ≥ 1
Iritis > 1
Redness ≥ 2
Chemosis ≥ 2</td></tr>
<tr><td>Irritant
Subcategory 2A
Reversible in 21 days</td><td>Mild irritant
Subcategory 2B
Reversible in 7 days</td></tr>
</table>

Table B-4. GHS Acute and Chronic Aquatic Toxicity

<table>
<tr><td>Acute Category I
Acute toxicity ≤ 1.00 mg/L</td><td>Acute Category II
Acute toxicity > 1.00 but ≤10.0 mg/L</td><td colspan="2">Acute Category III
Acute toxicity > 10.0 but < 100 mg/L</td></tr>
<tr><td>Chronic Category I
Acute toxicity ≤ 1.00 mg/L and lack of rapid biodegradability and log Kow ≥ 4, unless BCF < 500.</td><td>Chronic Category II
Acute toxicity > 1.00 mg/L but ≤ 10.0 mg/L and lack of rapid biodegradability, and log Kow ≥ 4, unless BCF < 500 and unless chronic toxicity > 1 mg/L.</td><td>Chronic Category III
Acute toxicity > 10.0 mg/L but ≤ 100.0 mg/L and lack of rapid biodegradability and log Kow ≥ 4, unless BCF < 500 and unless chronic toxicity > 1 mg/L.</td><td>Chronic Category IV
Acute toxicity > 100.0 mg/L and lack of rapid biodegradability and log Kow ≥ 4, unless BCF < 500 and unless chronic toxicity > 1 mg/L.</td></tr>
</table>