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16. Abstract

Dr. Harger has brought the review of published analytical methods for determining alcohol in body materials up-to-date. The review deals with analytical methods for alcohol in blood and other body fluids and tissues; breath alcohol methods; factors which may cause apparent, or real, errors in estimating BAC from breath analysis; and, proposed standards of accuracy for analytical methods which determine BAC by direct analysis of blood, or by estimation from breath analysis.

Breath alcohol instruments and alcohol detector tubes are described in detail, pictures and/or schematic representations are included, and studies(made by independent investigators) of the accuracy of the methods are included.

The author has occasionally exercised his editorial privilege by stating his opinion regarding possible deficiencies in experimental procedures or in the conclusions of the writer.

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CONTENTS

RECENTLY-PUBLISHED ANALYTICAL METHODS FOR DETERMINING ALCOHOL IN BODY MATERIALS

During the past 20 years, comprehensive reviews of the then-current procedures for estimating the concentration of alcohol in blood, urine or breath were published. The authors of some of the reviews, and the years of publication, are: Muehlberger, 1954 (1); Elbel and Schleyer, 1956 (2); Harger and Hulpieu, 1956 (3); American Medical Association, 1959 (4); Harger, 1961 (5); Harger and Forney, 1963 (6); Harger and Forney, 1967 (7); and American Medical Association, 1970 (8).

In keeping with the policy of these earlier reviewers, the recently-published analytical methods reviewed in this chapter will be described in greater detail than is usually found in the authors' abstracts which may accompany their papers. In our discussion of current analytical methods, we have occasionally exercised the editorial privilege of stating our opinion regarding possible deficiencies in experimental procedures or in the author's conclusions. In this chapter the unmodified word alcohol refers to ethanol. For brevity, we have continued to use mg% to express the concentration of alcohol in body tissues or fluids, which is defined as mg of ethanol per 100 ml of fluid or per 100 g of tissue. This unit is still widely used for expressing results of clinical laboratory analyses. Employment of this unit involved converting to mg% a variety of alcohol concentration units found in the papers reviewed, which units comprised ordinary percent, parts per thousand or pro mille (‰), parts per million (ppm), and molarity expressed as millimols (mM) or micromols (μM) per unit volume, or weight, of body material. In discussing a particular analytical method, we have also included results of studies of the accuracy of the method made by independent investigators in this field. The abbreviation BAC means blood alcohol concentration.

I. ANALYTICAL METHODS FOR ALCOHOL IN BLOOD AND OTHER BODY FLUIDS AND TISSUES

A. GAS CHROMATOGRAPHIC METHODS. Since 1960, when Cadman and Johns (9) introduced G-C analysis for alcohol in blood and other body materials, remarkable progress has been made in this field. Some of the earlier follow-up papers have been reviewed by Harger and Forney (6,7). We will now review ten modifications of the G-C procedure which have been reported since 1966, but will omit specifications for individual columns, which can be found in the authors' papers.

1. In a 1967 paper, Machata (10) described an automated apparatus using a Perkin-Elmer Multifract F 40 gas chromatograph which analyzed head-space air from a blood-internal standard mixture. One half ml of blood and 0.1 ml of 0.2% t-butanol are introduced into a 20 ml serum bottle, which is then closed with a plastic stopper, held in place by a clamped-on aluminum cap. The bottle is placed in one compartment of a rotating water bath kept at a temperature of 60°. Alcohol equilibrium between the air and liquid phases soon occurs, and an automatic pipette withdraws 0.5 ml of the head-space air and injects it into the G-C column. Nitrogen is used as the carrier gas. The fractions emerging from the column pass through a flame ionization column and impulses from it go to a strip recorder. The rotating water bath holds 30 samples and the analysis time per sample is about four minutes. A temperature of 60° was chosen for equilibrating the liquid and air in the serum bottle, because, for a given blood alcohol concentration, the ratio of the ethanol and t-butanol peaks heights is constant between 50° and 70°. Machata reported that the standard deviation with repeated analyses (precision) is ± 1.1%, with 95% of the results within ± 3.3%.

   Hauck and Terfloth (11) conducted a study of the operation of this Machata automatic G-C apparatus to check certain factors which might possibly reduce its accuracy. They found no significant error from deviations of ± 4° in the bath temperature, from varying the total volume of fluid equilibrated between 0.5 ml and 4 ml, or from loss of alcohol from blood or control. They did find that the volume of blood collected in the vacuum collecting tube caused a significant change in the ethanol/t-butanol peak ratio for a given blood sample, because the constant weight of NaF in the tube gave different concentrations of NaF in the blood, and this salting-out effect did not change the vapor tension of the two alcohols equally. Thus, changing the volume of blood collected from 1 ml to 8 ml caused a decrease of 5.5% in the ratio of the E/t-B peaks. They also reported that the calibration curve was not quite linear, but deviated from a straight line by -3% at a blood alcohol concentration of 200 mg% and by -11% for a level of 400 mg%.

   Greiner (12) conducted a statistical study of the results of duplicate analyses of 1022 blood samples made in his laboratory with the Machata automated G-C assembly. For these 1022 paired analyses, the standard deviation was ± 2.03% (1 sigma), which would mean a deviation of above 4.06% for 1 out of 20 samples. With 96 analyses on five water solutions containing known concentrations of alcohol, the standard error from the true value was 1.55%.

Machata (13) later modified his G-C procedure to analyze smaller samples of capillary blood, such as are used in Scandinavian countries. The equilibrated fluid is 0.1 ml of blood plus 0.1 ml of 0.5% t-butanol. The impulses from the flame ionization chamber go to a Perkin-Elmer integrator and the data are processed by a computer with a teletype attachment. Machata reported a standard error of ± 1.02% with this micro method.

2. In 1969, Glendening and Harvey (14) described another head-space method for blood analysis, employing a Backman GC-4 instrument connected to a Beckman recorder. To control the increased vapor tension of alcohol caused by NaF in the 1 ml of blood equilibrated with air in a 35 ml bottle, the latter contained 20 mg of NaF before introducing the blood. Since the blood sample already contained 10 mg/ml, or more, of NaF, this gave an approximately saturated solution of NaF, resulting in a constant salting-out effect. Much care was taken to hold the equilibration temperature constant at 27°, because the ethanol vapor tension from blood changes about 7% per degree C. Beef blood external standards are used. One ml of the equilibrated air is injected into the column and the analysis is completed in 5 minutes. The precision of duplicate analyses had a standard error of ± 2 mg%. The results with 10 samples of blood by this method, compared with those from the average of duplicate analyses with a dichromate method, showed maximum deviations of + 4% and -5%.

3. Bonnichsen and Ryhage (15) have developed a blood alcohol method using a conventional gas chromatograph with the exit of its fractionating column connected to an Edwards E 180 mass spectrometer. Only a small, fixed fraction of the gas from the G-C column enters the chamber of the mass spectrometer. The latter is so adjusted that charged particles of mass m/e 45 and 46 are discharged through a slit, and this ion current operates a strip recorder. This combination of instruments greatly enhances the specificity for ethanol. The fluid analyzed is injected directly, using up to 2 µl. A scatter diagram gives the analytical results with 14 aqueous solutions of ethanol. For 4 of the samples, the results with this complicated apparatus differed from the true values by -8%, -11%, -17% and +8%, respectively.

4. Luckey (16) has produced a G-C instrument for alcohol analyses of blood, urine or breath, which he calls an Alco-Analyzer. A schematic drawing of the apparatus is in Fig. 1. (See Appendix B) The oven of the Alco-Analyzer contains two columns, one for direct analysis of liquid samples, and the other for breath or head-space air. Instead of a flame ionization detector, the 0.1 ml exit

chambers from the columns each contains a thermistor probe, and the reading of the concentration of alcohol vapor in its fraction is made by thermal conductivity, using a Wheatstone bridge in the manner employed in certain combustible gas meters, e.g. the Mine Safety Appliances CO Gasoscope with its % Gas setting. With the Alco-Analyzer, the thermistor in the unused chamber serves as the reference point for the thermistor in the active chamber. The conductivity differential between the two thermistors operates the pen of a strip recorder. An external reference blood standard gives the control peak. One to 4 ml of the blood sample is equilibrated with air in a capped 35 ml serum bottle at a uniform temperature of 27°. The blood sample contains a fixed concentration of NaF (approx. 1%) to produce a constant salt effect. A 17 ml sample of the equilibrated air is manually withdrawn and is forced through a metal tube loop, with an inside volume of 10.5 ml, which is within the instrument housing. Then, the contents of the loop are automatically forced into the injection port of the column. Luckey reported the standard error of precision to be ± 3 mg%. With 5 samples of blood containing 125 mg% to 265 mg% alcohol, the deviations between the Alco-Analyzer results and those from two dichromate methods ranged from 2 mg% to 8 mg%. The volume of gas collected in the syringe is more than half the volume of the gas phase in the 35 ml bottle, but it may not contain half of the alcohol vapor in the gas phase in the bottle.

A 1960 paper by Chundela and Janak (17) describes results of alcohol analyses conducted with a British gas chromatograph having a thermal conductivity detector, which instrument was found to give erroneously low results.

5. A simplified G-C procedure with direct injection of the blood plus internal standard solution, was reported by Jain (18). He used a model 600-D Varian chromatograph with a Speedomax-W recorder. This chromatograph has a long percolumn injection port, and at its temperature of 160° all non-volatile solids are deposited in its lumen, so that only the volatiles enter the column, and the latter exhibited no deterioration in performance after several thousand determinations. At infrequent intervals, the solids deposited in the lumen of the precolumn port can be easily removed. The carrier gas is nitrogen.

   In the procedure, 0.5 ml of an 0.05% isobutanol solution in water (internal standard) is placed in a small tube, followed by 0.5 ml of the unknown blood sample, and the fluids are mixed

by being sucked up into the pipette and discharged back into the tube three times, after which 0.5 ml of the 1:1 diluted blood is injected into the precolumn port. With a column temperature of 100°, the ethanol and isobutanol peaks are reached, respectively, in 3.5 min. and 7.25 minutes. Retention times are also given for methanol, isopropanol, acetone, acetaldehyde, formaldehyde, propyl acetate, methyl ethyl ketone, chloroform, benzene, toluene and xylene, all of which retention times differ significantly from the values for ethanol and isobutanol. A water solution containing 0.05% ethanol and 0.05% isobutanol is similarly analyzed, and the blood ethanol concentration is calculated from the E-iso-B peak ratios of the unknown and control.

The paper gives a graph showing an excellent line relationship between the analytical findings and the true alcohol values for water solutions containing 50 mg% to 300 mg% ethanol. The accuracy with blood samples is about ± 5% (19).

6. A 1972 paper by Karnitis et al. (20) describes a G-C analytical procedure for alcohol in blood, using head-space air and an internal standard of n-propanol. The chromatograph is a Beckman GC-5. The equilibrating chamber is a 50 ml volumetric flask in which are placed 1 ml of the blood sample and 1 ml of 0.1% (w/v) n-propanol. Equilibration is conducted at 27° The paper gives a graph which shows excellent linear correlation between the E/n-P peak height ratio and the ethanol concentration. Data are presented for 10 samples of blood containing known concentrations of alcohol ranging from 100 mg% to 250 mg%, which were also analyzed by the Dubowski-Shupe dichromate method (21). With the G-C method, the deviations from the true values ranged from +3% to -6%, and with the dichromate method the deviations varied from -5% to +8%.

7. Siek (22) used a Hewlett-Packard gas chromatograph, Model 575, which was equipped with two columns and their accessories, so that two samples could be analyzed simultaneously, doubling the hourly output. The alcohol equilibrating chamber was a tightly-capped, 8 ml vial, kept at 30°. Into it were placed 1 gm of blood, 1 ml of 0.2% n-propanol, and about 1 gm of NaCl. Approximately 0.25 ml of the equilibrated air phase was injected into one of the columns. Using the two columns, duplicate analyses were made with 11 samples of blood having alcohol concentrations of 2 mg% to 426mg%. The deviations between the results from the two columns ranged from zero to 4 mg%. Although the E/n-P ratios for the two columns agreed

well, the actual peak heights from one of the columns were regularly higher than those from the other column. A portion of each of 25 samples of blood containing 11 mg% to 414 mg% alcohol was analyzed by Siek, using his G-C method, and other portions of the 25 samples were analyzed by three other laboratories. Two used G-C head-space methods and one a distillation-dichromate method. For the 25 samples, the maximum discrepancy between Siek's results and those of any one of the cooperating laboratories ranged from zero to 15%, averaging +3.4%. The true value for these blood samples is not stated.

8. A 1972 paper by Solon et al. (23) of the technical department of the Hewlett-Packard Co. describes the construction and operation of a very recent, highly-automated, model of that firm's gas chromatograph, and presents the results of a few analyses of water or blood containing known concentrations of ethanol.

   This blood alcohol analyzer is composed of a Hewlett-Packard gas chromatograph (model not stated), equipped with an automatic liquid sampler (pipette), electronic integrator, and data processor giving a printed record. An automated turntable holds thirty-six 8 ml vials. The first two vials contain a water solution of heparin, 200 U/ml. Vial 3 contains the ethanol control plus the n-propanol internal standard. The remaining 33 vials are for the blood samples.

   Before, and after, each analysis the automatic liquid sampler is rinsed with the heparin solution from vials 1 or 2. All analyses are conducted in duplicate, with three exceptions. If the first analysis of a given sample shows less than 50 mg% alcohol, no duplicate analysis is done. If the blood sample contains between 90 mg% and 110 mg% alcohol, the duplicate analyses are repeated. Finally, if the internal standard reading varies more than 10% from the reading of the first sample analyzed, the operation is automatically terminated until the defect is repaired.

   Into each vial are placed 0.5 ml of blood, followed by 1.0 ml of 0.16% (w/v) n-propanol and the vial is agitated on a Syntron vibrator for 1 minute. Unfortunately, the paper does not state the volume of liquid removed from the vials by the automatic pipette and injected into the column. The carrier gas is nitrogen.

   A graph shows excellent separation between the response curves for methanol, ethanol, isopropanol, acetone and n-propanol. A table gives the results obtained with this G-C analyzer with 5 samples of blood containing 40 mg% to 213 mg% ethanol. The

deviations from the true values ranged from 1 mg% to 4 mg%. The calibration graph for the instrument shows a straight line relationship between the ethanol concentration and the ratio of E.np area counts. After about 100 blood samples had been analyzed without changing the column, the response of both ethanol and n-propanol had decreased to about one-third of the values when the column was first used, but the E/n-P ratios were apparently not changed. Replacing the glass wool precolumn caused the response of the two alcohols to increase to about two-thirds of the initial values, but after a total of 500 analyses with the same column, the responses of the two alcohols became about constant at around one-fourth of the initial values.

9. In 1970, Gessner (24) announced the discovery that, in the G-C head-space procedure for alcohol analysis, if one adds sodium nitrite and oxalic acid to the alcohol solution in the equilibration chamber, the G-C detector response is increased about 200-fold. The possibility of such an effect was suggested by two papers published in 1924 and 1926 by Fischer and Schmidt (25, 26) describing a new method for determining methanol, ethanol and their homologs. In this method, sodium nitrite and acetic acid are added to the alcohol solution in a closed tube and the resulting HNO_2 converts the alcohol to its nitrite ester, which is quite volatile and poorly soluble in water. The nitrite ester is removed from the reaction tube by a stream of CO_2 and passes into a solution of KI plus HCI. The HCI hydrolyzes the nitrite ester and the HNO_2 formed reacts with the KI to form free iodine, which is titrated with thiosulfate. Before entering the KI-HCI flask, the gas passes through a strong solution of $NaHCO_3$ to remove oxides of nitrogen. Initially Fischer and Schmidt also added urea to the reaction tube, but later found it unnecessary and omitted it in the nitrous acid method for ethanol described in their second paper.

   Gessner has incorporated this nitrous acid reaction in a G-C method for determining aliphatic alcohols. He employed a model 220 Tracor Micro Tek gas chromatograph, with nitrogen as the carrier gas. Urea (0.2 gm) is placed in a 35 ml serum bottle and the bottle is closed with a rubber serum cap and wrapped in aluminum foil to exclude light, which accelerates the decomposition of HNO_2. Using hypodermic needles puncturing the cap, the air in the serum bottle is replaced with nitrogen. Then, with a tuberculin syringe and appropriate needle, the operator injects into the serum bottle sequentially: 1 ml of the alcohol solution to be analyzed, 0.5 ml of saturated $NaNO_2$

solution (about 50%, w/v), and 1.0 ml of saturated oxalic acid solution (about 12%). These additions are made on a time schedule and the fluid in the bottle is shaken between additions. At about 4 min. after the alcohol sample is placed in the bottle, the operator withdraws 0.5 ml of the equilibrated nitrogen gas and injects it into the inlet port of the chromatograph. Using an aqueous solution containing 10 μg each of methanol, ethanol, isopropanol, n-propanol, isobutanol and n-butanol, the G-C response curves were well separated and appeared in the order in which the alcohols are listed. The peak time for ethanol was 2 min., and that for n-butanol was 6 minutes. A graph shows the correlation of peak heights of 7 concentrations of ethanol in water ranging from 0.1 μg/ml to 1.0 μg/ml. With no alcohol in the equilibration bottle, the oxides of nitrogen from breakdown of the HNO_2 gave very low peaks. The graph gives a line showing the average peak height/ethanol ratio for the 7 concentrations used, but four of the ethanol analyses gave ratios which deviated from the average by +50%, +90%, -29% and -22%, so the accuracy of the method in this range of alcohol concentration was very poor. No blood analyses are reported, but Gessner does give directions for analyzing the total bodies of mice. They are frozen and then homogenized with 6 volumes of a water solution containing 8% of sulfosalicylic acid, plus 1 ml of a methanol solution as an internal standard. The homogenate is centrifuged and 1 ml of the supernate is analyzed by the nitrous acid - G-C method. No analytical results for mouse bodies are presented.

Since the boiling point of ethyl nitrite is 17° and its water-solubility is low, one can conclude that the fraction of the total ethyl nitrite in the equilibrating bottle which is in the gas phase is many times higher than that for ethanol alone, which at 25° would be only about 0.3% to 0.5% of the total ethanol present (27). If 60% of the ethyl nitrite was in the gas phase inside the bottle, the weight of combined ethanol in the 0.5 ml of equilibrated gas injected into the G-C column would be about 200 times that where the same weight of free ethanol was present in the 2.5 ml of aqueous fluid placed in the 35 ml bottle, assuming no sodium nitrite and acid to be present. Whether the ethyl nitrite vapor in the G-C column is hydrolyzed to ethanol and oxides of nitrogen is probably unimportant, because the latter gave only a feeble response in Gessner's experiments. The ionization response would be from the carbon atoms regardless of whether they were present as free ethanol, or as ethyl nitrite.

10. To minimize the amount of nonvolatile material injected into the G-C column, Gupta et al. (28) have reported a method in which the blood proteins are precipitated with trichloracetic acid (TCA), and the non-protein fraction is analyzed.

One-half ml of the blood is mixed with 0.5 ml containing 5% TCA and 0.079% isopropanol, the mixture is well shaken and then centrifuged, and 0.5 µl of the supernatant is injected into the column port of a model 2100 Varian chromatograph. The recorder tracing shows a good separation of the peaks of methanol, ethanol and isopropanol. There is also a peak from the TCA, but it appears almost two minutes after the last alcohol peak. A table gives the results by this method with 5 samples of blood containing 21 mg% to 114 mg% of ethanol, and also results of analyses of these same bloods by two other laboratories, also using G-C procedures. In general, the results from the three laboratories agreed within ± 2 mg%, but with two of the blood samples the values obtained by one of the cooperating laboratories exceeded those of Gupta et al. by 7% and 12%, respectively.

As regards specificity for determining ethanol in blood and other body materials, the G-C procedure is admittedly far superior to chemical methods, and perhaps slightly more reliable than ADH methods. However, in the matter of accuracy, the results given in the above-reviewed papers show no superiority for the G-C methods, at least in the hands of some operators.

A summary of certain details regarding the eight above-mentioned G-C methods is presented in Table 1. (See Appendix C)

B. ALCOHOL DEHYDROGENASE METHODS.

1. Goldberg and Rydberg (29) have developed an automated micro ADH procedure for alcohol analyses of blood and urine, which employs a modified Technicon Auto-Analyzer equipped with a rotating sample cup holder, a small dialyzing chamber using a Cuprophan coil membrane, an incubation bath held at 25°, a 15 mm flow-through micro cuvette, and a spectrograph set at 340 mµ. The fluid is the dialysate from the blood.

Capillary blood is used, and 0.1 ml is mixed in an Auto-Analyzer sample cup with 0.9 ml of water containing 0.2% NaF and 0.1% saponin. The paper by Goldberg and Rydberg contains a schematic drawing, which is reproduced in Fig. 2 (See Appendix B), showing the course of the 1:10 diluted blood from the rotating cup holder through the Auto-Analyzer. The first step is a slow passage

through a small dialysis chamber, where 30% to 34% of the alcohol passes into a parallel stream of a water solution containing a phosphate buffer with a pH of 817 and 8.3% of semicarbazide. The dialysate is then mixed with a water solution of NAD and yeast alcohol dehydrogenase (Y-ADH) and the mixture goes to the incubator bath where it remains for 10 min. at 25°. The final step is the automatic determination of the UV absorption from the NADH formed, which response is recorded in the usual manner on a moving strip of paper. As a control, 0.1 ml of a standard water solution of ethanol is analyzed in the same manner. Duplicate, or triplicate, samples of blood or standard are analyzed. The capacity of the automatic device is about 30 samples per hour.

The calibration curve of ethanol concentration vs spectrograph response is logarithmic, but the curve height is affected by the rate of flow of the diluted blood through the dialyzer. With a flow rate of 0.6 ml/min, the height of the resulting calibration curve differed about 14% from the curve when the flow rate was reduced to 0.23 ml/minute. The precision of duplicate or triplicate analyses of the same sample was found to be ± 0.9 mg%. Accuracy was checked by comparison of the analytical results with 27 samples analyzed by the automated ADH method and also by the Widmark method. A scatter diagram correlating results by the two methods shows a line of regression of unity, but with 9 of the samples the ADH values exceeded the Widmark values by 6% to 8%.

When a sample having a high BAC was followed by one with a much lower alcohol concentration, the results with the second sample were sometimes too high. In a typical case, a sample with 10 mg% ethanol followed one with 300 mg% ethanol, but the reading of the automated spectrograph for the first sample was 20 mg%. as mentioned above, there was a maximum variation of 11% in the fraction of the alcohol passing into the dialysate.

2. A very simple diffusion ADH method for blood was developed by Eskes (30). He stated that it is a simplification of earlier diffusion methods reported by Kirk et al. (31) and Alha and Tamminen (32).

   As a diffusion chamber, Eskes uses a 50 ml Erlenmeyer flask with a small, flat glass dish sealed to the inner wall of the flask about 2 cm above the bottom. In the bottom of the flask

are placed 2 ml of the reagent solution containing buffer, NAD, ADH and semicarbazide. With a micro syringe, 4 µl of the blood is discharged on a circle of filter paper in the glass dish and the flask is closed with a glass or plastic cap. After 90 min. of incubation at room temperature, absorbance of the incubated fluid was read with a B&L Spectronic 20 set at 35 mu, which is the lowest wavelength obtained with this instrument. The calibration curve was a straight line from zero to 300 mg% alcohol, and the standard deviation of the analytical results from the theoretical values was ± 1.1 mg%. Compared with the Widmark method, the Eskes procedure gave results which were higher by 0.0 to 9 mg%, averaging +0.4 mg%.

C. FREEZING POINT OSMOMETER METHOD. Redetzki (33) has investigated the use of freezing point determinations to quantitate the concentration of ethanol in water solutions. The instrument used was a freezing point osmometer model 31LAS, made by Advanced Instruments, Inc., Newton Highland, Mass. Using aqueous solutions of ethanol having concetrations of 460 mg%, 230 mg% and 115 mg%, he reported an average standard error of ± 0.1 mg%. He strongly recommends this simple, rapid osmometer method for checking the ethanol concentration of standards used in alcohol analyses for medicolegal purposes.

In an earlier paper, Redezki et al. reported (34) a study of the use of the freezing point osmometer to estimate the BAC of human subjects, and found the results to be approximately accurate and the procedure very simple and rapid.

D. AERATION PLUS BREATHALYZER ANALYSIS. Since quantitative breath alcohol instruments employing oxidation of the ethanol are widely available, Mac Donnell, Johnson and Greenberg (35) have developed a simple procedure in which the alcohol from a small blood sample in a closed flask is removed by a current of air which then passes through the conventional Breathalyzer reaction ampule and the remaining Breathalyzer procedure is completed in the usual manner.

The aeration chamber is a 50 ml Erlenmeyer flask with a standard taper joint at the neck, the male portion of the joint being a glass stopper having an inlet tube extending to about the middle of the flask, and an exit tube. With the Breathalyzer readied for analysis, but without the regular bubbler tube in the reaction ampule, 50 µm of the blood is collected in a micropipette and delivered onto a small square of filter paper at the bottom of the flask. The stopper is immediately replaced and the exit tube

is connected by rubber tubing to a 4 mm (i.d.) delivery tube inserted into the reaction ampule. Aeration of the blood sample is conducted for 5 min. at a rate of 300 ml/minute. The delivery tube is then removed from the ampule and the change in concentration of dichromate in the ampule is read in the Breathalyzer as usual. In this procedure the breath sampling tube and the metal alveolar air chamber are not used.

The factor employed for translating the Breathalyzer reading to BAC was determined empirically by analyses with the procedure of water solutions of ethanol of known concentration, and was found to be 0.0066% BAC per scale division.

The Breathalyzer needle should move one scale division for each 2.5 µg of ethanol added to the ampule fluid, as we have repeatedly confirmed, so the theoretical factor for this aeration-Breathalyzer method should be 0.005% per scale division, which means that the factor used is 32% too high. In other words, the Breathalyzer readings should simply be divided by two. One suspects that the time and temperature of the aeration did not remove all of the ethanol from the blood, or that some of the evolved ethanol was adsorbed in the rubber tube connecting the flask outlet with the delivery tube.

At any rate, using this aeration-Breathalyzer procedure and the factor of 0.0066% per scale division, the authors conducted 27 analyses of a water solution of ethanol having a concentration of 0.15%. The results obtained were: fifteen, 0.158%; one, 0.145%; two, 0.152%; seven, 0.165%; and one, 0.171%, giving an overall average error of +2.0 percent.

Fourteen years earlier, Lester and Greenberg (36) described a similar blood alcohol aeration procedure in which the alcohol evolved from the blood is analyzed with the Drunkometer reagent (37), which is a mixture of 10 ml of 16 N H_2SO_4 and 1 ml of 0.05 N $KMnO_4$. In this method the blood sample is added to a 50 ml aeration flask, which is then placed in boiling water and an air current of 100 ml/min is passed through the flask and then through a tube containing 10 ml of the 16 N H_2SO_4. At the end of the aeration, 1 ml of the 0.05 N $KMnO_4$ solution is added to the fluid in the tube and, after 5 min., the decrease in permanganate color is measured with an Evelyn colorimeter set at 520 mu. The standard error reported is ± 1.0 percent.

Table II summarizes certain details relative to the four above-mentioned analytical methods for alcohol in body fluids and tissues. (See Table II, Appendix C)

II. BREATH ALCOHOL METHODS

The first three practically-used breath alcohol instruments, namely, the Alcometer, Drunkometer and Intoximeter, are described with drawings in the 1970 AMA Manual (8), which publication also covers the initial Breathalyzer and the Drunkometer employing rebreathed air. In this chapter, we will discuss several recently-developed breath alcohol instruments and alcohol detector tubes. With all of these, as well as with the five breath alcohol instruments mentioned above, the anlysis conducted is simply a determination of the weight of alcohol in a given volume of alveolar air, or rebreathed air, namely, 2,100 ml of the deep lung breath, as it leaves the mouth.

A. QUANTITATIVE BREATH ALCOHOL METHODS. While the seven breath alcohol instruments described below each has a handle for carrying it, they are too cumbersome and fragile to be regularly carried in a patrol car, and are commonly kept in a special room at the police station.

1. Photoelectric Intoximeter[1]. This instrument was reported in 1958 by G. C. Forrester (38), and is a very greatly changed version of his earlier Intoximeter, mentioned in the first paragraph of this subsection. A schematic drawing of the construction and operation of the Photoelectric Intoximeter is given in Fig. 3. (See Appendix B) The instrument collects two samples of alveolar air. One is analyzed immediately in the device, and the other passes through a tube of anhydrous magnesium perchlorate, which adsorbs the alcohol for later analysis. The two breath samplying cylinders are much like the sampling cylinder of the Breathalyzer. One, S1, has a volume of 105 ml, and the other, marked S2, has a volume of 210 ml., which volumes are respectively, 1/20 and 1/10 of 2,100 ml. As the subject blows into the mouthpiece, the first portion of his breath is discarded into a plastic bag, W, with a volume of about 500 ml. Then the multiple route valve is turned and the breath, now approximately alveolar, fills the larger cylinder, S2, when the valve is again turned and the smaller cylinder, S1, is filled. On further turning the valve, the alveolar air in cylinder S1 goes through reaction ampule A containing 4 ml of a solution of about 18 N H_2SO_4 and 0.021% $K_2Cr_2O_7$, plus a small amount of a catalyst. After a minute or so, the decrease in the yellow dichromate color in ampule A is read in the photometer, which is a Klett colorimeter set at 420 mμ. The larger sample of alveolar air in cylinder S2 is

[1]Mfg. by Intoximeter Assn., Niagara Falls, N.Y.

is passed through the magnesium perchlorate tube T, which can later be sent to a chemist, who dissolves the perchlorate in water, distills the solution, and analyzes the distillate by a conventional ethanol method. The air pump is used to purge the air flow tubes of the instrument following an analysis. The procedure thus gives two separate values for the concentration of alcohol in the subject's alveolar air.

Roberts and Fletcher have reported a study (39) in which bloods from 21 drinking subjects were analyzed for alcohol by a dichromate method, and breath, collected simultaneously, was analyzed with the Photoelectric Intoximeter. With all of the blood-breath pairs except one, the breath values were lower than the blood results. The individual deviations of the breath results from the blood findings ranged from +1% to -26%, averaging -14.5%.

2. Alco-Tector[2]. This instrument represents almost a duplication of the model 100 Breathalyzer, with the omission of the two-way plastic tube valve of the latter. Figure 4, from a paper by Shupe and Pfau (40), is a schematic drawing of the working parts of the Alco-Tector. (See Fig.4, Appendix B) They reported a study of the performance of this instrument. Using 86 pairs of blood and breath samples from drinking subjects, they compared the Alco-Tector breath alcohol results with those from the blood analyses by the Dubowski-Shupe dichromate method. The data for this correlation study by Shupe and Pfau are summarized in Table III. (See Appendix C)

3. Breathalyzer, Model 1000[3]. This Borkenstein instrument is a recent adaptation of his model 100 Breathalyzer, making its operation almost fully automatic. There are two changes of the analytical procedure. One is the addition of a second metal cylinder and piston with a cpacity of 400 ml, which volume of the first exhaled breath is discarded prior to taking the 52.5 ml sample of alveolar air for analysis. The second is replacement of the manually operated two-way valve with a series of electrically-operated valves. Figure 5 is a diagram showing the general construction of the model 1000 instrument and the course of the breath through it. (See Fig. 5, Appendix B)

The only steps of the procedure which the operator must now perform are: to gauge the diameter of the reference and test ampules, place the ampules in their positions in the instrument case and close the

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[2] Mfg. by Decatur Electronics, Inc., Decatur, Ill.
[3] Mfg. by Smith & Wesson Electronics Co., Eatontown, N.J.

lid over them, insert and connect the bubbler tube, place the record card in its slot, and connect the mouthpiece to the sampling tube. As usual, the subject exhales as deeply as he can through the connected mouthpiece, after which the remainder of the operation is fully automated. The final result appears on a digital reader and also is printed on the record card, these two operations being reminiscent of the recording cash register.

The first 400 ml of the subject's breath go to the larger cylinder and, when it is filled, an automatic valve shunts the breath stream, now alveolar, into the smaller cylinder. When it is filled, a valve shunts the breath stream to the outside until the subject reaches his exhalation limit. The 52.5 ml[4] of alveolar air in the smaller cylinder is analyzed in exactly the same manner as with the model 100 Breathalyzer, except that the final null setting of the ammeter is performed by the robot mechanism, which also operates the digital reader and prints the result on the record card. At the end of an analysis, an automatic pump flushes out the tubes and chambers through which the breath passed.

Although there are, as yet, no published studies of the performance of the model 1000 Breathalyzer, since the actual analytical procedure is essentially the same as that of the model 100 Breathalyzer, one would expect that the two model would give about the same degree of precision and accuracy, but it is possible that the altered alveolar air sampling procedure used in model 1000 might result in improved accuracy for predicting the alcohol level in the blood.

The model 100 Breathalyzer has been, by far, the most widely used breath alcohol instrument in the U. S. and some other countries. As a result, many studies have been made of the accuracy of the Breathalyzer in estimating the BAC. The blood-breath correlation data from 12 such studies are summarized in Table III. (See Appendix C) Similar Breathalyzer-blood alcohol studies, which should probably have been included in Table III, are those of Hower et al. (41), Roberts and Fletcher (39), Preston (42), and Milner and Landauer (43). In most of the 15 above-mentioned studies, the Breathalyzer estimation of the BAC was lower than the value by direct blood analysis by averages ranging from about -8% to -15%. However, the model 100 Breathalyzer almost never gives erroneously high results, so no defense attorney could object to the use of these low results, which is really being over generous to his client.

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[4] The temperature inside the model 100 and model 1000 Breathalyzers is held at 50° to prevent moisture condensation, so the volume of alveolar air sampling cylinder is actually 56.5 ml, because 52.5 ml of the breath on *leaving the mouth at 34° will* expand 5.3% on being heated to 50° to give a volume of 55.3 ml, and a little of the alveolar air remains in the delivery tube to the test ampule.

4. Alcolinger Automatic[5]. This is a Swiss version of the model 100 Breathalyzer developed by Monnier et al. and described in a 1969 paper by them (44). The 52.5 ml cylinder-piston sampling chamber of the Breathalyzer is replaced with a coiled metal tube having the same internal volume, and its use eliminates any moving parts in the Alcolinger Automatic, except for a small membrane pump and some electrically-operated valves.

   In using this instrument, the operator first readies it in the same manner as with the Breathalyzer, making sure that the photometer light is positioned so that the null meter is centered and the scale reads zero. Then the subject exhales as deeply as possible through a mouthpiece connected to the inlet of the metal tube having the coiled section. At the end of the exhalation, two automatic valves close the ends of the coil, and the remainder of the anlysis is performed automatically, employing the same apparatus and reagents as those used in the Breathalyzer procedure, but with the pump forcing the alveolar air in the metal coil through the fluid in the test ampule. The operator then completes the final steps of turning the light balance knob until the null meter is centered, and then recording the scale reading. The use of the coiled metal tube to collect the alveolar air sample is essentially the method used by Haldane and Priestly in their pioneer study of alveolar air (45). In their experiments, the subject exhales through a glass mouthpiece connected to a 3' length of 1" hose, and at the end of a forced exhalation he closes the end of the mouthpiece with his tongue and some of the last breath discharged is collected by the operator in a gas sampling bulb connected to a tee on the mouthpiece. Due to the negligible gas resistance in the mouthpiece and hose, the collection operation involves no increase of gas pressure within the pulmonary chamber.

   The paper by Monnier et al. reports a few blood-breath experiments with three drinking subjects, with results which indicate a satisfactory correlation between the Alcolinger Automatic readings and the results of blood analyses.

   In 1970, Bonte et al. (46) reported a study of the performance of the Alcolinger Automatic in which they used 22 subjects who ingested 1.0 to 1.5 gm/kg of alcohol in 1 hour, and whose cubital vein blood and breath were taken for anlysis at 20, 50, 80, 110 and 140 min. after the end of drinking. Figure 6 gives two scatter diagrams from the paper by Bonte et al. showing the deviations of

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[5] Mfg. by Lucien Etzlinger, Inc., Geneva, Switzerland.

of the Alcolinger Automatic readings from the blood analysis values fro the individual blood-breath pairs. The upper diagram covers the intervals of 20 and 50 min. after the end of drinking, and the lower diagram presents data for the three remaining test times. (See Fig. 6, Appendix B) In the first tests the breath results were significantly higher than the corresponding blood values, but in the later period most of the blood-breath results agreed within ± 20 mg%, and the arithmetic mean Br/Bl deviation was +3.6%. Table III summarizes the overall blood-breath correlations for the last three test periods. Bonte et al. explained the higher breath/blood ratios in the first period as being due to the normal arteriovenous differential druing active absorption of alcohol. Although they agreed that the performance of the Alcolinger Automatic was fairly good in the second period, they questioned the use of its test results in court because the law in their country (West Germany) specifies blood alcohol values, and it might be unfair for the court to accept the higher BAC values given by the Alcolinger Automatic during the absorption period. (See Table III, Appendix C)

5. G-C Intoximeter[6]. This instrument was developed by M. R. Forrester, who is the som of G. C. Forrester, inventor of the first Intoximeter and the Photoelectric Intoximeter. The gas Chromatograph Intoximeter was first described in 1969 by Penton and M. R. Forrester (47). Their paper includes a functional diagram showing the chief components of the instrument and how it operates. We have reproduced this diagram as our Figure 7. (See Appendix B)

   The G-C Intoximeter is housed in a carrying case, and its chief components are a compact gas chromatograph with a flame ionization detector connected to a small strip recorder. The carrier gas is 60% N_2 + 40% H_2. A small aquarium pump furnishes a stream of air to burn the hydrogen in the ionization flame.

   The subject exhales deeply through a mouthpiece connected to the breath sampling tube leading to the inlet tube J, and the first part of his breath is discarded into a plastic bag. His now alveolar air then goes to the gas sampling valve B, which injects 0.25 ml into the G-C column.

   Forrester and Penton have also developed a field breath-sampling device, in which the subject exhales deeply through an indium tube and, with the tube finally filled with alveolar air, a short

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[6] Mfg. by Intoximeters, Inc., St. Louis, Mo.

section of the tube is crimped at both ends with a steel press making welded closures there. The indium capsule sample of alveolar air can be stored for some time. To analyze its contents with the G-C Intoximeter, the capsule is placed in a steel housing and a solenoid-operated needl punctures one end of the capsule and the contents are carried by an air stream to the field sampling valve C, from which a 0.25 ml portion of the alveolar air is injected into the G-C column. Figure 8 shows the construction and operation of the device for opening the indium capsule and transferring its contents to the field sampling valve C. In their earlier experiments with this indium capsule they encountered much trouble from loss of ethanol within the capsule. The difficulty was finally found to be due to bacterial contamination on the inner surface of the capsule, which defect has now been elininated by coating the inner surface of the capsule with a proprietary antiseptic (48). (See Fig. 8, Appendix B)

In their 1967 paper, Penton and Forrester presented the results of a blood-breath study with 33 drinking subjects, with the breath analyzed with their G-C Intoximeter. A summary of the results obtained is given in Table III. (See Appendix C)

A second evaluation of the performance of the G-C Intoximeter, Mark II Model, was made in 1972 by staff members of the Centre of Forensic Sciences, Toronto, Canada, under the auspices of the Canadian Society of Forensic Sciences (49). Using 25 drinking subjects with blood alcohol concentrations ranging from 18 mg% to 182 mg%, as determined by direct blood analysis, they analyzed simultaneously-obtained breath samples with the G-C Intoximeter. Table III gives a summary of the deviations of the breath results from the blood values for the individual blood-breath pairs. Results of a similar investigation, using the indium capsules, were also included in the Toronto study, and are summarized in Table III. It will be seen that estimation of the true blood alcohol concentration from the G-C Intoximeter analyses of breath was significantly improved when the alveolar air was first collected in the indium tubes and stored for periods of up to 14 days. Perhaps less pressure was used in filling the indium tubes, as compared with that when the subject exhaled directly into the tube leading to the gas sampling valve B. At least this discrepancy deserves further investigation. (See Table III, Appendix C)

Another evaluation of the performance of the G-C Intoximeter was reported by Schmutte et al. in 1972 (50). During a one-hour period, their 18 subjects drank beer or spirits to give later

blood alcohol peaks of 70 mg% to 200 mg%. During the following 190 min. 10 paired blood-breath samples were secured from each subject, first at intervals of 10 minutes, and later at intervals of 20 minutes. Blood was taken from the cubital vein and analyzed by the Machata head-space G-C method described in Section 1, and the G-C Intoximeter was used for the breath samples. Figure 9, copied from the paper by Schmutte et al., is a sort of scatter diagram showing the percent deviation of the breath results with the G-C Intoximeter from the blood results with the Machata method for 179 such blood-breath pairs. This scatter diagram really magnifies the deviations, because a ± 60% deviation would be three times greater than the ± 20% distance on the graph. We have estimated the values for the individual deviations from the dots on the graph and have classified the magnitude of these deviations in Table III (study 21) (See Appendix C). Inspection of the results of studies 16, 24, 25a and 25b listed in Table II (See Appendix C) will show that the degree of accuracy in estimating the BAC by breath analysis with the G-C Intoximeter is about the same in the 1969 determinations by Penton and Forrester and in the 1972 study of Schmutte et al. In the 1973 Toronto study, the performance of the G-C Intoximeter using direct analysis was about like that in studies 24 and 25, but with pre-collection of the alveolar air sample in the indium capsules, the results are much superior to those in any one of the other studies. (See Fig. 9, Appendix B)

Legislation in California provides that no quantitative breath alcohol instrument may be used in forensic traffic cases until it is thoroughly tested by the Clinical Chemistry Laboratory of the State Board of Health, using blood and breath from drinking subjects, and is found to meet certain requirements. This laboratory is headed by Dr. D. R. Morales. Reports of this extensive testing program have been issued in 1972 (51) and in 1974 (52). In the 1972 reprot, the G-C Intoximeter direct analysis procedure was approved, but not the procedure using the indium tubes. Following the improvement of the indium tube, mentioned above, the 1974 California report gives approval to both G-C Intoximeter procedures. Results of their blood-breath correlation employing the direct G-C Intoximeter procedure are given in Table III (study 26) (See Appendix C). While the blood-breath correlation in study 26 is slightly inferior to that in study 25b, it is far better than the correlations reported in studies 16, 24 and 25a, indicating that the 1973 G-C Intoximeter is capable of yielding a better estimation of the BAC than was found by Schmutte et al.

6. Alco-Analyzer[7]. This G-C instrument was devised by Luckey (16). It is designed to analyze both blood and breath, and its construction and operation are described on page 3 of this chapter. In a 1969 paper by Shupe and Pfau (40), they reported an investigation of the performance of this Alco-Analyzer in which they correlated the alcohol findings for 104 blood-breath pairs from drinking subject, with the BAC determined by a dichromate method. Their results are summarized in Table III (See Appendix C). The paper by Shupe and Pfau also gives a schematic drawing of the Alco-Analyzer, which is reproduced in Figure 1. (See Appendix B)

7. Intoxilyzer[8]. This is a compact infrared spectrophotometer operating on a wavelength of about 3390 mμ, at which wavelength the absorbance of ethanol is maximum. Figure 10 is a drawing showing the schematic of the optical system of the instrument. (See Fig. 10, Appendix B)

   The infrared beam from the light source is collamated by a fused silica lens (A) and is focused on mirror (B), which reflects the beam into the window (C) of the gas sampling cell. Within the cell a set of spherical, concave mirrors reflects the light beam back and forth several times, so that the complete path of the beam inside the cell is about 9 ft. before it emerges at window (D). From here mirror (F) directs the beam to the infrared photometer (H). The photometer readings, translated into BAC by the 2100:1 formula, is shown on a digital readout and is recorded on a printed card.

   The subject's alveolar air is collected in the conventional manner by exhaling as deeply as possible through the sample cell, and the remainder of the operation is automatic. A paper by Harte of the Omicron Corporation (53) describes the construction and operation of the instrument, and gives scatter diagrams for three drinking subjects correlating the Intoxilyzer breath results with those from blood samples, simultaneously obtained, and analyzed by a cooperating laboratory. The three graphs give the results for 12 blood-breath pairs. According to our estimation from these graphs, the deviation between the Intoxilyzer results and those from direct blood analysis ranged from +2% to -11%, with an arithmetric

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[7] Mfg. by Luckey Laboratories, Inc., San Bernardino, California
[8] Mfg. by Omicron Systems Corp., Palo Alto, California

mean of -3.2%. Only three deviations exceeded ±5%. In the Omicron Operator's Manual, it is stated that some other organic compounds, including methanol and isopropanol, will also give positive readings at the wavelength used. In his paper, Harte says:

> "Tests have indicated that no other interferants which possess some degree of light absorption at this wavelength (methyl alcohol, certain ketones and aldehydes) will be detectable when present in even toxic blood concentrations. The amount of consumed methyl alcohol or acetone required to produce a reading of 0.01% W/V in the Intoxilyzer exceeds the LD 50 values given in toxicology texts."

We do not know of any toxicology text which gives the alveolar air concentration of methanol or acetone when these compounds are present in toxic concentrations in the blood, although these values could be calculated from the clinical and biochemical literature. Unfortunately, Harte does not state what concentrations of these two compounds will yield significant readings with the Intoxilyzer.

In Table III, we have summarized the results of 27 blood-breath correlation studies employing eight quantitative breath alcohol instruments. For the benefit of those not familiar with statistical terminology, we have classified the blood-breath deviations in four categories. (See Table III, Appendix C)

B. DISPOSABLE ALCOHOL DETECTOR TUBES. These alcohol detector tubes are intended only as screening devices to check whether a quantitative analysis of the subject's blood or breath is indicated. They are patterned after the toxic gas detector tubes which have been marketed for years by industrial safety supply houses. The latter consist of a 2" to 4" length of glass tubing with an O.D. of ¼" to 3/8" which is packed with a granular, inert material, a section of which is impregnated with chemicals which become black, or change color, in the presence of the particular toxic gas. Thus, the impregnated section of the well-known Bureau of Standards CO detector tube is a mixture of sulfuric acid, palladium sulfate and a molybdate salt (54).

The first alcohol detector tubes were developed independently about 1952 by Grosskopf of Germany (55) and Kobayashi and Kitagawa of Japan (56). The inert packing material was white, granular, silica gel and its detector section was impregnated with a yellow mixture of sulfuric acid and chromic acid. In the presence of ethanol, part, or all, of the yellow color of this section changes to green chromic sulfate, and the length of this green section is somewhat proportional to the concentration of ethanol in the subject's breath. As sold, the ends of the tube are flame-sealed, preserving the detector

chemicals for a long time.

During the past 20 years, three other types of alcohol detector tubes have been developed and marketed. Each type of the presently-available alcohol detector tubes has been given a trade name. We will briefly describe these five brands of alcohol detector tubes and summarize certain published studies of their performance.

In 1971, Prouty and O'Neill reported (57) a comprehensive investigation of the reliability of the Kitagawa alcohol detector tube and three other brands of detector tubes which followed it. Their report gives a description of each of these four brands of alcohol detector tubes, with photographs. The data from this study will be reviewed at the end of this subsection.

1. Alcotest of Grosskop[9]. These alcohol detector tubes have been very widely used in Europe. Harger and Forney (6,7) have described the Alcotest and have reviewed studies by Grosskopf and others relative to its degree of accuracy for showing whether the BAC is near, or above, 80 mg%, indicating that a blood or urine sample should be taken for quantitative alcohol analysis.

   A 1968 paper by Day et al. (58), gives the results of a study by them of the accuracy of the Alcotest R80, which has a mark between two yellow portions indicating the length of the resulting green coloration when the BAC is close to 80 mg%. In their study, Day et al, analyzed 124 blood-breath pairs from 27 drinking subjects. Their data are summarized in Table IV, which gives the percent of false readings of the Alcotest for each of eight BAC zones. (See Table IV, Appendix C)

   Regarding the reliability of the Alcotest R80, Day et al. concluded:

   > "As a screen test for disease, it would be rejected out of hand by the medical profession because of the exceptionally high false positive levels".

   While there were no false negative Alcotest readings in the six pairs with BAC above 80 mg%, and while we might accept the false positive readings in the 70-80 mg% zone, one cannot excuse the occurrence of 42% to 96% false positive readings where the BAC was 30 mg% to 70 mg%.

   Recently, the Draeger company announced a new, improved Alcotest tube with the yellow area separated into five zones which were claimed to turn green successively at BAC values of 50, 80, 100, 130 and 150 mg%. With the new Alcotest, the subject first inflates a 1-liter plastic bag with his mixed expired air,

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[9] Mfg. by Draegerwerk, Lubeck, W. Germany

and then a mechanical device sucks the breath sample at a fixed rate through the Alcotest tube.

A 1973 governmental report of the city of Hamburg, West Germany (59) gives the results of an evaluation study of the new Alcotest conducted by Hamburg police technicians under the supervision of the Institute of Legal Medicine of the University of Hamburg. Breath samples from arrested, drinking drivers were analyzed with the new Alcotest, and the readings were compared with the results of analyses of venous blood samples, simultaneously obtained. Alcotest-blood data are summarized for 75 subjects with BAC below 160 mg%. With 13 of the blood-breath pairs, the results agreed within ± 5 mg%, and the deviations were within ± 6-10 mg%, with 17 other pairs. Deviations within ± 10 mg% were considered acceptable. However, with the remaining 45 pairs, the deviations between the Alcotest readings and the blood analyses ranged from 11 mg% to 91 mg%, with an average Alcotest:Blood difference of +30 mg% for 39 pairs and -25 mg% for the remaining six pairs. Alcotest readings are not given for 59 subjects with BAC above 160 mg%, where there were probably no false Alcotest readings. The investigators concluded that the new Alcotest offers no improvement over the earlier type, and that the use of either may lead to many unnecessary blood analyses. This Hamburg report makes no mention of the 1968 study of Day et al., which was reviewed above.

It is unfortunate that the Hamburg study did not employ fingertip or arterial blood, because, during the absorption phase, the alcohol concentration in cubital vein blood lags far behind that in fingertip or arterial blood and in brain.

2. Kitagawa Drunk-O-Tester[10]. These alcohol detector tubes are about 4" long with O.D. of 4mm, and have three narrow bands of yellow detector material (H_2SO_4 + chromic acid) separated by the white inert packing material. The subject inflates a rubber balloon with the mixed expired air, and 100 ml of this sample is drawn through the detector tube during a period of 2 minutes by means of the standard Kitagawa suction pump. The detector tube is then heated for 15 second with the flame of a match or cigarette lighter, and the green coloration(s) compared with a color chart furnished with the box of detector tubes. Harger and Forney (7) have reviewed publications on the reliability of earlier Kitagawa alcohol detector tubes.

3. Lion Alcolysers[11]. The Lion company markets three types of their alcohol detector kits: (a) model H, (b) model Iowa type; and (c) model 100. The detector tubes are about 3" long with O.D.

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10 Mfg. by Komo Chemical Industrial Co., Tokyo, Japan
11 Mfg. by Lion Laboratories, Inc., Cardiff, Wales

of 5/16", containing a section of yellow impregnated granules. In types (a) and (c), this section is 1" long, with a red line around the glass tube about midway between the ends of the detector section to indicate the reading with BAC of 100 mg%. With type (a), the ends of the glass tube are flame-sealed, while the ends of type (c) are closed with plastic plugs. Type (b) has a shorter length of the detector material and will not read above 100 mg% BAC. Type (c) has a drying powder at each end, which is poured out before the test. The subject blows through the detector tube to fill a 900 ml plastic bag connected to the exit end of the tube. If the BAC is 100 mg%, or above, the green color should reach, or pass, the red line.

4. B-D Breath Alcohol Detectors[12]. With this device, the subject exhales into a plastic bag having two chambers. The entrance to the first chamber is a large hole, while that of the second chamber is a pinhole. The exhaled breath stream fills the first chamber and then is shunted to the second chamber. The latter sample, which should be mostly alveolar air, is then passed through the detector tube containing the usual granular material impregnated with H_2SO_4-chromic acid, and the length of the resulting green section is compared with a scale giving the estimated BAC reading. Two models of this device are available. In No. 1, each compartment of the plastic bag has a volume of 625 ml, and a green coloration of about 9 mm in the detector tube indicates a BAC of 100 mg%. With No. 2, each bag compartment has a volume of 750 ml and the length of green coloration in the tube is compared with a printed scale reading BAC values of 50, 100, and 150 mg%.

5. Luckey Sober-Meters[13]. The detector tube in this kit is about 4" long with O.D. of 3/8", and contains three 5 mm zones of the usual yellow detector granules separated by the inert supporting material. The tube ends are closed with plastic plugs. There are two models of the device, both using the same detector tube. In model SM-1 the breath is collected in a rubber balloon which has entrance and exit openings. The exit opening is connected to the detector tube inlet with the exit of the tube plugged. The subject exhales through a one-way valve into the entrance opening of the balloon to inflate it to a volume of 2 or more liters, after which the plug is removed from the tube exit and the balloon contents slowly pass through the tube for exactly one minute. After waiting five minutes, the three zones are inspected for green color. The BAC is presumed to be 100 mg%, if the first zone is completely green, 200 mg% with two zones green, and 300 mg% with all three zones green.

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12 Mfg. by Becton-Dickinson, Rutherford, N.J.
13 Mfg. by Luckey Laboratories, Inc., San Bernadino, California

With model SM-6, the balloon has only one opening. It is inflated by the subject and attached to the detector tube inlet, with an 825 ml plastic bag attached to the other end, eliminating the timing procedure.

Prouty-O'Neill Evaluation Study of Eight Models of Disposable Alcohol Detector Tubes. The results of this extensive, well-planned investigation were published in 1971 as a 50-page Research Report of the Insurance Institute for Highway Safety (57). The disposable alcohol detector tubes studies were: Kitagawa Drunk-O-Tester, 1 model; Lion Alcolysers, 3 models; Becton-Dickinson alcohol detectors, 2 models; and Luckey Sober-Meters, 2 models.

The subjects employed in this investigation were 62 state highway patrol officers, each of whom was used for two days. On one day he was a drinking subject, and on the other his task was to observe and record the readings of the detector tubes used to test his drinking partner, with the actual testing procedure conducted by a trained laboratory technician in a separate room. Before attempting to read the result from the used detector tube, the patrol officer was fully instructed on how this was to be done.

During a drinking period of about two hours, following a noon lunch, the subject ingested alcohol beverage(s) to give a maximum BAC of 42 mg% to 199 mg%, with an average BAC of 118 mg%. At five hourly intervals after end of drinking, the subject's breath was tested with some of the eight screening devices and a sample of his fingertip blood was drawn for later G-C analysis. Also, Breathalyzer tests were made at the start and end of each of the five test sessions. (The Breathalyzer-blood correlations obtained are given in Table III). The BAC values at the end of the fifth testing session ranged from zero to 145 mg%, with an average of 78 mg%. (See Table III, Appendix C)

For the eight breath alcohol screening devices tested, the number of blood-breath pairs used ranged from 190 to 471, averaging 308 pairs. Since 100 mg% is the critical BAC in the chemical test laws of most of the states in the U.S., Prouty and O'Neill selected this value as the line of demarcation for showing, with each blood-breath pair, whether the reading of the screening device was true or false, as regards the need for a quantitative analysis of the subject(s) breath or blood. Thus, if the BAC from analysis of the blood, which we will call the true blood alcohol concentration (TBAC), and the detector tube reading (DTR), were both below, or both above, 100 mg%, these were designated as true readings. If TBAC was below 100 mg%, and DTR above, this would be a false positive reading of the detector tube. Conversely, if TBAC was above 100 mg%, but STR below, this is called a false positive reading of the

detector tube. The results for each of the eight screening devices are presented in the Prouty-O'Neill paper as a separate graph and as separate tables, showing the percent of the total number of blood-breath pairs in a given TBAC zone in which the DTR was a false positive, or a false negative. We have condensed the chief data in these eight tables into a single table, which is our Table V. (See Table V, Appendix C)

An inspection of Table V shows that there was a high frequency of false positive, or false negative, detector tube readings. However, the frequency of false readings was much less with the Alcolyser 100 and the two Becton-Dickinson devices. Since these devices are used only for screening purposes, we should accept some tolerance in their accuracy. If we ignore errors in the 81 mg% to 120 mg% TBAC zone, the reliability of the two Becton-Dickinson devices is perhaps sufficient to permit their use to indicate when a quantitative breath or blood analysis should be made. However, use of B-D #1 would free 1 out of 5 drivers with TBAC of 121-140 mg%, and use of B-D #2 would free 1 out of 25 drivers in this TBAC zone. From the standpoint of law enforcement, false negative readings by these screening devices are much more objectionable than false positive readings.

In our opinion, the results of this investigation by Prouty and O'Neill are a worthwhile contribution to our knowledge of the relative accuracy of these eight breath alcohol screening devices, and should serve as a model for those individuals in each state who are responsible for the approval, or rejection, of the numerous breath alcohol instruments or devices now being promoted by high-pressure salesmen.

C. SEMI-QUANTITATIVE, PORTABLE, BREATH ALCOHOL INSTRUMENTS. From the preceding subsection, one can conclude that the various disposable, detector tubes reviewed there have proved to be highly unreliable as screening devices for even approximately showing whether the BAC is above, or below, a specified limit.

The present-day sophisticated, automated, quantitative breath alcohol instruments are entirely too fragile, cumbersome, and expensive to be used as standard equipment in a patrol car, and must be housed in a special room of a centrally-located police station.

Since the work load of these quantitative breath alcohol instruments can be greatly lightened by the use of a reliable, portable screening device, scientists in the breath alcohol field have proposed the development of a small, rugged instrument having ample reliability for performing roadside screening breath tests and functioning properly over a wide range of temperatures. The Alcohol Countermeasures Section of the U.S. Department of Transportation (DOT) has contacted

a number of manufacturers of technical equipment to interest them in undertaking the development of such an instrument. The response has been favorable, due to the possibility of a large volume of sales to the traffic enforcement units of the various states and cities, with DOT defraying much of the purchase cost.

To date, at least eight such "pocket-size" screening instruments have been developed by as many companies, and several of the units have been purchased by certain states, after performance tests by the state chemical test control agency. The technical staff of the DOT Transportation System Center at Cambridge, Mass. has devoted much time to checking the performance of most of these portable screening instruments, and have developed a prototype of their own, which they call a DOT Alcohol Screening Device. However, it is not yet being manufactured for sale.

In this subsection, we will briefly describe these eight portable breath alcohol screening instruments, classified in accordance with the type of alcohol detector used. For much of this information we are indebted to technical representatives of some of the manufacturers. In addition, Dr. Walter F. Harriott, of the DOT Transportation Systems Center at Cambridge, Massachusetts, has kindly furnished us with a number of reports of performance studies of these instruments by himself and staff, together with pertinent photographs and drawings.

1. Fuel Cell Type

(a) Alco-Sensor of T.P. Jones and M.R. Forrester[1]. This fuel cell instrument was described in a 1972 paper by Jones and Williams of Wales (60), who stated that, for screening purposes, it is far superior to the disposable detector tubes which we have described in the preceding section. They called their instrument an Alcolyser FCD (Fuel Cell Detector). Subsequently, a modified form of this Alcolyser FCD was produced jointly be Jones and M.R. Forrester, and is called an Alco-Sensor. It is housed in a rectangular case 4" X 2½ X 1" and weighs about five ounces. A fuel cell in the device oxidizes the alcohol in the subject's breath to acetic acid and the resulting electric potential is amplified and read on a drum-type voltmeter. Figure II (See Appendix B) is a schematic drawing of this fuel cell showing its construction and electrical connections, and the course of the breath through the instrument. Figure 12 is a photograph of the Alco-Sensor case. (See Appendix B)

The fuel cell is a small, elongated chamber partitioned horizontally by a plastic membrane (M), which is coated on both sides with catalytic chemicals. The catalyst on the upper surface of the membrane, as seen in Fig. 11, is the cathode, and that on the lower surface is the anode. The lower (anode) chamber of the cell is sealed. The upper chamber of the cell has a

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[1] Mfg. by Intoximeters, Inc., St. Louis, Missouri

volume of 1 milliliter. Just above this 1 ml chamber there is a concave diaphragm-pump which can be held down in the empty position by the SET button above it.

Operation. The SET button is locked in the depressed position, which closes the entrance of the fuel cell and shorts the fuel cell terminals. The subject then exhales as deeply as possible into the breath sampling inlet, with the breath stream by-passing the fuel cell chamber. Near the end of the forced exhalation, the operator partly depresses the READ button. This unlocks the spring-loaded SET button and the diaphragm-pump draws the alveolar air into the fuel cell chamber. After 20 seconds, the READ button is pushed fully down and held in that position for about one minute. This operation of the READ button opens the shorting switch and closes the switch to the 22½ V battery, which furnishes power to amplify the potential from the fuel cell. The amplified current goes to the voltmeter, the indicator of which is a rotating drum beneath a rectangular window. The drum surface has a yellow area and a red area, which are separated by a diagonal line. At zero reading, the window is all yellow, at 50 mg% BAC the red zone covers about one-third of the rectangle, at 100 mg% BAC the rectangle is half red, and with BAC above 100 mg%, the rectangle is more than half, or all, red. In a later model, the rotating disc is replaced by three lights, green (SAFE), yellow (WARN 0.05 to 0.10 BAC), and red (FAIL, above 0.10% BAC).

Since temperature fluctuations within the instrument case will somewhat alter the fuel cell voltage, the diaphragm-pump contains a compensating thermistor, the voltage of which is oppositely affected by temperature changes.

Evaluation Studies of the Alco-Sensor. Mr. M.R. Forrester of Intoximeters, Inc., has kindly furnished us with copies of two unpublished performance investigations with the Alco-Sensor, with permission for us to review them in this chapter.

(i). The first report was by Jacobs and Goodson (61), and is dated January 5, 1973. They used four drinking subjects, with only one blood sample taken from each, but with three or more tests with each of four Alco-Sensor instruments performed very near to the time the venous blood samples were drawn. The four blood samples were analyzed by both ADH and G-C, which methods agreed within 6 to 12 mg%. The average BAC values for the four subjects were, 112 mg%, 113 mg%, 132 mg% and 183 mg%. With the first three subjects, there was a total of 38 Alco-Sensor tests, using four instruments. Seven of these Alco-Sensor readings were below 100 mg%, which means 18% of false negative readings in the BAC zone of 112-132 mg%. Only one instrument gave no false readings. Unfortunately, none of Jacobs and Goodson's

subjects had BAC's below 100 mg%.

(ii). The second evaluation of the Alco-Sensor was reported by Bailey of the University of Wales School of Pharmacy (62) and dated September 27, 1973. In his study, he used five drinking subjects, with fingertip blood employed for alcohol determinations. While we have not seen Bailey's complete data, we have read his summary. He observed no Alco-Sensor readings of above 100 mg%, where the BAC was 80 mg%, or below. With blood-breath pairs where the BAC was close to 120 mg%, one out of ten Alco-Sensor readings was below 100 mg% (10% false negative readings).

(iii). In a preliminary evaluation of one Alco-Sensor instrument, Forney et al. (63) have analyzed 23 blood-breath pairs from 12 drinking subjects, whose BAC's determined by G-C ranged from 62 mg% to 137 mg%. The results are given in Table VI. (See Table VI, Appendix C) This table also gives results of performance tests with the Alco-Sensor made by Harriott et al. of the DOT Transportation Systems Center.

(b) DOT-Transportation Systems Center (TSC) Alcohol Screening Device[2]. A schematic diagram of the construction of the fuel cell used in this instrument is shown in Fig. 13, and Fig. 14 (See Appendix B) in a photograph of the instrument case.

The DOT-TSC Alcohol Screening Device is briefly described in a report by Harriott, dated August 1, 1973 (64). The subject blows through a mouthpiece into the instrument, having a fixed internal resistance and set for a specified time. The first part of the breath is discarded, and the last, alveolar air portion, goes to the catalytic "burner" in the fuel cell. The change in resistance of the system employing a Wheatstone bridge operates a display system of three lights, or a digital recorder, The instrument weighs 2 lbs.-13 oz.

Dr. Harriott kindly sent us the data from his blood-breath correlation study of this instrument, using drinking subjects, but with the BAC estimated by breath analysis with a G-C instrument. These results are summarized in Table VI. (See Table VI, Appendix C)

2. Semi-Conductor Type

(a) Borg-Warner A.L.E.R.T.[3]. The ethanol sensor used in this instrument is the Taguchi Gas-Electric Transducer (TGS), which was invented around 1967 by Taguchi of Japan (65).

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2 Not yet in commercial production.

3 Mfg. by Borg-Warner Corp., Des Plaines, Ill.

Description of the Taguchi Sensor[4]. The TGS is a semi-conductor which has a high electrical resistance in air alone but, with air containing a combustible gas, the molecules of the latter are absorbed on the TGS causing a marked drop in its resistance. Figure 15 (See Appendix B) gives two drawings of the Taguchi gas-electric transducer assembly, one showing the unit with its normal flame-protective screen cover in place, and the other with this cover removed.

The transducer itself is the tiny rectangular block, 4.4 mm X 1.9 mm X 1.5 mm, which is supported by two wires embedded in it and welded to the four vertical terminals passing through the base of the assembly. According to the Taguchi patents (65), and a brochure issured by the manufacturer (66), the TGS is a sintered material made from stannic oxide, SnO_2, plus small amounts of gold or gold oxide. The two iridium-palladium wires passing through the sides of the tiny block have a diameter of about 0.1 mm and each is coiled inside the block to give a resistance of 2 ohms. Current from a 1.0-1.5 V battery is used to heat the transducer block. The electrical resistance of the block itself is measured by a higher voltage bridging the heating wires and leading to a fixed, external resistance load, the ends of which connect to a voltmeter. A decrease in the load resistance of the block thus causes a rise in the voltmeter reading, which is proportional to the concentration of the combustible gas. The presence of 1000 ppm of propane in air is said to increase the conductance of the block 20-fold from that for air alone. The brochure does not give the corresponding reading for ethanol, but 1 mg of ethanol in 2.1 L of air at 34° (≈BAC of 100 mg%) would be a concentration of 260 ppm. In its brochure the manufacturer states:

> "The characteristics of the TGS are not at present sufficiently reproducible to make it suitable for use in laboratory or analytical instruments where high accuracy is required. Still, the TGS has found wide acceptance for use in gas-leak detectors, alcohol detectors, automatic ventilation and fire alarms."

The TGS response is, of course, not specific for ethanol.

The Borg-Warner A.L.E.R.T. is housed in a rectangular box 7.75" X 4" X 2.75" and weighs 2.6 pounds. Figure 16 (See Appendix B) is a schematic drawing of the A.L.E.R.T. showing the route of the exhaled air through the instrument, the detector chamber containing a model #109 TGS, and the electrical circuits and display lights. Figure 17 is a photograph of the instrument case. (See Appendix B)

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[4] Mfg. by Figaro Engineering Inc., Osaka, Japan.

Operation. On pressing the START switch, the purge pump starts, and the READY light should appear in about two minutes, which ends the purge phase. Then the subject exhales deeply through the mouthpiece until the TEST and READY lights go off, the required breath pressure being about 11" of water. Most of the expired air is discarded through the exhaust orifice. At the end of expiration, the 5 ml detector chamber containing the TGS should be filled with alveolar air. The remainder of the test operation is automatic. The voltage reading from the TGS and its connections should be proportional to the ethanol concentration in the alveolar air sample. With BAC of zero to about 49 mg%, the green SAFE light should appear; with BAC between 50 mg% and just below 100 mg%, the increased voltage should extinguish the SAFE light and turn on the yellow WARN light; and with BAC's of 100 mg% and above, the still higher voltage should turn off the WARN light and turn on the red FAIL light. The dry cell batteries in the case are rechargable.

Evaluation Studies of the A.L.E.R.T. One such study was made by Dubowski, whose report is dated October 1, 1973 (67). He used four drinking subjects who consumed sufficient alcohol to reach peak BAC values of around 200 mg%, and who were tested during the declining phase of BAC. The total data include 20 blood samples and 48 tests with the A.L.E.R.T., which represent 48 blood-breath pairs. With 27 of the pairs, the BAC was below 80 mg%, and no A.L.E.R.T. test read above 100 mg% (FAIL), which means no false positive readings in this range. Five of the pairs were in the BAC range of 80 mg% to 110 mg%, and with two of these the A.L.E.R.T. readings was FAIL; the reading was WARN for the other three. With the remaining 36 pairs, the BAC's were above 110 mg%, and a-1 of the A.L.E.R.T. readings were FAIL (no false positive readings). Dubowski's results are included in Table VI. (See Table VI, Appendix C)

In some preliminary blood-breath tests by Forney et al.* with the Alco-Sensor, mentioned above, they also conducted tests with the A.L.E.R.T. For 13 blood-breath pairs, the BAC values ranged from 62 mg% to 109 mg% and all A.L.E.R.T. readings were WARN (no false positive readings). With the remaining 10 pairs, the A.L.E.R.T. reading was WARN for five pairs having BAC's of 115 mg% to 127 mg%, and was FAIL with the other five pairs with BAC's ranging from 115 mg% to 137 mg%. These results mean 50% false negative readings with these 10 blood-breath pairs in the BAC range of 115 mg% to 137 mg%. Table VI gives the data from this study, using 10 mg% BAC intervals.

(b) Ehlers Alcotron[5] (68). This very simple, inexpensive device also employs the Taguchi Gas-Electric Transducer model #109.

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* In half of this series, no blood sample was drawn and the BAC was estimated from the Drunkometer reading with rebreathed air.

5 Mfg. by Electric Products, Vienna, Virginia.

The Alcotron is housed in a rectangular box 4.5" X 2.75" X 1.5" and weighs about 8 ounces. The wire-mesh dome of the Taguchi gas sensor (TGS) (Fig. 15) (See Appendix B) projects through a hole in the lid of the Alcotron case, and the subject simply exhales slowly and deeply upon the exposed portion of the TGS and the maximum reading of the voltmeter is noted. The TGS block is warmed by four pencell batteries in parallel, and current from a 9 V battery passes through the TGS block and then to the voltmeter. At the equivalent of a BAC of 50 mg%, the voltmeter needle should move about 30° to the right of the zero point; at BAC of 100 mg% the needle should be about vertical; and with BAC's above 100 mg%, the needle should be in the section at the right of vertical. A few blood-breath studies with the Alcotron gave erroneously low results, and the battery life was short. A letter from the manufacturer states that an improved model of the Alcotron will soon be available. Also see comment by Reese in Chem. Eng. News of 8/20/73 (68).

3. Catalytic Combustion Type

(a) M.S.A. Alcohalt Detector[6]. This instrument is a modification of the well-known MSA Explosimeter, and their Gasoscope set at % LEL. It operates on the Wheatstone bridge principle, one limb of the bridge being a tiny glowing platinum filament contained in a small metal chamber. By adjusting a rheostat in the opposite limb, the ammeter bridging the twin circuits is zeroed, using air containing no combustible vapor. If the air passing through the chamber contains a combustible vapor, this vapor will burn with the oxygen present, the reaction being catalyzed by the glowing platinum filament. The temperature of the latter will rise, increasing its resistance and unbalancing the bridge, which gives an ammeter reading that is proportional to the concentration of the combustible g gas. Ethanol in the breath is such a combustible vapor.

The readout is made by pass-fail lights set for BAC of 0.10% (100 mg%). The instrument case is shown in Fig. 18 and weighs 3 lbs.-1 oz. (See Appendix B) Figure 19 is a schematic diagram of the working parts of the instrument. (See Appendix B) Performance tests with the instrument, conducted by DOT-TSC, are included in Table VI.

(b) Century System's Breath Alcohol Tester (BAT)[7]. This is also a catalytic combustion type instrument. It weighs 1 lb.-11 oz. Figure 20 is a picture of the instrument case. At the end of a deep expiration, the ammeter reading (in % BAC) is automatic. (See Figure 20, Appendix B) With both this instrument and the MSA Alcohalt, water vapor in the breath gives a false positive reading of about 0.02 BAC, and an adjustment

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[6] Mfg. by Mine Safety Appliances Co., Pittsburgh, Pa.
[7] Mfg. by Century Systems Corp., Arkansas City, Kansas.

must be made to correct for this. Blood-breath correlations made by DOT-TSC are given in Table VI.

4. Electrochemical Oxidation Type.
Alco-Limiter[8]. A technical description of this instrument is given in a 1972 paper by Bay et al. (69), which also includes references to earlier publications on this electrochemical oxidation procedure. Bay stated that this device is not a fuel cell (70). The detector cell contains an anode and a counter electrode, both of which are Teflon-bonded, platinum diffusion electrodes, and also contains a reference electrode. The electrolyte is concentrated sulfuric acid, and a potentiostat maintains the anode at a potential of 0.9 V to 1.5 V. Under these conditions, there is said to be no production of oxygen or hydrogen at the electrodes. The response from the oxidation of ethanol to acetic acid is read on an ammeter, which readings are stated to be proportional to the alveolar air concentration of ethanol. Figure 21 is a schematic drawing of the general construction and operation of the Alco-Limiter, and Fig. 22 is a picture of the instrument case, which weighs 9 lbs.-6 oz. (See Appendix B)

Evaluation of the Performance of the Alco-Limiter. Leavitt et al. of the Transportation Systems Center, U.S. Department of Transportation, have reported (71) a study of the Alco-Limiter using four drinking subjects, with the readings compared with Breathalyzer analyses conducted at the same time. The Breathalyzer readings ranged from 20 mg% to 120 mg%, and the Alco-Limiter readings varied from 30 mg% to 133 mg%. The results of replicate analyses with the Alco-Limiter generally varied less than those with the Breathalyzer. Unfortunately, no blood samples were analyzed in this study, so the results are not too informative, since the Breathalyzer readings are usually about 10% below the actual BAC values, as seen in Table III. Further performance studies with the Alco-Limiter made by DOT-TSC are given in Table VI. (See Table VI, Appendix C)

5. Infrared Light Absorption Type.
G-E Breath Analyzer (BAL-1)[9]. This screening device is somewhat similar to the infrared Omicron breath alcohol instrument described on pp. 28-29. The G-E Breath Analyzer (BAL-1) is pictured in Fig. 23, and its optical schematic is shown in Fig. 24. The BAL-1 weighs about 3½ lbs., its light absorption chamber has a volume of 300 ml., and it has a meter readout. (See Appendix B)

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[8] Mfg. by Energetics Science, Inc., New York, N.Y.
[9] Mfg. by General Electric, Ordinance Systems, Electronics Systems Div., Pittsfield, Mass.

As shown by Table VI, the DOT-TSC blood-breath study with the G-E BAL-1 showed the best correlation of the six screening devices which they tested. However, in Harriott's report (64), he stated:

"The instrument (G-E Bal-1) may only work well with a small temperature differential in the ambient as components are sensitive to temperature".

A brochure on this device published by General Electric reads, in part: "Accuracy - 10% at 0.1% BAC".

Our available information on the performance of these portable devices indicates that, for screening purposes, all but the Alcotron are far superior to the eight types of disposable detector tubes tested by Prouty and O'Neill, and presented in Table V. (See Table V, Appendix C)

In our opinion, whatever tolerance is permitted for these screening devices should be limited to some false positive readings in the BAC zone of 80 mg% to 90 mg%, where the lower legal limit of "under the influence" is 100 mg%. This would require some more quantitative breath or blood analyses, but is much more in the interest of justice than using the screening devices to release subjects with true BAC values above 100 mg%.

III. FACTORS WHICH MAY CAUSE APPARENT, OR REAL, ERRORS IN ESTIMATING BAC FROM BREATH ANALYSIS.

A. USE OF VENOUS BLOOD FROM THE EXTREMITIES FOR BLOOD-BREATH CORRELATIONS. At the end of drinking, the BAC of the arm or leg veins is usually much lower than the arterial BAC, with a maximum arterial/venous BAC differential sometimes greater than 2/1 (72, 73). At all times, the arterial BAC is practically identical all over the body. The reason for this lag in BAC in the veins of the extremities is that the rate of blood flow per pound of tissue is very much less in the arm and leg than in brain, liver and kidney. As a result, alcohol storage equilibrium in the extremities is usually not complete for ½ to 1½ hours after the end of drinking, and the blood returning from the limbs has a lower BAC than that in the arteries. When the limb tissues have finally stored their quota of alcohol, the BAC is equal in the limb veins and arteries.

On the other hand, the rate of blood flow per pound of brain is so great that, at all times, there is essential alcohol equilibrium between arterial blood and brain. Since the pharmacological effect of alcohol is primarily due to its concentration in the brain, during the alcohol absorption period arterial blood is far better

than venous blood from a limb for estimating the concentration of alcohol in the brain and for proof of intoxication. The arterial BAC also controls the concentration of alcohol in the alveolar air; so, for estimating the concentration of alcohol in the brain and diagnosing intoxication, during the absorption period the results of breath analysis are far more reliable than analysis of venous blood from a limb. This matter has been reviewed in publications by Harger and Forney (6,7). The above statements have been confirmed in a recent study by Gostomyzk et al. using rabbits (74). Part of their data are summarized in Fig. 25. (See Appendix B)

Thus, during the absorption period, the BAC estimated from breath analysis frequently greatly exceeds the BAC determined by analysis of venous blood from the arm or leg. The cubital (elbow) vein is the most common source of blood samples for alcohol analyses, and these analyses may give grossly erroneous conclusions regarding intoxication. The lag in BAC of the cubital vein as compared with the BAC estimated from breath analysis, which occurs soon after the end of drinking, is seen in Figs. 6 and 9. (See Appendix B)

That the use of cubital vein blood may lead to a faulty diagnosis regarding the question of alcohol intoxication, is shown by a study published by Brinkmann et al. in 1973 (75). Eighteen subjects were examined by experienced police physicians immediately after ingesting about 1.15 gm. of alcohol per kg in 20 minutes. Although the cubital vein BAC values ranged from only 15 mg% to 120 mg%, averaging 70 mg%, nine had symptoms of mild intoxication and the other nine showed frank intoxication. The chief data from this study are given in Table VII. (See Table VII, Appendix C) The results of these BAC values of the subjects' cubital vein blood immediately after drinking would have freed all but two in most jurisdictions, but breath analysis would probably have resulted in charges of intoxication for all of the subjects.

For these 18 subjects, the cubital vein BAC peaks were reached in 10 to 90 minutes, averaging 45 minutes, after the end of drinking. These BAC peaks varied from 130 mg% to 180 mg%, with an average of 146 mg%, and the diagnoses were: two, mild intoxication; and sixteen, frank intoxication. Having reached its peak, the cubital vein BAC was probably close to the arterial BAC, with both furnishing reliable evidence in the matter of intoxication.

B. RESIDUAL ALCOHOL IN THE TISSUES AND FLUIDS OF THE ORAL CAVITY IMMEDIATELY AFTER DRINKING. In 1971, SCIENCE published a communication from Spector (76) entitled, "Alcohol Breath TEsts: Gross Errors in Current Methods". In it, Spector reported the "discovery" that holding alcohol solutions ranging from 6% to 25% (v/v) for some minutes in the oral cavity of non-drinking subjects, who then expectorated the solution, resulted in very high Breathalyzer readings

immediately afterward, which readings rapidly decreased to zero in 15 to 20 minutes. Spector was apparently not aware that this phenomenon was reported 44 years earlier by Bogen (77), who recommended the avoidance of any error from residual alcohol in the mouth by waiting 15 minutes after drinking before determining the breath alcohol concentration for medicolegal purposes. A 1938 paper by Harger et al. (37) reported confirmation of Bogen's finding and agreement for the necessity of the waiting period between the end of drinking and sampling the breath for analysis.

A later issue of SCIENCE contained a communication by Edwards (79) stating that Spector had "raised a false alarm", because for 40 years this waiting period of 15 minutes had been universally practiced by operators of breath alcohol instruments. Edwards pointed out that Spector had ignored, or failed to read, a statement in a publication quoted by the latter, namely, the American Medical Association 1970 manual on chemical tests for intoxication (8), which statement reads as follows:

> "A period of approximately 15 minutes after the ingestion of alcohol, or its regurgitation, must elapse before the sample (of breath) is obtained to insure elimination of the possible effects of any residual mouth alcohol."

C. LOSS OF ALCOHOL FROM CONDENSATION OF WATER VAPOR. In their studies of the distribution of alcohol between water and air, where the equilibrator temperature was above that of the room and the equilibrated air was analyzed outside the constant temperature bath, Thomas (80), Dobson (81), and Harger et al. (27) all emphasized that the temperature of the exit tube must be kept equal to, or slightly above, that of the equilibrator. This is because the equilibrated air is saturated with water vapor and a drop in its temperature will result in the condensation of water with removal of some of the alcohol. The same precaution should be used for breath, which leaves the mouth at about 34°, saturated with moisture.

While the sampling chamber of most breath alcohol instruments is kept at a temperature of about 50°, the mouthpiece on the sampling tube is usually not pre-warmed and collects droplets of condensed water during the expiration. Harger and Forney (83) have found that, with such a mouthpiece at 23°, the temperature of the exhaled air dropped by an average of 1.6° on passing through the mouthpiece. Ettling and Adams (84) have made some determinations of the weight of water condensed in the mouthpiece and rubber sampling tube, using an equilibrator at 37°. They concluded, "There is some question of loss of the sample by condensation of water in the mouthpiece, but any error will be on the low side of the true blood alcohol value".

D. EXCESS INTRAPULMONARY GAS PRESSURE. With several of the breath alcohol instruments, the air passage between the lips and the gas-sampling chamber is sufficiently constricted to require an excess gas pressure in the oral cavity and lungs corresponding to a water column of 10" to 50" of water. In testing the instrument with an equilibrator, if the excess gas pressure in the equilibrator is equivalent to 21" of water, the equilibrated air will expand 5% to attain atmospheric pressure, causing its alcohol concentration and the instrument reading to decrease approximately 5% (one atmosphere = 407" of water). While we have not tested the effect of excess intrapulmonary pressure on the alcohol concentration of alveolar air samples from living subjects, we feel that the error will be the same as that resulting with an equilibrator. This question should receive some study, using accepted, accurate methods for determining the alcohol concentration in the alveolar air sample.

E. BREATH ALCOHOL ANALYSES CONDUCTED AT LOW BAROMETRIC PRESSURES. This matter was investigated by Leonelli et al. (85), using a low-pressure test chamber to give simulated altitudes of 5,000' and 10,000', which would correspond to barometric pressures of about 630 mm Hg and 520 mm Hg, respectively. In their study in the low-pressure chamber, they employed a Breathalyzer to analyze in-vitro equilibrated air and also the breath of six drinking subjects, taking blood samples from the subject for later alcohol analyses. They reported no significant differences between the results obtained in the low-pressure chamber from those conducted at the local altitude of about 700 feet. However, their explanation for the uniformity of their results is erroneous. They said:

> "The real basis for the validity of the instrument at altitude lies in the fact that the subject must lift an 87-gram weight in the collecting chamber as he expires. The chamber traps a constant volume for each sample and the weight assures sample collection at consistently the same pressure."

The model 900 Breathalyzer which they used has a vertical collection chamber with a diameter of 1.375", and a calculation will show that the excess pressure required to raise the 87 g piston (59 gm/sq. in) is only about 7 mm Hg. If Leonelli et al. will review Henry's Law and Dalton's Law of partial pressures, they will find that the vapor pressure of ethanol from a water solution having a specified temperature and ethanol concentration, is constant and is independent of the total gas pressure in the enclosure. In other words, their results are simply a demonstration of the validity of these two laws.

F. PHYSICAL EXERCISE AND/OR HYPERVENTILATION. In 1941, Jetter and Forrester (86) reported a study of the effect of extreme hyperventilation on the results with the original Intoximeter, which employed the alcohol-CO_2 ratio. When their subjects hyperventilated almost to the point of collapse, the resulting Intoximeter readings rose 50% to 100% above the values just before the hyperventilation, but returned to normal in about 2½ minutes. Here the chief effect was due to the marked decrease in the CO_2 content of the breath.

A 1965 paper by Monnier (87) describes a study in which drinking subjects were tested with the Breathalyzer before, and just after, running rapidly upstairs and down. Immediately after one up-and-down trip, the Breathalyzer reading was decreased 11% to 14%, and just after two trips the decrease was 22% to 25%. No data are given for recovery time.

Schmutte et al. published a paper in 1973 (88) on the effect of a short period of vigorous exercise and/or hyperventilation on breath alcohol concentration as determined with the G-C Intoximeter, with the results compared with blood alcohol analyses. They used 27 subjects whose drinking periods were 1, 2 or 4 hours. Their subjects were divided into four groups as regards experimental procedure, as follows:

(a) 5 subjects; resting, and following hyperventilation while sitting.

(b) 5 subjects; resting, and following hyperventilation while standing.

(c) 6 subjects; resting, and followed by a 100 meter sprint and hyperventilation.

(d) 11 subjects; resting, and followed by knee-bending (setting-up exercises) plus hyperventilation, with both tests conducted at six intervals during a period of about 2½ hours after the end of drinking.

The results for the four types of experiment are lumped together in two scatter diagrams of the type given in Fig. 6, (See Appendix B) with one diagram for the resting phase and the other for the exercise and/or hyperventilation experiments. Comparison of the two diagrams furnishes little information regarding the effect of exercise and/or hyperventilation, but the trends of scattering do show that, in both types of experiment, the average breath value was perhaps 15% below the corresponding blood value.

Schmutte et al. do give complete data for 6 of the 11 subjects in group (d). For one of these subjects, the data are presented as a graph correlating the blood and breath results at six intervals

during the period of 150 minutes after the end of drinking. This graph is reproduced as our Fig. 24. (See Appendix B) With this subject, the BAC rose to a sort of plateau, which persisted from about 40 minutes to 90 minutes after the end of drinking, indicating continued absorption of alcohol during this period. As seen in Fig. 26, (See Appendix B) exercise plus hyperventilation caused a distinct drop in the breath alcohol values, which decrease was about 20 mg% during the first 85 min., and about 10 mg% from 90 min. to 120 minutes. Please note that the resting breath alcohol values considerably exceed the cubital vein BAC values during the absorption period, but the two agree quite well during the remainder of the experiment. The authors call this graph "characteristic curves", but the lines joining the G-C Intoximeter readings do not constitute a true curve, but simply designate six pairs of Intoximeter readings each without, and with, exercise plus hyperventilation.

The complete data for five other subjects of group (d) are given in a table. The drinking period for these subjects was probably 4 hours, because the blood alcohol peaks had been reached, or almost reached, at the time of the first test, which was 10 min. after the end of drinking. In the resting tests, the average deviation of the Intoximeter readings from the BAC values for the five subjects ranged from -3 mg% to -28 mg%, the overall average being -16 mg%. Exercise plus hyperventilation caused slight further negative deviations in the breath values, ranging from 0 to -11 mg% and averaging -7 mg%. Thus, exercise plus hyperventilation caused only slight changes from the resting values for these five subjects.

This paper gives no data on the time required for recovery from the effects of exercise and/or hyperventilation.

G. CHRONIC BRONCHOPULMONARY DISEASE. Haas and Morris (89) have conducted a drinking study with 24 male subjects who were hospitalized for chronic obstructive pulmonary disease. All had various degrees of lung impairment as shown by five ventilatory tests.

Each subject ingested 60-70 gm of alcohol during a period of about one hour. At intervals of approximately 40 min., 70 min., and 100 min. after the end of drinking, each subject was given a Breathalyzer test and a blood sample was taken from the brachial artery by means of an indwelling catheter. The bloods were analyzed by a commercial laboratory, using a G-C method.

With 21 of the subjects, the average deviation of the Breathalyzer reading from the blood analysis ranged from -23 mg% to +12 mg%, the overall average being -2 mg%. For the three remaining subjects, the average Breathalyzer reading deviated -47 mg%, -31 mg%, and -36 mg% from the blood value, but these three subjects were tested on the same day, and the authors suggested that there might have been some common analytical error on that day.

Haas and Morris concluded:

> "Pulmonary function impairment had no systemic effect upon breath-alcohol analysis. It is concluded that the Breathalyzer method is valid in the presence of chronic bronchopulmonary disease."

IV. PROPOSED STANDARDS OF ACCURACY FOR ANALYTICAL METHODS WHICH DETERMINE BAC BY DIRECT ANALYSIS OF BLOOD, OR BY ESTIMATION FROM BREATH ANALYSIS.

A. GENERAL CONSIDERATIONS. All analytical procedures for determining the concentration of various compounds in body materials have some limit of accuracy, yielding errors which may be very slight, or may be sizeable. Most authors of such analytical methods report the observed deviations of the analytical results from perfect accuracy as the standard error, which is also called the probable error and the standard deviation.

When a layman on the bench or jury is told that a particular analytical method for alcohol in body materials has a probable error of only ± 3.0%, this value is perhaps more impressive than the facts warrant. True, the layman knows that, when the television meteorologist predicts "a 50% probability of rain during the next 24 hours", this prediction will be correct regardless of whether there is a deluge, a sprinkle, or no rain at all. What the layman usually does not know is that, on the average, only about two-thirds of the analyses by this particular analytical method will have an error within zero to ± 3.0% (one sigma), while almost one-third of the analyses will have errors between 1 sigma and 2 sigma (± 3.0% to ± 6.0%), and one analysis in 20 will have an error between 2 sigma and 3 sigma (± 6.0% to ± 9.0%). Therefore, in Table III, (See Table III, Appendix C) which gives the results of 27 blood-breath correlations involving 8 breath alcohol instruments, we have classified the deviations between BAC from direct analysis of blood and BAC estimated from breath analysis into four categories, namely, within ± 5%, within ± 10%, within ± 15%, and beyond ± 15%.

For BAC analytical procedures, the standard error (S.E.) is often expressed as an arithmetical deviation, expressed in mg% or its equivalent, but the S.E. is also frequently reported as per cent deviation. We prefer the latter unit because, with most scatter diagrams correlating the analytical results with the true results, or with the results by a second analytical method, the percent deviation is far more constant than the arithmetical deviation. Thus, with a standard arithmetical error of 10 mg%, for BAC values of 50 mg%, 100 mg%, and 200 mg% the percent errors would be, respectively, 20, 10 and 5.

B. ACCURACY OF METHODS FOR DIRECT ANALYSIS OF BLOOD AND OTHER BODY LIQUIDS AND TISSUES. On pp. 2 to 12 of this chapter, we have reviewed fourteen current procedures for direct analysis of blood and other body fluids and tissues. These comprise ten G-C methods, one osmometer method, and one method using aeration plus Breathalyzer analysis. In twelve of the papers, the authors have given an estimate of the accuracy of their particular methods, with the estimate of accuracy reported as standard error (S.E.), or as maximum error (M.E.). Table VIII summarizes these estimates by the authors of the twelve analytical methods. (See Table VIII, Appendix C)

In Table VIII, the estimated degree of accuracy is given as S.E. for two of the methods, and as M.E. for the other ten methods. In two of the latter, the M. E. is stated in mg% (arithmetical) deviations. For the remaining eight analytical methods, the M.E. values are in percent and range from +12% to -17%, with an overall average M.E. of about ± 7%.

Proposed Standard of Accuracy. In a 1971 paper by Gruner and Ludwig (97) dealing with the subject of back-calculation of BAC, the authors propose a standard deduction of 20 mg% from the reported BAC to correct for possible analytical error. From the results given in Table VIII, the "discount rate" proposed by Gruner and Ludwig seems logical, but slightly excessive.

C. ACCURACY OF ANALYTICAL METHODS WHICH ESTIMATE THE BAC FROM ANALYSIS OF ALVEOLAR AIR, OR REBREATHED AIR. Table III, (See Appendix C) summarizes the results of 27 blood-breath alcohol correlation studies, involving eight quantitative breath alcohol instruments. In eight of these studies (Nos. 1, 3, 10, 14, 15, 18, 25-b, and 27), the breath estimate and the direct analysis of the blood agreed within ± 10% for 70% to 87% of the blood-breath pairs, the average fraction being 79%. In six of these eight studies, the fraction of the total blood-breath pairs in which the deviation was beyond ± 15% ranged from only 2% to 9%. The six quantitative breath alcohol instruments used in these eight studies, where 70% to 87% of the blood-breath pairs agreed within ± 10%, were: Alcometer; Alco-Analyzer; Alco-Tector; Breathalyzer, using rebreathed air; Drunkometer, using rebreathed air; G-C Intoximeter, using direct analysis; and G-C Intoximeter, using delayed analysis of the Indium capsules. From inspection of the data in Table III, we have estimated that the standard deviation for these eight above-mentioned correlations to be between ± 8% and ± 10%.

In our opinion, the greater blood-breath deviations reported in the other 19 correlation studies listed in Table III are due to factors A, C or D described on pp. 34-37 of this chapter.

Proposed Standards of Accuracy for Quantitative Breath Alcohol Instruments. Two such proposals have been published:

1. California Advisory Committee on Evaluation of Instruments and Related Accessories for Breath Alcohol Analysis. The standards of accuracy proposed by this committee were listed in a report by D. M. Morales of the Clinical Chemistry Laboratory, California State Board of Health, dated April 6, 1972 (51).

   The California committee adopted two standards of accuracy for quantitative breath alcohol instruments:

(a) Performance of the Breath Alcohol Instrument in Analyzing Air Containing Known Concentrations of Alcohol Vapor. A specified concentration of alcohol vapor in air is produced by passing the air through an equilibrator containing the correct percent of dissolved alcohol in water, and held at 34° C. The tolerance of accuracy adopted by the California committee for the reading of the breath alcohol instrument is ± 0.010% (± 10 mg%) BAC for concentrations of alcohol vapor at, or above, 1 mg per 2.1 L of air, the latter being equivalent to a BAC of 0.10% (100 mg%). In using the breath alcohol instrument to analyze air equilibrated with a water solution of alcohol, the results are reported as the BAC reading of the instrument, expressed in three digits to the right of the decimal point.

(b) Performance of the Breath Alcohol Instrument in Estimating the BAC. Here the evaluation procedure involves the use of drinking human subjects from whom samples of blood and alveolar air are taken about simultaneously at specified intervals, beginning at least one hour after the end of drinking. The bloods are analyzed by the Kozelka-Hine method or by a modified Parker G-C procedure. The alveolar air is analyzed with the breath alcohol instrument being evaluated. The BAC values from the analyses of blood and breath are first expressed to three digits to the right of the decimal point, but the third digit is dropped before the results are correlated. This is because California regulations require the reporting of BAC to two significant digits only, which calls for "rounding down" the third digit. Thus, two BAC results of 111 mg% and 119 mg% would both be reported as 110 mg% (0.11%), giving the second individual the benefit of 9 mg% BAC. To compensate for this built-in tolerance in the state regulations, the California committee adopted a tolerance of ± 20 mg% (± 0.020%) for the correlation of blood and breath analytical results in the evaluation of a given breath alcohol instrument and comprising BAC values at, or above, 100 mg% (0.10%).

A second report of the California committee, dated February, 1974 (52) states that, based on satisfactory results from the above-mentioned testing procedures, the California committee had approved for use in that state the following quantitative breath alcohol instruments: G-C Alco-Analyzer; Breathalyzer, Models 400 and 900; G-C Intoximeter, for direct analysis, or for delayed analyses of alveolar air samples in the Indium capsules; and Intoxilyzer, Model 4011.

2. U.S. Department of Transportation and U.S. National Bureau of Standards, DOT-NBS, Proposals. These proposed performance standards for quantitative breath alcohol instruments are reported by W. Y. Howell in a federal publication dated November 3, 1973 (98). These standards represent a cooperative study by the DOT and the NBS. Two standards are suggested:

(a) Performance of the Breath Alcohol Instrument in Analyzing Air Containing Known Concentrations of Alcohol Vapor. For this type of analysis, the standards of accuracy proposed for three concentrations of alcohol in air are:

0.5 mg/2.1 L	± 10%
1.0 mg/2.1 L	± 5%
1.5 mg/2.1 L	± 5%

(b) Performance of the Breath Alcohol Instrument in Estimating the BAC. The procedure for evaluating the accuracy of the breath alcohol instrument in predicting the BAC is essentially the same as that of the California committee, namely the use of drinking human subjects with correlation of the blood-breath analytical results. However, the DOT-NBS evaluation of the results calls for the determination of the line of regression (bias) for all eight of the blood-breath pairs specified in the proposed procedure, with the deviations measured from this line. With seven of the eight pairs, no deviation may exceed ± 20 mg%. This communication does not list any quantitative breath alcohol instruments which have been approved by the DOT-NBS.

3. The Hamburg (W. Germany) Report Questioning the Reliability of Quantitative Breath Alcohol Instruments. Since the results of blood alcohol analyses constitute the only admissible chemical test evidence in prosecutions for drunk driving in the Hamburg area of W. Germany, the senate of Hamburg created a commission to report on the possible merits of breath alcohol procedures. The 15-page report of the commission is in German and is dated April 26, 1973 (59). Our somewhat free translation of the title follows:

"The Reliability of Methods of Breath Alcohol Analysis for Estimating the Blood Alcohol Concentration in Forensic Cases".*

The authors of this report are: J. J. Lamprecht, a senate director, and K. Lauschner, counsel for the Hamburg senate. While these two men are evidently not scientists, the conclusions which they present in the report are apparently based on the advice of certain staff members of the Institute of Forensic Medicine of the University of Hamburg, the director of which is Dr. W. Janssen.

Pages 3-5 of the report deal with a study of a recent modification of the Grosskopf Alcotest screening device. We have reviewed this portion of the Hamburg report on pp. 22-23 of this chapter.

Certain scientific evidence regarding the reliability of a few quantitative breath alcohol instruments is briefly considered on pp. 5-7 of the report. The Breathalyzer and Alcolinger Automatic are mentioned, with the comment that the latter is simpler and technically superior to the former, but the commission arbitrarily rejected both instruments on the ground that the dichromate-H_2SO_4 alcohol reagent is not absolutely specific for ethanol, although they did mention the 1970 study of the Alcolinger Automatic by Bonte et al. (46), which study we have reviewed on pp. 16-17 of this chapter.

The only blood-breath correlations with any quantitative breath alcohol instrument which were seriously considered by the commission are two performance studies of the G-C Intoximeter, one published by Schmutte et al. in 1972 (50) and a second published by Schmutte et al. in 1973 (88). We have reviewed the first paper by Schmutte et al. on pp. 18-19 of this chapter and the second paper by Schmutte et al. on pp. 38-39.

(a) Chief Conclusions in the Hamburg Report. These are briefly listed below:

(i) The commission's most serious criticism of breath alcohol instruments is that during rising BAC they give higher BAC estimates than the BAC values obtained by analyzing cubital vein blood. The report admits that there may be serious arteriovenous BAC deviations during the absorption period, but since their legal regulations specify the concentration of alcohol in blood, which is always cubital vein blood, they felt that the higher BAC values estimated from breath analysis during active absorption would be legally unfair to the arrested driver.

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* A brief review of this Hamburg report was published in the J.A.M.A. of November 26, 1973 (99).

(ii) While the commission would apparently accept a maximum divergence of ± 10 % between the breath instrument reading and the direct analysis of blood, they stated that this requirement was met by only 117 of the 179 blood-breath pairs in the G-C Intoximeter study published by Schmutte et al. in 1972 (50).

Therefore, the commission concluded that the G-C Intoximeter should not replace direct blood analysis in their jurisdiction. (However, the G-C Intoximeter reading exceeded the venous BAC by more than 10% in only 11 of the 179 blood-breath pairs).

(iii) While blood samples may be stored for months without alteration of alcohol content, this cannot be done with breath samples.

(iv) Under West German law, blood samples may be taken from the accused driver without his consent, but there is no such provision for obtaining breath samples.

(v) Active cooperation of the subject is required to properly analyze his breath, and with comatose subjects breath analysis is impossible.

(vi) The quantitative breath alcohol instruments are too expensive, cumbersome, and fragile to be routinely carried in a police vehicle.

(vii) There appears to be no scientific grounds for recommending that breath alcohol procedures should replace the official blood alcohol testing program in the Hamburg area, or even be used for screening purposes.

(b) Comments on the Hamburg Report. To us there appears to be certain defects in the conclusions of the Hamburg commission:

(i) Limited Scientific Basis for the Conclusions Reached. The relevant scientific data considered by the commission comprise just one study of 18 subjects, using a 1971 model of the G-C Intoximeter (50), which had been presented to Dr. Janssen by the manufacturer. The second study by Schmutte et al. dealt with the effects of hyperventilation and/or vigorous exercise on the instrument readings, and no intoxicated person would have sufficient presence of mind to use these antics to obtain a more favorable G-C Intoximeter reading, even if permitted to do so by the operator of the instrument. As mentioned on pp. 17-19 of this chapter, the 1971 G-C Intoximeter has recently been much improved and has been approved by the California evaluating committee. Furthermore, an inspection of Table III will show that there are at least six other breath alcohol instruments which were found to estimate the BAC with reasonable accuracy, most of which were available for

testing by Schmutte et al.

(ii) Storage of Breath Samples. Contrary to the commission's conclusion No. iii, methods are now available for storing the alcohol from breath samples, or preserving the breath itself. On this matter, see pp. 13-14 and pp. 17-18 of this chapter.

(iii) Possibility of False Conclusions from Using Cubital Vein Blood During Active Absorption. We have discussed this matter on pp. 34-35 of this chapter. As long as the Hamburg authorities persist in using cubital vein blood, they cannot expect agreement between these results and those of breath analysis, during the period of rising BAC. Here, the error is with the venous blood, and not with the breath analysis. Four recent papers by members of the technical staff of the Hamburg Institute of Legal Medicine all confirm that the use of cubital vein blood in medicolegal cases during rising BAC does, indeed, free many definitely intoxicated drivers. These four papers, with the year of publication, are: Naeve and Brinkmann, 1971 (100); Brinkmann et al., 1972 (101); Brinkmann et al., 1973 (75); and Naeve et al., 1974 (102).

(iv) Significant Discrepancies in the BAC of Bilateral Veins. In a 1971 paper (103), Naeve et al. describe a study in which 10 subjects ingested alcohol slowly during 1½ hrs. to give BAC values of 26 mg% to 142 mg% one hour later, at which time they ingested alcohol, 1 gm/Kg, in 10 minutes. Following this "sturztrunk", at 11 intervals during the next 2½ hours blood samples were simultaneously drawn from the cubital veins of the right and left arms and analyzed for alcohol by a modified Widmark method.

Of the 107 pairs of blood from the two arms, in 76 of the pairs the BAC values agreed within ± 7%, while with each of the remaining 31 pairs there was a significant difference in the BAC of the right and left cubital veins. On an arithmetical basis, these 31 veno-venous deviations ranged from 10 mg% to 36 mg%, averaging 20 mg%. A summary of the data from this study is given in Figure 27. (See Appendix B)

In Fig. 27, we have drawn horizontal lines to more easily estimate the magnitude of the 31 significant veno-venous differences, and also to express the deviations in percent. According to our calculations, the latter ranged from 7% to 21%, with an average of 12.5%.

When these percent deviations are classified in the manner used for the breath alcohol instruments in Table III, the correlation for the 107 veno-venous pairs becomes: within ± 7%*, 71%; within ± 10%, 84%; within ± 15%, 93%; and beyond ± 15%, 7%. The second figure for each bracket is the per cent

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* Naeve et al. list no veno-venous deviations below 10 mg%, which would be about 7% for the one deviation of 10 mg%.

of the 107 veno-venous pairs in that bracket. If the reader will compare these veno-venous deviations with the blood-breath deviations listed in Table III, he will see that, in the simple matter of predicting the BAC of the left cubital vein from that of the right C.V., or vice versa, the accuracy reported by Naeve et al. is no better than that of a few of the breath alcohol instruments in estimating the BAC. While the ten-minute rapid drinking period ("Sturztrunk") used by Naeve et al. is abnormal for most persons, we should emphasize that the significant veno-venous BAC deviations continued almost unabated for 2½ hours after the "sturztrunk". These findings, along with those of other investigators of variations of BAC in the vascular system do demonstrate that, at some times, the BAC does not have a Gibralter constancy. Also, with some of the blood-breath deviations listed in Table III, the value might have been different if the blood sample had had been drawn from the opposite arm vein.

Three years after the above-mentioned paper by Naeve et al. appeared, Teige et al. (104) reported an extensive follow-up study of this matter of veno-venous BAC deviations, which they claimed does not confirm the findings of Naeve et al. However, Tiege et al. did not duplicate the conditions used by Naeve et al. The alcohol dosage ranged from 1.0 gm/kg/ to 1.38 gm/kg and the drinking time varied from 8 minutes to 39 minutes. Each subject's forearms were immobilized by being held to the arms of his chair, and indwelling catheters remained in the cubital veins during the blood-sampling period of two hours to four hours, with blood samples drawn at 1 minute, or 2 minute, intervals. In the study of Naeve et al., one of a subject's arms may have been exercised more than the opposite limb, creating a more rapid blood flow to that limb, causing the forearm tissues to store alcohol more rapidly than occurred in the tissues of the opposite arm. This could cause a difference in the BAC of the venous return of the two arms. Also, the indwelling catheters may have somewhat impeded the venous return from both arms.

At any rate, the study by Teige et al. covered 667 veno-venous pairs, and the deviation for 94% of the pairs was within ± 8 mg%. With 6% of the pairs, the deviations ranged from ± 9mg% to ± 16mg%. The complete data for three of the subjects are tabulated, showing the BAC peaks for these subjects to be 116 mg%, 170 mg% and 126 mg%. With one subject, the paired samples read 112 mg% and 110 mg% at 30 minutes, fell to 92 mg% and 96 mg% at 33 minutes, and then rose to 110 mg% and 108 mg% at 44 minutes. The maximum change was 20 mg% in three minutes, which indicates at least some inconstancy in cubital vein BAC.

(v) Concluding Comment Regarding the Hamburg Report. It is to be hoped that the Hamburg forensic scientists will conduct further studies with later models of the G-C Intoximeter, and

with several other breath alcohol instruments, with the results compared with direct analyses of arterial blood or, at least, with fingertip blood, but not with cubital vein blood. For the breath alcohol analyses, they might try rebreathed air, since it gave about the best correlations with blood in the data listed in Table III.

APPENDIX A

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(See footnote *)

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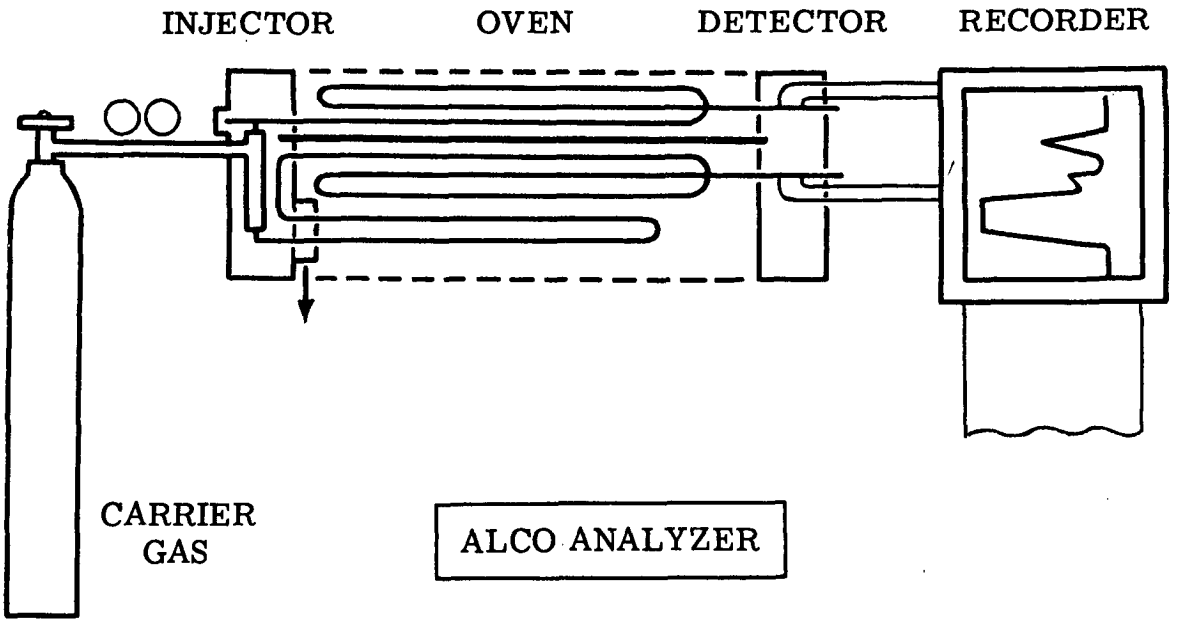

Fig. 1. Schematic drawing of the Luckey Alco-Analyzer. From Shupe and Pfau (40).

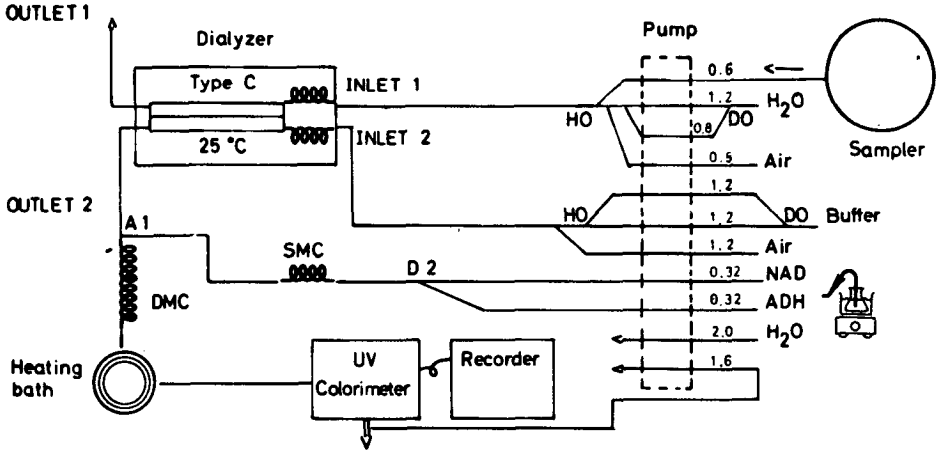

Fig. 2. Schematic drawing of automated apparatus for determination of alcohol in blood or urine by ADH procedure, and employing dialysis. From Goldberg and Rydberg (29).

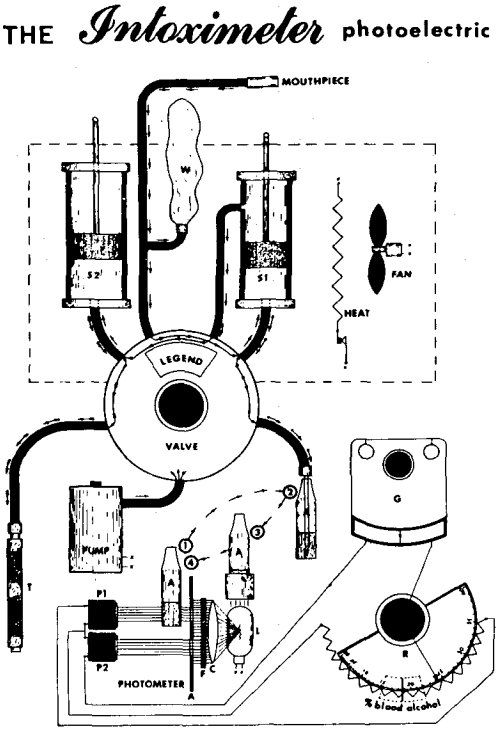

Fig. 3. Schematic drawing of the G. C. Forrester Photoelectric Intoximeter. (W), Plastic bag for discarding first portion of exhaled air. (S1) and (S2), Metal cylinders for collecting samples of alveolar air. (T), Alcohol absorption tube containing snhydrous $Mg(ClO_4)_2$. From Borkenstein et al. (78).

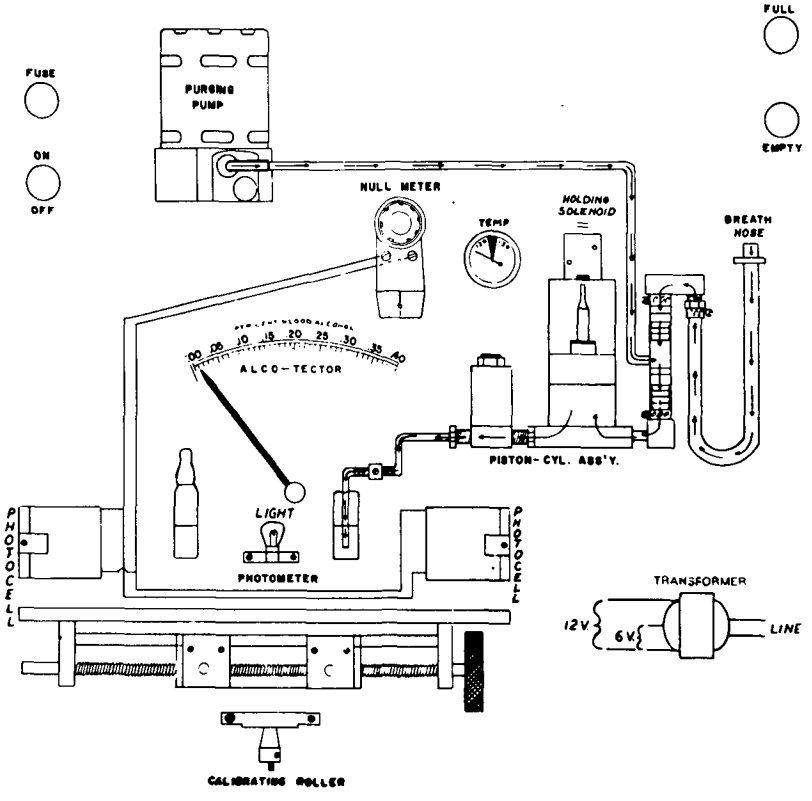

Fig. 4. Schematic drawing of Alco-Tester. From Shupe and Pfau (40).

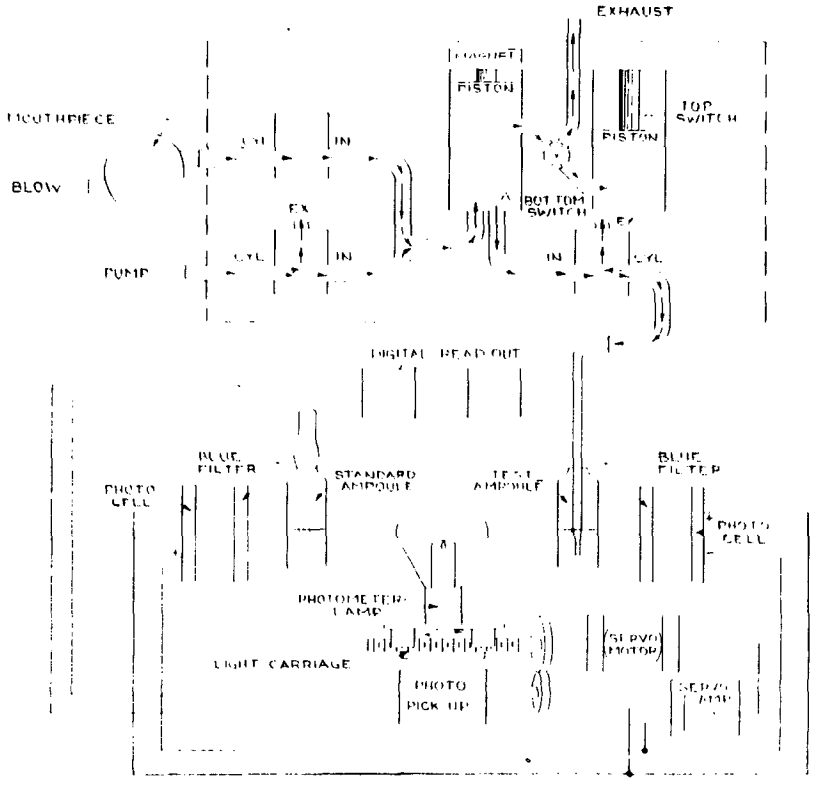

Fig. 5. Schematic drawing of Borkenstein Model 1000 Breathalyzer, which is almost fully automated. From Model 1000 Breathalyzer Operator's Manual, Smith & Wesson Electronics Co., Eatontown, N. J.

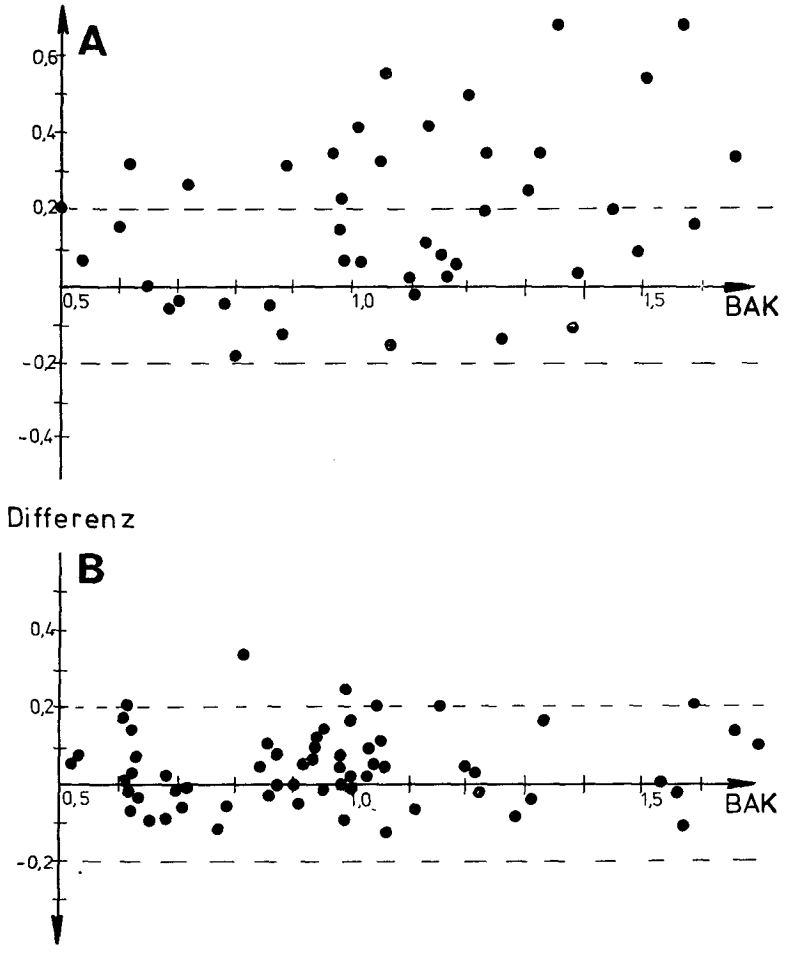

Fig. 6. Deviations of Alcolinger Automatic readings from cubital vein BAC of 22 subjects, with the blood-breath pairs taken at five time intervals after an alcohol intake of 1.0 to 1.5 gm/kg during 60-70 minutes. (A) 20 min., and 50 min. after end of drinking. (B) 80 min., 110 min., and 140 min. after end of drinking. The BAC (BAK) and breath deviation scales are in o/000. To translate these values to mg%, multiply by 100. Breath> blood deviations are above the BAK line, and breath <blood deviations below this line. From Bronte et al. (46).

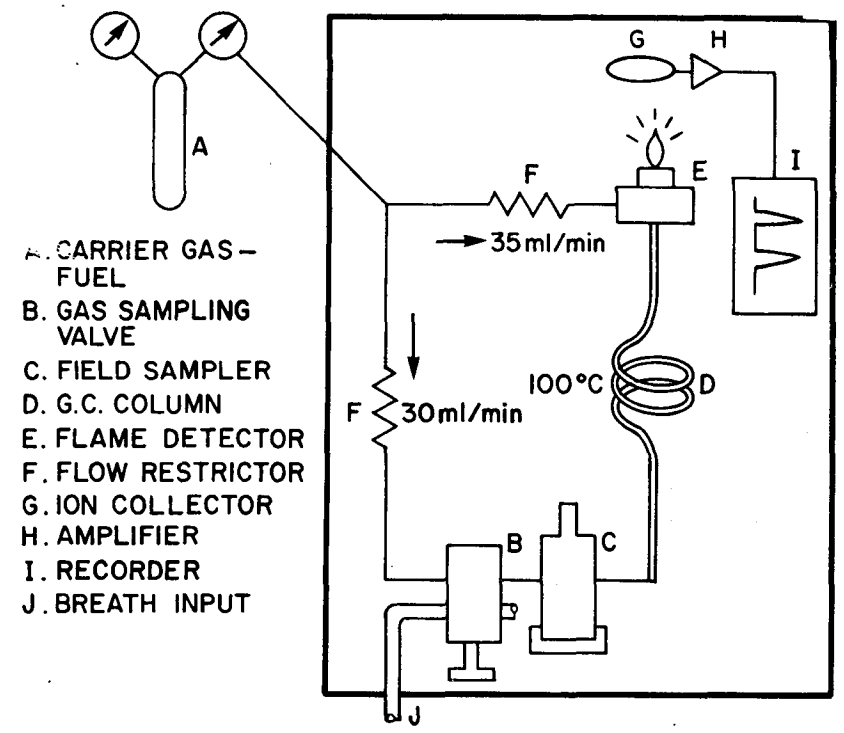

Fig. 7. Schematic drawing of the G-C Intoximeter of M. R. Forrester. From Penton and Forrester (47).

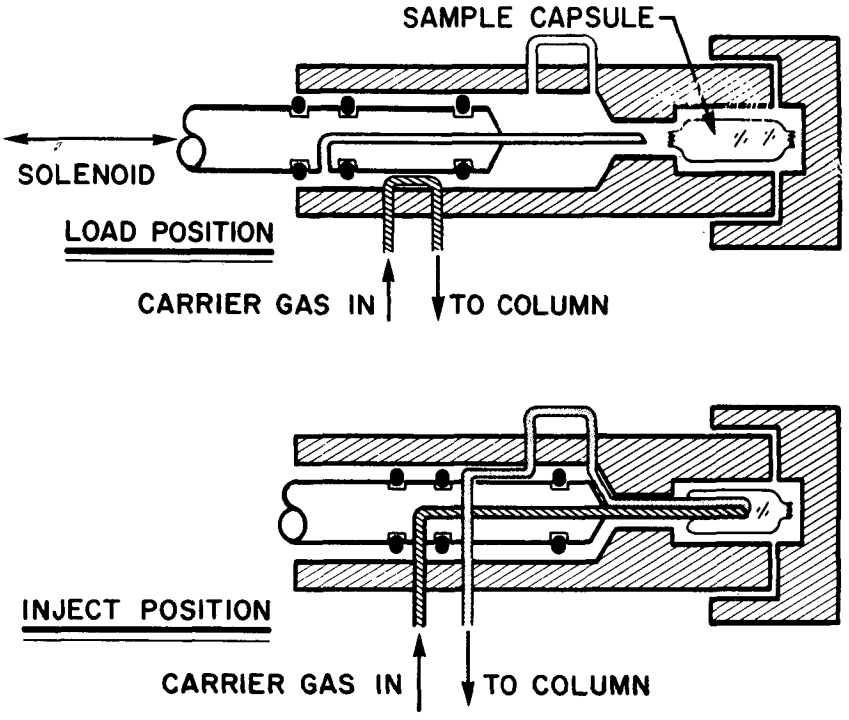

Fig. 8. Schematic drawing showing two steps in the transfer of alveolar air from a sealed indium capsule into the G-C Intoximeter. From Penton and Forrester (47).

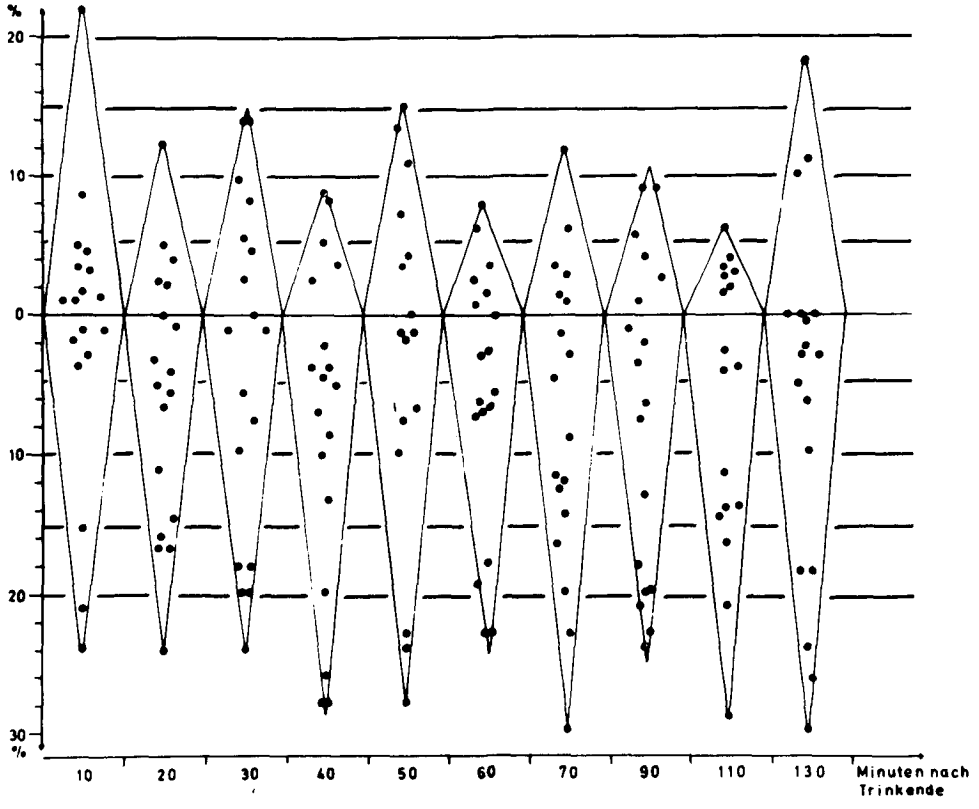

Fig. 9. Scatter diagram showing the present deviation of G-C Intoximeter readings from cubital vein BAC of 18 drinking subjects over a period of 130 min. after ingestion of alcohol during 1 hr. to give BAC peaks of 70 mg% to 200 mg%. The ordinate scale is in percent, with breath> blood deviations above the 0 line, and breath< blood below this line. Each double triangle encloses all data for one of the ten sampling times. Abscissa scale, minutes after end of drinking. These data are summarized in study 24 of Table IV. The ordinate scale magnifies the degree of deviation. From Schmutte et al. (50).

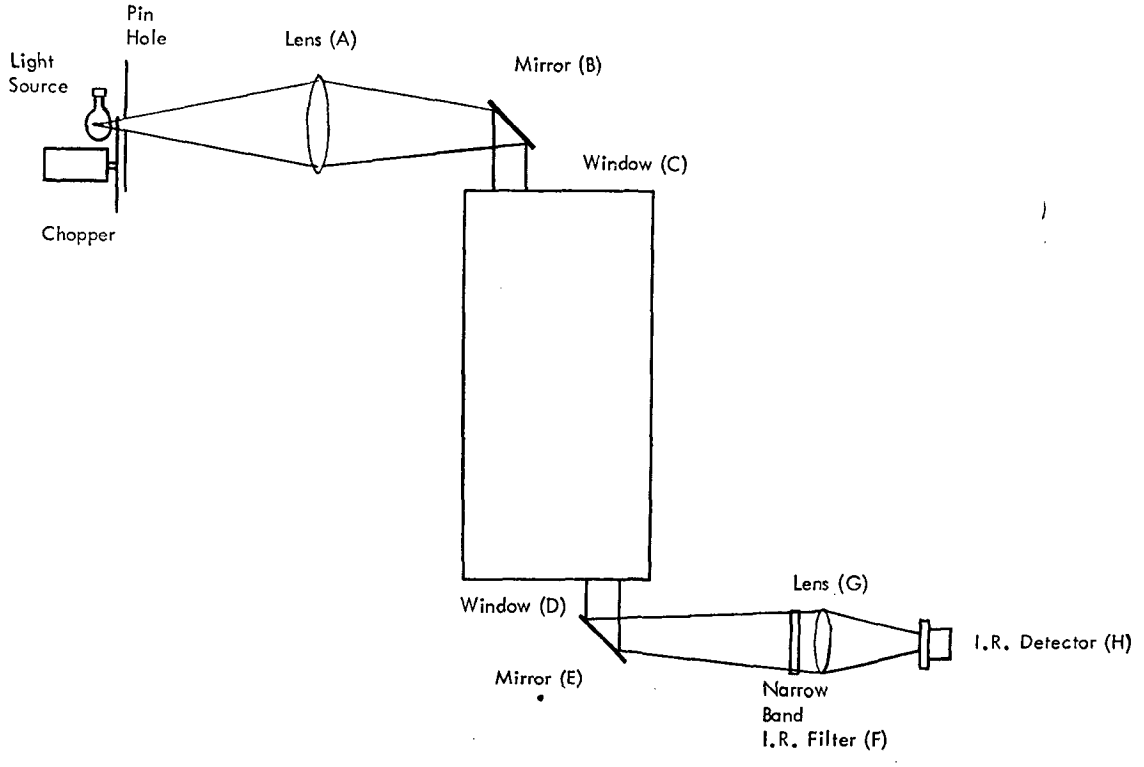

Fig. 10. Schematic drawing of Omicron Intoxilyzer showing the path of infrared light through the instrument. Multiple reversed light reflections of the light beam inside the sample chamber are not shown. From Intoxilyzer Operator's Manual, Omicron System Corp., Palo Alto, Cal.

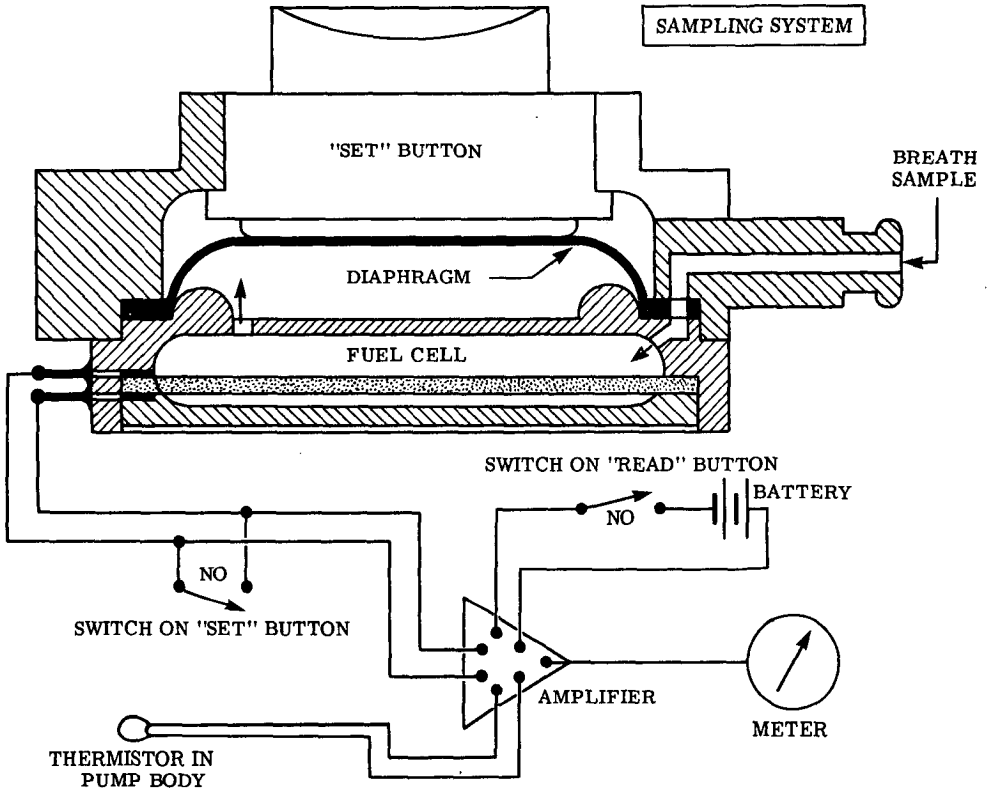

Fig. 11. Schematic diagram of the Forrester-Jones Alco-Sensor showing the fuel cell with its catalytic membrane, and the electrical circuits. (Courtesy of M. R. Forrester).

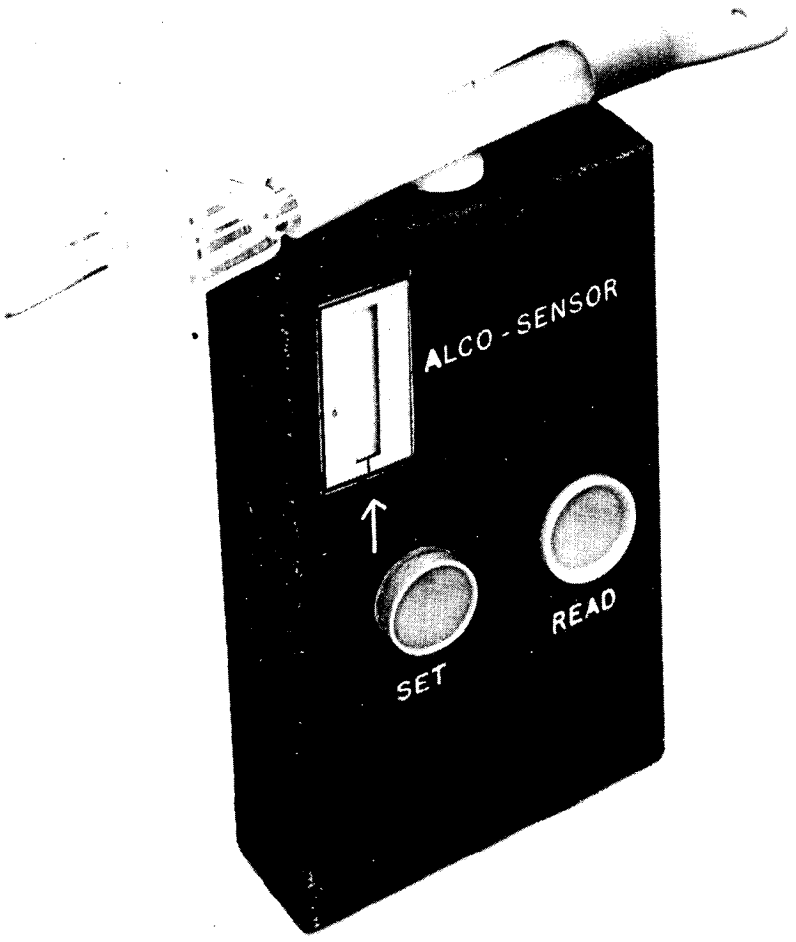

Fig. 12. Photograph of Forrester-Jones Alco-Sensor. Courtesy W. F. Harriott, DOT-TSC.

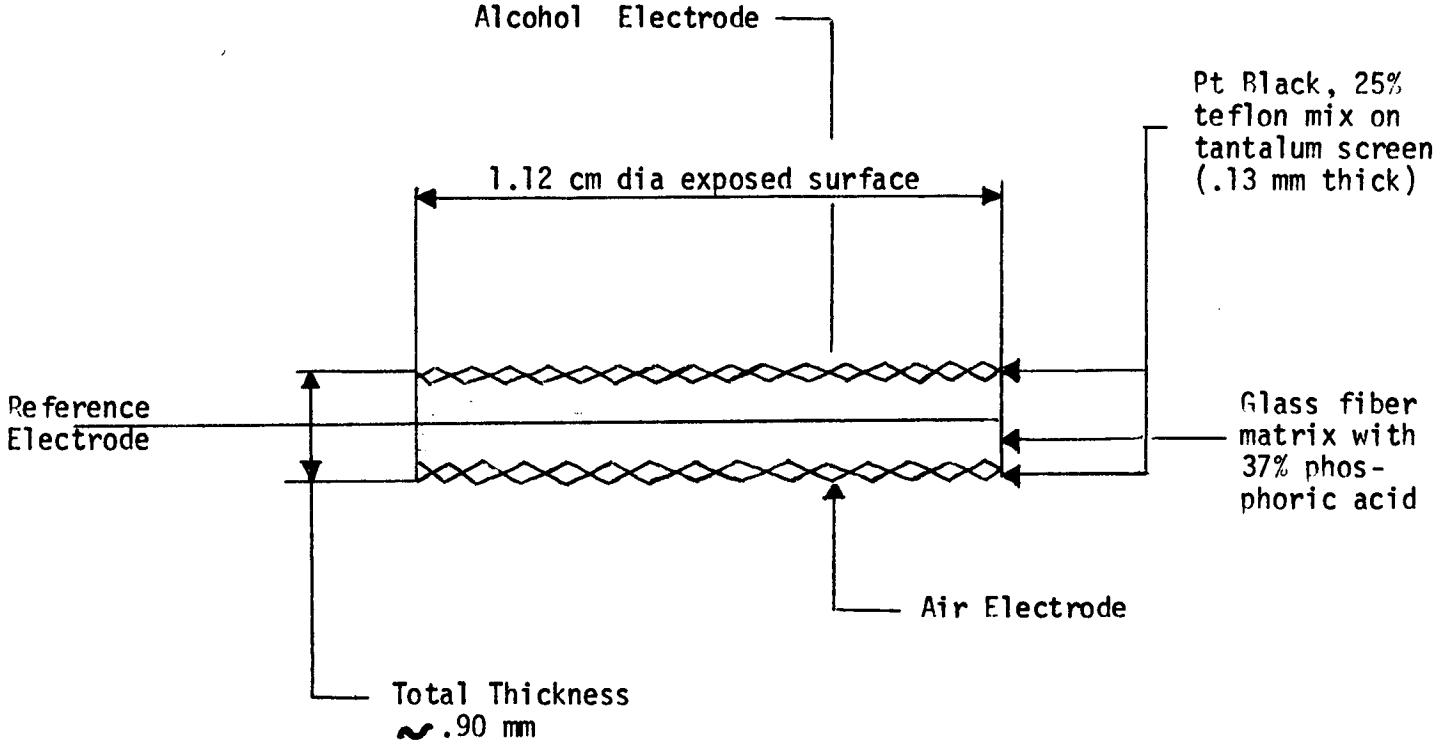

Fig. 13. Schematic drawing of fuel cell of DOT-TSC Alcohol Screening Device, Harriott (64).

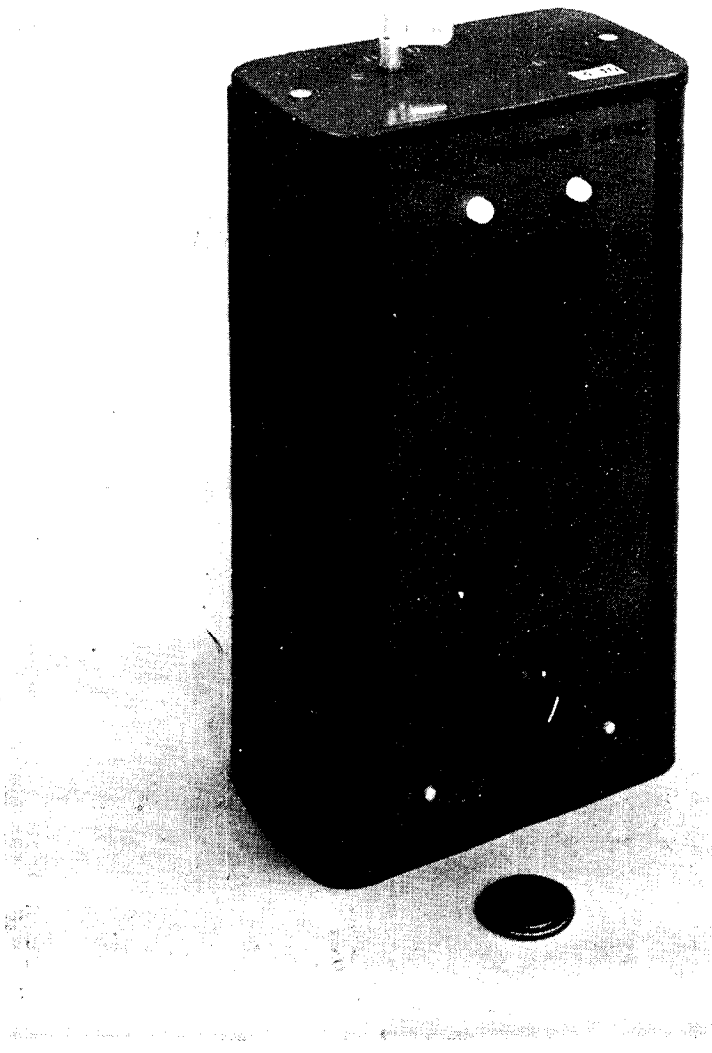

Fig. 14. Photograph of DOT-TSC Alcohol Screening Device. Courtesy W. H. Harriott of DOT-TSC. Note quarter in foreground for size comparison.

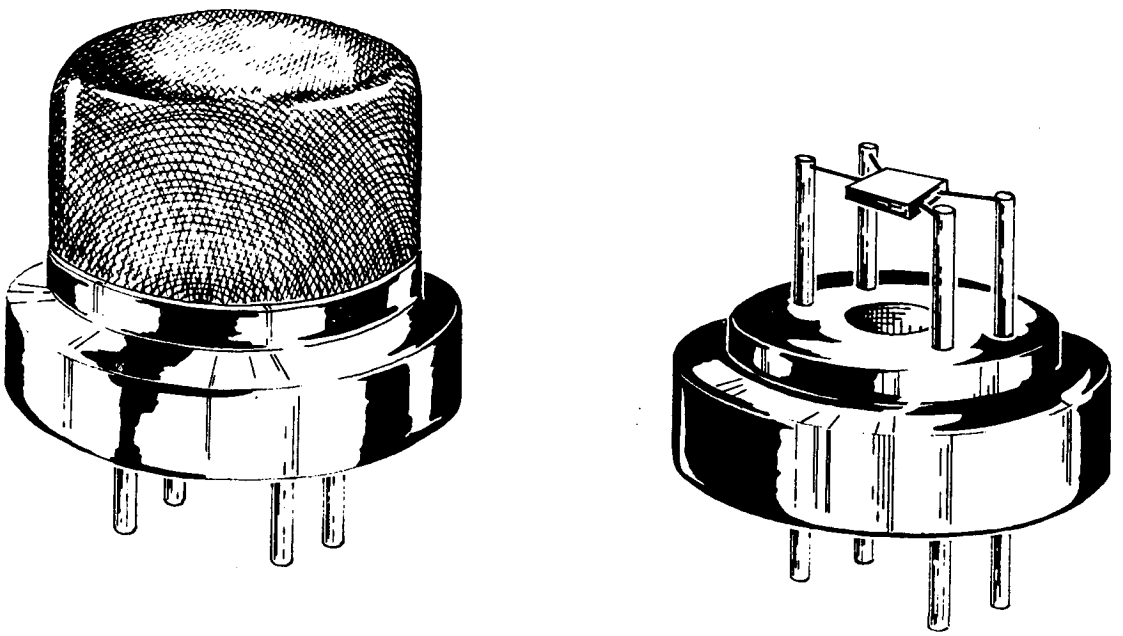

Fig. 15. Two drawings of the Taguchi Gas Sensor (TGS) assembly: left drawing, TGS assembly with wire mesh safety cover in place; right drawing, assembly with this cover removed. Overall diameter of assembly about 1.8 cm. Note the tiny TGS supported by wires welded to the four connector terminals.

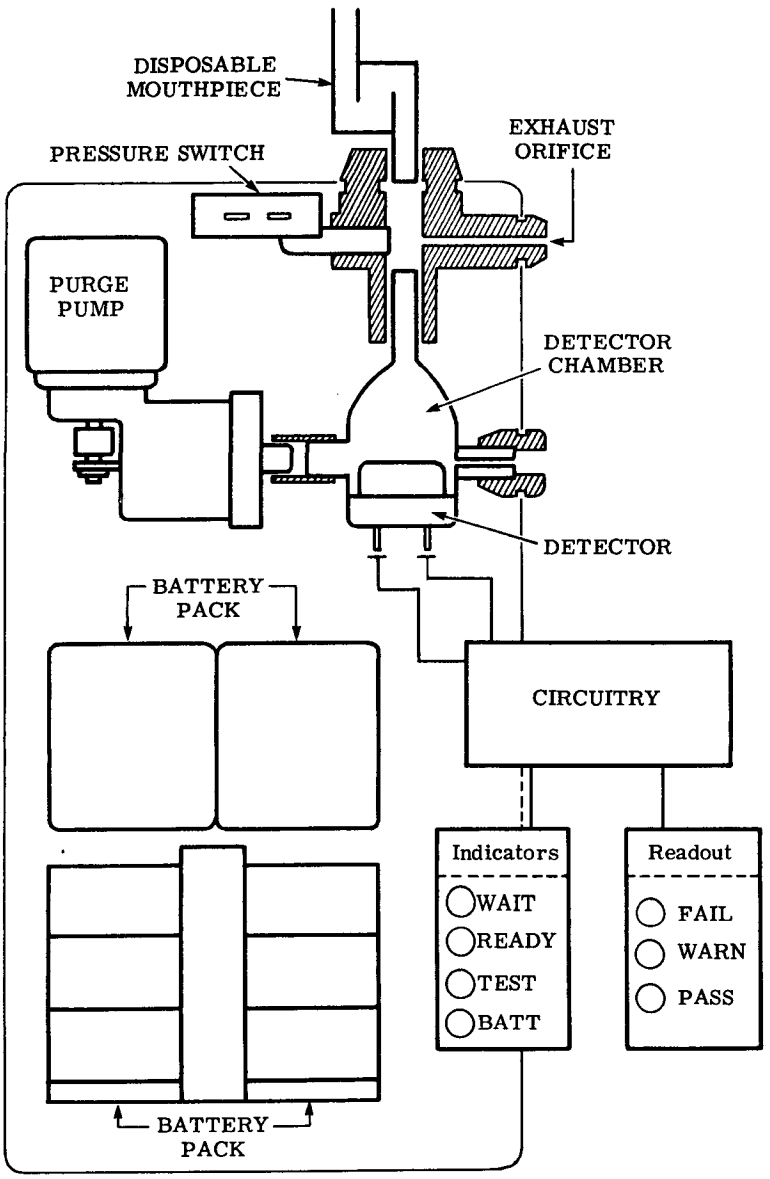

Fig. 16. Schematic drawing of the Borg-Warner ALERT showing the course of the breath through the detector chamber, and the electric circuitry. From a brochure published by Borg-Warner Corp., Des Plaines, Ill.

Fig. 17. Picture of Borg-Warner ALERT. Courtesy W. H. Harriott of DOT-TSC. Note quarter in foreground for size comparison.

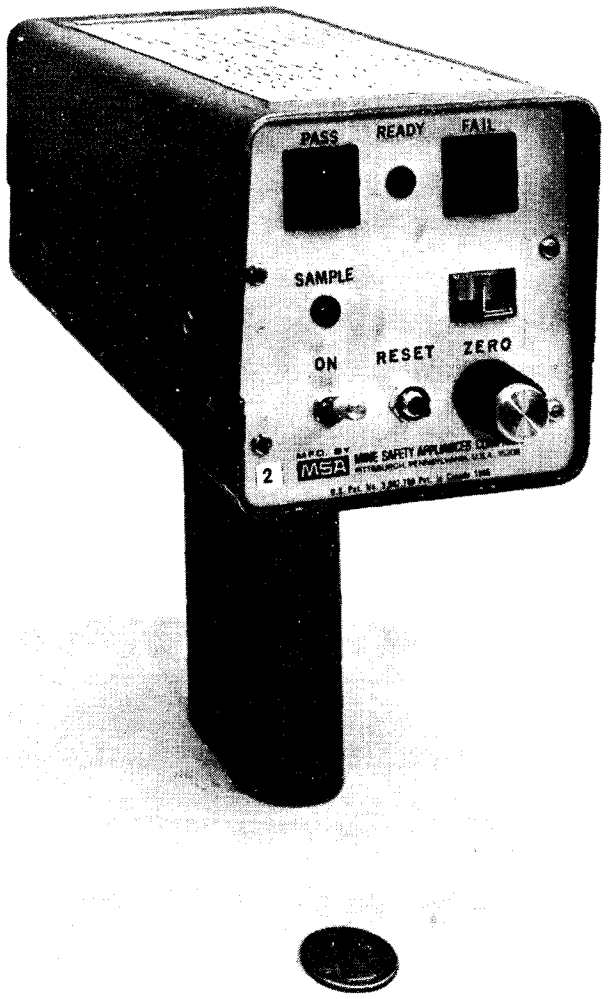

Fig. 18. Picture of M. S. A. Alcohalt Detector. Courtesy W. F. Harriott of DOT-TSC. Note quarter in foreground for size comparison.

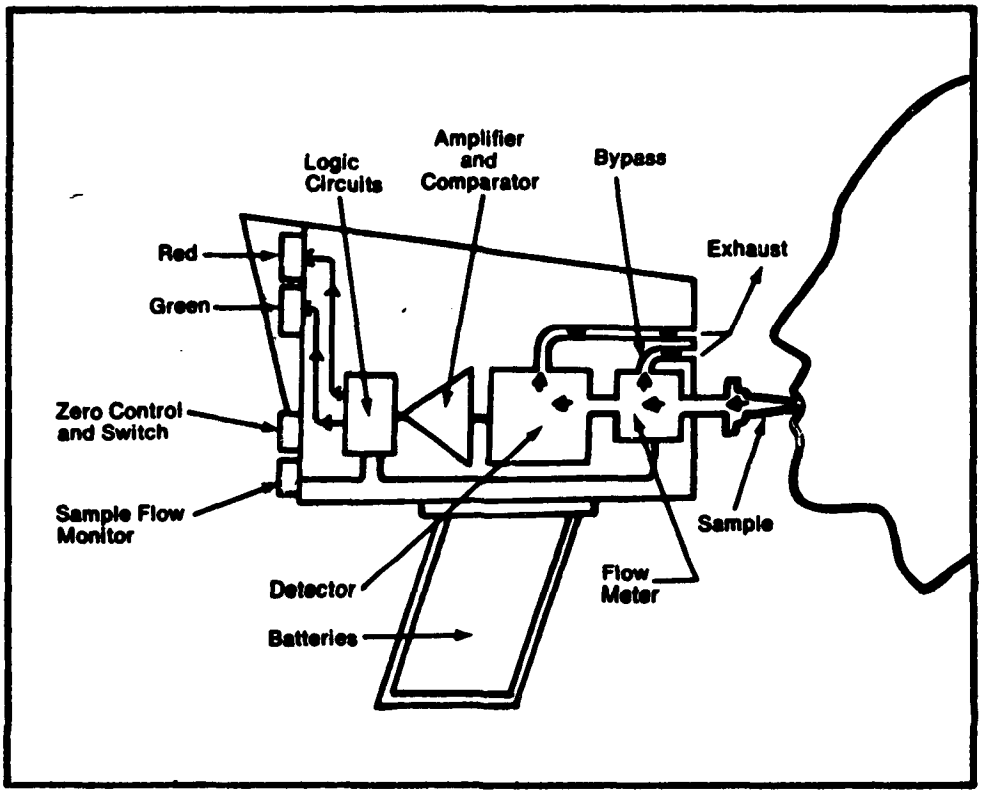

Fig. 19. Schematic drawing showing internal units of M. S. A. Alcohalt Detector. From brochure sheet published by Mine Safety Appliance Co., Pittsburgh, Pa.

Fig. 20. Picture of Century Systems Corp. Breath Alcohol Tester. Courtesy W. F. Harriott of DOT-TSC. Note quarter in foreground for size comparison.

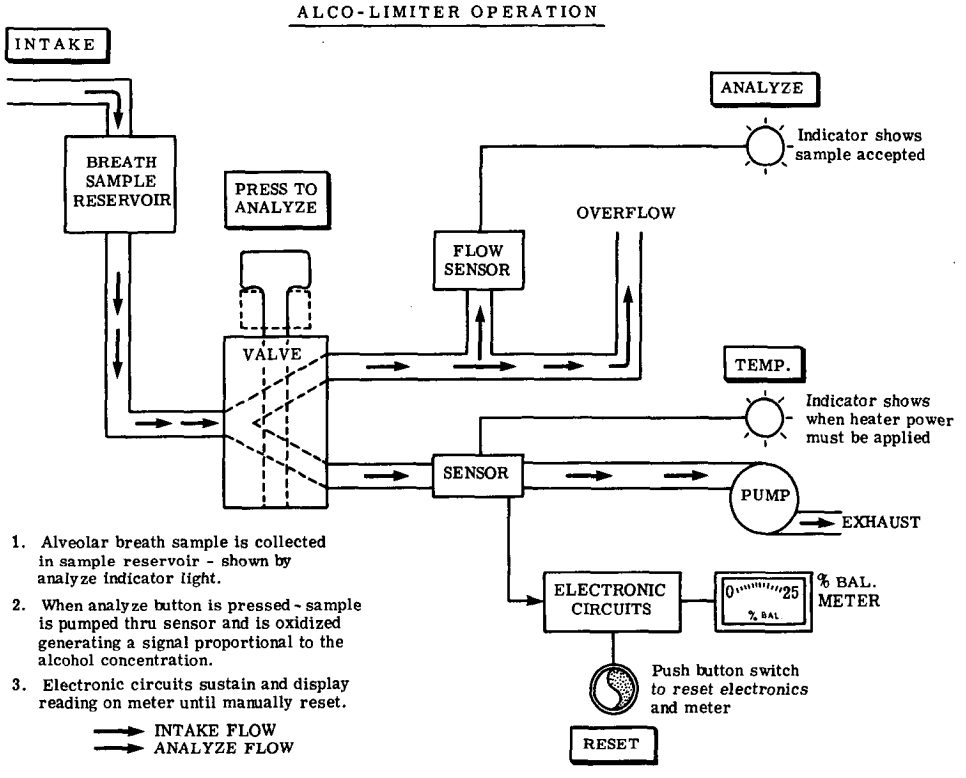

Fig. 21. Schematic drawing of the Alco-Limiter of Energetics Sci. Corp. showing the various parts and the divided paths of the breath through the discard route and through the sensor. From brochure published by Energetics Sci. Corp., New York, N. Y.

Fig. 22. Picture of Energetics Science, Inc., Alco-Limiter. Courtesy W. F. Harriott of DOT-TSC. Note quarter in foreground for size comparison.

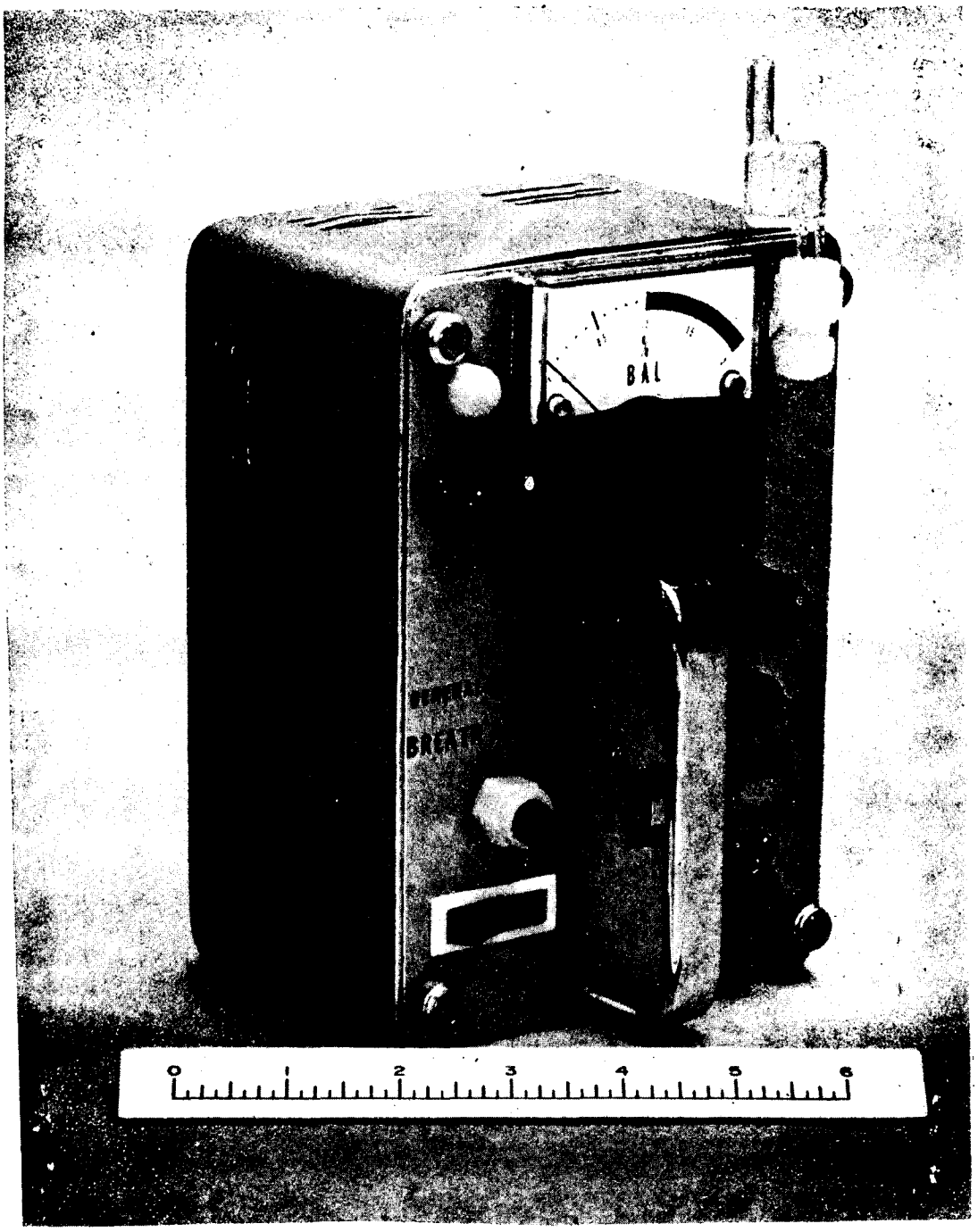

Fig. 23. Photograph of the General Electric BAL-1 Breath Analyzer. Courtesy W. F. Harriott of Dot-TSC.

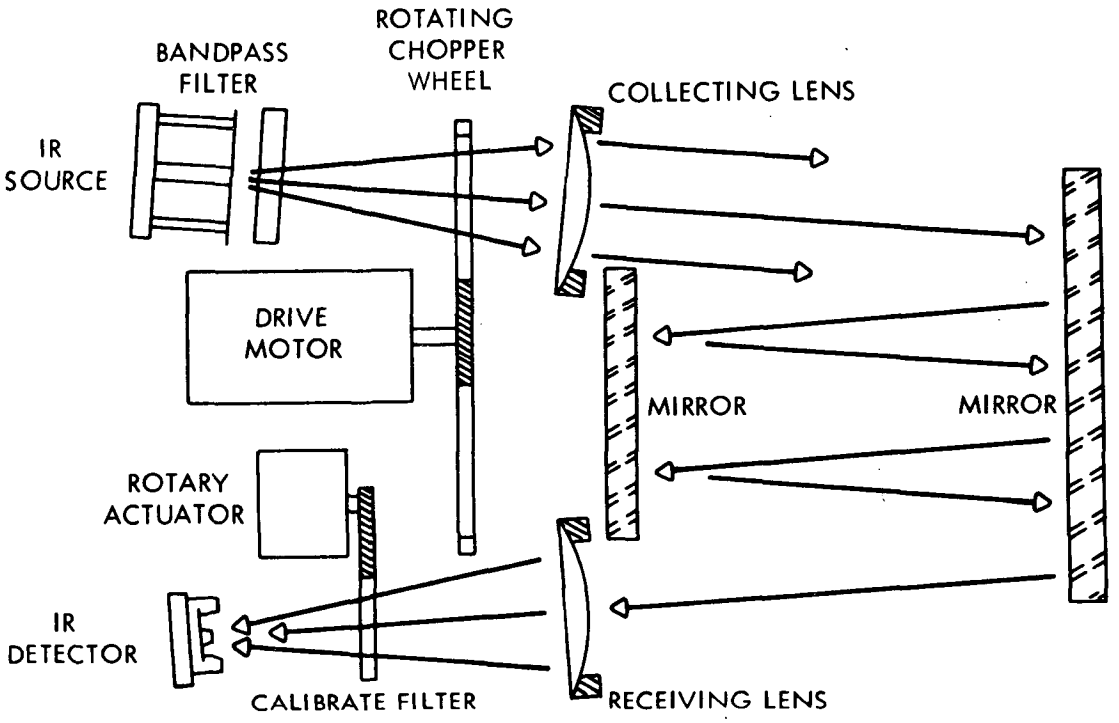

Fig. 24. Drawing showing the optical schematic of the General Electric Breath Analyzer, BAL-1. From brochures FS-46, (6-72), 100 published by General Electric, Ordnance Systems, Electronics Systems Div., Pittsfield, Mass.

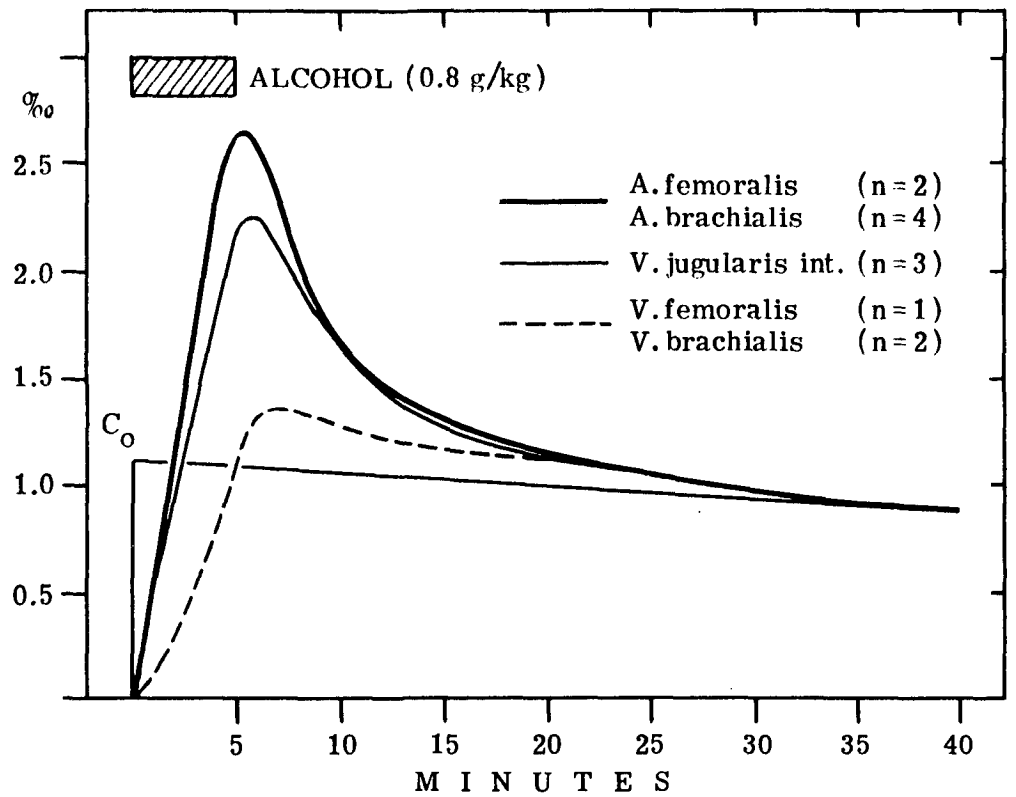

Fig. 25. Average BAC in certain arteries and veins of rabbits after i.v. administration of alcohol during 10 minutes. (C_0) Backward projection of the descending BAC line to 0 time. Ordinate scale, o/oo (per mil); to translate to mg%, multiply by 100. From Gostomzyk et al. (74).

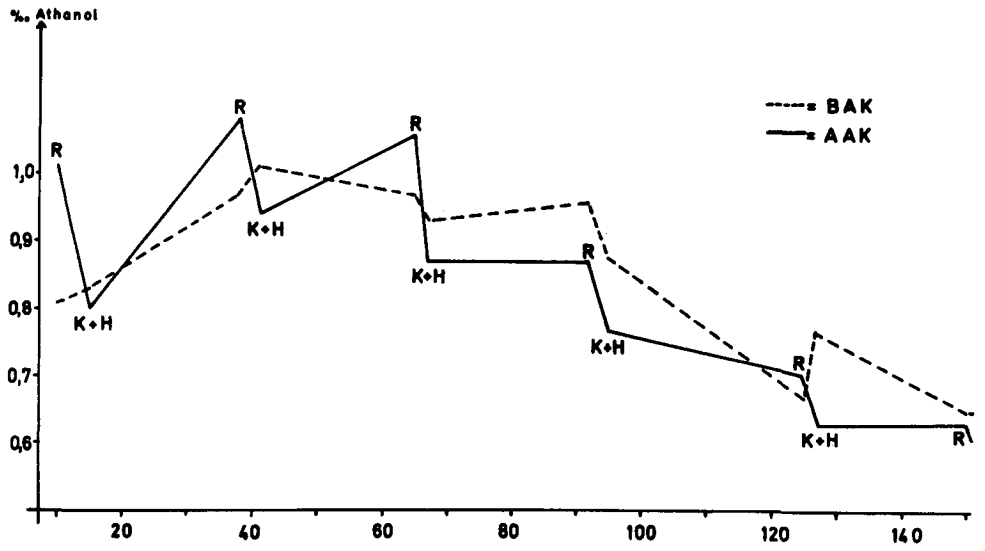

Fig. 26. Readings of the G-C Intoximeter (AAK = Atem Alkohol Koncentration), and BAC (BAK) of cubital vein samples from a subject who was tested at five intervals after alcohol ingestion, first while resting (R), then immediately after a short period of exercise (K), plus hyperventilation (H), with a sixth test while resting. The breath alcohol data do not show the recovery time after the exercise + hyperventilation period. The ordinate scale is in o/oo; to translate to mg%, multiply by 100. From Schmutte et al. (88).

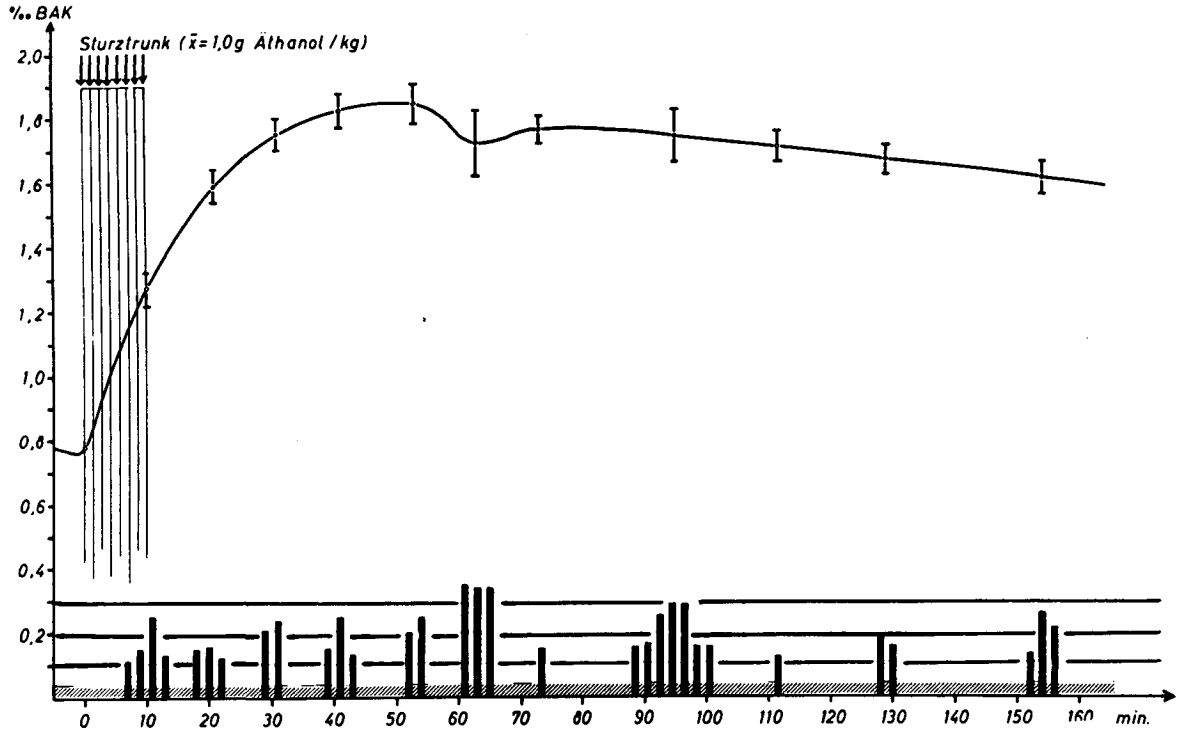

Fig. 27. Significant differences between BAC of right, and of left, cubital veins during 2½ hrs. after ingestion of alcohol, 1 gm/kg in 10 min. ("Sturztrunk" = drinking spurt). Ordinate scale o/oo BAC; to translate to mg%, multiply by 100. Each black column is the BAC difference for a single veno-venous pair; these comprise 31 of the 107 veno-venous pairs. Only differences above 0.1 o/oo (10 mg%) are recorded. Shaded areas, av. analytical error. We have added three parallel lines to facilitate calculation of the approx. % deviation. Curve, av. BAC for the 10 subjects, with standard deviations. From Naeve et al. (103).

TABLE I APPENDIX C

RECENTLY-PUBLISHED GAS CHROMATOGRAPHIC METHODS FOR ALCOHOL IN BODY FLUIDS AND TISSUES

NO.	Author(s) and date	Chief innovation(s)	G-C Instrument Used	Material Injected	Standard Used
1.	Machanta 1967 & 1970	Automation	Perkin-Elmer Multifract F40	Head-space gas, 0.5 ml.	Internal, t-butanol
2.	Glendening & Harvey 1969	Blood saturated with NaF to control alcohol V.P.	Beckman GC-4	Head-space gas, 1.0 ml	External, blood
3.	Bonnichsen 1971	Combination of G-C and mass spectrometer	Conventional G-C Edwards M.S.	Blood, 2 µl	Not stated
4.	Luckey 1971	Thermistor ethanol detector	Luckey, small & compact	Head-space gas, 10.5 ml	Not stated
5.	Jain 1971	All blood solids deposited in long pre-injection port	Varian 600-D	Blood diluted 1:1 with int. standard, 0.5 µl	Internal, isobutanol
6.	Karnitis & Porta 1972	Minor	Beckman GC-5	Head-space gas, 0.5 ml	Internal, n-propanol
7.	Siek 1972	Diluted blood saturated with NaCl	Hewlett-Packard 575 with twin columns	Head-space gas, 0.25 ml	Internal, n-propanol
8.	Solon et al. 1972	Almost full automation	Hewlett-Packard	Blood, vol. not stated	Internal, n-propanol
9.	Gessner 1970	Ethanol converted to its nitrite ester by $NaNo_2$ + oxalic acid	Tracer 200 Micro Tec	Head-space gas, 0.5 ml	External
10.	Gripta et al. 1972	Blood proteins precipitated with trichloracetic acid	Varian 2100	Protein-free fraction, 0.5 µl	Internal

TABLE II

RECENTLY-PUBLISHED ENZYMATIC, OXIDATION, AND PHYSICAL METHODS FOR ALCOHOL IN BODY FLUIDS AND TISSUES

NO.	Author(s) and date	Method Used	Chief Innovation(s)
1.	Boldberg & Rydberg, 1965	ADH, using dialy- state of blood	Almost full automation, using standard Technicon Auto-Analyzer
2.	Eskes, 1969	ADH	Diffusion in closed flask, transferring alcohol from 4 µl of blood to enzyme reagent
3.	MacDowell, Johnson & 1972	Oxidation with H_2SO_4 -$K_2Cr_2O_7$ reagent	Aeration of 50 µl of blood in closed flask, with EtOh transferred to Breathalyzer test ampule and color change read with Breathalyze. photometer
4.	Redetzki 1973	Physical, Advanced Instruments, Inc., model 31LAS Osmometer	Freezing-point osmometry; very simple and rapid

TABLE III

BLOOD/BREATH ALCOHOL CORRELATIONS CONDUCTED BY VARIOUS INVESTIGATORS WITH NINE QUANTITATIVE BREATH ALCOHOL INSTRUMENTS ADJUSTED TO EMPLOY THE 2100/1 RATIO FOR BLOOD/ALVEOLAR AIR, OR BLOOD/REBREATHED AIR

Study No.	Date	Instrument and Investigator(s)	ACCURACY OF BLOOD-BREATH CORRELATION: Fraction within -5% %	Fraction within -10% %	Fraction within -15% %	Fraction beyond -15%	Arith. mean of Br/Bl. deviation
1	1956	Drunkometer; Reb. Air Harger et al. (82)	54	87	98	2	1.3%
2	1957	Breathalyzer Chastain et al. (90)	38	62	91	9	-6.7%
3	1957	Alcometer Chastain et al (90)	53	78	95	5	-1.3%
4	1959	Breathalyzer Coldwell&Smith (91)	30	51	68	32	-10%
5	1959	Breathalyzer Fennell (92)	40	68	84	16	-6.1%
6	1960	Breathalyzer Bayley et al. (93)	26	52	72	28	-8.5%
7	1963	Breathalyzer Scroggie (94)	Only mg% given				-12 mg%
8	1964	Breathalyzer Begg et al. (95)	5	17	38	62	-17.5%*
9	1964	Kitagawa-Wright, Hermes Begg et al. (95)	31	49	68	32	-1.9%*
10	1964	Drunkometer; Reb. Air (Arterial blood) Forney et al. (73)	64	86	93	7	-4.0%
11	1969	Breathalyzer; w. blood Franklin (96)	33	59	87	13	-9.7%
12	1969	Breathalyzer; Plasma Franklin (96)	28	59	76	24	-9.9%
13	1969	Breathalyzer Shupe&Pfau (40)	42	61	84	16	-0.3%
14	1969	G. C. Alco Analyzer Shupe&Pfau (40)	60	70	75	25	-4.9%
15	1969	Alco Tector Shupe&Pfau (40)	51	78	88	12	1.7%

TABLE III (cont'd)

16	1969	G. C. Intoximeter Penton & Forrester (47)	58	61	73	27	-4.3%
17	1969	Breathalyzer Harger&Forney (83)	25	61	80	20	-7.1%
18	1969	Breathalyzer; Reb. Air (These tests followed the preceding tests almost immediately, using the same Breathalyzer and subjects) Harger & Forney (83)	57	74	92	-2.2%	
19	1970	Alcolinger Automatic Bonte et al. (46)	45	66	85	15	+3.6%
20	1971	Intoxilyzer; 12 tests only; +2% to -11% Harte (53)					-3.2%
21	1971	Breathalyzer Prouty & O'Neill (57)	25	57	74	26	-5.2%
22	1972	Breathalyzer Morales (51)	31	58	82	18	-0.7%
23	1972	G-C Alco Analyzer Morales (51)	15	31	66	34	-13.7%**
24	1972	G-C Intoximeter Schmutte et al. (50)	45	65	82	23	-4.4%**
25	1973	G-C Intoximeter a. Direct analysis b. Indium capsules Hoday (49)	15 61	63 79	77 97	23 3	-10.2% + 1.8%
26	1974	G-C Intoximeter Morales (52)	34	82	90	9	-6.6%**
27	1974	Intoxilyzer Morales (52)	28	65	86	14	-10%**

* In studies 8 and 9, BAC values below 50 mg% are omitted

** Correlation values in the five columns were estimated from a scatter diagram in the authors' paper, or report.

TABLE IV

READINGS OF THE ALCOTEST R80 AT VARIOUS BLOOD ALCOHOL CONCENTRATIONS

Condensed from table in paper by Day et al. (58)

Blood alcohol zone* mg%	Number of blood-breath pairs	Alcotest Readings		Fraction of false readings
		Number below 80 mg%	Number above 80 mg%	
20-30	2	2	0	None
30-40	12	7	5	42%
40-50	26	6	20	77%
50-60	36	11	25	69%
60-70	24	1	23	96%
70-80	18	0	18	100%
80-90	4	0	4	None
90-100	2	0	2	None

*Values determined by direct analysis of blood

TABLE V

FREQUENCY OF ERRONEOUS READINGS WITH EIGHT BREATH ALCOHOL SCREENING DEVICES

Correlation tests with drinking human subjects conducted by Prouty and O'Neille. (57)

(Condensed from eight tables in the authors' paper)

Screening Device	Blood Alcohol Concentration from Direct Analysis								
	mg% 21 to 40 %	mg% 41 to 60 %	mg% 61 to 80 %	mg% 81 to 100 %	mg% 101 to 120 %	mg% 121 to 140 %	mg% 141 to 160 %	mg% 161 to 180 %	mg% 181 to 200 % *
Alcolyser H	29	17	20	19	77	59	38	41	17
Alcolyser (Iowa)	-	27	36	43	47	32	34	21	-
Alcolyser 100	-	7	20	39	60	50	0	-	-
Becton-Dickinson #1	0	5	5	35	61	20	14	0	0
Becton-Dickinson #2	-	0	33	46	23	4	0	-	-
Kitagawa	0	10	0	17	75	93	64	50	33
Sober-Meter, SM1	23	29	54	66	32	24	7	14	33
Sober-Meter, SM6	14	42	67	73	16	21	10	5	17

* The values in the nine vertical columns beneath the % symbols indicate the percent of the total tests in a given blood alcohol zone where the detector tube reading (DTR) was wrong. With the values to the left of the vertical line, the true blood alcohol levels as shown by direct blood analysis, (TBAC), were all below 100 mg% (0.10%), or just 100 mg%, while the DTR was above 100 mg% in the stated percent of the total tests in that TBAC zone. These are false positive readings. The values to the right of the vertical line give the percent of false negative readings. Here the TBAC values were all above 100 mg%, but in the stated percent of all tests in a given blood alcohol zone, the DTR was below 100 mg% (0.10%).

TABLE VI

FREQUENCY OF ERRONEOUS READINGS OF SIX PORTABLE BREATH ALCOHOL INSTRUMENTS, WHEN USED TO TEST WHETHER THE BAC IS BELOW, OR ABOVE, 100 mg%

False positive: BAC $\leq$ 100 mg%, but instrument reading $\geq$ 100 mg%.
False negative: BAC $\geq$ 100 mg%, but instrument reading $\leq$ 100 mg%.

	No. of blood-breath pairs	mg% 41 to 50 %	mg% 51 to 60 %	mg% 61 to 70 %	mg% 71 to 80 %	mg% 81 to 90 %	mg% 91 to 100 %	mg% 101 to 110 %	mg% 111 to 120 %	mg% 121 to 130 %	mg% 131 to 140 %	mg% 141 to 150 %
Alco-Limiter Harriott (64)	212	0	0	0	0	0	0	88	80	22	0	0
Alco-Sensor Harriott (64)	68	0	0	0	0	0	67	40	0	50	11	0
M.S.A. Alcohalt Harriott (64)	24	0	0	0	0	33	25	67	0	0	0	0
Century Systems BAT Harriott (64)	52	-	20	0	0	33	40	20	0	0	0	-
G-E Infrared Breath Analyzer (17) Harriott (64)	17	0	0	0	0	0	0	33	-	0	0	-
DOT-TSC Alcohol Screening Device Harriott (64)	474	0	0	0	0	0	5	37	0	0	0	0
ALERT Dubowski (67)	68	0	0	-	-	0	100	100	-	-	0	0
ALERT Forney et al. (63)	23	-	-	0	-	0	0	100	57	50	0	-
Alco-Sensor Forney et al. (63)	23	-	-	0	-	0	0	100	57	0	0	-
		False positive readings % of total tests						False negative readings % of total tests				

- = No pairs in this BAC range

TABLE VII

CUBITAL VEIN BLOOD ALCOHOL CONCENTRATION AND DEGREE OF INTOXICATION, FOLLOWING RATHER RAPID DRINKING

(Alcohol dosage, 1.1 to 1.2 gm/kg ingested in 20 min.)

Condensed from two tables in paper by Brinkmann et al. (75)

Subject No.	Ten min. after end of drinking		At time of blood alcohol peak	
	Blood alcohol concentration mg%	Degree of intoxication	Blood alcohol concentration mg%	Degree intoxication
1.	15	Mild intox.	170	Mild intox.
2.	30	Frank intox.	130	Frank intox.
3.	30	Frank intox.	135	Frank intox.
4.	40	Mild intox.	130	Frank intox.
5.	50	Frank intox.	140	Frank intox.
6.	50	Mild intox.	153	Frank intox.
7.	55	Mild intox.	130	Frank intox.
8.	65	Frank intox.	130	Frank intox.
9.	65	Mild intox.	155	Frank intox.
10.	70	Mild intox.	155	Frank intox.
11.	75	Frank intox.	130	Frank intox.
12.	75	Frank intox.	160	Frank intox.
13.	80	Frank intox.	165	Frank intox.
14.	85	Mild intox.	130	Mild intox.
15.	85	Mild intox.	130	Frank intox.
16.	90	Mild intox.	175	Frank intox.
17.	100	Frank intox.	140	Frank intox.
18.	120	Frank intox.	180 1	Frank intox.

TABLE VIII

ACCURACY OF TWELVE BLOOD ALCOHOL METHODS REPORTED BY THE RESPECTIVE AUTHORS.

Author(s)	Method	Accuracy Claimed	
Machata (13)	G-C	S.E.*	± 1.1% #
Glendening and Harvey (14)	G-C	M.E.**	+ 4% to -5%
Bonnichsen and Ryhage (15)	G-C + Mass spectrometer	M.E.	+ 8% to -17%
Luckey (16)	G-C + Thermistor	M.E.	+8 mg% to -5 mg%
Jain (19)	G-C	M.E.	± 5%
Karnitis et al. (20)	G-C	M.E.	+ 3% to -6%
Siek (22)	G-C	M.E.	+ 16%
Solon et al. (23)	G-C	M.E.	4 mg%
Gupta et al. (28)	G-C	M.E.	+ 12% to -1%
Goldberg and Rydberg (29)	ADH	M.E.	+ 8%
Eskes (30)	ADH	S.E.	± 1.1 mg%
MacDonnell et al. (35)	Aeration + Breath-alyzer analysis	M.E.	± 8%

* S.E. = Standard error

** M.E. = Maximum error

\# Greiner (12) calculated the standard deviation (precision) of the Machata G-C method for duplicate analyses of 1022 samples of blood, and reported it to be ± 2.03% (see p. 3).