TECHNICAL REPORT 2

THE PROBABILITY OF FATALITY IN OXYGEN ENRICHED ATMOSPHERES DUE TO SPILLAGE OF LIQUID OXYGEN

REVISION 2: 2018

British Compressed Gases Association

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PREFACE

The British Compressed Gases Association (BCGA) was established in l971, formed out of the British Acetylene Association, which existed since l901. BCGA members include gas producers, suppliers of gas handling equipment and users operating in the compressed gas field.

The main objectives of the Association are to further technology, to enhance safe practice, and to prioritise environmental protection in the supply and use of industrial gases, and we produce a host of publications to this end. BCGA also provides advice and makes representations on behalf of its Members to regulatory bodies, including the UK Government.

Policy is determined by a Council elected from Member Companies, with detailed technical studies being undertaken by a Technical Committee and its specialist Sub-Committees appointed for this purpose.

BCGA makes strenuous efforts to ensure the accuracy and current relevance of its publications, which are intended for use by technically competent persons. However this does not remove the need for technical and managerial judgement in practical situations. Nor do they confer any immunity or exemption from relevant legal requirements, including by-laws.

For the assistance of users, references are given, either in the text or Appendices, to publications such as British, European and International Standards and Codes of Practice, and current legislation that may be applicable but no representation or warranty can be given that these references are complete or current.

BCGA publications are reviewed, and revised if necessary, at five-yearly intervals, or sooner where the need is recognised. Readers are advised to check the Association's website to ensure that the copy in their possession is the current version.

This document has been prepared by BCGA Technical Sub-Committee 1. This document replaces BCGA Technical Report 2, Revision 1: 2013. It was approved for publication at BCGA Technical Committee 158. This document was first published on 08/10/2018.
For comments on this document contact the Association via the website www.bcga.co.uk.

CONTENTS

* Throughout this publication the numbers in square brackets refer to references in Section 6. Documents referenced are the edition current at the time of publication, unless otherwise stated.

FOREWORD

This revision of Technical Report 2 was prepared under the guidance of BCGA TSC6.

No technical changes have been introduced in this revision. The reason for Revision 2 was to update the structure and formatting of the document to align this document with other BCGA publications.

TERMINOLOGY AND DEFINITIONS

May	Indicates an option available to the user of this Technical Report.
Shall	Indicates a mandatory requirement for compliance with this Technical Report and may also indicate a mandatory requirement within UK law.
Should	Indicates a preferred requirement but is not mandatory for compliance with this Technical Report.

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LIQUID OXYGEN – OFFSITE RISKS

This document presented a case for revising the method of estimating off-site risks from the bulk storage of liquid oxygen first described in 1984 in a British Compressed Gases Association (BCGA) report proposed by the BCGA/HSE/SRD working group (refer to BCGA Technical Report (TR) 1 [1], *A method for estimating the offsite risks from bulk storage of liquefied oxygen*). It addresses the probability of serious injury or death due to a liquid oxygen spillage. It does not address or update the dispersion of cold oxygen or the probability of the failure event. These issues have been covered in other publications on the development of consequence and risk analysis.

1. INTRODUCTION

There was a belief by those using the BCGA methodology (refer to BCGA TR 1[1]) that the results obtained from it are conservative, leading to planning decisions that are over-stringent, not supported by incident experience and opposed by conventional wisdom. A working group was convened of representatives from the BCGA and the Health and Safety Executive (HSE) which reviewed the methodology and produced this document.

Since 1984, there have been very few major accidents world-wide reported with significant consequences off site involving liquid oxygen spills. This can be directly attributed to the high standards adopted for cryogenic liquid storage installations. There are only a relatively small number of companies involved in the industrial gases industry; they work closely on safety issues (through trade associations such as BCGA, the European Industrial Gases Association (EIGA), the American Compressed Gases Association (CGA), etc.) resulting in high standards throughout the industry.

The BCGA methodology is based on a small number of data under experimental conditions. To extrapolate these data to actual situations is a complex issue and more cognisance should be taken of actual events if we want to accurately predict risks from the release of liquid oxygen (LOX). The instances where there was multiple loss of life has involved some form of confinement, e.g. ship's compartment, car, building, etc. There have been no major releases of liquid oxygen where people exposed in the open air have received serious injuries. This data tell us something regarding the risks from a liquid oxygen release. Refer to Appendix 1 for a list of some liquid oxygen release accidents occurring after 1984.

The nature of the hazard under review

The review is restricted to the situation where people find themselves at risk in oxygen-enriched circumstances. It is worth reminding ourselves here of the unusual nature of the risk. Unlike toxic contamination that will affect all living creatures or flammable gas escapes that need only a source of ignition to engulf all unfortunate enough to be in the cloud, oxygen enrichment is essentially harmless unless or until it coincides with the presence of fuel and a

means of ignition. However, oxygen enrichment can be difficult to detect, due to the lack of smell or other physiological effects.

The other risk of cryogenic burning was extensively studied in BCGA TR 1 [1] and is not considered in this document. The probability of sustaining a serious low temperature injury outside the works is extremely small and is subsumed by the cautious treatment of factors later in this document.

The case study
In this simplified case, the spill has occurred and enrichment reached areas where people are assembled or working. The steps leading to serious injury or fatality require consideration and comparison with the view taken by the authors of BCGA TR 1 [1]. For this simplified case the steps are taken as:

- Probability of ignition source being present.
- Probability of ignited clothing.
- Probability of fatal or serious injury.

2. PROBABILITY OF IGNITION SOURCE BEING PRESENT

The sources of ignition
Without a source of ignition, the enrichment incident passes by, unnoticed by many. With a source of ignition, clothing may ignite; smoking is the most obvious source. BCGA TR 1 [1] assumes a smoking population based upon data published in 1976. Since then, smoking in the UK has reduced considerably, refer to Appendix 2. For example, in 1976, 46 % of men and 38 % of women smoked cigarettes. By 1992, these numbers had fallen to 29 % and 28 %. Furthermore, over the six years to 1994 / 95, the amount of tobacco consumed has fallen. The previously approximated patterns of smoking can still be used conservatively. Smoking occupies 5 % of the time at work and 10 % of the time away from work (including time asleep) based upon a 7½ minute duration for smoking a cigarette. Some reduction of the smoking population used in BCGA TR 1 [1] is proposed. Whereas, the report used 40 %, it is now suggested that 35 % is more appropriate, thus adjusting the population at risk from 2 % (whilst at work) and 4 % (whilst elsewhere) to 1.75 % and 3.5 %.

Smoking is not the only source of ignition: cooking, use of open flames, use of electrical equipment, could be relevant. No data are available but the authors perceive an increased risk from a growing use of personal electronics and DIY activities. However they do not feel that this is a significant increase in risk compared to the cautious use of smoking statistics. On the other hand, car fires are likely to reduce as diesel engines, fuel injected engines and computer controlled engine management systems replace the older carburettors / contact breaker types. In these modern systems there is no petrol reservoir to burn, less external sparking to act as ignition source and more likelihood that the newer engines will keep running with a short-term unusual oxygen high mixture. On balance the authors believe that these factors do not change their decision to reduce the number of “smokers” to 35 % in this review.

3. PROBABILITY OF IGNITED CLOTHING

BCGA TR 1 [1] concentrates on smokers and match users as being the persons most at risk. The authors perceive an increase in the usage of lighters which removes, almost entirely, the risk from a flaring / breaking / dropped match. The use of a lighter ensures that a flame exists for a short time only at the tip of the cigarette. In an enriched atmosphere, the more rapidly burning end may fall off in a shower of sparks but below 30 % that would not provide the 20 seconds (or so) heating required for fire to become established. Refer to Appendix 3. Above 30 %, the situation changes as the cigarette is likely to burn (and be dropped) and clothing takes less time (say 10 seconds) to catch fire, refer to BCGA TR 1 [1], Appendix 1, Sheet 1.

Thus, it is proposed that:

a) 5 % probability of igniting clothing be assigned to 25 % oxygen. As can be seen from BCGA TR 1 [1], Figure A.1.2, the materials tested show little difference in ignition time from air. Clothing will burn in air but we have no evidence that people are being seriously injured from clothing fires outdoors.

b) 30 % probability of igniting clothing be assigned to 30 % oxygen.

c) 50 % probability of igniting clothing be assigned to 35 % oxygen. This estimate approximately fits the curve.

d) 90 % probability of igniting clothing be assigned to 40 % oxygen. In 40 % oxygen, a lit cigarette will flare. If it is dropped, there is a high risk that it will contact and ignite clothing.

4. PROBABILITY OF FATAL OR SERIOUS INJURY

Speed of ignition
BCGA TR 1 [1], Appendix 1, estimated the relative rate of burning of materials in oxygen, refer to Table 1.

Oxygen concentration %	25	30	35	40
Relative burning rate	1	1.25	1.7	3

Table 1: Relative rate of burning of materials in oxygen

Ability to react
BCGA TR 1 [1], Figure A.3.1, plots the percentage of population capable of making a manual response against reaction time in seconds. Almost all can react in 20 seconds and none in 5 seconds. Instinctively, one feels the latter is very conservative; grit in an eye or hot water on a hand is enough to generate a response in less than a second. The probability of successful reaction at increased burning rates, and the involvement of other parties in reacting and becoming casualties has also be considered. Continuing to use BCGA TR 1 [1], Figure A.3.1 unmodified, emphasises the conservative nature of this reassessment.

The probability of fatal or serious injury if clothing ignited

In 1991, it was reported [2] that mortality associated with burns and scalds had decreased by 19 % compared to that reported in 1971. This favourable trend followed the 50 % reduction in deaths over the previous 40 years. Burns from clothes catching fire have reduced in the thirty years to 1981 by half and deaths by two-thirds. Better awareness of fire risks, popular use of jeans, less open-fire heating, etc. has contributed to the reduction in number burned while improved medical treatment has reduced the mortality rate. For example by the 1990's, cases are known of men in their mid 30's surviving 92 % + burns.

These facts persuade the authors that an assumption of increase in mortality due to oxygen rich fires are not required. Furthermore, by choosing to take no account of the improving situation, the authors retain and extend the conservative policy of BCGA TR 1 [1].

Thus, it is proposed that the following conservative values be adopted for probability of fatal or serious injury, where the relationship of probability of fatal or serious injury is proportional to the square of the burning rate to oxygen enrichment (refer to Table 1):

a) 10 % probability of fatality or serious injury be assigned to the case where clothing is ignited in 25 % oxygen.

b) 16 % probability of fatality or serious injury be assigned to the case where clothing is ignited in 30 % oxygen.

c) 29 % probability of fatality or serious injury be assigned to the case where clothing is ignited in 35 % oxygen.

d) 90 % probability of fatality or serious injury be assigned to the case where clothing is ignited in 40 % oxygen.

5. CONCLUSION

The reappraisal of some of the aspects of BCGA TR 1 [1] described in the text lead to the results shown in Table 2. In comparison to BCGA TR 1 [1], in Table 3, the assumed probabilities of fatal or serious injury are significantly lower.

The HSE in assessment of risks use the concept of a defined dangerous dose. This is suitable criteria for assessing the wide range of susceptibility of the general public. The conclusions of this reappraisal (this Technical Report) were reviewed by the Major Hazards Assessment Unit of HSE in 1998, and a dangerous dose for liquid oxygen spills has consequently been defined by HSE as 35 % total oxygen concentration.

OXYGEN CONCENTRATION %	25	30	35	40
Probability of ignition source being present Based on 30 % of population as smokers and 10 % of time away from work spent smoking (7.5 minutes per cigarette).	3.5	3.5	3.5	3.5
Probability of ignited clothing Based on time to ignite clothing. Type of ignition source (match, lighter, cigarette). Type of material.	5	30	50	90
Probability of Fatal or Serious Injury Based on burning rate of material and reaction time of victim.	10	16	29	90
Probability of Fatal or Serious Injury	0.018	0.17	0.53	2.8

Table 2: Probability of fatality in oxygen enriched atmosphere

Oxygen concentration	Probability of fatal or serious injury		Reduction in probability %
	BCGA Report	Simplified approach	
25	0.02	0.018	10
30	0.6	0.17	72
35	1.6	0.53	67
40	3.9	2.8	28

Table 3: Probability of fatal or serious injury

6. REFERENCES

	Document Number	Title
1.	BCGA Technical Report 1	A method for estimating the offsite risks from bulk storage of liquefied oxygen
2.		Fire Safety Journal 7 (1991) pp 205-215

Further information can be obtained from:

Health and Safety Executive (HSE)	www.hse.gov.uk
European Industrial Gases Association (EIGA)	www.eiga.eu
British Compressed Gases Association (BCGA)	www.bcga.co.uk
USA Compressed Gases Association (CGA)	www.cganet.com
Action on Smoking and Health (ASH)	www.ash.org.uk

INCIDENTS INVOLVING LIQUID OXYGEN

1. Liquid oxygen release near welding shop - Australia (1985)

A liquid oxygen tanker was parked on a sharp incline, filling a customer tank. The tanker driver built up the pressure in the tanker using the pressure-raising coil, but unfortunately the vapour vent in the tanker was now below liquid level because of the slope. Liquid began to run from the vent down the sharp incline and below the shutter doors of a small engineering company. Two employees in the shop were conducting brazing / welding operations and both died from injuries sustained when their clothing caught fire.

2. Road tanker traffic accident - USA (1987)

A road tanker containing liquid oxygen side-swiped a car on an express way. The tanker crashed into an abutment and exploded.

3. Large release of liquid oxygen from a storage tank - USA (1988)

The bonnet connection of a 3-inch valve from a large low-pressure liquid storage tank failed because the bolts were of the wrong material. The full contents of the tank, approximately 1500 tonne, were released vertically from the top of the valve into the atmosphere. There was a dense, white vapour cloud surrounding the site up to about a height of 2 m, and this extended to the edges of the site, about 200 m. Gas detection equipment verified that the oxygen concentration outside of this white cloud was only slightly above atmospheric air. There was also a large frost pool immediately below the valve where the liquid had obviously accumulated. There were no injuries or damage reported.

4. Liquid oxygen release - car caught fire - USA (1989)

A 3 position valve at a road tanker loading facility was turned to manual mode and instantly discharged oxygen onto the ground. The fill valve was closed but liquid oxygen spilled onto the roadway. A contractor's vehicle drove through the liquid oxygen and the car stalled. When the contractors attempted to restart the engine a fire occurred. The car caught fire and was subsequently destroyed. There were no injuries.

5. Liquid oxygen release from ISO container - UK (1990)

A 20 tonne ISO container had just been filled when the hose connection to the tank became detached, and the contents of the ISO container were released into the atmosphere. There were no injuries or damage reported.

6. Germany (1990)

A liquid oxygen rail car was being filled from a large storage tank in an air separation plant. The liquid oxygen was transferred from the storage tank to the rail tanker by hose. Due to the distance, two hoses were connected together to achieve a suitable length of filling hose. After filling had commenced, it was seen that the connection between the two hoses was not completely leak tight. During the filling process liquid oxygen escaped into the groove of the rail line close to a point where the rails were connected by screwed fish plates. Approximately three metres of the rail were frozen and, due to contraction of the rail, the bolts connecting the rail and fish plates together ruptured and an explosion occurred. The pavement stones and part of the rail connection were ejected to distances over 100 metres away, but fortunately no one was injured. The investigation revealed that while the surface of the roadway around the rails was reasonably clean, below the surface the bolts, which connected the fish plates to the rails, were lubricated with a black hydrocarbon grease. The source of ignition was most likely the rupturing bolts which ignited the black grease / liquid oxygen mixture.

7. Liquid oxygen release in residential area – Philippines (1993)

A liquid oxygen tank that was located in a building was being filled from a tanker. The brazed connection from the valve to the tank failed and 13 tonnes of liquid oxygen was released into the building, which had several openings. The cold oxygen vapours exited from the building and flowed down walled streets into an area where there were food stalls and open fires. Members of the public were smoking and one person reported seeing sparks on his feet as he entered his vehicle to start it. Another person's clothing went on fire, but they managed to douse the flames in a local canal. One person was burned, mainly on the lower parts of the body. An administration building was burned down and also a vehicle.

8. Liquid oxygen venting and injury to employee – Canada (1996)

Out of specification liquid oxygen was being vented through a disposal stack when it ran along the ground and entered a control room. As an employee entered the building he quickly became engulfed in flames, although several fire extinguishers were used on him it was almost impossible to put out the flames. The flames started around the legs of the employee and most of the burn injuries were below waist level.

9. Liquid oxygen release from instrument connection on a storage tank – USA (1997)

A tank was being emptied and vented. When pressure reached atmospheric, the lower liquid level tapping drain valve was opened. No liquid issued out and the operator assumed the tank was empty. The drain was left open. Over time the heat leakage into the tank caused a build-up of pressure which forced a few tonnes of liquid out of the drain. An oxygen vapour cloud spread across the boundary onto an adjacent road less than 20 metres away. A car drove through the cloud and caught fire. The driver escaped but the car was destroyed.

ACTION ON SMOKING & HEALTH – SMOKING STATISTICS

16 Fitzhardinge Street, London W1H 9PL Tel: 0171 224 0743 Fax:0171 224 0471

FACT SHEET NO. 1

ASH
Action on Smoking
and Health

November 1997

SMOKING STATISTICS

Number of smokers

The highest recorded level of smoking among men was 82 % in 1948, when surveys started. Among women, smoking preference remained fairly constant between 1948 and 1970 and peaked at 45 % in 1966. Overall prevalence among adults (aged 16+) has fallen steadily since the early 1970s, faster among men than women, so that there is now effectively no difference between the sexes. Smokers have been a minority in the adult population since 1976 [1,2].

Prevalence of cigarette smoking – percentage of adult population [1]

	1976	1980	1982	1984	1986	1988	1990	1992	1994	1996
Men	46	42	38	36	35	33	31	29	28	29
Women	38	37	33	32	31	30	29	28	26	28

There are about 12.1 million adult cigarette smokers in Great Britain and another 2 million who smoke only pipes and/or cigars. There are about 9.4 million ex-smokers [1].

Tobacco consumption

Cigarette consumption among men rose steadily from 1980 until 1945 when it reached a peak of 12 cigarettes per adult male per day. For the next 30 years it stayed between 9 and 11 cigarettes per adult male per day but then fell, reaching 6.3 by 1987 and 4.6 by 1992. Measurable cigarette smoking among women began about 1920 and rose rapidly to a maximum of 7 cigarettes per adult female per day in 1974, since then there has been a decline to 5.1 in 1987 and 3.9 in 1992. [1,2].

Average weekly cigarette consumption per smoker in Great Britain [1]

	1976	1980	1982	1984	1986	1988	1990	1992	1994
Men	129	124	121	115	115	120	118	112	114
Women	101	102	98	96	97	99	97	97	97

Since the early 1960s there has been a decline in the total weight of tobacco sold. This was initially due to the introduction of filter cigarettes in 1964 which reduced the amount of tobacco in each cigarette. The total number of cigarettes consumed began to decline in the mid-1970s and fell by some 25 % over the next 10 years [2].

Estimated amount of both home produced and imported tobacco products released for consumption in the UK [3]
(Comment: year to year variations in releases of tobacco to the market in part represent (de-)stocking by the trade)

	1990/91	1991/92	1992/93	1993/94	1994/95	1995/96	1996/97
Cigarettes (millions)	97,811	93,496	94,080	74,514	85,205	80,833	81,344
Cigars (1000 kg)	2,315	2,105	1,955	1,724	1,679	1,501	1,453
Rolling tobacco (1000 kg)	4,205	4,057	3,822	3,161	3,036	2,558	2,204
Other tobacco (1000 kg)	2,222	2,081	2,027	1,785	1,565	1,347	1,221

Cigarette smoking and socio-economic group

There is a strong link between cigarette smoking and socio-economic group. In 1994, 35 % of men and 31 % of women in manual occupations smoked compared to 21 % of men and 21 % of women in non-manual occupations. There is a slower decline in smoking among manual groups, so that smoking is increasingly concentrated in these groups [1].

Cigarette smoking and age

In 1994, those aged 16-19 were less likely to be cigarette smokers than those aged 20-24 (28 % and 40 % respectively): but thereafter in older age groups there were progressively fewer smokers. This pattern has only emerged since the mid-1980s – prior to that, prevalence was similar in all except the oldest and youngest age groups. This change reflects the increase in the number of men and women aged 35 and over who are giving up smoking [1].

Deaths caused by smoking

In 1990 about 138,000 people in the UK were killed by smoking, accounting for one fifth of all UK deaths [4]. Half of all teenagers who are currently smoking will die from diseases caused by tobacco if they continue to smoke. One quarter will die after 70 years of age and one quarter before, with those dying before 70 losing on average 23 years of life [5]. Between 1950 and 2000 it is estimated that six million Britons and 60 million people worldwide will die from tobacco-related diseases [4]. Most die from one of the three main diseases associated with cigarette smoking: lung cancer, chronic obstructive lung disease (bronchitis and emphysema) and coronary heart disease. Based on UK mortality data for 1990, it is estimated that approximately 90 % of deaths from lung cancer, 76 % from chronic obstructive lung disease and 16 % of deaths from vascular disease are caused by smoking [4]. The table below shows the total number of deaths from these diseases.

DEATHS BY CAUSE 1993 [6]				
	England and Wales	Scotland	Northern Ireland	Total
Malignant neoplasm: trachea, bronchus, lung (ICD 162)				
Men	21,665	2,755	543	24,963
Women	10,944	1,544	269	12,757
Total:	32,609	4,299	812	**37,720**
Ischaemic heart disease (ICD 410-414)				
Men	79,509	8,942	2,323	90,774
Women	66,926	7,963	1,922	76,831
Total:	146,435	16,925	4,245	**167,605**
Bronchitis, emphysema (ICD 490-492, 494-496)				
Men	16,810	1,600	416	18,826
Women	10,324	1,265	259	11,848
Total:	27,134	2,865	675	**30,674**

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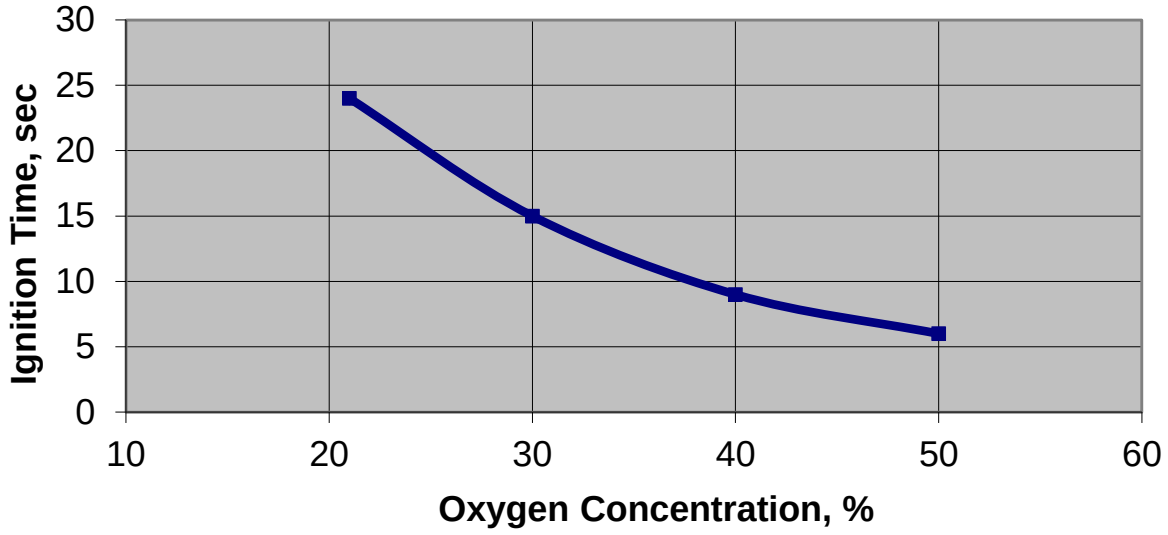

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