A CRITIQUE ON REQUIREMENTS FOR DETERMINATION AND INTERPRETATION OF FUMIGANT RESIDUES[1]

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ABSTRACT: Major factors that influence the type and amount of fumigant residues in stored foods treated with fumigants are: the nature and the amount of fumigant applied, nature of substrate (stored product), temperature, moisture content, gas concentration, and contact time (duration of exposure). Current experiments show that residue levels also depend on location and humidity. The author's current research on measurement by GC of unassisted air movement in stored grain under field conditions indicate that air in a bin moves between 0.5 to 7.5 x 10^{-4} miles per hour (=3 to 45 inches per hour) in the grain microclimate. Temperature gradients accordingly influence the movement of air, fumigant distribution-persistence patterns and residues.

The term "residue" is defined. Advantages and limitations of chemical and biological evaluation of fumigants are outlined. Fumigant residues are of two main types: (a) physically bound residues (pbr), which are reversible, temporary, nonspecific with respect to the target or substrate, generally reach a maximum rapidly, and can be desorbed by prolonged aeration, solvents, reduced pressure or increased temperature, and (b) chemically bound residues (cbr), which are permanent, irreversible and in various respects are the opposite or converse of pbr's. Examples of both types are given. The influence of chromatographic properties of stored products on sorption phenomena is outlined. Data are given on reduction of residues through use of optional methods of application, e.g., use of controlled atmospheres.

It is good that you and I, as practitioners in and contributors to the world-wide, man-oriented "knowledge industry", occasionally rest from our fact-finding and problem-solving endeavors to examine the adequacy, advantages and limitations of our research methods. To provoke thought and your incisive criticism, this critique deals with requirements for determination and interpretation of fumigant residues.

Before we review briefly the advantages and limitations of of chemical and biological methods of assessment of fumigants and fumigant residues, it is worth noting that "results are generally a function of method" [1]. Thus, our current ability to

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identify and measure numerous molecular species in the biosphere at nanogram (ng = 10^{-9}g = ppb = parts per billion) and picogram (pg = 10^{-12}g = ppt = parts per trillion) levels stems from improved analytical methods.

Residue tolerances have in some instances been revised downwards and regulatory policy readjusted because of results obtained by assay methods of improved specificity and greater sensitivity. The contribution of improved methodology to environmental protection is reflected in the proliferation of new data and better toxicological back-up needed to answer increasing public concern about long-term (chronic) effects of trace amounts of pesticides and other chemicals in the biosphere.

We speak glibly of determining ppm and ppb amounts of a particular molecular species. To get such amounts in correct perspective, consider that 1 ppm is the equivalent of the ratio of 1 inch in 1 million inches, i.e., 1 inch in 15 3/4 miles, and that 1 ppt (part per trillion) is one million times smaller, i.e., 1 inch in 15,750,000 miles! Quite apart from chronic hazards, nanogram (10^{-9}) and picogram (10^{-12}) amounts are in the range encountered by insects, moulds, bacteria and miscellaneous plant and animal cells in their daily lives. At the same time, stretching our analytical capabilities to attain ever-decreasing limits poses serious problems. Thus, Gunther [2,3]; points out that background values increase disproportionately, contamination becomes a major problem, instrumental "temperament" is more difficult to control, and the interpretive skill of the analyst is strained. Also, one might add, the analyst may become quite unsociable!

ADVANTAGES OF CHEMICAL METHODS OF ASSESSMENT OF PESTICIDE RESIDUES: The advantages of chemical methods of evaluation are: 1. Specificity. It is presently possible to determine with considerable specificity hundreds of different biological active compounds, including some that may be chemisorbed or conjugated, or that undergo gradual decomposition with time, temperature, light, metal ions, humidity, etc. Mixtures of pesticidal molecules can be resolved. 2. Sensitivity. With the aid of modern instrumentation, lower limits of detection by some methods are presently down to ppt levels. Low limits of detectability are needed to assess physical and chemical binding, rate of excretion, volatilization, and chronic hazards, including carcinogenic properties and possible genetic damage [4]. 3. Wide range of methods. There are at least 30 classes and subclasses of chemical methods, yielding a potential of hundreds of different methods that could be applied in biological research, and also be used to confirm the validity of particular data.

LIMITATIONS OF CHEMICAL METHODS OF ASSESSMENT: The limitations of chemical methods of assessment include: 1. Artifact results. False positives may be obtained. 2. Differences in methods performance. Results obtained by different methods do not always agree, because of differences in extraction efficiency, substrate, moisture content, etc. 3. Intefering substances. Naturally

occurring constituents (lipids, proteins, gums, etc.) in a sample, classified as unknowns or "gunk" by the chemist, may be co-extracted. These interfere with or mask the determination of trace amounts of molecular species that are sought. Inteferences from polynuclear hydrocarbons in the air (e.g., smog) or in various foods, marine flora and fauna from oilspills have been found. It is much like looking for very small specific needles in a very large heterogeneous haystack composed of thousands of other molecular species. (Note. The residue chemist counteracts or eliminates interferences by special "clean-up" treatment of the extract designed to obtain maximum recovery of the pesticide molecules sought.)

ADVANTAGES OF BIOLOGICAL METHODS OF ASSESSMENT: The main advantages are: 1. Direct function. Biological methods are a direct measure of the physiological effectiveness of toxic molecules. 2. Wide range. A wide range of methods is available to determine dosage-mortality effects, such as LD_{50}, LT_{50}, etc. 3. Low cost. The cost of operation in many instances is low.

LIMITATIONS OF BIOLOGICAL METHODS OF ASSESSMENT: There are at least 5 limitations, namely: 1. Non-selective. They are non-selective for specific molecules. Not suitable for determining effects of individual components of a multicomponent mixture, especially its changes in composition. 2. Environment-dependent. They may be environment-dependent, and affected by nutrition, rearing conditions, atmospheric composition, etc. [5,6]. 3. Differences in response. Response may depend on the test species. Extrapolation of toxicological conclusions to another species or higher animals may not be acceptable [7]. 4. Hidden effects. Chronic (sublethal) dosages may have obscure, hidden or delayed effects, which may not be detected by biological methods of evaluation. 5. Interferences. Oily or waxy substances that are co-extracted may be toxic to the test species, or may encapsulate the pesticide molecules. Thus, false positive or false negative (artifact) results may be obtained [8].

The key points I wish to stress at this stage are: a. Conclusions may be method-dependent. Methods vary in accuracy, precision, specificity and limits of detectability. These criteria in turn are affected by the nature and physical state of the substrate, the nature and dosage of the toxicant, the type of formulation, and the age, sex, nutrition, life stage and physiological resistance of the test species [1,9]. Differences in response to toxicants among different species are readily demonstrated. We can assume that biologists are aware of such sources of variability. Nevertheless, we need reminding that our great scientific findings may rest on considerable variability. For the most part, researchers use methods of assay primarily as tools to evaluate effects, and have only peripheral interest, at best, in checking methods performance along the lines indicated. Stated simply, few bother about methods research, even though the validity of their experimental results depends on it.

b. Investigations are generally and sometimes advisedly narrow. Interactions pose problems that are not readily resolved by computers or mathematical models.

c. The limitations of a given method may be reduced or counteracted by using a variety of chemical and biological methods.

FACTORS THAT INFLUENCE EFFECTIVENESS AND DISTRIBUTION-PERSISTENCE OF FUMIGANTS: At least 14 factors influence the effectiveness and distribution-persistence (concentration-space-time relationships) of fumigant gases [1,10]. The storage environment has a major many-sided influence on insecticidal effectiveness of fumigants, and on the traces of fumigant residues that remain in or on the treated commodity or substrate. In this regard, fumigant residues are mainly dependent on gas concentration, the nature of the substrate, its particle size and on temperature, moisture content, and contact time (duration of exposure).

We have since found additional factors to be involved, such as temperature gradients, which promote differential air movement patterns and thus help to explain differences in fumigant residues due to sample location and time of sampling [11]. Thus, one may encounter different intensities and direction of updraft, downdraft and lateral movement of air depending on the magnitude and location of the temperature gradients that exist in a given situation. Under field conditions, we found significant diurnal differences in %R.H., CO_2 and O_2 levels due, we feel, to differences in direction and velocity of air movement, as an integral part of the internal weather or microclimate of a particular grain storage facility [12].

With the use of sulfur hexafluoride, SF_6, as a micrometeorological marker, we can determine the interstitial air movement of stored grain at speeds as low as 3 inches per hour (= 5×10^{-5} miles per hour). We use gas chromatography with an electron capture (EC) detector and are able to measure amounts as small as 0.1 picolitres (10^{-13} l.) of SF_6. Figure 1 shows our calibration curve for SF_6 in the range 0 - 35 picolitres. We have yet to superimpose the air movement rates of different fumigant gases and resultant fumigant residues into this new line of investigation [11]. Definition of Fumigant Residue. Before we outline fumigant residues in greater detail, I would like you to consider the following definition: "Fumigant residue" is the amount of original or unchanged gas or vapor (parent molecule), or degradation product (metabolite), adduct or conjugate thereof (offspring molecule) that remains on or in a substrate (animal, plant or mineral) after application of the fumigant gas or vapor. Please note the toxicity as such is not mentioned, although we know that the parent molecule or its offspring derivative must be toxic to the metabolism of insects, mites, nematodes, etc., to be effective.

Fumigant residues are not necessarily toxic. Thus, by chemical transformation (photodecomposition, biodegradation, etc.) they may be converted to inorganic phosphate, sulfate, bromide, chloride, etc. [9]. The mammalian toxicity would then be minimal. However, there could be other considerations in the toxicity

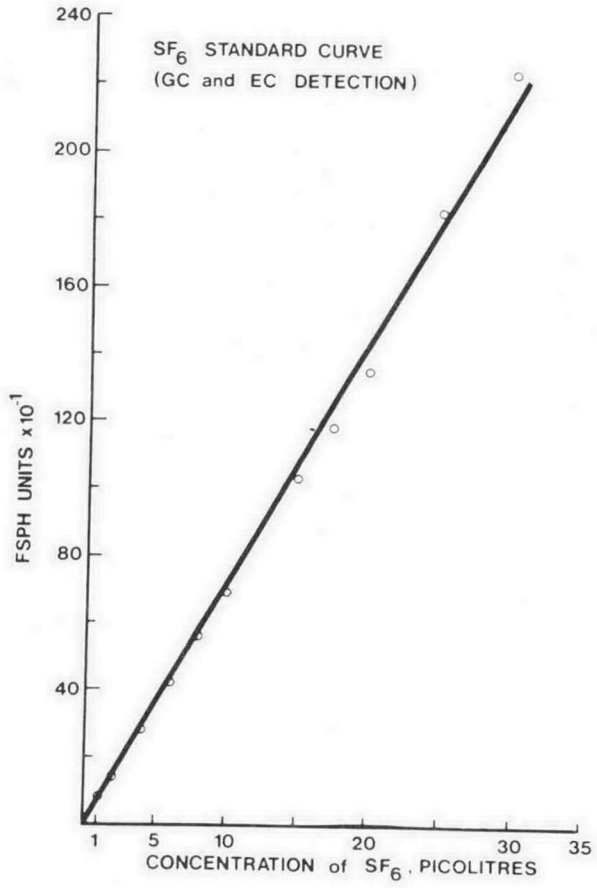

FIGURE 1. Standard curve, range 1-35 picolitres SF_6 in air, determined by gas chromatography with a Ni^{63} EC detector.

syndrome, e.g., carcinogenic factors. The main questions that need answers are: (a) Toxic to what? (b) Under what conditions? (e.g., dosage, period of exposure, species, age, etc.) (c) What toxic effects? (e.g., circulatory effects, hair loss, lowered energy output, hypersensitivity, allergenic, abnormal seed germination, etc.)

Types of Fumigant Residues - Sorption phenomena influence fumigant behavior and fumigant residues. Sorption may be (a) physical in nature (e.g., adsorption, involving Van der Waal's forces), or (b) chemical, involving covalent interlocks or bonding, which are permanent.

There are two main types of fumigant residues:

A. Physically bound residues (pbr) are reversible, temporary, non-specific with respect to target or substrate, generally reach a maximum rapidly, are sorbed more rapidly at lower temperatures, and can be desorbed by solvents, reduced pressure, increased temperature or prolonged aeration.

B. Chemically bound residues (cbr) are permanent, irreversible, specific, and increase when temperature and time of contact (exposure) are increased. Cbr's involve only a small amount (generally less than 1%) of the total amount applied. At low concentrations, the amount of gas chemisorbed is a direct function of applied concentration [13]. Depending on the environmental conditions,

all fumigants show cbr capabilities to some extent. Even so-called inert substances such as nitrogen, krypton, argon, etc. are chemisorbed, some at low temperatures [14].

One of the most common examples of chemisorption is that of corrosion, in which traces of atmospheric O_2 in the presence of water vapor are chemically bonded with iron to form iron oxide (rust). Only a small amount of the total oxygen in the atmosphere is thus involved.

Some Effects of Storage Environments - Measurement of fumigant residues as such would be meaningless if the results were not related to the storage environment and to the concomitant sorption affinities pertaining to a particular measurement. Our data show that atmospheric composition can influence biological effectiveness. Thus, traces of volatiles generated during grain storage under high moisture conditions can have a synergistic (potentiation) effect on fumigant gases.

The effects of storage environments on fumigant residue levels need much more research. Our laboratory rests with glass micro storage "bins" show that grain of high moisture content (e.g., 20% m.c.) can be stored for at least 3 years without spoilage, if the temperature is held between -6.5° and 0°C (20° and 32°F). Most of the bacteria, yeasts, and molds can thus be kept in a "hold" position.

Storage conditions have a primary influence on the quality and infestation level of stored products. Under "good" storage conditions, the bacterial, mold, mite, and/or insect populations increase very slowly or not at all. Since storage under field or commercial conditions is generally not as good as it might be, we use chemical aids to control the population increases of bacteria, molds, and insects that may result. The central point is that we could minimize losses due to infestation and lower costs of treatment by improving storage conditions. Use of less fumigant would also mean lower fumigant residues [12].

Health protection and Food and Drug agencies are presently increasing their surveillance of stored products not only for pesticide residues but also for mycotoxins, bacterial toxins, Salmonella, etc. Greater interest in consumer protection and consumer safety is thus broadening the scope of inspection services pertaining to stored products.

Chromatographic Behavior of Wheat - The chromatographic column, and its ability to separate molecular species by selectively retarding their passage through the column, is the nucleus of gas chromatography. The possibility that stored wheat could behave as a chromatographic column towards fumigant gases was advanced by [15]. The concept was based initially on differences in the rates and amounts of fumigants observed to migrate downward during fumigation of grain in country elevator bins. The wheat was regarded as a heterogeneous, coarse-grained solid support, coated with natural stationary liquid phases with surface-active properties, capable of differential sorption of fumigants applied to the surface of the wheat pile.

Differential sorption of fumigants and different affinities of cereal substances were thus demonstrated by use of (a) columns containing 1-bushel amounts of whole cereals [16], (b) 50-g amounts of 36 different cereal substrates [17], and (c) rapid micro fumigation tests employing 1/4-inch diam. glass columns, 1/4 inch to 6 inches in length, containing different cereal products [18]. The latter was the first on-column fumigation with phosphine, PH_3, and employed a residence time of 4 to 6 seconds, and was designated as the "fastest fumigation in the West" [19].

Moisture content and temperature of the column were principal factors in differences in retention time. The peaks were displaced to longer retention times when the temperature was lowered. The response to increased temperature (comparative increase in retention by the substrate) was used as an index of chemisorption [18].

Comments on Sampling - Pesticide residues in general, and fumigant residues in particular, may vary considerably in a given sample. The residue levels are influenced by the sample size, storage, and method of preparation and processing of the sample. The stability of pesticide molecules that are volatile, or are unstable to light, heat, moisture, metallic ions, etc., must be ascertained beforehand. Regarding sample size, the smaller the sub-sample, the larger the variability, especially when the substrate is not homogeneous in composition or physical properties. Thus, one sq. foot of soil may differ considerably from another from the same farm, even though we may assume that the particular pesticide had been uniformly applied. We tacitly assume that several pounds of subsample is representative of a carload of stored grain, or of 640 acres of land, or of 1 million gallons of river water, etc. While air and water samples are generally more uniform than samples of solid material, significant differences in pesticide levels can occur, depending on location. Thus, the dissolved oxygen (DO) and suspended solids content of river water to which DDT was applied as a black-fly larvicide varied greatly, depending on the location of the sampling points and time of year [20]. The composition of the interstitial air, particularly at the perimeter areas of a large bulk of conventionally stored grain, may vary considerably, and was influenced by the time of day or night and the temperature gradients that pertain [12].

Examples of Differences in Uptake - As had been stated, the nature of a commodity (substrate), its particle size, moisture content, storage temperature, exposure period (contact time), nature of the fumigant and method of application are among 14 factors that influence fumigant residues [10]. Thus, Berck obtained differential uptake of the components of fumigant mixtures after fumigation of walnut meats [21]; wheat [15]; [22]; [17] and wheat fractions [10; 17].

There is considerable interest in phosphine, a remarkably effective fumigant. Tables I-III show in compressed form designated for slides some of many data obtained when PH_3 was applied in the gas phase to various substrates.

Table I shows differences in uptake of PH_3 by different wheat fractions stored at 35°C [13].

TABLE I. % Uptake of PH_3 by wheat fractions at 35°C. (95°F)

Substrate	Moisture Content %	% Uptake, Days 1	3
Flour, 1st Patent	14.1	7.1	11.1
Flour, 2nd Patent	14.0	13.7	20.1
Wheat Starch	9.3	12.3	16.8
Wheat Gluten	5.5	48.9	77.8
Wheat Germ, Raw	13.0	12.1	37.3
Wheat Bran	14.0	46.2	77.0

These and related data show that the % uptake varies not only with the type of product but with the storage period. In a subsequent study, different amounts of PH_3 were sorbed by different species of insects. We found that heterogeneity of response was "normal".

Table II shows the % chemisorption of PH_3 by 1st patent flour, starch and gluten powder at 2 temperatures and 2 storage

TABLE II. % Chemisorption of PH_3 by flour, starch and gluten

Wheat Product	Moisture %	Temp. °C.	% Chemisorption 1 Day	3 Days
Flour 1st Patent	14.1	24	2.8 ± 0.8	4.9 ± 1.0
		35	7.1 ± 2.1	11.1 ± 0.5
Starch, commercial	9.3	24	8.0 ± 0.6	12.1 ± 0.8
		35	12.3 ± 1.2	16.8 ± 0.5
Gluten, powdered	5.5	24	35.0 ± 0.8	51.2 ± 0.5
		35	48.9 ± 0.7	77.8 ± 1.2

periods. The amounts of substrate used were the same on a dry weight basis. In this instance the nature of the substrate rather than the moisture content as such has a major role. For gluten powder, its greater chemical (covalent) binding forces would explain its greater affinity for PH_3 (shown also by powdered casein, fish protein concentrate, soy and peanut flours, etc.). The % uptake was further increased when the exposure period was increased, but only a minor increase in uptake was obtained by flour and starch, respectively [18].

Table III shows % chemisorption of PH_3 by whole wheat kernels compared to the same kernels ground coarsely, both of 15% m.c. and held at 3 storage temperatures for 1 and 3 days, respectively. When the particle size of the kernels was reduced by coarse grinding, chemisorption was increased due to the increased availability of sites for chemical action. Similarly, increase in both temperature

TABLE III. % Chemisorption of PH_3 by whole vs. coarse ground wheat, 15% m.c.

Substrate	Temp., °C	% Chemisorption 1 Day	% Chemisorption 3 Days
Wheat, HRS, 15% m.c., whole kernel	4	0.0 ± 0.0	20.8 ± 3.9
	24	12.6 ± 0.7	34.8 ± 1.3
	35	29.4 ± 2.0	69.7 ± 2.3
Wheat, HRS, 15% m.c., coarse ground	4	5.8 ± 0.3	28.0 ± 2.2
	24	22.8 ± 2.4	43.8 ± 1.9
	35	40.5 ± 1.2	71.2 ± 2.5

and exposure time also increased % chemisorption [13].

These and other indications that PH_3 could be chemisorbed by wheat [13,18] were corroborated by other researchers using radioactively-labelled PH_3. By use of $^{32}PH_3$, Tkachuk [23] and Disney and Fowler [24] obtained PH_3 residues of an irreversible nature in wheat, and Robinson and Bond [25] in flour.

In wheat of 14% m.c., Tkachuk [23] obtained approximately 3.3 ppm of non-PH_3 residues from a commercial fumigant dosage rate of 6.6 ppm PH_3, w/v, calculated on the basis of 186 Phostoxin tablets/1,000 ft^3 (28,400 l.) of space. The distribution of residues was 85, 12 and 4% in the bran, endosperm and germ fractions. The residues were permanent and could not be removed by prolonged aeration or vacuum treatment. About 2/3 of the non-PH_3 residues in bran were water-soluble and were estimated to be 88% hypophosphite, H_2PO_3, and 12% pyrophosphate, $H_2P_2O_7^{--}$, (cf. 70% hypophosphite and 30% orthophosphate estimated by Robinson and Bond [25]. Tkachuk [23] also found, as did Berck [13], that proportionately more PH_3 was chemisorbed at smaller dosages. In passing, Berck [26,27] stated that inorganic phosphates would probably be formed as non-volatile residues due to the strong reducing properties of PH_3.

In an investigation of release of PH_3 from zinc phosphide, Zn_3P_2, broadcast by airplane as a rodenticide in sugarcane fields in Hawaii, Robinson and Hilton [28] obtained 42% irreversible uptake of PH_3 by sugarcane in aqueous acid medium. In their supplementary tests with $^{32}PH_3$, 30% of the PH_3 reacted irreversibly to yield water-soluble P compounds; 10% was inextricably bound in the fibre, possibly in the form of insoluble iron or aluminum salts (cf. irreversible capture of PH_3 by mineral substrates obtained by Berck and Gunther, [18].

Additional corroboration of the non-recoverability of some of the applied PH_3 was provided by Dr. S. A. Bellin [29] on tobacco, and Dr. S. K. Majumder [30] on miscellaneous agricultural products including wheat, cottonseed and pulse. Thus, whether or not one considers that formation of non-PH_3 residues is an "academic" point as stated by Bond [31], it is clear that semantics are involved in the interpretation of the term "residue". Thus, does absence of PH_3, methyl bromide, hydrogen cyanide, etc., in a product after aeration

mean that residues are absent?

The controversy regarding an acceptable all-inclusive definition of fumigant residues will evidently continue in the foreseeable future. A key point in this critique is that fumigant residues need not be toxic, or they may be of low mammalian toxicity after interaction of the fumigant with the substrate. In either case, toxicological back-up would be a prerequisite.

Reduction of Residue Levels - Controlled atmosphere (CA) storage using high levels of CO_2 or N_2 (e.g., [32] has considerable potential as a non-chemical means of controlling stored product insects. Problems of chemical residues and insect resistance to conventional chemical control may thus be circumvented. Calderon and Carmi [33] applied a 1:4 w/w combination of methyl bromide (MB): dry ice (solid CO_2) to wheat of 10 - 10.5% m.c. at 20° - 24°C and obtained increased downward penetration of MB, and increased mortality of test insects positioned at the bin bottom. Experimental bioassays of the headspace and interstitial atmospheres of high moisture wheat (15% - 22.5% m.c.) in hermetic and CA storage showed fungistatic and insecticidal properties that enhanced the biological control properties of CO_2 and N_2 as such [34]. Berck also obtained improved insecticidal effectiveness with a 1:9 v/v mixture of MB: CO_2 (1964, unpublished), and in preliminary experiments with a 1:9 v/w mixture of MB:CO_2 in 5-ft. steel columns. The downward penetration of MB was greater in HRS wheat of 12.5% m.c. than in wheat of 15.0% m.c. (1972, unpublished).

The point of this particular aspect is that there is much yet to be developed in improved knowledge of storage environments, including hermetic and CA storage to reduce dependence on chemical methods of control.

CLOSING COMMENTS: To improve our collective fumigant research, we need clear understanding of the multi-faceted role of storage environments on the concentration-space-time interrelations of fumigants and fumigant residues. We should use a variety of research methods to compensate the limitations of particular biological methods of assessment with the advantages of chemical assay methods. A primary need is the identification of the particular toxicants, their interactions and terminal residues under a range of environmental conditions.

Examination of bioassay procedures generally show considerable empiricism piled on someone's previously developed method. Premises based on C-T (concentration-time) relationships should be checked for validity at low concentrations and long contact periods, and at varying absolute humidities and temperatures. Water vapor in the environment has a primary influence on the effectiveness of fumigation.

The advantages of chemical assay are the limitations of bioassay methods and vice versa. This reciprocal relationship should be applied much more than is presently the case. Thus, bioassay results based on different dosage increments would be more valid when the exact amount of pesticide available to the test

species in its natural habitat is known at any given point in time.

No substance is absolutely inert, only relatively so. Fumigant gases can be sorbed both physically and chemically by a wide variety of substances including insects. It should therefore be no surprise that some cereal substrates have a greater affinity for fumigant residues than others. It was previously indicated that the reactivity and retention characteristics of a substrate can be modified, in much the same way as a column packing used in gas chromatography [13].

Storage environments and their different microclimates affect both the insecticidal effectiveness of fumigants and the amount and kind of fumigant residues. Fumigant residues are of two main types, namely, physically bound and chemically bound residues (pbr and cbr). The kind of cereal product, the particle size, moisture content, temperature, exposure time, nature and amount of fumigant, dockage, aeration intensity, etc., can influence the ratio as well as the absolute amounts of pbr and cbr. The extraction, isolation and identification of the pbr and cbr fractions are challenging and exacting analytical tasks for the residue chemist.

Our greatest need is for more complete analytical and toxicological data to make possible a rational interpretation of fumigant residues. At the moment, there is considerable emotion and thus incorrect assumptions about the connotations of the term "residue".

As a parting shot, I am somewhat critical of those who rush onto the computer science bandwagon before adequate examination of the assumptions on which their methods are founded. I am of the impression that incorrect or misleading conclusions can emanate from computer science if a given investigation is founded on "wrong" premises, inadequately understood concepts, or half-truths and missing links. Pertaining to these points, Dr. Mike Saunders [31] correlated increased work pressure with the rationalization of the practice presently developing in many areas of shovelling multivariate data into a computer. He stated that this could be of value when there is a step-by-step comprehension of what is happening to the data, and the meaning of the output. In the past, tackling complicated statistical procedures by hand was tedious but useful because of the motivation of dire necessity and clearer understanding of the basics of the problem. Presently, however, exotic procedures cloaked in new language and comprehensible only to the inner sanctum pose the threat of burying the inadequacies of experimental methods under mountains of print-out data, rendering more difficult (even for computers and computricians) the task of isolating the cause-and-effect relationships. The twin computerized acronyms GIGO ("garbage in, garbage out") and FIGO ("facts in, garbage out") might, in some cases at least, be difficult to separate. Despite these critical remarks, I nevertheless appreciate the great value of computer science.

In closing, I hope that my comments in this critique have provided you with food for thought and revived critical attitudes. I have in any event thoroughly enjoyed the beautiful Savannah

weather, the great hospitality and the opportunity of renewing acquaintanceships, meeting new faces, and exchanging information and viewpoints with the many participants at this well-organized International Work Conference.

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