EXAMINING THE RISKS OF CARBON DIOXIDE AS A FIRE SUPPRESSANT

Presented by Stephanie R. Skaggs*
for ICF Incorporated, Washington, DC USA

Carbon dioxide (CO_2) has many of the positive attributes of **a** clean fire extinguishing agent for fire extinguishing applications. Because of this, CO_2 has been and is being used for fire protection in a number of hazard situations. One drawback to using carbon dioxide, however, **is** that its mechanism of fire suppression is through oxygen dilution, and not, as is the case for halon, through chemical disruption of the catalytic combustion chain. **As** such, the range of concentrations needed to extinguish various fuel fires is between 34 and 72% v/v, with resulting oxygen concentrations being between 15.7 and 8.1%. Exposures to carbon dioxide concentrations of 25-30% v/v will quickly (within seconds) lead to unconsciousness, convulsions, and death. Because resulting oxygen concentrations in atmospheres with 25-30% v/v CO_2 are above levels required to sustain life (in the absence of CO_2), it is the presence of CO_2 that imparts the mechanism of lethality (i.e., severe CNS depression effects resulting in death).

Because the normal design concentration for CO_2 is above the nearly immediate acute lethality level, an extremely narrow safety margin exists for these systems. To better characterize the potential dangers associated with CO_2 use, a review of accidents related to CO_2 use as a fire suppressant was performed. **A** number of literature databases and domestic and foreign fire protection industry professionals, fire safety organizations, and military representatives were contacted, to collect accident information.

The search resulted in the identification of incidents dating back to the 1940s. The information was separated into those records that occurred before 1975 and those that occurred after 1975, mainly because a number of more organized and/or computerized records keeping devices came into existence about this time. From 1940 to 1975, 11 release incidents involving CO_2 were located. Seven injuries and 90 deaths were associated with these incidents. Of these 11 incidents, **3** were military related and 7 were nonmilitary, and 1 was unknown; additionally, 8 were domestic and 3 were foreign. None of the foreign incidents was military related. Of the 90 deaths, 43 occurred as a result of a plane crash. The cause was determined to be a discharge of the forward cargo compartment CO_2 system just prior to the crash.

From 1975 to the present, 40 incidents involving CO_2 were located. Ten (10) of these were military related and 30 were nonmilitary. Nineteen (19) occurred in the US or Canada, while 21 occurred in foreign locales. Of the 19 domestic events, 13 involved marine applications. None of the foreign incidents was military related. There were a total of 85 injuries and *56* deaths associated with these incidents.

* Stephanie R. Skaggs, Universal Technical Services, Inc., 5850 Eubank Blvd., NE, Suite B-49, Albuquerque, NM 87111, USA.

The largest cause of death or injury was found to be accidental exposure to carbon dioxide during maintenance or testing. A breakdown of the known causes of the release incidents is as follows:*

- Accidental discharge during maintenance or repair of the CO_2 system itself **(14** incidents)
- Accidental discharge during maintenance in the area surrounding the CO_2 system **(12** incidents)
- Operator error wherein the CO_2 was activated instead of some other system **(3** incidents)
- Accidental discharge because of a faulty system part or function (2 incidents)
- Intentional discharge during testing or training (2 incidents)
- Intentional discharge during a fire situation (2 incidents)
- Accidental discharge during testing (1 incident)
- Accidental discharge during a fire (1 incident)

When the causes of death or injury during maintenance to the C02 system itself or to the surrounding area were examined, it was apparent that several factors were significant. In some instances, adequate safety procedures were lacking, resulting in inadvertent actuation of the CO_2 system. In other instances, the safety procedures were in place, but were not followed properly. This failure to adhere to safety procedures demonstrates the Iack of understanding and appreciation of the dangers associated with CO_2 use. Lastly, in certain instances, a lack of technical proficiency of the personnel regarding the CO_2 system was apparent. This factor was most obvious in situations where the systems were accidentally discharged while personnel were doing maintenance in the vicinity of the systems. In these situations, personnel had inadvertently hit, stepped on, or fallen on some part of the CO_2 system, thereby discharging the system.

In conclusion, the search uncovered 146 deaths associated with the use of CO_2 in fire suppression systems. These deaths point to a need for additional safety measures when using CO_2. A large proportion **(68%)** of the post-1975 incidents was marine-related. Examination of the causes of the incidents indicated that only a limited number of crewmembers had the training and authority to activate the systems. Those crewmembers without training may not have had a true appreciation of the dangers that surround exposure to high CO_2. Consequently, additional safety measures might be warranted for marine applications.

Finally, when considering the use of CO_2 as a halon replacement agent, the benefits must be weighed heavily against the potential risks associated with its use. In current applications, perhaps additional training is warranted. Also, users and Authorities Having Jurisdiction (AHJ) should evaluate the applicability of the agent of choice for certain applications. Given the essential zero safety tolerance associated with CO_2, users and AHJs need to examine the risk they are willing to tolerate, because the risk is high.

ACKNOWLEDGMENTS

The author is gratefull for the assistance of Bob Darwin, US Navy (HTOC); Matt Gustafson, US Coast Guard; Matsuo Ishiyama, Nohmi Bosai (HTOC); Charles Willms, **FSSA** Tech Advisor; Richard Bromberg, Gespi (HTOC); Walter Brunner, Envico AG (HTOC); Roy Young, UK LPC (HTOC); and Participant of the Fire-List.

* These statistics do not reflect situations where personnel died in fires because the CO_2 system was deliberately not activated, since exposure to CO_2 would have been lethal.

Carbon Dioxide as an Extinguishing Agent

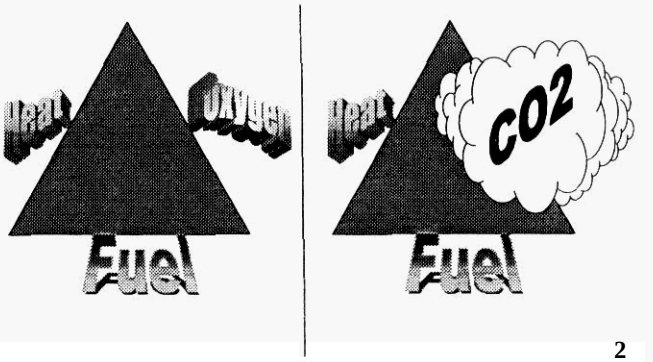
- Long Use History
- Effective on Most Fire Types
- Used As Total Flooding & Streaming Agent
- Self-pressurizing & 3-dimensional
- No Residue, Non-reactive
- Electrically Non-conductive
- Does Not Produce Agent Decomposition Products

Uses of Carbon Dioxide Extinguishers*

- Flammable Liquids
- Electrical Hazards
- Rotating Equipment
- Engines
- Ordinary Combustibles

* NFPA 12

Carbon Dioxide Extinguishing Mechanism



Carbon Dioxide Extinguishing Concentration on Various Fuels

Fuels	Minimum CO_2 Design Conc., %	**Resulting O_2 Conc., %
Carbon Disulfide	72	8.1
Ethylene	49	12.5
Ethanol	43	14.2
Propane	36	14.9
Hexane	35	15.0
Methane	34	15.7

Acute Health Effects of High Conc. Carbon Dioxide

CO_2 Conc., %	Time	Effects
25-30	Seconds	Convulsions, coma, death
11	1 minute	Unconsciousness, death
10	2 minutes	Unconsciousness
7-10	Several minutes	Headache, increased heart rate, shortness of breath, dizziness, sweating, rapid breathing, mental depression, shaking, visual
5	10-20 minutes	Shortness of breath, headache, vomiting

Ensuring Safe Use of Carbon Dioxide

- Authorities Having Jurisdiction (AHJ) Regulate Design, Installation, Testing, Maintenance & Use
- Example AHJ: US Coast Guard, IMO, OSHA, IRI, Military
- AHJ Determined by Location, Scenario, System Type
- AHJ Often Use NFPA 12 As Guidance Document or Governing Fire Code

AHJ Approval Process for Carbon Dioxide Systems

- Component Listing
- Design and Specification
- Installation and Testing
- Use
- Maintenance

Component Listing, Design and Specification

System components Listed with FM or UL (VdS in Germany)

System Designed by "Experienced" or "Qualified" Person Using Listed Components

System Specification, Instruction, Maintenance Manual Developed

Designs and Specifications Approved by AHJ or Conform to AHJ standards

Installation and Testing

Installation Done by Manufacturer-Trained Installer

(Not Certified or Accredited in the US and Many Other Countries)

System Inspected & Tested by Personnel to Meet AHJ Requirements

Full discharge Test to Check System Integrity and Design Concentration

Operational Check of Detection, Alarm, Actuation Devices

Check Signage, Warnings, Labels

Inspect Hazard Area

Use Controls

- Requirements Specified Under NFPA 12, SOLAS (International Maritime), 46 CFR (US Maritime), 29 CFR (OSHA)
- Even though CO, Best Minimum Design Concentration 2X Lethal Level, CO, Is Not Limited to Use in Unoccupied Areas

Safeguard Requirements

- Safeguards for Prompt Evacuation Prior to Discharge
- Prevent Re-entry Into Area Where CO, Was Discharged
- Ensure Prompt Evacuation for Trapped Personnel
- Warn Personnel of Hazards With CO_2
- Train Personnel on Alarms and Evacuation
- Provide "Lockout" to Prevent Unwanted Discharge

Survey of Accident Records

- Literature Searches
- Internet Searches
- Database Searches
- Professional Organizations

- OSHA, NLM, EnergySciTec
- NTIS
- GPO
- IAC
- Life Sci
- Ei Compendex
- Wilson
- Chemical Safety

List of Professional Contacts

- SFPE
- NAFED
- FSSA
- Manufacturers
- Japan Fire Ext. Sys. Manufacturers
- German Authorities
- Australia Maritime Safety Authority
- IRI
- National Defense Canada
- US Navy, Coast Guard
- NIOSH
- OSHA
- Canadian Res. Council
- UK MOD

Survey Results

(1940's - 1975)

- 11 Incidents
  - 3 Military, 7 Non-mil., 1 Unknown
  - 8 Domestic, 3 Foreign
- 7 Injuries
- 90 Deaths (43 Plane Crash)

(1975 - Present)

- 40 Incidents
  - 10 Military, 30 Non-mil.
  - 19 Domestic, 21 Foreign
- 85 Injuries
- 56 Deaths (13/19 Domestic Incidents Were Marine)

Total Deaths Linked to Carbon Dioxide Equals 146

Reported Causes of Accidental Injuries or Death (Post 1975)

- Accidental Discharge During Maintenance/repairs to CO_2 System Itself **(14)**
- Accidental Discharge During Maintenance in Vicinity of CO_2 System (12)
- Accidental Discharge From Operator Error **(3)**
- Accidental Discharge From Faulty System (2)
- Intentional Discharge During Testing (2)
- Intentional Discharge During Fire (2)
- Accidental Discharge During Testing (1)
- Accidental Discharge During Fire (1)

Causes of Death/Injury During Maintenance

- Lack of Adequate Safety Procedures
- Failure to Adhere to Safety Established Safety Procedures
- Low Technical Proficiency of Personnel

Factors or Practices Leading to Marine Accidents

- Limited Number of Crew Have Training and Authority to Activate CO_2 System
- Other Crew Members **Do** NOT Have Training Proficiency
  - Disregard Warning Signs or Alarms
  - Unfamiliarity With System Activation Mechanism
- Additional Safety Requirements May Be Needed

Conclusion

- 146 Lives Have Been Lost in Relation to Use of CO_2 **As** a Fire Suppression Agent
- May Need Other Safety Mechanisms
- May Need Additional Personnel Training
- May Need to Review Applicability of System Selection by User or AHJ
  - Determine What Level of Risk Is Tolerable
  - Determine What Agents Are Best Suited to Deliver Tolerable Risk
- May Need Better Record Keeping Practices to Track Incident Numbers and Causes