VERTEX

THE SCIENCE *of* POSSIBILITY

IMPROVING LAB SAFETY IN ACADEMIA: FREE AND INEXPENSIVE METHODS TO IDENTIFY HIGH-RISK CHEMISTRY

JEFFREY B. SPERRY, PH.D.

MAY 2023

Jeffrey_Sperry@VRTX.com

@SafeChem79

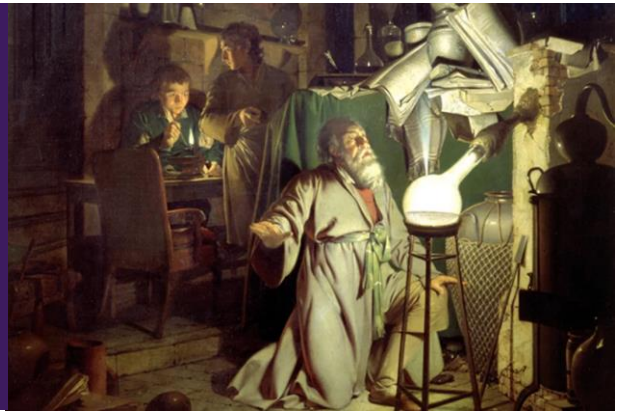
www.linkedin.com/in/jeffreybsperry

OUTLINE

LABORATORY SAFETY – A JOURNEY

THE EVOLUTION OF LABORATORY SAFETY

Where we started



THE EVOLUTION OF LABORATORY SAFETY

Where we are

Yale University

Princeton University

Carelton University

THE EVOLUTION OF LABORATORY SAFETY

Where we are

Yale University

VERTEX
THE SCIENCE of POSSIBILITY

Princeton University

Carelton University

THE EVOLUTION OF LABORATORY SAFETY

The journey

Texas Tech (2010)
https://www.csb.gov/csb-releases-investigation-into-2010-texas-tech-laboratory-accident-case-study-identifies-systemic-deficiencies-in-university-safety-management-practices/

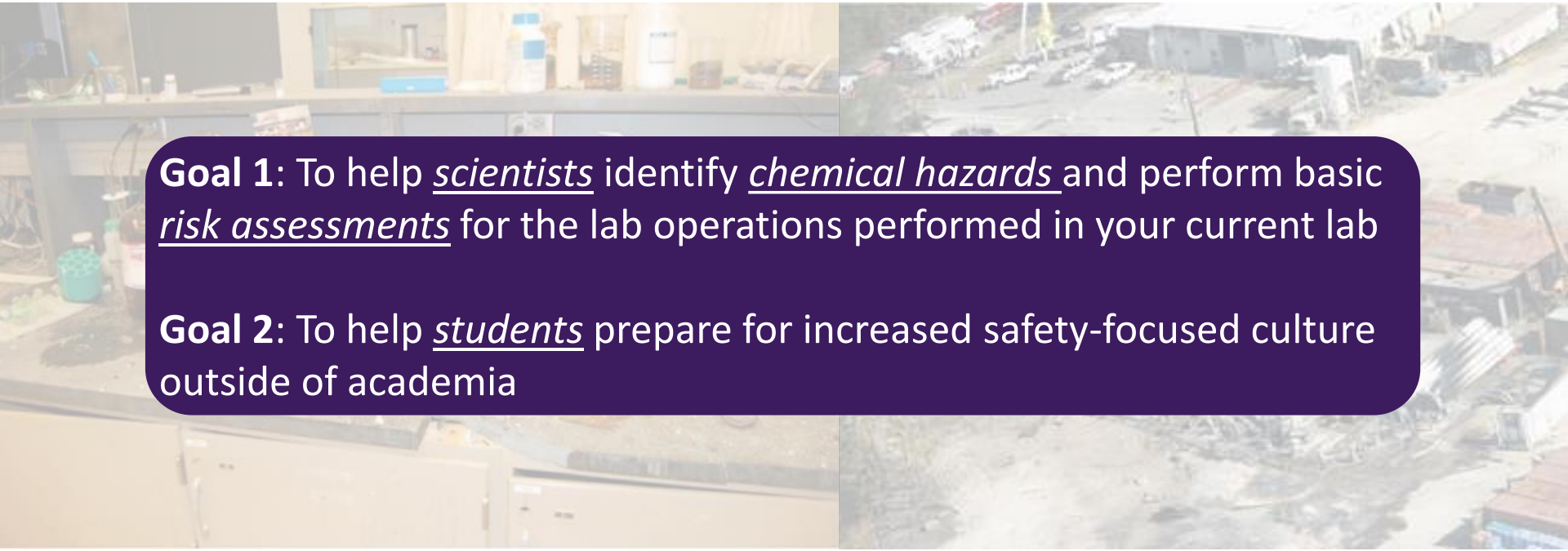
University of Hawaii (2016)
https://cen.acs.org/articles/94/web/2016/04/Spark-pressure-gauge-caused-University.html

Four students injured in science experiment gone wrong at Bronx school

By ESHA RAY and GRAHAM RAYMAN
NEW YORK DAILY NEWS | NOV 22, 2017 AT 2:31 PM

PRESENTATION GOALS

PRESENTATION GOALS



Goal 1: To help *scientists* identify *chemical hazards* and perform basic *risk assessments* for the lab operations performed in your current lab

Goal 2: To help *students* prepare for increased safety-focused culture outside of academia

PRESENTATION GOALS

nature chemistry

REVIEW ARTICLE

https://doi.org/10.1038/s41557-019-0375-x

A review and critique of academic lab safety research

A. Dana Ménard[1*] and John F. Trant[2*]

Over the past ten years, there have been several high-profile accidents in academic laboratories around the world, resulting in significant injuries and fatalities. The aftermath of these incidents is often characterized by calls for reflection and re-examination of the academic discipline's approach to safety research and policy. However, the study of academic lab safety is still underdeveloped and necessary data about changes in safety attitudes and behaviours has not been gathered. This Review article critically examines the state of academic chemical safety research from a multifactorial stance, including research on the occurrence of lab accidents, contributors to lab accidents, the state of safety training research and the cultural barriers to conducting safety research and implementing safer lab practices. The Review concludes by delineating research questions that must be addressed to minimize future serious academic laboratory incidents as well as stressing the need for committed leadership from our research institutions.

https://www.nature.com/articles/s41557-019-0375-x.pdf?origin=ppub

PRESENTATION GOALS

"In one survey from Nature and UCLA of 2,400 scientists, 30% reported having witnessed a lab injury severe enough to warrant attention from a medical professional"

nature chemistry

REVIEW ARTICLE

https://doi.org/10.1038/s41557-019-0375-x

A review and critique of academic lab safety research

A. Dana Ménard[1*] and John F. Trant[2*]

Over the past ten years, there have been several high-profile accidents in academic laboratories around the world, resulting in significant injuries and fatalities. The aftermath of these incidents is often characterized by calls for reflection and re-examination of the academic discipline's approach to safety research and policy. However, the study of academic lab safety is still underdeveloped and necessary data about changes in safety attitudes and behaviours has not been gathered. This Review article critically examines the state of academic chemical safety research from a multifactorial stance, including research on the occurrence of lab accidents, contributors to lab accidents, the state of safety training research and the cultural barriers to conducting safety research and implementing safer lab practices. The Review concludes by delineating research questions that must be addressed to minimize future serious academic laboratory incidents as well as stressing the need for committed leadership from our research institutions.

https://www.nature.com/articles/s41557-019-0375-x.pdf?origin=ppub

PRESENTATION GOALS

"In one survey from Nature and UCLA of 2,400 scientists, 30% reported having witnessed a lab injury severe enough to warrant attention from a medical professional"


nature chemistry
REVIEW ARTICLE
https://doi.org/10.1038/s41557-019-0375-x

A review and critique of academic lab safety research

A. Dana Ménard[1*] and John F. Trant[2*]

Over the past ten years, there have been several high-profile accidents in academic laboratories around the world, resulting in significant injuries and fatalities. The aftermath of these incidents is often characterized by calls for reflection and re-examination of the academic discipline's approach to safety research and policy. However, the study of academic lab safety is still underdeveloped and necessary data about changes in safety attitudes and behaviours has not been gathered. This Review article critically examines the state of academic chemical safety research from a multifactorial stance, including research on the occurrence of lab accidents, contributors to lab accidents, the state of safety training research and the cultural barriers to conducting safety research and implementing safer lab practices. The Review concludes by delineating research questions that must be addressed to minimize future serious academic laboratory incidents as well as stressing the need for committed leadership from our research institutions.

"In 2016, Grabowski and Goode found that only 8% of the 726 chemistry journals they identified required safety factors to be mentioned in the manuscript."

https://www.nature.com/articles/s41557-019-0375-x.pdf?origin=ppub

PRESENTATION GOALS

"In one survey from Nature and UCLA of 2,400 scientists, 30% reported having witnessed a lab injury severe enough to warrant attention from a medical professional"

"In 2016, Grabowski and Goode found that only 8% of the 726 chemistry journals they identified required safety factors to be mentioned in the manuscript."

"In Ayi and Hon's study, 27% of participants, active experimental researchers, stated that they never conducted any kind of risk assessment before performing laboratory work"

https://www.nature.com/articles/s41557-019-0375-x.pdf?origin=ppub

PRESENTATION GOALS

nature chemistry

REVIEW ARTICLE

https://doi.org/10.1038/s41557-019-0375-x

A review and critique of academic lab safety research

A. Dana Ménard[1*] and John F. Trant[2*]

Over the past ten years, there have been several high-profile accidents in academic laboratories around the world, resulting in significant injuries and fatalities. The aftermath of these incidents is often characterized by calls for reflection and re-examination of the academic discipline's approach to safety research and policy. However, the study of academic lab safety is still underdeveloped and necessary data about changes in safety attitudes and behaviours has not been gathered. This Review article critically examines the state of academic chemical safety research from a multifactorial stance, including research on the occurrence of lab accidents, contributors to lab accidents, the state of safety training research and the cultural barriers to conducting safety research and implementing safer lab practices. The Review concludes by delineating research questions that must be addressed to minimize future serious academic laboratory incidents as well as stressing the need for committed leadership from our research institutions.

"In one survey from Nature and UCLA of 2,400 scientists, 30% reported having witnessed a lab injury severe enough to warrant attention from a medical professional"

"In 2016, Grabowski and Goode found that only 8% of the 726 chemistry journals they identified required safety factors to be mentioned in the manuscript."

"In Ayi and Hon's study, 27% of participants, active experimental researchers, stated that they never conducted any kind of risk assessment before performing laboratory work"

"…who found that only 40% of their participants and academic researchers reported wearing PPE at all times when working"

https://www.nature.com/articles/s41557-019-0375-x.pdf?origin=ppub

INTRODUCTION TO HAZARD AND RISK

INTRODUCTION TO HAZARD AND RISK (I'M SORRY)

DEFINITIONS OF HAZARD AND RISK

Hazard: A Hazard is a *potential source of harm or adverse health effect* on a person or persons

DEFINITIONS OF HAZARD AND RISK

Hazard: A Hazard is a *potential source of harm or adverse health effect* on a person or persons

Risk: Risk is the ***probability*** that a person may be harmed or suffers adverse health effects if exposed to a ***hazard*** x ***severity*** of the exposure

DEFINITIONS OF HAZARD AND RISK

What is the hazard?

DEFINITIONS OF HAZARD AND RISK

What is the hazard? *Unsafe working at height*

DEFINITIONS OF HAZARD AND RISK

What is the hazard? *Unsafe working at height*

What is the *risk* that the person may be harmed?

DEFINITIONS OF HAZARD AND RISK

Probability	Critical: 3	Moderate: 2	Marginal: 1
Probable: 3	High - 9	High - 6	Medium - 3
Occasional: 2	High - 6	Medium - 4	Low - 2
Improbable: 1	Medium - 3	Low - 2	Low - 1

Probability × **Severity** = **Risk**

DEFINITIONS OF HAZARD AND RISK

Probability	Severity		
	Critical: 3	Moderate: 2	Marginal: 1
Probable: 3	High - 9	High - 6	Medium - 3
Occasional: 2	High - 6	Medium - 4	Low - 2
Improbable: 1	Medium - 3	Low - 2	Low - 1

Probability × **Severity** = **Risk**

Improbable = 1 × Moderate = 2 = Low = 2

DEFINITIONS OF HAZARD AND RISK

What is the hazard?
Unsafe working at height

DEFINITIONS OF HAZARD AND RISK

What is the hazard?
Unsafe working at height

What is the risk that the person may be harmed?

DEFINITIONS OF HAZARD AND RISK

What is the hazard?
Unsafe working at height

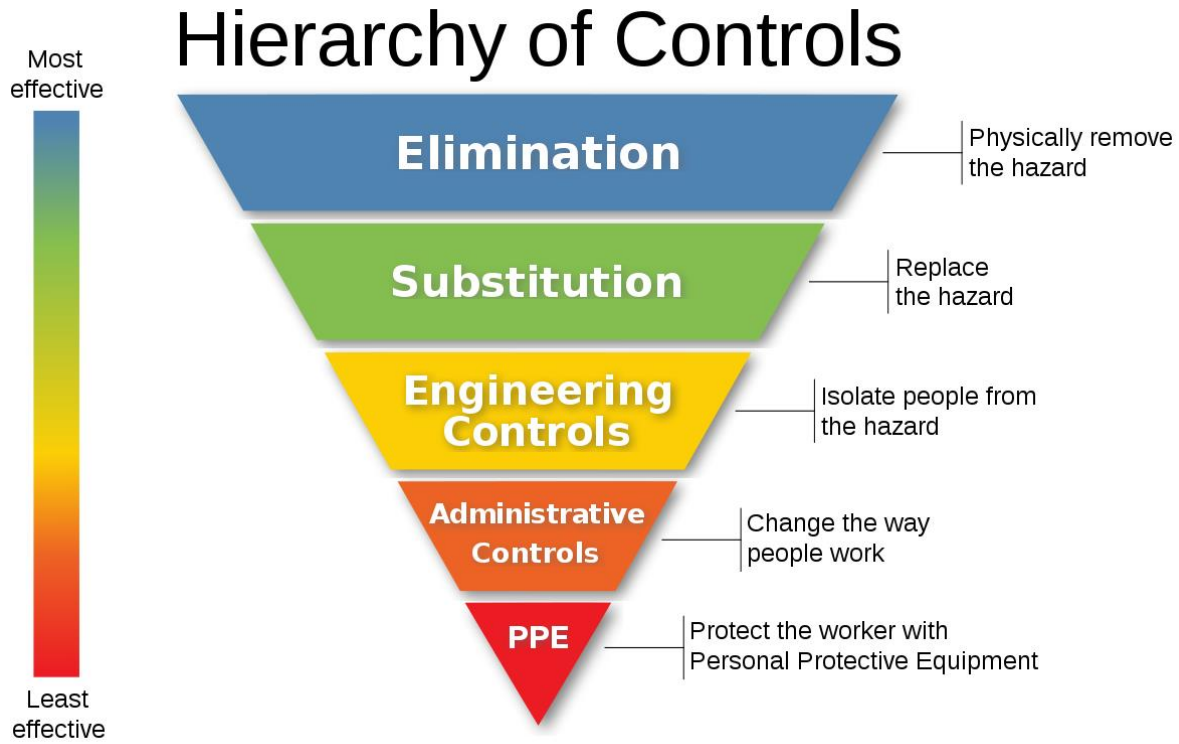
What is the risk that the person may be harmed?

Low Risk

The hazard is the same, but the risk of injury is different!

High Risk

HOW DO WE REDUCE RISK OF EXPOSURE TO A HAZARD?



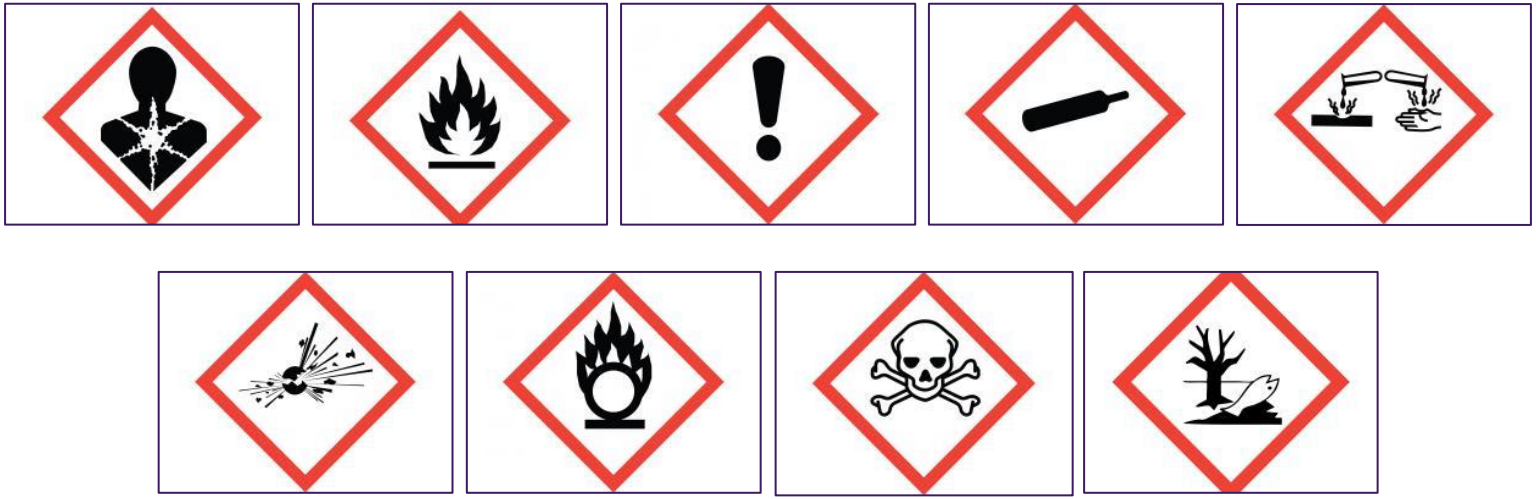
https://www.cdc.gov/niosh/topics/hierarchy/

IDENTIFYING GENERAL CHEMICAL HAZARDS

IDENTIFYING CHEMICAL HAZARDS

In 2016, OSHA implemented the Globally Harmonized System of Classification and Labeling of Chemicals (GHS) in the U.S.

The GHS system, part of OSHA's Hazard Communication Standard (HCS), consists of nine symbols providing recognition of the hazards associated with certain substances. Use of eight of the nine are mandatory in the U.S., the exception being the environmental pictogram.



IDENTIFYING CHEMICAL HAZARDS

Health Hazard

Carcinogen, mutagenicity,
reproductive toxicity,
respiratory sensitizer,
target organ toxicity,
aspiration toxicity

Flame

Flammables, pyrophorics,
self-heating,
emits flammable gas,
self-reactives,
organic peroxides

Exploding Bomb

Explosives,
self-reactives,
organic peroxides

Exclamation Mark

Irritant (skin and eye),
skin sensitizer,
acute toxicity (harmful),
narcotic effects,
respiratory tract irritant,
hazardous to ozone layer

Gas Cylinder

Gases under pressure

Corrosion

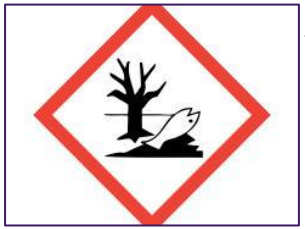
Skin corrosion/burns,
eye damage,
corrosive to metals

Flame Over Circle

Oxidizers

Skull and Crossbones

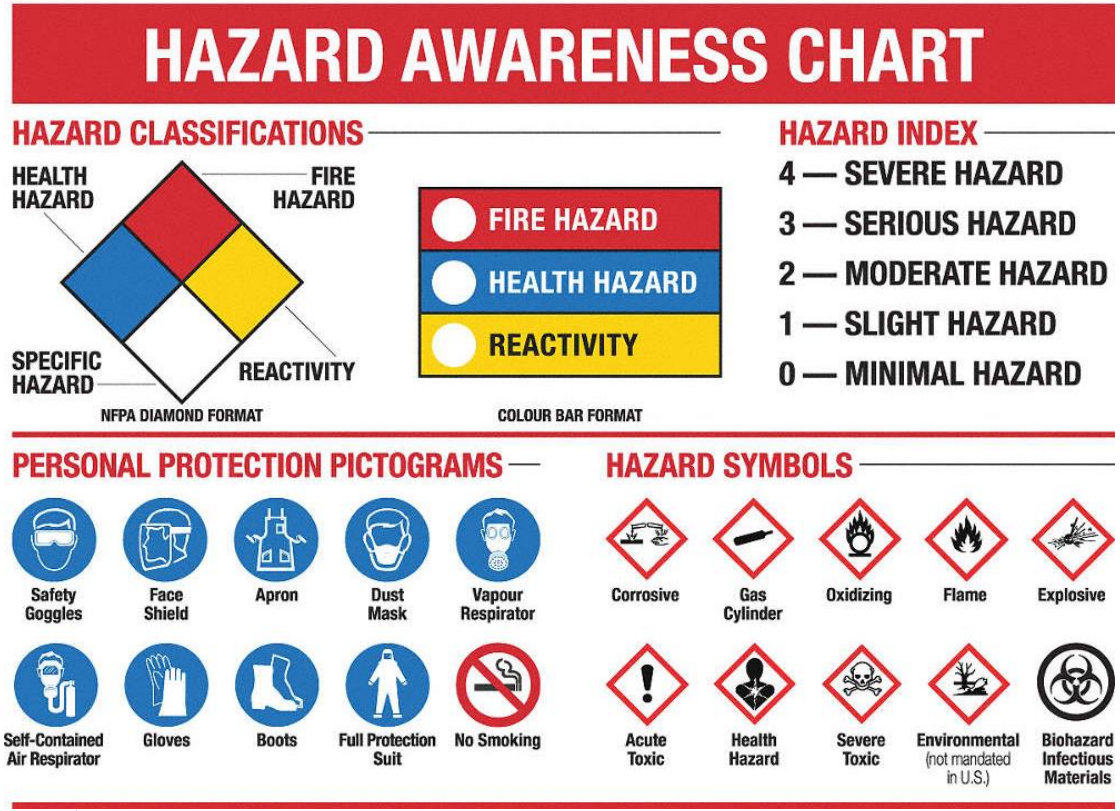
Acute toxicity (death)



Environmental

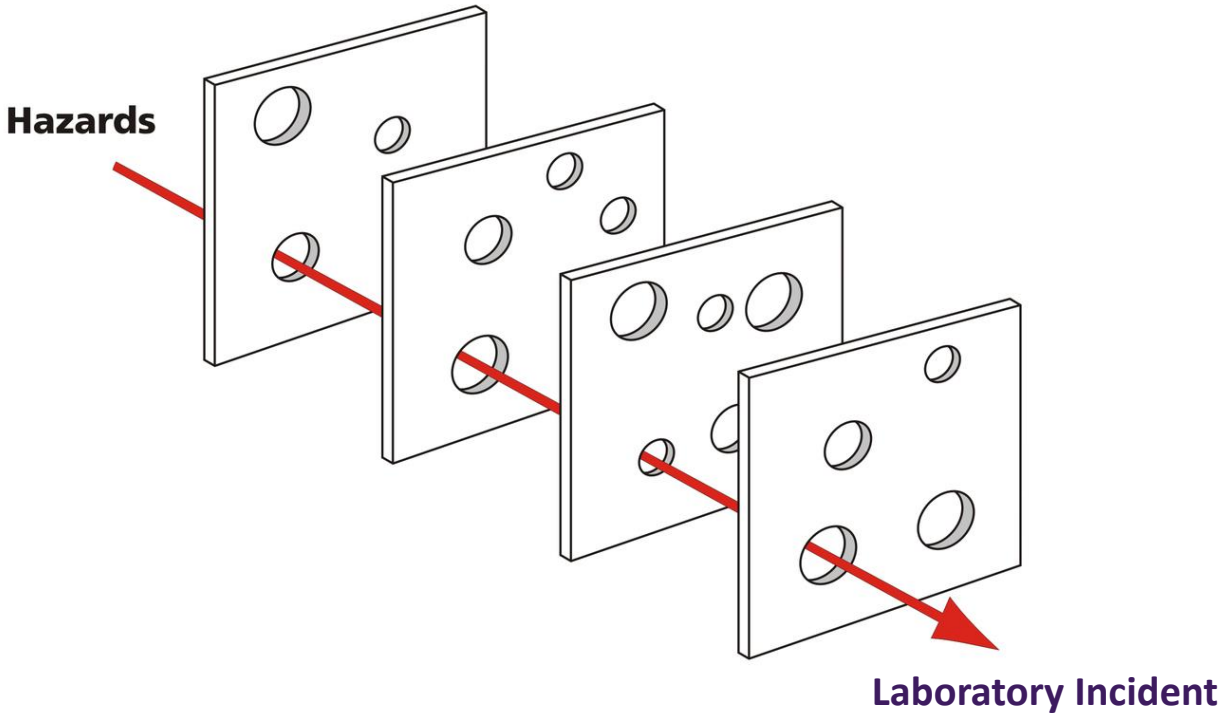
Environmental toxicity

IDENTIFYING CHEMICAL HAZARDS



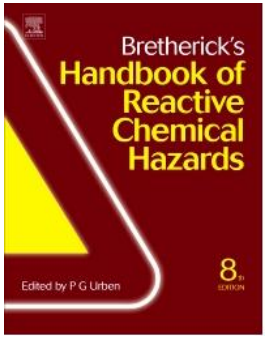
IDENTIFYING SPECIFIC CHEMICAL HAZARDS

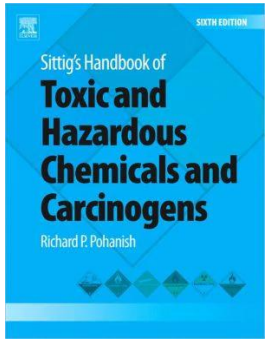
IDENTIFYING CHEMICAL HAZARDS - SWISS CHEESE MODEL

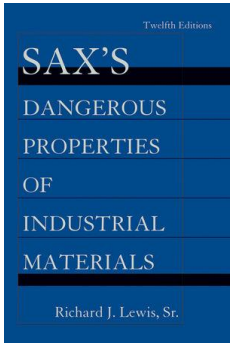


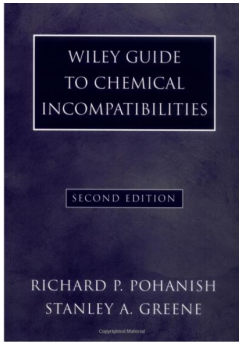
IDENTIFYING CHEMICAL HAZARDS

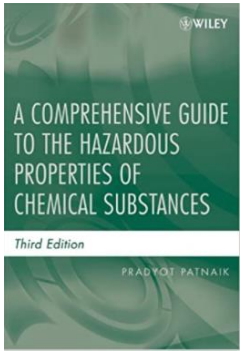
- **Inexpensive (< $1,000)**
  - Bretherick's Handbook of Reactive Chemical Hazards
  - Sittig's Handbook of Toxic and Hazardous Chemicals and Carcinogens
  - Sax's Dangerous Properties of Industrial Materials
  - Wiley Guide to Chemical Incompatibilities
  - Comprehensive Guide to the Hazardous Properties of Chemical Substances





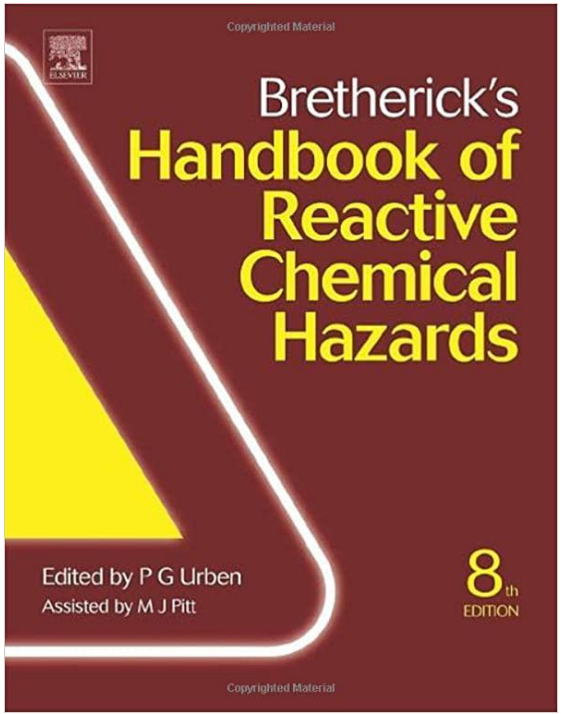






BRETHERICK'S HANDBOOK OF REACTIVE CHEMICAL HAZARDS

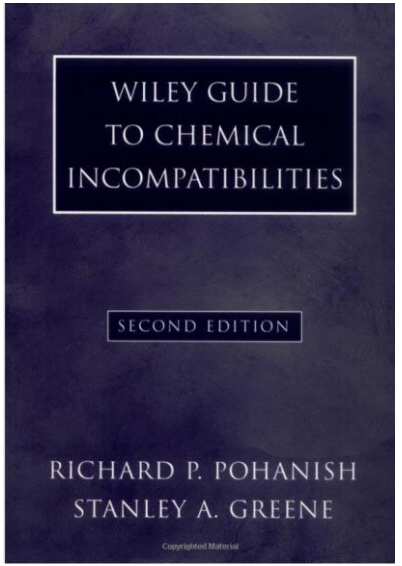
- The “Gold Standard” for reactive chemical hazards
- Covers unexpected loss of containment and explosion hazards from chemicals
- Also discloses incidents, some anecdotal
- Easily searchable, good reference list
- Cost: ~$550; Also available online!



https://www.sciencedirect.com/book/9780081009710/brethericks-handbook-of-reactive-chemical-hazards

WILEY GUIDE TO CHEMICAL INCOMPATIBILITIES

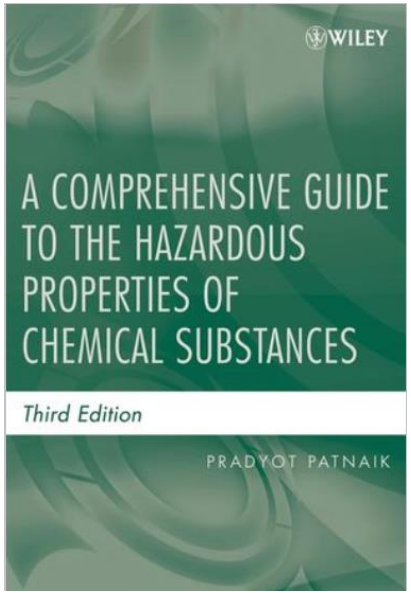
- My #2 recommendation (Bretherick's is #1)
- Hard-to-find data on over 11,000 chemical substances
- Easy to search alphabetical organization and CAS numbers to avoid confusion
- Cost: ~$800 (3rd Edition); ~$200 (2nd Edition)



https://onlinelibrary.wiley.com/doi/book/10.1002/9780470523315

COMPREHENSIVE GUIDE TO THE HAZARDOUS PROPERTIES OF CHEMICAL SUBSTANCES

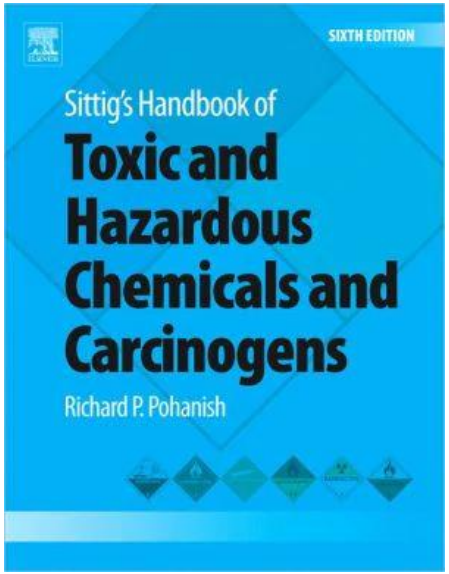
- Examines organics, metals and inorganics, industrial solvents, common gases, particulates, explosives, and radioactive substances, covers toxicity, carcinogenicity, flammability, explosive reactivity, handling, and disposal practices
- Arranges hazardous chemical substances according to their chemical structures and functional groups for easy reference
- Includes updated information on the toxic, flammable, and explosive properties of chemical substances
- Covers additional metals in the chapters on toxic and reactive metals
- Cost: ~$250



https://www.wiley.com/en-ie/A+Comprehensive+Guide+to+the+Hazardous+Properties+of+Chemical+Substances,+3rd+Edition-p-9780471714583

SITTIG'S HANDBOOK OF TOXIC AND HAZARDOUS CHEMICALS AND CARCINOGENS

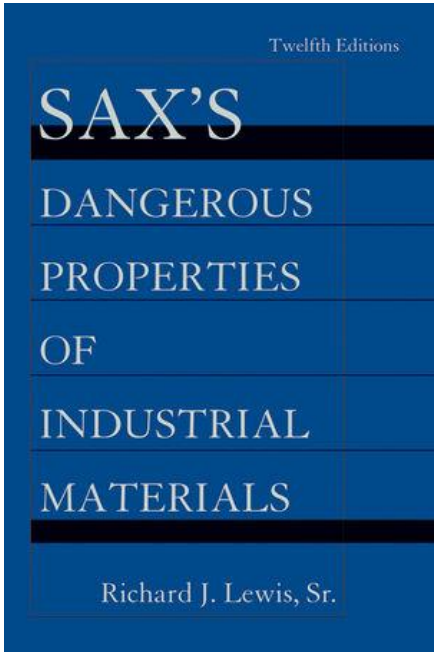
- Covers 2,100 of the most heavily used, transported and regulated chemicals of both occupational and environmental concern
- Chemicals are presented alphabetically and classified as a carcinogen, hazardous substance, hazardous waste, or toxic pollutant
- Highly valuable to engineers and manufacturing personnel
- Cost: ~$475



https://www.elsevier.com/books/sittigs-handbook-of-toxic-and-hazardous-chemicals-and-carcinogens/pohanish/978-1-4377-7869-4

SAX'S DANGEROUS PROPERTIES OF INDUSTRIAL MATERIALS

- Three volume set first introduced in the 1950s
- Only reference that combines data on toxicological, fire, reactivity, explosive potential, and regulatory information
- Now in its twelfth edition, it contains extensive data on approximately 28,000 substances, including 2000 new entries
- Cost: ~$750

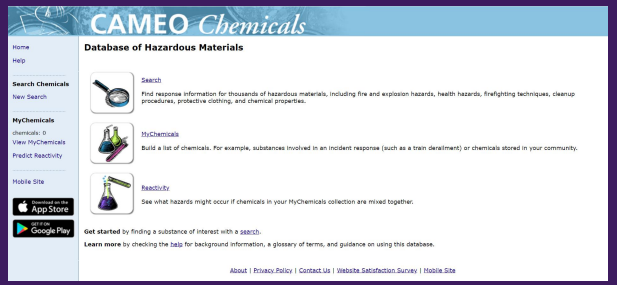


https://www.wiley.com/en-us/Sax's+Dangerous+Properties+of+Industrial+Materials,+5+Volume+Set,+12th+Edition-p-9780470623251

IDENTIFYING CHEMICAL HAZARDS – FREE RESOURCES

IDENTIFYING CHEMICAL HAZARDS – FREE RESOURCES

CAMEO Incompatibility Matrix



Safety Data Sheets

HEFG List

High Energy Functional Groups (HEFG)

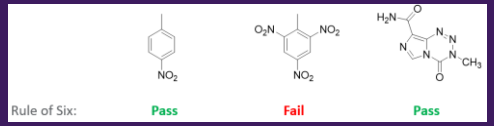
All Substances Containing:

	Acetylenic, metal acetylides, haloacetylene derivatives, allenes, etc.		X= C,O,N. Cyclopropanes, epoxides, and aziridines
	X= O,N. Oxetanes and azetidines		X= C,N. 1,3,5-triazines and pyrimidines
	Hydrazines, hydrazones, etc		N-N double or triple bonds, i.e. pyridizines, azo, diazonium salts, azides, diazirines and other high nitrogen containing compounds like triazoles, triazenes, tetrazoles, etc.
	O-O bonds, i.e. peroxides, peroxyacids and their salts, hydroperoxides, peroxyesters, etc.		Halogen azides, N-halogen compounds, N-haloimides, etc.
	Alkyl perchlorates, aminium perchlorates, chlorite salts, halogen oxides, hypohalites, perchloryl compounds, etc. including bromates and iodates.		N-O bonds, such as isozazoles, nitro, nitroso, hydroxylamines, nitrite, nitrate, fulminates, oximes, oximates, etc.
	Metal nitrides, amides, hydrazides, imides, cyanamide. Main concern is the pyrophoric nature of the pure solid material. Dilute solutions of metal amides and substituted amides (i.e. LDA, LiHMDS) are generally acceptable depending on use and fate of excess quantities.		Non-catalytic use of haloarylmetals, haloarenemetal pi-complexes. Note: Only Grignards of concern are halo-phenyl Gringnards containing trifluoromethyl moieties.

ExFG List

Structural Feature	Examples
C – C Unsaturation	Acetylene, acetylides, 1,2-dienes (allenes)
C-Metal, N-Metal	Grignard reagents, organo-lithium species
Contiguous nitrogen atoms	Azides, aliphatic azo compounds, diazonium salts, hydrazines, sulfonyl hydrazides
Contiguous oxygen atoms	Peroxides, ozonides
N-O	Nitro, nitroso, nitrates, hydroxylamines, N-oxides, 1,2-oxazoles
N-halogen, O-halogen	Chloramines, fluoroamines, chlorates, perchlorates, iodosyl compounds

Rule of Six

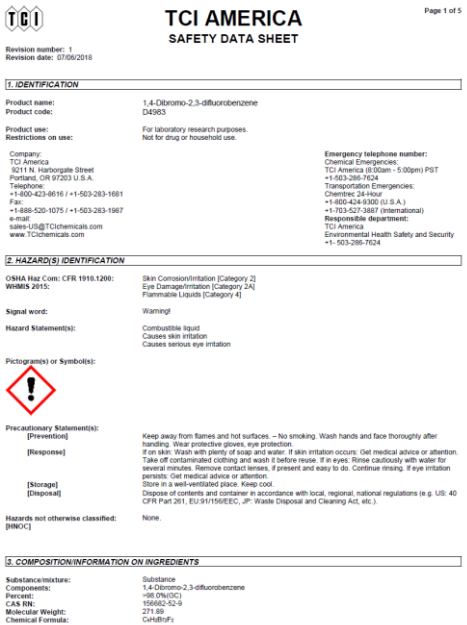


Oxygen Balance Calculation

$$Oxygen\ Balance = \frac{\left[-1600\left(2X + \frac{Y}{2} - Z\right)\right]}{MW}$$

IDENTIFYING CHEMICAL HAZARDS – SAFETY DATA SHEETS

- The Hazard Communication Standard (HCS) (29 CFR 1910.1200(g)), revised in 2012, requires that the chemical manufacturer, distributor, or importer provide Safety Data Sheets (SDSs) for each hazardous chemical to downstream users to communicate information on these hazards.
- SDSs are required to be presented in a consistent user-friendly, 16-section format.



TCI AMERICA
SAFETY DATA SHEET

Page 1 of 5

Revision number: 1
Revision date: 07/06/2018

1. IDENTIFICATION

Product name: 1,4-Dibromo-2,3-difluorobenzene
Product code: D4983

Product use: For laboratory research purposes.
Restrictions on use: Not for drug or household use.

Company:
TCI America
9211 N. Harborgate Street
Portland, OR 97203 U.S.A.
Telephone:
+1-800-423-8616 / +1-503-283-1681
Fax:
+1-888-520-1075 / +1-503-283-1987
e-mail:
sales-US@TCIchemicals.com
www.TCIchemicals.com

Emergency telephone number:
Chemical Emergencies:
TCI America (8:00am - 5:00pm) PST
+1-503-286-7624
Transportation Emergencies:
Chemtrec 24-Hour
+1-800-424-9300 (U.S.A.)
+1-703-527-3887 (International)
Responsible department:
TCI America
Environmental Health Safety and Security
+1- 503-286-7624

2. HAZARD(S) IDENTIFICATION

OSHA Haz Com: CFR 1910.1200:
WHMIS 2015:
Skin Corrosion/Irritation [Category 2]
Eye Damage/Irritation [Category 2A]
Flammable Liquids [Category 4]

Signal word: Warning!

Hazard Statement(s):
Combustible liquid
Causes skin irritation
Causes serious eye irritation

Pictogram(s) or Symbol(s):

Precautionary Statement(s):
[Prevention] Keep away from flames and hot surfaces. – No smoking. Wash hands and face thoroughly after handling. Wear protective gloves, eye protection.
[Response] If on skin: Wash with plenty of soap and water. If skin irritation occurs: Get medical advice or attention. Take off contaminated clothing and wash it before reuse. If in eyes: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing. If eye irritation persists: Get medical advice or attention.
[Storage] Store in a well-ventilated place. Keep cool.
[Disposal] Dispose of contents and container in accordance with local, regional, national regulations (e.g. US: 40 CFR Part 261, EU:91/156/EEC, JP: Waste Disposal and Cleaning Act, etc.).

Hazards not otherwise classified: [HNOC] None.

3. COMPOSITION/INFORMATION ON INGREDIENTS

Substance/mixture: Substance
Components: 1,4-Dibromo-2,3-difluorobenzene
Percent: >98.0%(GC)
CAS RN: 156682-52-9
Molecular Weight: 271.89
Chemical Formula: $C_6H_2Br_2F_2$

IDENTIFYING CHEMICAL HAZARDS – SAFETY DATA SHEETS

Section 1. Identification	Section 9. Physical and Chemical Properties
Section 2. Hazard(s) Identification	Section 10. Stability and Reactivity
Section 3. Composition/Information on Ingredients	Section 11. Toxicological Information
Section 4. First-Aid Measures	Section 12. Ecological Information (non-mandatory)
Section 5. Fire-Fighting Measures	Section 13. Disposal Considerations (non-mandatory)
Section 6. Accidental Release Measures	Section 14. Transport Information (non-mandatory)
Section 7. Handling and Storage	Section 15. Regulatory Information (non-mandatory)
Section 8. Exposure Controls/Personal Protection	Section 16. Other Information

IDENTIFYING CHEMICAL HAZARDS – SAFETY DATA SHEETS

Section 1. Identification	Section 9. Physical and Chemical Properties
Section 2. Hazard(s) Identification	Section 10. Stability and Reactivity
Section 3. Composition/Information on Ingredients	Section 11. Toxicological Information
Section 4. First-Aid Measures	Section 12. Ecological Information (non-mandatory)
Section 5. Fire-Fighting Measures	Section 13. Disposal Considerations (non-mandatory)
Section 6. Accidental Release Measures	Section 14. Transport Information (non-mandatory)
Section 7. Handling and Storage	Section 15. Regulatory Information (non-mandatory)
Section 8. Exposure Controls/Personal Protection	Section 16. Other Information

IDENTIFYING CHEMICAL HAZARDS – SAFETY DATA SHEETS

Section 1. Identification	Section 9. Physical and Chemical Properties
Section 2. Hazard(s) Identification	Section 10. Stability and Reactivity
Section 3. Composition/Information on Ingredients	Section 11. Toxicological Information
Section 4. First-Aid Measures	Section 12. Ecological Information (non-mandatory)
Section 5. Fire-Fighting Measures	Section 13. Disposal Considerations (non-mandatory)
Section 6. Accidental Release Measures	Section 14. Transport Information (non-mandatory)
Section 7. Handling and Storage	Section 15. Regulatory Information (non-mandatory)
Section 8. Exposure Controls/Personal Protection	Section 16. Other Information

IDENTIFYING CHEMICAL HAZARDS – SAFETY DATA SHEETS

SECTION 2. HAZARDS IDENTIFICATION

EMERGENCY OVERVIEW

Powder
White to tan or light pink
Odor unknown
Toxic if swallowed.
Prolonged exposure may cause serious health effects.
May be irritating to skin and eyes.
Mutagen.
May cause cancer.
May cause allergic reactions in susceptible individuals.
Causes birth defects.
Causes impaired fertility.
Causes effects to:
gastrointestinal tract
blood
bone marrow
immune system
male reproductive system
fetus
May cause effects to:
eye
skin
liver
respiratory system
Harmful to aquatic organisms.
May cause long-term adverse effects in the aquatic environment.

IDENTIFYING CHEMICAL HAZARDS – SAFETY DATA SHEETS

Section 1. Identification	Section 9. Physical and Chemical Properties
Section 2. Hazard(s) Identification	Section 10. Stability and Reactivity
Section 3. Composition/Information on Ingredients	Section 11. Toxicological Information
Section 4. First-Aid Measures	Section 12. Ecological Information (non-mandatory)
Section 5. Fire-Fighting Measures	Section 13. Disposal Considerations (non-mandatory)
Section 6. Accidental Release Measures	Section 14. Transport Information (non-mandatory)
Section 7. Handling and Storage	Section 15. Regulatory Information (non-mandatory)
Section 8. Exposure Controls/Personal Protection	Section 16. Other Information

IDENTIFYING CHEMICAL HAZARDS – SAFETY DATA SHEETS

SECTION 8. EXPOSURE CONTROLS AND PERSONAL PROTECTION

The following guidance applies to the handling of the active ingredient(s) in this formulation. The end-user should perform an appropriate risk assessment when handling other forms or formulations of this active ingredient.

OCCUPATIONAL EXPOSURE BAND (OEB):
OEB 5: <1 mcg/m^3. Materials in an OEB 5 category are considered extreme health hazards. The OEB is a range of airborne concentrations expressed as an 8-hour Time Weighted Average (8-hr. TWA) and is intended to be used with Industrial Hygiene Risk Assessment to assist with industrial hygiene sampling and selection of proper controls for worker protection. Consult your site safety and industrial hygiene staff for guidance on handling and control strategies.

INTERNAL OCCUPATIONAL EXPOSURE LIMIT (8-hr TWA):
0.6 mcg/ m3

Wipe Limit:
6 mcg/100 cm2

IDENTIFYING CHEMICAL HAZARDS – SAFETY DATA SHEETS

Section 1. Identification	Section 9. Physical and Chemical Properties
Section 2. Hazard(s) Identification	Section 10. Stability and Reactivity
Section 3. Composition/Information on Ingredients	Section 11. Toxicological Information
Section 4. First-Aid Measures	Section 12. Ecological Information (non-mandatory)
Section 5. Fire-Fighting Measures	Section 13. Disposal Considerations (non-mandatory)
Section 6. Accidental Release Measures	Section 14. Transport Information (non-mandatory)
Section 7. Handling and Storage	Section 15. Regulatory Information (non-mandatory)
Section 8. Exposure Controls/Personal Protection	Section 16. Other Information

IDENTIFYING CHEMICAL HAZARDS – SAFETY DATA SHEETS

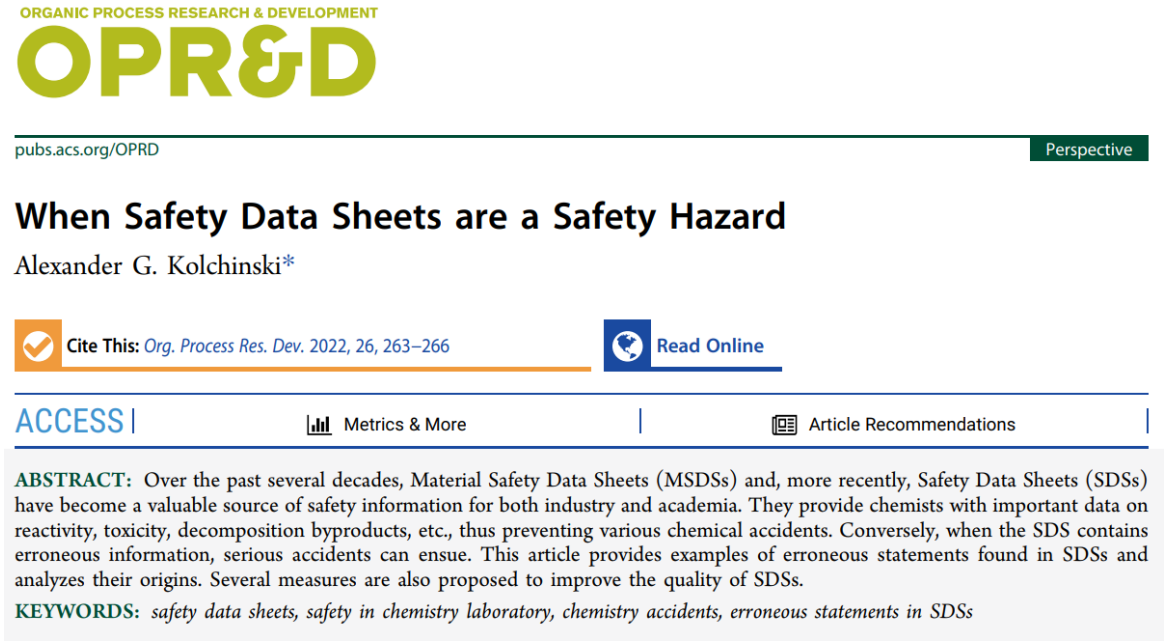
SECTION 10. STABILITY AND REACTIVITY

STABILITY/ REACTIVITY:
Stable under normal conditions.

INCOMPATIBLE MATERIALS / CONDITIONS TO AVOID:
Heat. Oxidizers. Strong acids and bases.

HAZARDOUS DECOMPOSITION PRODUCTS / REACTIONS:
Carbon oxides (COx). Nitrogen oxides (NOx).

IDENTIFYING CHEMICAL HAZARDS – SAFETY DATA SHEETS



ORGANIC PROCESS RESEARCH & DEVELOPMENT

OPR&D

pubs.acs.org/OPRD Perspective

When Safety Data Sheets are a Safety Hazard

Alexander G. Kolchinski*

Cite This: *Org. Process Res. Dev.* 2022, 26, 263–266 Read Online

ACCESS | Metrics & More | Article Recommendations

ABSTRACT: Over the past several decades, Material Safety Data Sheets (MSDSs) and, more recently, Safety Data Sheets (SDSs) have become a valuable source of safety information for both industry and academia. They provide chemists with important data on reactivity, toxicity, decomposition byproducts, etc., thus preventing various chemical accidents. Conversely, when the SDS contains erroneous information, serious accidents can ensue. This article provides examples of erroneous statements found in SDSs and analyzes their origins. Several measures are also proposed to improve the quality of SDSs.

KEYWORDS: *safety data sheets, safety in chemistry laboratory, chemistry accidents, erroneous statements in SDSs*

https://pubs.acs.org/doi/pdf/10.1021/acs.oprd.1c00427

IDENTIFYING CHEMICAL HAZARDS – SAFETY DATA SHEETS

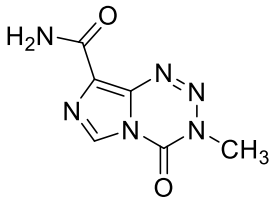
SECTION 8. EXPOSURE CONTROLS AND PERSONAL PROTECTION

The following guidance applies to the handling of the active ingredient(s) in this formulation. The end-user should perform an appropriate risk assessment when handling other forms or formulations of this active ingredient.

OCCUPATIONAL EXPOSURE BAND (OEB):
OEB 5: <1 mcg/m^3. Materials in an OEB 5 category are considered extreme health hazards. The OEB is a range of airborne concentrations expressed as an 8-hour Time Weighted Average (8-hr. TWA) and is intended to be used with Industrial Hygiene Risk Assessment to assist with industrial hygiene sampling and selection of proper controls for worker protection. Consult your site safety and industrial hygiene staff for guidance on handling and control strategies.

INTERNAL OCCUPATIONAL EXPOSURE LIMIT (8-hr TWA):
0.6 mcg/ m3 for

Wipe Limit:
6 mcg/100 cm2



Temozolomide (TMZ)

IDENTIFYING CHEMICAL HAZARDS – SAFETY DATA SHEETS

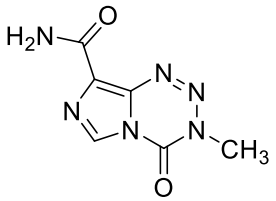
SECTION 8. EXPOSURE CONTROLS AND PERSONAL PROTECTION

The following guidance applies to the handling of the active ingredient(s) in this formulation. The end-user should perform an appropriate risk assessment when handling other forms or formulations of this active ingredient.

OCCUPATIONAL EXPOSURE BAND (OEB):
OEB 5: <1 mcg/m^3. Materials in an OEB 5 category are considered extreme health hazards. The OEB is a range of airborne concentrations expressed as an 8-hour Time Weighted Average (8-hr. TWA) and is intended to be used with Industrial Hygiene Risk Assessment to assist with industrial hygiene sampling and selection of proper controls for worker protection. Consult your site safety and industrial hygiene staff for guidance on handling and control strategies.

INTERNAL OCCUPATIONAL EXPOSURE LIMIT (8-hr TWA):
0.6 mcg/ m3 for

Wipe Limit:
6 mcg/100 cm2



Temozolomide (TMZ)

---

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

8.1 Control parameters

Components with workplace control parameters

This product contains no substances with occupational exposure limit values.

8.2 Exposure controls

Engineering controls

Ensure adequate ventilation. Provide accessible safety shower and eye wash station.

Personal protective equipment

Eye protection	Safety goggles with side-shields.
Hand protection	Protective gloves.
Skin and body protection	Impervious clothing.
Respiratory protection	Suitable respirator.
Environmental exposure controls	Keep the product away from drains, water courses or the soil.
	Clean spillages in a safe way as soon as possible.

IDENTIFYING CHEMICAL HAZARDS – SAFETY DATA SHEETS

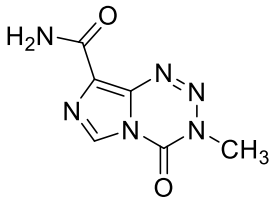
SECTION 8. EXPOSURE CONTROLS AND PERSONAL PROTECTION

The following guidance applies to the handling of the active ingredient(s) in this formulation. The end-user should perform an appropriate risk assessment when handling other forms or formulations of this active ingredient.

OCCUPATIONAL EXPOSURE BAND (OEB):
OEB 5: <1 mcg/m^3. Materials in an OEB 5 category are considered extreme health hazards. The OEB is a range of airborne concentrations expressed as an 8-hour Time Weighted Average (8-hr. TWA) and is intended to be used with Industrial Hygiene Risk Assessment to assist with industrial hygiene sampling and selection of proper controls for worker protection. Consult your site safety and industrial hygiene staff for guidance on handling and control strategies.

INTERNAL OCCUPATIONAL EXPOSURE LIMIT (8-hr TWA):
0.6 mcg/ m3 for

Wipe Limit:
6 mcg/100 cm2



Temozolomide (TMZ)

---

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

8.1 Control parameters

Components with workplace control parameters

This product contains no substances with occupational exposure limit values.

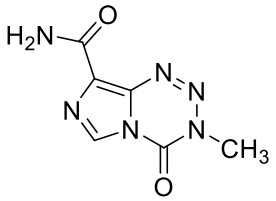
8.2 Exposure controls

Engineering controls

Ensure adequate ventilation. Provide accessible safety shower and eye wash station.

Personal protective equipment

Eye protection	Safety goggles with side-shields.
Hand protection	Protective gloves.
Skin and body protection	Impervious clothing.
Respiratory protection	Suitable respirator.
Environmental exposure controls	Keep the product away from drains, water courses or the soil. Clean spillages in a safe way as soon as possible.



Temozolomide (TMZ)

IDENTIFYING CHEMICAL HAZARDS – HEFG LIST

IDENTIFYING CHEMICAL HAZARDS – HEFG LIST

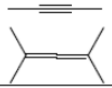
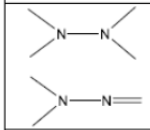
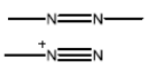
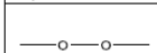
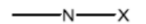
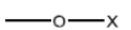
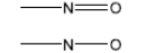
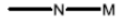
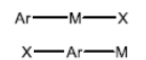
- A high-energy functional group (HEFG) is any functional group that is known to contribute to the exothermic decomposition of a molecule
- Compounds containing one or more HEFGs may be unsafe at any temperature
- The more HEFGs a compound has, the more exothermic its decomposition and the less stable

IDENTIFYING CHEMICAL HAZARDS – HEFG LIST

- A high-energy functional group (HEFG) is any functional group that is known to contribute to the exothermic decomposition of a molecule
- Compounds containing one or more HEFGs may be unsafe at any temperature
- The more HEFGs a compound has, the more exothermic its decomposition and the less stable

High Energy Functional Groups (HEFG)

All Substances Containing:

	Acetylenic, metal acetylides, haloacetylene derivatives, allenes, etc.		X= C,O,N. Cyclopropanes, epoxides, and aziridines
	X= O,N. Oxetanes and azetidines		X= C,N. 1,3,5-triazines and pyrimidines
	Hydrazines, hydrazones, etc		N-N double or triple bonds, i.e. pyridizines, azo, diazonium salts, azides, diazirines and other high nitrogen containing compounds like triazoles, triazenes, tetrazoles, etc.
	O-O bonds, i.e. peroxides, peroxyacids and their salts, hydroperoxides, peroxyesters, etc.		Halogen azides, N-halogen compounds, N-haloimides, etc.
	Alkyl perchlorates, aminium perchlorates, chlorite salts, halogen oxides, hypohalites, perchloryl compounds, etc. including bromates and iodates.		N-O bonds, such as isozazoles, nitro, nitroso, hydroxylamines, nitrite, nitrate, fulminates, oximes, oximates, etc.
	Metal nitrides, amides, hydrazides, imides, cyanamide. Main concern is the pyrophoric nature of the pure solid material. Dilute solutions of metal amides and substituted amides (i.e. LDA, LiHMDS) are generally acceptable depending on use and fate of excess quantities.		Non-catalytic use of haloarylmetals, haloarenemetal pi-complexes. Note: Only Grignards of concern are halo-phenyl Gringnards containing trifluoromethyl moieties.

IDENTIFYING CHEMICAL HAZARDS – EXFG LIST

- An explosive functional group (ExFG) is a functional group that can give a molecule explosive properties
- Every ExFG is also an HEFG but not all HEFGs are ExFGs
- The more ExFGs a compound has, the more likely it is to be classified as an explosive material

IDENTIFYING CHEMICAL HAZARDS – EXFG LIST

- An explosive functional group (ExFG) is a functional group that can give a molecule explosive properties
- Every ExFG is also an HEFG but not all HEFGs are ExFGs
- The more ExFGs a compound has, the more likely it is to be classified as an explosive material

Structural Feature	Examples
C – C Unsaturation	Acetylene, acetylides, 1,2-dienes (allenes)
C-Metal, N-Metal	Grignard reagents, organo-lithium species
Contiguous nitrogen atoms	Azides, aliphatic azo compounds, diazonium salts, hydrazines, sulfonyl hydrazides
Contiguous oxygen atoms	Peroxides, ozonides
N-O	Nitro, nitroso, nitrates, hydroxylamines, N-oxides, 1,2-oxazoles
N-halogen, O-halogen	Chloramines, fluoroamines, chlorates, perchlorates, iodosyl compounds

https://pubs.acs.org/doi/pdf/10.1021/acs.oprd.0c00467

IDENTIFYING CHEMICAL HAZARDS – RULE OF SIX

IDENTIFYING CHEMICAL HAZARDS – RULE OF SIX

Rule of 6

- Introduced by Peer in 1998
- Originally applied to azides but has since been applied to other materials containing explosive functional groups
- The "Rule of Six" states: **If a substance presents at least six atoms of carbon (or other atoms of approximately the same size) per energetic functionality (ExFG), this should render the molecule relatively safe to handle**

Peer, M. *Spec. Chem*. **1998**, *18*, 256 - 263.

IDENTIFYING CHEMICAL HAZARDS – RULE OF SIX

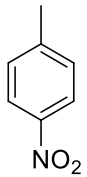
If a substance presents at least six atoms of carbon (or other atoms of approximately the same size) per energetic functionality (ExFG), this should render the molecule relatively safe to handle

Rule of Six **Pass** or **Fail**?

IDENTIFYING CHEMICAL HAZARDS – RULE OF SIX

If a substance presents at least six atoms of carbon (or other atoms of approximately the same size) per energetic functionality (ExFG), this should render the molecule relatively safe to handle

Rule of Six Pass or Fail?



Rule of Six:

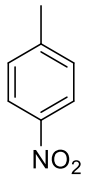
Explosive?

Safe to Handle?

IDENTIFYING CHEMICAL HAZARDS – RULE OF SIX

If a substance presents at least six atoms of carbon (or other atoms of approximately the same size) per energetic functionality (ExFG), this should render the molecule relatively safe to handle

Rule of Six Pass or Fail?



Rule of Six: **Pass**

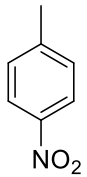
Explosive? **No**

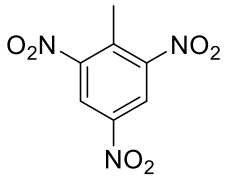
Safe to Handle? **Yes**

IDENTIFYING CHEMICAL HAZARDS – RULE OF SIX

If a substance presents at least six atoms of carbon (or other atoms of approximately the same size) per energetic functionality (ExFG), this should render the molecule relatively safe to handle

Rule of Six Pass or Fail?





Rule of Six: **Pass**

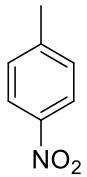
Explosive? **No**

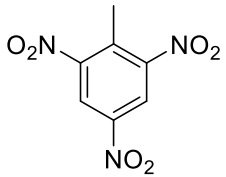
Safe to Handle? **Yes**

IDENTIFYING CHEMICAL HAZARDS – RULE OF SIX

If a substance presents at least six atoms of carbon (or other atoms of approximately the same size) per energetic functionality (ExFG), this should render the molecule relatively safe to handle

Rule of Six Pass or Fail?



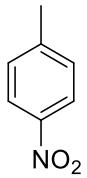


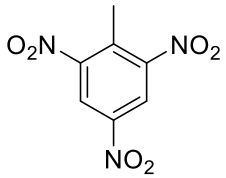
Rule of Six:	**Pass**	**Fail**
Explosive?	**No**	**Yes**
Safe to Handle?	**Yes**	**No**

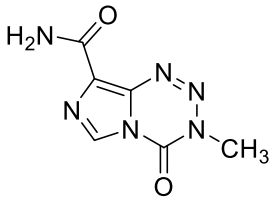
IDENTIFYING CHEMICAL HAZARDS – RULE OF SIX

If a substance presents at least six atoms of carbon (or other atoms of approximately the same size) per energetic functionality (ExFG), this should render the molecule relatively safe to handle

Rule of Six Pass or Fail?





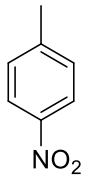


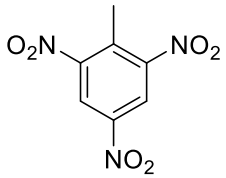
Rule of Six:	**Pass**	**Fail**
Explosive?	**No**	**Yes**
Safe to Handle?	**Yes**	**No**

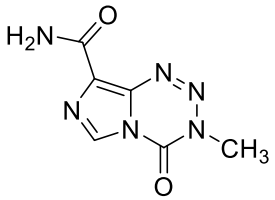
IDENTIFYING CHEMICAL HAZARDS – RULE OF SIX

If a substance presents at least six atoms of carbon (or other atoms of approximately the same size) per energetic functionality (ExFG), this should render the molecule relatively safe to handle

Rule of Six Pass or Fail?





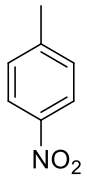


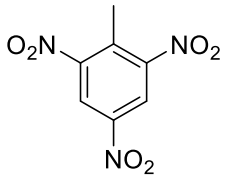
Rule of Six:	**Pass**	**Fail**	**Pass**
Explosive?	**No**	**Yes**	**Yes**
Safe to Handle?	**Yes**	**No**	**Yes**

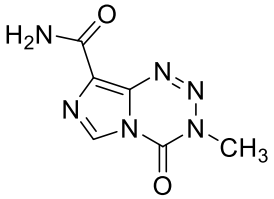
IDENTIFYING CHEMICAL HAZARDS – RULE OF SIX

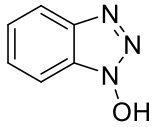
If a substance presents at least six atoms of carbon (or other atoms of approximately the same size) per energetic functionality (ExFG), this should render the molecule relatively safe to handle

Rule of Six Pass or Fail?







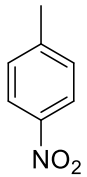


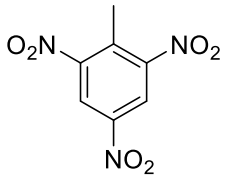
Rule of Six:	**Pass**	**Fail**	**Pass**
Explosive?	**No**	**Yes**	**Yes**
Safe to Handle?	**Yes**	**No**	**Yes**

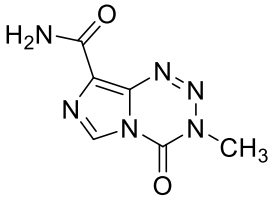
IDENTIFYING CHEMICAL HAZARDS – RULE OF SIX

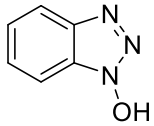
If a substance presents at least six atoms of carbon (or other atoms of approximately the same size) per energetic functionality (ExFG), this should render the molecule relatively safe to handle

Rule of Six Pass or Fail?







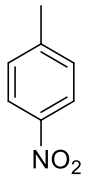


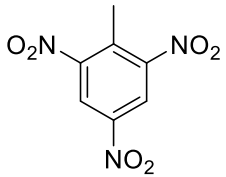
Rule of Six:	Pass	Fail	Pass	
Explosive?	No	Yes	Yes	Yes
Safe to Handle?	Yes	No	Yes	No

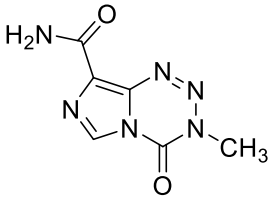
IDENTIFYING CHEMICAL HAZARDS – RULE OF SIX

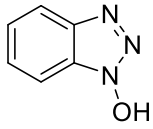
If a substance presents at least six atoms of carbon (or other atoms of approximately the same size) per energetic functionality (ExFG), this should render the molecule relatively safe to handle

Rule of Six Pass or Fail?







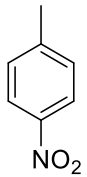


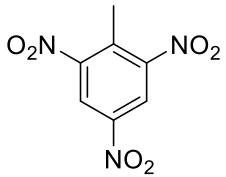
Rule of Six:	**Pass**	**Fail**	**Pass**	**Depends**
Explosive?	**No**	**Yes**	**Yes**	**Yes**
Safe to Handle?	**Yes**	**No**	**Yes**	**No**

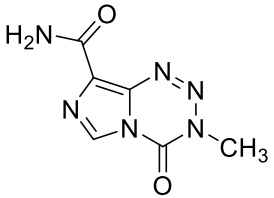
IDENTIFYING CHEMICAL HAZARDS – RULE OF SIX

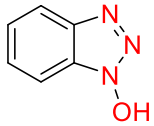
If a substance presents at least six atoms of carbon (or other atoms of approximately the same size) per energetic functionality (ExFG), this should render the molecule relatively safe to handle

Rule of Six Pass or Fail?







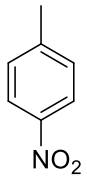


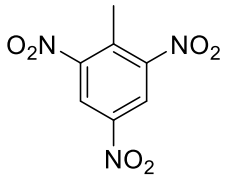
Rule of Six:	**Pass**	**Fail**	**Pass**	**Depends**
Explosive?	**No**	**Yes**	**Yes**	**Yes**
Safe to Handle?	**Yes**	**No**	**Yes**	**No**

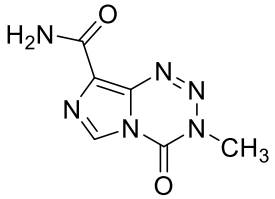
IDENTIFYING CHEMICAL HAZARDS – RULE OF SIX

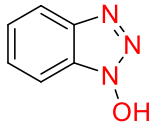
If a substance presents at least six atoms of carbon (or other atoms of approximately the same size) per energetic functionality (ExFG), this should render the molecule relatively safe to handle

Rule of Six Pass or Fail?









Rule of Six:	**Pass**	**Fail**	**Pass**	**Depends 1 ExFG = Pass; 2 ExFG = Fail**
Explosive?	**No**	**Yes**	**Yes**	**Yes**
Safe to Handle?	**Yes**	**No**	**Yes**	**No**

IDENTIFYING CHEMICAL HAZARDS – OXYGEN BALANCE CALCULATION

Oxygen Balance: For an organic compound with a molecular formula of $C_XH_YO_Z$ and molecular weight (MW), the OB can be obtained by the following equation:

Shanley, E. S.; Melhem, G. A. *Process Saf. Prog.* **1995**, *14*, 29– 31

IDENTIFYING CHEMICAL HAZARDS – OXYGEN BALANCE CALCULATION

Oxygen Balance: For an organic compound with a molecular formula of $C_XH_YO_Z$ and molecular weight (MW), the OB can be obtained by the following equation:

$$Oxygen\ Balance = \frac{\left[-1600\left(2X+\frac{Y}{2}-Z\right)\right]}{MW}$$

Shanley, E. S.; Melhem, G. A. *Process Saf. Prog.* **1995**, *14*, 29– 31

IDENTIFYING CHEMICAL HAZARDS – OXYGEN BALANCE CALCULATION

Oxygen Balance: For an organic compound with a molecular formula of $C_XH_YO_Z$ and molecular weight (MW), the OB can be obtained by the following equation:

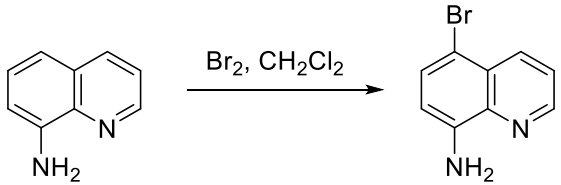
$$Oxygen\ Balance = \frac{\left[-1600\left(2X+\frac{Y}{2}-Z\right)\right]}{MW}$$

Shanley, E. S.; Melhem, G. A. *Process Saf. Prog.* **1995**, *14*, 29– 31

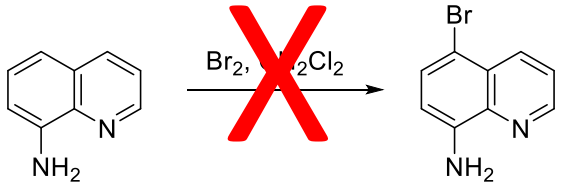
IDENTIFYING CHEMICAL HAZARDS – OXYGEN BALANCE CALCULATION

Compound	Oxygen Balance	Oxygen Balance Hazard Rank	Observed Hazard Rank
Hydrogen Peroxide	47	High	Medium-High
Water	0	High	None
Oxalic Acid	-18	High	None
Hydrazoic acid	-19	High	High
Acetyl peroxide	-95	High	High
Diazomethane	-114	High	High
t-Butyl Peroxide	-252	Low	High
Ethylene	-286	Low	Medium
Acetylene	-308	Low	High

IDENTIFYING CHEMICAL HAZARDS – CAMEO INCAPABILITY MATRIX

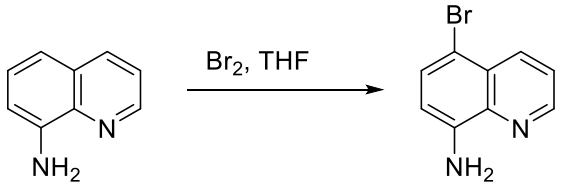


IDENTIFYING CHEMICAL HAZARDS – CAMEO INCAPABILITY MATRIX

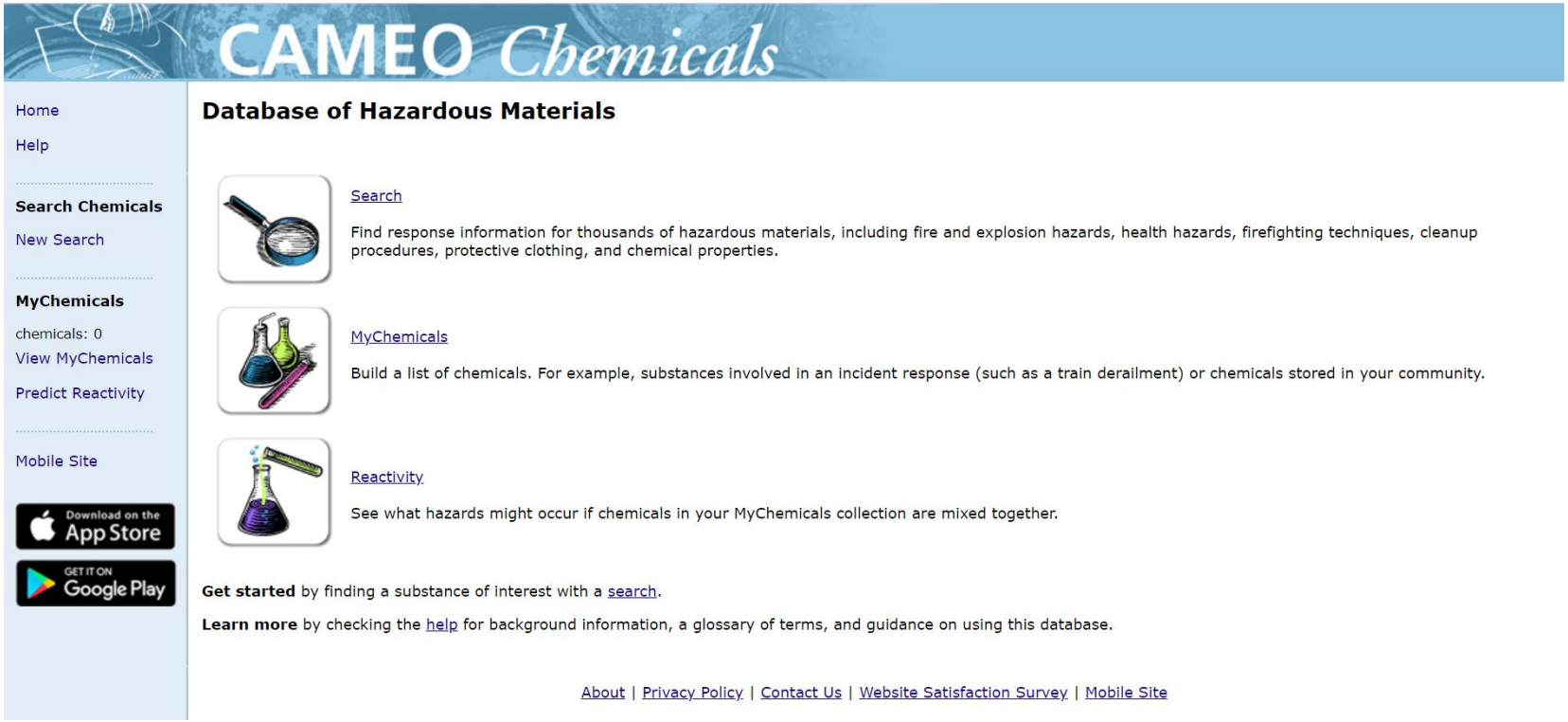


Insoluble in DCM

IDENTIFYING CHEMICAL HAZARDS – CAMEO INCAPABILITY MATRIX

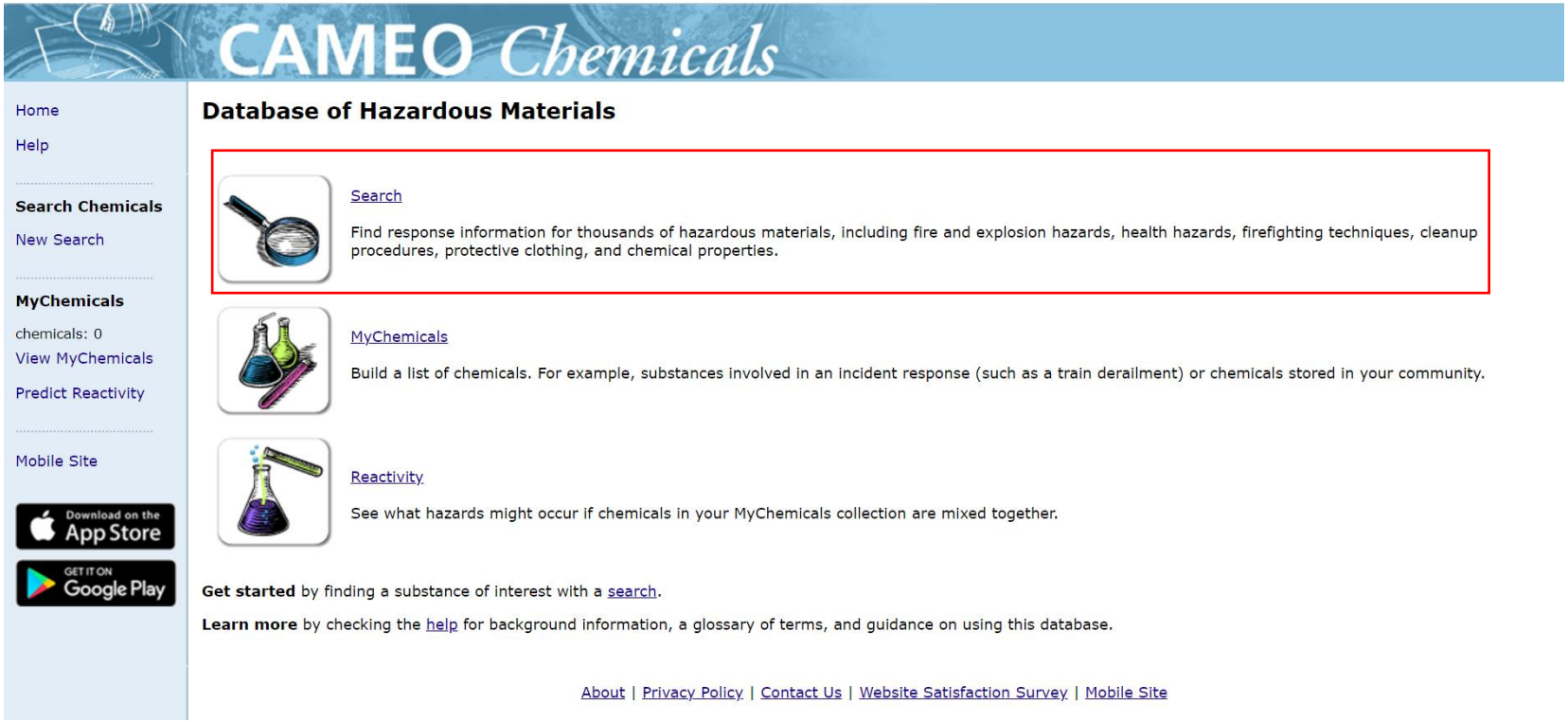


IDENTIFYING CHEMICAL HAZARDS – CAMEO INCOMPATIBILITY MATRIX



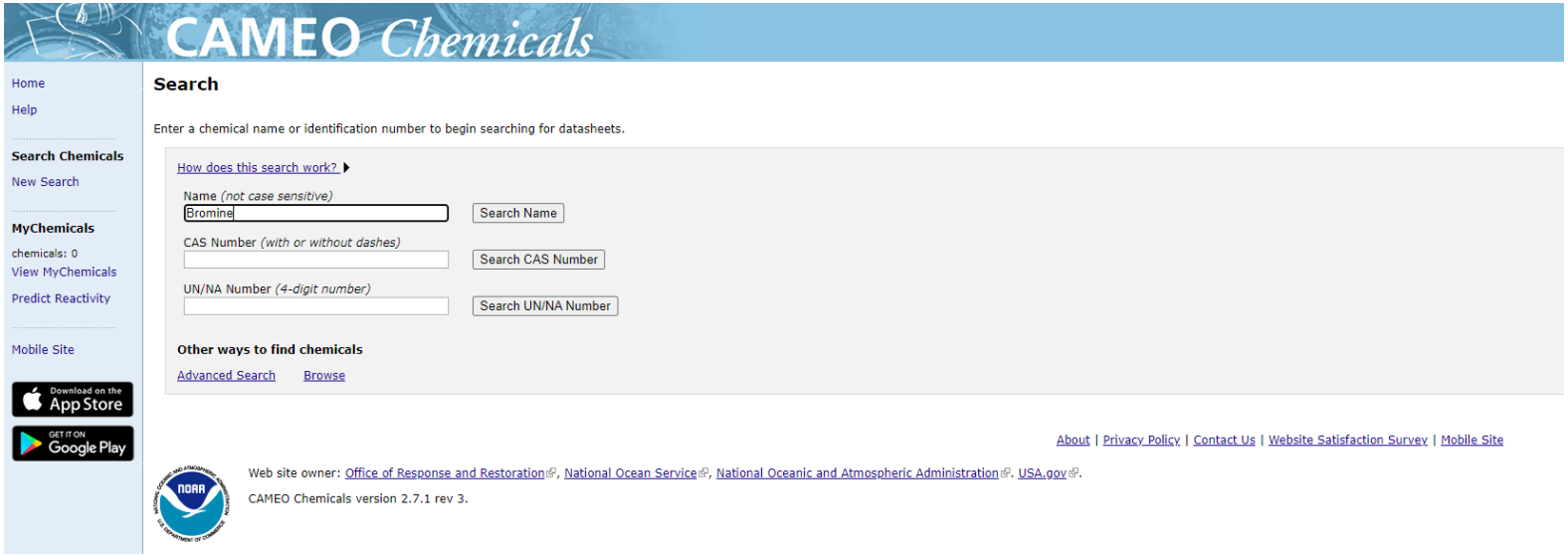
https://cameochemicals.noaa.gov/

IDENTIFYING CHEMICAL HAZARDS – CAMEO INCOMPATIBILITY MATRIX

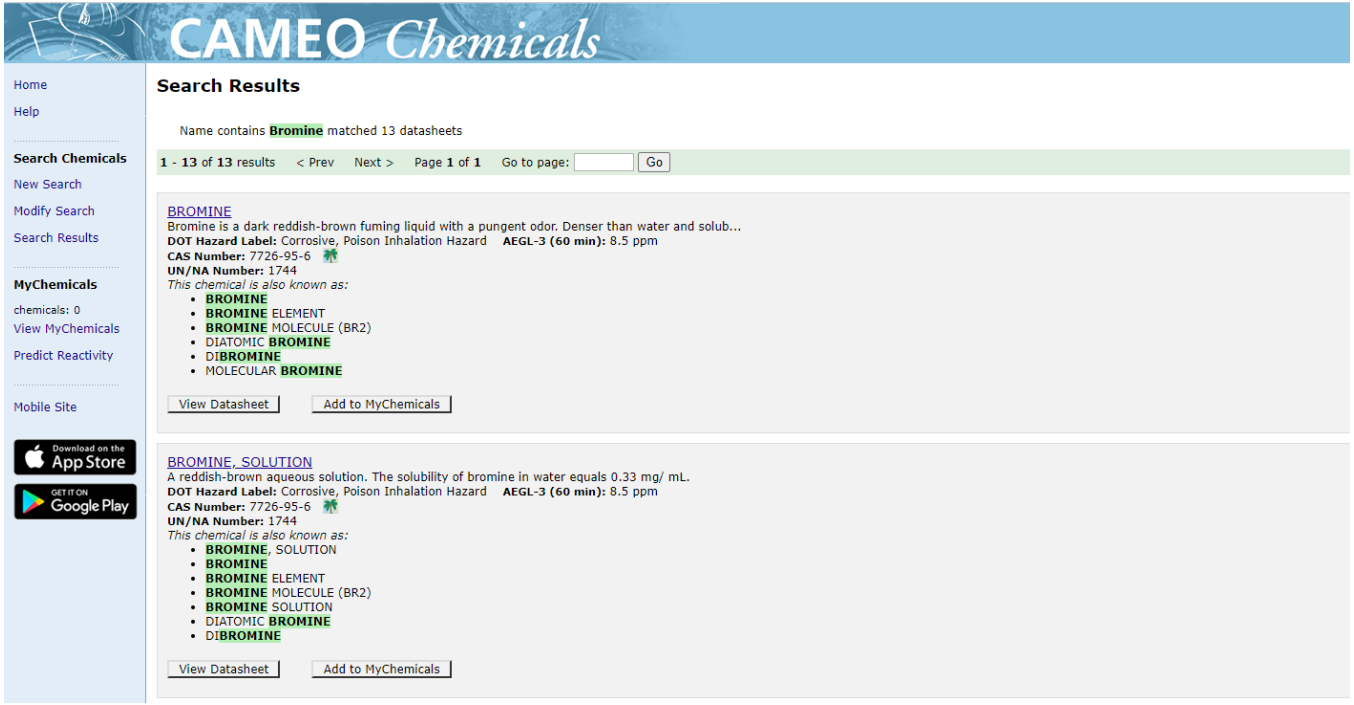


https://cameochemicals.noaa.gov/

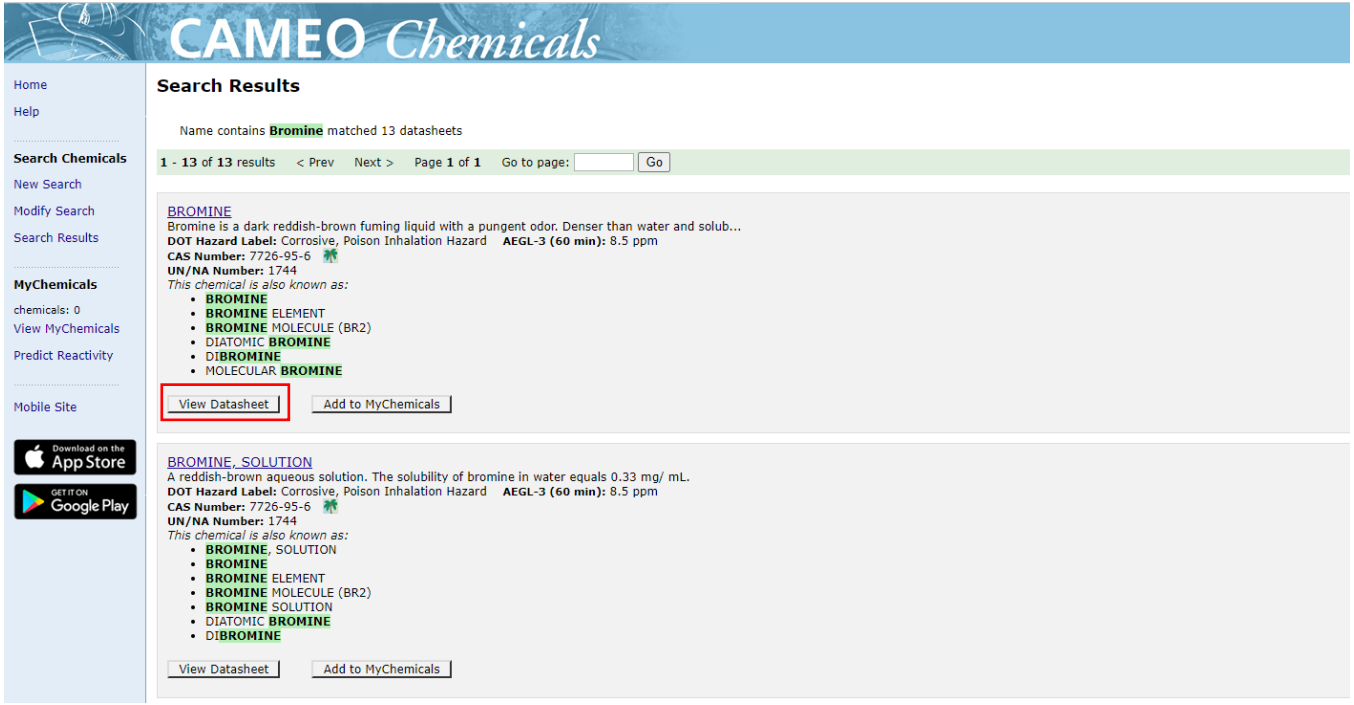
IDENTIFYING CHEMICAL HAZARDS – CAMEO INCOMPATIBILITY MATRIX



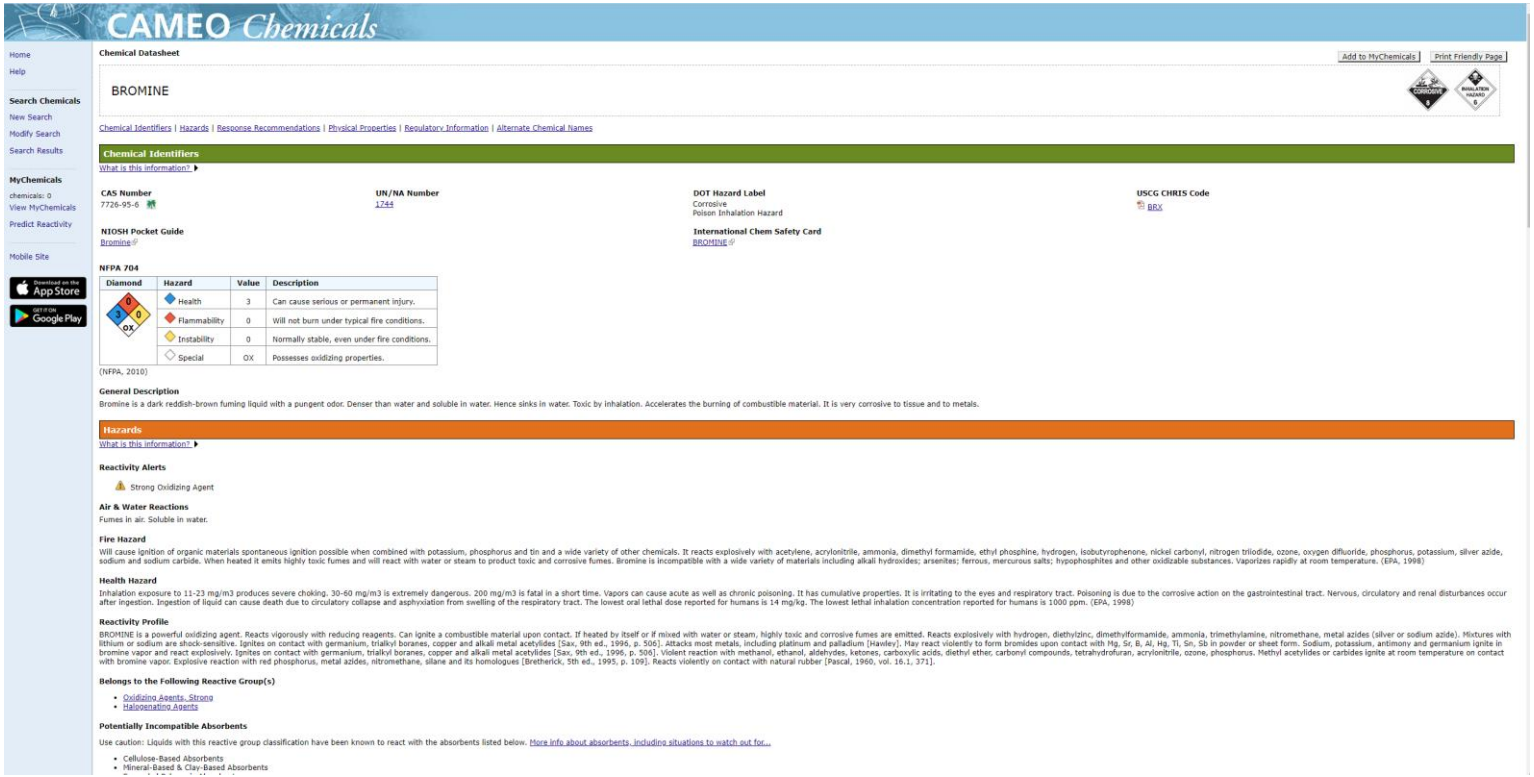
IDENTIFYING CHEMICAL HAZARDS – CAMEO INCOMPATIBILITY MATRIX



IDENTIFYING CHEMICAL HAZARDS – CAMEO INCOMPATIBILITY MATRIX



IDENTIFYING CHEMICAL HAZARDS – CAMEO INCOMPATIBILITY MATRIX



CAMEO Chemicals

Home
Help

Search Chemicals
New Search
Modify Search
Search Results

MyChemicals
chemicals: 0
View MyChemicals
Predict Reactivity

Mobile Site

Download on the App Store
GET IT ON Google Play

Chemical Datasheet

Add to MyChemicals | Print Friendly Page

BROMINE

Chemical Identifiers | Hazards | Response Recommendations | Physical Properties | Regulatory Information | Alternate Chemical Names

Chemical Identifiers

What is this information?

CAS Number
7726-95-6

UN/NA Number
1744

DOT Hazard Label
Corrosive
Poison Inhalation Hazard

USCG CHRIS Code
BRX

NIOSH Pocket Guide
Bromine

International Chem Safety Card
BROMINE

NFPA 704

Diamond	Hazard	Value	Description
	Health	3	Can cause serious or permanent injury.
	Flammability	0	Will not burn under typical fire conditions.
	Instability	0	Normally stable, even under fire conditions.
	Special	OX	Possesses oxidizing properties.

(NFPA, 2010)

General Description
Bromine is a dark reddish-brown fuming liquid with a pungent odor. Denser than water and soluble in water. Hence sinks in water. Toxic by inhalation. Accelerates the burning of combustible material. It is very corrosive to tissue and to metals.

Hazards

What is this information?

Reactivity Alerts
Strong Oxidizing Agent

Air & Water Reactions
Fumes in air. Soluble in water.

Fire Hazard
Will cause ignition of organic materials spontaneous ignition possible when combined with potassium, phosphorus and tin and a wide variety of other chemicals. It reacts explosively with acetylene, acrylonitrile, ammonia, dimethyl formamide, ethyl phosphine, hydrogen, isobutyrophenone, nickel carbonyl, nitrogen triiodide, ozone, oxygen difluoride, phosphorus, potassium, silver azide, sodium and sodium carbide. When heated it emits highly toxic fumes and will react with water or steam to product toxic and corrosive fumes. Bromine is incompatible with a wide variety of materials including alkali hydroxides; arsenites; ferrous, mercurous salts; hypophosphites and other oxidizable substances. Vaporizes rapidly at room temperature. (EPA, 1998)

Health Hazard
Inhalation exposure to 11-23 mg/m3 produces severe choking. 30-60 mg/m3 is extremely dangerous. 200 mg/m3 is fatal in a short time. Vapors can cause acute as well as chronic poisoning. It has cumulative properties. It is irritating to the eyes and respiratory tract. Poisoning is due to the corrosive action on the gastrointestinal tract. Nervous, circulatory and renal disturbances occur after ingestion. Ingestion of liquid can cause death due to circulatory collapse and asphyxiation from swelling of the respiratory tract. The lowest oral lethal dose reported for humans is 14 mg/kg. The lowest lethal inhalation concentration reported for humans is 1000 ppm. (EPA, 1998)

Reactivity Profile
BROMINE is a powerful oxidizing agent. Reacts vigorously with reducing reagents. Can ignite a combustible material upon contact. If heated by itself or if mixed with water or steam, highly toxic and corrosive fumes are emitted. Reacts explosively with hydrogen, diethylzinc, dimethylformamide, ammonia, trimethylamine, nitromethane, metal azides (silver or sodium azide). Mixtures with lithium or sodium are shock-sensitive. Ignites on contact with germanium, trialkyl boranes, copper and alkali metal acetylides [Sax, 9th ed., 1996, p. 506]. Attacks most metals, including platinum and palladium [Havley]. May react violently to form bromides upon contact with Mg, Sr, B, Al, Hg, Tl, Sn, Sb in powder or sheet form. Sodium, potassium, antimony and germanium ignite in bromine vapor and react explosively. Ignites on contact with germanium, trialkyl boranes, copper and alkali metal acetylides [Sax, 9th ed., 1996, p. 506]. Violent reaction with methanol, ethanol, aldehydes, ketones, carboxylic acids, diethyl ether, carbonyl compounds, tetrahydrofuran, acrylonitrile, ozone, phosphorus. Methyl acetylides or carbides ignite at room temperature on contact with bromine vapor. Explosive reaction with red phosphorus, metal azides, nitromethane, silane and its homologues [Bretherick, 5th ed., 1995, p. 109]. Reacts violently on contact with natural rubber [Pascal, 1960, vol. 16.1, 371].

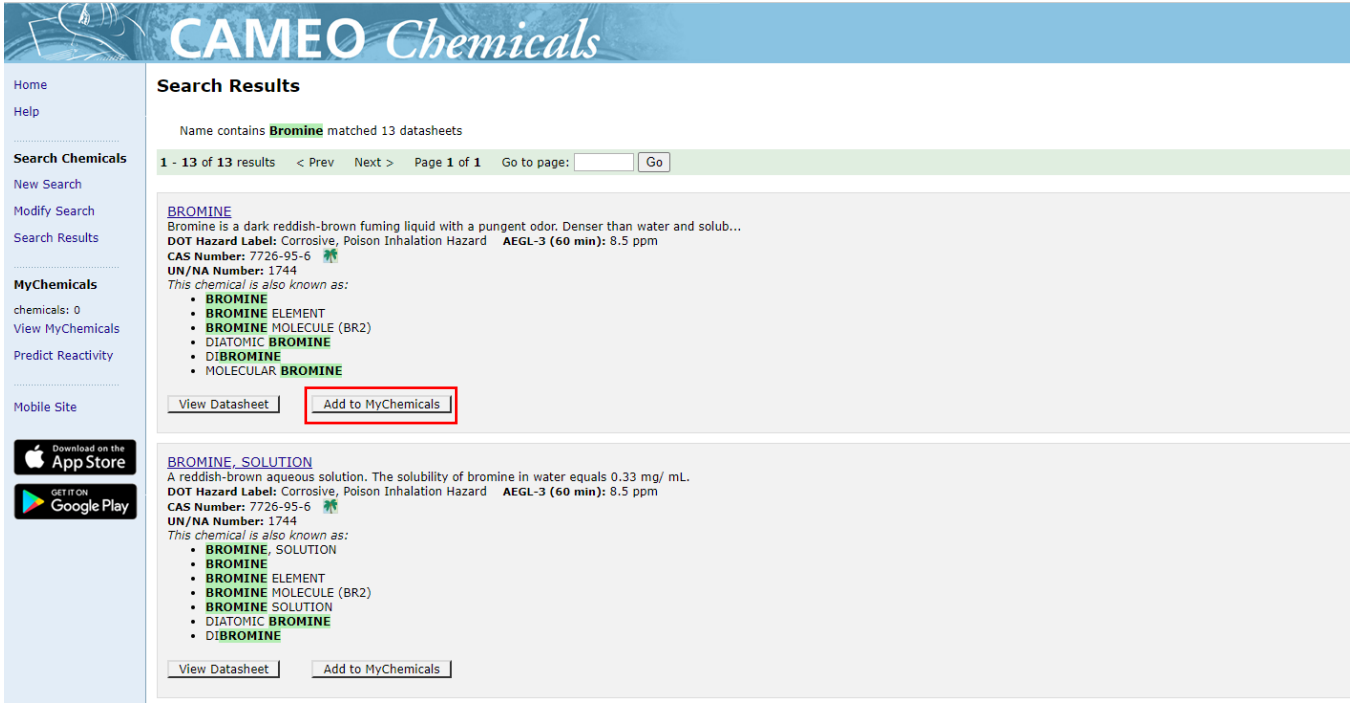
Belongs to the Following Reactive Group(s)

- Oxidizing Agents, Strong
- Halogenating Agents

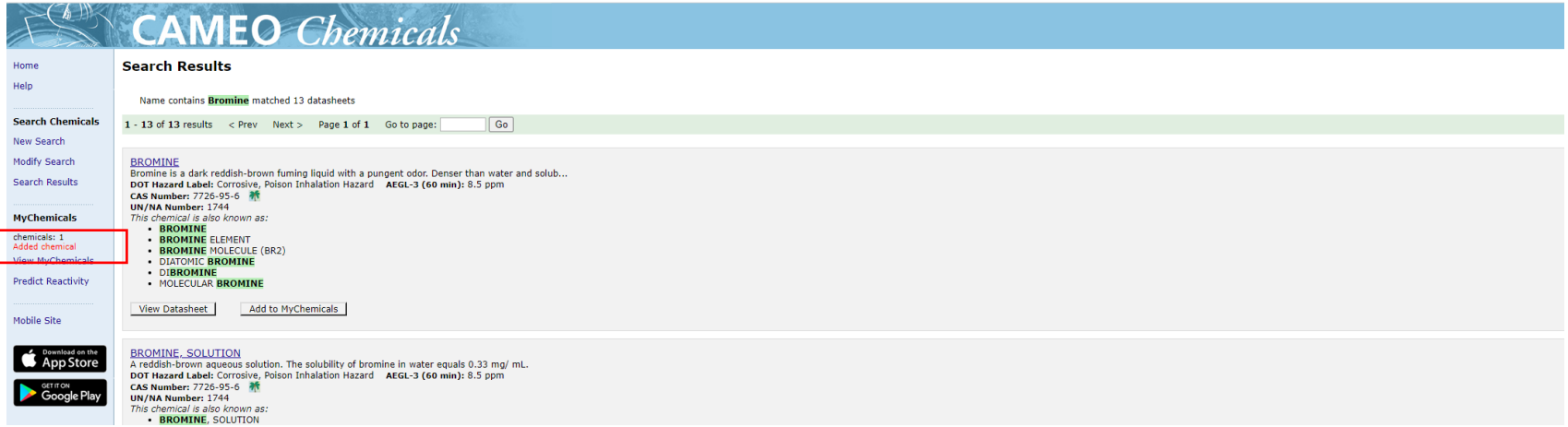
Potentially Incompatible Absorbents
Use caution: Liquids with this reactive group classification have been known to react with the absorbents listed below. More info about absorbents, including situations to watch out for...

- Cellulose-Based Absorbents
- Mineral-Based & Clay-Based Absorbents

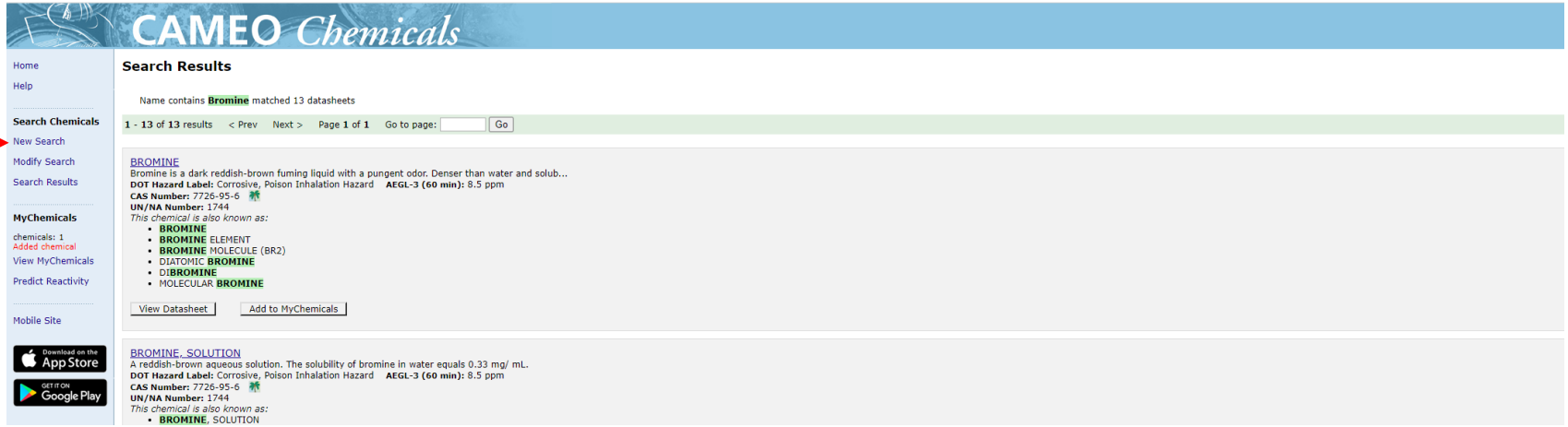
IDENTIFYING CHEMICAL HAZARDS – CAMEO INCOMPATIBILITY MATRIX



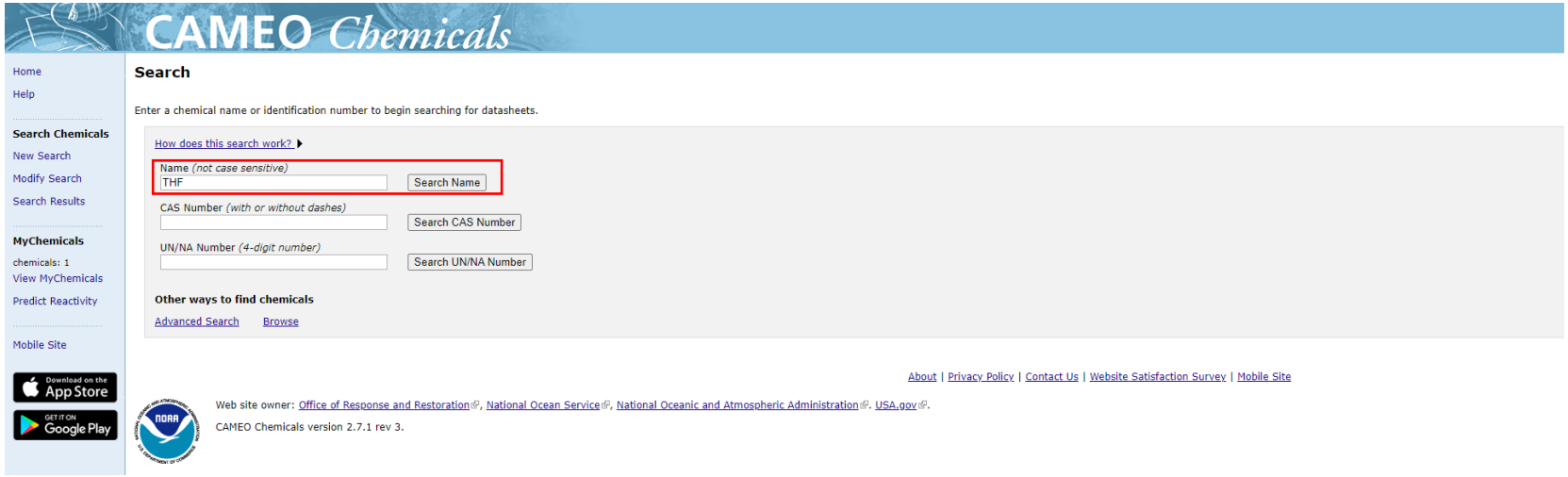
IDENTIFYING CHEMICAL HAZARDS – CAMEO INCOMPATIBILITY MATRIX



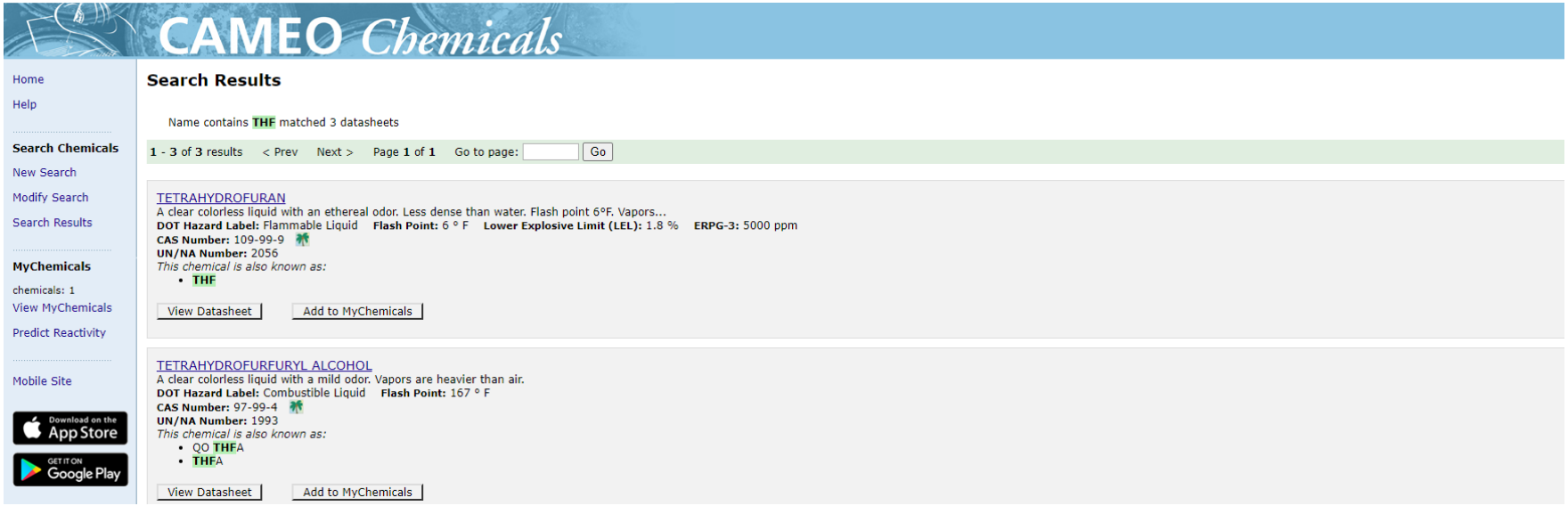
IDENTIFYING CHEMICAL HAZARDS – CAMEO INCOMPATIBILITY MATRIX



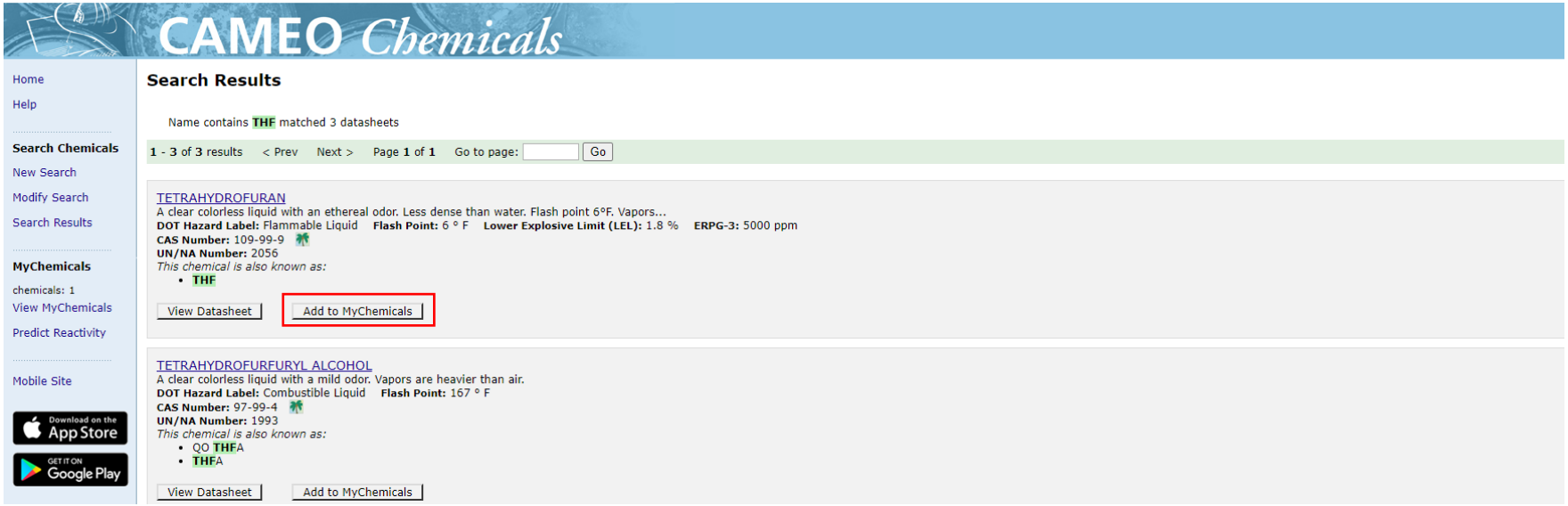
IDENTIFYING CHEMICAL HAZARDS – CAMEO INCOMPATIBILITY MATRIX



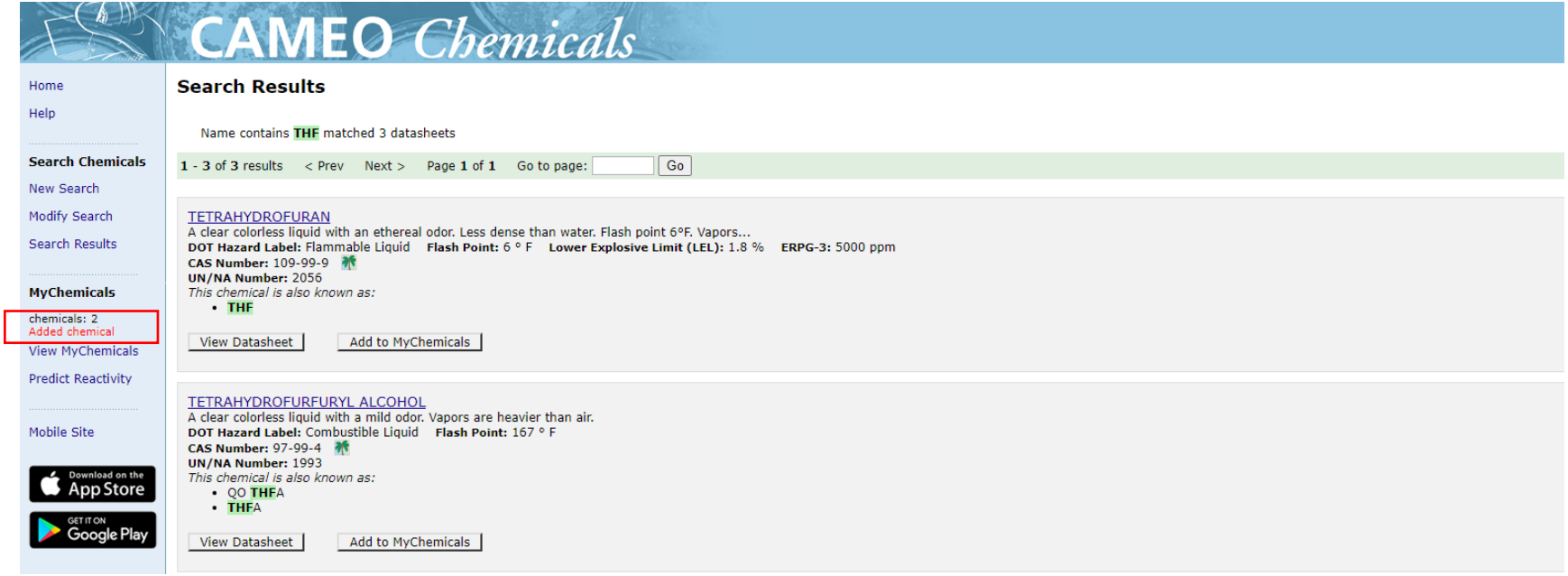
IDENTIFYING CHEMICAL HAZARDS – CAMEO INCOMPATIBILITY MATRIX



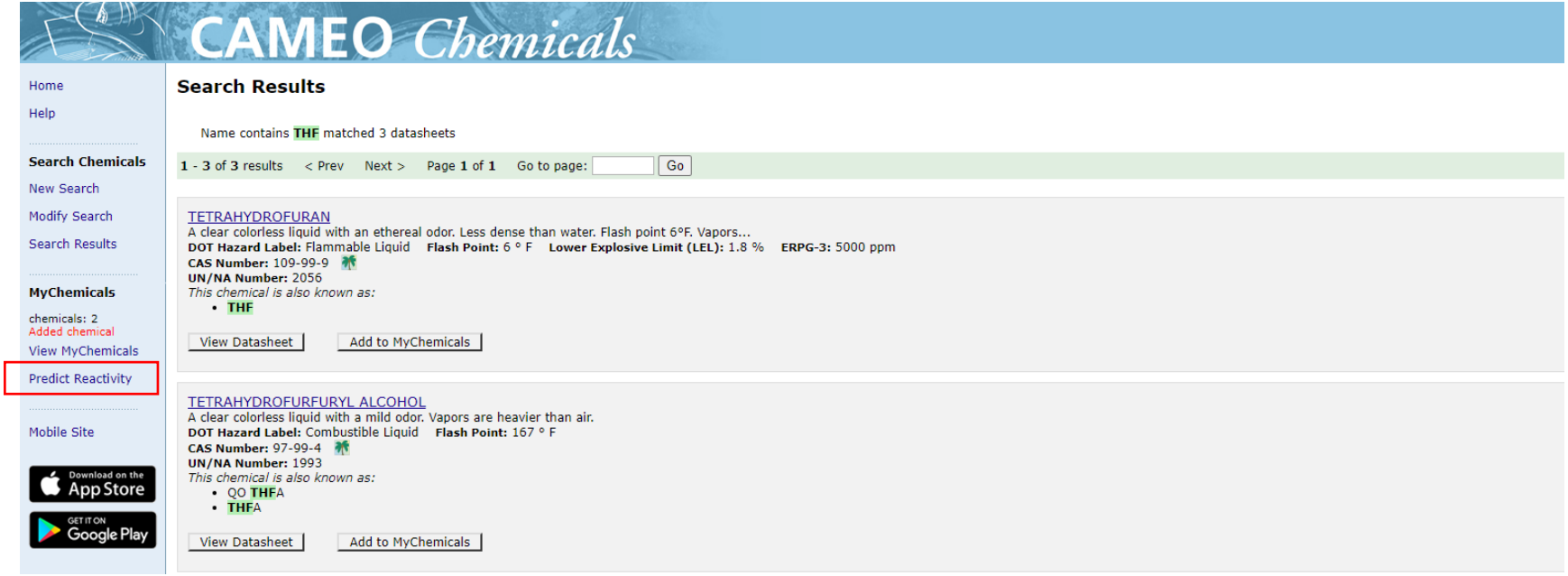
IDENTIFYING CHEMICAL HAZARDS – CAMEO INCOMPATIBILITY MATRIX



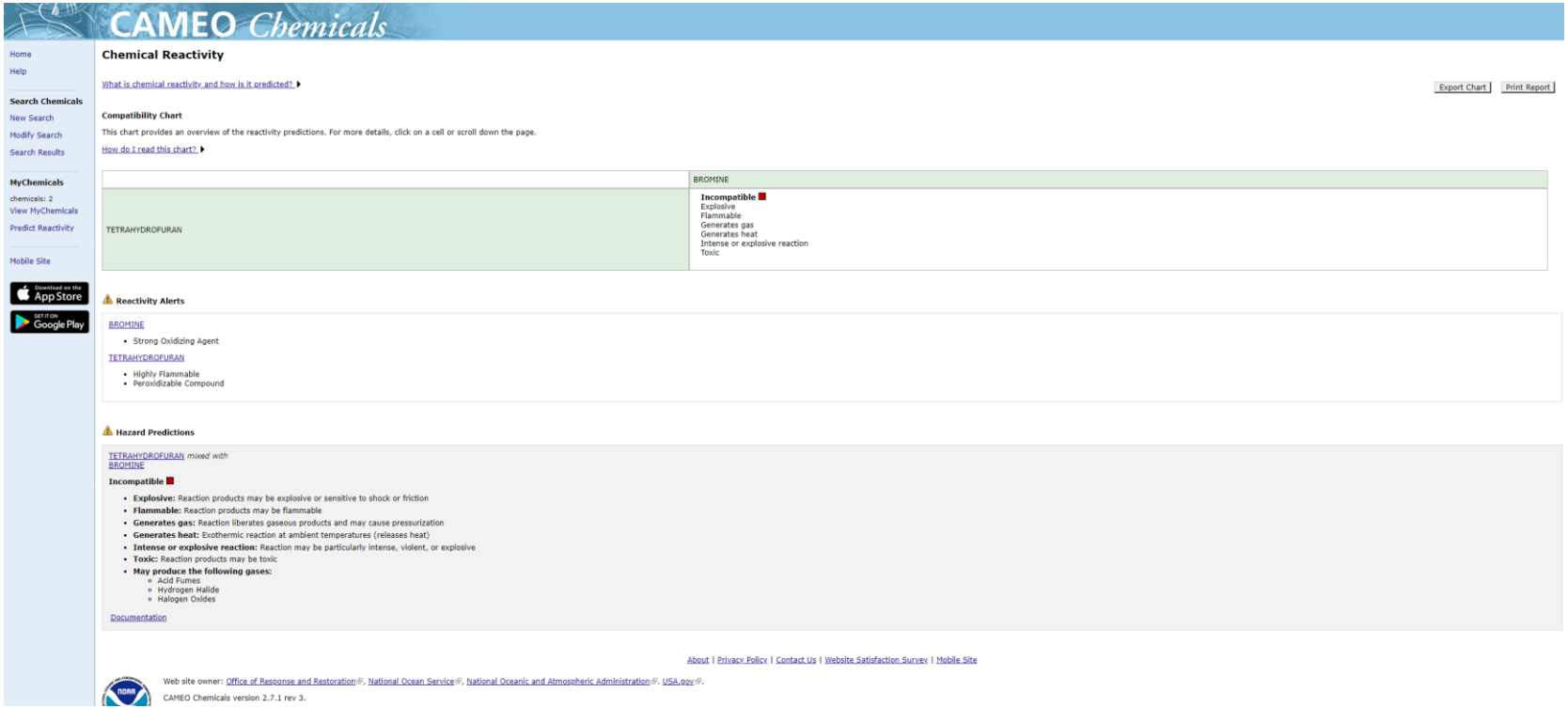
IDENTIFYING CHEMICAL HAZARDS – CAMEO INCOMPATIBILITY MATRIX



IDENTIFYING CHEMICAL HAZARDS – CAMEO INCOMPATIBILITY MATRIX



IDENTIFYING CHEMICAL HAZARDS – CAMEO INCOMPATIBILITY MATRIX



IDENTIFYING CHEMICAL HAZARDS – CAMEO INCOMPATIBILITY MATRIX

	BROMINE
TETRAHYDROFURAN	**Incompatible** ■ Explosive Flammable Generates gas Generates heat Intense or explosive reaction Toxic

⚠ Reactivity Alerts

BROMINE

- Strong Oxidizing Agent

TETRAHYDROFURAN

- Highly Flammable
- Peroxidizable Compound

⚠ Hazard Predictions

TETRAHYDROFURAN *mixed with*
BROMINE

Incompatible ■

- **Explosive:** Reaction products may be explosive or sensitive to shock or friction
- **Flammable:** Reaction products may be flammable
- **Generates gas:** Reaction liberates gaseous products and may cause pressurization
- **Generates heat:** Exothermic reaction at ambient temperatures (releases heat)
- **Intense or explosive reaction:** Reaction may be particularly intense, violent, or explosive
- **Toxic:** Reaction products may be toxic
- **May produce the following gases:**
  - Acid Fumes
  - Hydrogen Halide
  - Halogen Oxides

Documentation

IDENTIFYING CHEMICAL HAZARDS – CAMEO INCOMPATIBILITY MATRIX

	BROMINE
TETRAHYDROFURAN	**Incompatible** ■ Explosive Flammable Generates gas Generates heat Intense or explosive reaction Toxic

⚠ Reactivity Alerts

BROMINE

- Strong Oxidizing Agent

TETRAHYDROFURAN

- Highly Flammable
- Peroxidizable Compound

⚠ Hazard Predictions

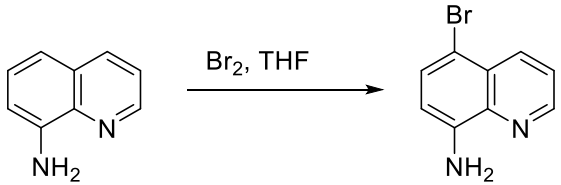
TETRAHYDROFURAN *mixed with*
BROMINE

Incompatible ■

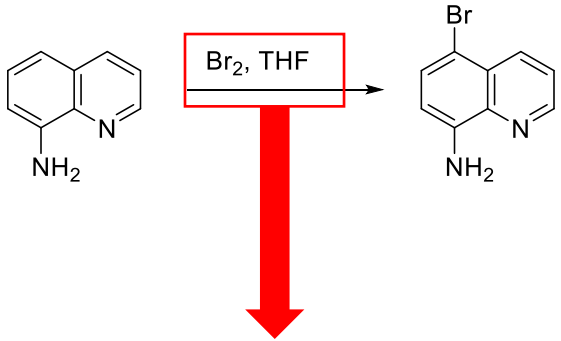
- **Explosive:** Reaction products may be explosive or sensitive to shock or friction
- **Flammable:** Reaction products may be flammable
- **Generates gas:** Reaction liberates gaseous products and may cause pressurization
- **Generates heat:** Exothermic reaction at ambient temperatures (releases heat)
- **Intense or explosive reaction:** Reaction may be particularly intense, violent, or explosive
- **Toxic:** Reaction products may be toxic
- **May produce the following gases:**
  - Acid Fumes
  - Hydrogen Halide
  - Halogen Oxides

Documentation

IDENTIFYING CHEMICAL HAZARDS – CAMEO INCOMPATIBILITY MATRIX



IDENTIFYING CHEMICAL HAZARDS – CAMEO INCOMPATIBILITY MATRIX

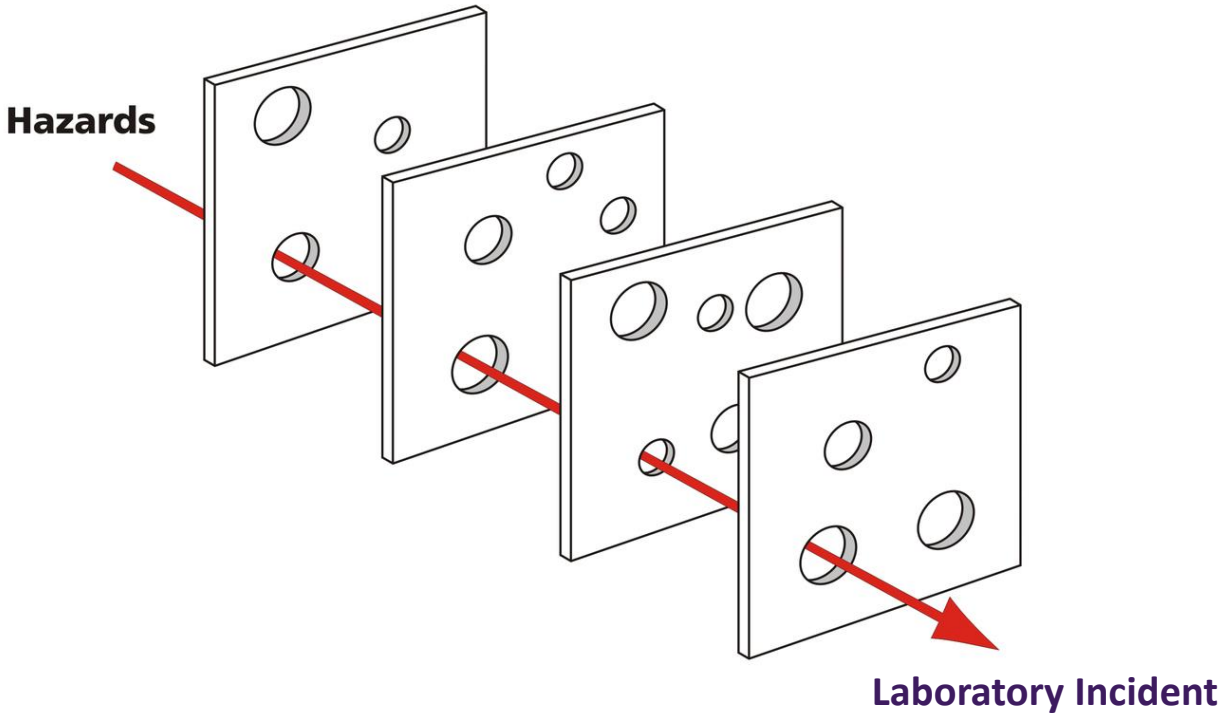


Highly reactive – never mix bromine and THF

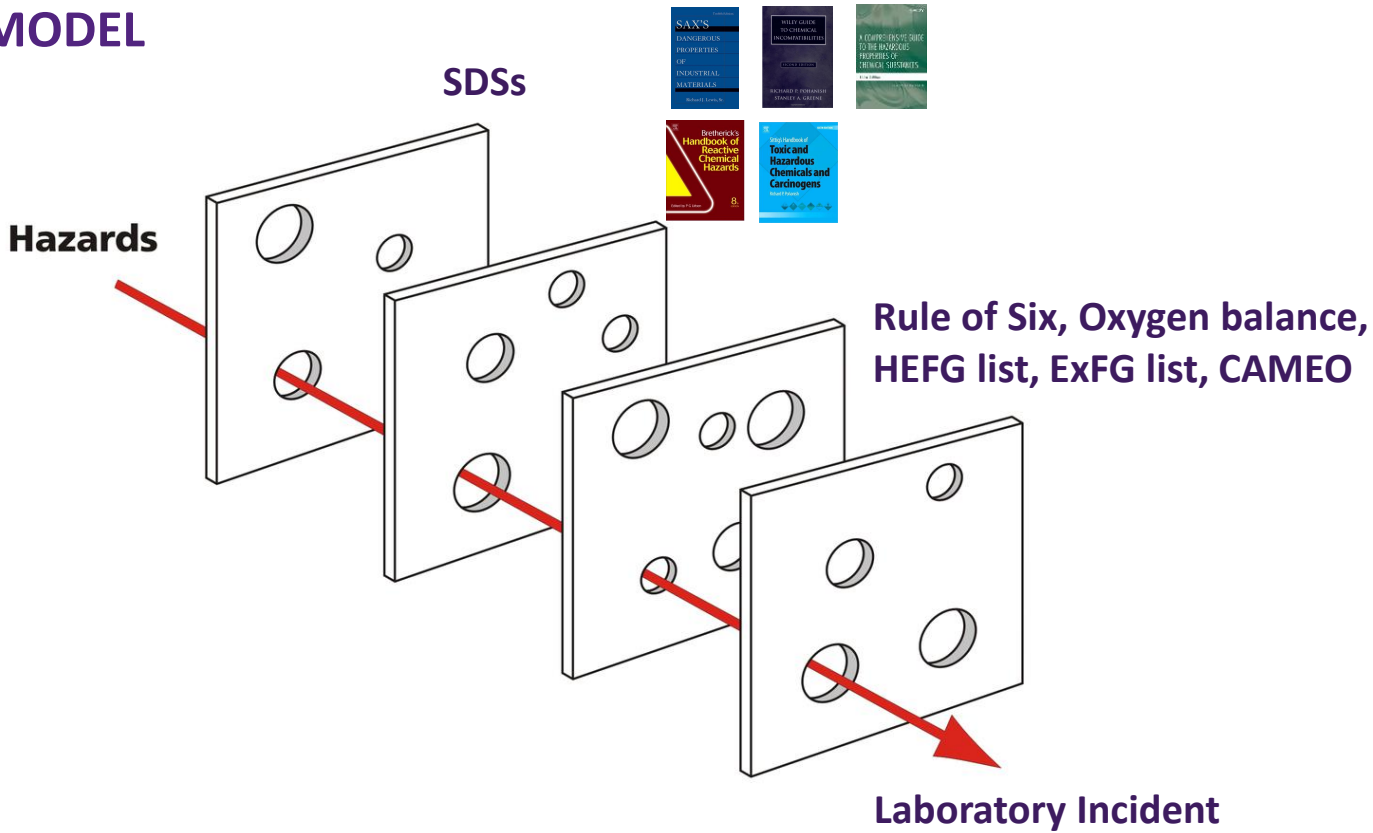
IDENTIFYING CHEMICAL HAZARDS – CAMEO INCOMPATIBILITY MATRIX

	ALKYL SULFONIC ACIDS, LIQUID, WITH NOT MORE THAN 5% FREE SULFURIC ACID	DICHLOROMETHANE	THIOPHENE	ACETONE	SODIUM HYDROXIDE SOLUTION	HYDROCHLORIC ACID, SOLUTION	WATER	METHANOL	Ketones	METHYL TERT-BUTYL ETHER	N-HEPTANE
DICHLOROMETHANE	**Incompatible** Corrosive Explosive Generates gas Intense or explosive reaction Toxic	DICHLOROMETHANE									
THIOPHENE	**Incompatible** Explosive Flammable Generates gas Intense or explosive reaction Toxic	**Incompatible** Generates gas Toxic	THIOPHENE								
ACETONE	**Incompatible** Generates gas Intense or explosive reaction Toxic	**Compatible**	**Compatible**	ACETONE							
SODIUM HYDROXIDE SOLUTION	**Incompatible** Corrosive Generates gas Generates heat Intense or explosive reaction Toxic	**Incompatible** Corrosive Flammable Generates gas Intense or explosive reaction Toxic	**Incompatible** Flammable Generates gas Generates heat Toxic	**Incompatible** Generates heat	SODIUM HYDROXIDE SOLUTION						
HYDROCHLORIC ACID, SOLUTION	**Incompatible** Corrosive Explosive Flammable Generates gas Generates heat Intense or explosive reaction Toxic	**Caution** Corrosive Generates gas Generates heat Intense or explosive reaction Toxic	**Incompatible** Flammable Generates gas Generates heat Toxic	**Compatible**	**Incompatible** Corrosive Generates gas Generates heat Intense or explosive reaction Toxic	HYDROCHLORIC ACID, SOLUTION					
WATER	**Caution** Corrosive Generates gas Generates heat Toxic	**Caution** Corrosive Generates gas	**Caution** Flammable Generates gas Toxic	**Compatible**	**Caution** Corrosive Generates gas Generates heat Toxic	**Caution** Corrosive Generates gas Generates heat	WATER				
METHANOL	**Incompatible** Explosive Flammable Generates gas Intense or explosive reaction Toxic	**Compatible**	**Compatible**	**Caution** Explosive Unstable when heated	**Incompatible** Flammable Generates gas Generates heat	**Caution** Generates heat	**Compatible**	METHANOL			
Ketones	**Incompatible** Generates gas Intense or explosive reaction Toxic	**Compatible**	**Compatible**	**Compatible**	**Incompatible** Generates heat	**Compatible**	**Compatible**	**Caution** Explosive Unstable when heated	Ketones		
METHYL TERT-BUTYL ETHER	**Incompatible** Generates heat Intense or explosive reaction	**Compatible**	**Compatible**	**Compatible**	**Compatible**	**Incompatible** Explosive Flammable Generates gas Generates heat	**Compatible**	**Compatible**	**Compatible**	METHYL TERT-BUTYL ETHER	
N-HEPTANE	**Incompatible** Generates gas Generates heat Toxic	**Compatible**	**Compatible**	**Compatible**	**Compatible**	**Compatible**	**Compatible**	**Compatible**	**Compatible**	**Compatible**	

SWISS CHEESE MODEL



SWISS CHEESE MODEL



CONCLUSIONS

TAKEAWAYS

1. All scientists should be able to identify the 9 GHS chemical hazard symbols

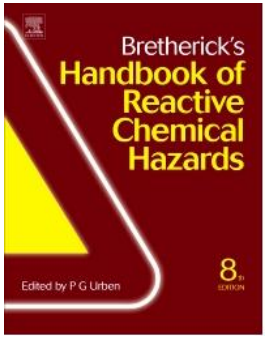
TAKEAWAYS

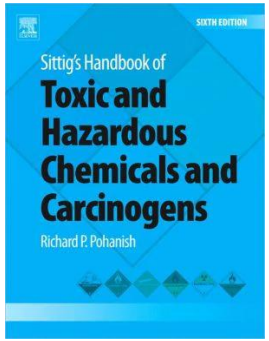
1. All scientists should be able to identify the 9 GHS chemical hazard symbols
2. All scientists should be able to perform basic risk assessments and identify high risk chemistry

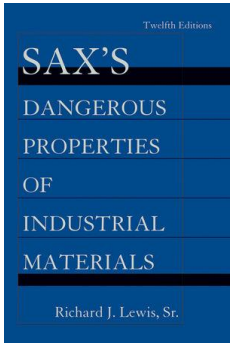
Probability × **Severity** = **Risk**

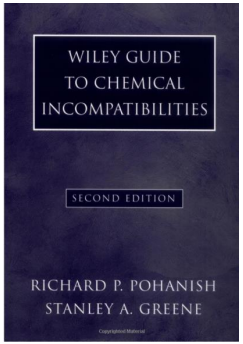
TAKEAWAYS

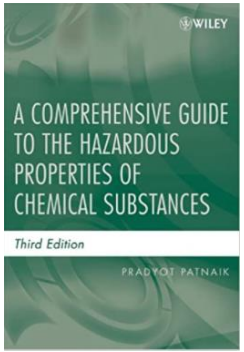
1. All scientists should be able to identify the 9 GHS chemical hazard symbols
2. All scientists should be able to perform basic risk assessments and identify high risk chemistry
3. Five of my favorite references for identifying chemical hazards were discussed





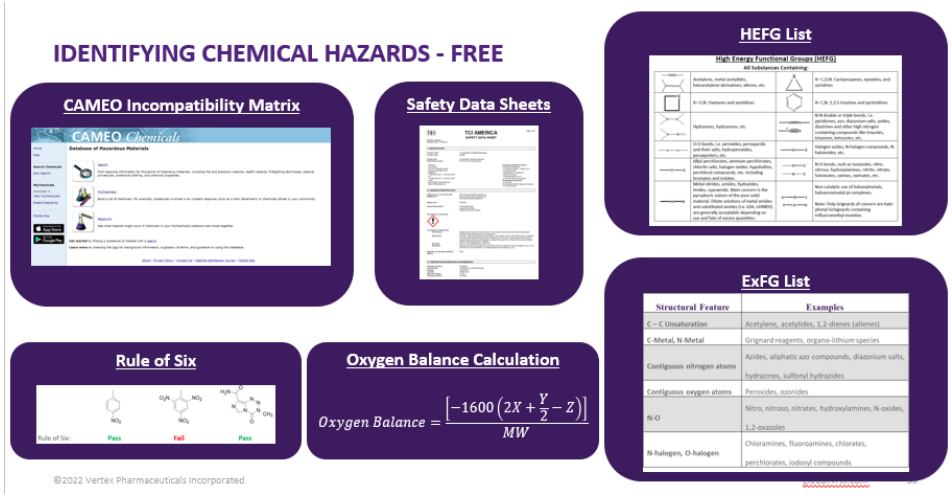






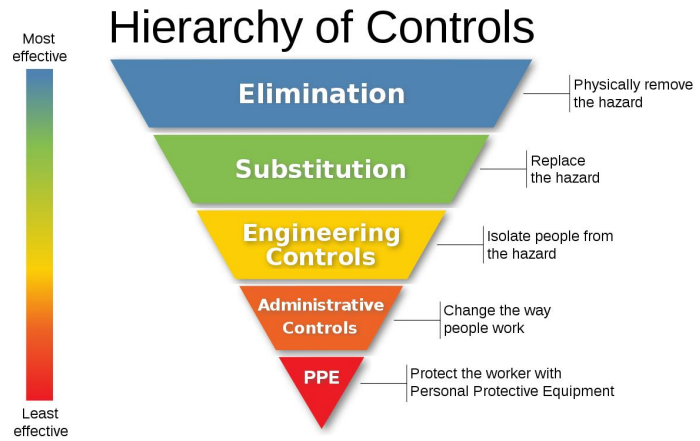
TAKEAWAYS

1. All scientists should be able to identify the 9 GHS chemical hazard symbols
2. All scientists should be able to perform basic risk assessments and identify high risk chemistry
3. Five of my favorite references for identifying chemical hazards were discussed
4. Six free methodologies for identifying chemical hazards were also presented



TAKEAWAYS

1. All scientists should be able to identify the 9 GHS chemical hazard symbols
2. All scientists should be able to perform basic risk assessments and identify high risk chemistry
3. Five of my favorite references for identifying chemical hazards were discussed
4. Six free methodologies for identifying chemical hazards were also presented
5. The Hierarchy of Controls can be utilized to reduce risk of exposure to a hazard



TAKEAWAYS

1. All scientists should be able to identify the 9 GHS chemical hazard symbols
2. All scientists should be able to perform basic risk assessments and identify high risk chemistry
3. Five of my favorite references for identifying chemical hazards were discussed
4. Six free methodologies for identifying chemical hazards were also presented
5. The Hierarchy of Controls can be utilized to reduce risk of exposure to a hazard

My final words:

YOU are responsible for understanding the hazards of the chemicals you are working with.

Just because it is commercially available or labeled as a “safe alternative to…” does not mean that using the material is free from risk.

VERTEX

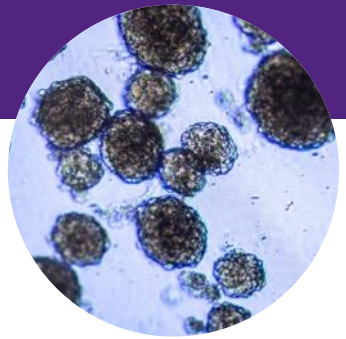
THE SCIENCE *of* POSSIBILITY

ABOUT OUR COMPANY

WE ARE VERTEX

We invest in scientific innovation to create transformative medicines for people with serious diseases with a focus on specialty markets.

Patients are at the heart of everything we do



We strike at the core of serious diseases to change people's lives

We're not afraid to take on the impossible

For the lives we have changed and for those who are still waiting, we will never stop fighting until we discover cures.

QUICK FACTS

Founded:
1989

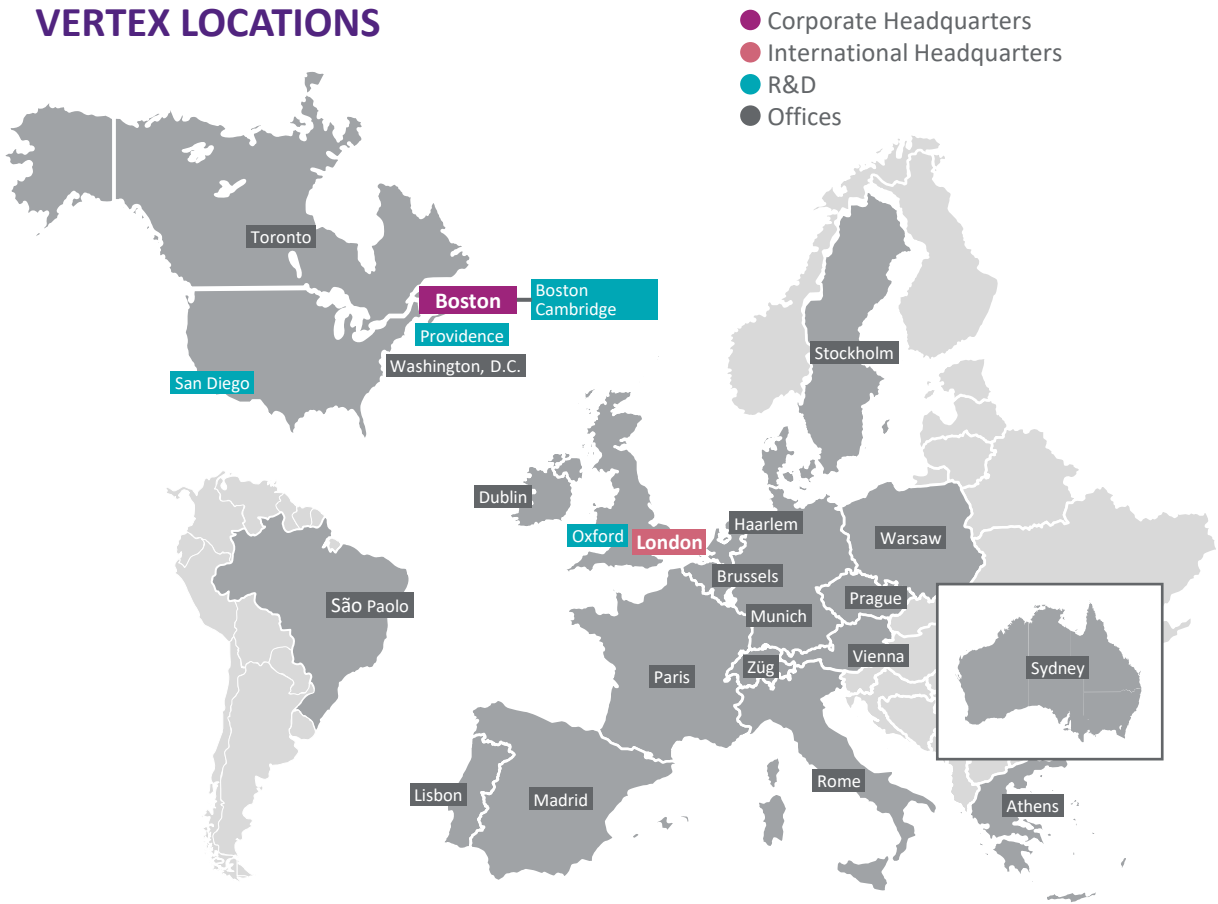
Headquarters:
Boston

~4,500
Employees worldwide
(~3,500 in the U.S.)

$58B
Market Cap
(as of Jan. 2022)

$7.6B
2021
Revenue

VERTEX LOCATIONS



LEADING THE WAY

Our leadership team collectively brings decades of experience to our mission

Reshma Kewalramani, M.D.
Chief Executive Officer
and President

Jeffrey Leiden, M.D., Ph.D.
Executive Chairman

David Altshuler, M.D., Ph.D.
Executive VP, Global Research and
Chief Scientific Officer

Stuart A. Arbuckle
Executive VP and Chief Operating
Officer

Jonathan Biller
Executive VP and Chief Legal
Officer

Carmen Bozic, M.D.
Executive VP, Global Medicines
Development and Medical Affairs,
and Chief Medical Officer

Amit K. Sachdev
Executive VP and Chief Patient
Officer

Nia Tatsis, Ph.D.
Executive VP and Chief Regulatory
and Quality Officer

Bastiano Sanna, Ph.D.
Executive VP, Chief of Cell and
Genetic Therapies and VCGT
Site Head

Charles F. Wagner
Executive VP and Chief Financial
Officer

OUR STRATEGY AND BUSINESS MODEL

A blueprint for serial innovation

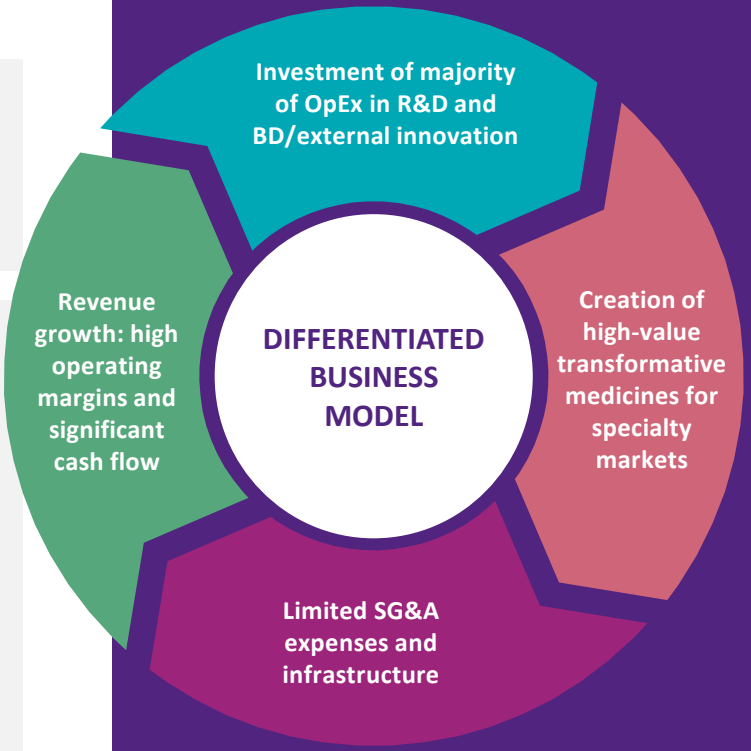
CORPORATE STRATEGY

Vertex invests in scientific innovation to create transformative medicines for people with serious diseases with a focus on specialty markets

RESEARCH AND DEVELOPMENT STRATEGY

Combine transformative advances in the understanding of human disease and in the science of therapeutics to dramatically advance human health

- Focus on validated targets that address causal human biology
- Create predictive lab assays and clinical biomarkers
- Identify rapid path to registration and approval
- Discover and develop medicines that offer transformative benefit, regardless of modality



RESEARCH & DEVELOPMENT

PUTTING SCIENCE FIRST

We believe in the promise and potential of science to have a transformative impact for people living with serious diseases.

>70% of our operating expenses are dedicated to R&D, well above the average of the top pharma and biotech companies in the industry*

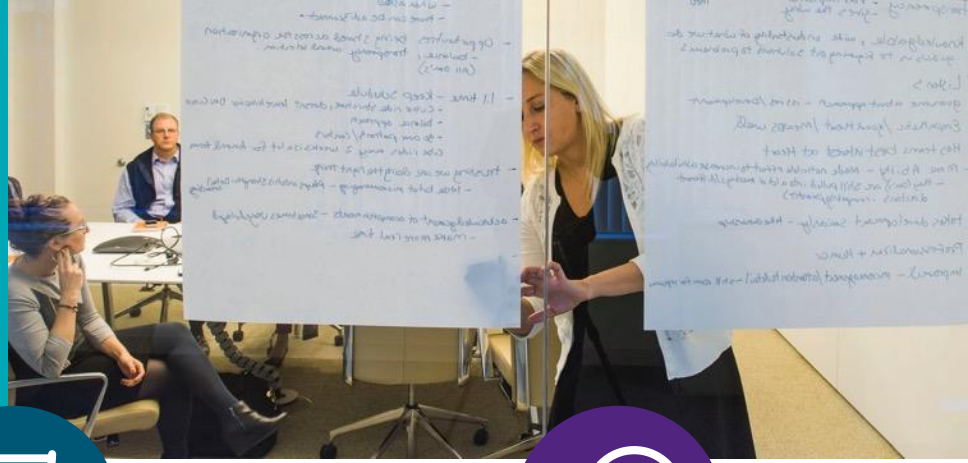
3 out of 5 Vertex employees are dedicated to R&D

Vertex is one of only a handful of companies to have internally discovered and developed five or more innovative medicines.**

*2021 GAAP figures. Operating expenses defined as R&D + Sales, General & Administrative.
**Among biotech companies founded since 1976 as of December 2021

OUR STRATEGY IN ACTION

No matter the disease, our work is defined by a common strategy that drives a culture of innovation and scientific discovery.



Pioneers in CF research and development

We discovered, developed and produced the first medicines to target the underlying cause of cystic fibrosis.

Complementing our small molecule expertise with a toolkit in cell and genetic therapies

Vertex Cell and Genetic Therapies brings together our industry leading portfolio of technologies, teams and manufacturing capabilities.

A disease-first approach to development

When we decide to work on a disease, we investigate it from every angle.

OUR JOURNEY IN CYSTIC FIBROSIS

Cystic fibrosis (CF) is a rare, chronic, genetic disease that affects multiple organs, including the lungs, liver, gastrointestinal tract, pancreas, sinuses, sweat glands and reproductive tract.

Our track record in CF serial innovation

- 20+ years of R&D
- 4 approved medicines with the potential to treat up to ~90% of all people with CF
- ~20 ongoing clinical trials

Our commitment to finding treatments for all people with CF

1. Expanding access to our existing medicines
2. Discovering and testing additional combination therapies
3. Investigating genetic therapy approaches, like mRNA

ADVANCING OUR RESEARCH PROGRAMS IN SICKLE CELL DISEASE AND BETA THALASSEMIA

*"It's not just the hospitalizations or the crises, but **just the daily aspects of living** with sickle cell disease that can be extremely challenging if you don't balance it very well."*

– 39-year-old mother, wife and advocate living with sickle cell disease

Sickle cell disease

Sickle cell disease causes severe pain, organ damage and a shortened life span due to misshapen or "sickled" blood cells.

Our approach:

- Gene editing
- Small molecules

Beta thalassemia

Beta thalassemia primarily presents as anemia, or a lack of red blood cells. This can lead to many different complications and medical problems.

Our approach:

- Gene editing
- Small molecules

PIONEERING A POTENTIAL CELL THERAPY FOR TYPE 1 DIABETES

"Living with type 1 ***takes all of one's mental capacity and energy****; it's difficult to focus on anything else..."*

– Adult living with type 1 diabetes

Type 1 diabetes

Type 1 diabetes is a metabolic, autoimmune disease where the cells in the pancreas (beta cells) that produce insulin are destroyed. Without proper management, it can lead to kidney disease, eye disease, nerve damage and even death.

Our approach:

- Cell therapy with immunosuppression
- Encapsulated islet cell therapy
- Cells that can evade (or hide from) the immune system

DISCOVERING POTENTIAL THERAPIES FOR APOL1-MEDIATED KIDNEY DISEASE

"For me, in my particular disease, it happened so rapidly — I felt like we were always more than one step behind in the treatment process."

– 45-year-old living with APOL1-mediated focal segmental glomerulosclerosis

APOL1-mediated kidney disease

APOL1-mediated kidney disease is a kidney disease associated with certain *APOL1* genetic mutations that can have various clinical presentations, including focal segmental glomerulosclerosis and other severe kidney disease. These diseases are more aggressive when associated with *APOL1* mutations and can lead to rapidly progressive kidney damage and potentially kidney failure.

Our approach: Small molecules

PURSUING INNOVATIVE THERAPIES FOR PAIN

"Pain is the determining factor that decides what I can accomplish during any given day. If my pain level is 10, there is no way to possibly concentrate on tasks at hand or socialize with family."

– 60-year-old living with pain

Pain

Pain is a potentially debilitating condition that develops from a variety of circumstances; it can be acute or chronic and range in severity.

Poorly managed pain can lead to a significant decrease in quality of life and is often associated with complications such as sleep interruption, immobility, inability to work and major depression.

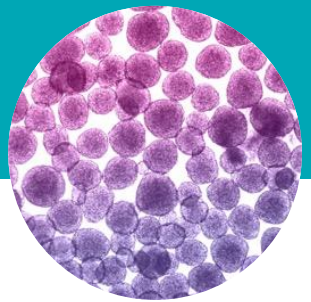
Our approach: Small molecules

R&D PIPELINE AS OF OCTOBER 1, 2022

Cystic Fibrosis	VX-121/tezacaftor/VX-561 (Small Molecule)	Phase 3
	Additional Small Molecules	Research
	CRISPR/Cas9	Research
	mRNA Therapeutics	Research
Sickle Cell Disease	Exa-cel (CRISPR/Cas9)	Phase 1/2/3
	Small Molecule	Research
Beta Thalassemia	Exa-cel (CRISPR/Cas9)	Phase 1/2/3
	Small Molecule	Research
Pain	VX-548 (Small Molecule)	Phase 3
	Additional Small Molecules	Research
APOL1-Mediated Kidney Disease	Inaxaplin (Small Molecule)	Phase 2/3
	Additional Small Molecules	Research
Type 1 Diabetes	VX-880 (Cell Therapy)	Phase 1/2
	Encapsulated Islet Cells	Research
Alpha-1 Antitrypsin Deficiency	Small Molecules	Research
Duchenne Muscular Dystrophy	CRISPR/Cas9	Research

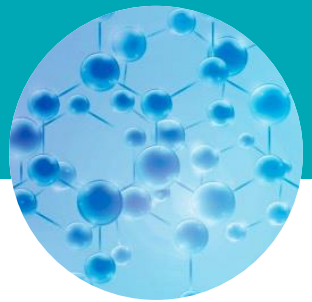
There is no guarantee that the investigational compounds listed will be approved by a Health Authority or will be marketed. Safety and effectiveness of investigational medicines have not been established.

COLLABORATIONS EXPAND OUR DRUG DISCOVERY TOOLBOX



Targets and Human Cell Models

- Q-State Biosciences
- Genomics plc



Innovation in Small Molecule Therapeutics

- Kymera Therapeutics
- Ribometrix
- Skyhawk Therapeutics
- X-Chem

Genetic Therapies

- Affinia Therapeutics
- Arbor Biotechnologies
- CRISPR Therapeutics
- Mammoth Biosciences
- Moderna
- Obsidian Therapeutics
- Verve Therapeutics

CORPORATE RESPONSIBILITY

OUR DEEP COMMITMENT TO CORPORATE RESPONSIBILITY AND ENVIRONMENTAL, SOCIAL AND GOVERNANCE (ESG)

As a leading global biotech company, we're committed to operating our business responsibly. We focus our efforts on four corporate responsibility priorities.

Improve the lives of people with serious diseases

$3B R&D investment in 2021

Foster an ethical culture that embraces innovation, inclusion, diversity & equity

>10 Best Places to Work, Culture and ID&E awards

Make a positive impact in the communities where we are based

~2000 nonprofit organizations supported through the Vertex Foundation Matching Gift Program for employees

Carefully manage our operations and environmental footprint

20% goal to reduce carbon emissions reduction globally by end of 2023

B score on CDP Climate Change Survey

Newsweek
AMERICA'S MOST RESPONSIBLE COMPANIES
2022

2022
People®
COMPANIES THAT CARE

POSITIVELY IMPACTING OUR COMMUNITIES

The Vertex Foundation is a key part of our corporate giving commitment.

The Foundation seeks to improve the lives of people with serious diseases and contribute to the communities where Vertex is located through education, innovation and health.

VERTEX | THE VERTEX FOUNDATION

INVESTING IN THE NEXT GENERATION OF SCIENTISTS

VERTEX LEARNING LAB

Boston

- Summer internship program
- Afterschool program
- Vertex Science Leaders scholarship

San Diego

- Summer internship program
- Afterschool program
- Vertex Science Leaders scholarship (*launching in 2022*)

Oxford, U.K.

- Summer internship program
- Weekly engagements with UTC Oxfordshire

In 2021:

20,000+
hours spent by students in Learning Lab programming

960+
hours volunteered by Vertex employees

10th
anniversary of paid internship program in Boston

10
interns completed a biotech curriculum with Year Up

WORKING HERE

THE VERTEX CULTURE

Different for a reason

We believe we can use **science** and **innovation** to do the impossible. We are **relentless** and **intense** in our approach, which is driven by our **strong sense of urgency** to bring transformative medicines to **patients** as quickly as we can. We are **inclusive**, roll up our sleeves and believe that good ideas come from everyone **-** we **debate vigorously,** hold each other **accountable** and **celebrate** our successes and **learn** from our failures to drive results.

OUR VALUES

"Our values and our culture have been a key driver of our success, and they're the reason our work environment is so productive, collaborative, inclusive and rewarding. It makes me proud to be a Vertexian."

Reshma Kewalramani, M.D.,
Chief Executive Officer and President
she/her/hers

OUR INCLUSION, DIVERSITY AND EQUITY (ID&E) PRIORITIES

Inclusion:

Equip all Vertexians with the skills and resources to activate and live ID&E in their day-to-day interactions and decisions

Diversity:

Invest to address gaps in representation in our talent pipeline, with a focus on racial, ethnic, cultural and gender equity

Equity:

Embed inclusive and equitable practices throughout the employee experience

- **Delivered research-backed ID&E curriculum** to enable all Vertexians to **L**earn, **I**mplement, **V**alidate and **E**mbed (**LIVE**) ID&E into their ways of working
- **Expanded career opportunities in biotech to talent from historically underrepresented populations** by launching a first-of-its-kind biotechnology workforce development program with Boston-based Year Up
- **Through 4 global employee-led resource networks,** amplified the voices of Vertexians
- **Furthered inclusive practices** by enabling Vertexians to share their pronouns across multiple platforms

WE'RE CONSISTENTLY RECOGNIZED AS A TOP PLACE TO WORK

Science 2021 TOP EMPLOYER

The Boston Globe TOP PLACES TO WORK 2021 MASSACHUSETTS

BioSpace IDEAL EMPLOYER

SAN DIEGO BUSINESS JOURNAL BEST PLACES TO WORK 2022

FORTUNE BEST WORKPLACES IN BIOPHARMA 2022

BOSTON BUSINESS JOURNAL 2022 BEST PLACES TO WORK BPTW Vertex Pharmaceuticals

Great Place To Work. Certified AUG 2021-AUG 2022 USA

seramount 100 BEST COMPANY 2022

LEARN MORE ABOUT VERTEX AND THE COMMUNITIES WE SERVE

Visit **www.vrtx.com** and follow us on our social media channels for the latest news and stories about our people and programs.

Our Social channels:

Facebook Page: @VertexPharmaInc

Instagram Page: @vertexpharmaceuticals

LinkedIn Page: @Vertex Pharmaceuticals

Twitter Page: @VertexPharma and @VertexScience

YouTube Page: Vertex Pharmaceuticals

For the lives we have changed and for those who are still waiting, we will never stop fighting until we discover cures.