Guidelines for Alcohol Calculations

Version 4.3
10th August 2021

CONTENTS

ABBREVIATIONS

Abbreviation	Meaning
µg	Microgram
ABV%	Percentage alcohol by volume
ATD	Alcohol Technical Defence
BAC	Blood alcohol concentration
BBR	Blood-breath ratio
BMI	Body mass index
BrAC	Breath alcohol concentration
cL	Centilitre, 10mL
cm	Centimetre
dL	Decilitre, 100mL
ft	Feet
F_{water}	Fraction of blood volume that is water
h	Hour
kg	Kilogram
L	Litre
mg	Milligram
mL	Millilitre
NB	*Nota bene*
st	Stones
TBW	Total body water
UK	United Kingdom
V	Apparent volume of distribution

1 INTRODUCTION

This version of the Guidelines updates version 2.1, issued in December 2014 (1), and encompasses recent investigations into uncertainty in total body water, validity of the Watson *et al.* and Forrest equations and in the strengths of alcoholic beverages.

Alcohol calculations may be required in numerous casework situations. There are potentially many parameters that could be used for such calculations which could produce a different evidential outcome from the same information. These Guidelines are designed to ensure, where possible, a consistent approach to alcohol calculation casework within the United Kingdom and Republic of Ireland. The guidelines are designed to minimise potential problems with forensic alcohol calculations, they are not prescriptive instructions on 'how to perform' these calculations.

2 DRINK DRIVING AND THE LAW

2.1 UK LEGISLATION

In England, Wales and Scotland the relevant legislation is contained within the Road Traffic Offenders Act 1988, Sections 15(2) and 15(3) (2) and in Northern Ireland in Sections 18(2) and 18(3) of the Road Traffic Offenders (Northern Ireland) Order 1996 (3):-

(15.2) Evidence of the proportion of alcohol or any drug in a specimen of breath, blood or urine provided by, or taken from, the accused shall, in all cases (including cases where the specimen was not provided in connection with the alleged offence), be taken into account and—

(a) it is to be assumed, subject to subsection (3) below, that the proportion of alcohol in the accused's breath, blood, or urine at the time of the alleged offence was not less than in the specimen.

(b) it is to be assumed, subject to subsection (3A) below, that the proportion of a drug in the accused's blood or urine at the time of the alleged offence was not less than in the specimen.

(15.3) The assumption in subsection (2)(a) above shall not be made if the accused proves—

(a) that he consumed alcohol before he provided the specimen, or had it taken from him, and—

(i) in relation to an offence under section 3A, after the time of the alleged offence, and

(ii) otherwise, after he had ceased to drive, attempt to drive or be in charge of a vehicle on a road or other public place, and

(b) that had he not done so the proportion of alcohol in his breath, blood or urine would not have exceeded the prescribed limit and, if it is alleged that he was unfit to drive through drink, would not have been such as to impair his ability to drive properly.

2.2 Republic of Ireland Legislation

In the Republic of Ireland the Road Traffic Act 2010 (4) covers drink driving legislation. While ATD is not accounted for in the legislation it may be used in civil cases and cases of frustration where a drink has been taken after driving in order to distort the alcohol level.

RTA 2010, Number 25 of 2010 (Chapter 5, section 18)

'(3) (a) A person shall not take or attempt to take any action (including consumption of alcohol but excluding a refusal or failure to provide a specimen of his or her breath or urine or to permit the taking of a specimen of his or her blood) with the intention of frustrating a prosecution under section 4 or 5. (b) A person who contravenes this subsection commits an offence and is liable on summary conviction to a fine not exceeding €5,000 or to imprisonment for a term not exceeding 6 months or to both'

3 EXAMPLES OF ALCOHOL CALCULATION SCENARIOS

Situations where a forensic scientist can be requested to perform calculations include: -

3.1 Post-Incident Drinking (The "Hip Flask" Defence)

Where an individual claims to have consumed alcohol after driving, but before their evidential sample has been supplied, and it is therefore necessary to calculate the contribution from this additional alcohol consumed.

3.2 Laced Drinks Defence (“Special Reason” For Not Disqualifying)

Where an individual claims to have unknowingly consumed alcohol e.g. where extra alcohol has been added to a drink, and calculations are required to account for this extra alcohol.

3.3 Back-Calculation

A calculation to determine the alcohol concentration at a previous time, which may take into account any claimed post-incident drinking. It is also a requirement of Section 3A of the Road Traffic Act 1988 (e.g. causing death by careless driving); regional variations may apply (2).

3.4 Time to Driving

A calculation based upon the evidential alcohol concentration, and a time after the evidential specimen was obtained. The time is usually a time given by the motorist as the time they intended to drive (but note that the law requires assessment of “likelihood” and not “intention” (Road Traffic Act 1988 S5(2)). More rarely, the practitioner may be asked at what time the alcohol concentration would have fallen below the prescribed limit.

4 RECOMMENDATIONS FOR PRACTITIONERS

Recommendations on the information required to carry out such calculations, what calculations should be performed and what parameters should be used are detailed below: -

4.1 Information Required

To be able to carry out the calculations that may be required, the following information should be obtained: -

4.2 Tests & Circumstances

- Time of driving incident
- Time of preliminary breath test and result
- Time and result of evidential specimen

4.3 Subject Details

- Name
- Age or date of birth
- Sex at birth
- Height
- Weight

If the weight or height of the subject is not available then an estimate of either, or both, can be used. However, if that is the case, this should be stated, and the basis for the estimate should be given by the practitioner. It should be borne in mind that the uncertainty of the calculated results will increase if estimates are used (5).

4.4 Food & Drink Consumption

- Details of alcohol consumption over the previous 24 hours. It is important to include as much detail as possible
  - The start and finish times of each drinking episode
  - Volumes consumed
  - Type of drink(s) (beer, wines, spirits etc.)
  - Brand(s)
  - Alcoholic strength (ABV%)
- Details of food consumption within previous 24 hours
- Details of medication (if any)
- Medical conditions (if any)

4.5 Drink measures in Retail Premises

4.5.1 Spirits

A normal bottle of spirit is 70 cL (700 mL) but 1 litre bottles (1000 mL) are readily available. Bottles are also available at half-sizes (350mL) and small (200 mL). Miniatures, where available, are generally 50 mL in volume.

4.5.2 Wine

A standard bottle of wine is 750 mL; half-bottles are increasingly available, 375 mL, but 500 mL bottles and quarter bottles (normally 187 mL) may also be sold.

4.5.3 Beer
Bottled beer is available in 750, 660, 568 (a pint), 500, 330, and 275 mL sizes. Likewise, canned beer is available in many different sizes. The most common can sizes are 568, 500, 440, and 330 mL, but others are available.

4.5.4 “Alcopops”
“Alcopop” bottles are generally 275 mL in size but 700 mL bottles are also available.

4.6 Drinks measures in Licensed Premises

4.6.1 United Kingdom
Spirits are sold in measures of either 25 or 35 mL for a single. If information is not known, 25 mL should be assumed but clearly stated in the report/statement. In the Isle of Man spirits are measures are 28.4 mL (1/5 gill).

Wine is sold in various sizes of glass, depending on the establishment’s policy: -

- 125 mL (small); NB: this is ‘standard’ for champagne and other sparkling wines
- 175 mL (standard)
- 250 mL (large)

A standard measure for a fortified wine (such as port) is 50 mL

4.6.2 Republic of Ireland
A standard measure of spirit is 35.5 mL (1/4 gill) and 187 mL (1/4 bottle) is a standard glass of wine.

4.6.3 Drink strengths
The alcohol content, percentage alcohol by volume (ABV%) of stated brands of drinks can be found readily *via* internet searches or by contacting the manufacturer or distributor. But the drink strength may differ, even within brand, depending on whether it is in a can, bottle, or is being sold as draught. In addition, the accuracy of the quoted ABV may vary by a small amount ± 0.5 to 1.0 %v/v Maskell et al (6). The variation is likely to be larger in “craft” beers from small producers (± 0.53 %v/v; Maskell, Holmes (7)) than in those products from larger producers (± 0.1% v/v; Reid, Maskell (8)).

If the can/bottle is not available, or the brand is unknown, the modal average values (Table 1) (adapted from Maskell et al. (6)), are suggested as typical values. Whatever value is used should be clearly stated in the report/statement although every effort should be made to obtain details of the brand consumed.

5 CALCULATIONS

The equations most commonly used in alcohol calculations include various terms that are needed to perform the alcohol calculations. Depending on the calculation being performed they include: -

a) BAC result of evidential specimen (paragraph 4.2)
b) Amount (mass) of ethanol consumed (paragraph 5.1.1)
c) The alcohol distribution of the individual (paragraph 5.1.2)
d) Ethanol absorption (paragraph 5.1.5)
e) Alcohol elimination rate (paragraph 5.1.6)
f) Body mass, height and sex of individual (paragraph 4.3)

5.1.1 Amount (mass) of alcohol in a drink

The amount (mass) of ethanol in a drink can be calculated using a standard equation. The density of ethanol used in these calculations should be 0.789g/mL.

$$\text{Alcohol (g)} = \frac{Drink\ Strength\ (ABV\%) \times Ethanol\ Density\ (g/mL) \times Volume\ Drunk\ (mL)}{100}$$

5.1.2 The alcohol distribution of the individual

Alcohol calculations are based on the pioneering work of Erik Widmark carried out in the 1920s (9). Widmark recognised that alcohol distribution in the human body was determined by an individual's weight and sex. He determined two constants, one for men and another for women, the so called Widmark factor r (10, 11). Since we now have a better understanding of pharmacokinetics, it is recognised that Widmark's r, when multiplied by body weight, is simply an estimate of an individual's apparent volume of distribution (V) for ethanol.

Rather than use the fixed values suggested by Widmark, we can now estimate an individual's apparent volume of distribution of ethanol using equations derived by Watson, Watson (12) or Forrest (14). Both authors use an individual's sex, weight, and height to estimate the individual's Total Body Water (TBW), and from that their apparent volume of distribution can be calculated. Within a narrow range of body mass indices (BMI), 17 to 35 kg/m^2, both the Watson and the Forrest equations give very similar results, but for BMIs above 35 kg/m^2 the Forrest equations underestimates both V and TBW (15). For this reason, and for consistency, UKIAFT would recommend that, regardless of an individual's BMI, the equations derived by Watson (12) be used for ATD calculations rather than those of Forrest (14) unless the age of the motorist cannot be obtained and/or the BMI of the individual is < 35 kg/m^2. Other equations are available to determine V but are not as accurate or precise (16).

For estimation of Total Body Water, use the Watson equations for men (paragraph 5.1.2.1) and women (paragraph 5.1.2.2) below.

5.1.2.1 Watson equation for men

$$TBW = 2.447 - 0.09516 \times Age + 0.1074 \times Height + 0.3362 \times Weight$$

5.1.2.2 Watson equation for women

$$TBW = -2.097 + 0.1069 \times Height + 0.2466 \times Weight$$

In the two equations above, TBW is in Litres, Age in years, Height in centimetres, and Weight in kilograms.

Both of these equations have wide applicability and have been validated in Caucasians, African Americans, Hispanics, Asians, Koreans, and Puerto Ricans (15, 17).

5.1.3 Minimum Total Body Water Values to be used in a calculation.

There is of a course a minimum total body water that should be used in any calculations due to physiological limitations in normal adults. Based on the TBW data in a wide range of males and females (15) minimum expected values for TBW can be determined. We suggest that if the calculated TBW is below 23 L (females) or 3 0L (males) then the TBW calculated are likely invalid and should not be used.

5.1.4 Total Body Water Uncertainty

A study of a large number of males and females determined that the uncertainty (k = 1) for TBW in males and female was ± 9.09 % (5).

5.1.5 Ethanol Absorption

The alcohol calculations assume that the entire amount of ethanol consumed is absorbed (100% bioavailability). The absorption of ethanol is reviewed by Jones (18). Practitioners should give details and references to scientific literature when allowances for bioavailability are made in alcohol calculations.

5.1.6 Alcohol Elimination rate

In an evidence-based survey from forensic casework, the elimination rates of ethanol from blood, the rate of ethanol elimination was found to be normally distributed (19). In the 1090 individuals studied, the mean elimination rate was 19.1mg/dL/h (median 18.8 mg/dL/h).

5.1.7 Uncertainty in Alcohol Elimination

Following discussions as to the most appropriate studies for elimination rates in drinking and driving scenario it was agreed to adopt those suggested by (19) which showed a range from 9 to 29 mg/dL/h with a most likely rate of 19 mg/dL/h. The quoted range is a 95% confidence interval. Therefore 1 in 20 individuals may fall outside of this range. Any calculations from blood alcohol concentrations lower than 20 mg/dL would have to consider the non-linearity of ethanol elimination and Michaelis-Menten kinetics (20).

5.1.8 Concentration of ethanol in blood

To calculate the blood alcohol concentration (BAC) for a given amount of ethanol using total body water (TBW) requires in addition a value for the fraction of blood volume that is water (F_{water}). In men this is on average 0.825 %w/v, and for women 0.838 %w/v (5, 21). The small difference is mainly attributed to lower haematocrit in women's blood.

$$BAC\ (mg/dL) = \frac{amount\ of\ ethanol\ (g) \times F_{water} \times 100}{TBW\ (L)}$$

5.1.9 Uncertainty in the concentration of ethanol in blood

When calculating the blood alcohol concentration uncertainty should be taken into account. The uncertainty given should be calculated to the relevant confidence interval for the case circumstances 68 % (k = 1), 95 % (k = 2) or 99.7 % (k = 3). The uncertainty encompassing all of the variables for the calculation of BAC can be determined using error propagation (5, 22, 23). At a minimum the practitioner should use either the uncertainty associated with either alcohol distribution (paragraph 5.1.2) or alcohol elimination (paragraph 5.1.7) or both in their estimation of the concentration of ethanol in blood depending on the calculation being carried out. Whichever method is used to determine uncertainty should be clearly stated in any evidential report.

5.1.10 Blood to Breath Ratio (BBR) and Blood to Urine Ratio

A review of the evidence of the relationship between blood alcohol concentration (BAC) and breath alcohol concentration (BrAC) for the UK's Department for Transport concluded that "*the notion of a constant venous blood-breath ratio (BBR) of alcohol is false* …" (24). Nevertheless, when calculating the breath alcohol concentration from a stated alcohol intake the blood to breath partition ratio (i.e. the arterial blood to breath ratio) is relevant and should be taken as 2300 to 1. No ranges should be applied to this ratio.

Likewise, the ratio of urine alcohol concentration to blood alcohol concentration should be taken as fixed at 1.34, as the legal limit for urine alcohol concentration is 107 mg/dL (107 mg/dL divided by 80 mg/dL ≡ urine to blood ratio 1.34 to 1). For non-Road Traffic calculations, when calculations from urine alcohol concentrations are made, the time of the urination of the evidential sample and that of the previous specimen need to be known. The blood equivalent concentration relates to the mid-point between the times of voiding the first and second specimens.

6 PERFORMING THE CALCULATIONS

6.1 SUGGESTED APPROACH

The standard approach suggested is as follows: -

1) Calculate the expected alcohol concentration at the time of the evidential specimen using the total alcohol consumption claimed by the individual. The concentration is derived by calculation of the maximum contribution from all the drinks consumed and then allowing for alcohol elimination between the start of drinking and the time of the evidential test, having considered the provisions in see Section 6.2 below.
2) Calculate the alcohol concentration at the time of the incident, taking into account any claimed post-incident drinking by “back-calculation” from the result and time of the evidential sample to the time of the incident, considering the provisions in Section 6.2 below.
3) Calculate the contribution of the alleged post-incident alcohol consumption (or the alcohol contained in any laced drink) to the evidential alcohol concentration, and subtract the value calculated from the result of the evidential analysis

6.2 VALIDITY OF THE CALCULATION

Standard back-calculations should not normally be performed where the individual has consumed alcohol within one hour of the incident.

If a meal has been eaten, then caution should be applied if a back-calculation is required less than two hours after the last drink. If no food has been consumed, and the last drink was more than 1 hour prior to the incident, a standard back-calculation is considered safe. If a meal has been consumed during the claimed pre-incident drinking pattern, then consideration should be given as to whether one hour between the end of the last drink and the incident is appropriate for a standard back calculation. Even if a meal has been consumed, and the last drink was more than 2 hours prior to the incident, a standard back-calculation is considered safe.

The stated drinking scenario should be thoroughly examined to ensure that the individual's blood alcohol concentration would not have fallen to zero at any point in the period under investigation (e.g. between drinks). If this could have occurred, the calculation must be modified accordingly. It may be that a blood alcohol concentration could have fallen to zero at a fast elimination rate but not a slow one and this should be considered.

Some cases involving no claimed post-incident drinking, may require only a simple back calculation between the time of an incident and the evidential analysis (which may be below the limit). Standard back-calculations should only be undertaken when a measured blood alcohol concentration, or equivalent breath, or urine, concentration, is 20 mg/dL or more. Below this concentration, Michaelis-Menten kinetics would predominate, and a standard back-calculation should not be attempted. Any calculation using Michaelis-Menten kinetics should only be carried out by practitioners familiar with this type of calculation. If the claimed post-incident alcohol consumption accounts for the measured alcohol concentration a back-calculation may not be required.

6.3 REPORTS

Report content and format can vary depending on the case circumstances, and the customer requirement, but the following components are suggested as a minimum for the content. Streamlined/abbreviated statements/reports should be used with caution for ATD casework and must contain sufficient information for decisions to be made by the court. The suggested content is made to provide clarity and consistency between practitioners.

6.3.1 Report content

The following information should be included in all statements and reports: -

1) Practitioner's qualifications and experience
2) Purpose of statement/report
3) Information received
4) Receipt and results of examination of any items submitted
5) The scientific basis of the calculation (this can be included as a standardised appendix)
6) The information/assumptions on which the calculations are based
7) Comments including calculations
8) Conclusions

9) A statement confirming that the report or statement has been peer reviewed, and the calculations checked, by another competent practitioner, see Section 16.3 "Checking and review" FSR Codes of Practice and Conduct, FSR-C-100, (26)
10) A comment that the report/statement has been compiled in accordance with published UKIAFT ATD Guidelines, including version number, should also be included.

6.3.2 Calculations reported

In post-incident drinking and laced drink cases, the following calculations should be included. In order to maximise the clarity of the report/statement it is suggested that each calculation is easily identified in the report. For each calculation reported, the minimum, maximum, and most likely values should be stated. The order suggested follows the standardised approach: -

1) The contribution due to the additional alcohol;
2) The estimated result in the absence of the post-incident, or laced drink, at the time of the test;
3) The estimated concentration in the absence of the post-incident, or laced drink, contribution at the time of the incident;
4) The expected alcohol concentration at the time of the evidential test based upon the total intake of alcohol as claimed by the individual;
5) A comment stating whether the drinking pattern stated by the individual could have given rise to the measured concentration. If the result is only possible with the claimed pattern at one extreme, this should be stated and may be important to the court when assessing the likelihood or otherwise of evidence presented. If the lower end of the range in a breath calculation falls between the prescribed limit and charging threshold (i.e. prosecution limit) this should be clearly stated).

If the calculations suggest that the evidential result is not compatible with the claimed drinking pattern, a warning should be included that caution is required when considering the remainder of the practitioner's statement. This can occur whether the claimed drinking pattern contains too much, or not enough, alcohol, but care should be taken to consider all of the case circumstances before including an adverse comment on the claimed drinking pattern.

Where the reported alcohol consumption is too low to support the measure amount, the ATD practitioner should, if possible, avoid detailing the amount of alcohol "missing" from an individual's account as this would enable an individual to change their drinking history and approach another practitioner for a report (27).

As it is not known which alcohol concentration will be used in court, calculations to the time of the incident, as well as to the time of the evidential test, are recommended to be included in a report. All information is then available for the defence or prosecution to proceed as they wish.

The practitioner should always carefully consider the assumptions made in their calculations, particularly when they are aware of uncertainties surrounding case information such as the nature and volume of the alcohol consumed and possible inaccuracies in weight, height, the measured blood, urine or breath alcohol concentration etc.

When a calculated range is close to the prescribed limit or the charging threshold (prosecution limit) extra care should be taken in wording statements and any uncertainties clearly expressed to avoid possible miscarriages of justice.

In a situation where clearly more alcohol has been consumed than stated, as we cannot say when this extra alcohol had been consumed, the statement must clearly reflect that it is not possible to specify whether this additional alcohol consumption occurred before or after the incident, or both.

7 CONCLUSION

The guidelines above have been based on sound scientific principles and are extensively referenced. They have made allowances for the uncertainties in the pharmacokinetics of ethanol and are based on published reports. It is hoped that practitioners will follow these guidelines when carrying out calculations in forensic situations involving alcohol. This will ensure that the courts get statements and reports which are based on reliable assumptions and calculations, and present information in a consistent manner.

Table 1 Suggested values for ABV of alcoholic beverages, adapted from Maskell et al (6).

Type of Beverage	Modal Alcohol concentration by volume (ABV)
"Alcopops"	4.0%
Premixed spirits	5.0%
Lager (draught)	5.0%
Lager (bottled/can)	5.0%
Bitter/ale (draught)	5.0%
Craft beer (bottled)	5.6%
Stout/Porter (bottled)	4.0%
Cider	4.5%
Cider (cans)	4.5%
Cider (bottled)	4.0%
Red wine	13.5%
White wine	12.5%
Rose wine	12.0%
Champagne	12.5%
Prosecco	11.0%
Sherry	17.5%
Port	20.0%
Vodka	37.5%
Gin	37.5%
White rum	37.5%
Dark rum	40.0%
Spiced rum	35.0%
Whisk(e)y	40.0%
Brandy (Cognac)	36.0%

8 VERSION CONTROL

Version	**Authors**	**Release Date**	**Amendment**
1.0	M. Scott-Ham	Nov 2013	First draft
1.1	M. Scott-Ham	Apr 2014	Second draft
1.2	M. Scott-Ham	May 2014	Third draft
2.0	M. Scott-Ham	May 2014	Released version
2.1	M. Scott-Ham	Oct 2014	Minor changes
3.0	M. Scott-Ham	Jan 2019	Draft version including (1) Uncertainty in TBW and ABV (2) Updating ABV table for drinks where brand not known
4.0	A. Johnston, P.D. Maskell & M. Scott-Ham	July 2020	Draft Version - Major re-write in response to feedback to Version 3.0
4.1	A. Johnston, P.D. Maskell & M. Scott-Ham	October 2020	Draft Version re-written to take into account feedback on Version 4.0
4.2	A. Johnston, P.D. Maskell & M. Scott-Ham	February 2021	Publication Version, minor changes and corrections to 4.1

4.3	A. Johnston, P.D. Maskell & M. Scott-Ham	August 2021	Revised Publication Version, minor changes and corrections to 4.2 based on feedback.

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