Breath Alcohol Analysis by Gas Chromatography: Two Years’ Experience with Field Collected Samples

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Before launching into a detailed description of our current breath alcohol testing program, it would be appropriate to review briefly the conditions which prevailed prior to the introduction of the program in the geopolitical unit under consideration, which is the entire State of Vermont.

Vermont is a rural state, with 500,000 residents and about 20,000 tourists at any given time. The largest community in the state is a city with a population of 38,000. The state has an area of $9.6 \times 10^3$ square miles, and there are over 14,000 miles of highways within its borders.

A large segment of Vermont’s resident and tourist populations enjoy their favorite alcoholic beverage away from home. This is particularly true in the summer and autumn months. This practice puts a steady stream of drinking drivers on our highways and, because many of our roads are rural, this driving is often done at high speeds.

BACKGROUND TO THE PROGRAM

In the years prior to 1971, the practice of drunk driving could be carried out on Vermont highways with relative impunity. Even if one were apprehended by a duly authorized police officer, there was small chance of eventual arrest, conviction or licence revocation. There are numerous reasons for this state of affairs.

First of all, by state statute, conviction of a contested charge of driving while intoxicated (DWI) required the introduction of a chemical test of either blood or breath — the choice was the respondent’s. From the point of view of the intercepted driver the breath test was preferable because, in most jurisdictions, the methods of breath testing were antiquated, poorly administered and therefore open to legal challenge. Thus, with a good lawyer, a driver could nearly always be sure of “getting off the hook” if charged with DWI, regardless of the blood alcohol level at the time of apprehension and testing.

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2 The authors are greatly indebted to Mr. Brian MacPherson of the Department of Epidemiology and Environmental Medicine, College of Medicine, University of Vermont, for his assistance with the statistical analyses.
In addition, there is a law in the statutes of the State of Vermont which specifies that any sample of blood or breath collected for the purposes of evidence in a drunk-driving prosecution is to be collected in duplicate, so that the accused driver can have access to an independent laboratory analysis of the test sample. As the law currently exists, the state laboratory is required to retain this 'duplicate sample' for a period of 90 days after the date of arraignment, during which time the respondent and/or his legal counsel can avail themselves of the opportunity for an independent laboratory analysis, if they so desire. Of course, this provision allows defense counsel to take even greater liberties with the evidence; any minor difference between the state's laboratory result and that of the independent laboratory, introduced into evidence in a jury trial, could be inflated far out of realistic proportion for the purpose of discrediting the chemical testimony.

Also, the enforcement of DWI laws in Vermont has become encumbered in recent years by two developments within the legal profession. Firstly, there has been massive immigration of energetic, young lawyers to Vermont, seeking a home and a career in a quiet non-urban environment. Their numbers are such, in fact, that it was recently noted by one astute observer that Vermont now seems to have more lawyers than people. The effect of this excess of legal minds has been to provide eager, aggressive defense lawyers in private practice to represent accused persons in courts of law. In a state which still insists that an accused person has the right to a trial by a jury of his peers, regardless of the nature of the offense, this abundance of lawyers has led to a situation in which a DWI trial before a jury is often given the same attention and weight as a trial for the charge of homicide.

Secondly, there has been an ongoing trend in U.S. jurisprudence toward lenience and humanitarian liberality in the prosecution of certain offenses, and in particular toward those offenses in which the accused may be asserted to be suffering from alcoholism. This trend is clearly reflected in a recent U.S. Supreme Court declaration that alcohol abuse is a disease process — a 'natural' disease. In this context, juries have often been persuaded to be sympathetic toward the accused, on the mistaken thesis that "there but for the grace of God go I".

One result of these legal developments, was the advent of plea-bargaining on a large scale: in a case charged with driving while intoxicated, reduction of the charge to one of reckless driving was the usual course of action by the prosecution. Understandably enough, a secondary result of this practice, at least until the initiation of the federal Alcohol Safety Action Program in 1971, was a perpetually low level of morale and performance of police officers when it came to the pursuit and apprehension of drunken drivers.

To summarize: in Vermont in the years just prior to 1971 the breath testing program was inadequate and open to challenge and repudiation in court; plea-bargaining to a lesser charge was available to those who could afford a lawyer; and the morale of the law enforcement community on patrol on the highways was understandably at a low ebb. The police had little incentive to pursue a drunken driver and, in fact, many reasonable arguments against going to the trouble of apprehension and arrest.

THE BREATH-TESTING PROGRAM

Given the circumstances which I have just outlined, the ideal breath-testing procedure for Vermont is one which provides for the collection of a duplicate sample for each
respondent. Because of the 90 day provision in our statutes, the ‘shelf life’ of the duplicate sample has to be in terms of months, with little or no deterioration in that time-span. Further, because of our widely spread driving population, the system should be one which provides for collection of the specimens at numerous remote sites. It must also provide a method of collection requiring a minimum of technical expertise, inasmuch as budgetary constraints preclude the training and maintenance of a specialized cadre of breath-specimen collecting personnel. Lastly, the overall system has to provide accurate, reliable results which are credible in our courts.

Through late 1970 and early 1971, we investigated several of the breath testing systems then available. We settled on the gas chromatographic method of Forrester’s Intoximeters Incorporated — specifically, the “Gas Chromatograph Intoximeter” (GCI) system, utilizing the so-called “Field Collecting Devices” (Crimper Boxes) manufactured by that company.

The analytic method is basically pure gas chromatography. The GCI instrument is designed to accept an encapsulated breath sample which is trapped in a cylindrical tube of soft indium metal. The preset volume of each encapsulated breath sample is 0.25 ml, and all test standardizations are based upon this volume. A photoelectric cell registers the excitation of a flame at the distal end of the chromatographic column, imparting to a flat-bed recorder an electronic signal, the strength of which is proportionate to the quantity of combusted eluate. The tracing which results is thus quantitative and qualitative. The major peak shown is identified as ethanol by its Rf value, and its quantity is calculated on the basis of the peak deviation from the baseline. Minor peaks with other Rf values, indicating the presence of methanol or acetone, for example, are possible to identify. We use a standard solution of ethanolic vapor as an internal standard. Our external standardization uses two methods, both of which give us excellent agreement: one is based upon simultaneous venous blood and breath samples from volunteer drinking subjects; the second is based upon prepared, analytic reagent solutions, as recommended by the manufacturer. Intercurrent standardizations were routinely conducted to check the reproducibility of the method in respect to internal and external standard solutions. Each standardization method gave us reproducibility within 95% confidence limits.

The breath samples on which we base this report were all law enforcement samples, and all were collected in the field by means of a crimper box by a trained, full-time officer of the law.

One of us (LSH) conducted classes for several months in 1970 through 1972, instructing a course in the theory and practice of breath sampling by crimper box. These classes were conducted at a Police Training Academy and were attended by state, city and town police officers, as well as sheriffs and their deputies.

The use of the crimper as a breath sampling device is straightforward and simple. With few exceptions our law officers were able to become proficient within the hour or two of instruction.

The crimper box with indium tube and template in place is preheated for 15-20 minutes prior to sampling. The heat source is internal and is motivated by standard AC house current or by 12 volt DC circuitry, for example from a dashboard cigarette lighter in a patrol car. The achievement of proper heat is indicated by the thermostatic activation of a light signal. The properly connected tube assembly consists of a waste bag (volume 1100 ml) connected in parallel with the indium tube encased in its template. A filter is interposed at the proximal end of the indium tube. On filling the waste bag with breath from the ‘physiologic dead space’, the remaining breath in that exhalation should consist of alveolar breath, and thus should best reflect the alcohol
concentration of deep lung air. The sampling is done near the end of such an exhalation, and is performed by firmly squeezing the handle of the instrument, which closes the jaws of the device on the indium tube at four sites, thus sealing the tube into three individual segments of 250 microliters volume each. The reverse passage of waste bag contents is blocked by a one-way valve, and we recommend using a similar one-way valve at the distal end of the indium tube to preclude the inhalation of room air into the sampling tube.

Over 3,400 law enforcement breath samples were collected and analyzed in the two years under consideration. As noted, throughout this period intercurrent external standards were used to verify our test results, in addition to the internal standards which were run with each sample tested.

Samples were transmitted to a central laboratory by certified mail. Each sample was divided into its respective segments, and the distal and middle segments were analyzed and formed the basis of our reports to the prosecuting attorneys in each case. Our instrumentation and calibration gave us results to three significant figures — as equivalent to a blood alcohol concentration (BAC) in thousandths of a g/100 ml. The results from the distal and middle segments were averaged and the mean value thus calculated was rounded to two digits — equivalent to hundredths of a g/100 ml BAC. This average value was reported to the prosecutor. The proximal sample segment was stored at room temperature for possible future use by the respondent, and was kept for at least 90 days from the day of arraignment.

Method of Evaluation

An attempt was made to evaluate the program as it operated during the calendar years 1972 and 1973. This evaluation may be limited in certain respects, but overall, it should provide a set of data with which to appraise the worth of this particular system of breath alcohol analysis for law enforcement purposes.

One major limitation to a fuller evaluation is the absence of the knowledge of what the true BAC was at the time of breath sampling in any given test. However, other studies (1,2,3,4) have demonstrated these blood/breath alcohol ratios with this instrumentation, and with the routine use of internal and external standards, we believe we can be quite confident that the equivalent BACs determined by this breath method give reliable figures, at least when subjected to the criteria described below.

This evaluation encompasses and surveys the entire methodology, from the manufacture of the indium tubes to the actual gas chromatograph (GC) analysis itself. Each of the intervening processes such as sampling, the physical handling of the specimen in transit, the passage of time between collection and analysis, the gas chromatographic process, the electronic instrumentation and the recording of the results also represent a source of possible error. Thus, our task is one of defining the precision and reliability of the entire method, from beginning to end.

Part of this evaluation will be descriptive and part will be statistical. More than two years’ experience has provided insights into practical, everyday problems in the method, and over that period enough duplicate and triplicate breath samples have accumulated to provide a data base for a statistical definition of precision, reproducibility and reliability.

Recognizable Sources of Error

Early on in our work, we noted the occurrence of an occasional sample in which one
segment, usually the distal third of the tube, showed a low alcohol content when compared to the middle and proximal segments. This phenomenon occurred infrequently enough, but each occasion was disturbing, since each represented the potential loss of the specimen for prosecution purposes. We discovered after a short time that each of these so-called 'defective crimp' samples presented a similar physical appearance on close inspection. Figure 1 illustrates the nature of the flawed samples. In a close-up (Figure 2), using an early version of the template with a circular opening, a mark can be seen where the misaligned template was pinched between the jaw faces. The indium tube, was often not completely sealed at this site, and in such a condition, the contents of at least one segment were lost, either immediately or over the next few hours. We recommended that the manufacturer redesign the template, and this was done, as noted by a comparison of the designs in Figures 1 and 2. We have called this the "defective crimp error".

Properly Crimped

Improperly Crimped

Figure 1 Indium tubes in templates.

Figure 2 Defectively crimped breath samples.
Other sources of error became apparent to us as well: one was found to be due to maladjustments within the crimper box, usually within the adjustment of the grip-handle. This problem manifested itself as uniformly incomplete crimp-marks on the indium tube and with associated low or absent BAC values across all segments. This source of error was corrected by a schedule of maintenance which routinely checked this feature on the crimper boxes from time to time.

Each of the sources of error just noted produced a low reading of equivalent BAC — a false negative result.

Two other factors led to false positives and to elevations of the apparent BACs which are simply not credible on physiologic grounds. The first of these is the practice of sample collection in a cold indium tube. This results in condensation of alcohol in physical droplets, if alcohol is present, and on analysis these droplets are vaporized into concentrations equivalent to BACs of one g/100 ml or more.

A second source of a false positive result is the infrequent instance in which the test subject actually belches during the exhalation phase, or in which regurgitation of gastric contents into the mouth of the respondent has occurred just prior to or during the sampling process. In cows, we call this process rumination, and that term should apply here; we call it the ‘ruminative error’. In our experience, this error also results in physiologically impossible readings.

Lastly, there are a variety of sampling process errors which occur at a random rate within the larger sample population. We have traced most of this last group of errors (all of which are of the false negative variety,) to a very small group of slow learners in the law enforcement population. These errors represent a minute but intractable source of trouble. We have attributed their presence to the thermodynamic laws of entropy.

It should be noted that each of these sources of error result either in decreasing the equivalent BAC, thus erring on the side of the respondent, or to invalidation of the sample, resulting in no prosecution. Table I presents the occurrence of these particular errors which we found could be recognized and identified on descriptive bases or by deduction. It can be seen from this Table that the defective crimp error makes up a major portion of the overall occurrence of such errors, and that this error source has largely been eliminated, leaving a residual failure frequency of 1.6%.

One additional problem should be mentioned at this juncture which was first reported to us by law officers in the field. They informed us that about one person in 200, apprehended for DWI charges, cannot be tested by this breath method because of chronic pulmonary disease, specifically chronic obstructive pulmonary emphysema. In such instances, the law officer must obtain a blood sample for alcohol analysis, which fortunately is legally possible under our current statutes. It should be noted, however, that such cases do not appear in our statistics, and that the absence of these figures represents a deficiency in the breath analysis program. Perhaps such a failing will appear in any breath testing program, but it should be recognized.

Statistical Evaluation

In the two years of sample collection, 3,438 breath samples were collected and analyzed. Of these, 268 (7.8%) were not used as prosecution evidence because of gross sampling errors which were recognized on the bases just outlined.

Thus, 3,170 samples (92.2%) were deemed valid for evidentiary use. All of these were available to us in this study in duplicate, and 2,880 were available in triplicate. It should be remembered that our analyses of ‘unclaimed’ triplicate segments took place
TABLE 1  Occurrence of Recognizable Error in the Measurement of Breath Samples. N=3438

<table>
<thead>
<tr>
<th>Type/Source of error</th>
<th>Per cent frequency</th>
<th>Correction</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;Defective crimp&quot;</td>
<td>6.2</td>
<td>Eliminated by template redesign</td>
</tr>
<tr>
<td>Maladjustment of crimper</td>
<td>0.5</td>
<td>Routine maintenance</td>
</tr>
<tr>
<td>Cold indium tube</td>
<td>0.3</td>
<td>Re-educate testers</td>
</tr>
<tr>
<td>Belching/&quot;rumination&quot;</td>
<td>0.2</td>
<td>Re-educate testers</td>
</tr>
<tr>
<td>Irrational/entropic</td>
<td>0.6</td>
<td>Probably none</td>
</tr>
<tr>
<td>TOTAL</td>
<td>7.8</td>
<td></td>
</tr>
</tbody>
</table>

at least 90 days after the initial testing of the first two segments of the sample, again in accordance with Vermont law.

The best statistical evaluation of such data is one based on coefficients of correlation. The data presented below are based on comparisons of the distal and middle segments of each breath sample in the first instance, and on the proximal segment and the average of the distal and middle segments in the second instance. It should be remembered that the proximal segment was analyzed at least 90 days after the first analysis of the distal and middle thirds of the sample. Thus, the second set of data may also reflect the 'shelf life' of the sample, that is, the effect of the passage of more than 90 days at room temperature on alcoholic vapors enclosed within the indium tube segments.

In the first comparison (between the distal and middle segments of indium tube encapsulated breath samples), where N = 3,170, the coefficient of correlation (r) equals 0.999. A regression analysis (Figure 3) based upon these data (middle segment versus distal segment) shows a tight fit of values within the 95 and 99% confidence limits.

However, if the security of a 99% confidence level is desired, the standard error of these data increases to plus-or-minus 18% at BAC levels of 0.10 g/100 ml. At such confidence intervals, precision is reduced further, as can be seen in Figure 3.

Moreover, a closer analysis of the data, particularly those points at or near our statutory definition of DWI (0.10 g/100 ml) reveals that an error of ±13% exists at this level (Figure 4). Thirteen per cent of 0.10 g/100 ml is 0.013 g/100 ml. Thus, assuming the usual scientific standard of a 95% confidence limit, we must admit to a lack of precision of 13% at the critical enforcement level which defines the legal offense.

Figure 4 shows how such a per cent error distorts the precision of the lower readings of BAC. It is most disturbing that precision is lost in this range, not only for Vermont with its 0.10 law, but for those jurisdictions with 0.07 and 0.08 statutory levels, where the per cent error is even larger.

At the same time, we should point out that the per cent error falls to clearly acceptable levels of BAC in higher ranges of measurement, and that the precision of the method at these levels, is correspondingly better.

In a comparison of test results between the mean of the first two segments and the most proximal segment (Figure 5), the latter test carried out at least 90 days after the former, our calculations indicate a correlation coefficient of .998, slightly less than
Figure 3  Regression of $X_2$ on $X_1$ with 95% and 99% confidence limits. $N = 3170$, correlation coefficient = .999. $X_1 =$ distal segment, $X_2 =$ middle segment.

Figure 4  Per cent error by BAC – assuming 95% confidence limits.
in the previous instance. The standard error of these data, based upon 2,880 sample comparisons, is plus or minus 20 per cent of the 0.10 g/100 ml BAC level — or 20 mg/100 ml, again with 95% confidence levels. At the 99% confidence level, the error of these data is 26%.

This greater scatter of the data may well represent a slight, gradual decay of ethanol concentrations in the encapsulated samples, or may be due to other, unknown factors. In any instance, such an error in operational precision in the method suggests that the system is on shaky ground when test results in the range .10-.13 are to be used for evidence in prosecution, particularly in Vermont where the law states that a portion of the test sample shall be retained for independent analysis for a period of up to 90 days. These calculations, of course, are solely concerned with the precision of the entire method as this is reflected in reproducibility and internal consistency. Thus, serious questions are posed when test results in the 0.10 g/100 ml range are to be transposed into court testimony.
This breath-testing system presents several advantages in a rural State with a widely dispersed drinking-driver population. The portability of the remote field collecting devices is a distinct improvement over methods which require testing in a fixed location, such as a State Police Outpost or station house. The existence of a single central testing facility greatly eases several problems in logistics and in the communication of test results. It has also been a great advantage to locate our testing facility in an academic setting, as we have done; this feature alone has greatly increased the credibility of the method to a jury.

This particular system does have disadvantages, some of which are noted above. Like other breath tests which attempt to sample alveolar air at end-expiration, we have encountered a persistent number of subjects who are physically incapable of deep exhalation because of chronic pulmonary disease. Another disadvantage concerns the initial attitudes of our police officers to the procedure. In earlier years, the officers had become accustomed to getting a breath test result within hours of the apprehension and testing of a suspect driver; with the present system, they are forced to wait for 3-4 days before they learn of the test result. Many officers are not comfortable with this arrangement, and they have communicated their displeasure to us.

Another disadvantage, incurred in the first year of our experience, is that which we have called the defective crimp error. The manufacturer has changed the template design, however, and as we have noted, the number of samples lost due to this mechanism has dropped to less than 1%. A persistent number of samples are still lost due to various other error sources, but this persistent loss rate is currently level at approximately 2% of the total.

Finally, there is the question of the precision of the overall method when subjected to statistical analysis of breath sample segments simultaneously collected. The presence of an error of ±13% at 95% confidence levels is disturbing indeed. In a jurisdiction which observes a statutory BAC of 0.10 g/100 ml it means essentially that BAC levels of less than 0.13 should be prosecuted with caution, and preferably along with other evidentiary material.

Our figures that indicate a decay process over 90-plus days of storage, resulting in an additional, significant loss of precision and reproducibility of the test results over time are relevant to those jurisdictions which also require the retention of an extra sample for independent analysis.

However, we have been moderately successful with this method particularly when compared to the 'non-method' which existed prior to its introduction.

Figures 6 and 7 present a precis of our two year experience. It must be remembered that Vermont is subject to fluctuations in traffic volume as it has a relatively small driving population but is inundated with tourists in late summer and autumn. This traffic volume is reflected in Figure 6.

Figure 7 shows BAC distribution for the drivers tested in our two-year collection. The incidence of drivers with zero alcohol by test (2.3%) is a reflection of those drivers stopped and tested because of a serious injury or fatal auto crash or because of other erratic driving behavior. The incidence of those drivers tested who were below 0.10 g/100 ml by test result is comparable, we think, to other experiences in other jurisdictions. The results in Figure 7 could be interpreted as an index of police selectivity in arrest and testing behavior. In this regard, we find it interesting that the number of persons thus selected for a breath test more than doubles in the interval between 0.07 and 0.09 g/100 ml. This observation lends support to those who argue
Figure 6  Number of breath samples per month, Vermont: 1972-1973.

Figure 7  Number of drivers tested by BAC.
that a BAC of 0.10 g/100 ml is too conservative for use as a statutory, chemical
definition of driving under the influence of alcohol.

TABLE II  Number of Prosecutions and DWI Convictions
and BAC Results for 1970-71 and 1972-73

<table>
<thead>
<tr>
<th>Years</th>
<th>Total prosecuted</th>
<th>Convicted of DWI</th>
<th>Average BAC (g/100 ml)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1970-71 Prior to program</td>
<td>1720</td>
<td>1359 79</td>
<td>0.215</td>
</tr>
<tr>
<td>1972-73 During program</td>
<td>4158</td>
<td>3271 77</td>
<td>0.147</td>
</tr>
</tbody>
</table>

Finally, Table II presents a summary of court behavior in our jurisdiction in the
two years prior to the introduction of our new breath testing program, compared to
the first two years of its application in courts of law. It can be seen that while the
number of persons before the bar on charges of DWI has more than doubled in 1972-73, the conviction rate has remained essentially unchanged — at slightly less than 80%. The single striking finding, however, is that the average chemical test result has dropped from 0.215 g/100 ml to 0.147 g/100 ml. This suggests to us that our law officers are apprehending, arresting and testing out drinking-driving population with a
greater awareness of the proper selection criteria and an appreciation of the gravity of
the problem. At least we are sampling a little closer to the waterline of the iceberg, and
the authors would like to think that the introduction of this breath testing program
has contributed to this result.

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