# CARBON MONOXIDE FAULT TREE STUDY

***Final Report***

*Date Issued:*
***July 31, 2018***

*Prepared for:*
**Technical Safety BC**

# VANCOUVER, BRITISH COLUMBIA

Date of Workshop
May 3-4, 2018


*Prepared by:*
**Jeff Dancey**


*BakerRisk Project No.*
**01-06563-001-18**


BAKERRISK

**BAKER ENGINEERING AND RISK CONSULTANTS, INC.**
5575 N Service Rd, Ste 103
Burlington, ON, L7L 6M1 Canada
Tel: (289) 288-0100
Fax: (289) 288-0094
www.BakerRisk.com

# Notice

Baker Engineering and Risk Consultants, Inc. (BakerRisk®) made every reasonable effort to perform the work contained herein in a manner consistent with high professional standards.

The work was conducted on the basis of information made available by the client or others to BakerRisk. Neither BakerRisk nor any person acting on its behalf makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information provided. All observations, conclusions and recommendations contained herein are relevant only to the project, and should not be applied to any other facility or operation.

Any third party use of this Report or any information or conclusions contained therein shall be at the user's sole risk. Such use shall constitute an agreement by the user to release, defend and indemnify BakerRisk from and against any and all liability in connection therewith (including any liability for special, indirect, incidental or consequential damages), regardless of how such liability may arise.

BakerRisk regards the work that it has done as being advisory in nature. The responsibility for use and implementation of the conclusions and recommendations contained herein rests entirely with the client.

# Executive Summary

Baker Engineering and Risk Consultants, Inc. (BakerRisk®) has completed the carbon monoxide exposure fault tree workshop, which was conducted on May 3-4, 2018 at the offices of Technical Safety BC (TechSafeBC) in Vancouver. During the course of this workshop, a fault tree was developed on potential causes of carbon monoxide exposure from industrial, commercial, and residential combustion equipment. Recommendations were made after the tree was developed to address the key causal factors behind those risks, as identified in the fault tree.

The generated fault tree for carbon monoxide exposure is provided as an attachment in Appendix A. Due to the size of the fault tree, it is not included in the main body of the report.

There were seventeen recommendations made by the working group for further action after the fault tree was generated. These recommendations appear in full in Section 3 of this report. There were three key causal factors that were identified during the fault tree sessions:

1. Misuse of equipment that generates carbon monoxide (use of outdoor equipment inside enclosures, improper venting of equipment, using equipment sized inappropriately for the application, etc.) was common to all types of use and facilities, and tied closely with what is perceived as an overall lack of knowledge of carbon monoxide hazards within both the public and industry. Several recommendations were made to address this perceived gap.
2. A number of regulatory gaps were identified regarding oversight of carbon monoxide-producing equipment and installations. This is in part due to the nature of the equipment and the hazard itself; the issues created cross a number of jurisdictional boundaries and can be lost when jurisdiction switches between different regulatory bodies. Recommendations were made to investigate improvements that could be made on oversight and enforcement.
3. Remote community support was identified as an issue during the workshop. There is a lack of availability of certified workers and inspectors in remote communities, which may lead to increased risks for inhabitants of those areas. Recommendations were made to attempt to improve the support for these remote areas.

# Table of Contents



# Appendices



# List of Figures

# 1 INTRODUCTION

On May 3-4, 2018, a two-day workshop was conducted by BakerRisk with TechSafeBC personnel to create a fault tree that examined the risks associated with carbon monoxide exposures in British Columbia. This workshop was a follow-up to a fault tree that had been internally generated by TechSafeBC in 2017, and the last of four workshops conducted by BakerRisk in 2018 covering four different risk topics of interest to TechSafeBC: escalator operation, electrical shock, ammonia exposure, and carbon monoxide exposure.

At the beginning of the session, the working group defined the final event to be analyzed as a carbon monoxide exposure to a human at above normal background levels. The level of potential harm was not defined, merely that the exposure occurred. The fault tree generated during this study is included in Appendix A. The original fault tree created in 2017 is included in Appendix B. A table listing all causal factors identified in the tree is shown in Appendix C.

Section 2 of this report includes a brief overview of fault tree methodology. Section 3 includes a full listing of all recommendations made by the working group, and Section 4 provides a summary and conclusion for the project.

# 2 FAULT TREE ANALYSIS

## 2.1 History

Fault tree analyses were first created and performed in the 1960's by Bell Laboratories in the U.S. in order to evaluate the risks associated with the potential inadvertent launching of Minuteman missiles and the potential unauthorized arming of nuclear devices. In the 1970's, the fault tree methodology was adopted by the U.S. nuclear industry as a way to evaluate the reliability of reactor safety, including the potential for reactor runaway, and the release of radioactive materials. It is still used in the U.S. nuclear industry to analyze risks and failure rates of critical systems.

Through the 1980's and beyond, fault trees have occasionally been used in chemical and petrochemical companies to provide detailed risk analyses where less detailed methods such as hazard and operability studies (HazOps) have not provided a clear resolution to risk decisions.

## 2.2 Basic Method

A fault tree is generated by choosing a specific final event of interest – such as a chemical release in a specific location, or an explosion from a reactor that leads to a fatality. After choosing the final event, the participants in the fault tree study work backwards to identify all of the causes that could lead to that particular final event. In most fault tree studies, each initiating cause that is identified is assigned a specific probability, allowing the organization creating the fault tree to identify the dominant cause or groups of causes that led to that final event, so that they can be addressed.

Fault trees use logic gates to create a map of sub-causes from the original event to the multiple potential root causes for that event. In Figure 1, the logic gate symbols used in fault trees are shown.

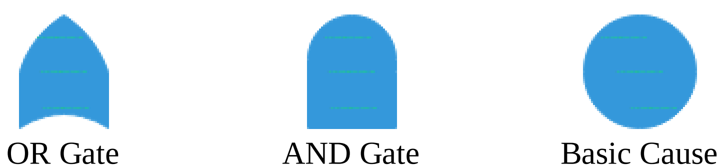


**Figure 1. Logic Gate Symbols**

Figure 2 shows an example tree created to demonstrate the fault tree map that be used to assess the failures that could result in a light bulb not turning on.

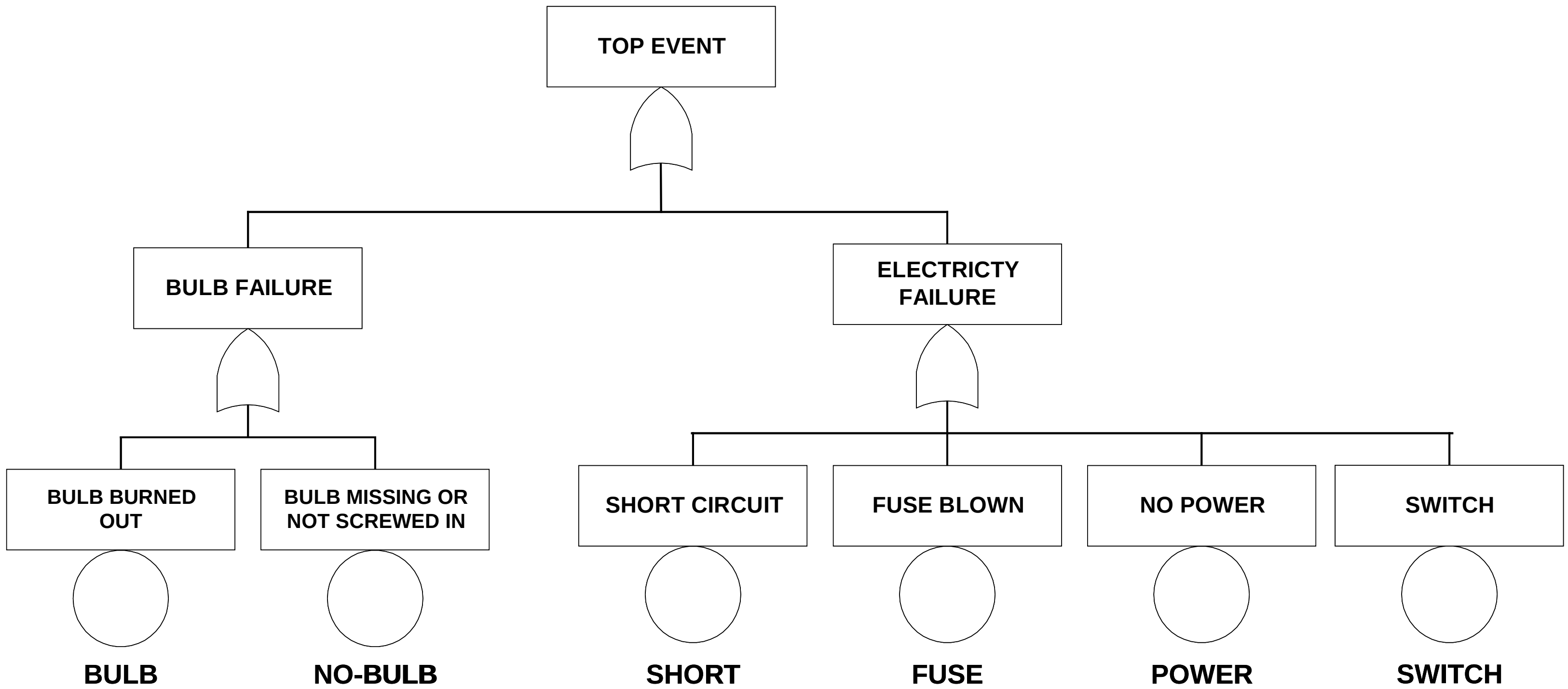


**Figure 2. Fault Tree Example – Light Bulb Fails to Light**

# 3 RECOMMENDATIONS

At the conclusion of the carbon monoxide exposure workshop, the working group reviewed the fault tree that had been created and identified the common causal factors that appeared in the tree; either factors that were repeated in numerous locations, or factors that were deemed critical by those participating.

The group then held a brainstorming session to develop actions and recommendations that could be carried forward by TechSafeBC to attempt to reduce the risks associated with carbon monoxide exposure. These recommendations appear in full, below:

1. Consider developing public education and awareness programs that target the misuse of combustion equipment and the risks of carbon monoxide exposure that accompany such misuse. This program should include information on when and how to hire a licensed contractor to work on combustion equipment, and the importance of proper maintenance and servicing.
2. Consider undertaking a review of the current syllabus and training materials included for apprenticeship programs for all Certificate of Quality (C of Q) programs to ensure that the materials being taught meet the curriculum requirements set forth by regulators. This should include provision for conducting reviews and ongoing regular audits of training providers to ensure their compliance with syllabus requirements.
3. Consider developing regulatory requirements and standards governing continuing education for all C of Q certificate holders, with the intent that a minimum level of continuing education be undertaken and that the education meet standards for applicability of content as set by the regulator.
4. Consider developing a program to promote Quality First and CSA B214 (Hydronic code) design programs with municipalities that do not currently require this system as part of their permitting program. Include educational material to demonstrate the effectiveness of these programs in improving residential installation practices.
5. Consider developing an educational seminar or information booklet for facility owners on the impacts of changes in use of combustion equipment on safe facility operation. Include material on the impact of introducing new combustion sources (such as propane forklifts) on the carbon monoxide load on ventilation equipment.
6. Consider requiring an operating permit (under GSR29) for all commercial fired equipment, to ensure that regulatory oversight of maintenance and servicing is maintained.
7. Consider implementing a practice that requires terms and conditions for industrial/commercial operating permits that mandate and clarify the requirements for

logbooks used in conjunction with fired heater operation. There is a concern that the current practice of maintaining log books is insufficiently detailed, and that minimum standards for requiring specific details do not exist.

8. Consider creating a program to educate owners, operators, and contractors of their duties, responsibilities, and liabilities under the current regulations. This could include targeted programs for different user bases, such as industrial fired heater operators, portable fired equipment rental companies, or commercial operators of gas fired stoves and appliances.
9. Research regulatory options available to improve oversight and control of the gas service industry, including what enforcement or inspection methods are viable, and what options are available to improve compliance by homeowners in using licensed and qualified personnel for maintenance, installation, and servicing requirements.
10. Review the existing design registration program as it applies to industrial fired heater applications and perform a gap analysis to identify shortcomings in the current program. Once the analysis is complete, consider developing additional regulation or programs to address the identified gaps.
11. Explore regulatory or policy options to ensure permits are taken out and inspections are performed when gas fired equipment is installed. As an adjunct to this, TechSafeBC should consider collecting and analyzing available data on CO exposures and incidents to determine what portion of those exposures are from unpermitted installations as opposed to those that were properly permitted and inspected.
12. Consider creating an educational campaign to create awareness around CO hazards and incidents. One focus should be to ensure that reporting of incidents and near-misses other than injuries or fatalities by first responders is done to improve data around CO exposures. An expansion of the existing red tag program to include other utilities should be considered as well.
13. Explore the development of programs, mechanisms, and tools to allow information sharing between different agencies to allow better communication of identified risks and hazards associated with CO exposures.
14. Explore potential new or additional data sources for CO exposure monitoring; i.e., hospital data, out-of-province data, industry/trade data, and data from other government agencies. There is a concern that the existing data is not broad enough to allow appropriate targeting of actions to address CO hazards.
15. Consider developing a program to work with regional districts in the smaller/remote communities to promote, educate, or recommend sources of information on carbon monoxide to improve the resources available for remote regions.
16. Consider expanding the existing regulation, GSR 26, to include commissioning requirements. Currently, there is a requirement that an inspection be done after the installation of a fixed fired heater, but there is no requirement for regulatory presence

during commissioning of new equipment, nor is there any requirement to report the results of commissioning tests to the regulator. Adding a requirement for a formal pre-start-up safety review (PSSR) prior to starting any fixed fired heater installation could be considered as one method to improve safety in this area.

17. Consider creating a program to educate owners and operators on existing ventilation requirements as included in the current codes and regulations. This should include promoting the existing resources available at WorkSafeBC. Consider cross-linking TechSafeBC and WorkSafeBC resources.

# 4 SUMMARY

On May 3-4, 2018, a working group formed by Technical Safety BC met to update the fault tree analysis done in 2017 on carbon monoxide exposure risks in the province of British Columbia. During this workshop, the working group generated a fault tree dedicated to identifying the causal factors associated with carbon monoxide exposures.

At the conclusion of the two-day workshop, seventeen recommendations to address the common or critical causal factors identified in the creation of the fault tree were made, as outlined in Section 3. The critical deficiencies identified during this workshop were largely associated with the lack of knowledge and understanding of carbon monoxide risks within both the public and industry.

Associated with this lack of knowledge is the ongoing issue that changes made to combustion equipment or new installations after initial inspections may introduce an increased level of risk without any recognition on the part of the owner or operator that this has occurred. At the homeowner level, this is difficult to address except via public awareness campaigns. At an industrial or commercial level, TechSafeBC should consider adding a regulatory requirement that requires an annual carbon monoxide survey be performed at any facility where a minimum level of combustion equipment is in operation. Similar surveys are commonly required for noise levels in industry on an annual basis. Establishing a baseline CO level in a facility and monitoring that on a yearly basis will provide some level of reassurance that facility changes or aging equipment isn’t leading to an increased risk over time. It will also raise the awareness of carbon monoxide levels within the industry in general.

# APPENDIX A. FAULT TREE

Due to the large size, the fault tree created during this workshop is attached as a .pdf file to this report. The file name is *Carbon Monoxide Exposure.pdf*.

# APPENDIX B. ORIGINAL FAULT TREE

The original fault tree developed by TechSafeBC is attached as a Microsoft Visio file. The file title is *Event Tree – Carbon monoxide exposure v5.vsd*

# APPENDIX C. CAUSAL FACTORS

| Causal Factor | Number of Appearances |
|---|---|
| Cost/Time Constraints | 30 |
| Corporate Culture | 29 |
| Code Gap | 15 |
| Lack of CO Awareness | 13 |
| Lack of Duty Holder Oversight | 12 |
| Lack of Knowledge/Training | 11 |
| Personnel Availability | 10 |
| Specification Availability | 10 |
| Lack of Training/Certification | 9 |
| Oversight Gap | 8 |
| Risk Tolerance/Complacency | 7 |
| Lack of PM/Inspection Program | 6 |
| Unfamiliar with New Technology | 6 |
| Regulatory Gap | 5 |
| External Party Training Required | 4 |
| Inadequate Design/Instruction | 4 |
| Lack of Awareness | 4 |
| Poor Dissemination | 4 |
| Calibration/Testing Issues | 2 |
| Code Non-compliant | 2 |
| Cost Constraints | 2 |
| Environmental Effects | 2 |
| Environmental/Comfort | 2 |
| Equipment Changed After Inspection | 2 |
| Instruction Availability | 2 |
| Jurisdiction Gap | 2 |
| Lack of Initial Inspection | 2 |
| Lack of Maintenance Process | 2 |
| Manufacturing Defect | 2 |
| Material Availabiltiy | 2 |
| Obsolescence | 2 |
| OEM Specific Parts | 2 |
| Parts Availability | 2 |
| Poor OEM Design | 2 |
| Tool Availability | 2 |
| Uncertified Equipment | 2 |
| Certification Gap | 1 |
| Contaminated Supply | 1 |
| Equipment Availability | 1 |
| Equipment Degradation | 1 |
| Equipment Mobility | 1 |
| External Certifications | 1 |
| Fuel Age | 1 |
| Hose Too Long | 1 |
| Human Presence | 1 |
| Increasing Complexity | 1 |
| Increasing Hazard | 1 |
| Lack of Change Control | 1 |
| Lack of Dissemination | 1 |
| Lack of Monitoring Program | 1 |
| Misuse | 1 |
| Non-Utility Service Community | 1 |
| Power Failure | 1 |
| Regulator Sized/Set Wrong | 1 |
| Replacement Strategy | 1 |
| Storage Tank Contaminated | 1 |
| Tank Too Small | 1 |
| Temporary Install | 1 |
| Truck Contaminated | 1 |
| Unaware of Maintenance Requirement | 1 |
| Use of Outdated Code | 1 |