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TOXICOLOGICAL CONSEQUENCES OF PESTICIDAL USE

IN THE

REPUBLIC OF SOUTH AFRICA

by

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in fulfillment of the requirements for
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STATEMENT OF ORIGINALITY

The work presented in this thesis is original except where otherwise stated and acknowledged in the text.

With respect to Chapter 3, most of the 5 538 ~~feed~~ samples (from 13 locations) were collected by others under the direction of the candidate, so as to sample all locations simultaneously.

Chapter 4 is based on the returns of a questionnaire designed by the candidate (see page 114).

With regard to Appendix 1, it should be noted that "all material used in the monograms are from the clinical literature" (page X of Appendix 1).

Signed

H.O. FOURIE

The Lord is my strength
and my shield; my heart
trusted in Him, and I am
helped: therefore my
heart greatly rejoiceth;
and with my song will I
praise Him.

Psalm 28:7

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ABSTRACT

Chemicals used in agricultural activities, could possibly be the most potent group of compounds used on a regular basis by employees representing a significant fraction of the unskilled, economically active, labour market of a country. Certainly such a statement will hold true for South Africa and probably for most Third World and developing states. All chemical compounds contain the inherent property of being toxic and/or hazardous. However, pesticides are chemicals intentionally used to kill. They are therefore not avoidable and in contrast to other chemicals are used only because of their ability to kill.

As in most other countries in the world, poisoning in the Republic of South Africa is to be expected due to the use of pesticides. In the handling of pesticides, statistics show South Africa to be vulnerable to an appreciable number of deaths and poisoning cases. There could be a number of reasons for this phenomenon, two of them probably being ignorance and negligence on the part of officers in charge of handling pesticides, and perhaps the most important, the exploitation of unskilled labour in applying and handling pesticides. It is believed that the South African agricultural industry represents both the First and Third World and should thus be ideally suited for investigating:

- (1) acute intoxication due to chemicals used in the agricultural industry. It was found that the annual consumption of pesticides in the Republic of South Africa results in a dose of approximately 250 mg/m^2 which compares very favourably with consumption rates of developed countries. An analysis of the products registered indicates a total of 1 211 products containing 359 different active ingredients. The three chemical groups responsible for 73% of the poisoning cases (organophosphates 55%, carbamates 14%, organochlorines 4%) are with the exception of pyrethroids, also the chemicals most frequently formulated. Products containing these three chemical groups constitute only 41% of all formulated products, but are responsible for 73% of all intoxications. It is concluded that the poisoning rate by pesticides is appreciably

higher than officially notified, and that the fatality rate could be two orders of magnitude higher than developed countries. A compendium - the first of its kind in South Africa - for use by hospitals and clinical practitioners and containing trade names, chemical classification, active ingredients, toxicology, symptomatology and proposed treatment procedures for each product, is presented as an appendix.

- (2) chronic exposure to residues of agricultural products in the diet of South Africans is investigated. Food intake data was calculated from 24-hour dietary recall studies. Residues of only 4 compounds were present in 33 composite, ready-to-eat foods, consisting of 5 538 foodstuffs sampled over a period of one year country wide, and representing 142 different food items categorised into 11 food groups. The residues found were well within acceptable levels and compare very favourably with those found in the diets of developed countries. It has to be concluded that possible chronic exposure due to agricultural chemical contaminants, to the white population at least, does not exist, and emphasises a sound regulatory policy towards the use of these chemicals in South Africa.

- (3) a hypothesis of this study that it is not possible that neither the inherent toxicities of pesticidal compounds, nor a paucity of knowledge about the toxicological, chemical and physical properties of these compounds could be mainly responsible for the numerous intoxications recorded annually. An epidemiological 400 case study (descriptive design), investigated the contribution by occupational, environmental, cultural and socio-economic variables to poisoning. The numerous effects by these variables are described and amongst many others, it is concluded that the recommendations of the World Health Organization to classify pesticides by hazard, is confusing to illiterate and semi-educated users and should not be recommended to developing countries.

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August, 1986.

Fertilizers: - grow bigger crops
Insecticides, herbicides, fungicides: -
protect crops against a
variety of pests.

CHAPTER I

INTRODUCTION

1.1 Production and uses of chemicals

Chemicals are indispensable commodities for the survival of mankind, and for all forms of life for that matter. We acknowledge the fact that chemical compounds make up the air we breathe, the food we eat and the energy we use. Scientific literature is literally a vast body of data on the necessity of chemicals for survival on the one hand, and of disasters and effacement on the other hand. Even the use of chemicals to destroy one form of life to enable the survival of another, is reported to have been employed as early as 35 centuries ago. Creeger (1982) reports: "The earliest references I have seen regarding specific chemical agents being used as pesticides goes back about 35 centuries when Joseph tells Pharaoh how he plans to use salt, silver dust and sawdust with preservative properties to preserve the food collected in the 7 years of plenty for the 7 years of famine." The importance of such a reference should not be overlooked. It implies that man, since the earliest days, has recognised (1) the beneficial uses of chemicals; (2) the ability of a chemical to destroy. It also implies, indirectly, that man proved centuries ago that it is not the chemical which is ultimately beneficial or "evil" but that it is man by his actions who determines the fate of the chemical. It has not changed since. At present man can isolate chemicals from natural products or prepare them synthetically in larger amounts than ever and will continue to do so. We need chemicals to feed the world's ever growing population, to cure the sick and to provide energy to sustain all forms of living matter. We need chemicals to grow bigger crops (fertilizers), to protect crops against a variety of pests (insecticides, herbicides, fungicides), to produce medicine to combat disease (pharmaceuticals) and to produce energy for industry and transport. Thus it is obvious that chemicals are essential to keep an ever growing world population healthy, prosperous, happy and satisfied, because a sound growth in the economy and the prosperity of a state is reflected in the mental and physical condition of its inhabitants.

However, a reminder of Sir Isaac Newton's Third Law of Motion, one of the

fundamental laws on which chemical dynamics is based, would not be inappropriate: for every action there is an equal and opposite reaction! If not used correctly, responsibly, with great care and respect, chemicals can have a very serious detrimental effect on man and the ecology. Man is directly exposed to chemicals when the chemicals per se are consumed orally or through the skin and indirectly when consumed through the environment, such as air, water and foodstuffs. Ingesting chemicals through foodstuffs, for example, can be very serious because many a chemical compound has a long effective life with the tendency to accumulate to extraordinary concentrations in the food chain. Many of these chemical compounds are also subjected to biochemical changes which could introduce a totally different compound with even more hazardous properties than the parent compound.

The effect of chemicals on the health of man depends on their chemical and physical properties, the duration and frequency of exposure, accumulation and metabolism and the ability of the human being to offer resistance. The embryo, foetus and certain segments of the general population such as children, the elderly and the sick are more susceptible to the toxic affect of chemicals. Accidental exposure to toxic compounds has reached epidemic proportions in the past two or three decades. An example of such an event is the mass poisoning by organo~~o~~mercury compounds in Japan. Chemicals can have a detrimental effect on fauna and flora such that species may be endangered, while chemicals could also influence local and global weather conditions. Examples are the effects of air pollution and of oxides of nitrogen and fluoroc~~o~~carbons on the ozone layer in the upper atmosphere. It is obvious to what extent chemicals can pollute fresh and marine water systems. Aquatic life is very vulnerable to very low concentrations of metal pollution and it is easy to pollute to the extent where aquatic life could be exterminated.

The modern chemical industry produces a large quantity of chemicals to be used in virtually every commodity and it would not be wrong to state that these chemicals should protect, prolong and enhance life. However, the indiscriminate use of such chemicals could achieve just the opposite. Although the literature differs (understandably) on the exact amount of chemicals produced worldwide, estimates are all within the same order of magnitude. Table 1.1 shows an estimate by the World Health Organization of the number of compounds used in daily activities (WHO, 1978).

TABLE 1.1CHEMICAL COMPOUNDS USED IN DAILY ACTIVITIESAN ESTIMATE BY THE WHO

Number of compounds isolated from natural products or prepared synthetically	4 000 000
Compounds used daily	60 000
This could be subdivided as follows:	
Active ingredients in insecticidal formulations	1 500
Tranquilizers	4 000
Additives in Food Industry	5 500
Industrial chemicals, agricultural products, fuels and chemical consumer goods	49 000
Annual growth in number of new products	200 - 1 000

These estimates by WHO do not differ significantly from those reported by Leslie Roberts (1984): 5 000 000 known chemical substances of which only about 7 000 have been tested for carcinogenicity. Of these, 1 500 have been identified as being carcinogenic in animal studies, of which 30 have definitely been linked to cancer in humans. With reference to pesticidal chemicals in relation to total chemicals, the impact of pesticidal chemicals on environmental quality has received much more attention. This is an anomaly which should be rectified as total chemicals, with an annual world production of several hundred million tons, need to be considered (Korte, 1980). Studies in the aquatic environment on a worldwide basis have identified 2 221 different organic compounds of which 765 are in drinking water. Of these, 43 are suspected carcinogens, 56 are mutagenic contaminants and 18 are carcinogenic promoters (Bedding, N.D. et al, 1983). Chemicals are a natural entity in the environment and natural chemical processes occur in the environment. If not interfered with, the distribution, reactions, pathways and thermodynamics of chemicals would be in equilibrium with the total environment. However, this is not possible. More than five million chemical compounds have been synthesized or isolated from nature through industrial activities and the chemical industry produces about a hundred and fifty million tons of synthetic chemicals annually. Billions of tons of oil and large quantities of

organic and inorganic materials are released annually from their natural deposits or the environment (Hutzinger, 1984). On the production of chemicals, Table 1.2 (Korte and Klein, 1982) gives an indication of which chemicals are produced in excess of 50 000 tons annually, while Table 1.3 (Hutzinger, 1984) is a summary of the production of the main groups of anthropogenic chemicals with indications as to their uses, toxicology and ecotoxicology.

TABLE 1.2

SELECTION OF CHEMICALS WITH ANNUAL GLOBAL PRODUCTION > 50 000 TONS
(COMPILED FOR OECD BY GERMAN AD HOC GROUP)

Organics	1 000 tons	Inorganics	1 000 tons
Acetaldehyde	2 400	Aluminium oxide	17 000
Acrylonitrile	2 700	Ammonia	40 000
Alkylbenzenes	700	Chlorine	24 600
Benzene	14 400	Iron sulfate	450
Carbon tetrachloride	1 000	Lead oxides	363
Chloroparaffins	270	Nitric acid	23 000
Cyclohexane	2 800	Phosphoric acid	13 000
Dibutyl phthalate	230	Sodium chlorate	600
Phthalic acid anhydride	2 300	Sodium chromate	
Toluene	8 500	+ bichromate	450
Trichloroethylene	700	Sulfuric acid	108 300
Vinyl chloride	7 730	Zinc oxide	420

TABLE 1.3

SOME ANTHROPOGENIC COMPOUNDS

Compound	Annual Production	Application	Toxicology and persistence	Ecotoxicology & persistence
Mercury	10×10^6 kg	Industrial Agricultural Pharmaceutical	$T_{1/2}$ = 70 days carcinogenic teratogenic embryotoxic	$T_{1/2}$ in fish : 1 - 3 yr. When confined, active for 100 years
Cadmium	14×10^6 kg	Industrial	$T_{1/2}$: 13 - 47 yr. critical organ : kidney	Accumulative in food chain
Fluorocarbons	754×10^9 kg	Aerosol propellants Refrigerants Plastic industry	Complete elimination in 1 hour if oxygen supplied	Atmospheric residence time = 50 - 100 years
Chlorinated Paraffins C ₁₀ - C ₃₀	$2,3 \times 10^6$ kg	Plasticizer Lubricants Paints Flame retardants	Probably as for PCB but with lower potential	Data very limited : Accumulation coefficient: 10 - 770 and decreases with increasing carbon chain length $T_{1/2}$ = 7 - 34 days
Chlorophenols	15×10^7 kg	Wood preservatives Pesticides Pulp, paper and hide industry	Rapid elimination from body: + 90% in 3 days	Persistence: water - 6 months sediments - 8 yr
Organic dyes and pigments	6×10^8 kg	Textile dyes Paper/leather dyes Organic pigments	Varies from very low toxicity (organic pigments) to carcinogenic (some food, cosmetic colourants and azo-dyes)	6×10^7 kg lost to environment Estimated fairly persistent
Lead	$3,6 \times 10^9$ kg	Paints Cables and sheeting Batteries Fuels Alloys	Effects on : Haemopoietic system Nervous system Renal system Cardiovascular system Reproductive system Endocrine organs	Residence times :- atmosphere : 3 - 26 hours sediments and oceans : 600 to 2 000 years
Arsenic	5×10^7 kg (As ₂ O ₃)	Pesticides Alloys Colouring Light-emitting diodes	Gastrointestinal damage Cardiac abnormalities Possibly carcinogenic : skin and lung	Nonaccumulative in air, plant and water phases of agronomic ecosystem. Mobile in environment - soil is sink
Beryllium	3×10^6 kg	Alloys Nuclear applications	Not retained but excreted by body. Produces ulcers, rhinitis and several chronic effects	Very little released to environment
Selenium	1×10^6 kg	Glass Pigments Plastics Paints Lubricants Electronic industry	Pulmonary edema Haemorrhaging Vascular disruptions Animals : vitality loss lameness disfigured hooves loss of hair/fur	Strongly accumulated by plants, algae, etc. Water pollution minimal due to insoluble selenite
Vanadium	U.S.A. consumption: 5×10^3 kg	Alloys Nuclear applications Dyes	Administered orally, then toxicity high - increases with valence	Widely distributed in nature. Strongly accumulated.
Aliphatic Hydrocarbons	30×10^9 kg	Solvents Fumigants Plastics Scavengers Synthetic rubbers	Liver damage Possible carcinogens	9×10^9 kg annual input to environment, mainly atmosphere
Halogenated Aromatics	PcB 7×10^4 kg PcT 5×10^6 kg PcN 5×10^6 kg PBB 5×10^6 kg Benzene derivatives 9×10^8 kg	PcB: electrical, hydraulic, plasticizers, paints, adhesives. PcT: adhesives, sealant PcN: electrical, oil adhesives Benzene derivatives: solvents, odorizers, intermediates	Chloracne Hepatic porphyria Liver damage Blood disorders	PcB: cumulative to environment. Between 1929 - 1970 about 3×10^8 kg released to environment. Between 25% - 75% of total amount ($7,5 \times 10^8$ kg) produced is still in existence. Benzene derivatives: few hundred kg released to environment per annum.
Volatile Aromatics	Benzene: 15×10^9 kg Toluene: 5×10^9 kg Xylene, Ethyl benzene and styrene: 20×10^9 kg Chlorinated benzene: 6×10^8 kg	Solvents Intermediates Paints Printing industry	Benzene: chromosome damage, leukaemia	Benzene $T_{1/2}$ = 37 minutes

It is to be expected that an estimate of the production of chemical substances on a worldwide basis will vary. A summary of global production figures which is regarded as probably reasonable, is given in Table 1.4 (Miller, 1978).

TABLE 1.4

PRODUCTION OF CHEMICAL SUBSTANCES

Amount produced (metric tons/year world-wide)	Number of substances produced in excess of this level
500	1 500
50 000	100
1 000 000	50

The variation in the use of such chemical substances is illustrated by the enormous rate of change in, for example, "drugs" listed in the U.S. Pharmacopoeia where 90% of the compounds listed in 1940 are absent today (Robertson, 1978). Although production figures of the magnitudes given in Tables 1.1 - 1.4, could be regarded as alarming and posing a potential threat to the total environment particularly when localised, concentrations of such substances on a global basis may be regarded as negligible (Miller, 1978). Should 500 tons of chemicals be uniformly distributed over the earth's land area (land area = $\pm 1,7 \times 10^{14} \text{ m}^2$), the surface dose would only be $3 \mu\text{g}/\text{m}^2$. Miller calculated that even if distributed over agricultural areas only, the dose would still only be $12 \mu\text{g}/\text{m}^2$. It would seem inappropriate in a calculation of this kind to use the figure of 500 tons as being the global production of chemicals per annum when from Tables 1.1 - 1.3 it is evident that this figure is substantially more. However, it should be remembered that most of these chemicals are industrial chemicals which have a relatively high vapour pressure and therefore enter the atmosphere in very significant quantities. In fact, chemicals with low vapour pressures ($<10^{-6}$ bar) which are

also persistent against biodegradation (DDT, HCB, PCB) can and do enter the atmosphere in significant quantities (Korte and Klein, 1982). It has been demonstrated (Klein and Scheunert, 1978) that aldrin and similar chemicals volatilise by 50% from the soil within 5 years of application and that absorption by plants and leaching by water during the 5 years are of minor importance. Aldrin residues in the soil after 5 years were 34,5%, absorption by plants 0,6%, leaching by water 10,6% and volatilization 54,3%. Most significant is the conclusion that transport and movement in the biota does not play a significant role in the long-term dispersion of these chemicals, which means that physical and physicochemical factors must be mainly responsible. With reference to the future it is suggested (Korte and Klein, 1982; Miller, 1978) that with an estimated growth rate of 2% per annum in the chemical industry - which must be very modest - a sevenfold increase in use will result and a 700-fold increase in environmental concentration within one hundred years. Although Korte and Klein (1982) claim that, with reference to biologically active chemicals, an increase of such a nature will do no significant harm, it must be of prime concern, as a uniform distribution in the environment globally, is only possible from a theoretical point of view.

The uses and applications of chemicals have over the decades mainly resulted in (1) economic benefits; (2) poisoning of man; and (3) detrimental effects to the environment, either by accident or deliberately through the generating of wastes. Perhaps one of the most beneficial uses of chemicals known to man is the use of chemicals to overcome the problem of malaria. To illustrate the economic benefits due to malaria control, it is interesting to observe the results in Greece during the early sixties (Hayes, 1975) as shown in Table 1.5.

TABLE 1.5Estimated annual losses recovered by malaria control in Greece

Factor responsible	US \$
1. Time lost from work (recognised cases)	12 000 000
2. Expense for drugs	1 000 000
3. Expense for medical care	2 500 000
4. Economic loss due to mortality caused by malaria	7 500 000
5. Loss due to mortality caused indirectly by malaria	3 000 000
Total annual loss	26 000 000

In contrast, the annual cost of the program did not exceed \$ 1 500 000! However, these economic benefits are sadly counterbalanced by the detrimental effects to man. In some rough estimates (Goldfrank, 1978) the magnitude of this kind of problem is demonstrated in the United States today:

- 500 000 persons are narcotics addicts
- 2 000 000 children ingest toxic products each year
- 1 000 - 2 000 children succumb to ingestants each year
- 600 000 persons attempt suicide (by using chemicals) each year
- 6 000 persons commit suicide by ingesting toxic products
- 90% of all poisoning victims are children
- 80% - 90% of childhood poisonings occur in children under 5 years of age
- 10% - 20% of all admissions to adult medical services are for toxic ingestions
- 2% - 5% of all admissions to paediatric medical services are for toxic ingestions
- over 250 000 drugs and commercial products are available for ingestion
- \$11 billion are spent in the United States each year on prescribed medicine

- more than 2,8 billion drug orders and prescriptions are written annually.

The generation and disposal of wastes are similar problems. Through (1) dispersion in air and water, (2) the relative ease of environmental degradation and (3) the often resultant toxicity of the degraded chemicals, waste disposal could be the major disaster to ecosystems and to man and his environment. On pages 6 and 7 the fate of chemicals mainly introduced →

into the geosphere was discussed and it was emphasised that (1) 50% of chemicals volatilise from the soil within 5 years and (2) that transport and movement in the biota does not play a significant role in the long-term dispersion of chemicals. However, the probability that these two factors reduce the environmental impact of released or dumped wastes, could be challenged. The fact that such wastes are (1) usually dumped in enormous amounts in a very confined area; (2) usually in drums or other containers which inhibit degradation and facilitate a continuous release and (3) usually of a mixed and very complex chemical nature, emphasizes the much greater possibility of local contamination rather than an evenly dispersed, less densely concentrated phenomenon.

Thus, chemical wastes generated by domestic, agricultural and industrial activities would ultimately contaminate natural waters and therefore affect survival, growth and reproduction of organisms. Recreational and agricultural interests in aquatic ecosystems will likewise not only be negatively affected by the release of wastes but could also affect the health detrimentally through toxic contaminants in drinking water. Wastes must therefore be regarded as potential pollutants with poisoning properties. In fact, it has been suggested that from an environmental and ecotoxicological point of view, a waste should be regarded as a poison causing pollution and that a waste could be defined as a substance or material which falls into disuse and differs in its chemical or physical properties from its natural or original occurrence in nature, or which, due to synthetic preparation, does not naturally occur in nature. The seriousness of wastes being a pollutant can be illustrated by properties such as (1) toxicants being highly potent and selective as lethal and sublethal agents; (2) resistance to denaturation; (3) changes to more toxic forms; and (4) accumulation and magnification within the food chain (Anderson, 1978).

The extent to which waste is generated worldwide is not known. For some reason such data, as far as volumes are concerned, are also not dealt with in scientific literature. It is, however, dealt with in the day-to-day press, from which it is possible to get some idea of the magnitude of the problem:-

1. "The Canadian federal government estimated in 1982 that at least 3,2 million tons of hazardous wastes are generated in Canada each year" (Jackson, 1982).
2. "State and federal officials have filed a \$40 million lawsuit against 31 defendants who owned, operated or disposed of toxic wastes at the notorious Stringfellow Acid pit in Riverside county" (Los Angeles Times, 1983).
3. "The EPA has identified at least 11 000 additional sites that remain active, as toxic wastes continue to pour in. Other estimates place the figure as high as 50 000" (Washington Post, 1983).
4. "In 1980, according to EPA figures, US industry generated more than 400 pounds of hazardous waste for every man, woman and child in the country. It all went to an incinerator, as landfill or some other storage facility. EPA has estimated that 90% of these facilities have inadequate environmental safeguards and 75% of the landfill sites are close to wetlands, aquifers or flood plains" (Washington Post, 1983).
5. "... about 200 drums had identifying marks. Asked how many drums were removed during that phase, he replied: 'Somewhere between 4 400 and 4 700'" (Washington Post, 1983).
6. "At the Seymore recycling dump near Seymore, 24 firms ... to pay \$7,7 million to clean up ... more than 50 000 drums and 500 000 gallons of liquid waste" (Washington Post, 1983).
7. "... and made a ghost town of Times Beach, Missouri, permanently evacuated in 1983. Dusty dirt roads there had been sprayed a decade earlier with oil contaminated by dioxin" (National Geographic, March 1985).

8. "EPA lists 786 Superfund sites nationwide, has fully cleaned 12 and expects eventually to purge 1 500 to 2 500 at a cost of as much as 23 billion dollars" (National Geographic, 1985).

Although these citations are only representative for the United States of America and for Canada, there is no reason why they should differ from other industrialised countries. On the other hand, many other countries, of which the Republic of South Africa is one, will become heavily industrialised in the near future and it would be grossly irresponsible not to take cognizance of the problems encountered by the developed countries when industrialisation took place without a firm national policy on waste management.

In agriculture a great variety of chemicals is used. They can be classified into groups according to their chemical structure and properties (Appendix 1). From a toxicological point of view some of these groups are very poisonous (e.g. organophosphates and carbamates) but have the advantage that they are relatively easily biodegradable. Others may have a relatively low acute toxicity (e.g. organochlorines) but have the disadvantage of being more detrimental to the ecology and only biodegrade very slowly.

Most of the pesticides currently used, lose their toxic properties through hydrolysis in the environment. In Table 1.6 (Korte, 1978) the environmental halflives of several organophosphorous compounds are presented and the breakdown, or decreasing stability with increasing temperature, is illustrated.

TABLE 1.6Halflives ($t_{1/2}$) of Organophosphorous Compounds in Aqueous Solution

Compound	Temperature (°C)						
	0	10	20	30	40	50	60
	Days						
Parathion	13 800	3 000	690	180	50	15	5
Methyl-parathion	3 600	760	175	45	12,5	4	1,3
Chlorthion	2 900	600	138	36	10	3	1
Metasystox R1	4 800	970	236	62	18	5	1,7
Disulfoton	23 200	4 830	1 110	290	78	24	8
Azinphosmethyl	5 200	1 070	240	62	18	5,5	2
Trichlorphon	11 600	2 400	586	140	41	11	3

From Korte (1978)

Although hydrolysis is also important in the breakdown of the more persistent compounds (e.g. organochlorides), these compounds are more persistent in the environment. DDT, for example, has an environmental half-life of about ten years, while its breakdown products, DDE for example, can persist for decades (Duffos, 1980). Less persistent are aldrin and dieldrin, which require 2½ years in the soil for 95% degradation (Duffos, 1980) but do not transport deeply into the soil due to their low water solubility and very strong tendency to be absorbed into soil.

Pesticides must be regarded as chemicals used as poisons per se, for the environment as well as for man. It should be recognised that it is not always possible to use such compounds without any effect on organisms other than the target species. Not only can non-target species be detrimentally affected at the point of introduction but also in the immediate surrounding areas, due to local transport mechanisms. A model, which indicates the possible pathways of pesticides and fertilizers, is given in Fig. 1.0 (Korte, 1978).

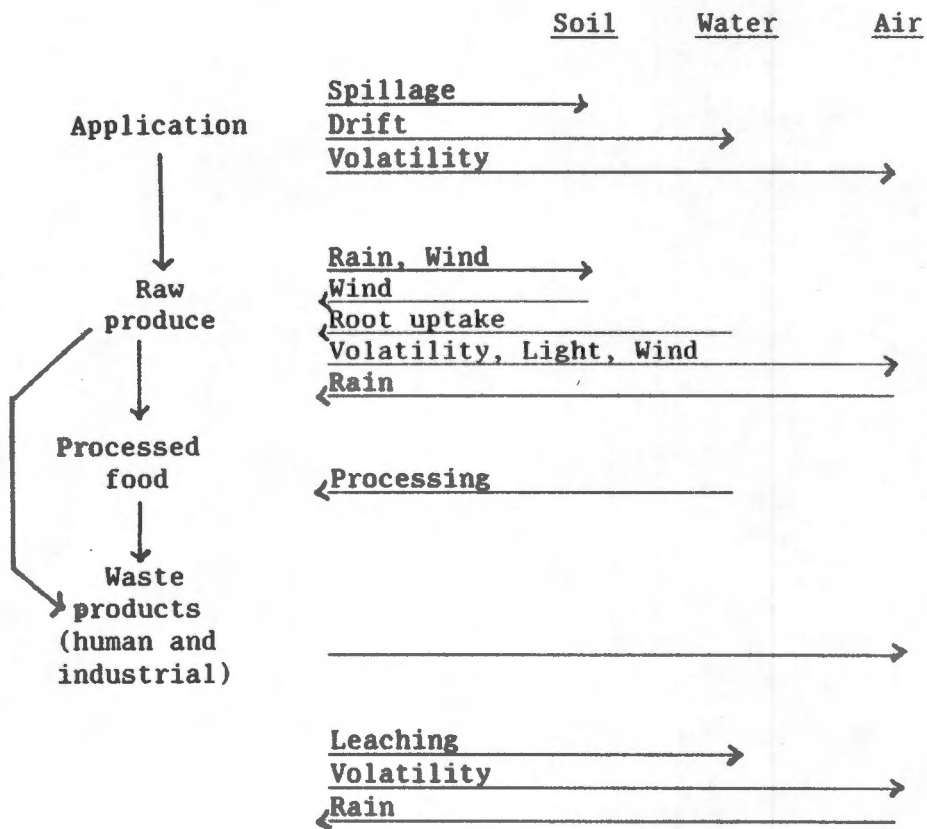
It should be stressed, however, that pesticides will not adversely threaten the environment or human life when used according to correct, prescribed conditions, notwithstanding the fact that these are chemicals intentionally and deliberately released to the environment to kill.

A relatively small surface area in the Republic of South Africa is available for agricultural production of food. Thus for a fast-growing population, more food has to be produced per unit area to provide for domestic needs. This means that use has to be made of agricultural chemicals. The annual consumption in the RSA during the period 1978 - 1979 is given in Table 1.7.

This consumption of 24 298 metric tons ($2,4 \times 10^{10}$ g), evenly distributed over the total area of 1×10^{11} m² currently used for production of a variety of crops in the Republic results in a dose of 250mg/m². This figure compares favourably with those of some other countries, available from the literature (Table 1.8). However, if compared with the figures of 3 µg and 12 µg per meter as a surface dose distributed uniformly worldwide (page 6), it illustrates that this kind of calculation is of a purely theoretical nature and although it might be of some significance for a global estimate, it certainly does not apply under local conditions.

FIGURE 1.0

FATES OF CHEMICALS IN THE ENVIRONMENT



From Korte (1978)

TABLE 1.7

ANNUAL PESTICIDAL USE IN THE REPUBLIC OF SOUTH AFRICA
1978 - 1979

	<u>Active ingredient</u> <u>(metric tons)</u>
<u>Insecticides:</u>	
Organochlorines	666
Carbamates	1 224
Organophosphates	1 220
Pyrethroids	14
Mineral Oil	4 758
Carbaryl	1 017
Sulphur	375
Parathion	230
Mercaptothion	185
<u>Herbicides:</u>	
Triazines	1 958
Phenoxy derivatives	1 316
Ureas and uracils	1 094
Aliphatics	711
Carbamates and thiocarbamates	444
Amides	431
Bipyridyliums	129
<u>Fungicides:</u>	
Sulphur	2 432
Dithiocarbamates	1 717
Copper oxychloride	519
Systemic fungicides	26
Carboximides	47
Fumigants	3 300
Plant growth regulators	291
Seed dressings	94
Acaricides	90
Vermin killers	2
Slug and snail killers	8

TABLE 1.8ANNUAL CONSUMPTION OF PESTICIDES

Location	Area		Consumption g	Consumption / Area mg/m ²	References
	ha	m ²			
Brazil (Parana)	7,8 x 10 ⁶	7,8 x 10 ¹⁰	5,6 x 10 ¹⁰ (40% of total use in Brazil)	720	Amaral 1982
India	8 x 10 ⁷	8 x 10 ¹¹	6,5 x 10 ¹⁰	81	Kashyup 1982
R.S.A.	1 x 10 ⁷	1 x 10 ¹¹	2,4 x 10 ¹⁰	250	
Japan	-	-	-	1 200	Kashyup 1982
U.S.A.	-	-	-	300	Kashyup 1982
Hungary	-	-	8 x 10 ⁷	-	Borda's 1982

1.2 Toxicology : Definitions, theories and principles

1.2.1 Introduction

The science which studies the detrimental or adverse effects by chemicals on a living cell is called toxicology. It is the study of the quantitative effects of chemicals on biological tissue (Loomis, 1978); the science by which a qualitative and quantitative study is made to observe the alterations of structure and response in living systems caused by chemical and physical agents (Fourie, 1984); the study of the injurious effects of chemical substances on living organisms, usually mammals (Hathway, 1984). Toxicology is concerned with the toxic lesions produced by exposure to chemicals (WHO, 1978).

The definitions quoted above have essentially two concepts in common: (1) Effects occur (due to chemical and/or physical agents) which must be described as undesirable, i.e. detrimental, adverse, alterations of structure, injurious and toxic; and (2) the (undesirable) effects occur with reference to some kind of life, i.e. living cells, biological tissue, living systems, living organisms and mammals. The two concepts are usually united in expressions such as toxic, toxicity and harmful or harmfulness. The indiscriminate use of these expressions to indicate an undesirable effect, or to make comparisons between the agents responsible for an effect, or even worse, to use such expressions in "evaluating" the agents with the objective of predicting their behaviour, must be deplored. Toxic is an expression indicating that an agent is harmful, but such an indication is only of value when reference is made to a specific biological entity. What may be toxic to a specific biological cell, could have no effect on another and could even be desirable. Harmful should only be used to give expression to an impaired or destroyed function by a specific agent, when the amount, volume or dosage of the agent is known. Irrespective of the fact that an agent or chemical compound has a threshold value below which it will exert no harmful effects, the knowledge that a harmful effect does occur is meaningless if the dosage is not known. Toxicity is perhaps the term most frequently used incorrectly, especially by non-toxicologists. Commonly toxicity, and the numerical value assigned to this term, is used in isolation and used as if it is an inherent property such as for example physical-chemical properties of

chemical compounds. This is not true.

Toxicity is nothing more than a relative term (numeric value) which could be used to compare one compound with another, taking into consideration the conditions under which the effect takes place as well as the biological mechanisms involved. Although this concept is elementary, a thorough understanding of definitions is of the utmost importance before proceeding to the theories and principles of classical toxicology, ecotoxicology and eventually risk assessment and regulatory toxicology.

The subject of toxicology tends to be fragmented or sub-divided for reasons which are not clear. For example, in Essentials of Toxicology (Loomis, 1978) the author divides toxicology into environmental toxicology, economic toxicology and forensic toxicology, while in Molecular aspects of Toxicology (Hathway, 1984) the author notes the division of toxicology into chemical, cosmetic, environmental, food and drug, industrial and pesticide toxicology and the toxicology of atmospheric pollution. I do not suggest that toxicologists should not specialise in one or other field or discipline of toxicology, but there is no reason for fragmentation with both subsequent negligence of the subject *per se* as well as creating confusion about the terms of reference of the subject.

When the term toxicology is used without reference to the organism being studied, then the subject refers to (1) man; (2) the individual; and (3) only those effects once the agent is absorbed. Should the term toxicology be used with any other form of life, then it should be clearly stated, e.g. toxicology of the rabbit. But once again it only refers to the individual and the effects after absorption. The concepts Environmental Toxicology and Ecotoxicology are totally different concepts and are dealt with in sections 1.3 and 1.4 respectively.

1.2.2 Absorption

Before a reaction can take place between two chemicals, certain conditions must prevail: there has to be physical contact, some solubility in a solution or carrier must exist and, rather important, should the product of such a reaction in a given medium not be removed, equilibrium will be reached due to the incompleteness of the reaction. This is true not only

for chemical reactions in general, but also for those in a biological system.

Three natural routes of exposure for the absorption of a chemical into the body exist: ingestion into the gastrointestinal tract, inhalation and dermal absorption. All three of these routes are equally important. In accidental poisoning, children are mainly the victims of the ingestion of xenobiotics; in the agricultural sector where pesticides have to be applied, dermal absorption is a major problem and the inhalation of gases, aerosols and fibres with a small particle size, is frequently encountered in many industrial processes. It is perhaps too generally accepted that the rate of absorption of a chemical is inhalation > gastrointestinal > dermal which is an over simplification of the routes of exposure and resultant effects, leading not only to ignorance but also to biological harm which could have been avoided.

In the gastrointestinal tract absorption occurs mainly in three sections: the mouth, stomach and intestines. Effects within the gastrointestinal tract are limited to the surfaces of mucosal cells - gastric contents do not really form part of body fluids - and a chemical would not exert any further toxic effect unless it is absorbed. To a certain extent, and in comparison with the other routes of exposure, this could be regarded as some sort of safety mechanism or safety factor, although the same argument is valid for intoxication by absorption from the respiratory tract where particle size is an important criterion.

It is well known that certain chemicals and drugs can be absorbed through the mouth and oesophagus but normal conditions, such as a chemical not being exposed to digestive juices and metabolising enzymes, inhibit any significant degree of absorption. On the other hand, such chemicals are not transported by the hepatic portal system to the liver, which may preclude rapid metabolism and therefore prolong their effect (WHO, 1978).

Chemicals and other xenobiotics are absorbed significantly from the stomach (Schanker, 1957) through passive diffusion (section 1.2.3). Several factors will influence absorption from the stomach. Acidity (pH), ionisation of weak acids and bases, lipid solubility, pre-existing stomach contents as well as secretions, are all factors which could alter the state of the free chemical and thereby influence the absorption rate of a

substance.

Absorption from the small intestine is similar to that from the stomach but the rate could be influenced by different pH and additional gastric contents. It is reported (WHO, 1978) that an aqueous pore size of 4Å limits absorption by filtration to molecules having a molecular weight of less than about 200. The many interesting and important factors which can effect absorption from the gastrointestinal tract have been reviewed and documented by the World Health Organization (WHO, 1978).

Absorption of chemicals by inhalation is most common in industrial situations, where the individual is exposed to a working environment which differs from the "normal" due to specific enclosed industrial activities, while agricultural workers are mainly exposed to specific chemicals in a non-confined environment. Thus generally some sort of dilution factor may be responsible for respiratory absorption being less hazardous than other routes of exposure. However, with reference to pesticides, such a hypothesis could be dangerous because many insecticides are systemic and are applied by Ultra Low Volume where the droplets could approach a size smaller than 30 microns. In fact W.J. Hayes, Jnr. reports in Toxicology of pesticides that 80% of the droplets of commercial aerosols are less than 30 µm in diameter, with an average size of between 10 and 15 µm.

Because alveolar membranes are physically very thin and because blood supply is abundant, absorption will be rapid once a particle has reached the alveoli of the lung. However, it is estimated that only 25% of inhaled material is deposited in the lower part of the respiratory passages (Hayes, 1975). Thus, if the absorption of a substance by inhalation, to exercise a toxic effect, depends only on factors such as particle size, retention in alveoli, water solubility and lipid solubility, it might be postulated that this specific route only seriously affects those confined to specific hazardous environments such as found in industry. However, when the inhaled substance is a systemic acting toxicant - such as many pesticides - then the importance of such characteristics is to a large extent diminished.

The simplest exposure to chemicals is through contact with the skin. However, for many decades absorption by this route was considered of little importance due to the concept that the skin presents a strong

barrier to most chemicals. This concept has changed, and it is currently widely accepted that the skin, although an unquestionable barrier to the transfer of chemicals, is equally important in comparison with other routes of absorption. With reference to pesticides, this change of attitude must be regarded as timely. There is no doubt that in at least the Third World, or in developing countries where agriculture is the main trade and industry, this route could be the main one leading to sub-acute or chronic poisoning, whether accidental or due to ignorance.

Absorption through the skin is defined as the transfer of a chemical through the horny layer, epidermis, corneum and into the systemic circulation (Loomis, 1978). Although no part of the skin is completely impervious - absorption even through the nails has been proved (Hayes, 1975) - penetration of a chemical through the epidermal cells is probably the main avenue of penetration, although it is accepted that for deep penetration, absorption is associated with the follicular walls and sebaceous glands. It is understandable that the barrier properties of the skin differ depending on the kind of skin. An excellent example is the marked difference in the rate of absorption between the thumb and the rest of the hand, the rate of absorption through the hand being twenty times that through the thumb (Hayes, 1975).

Two more factors influencing percutaneous absorption is alteration of skin texture and the physicochemical properties of the chemical compound under consideration. The pH, ionisation potential, molecular size, temperature, lipid and water solubility and blood flow are all factors and properties involved in percutaneous absorption. Although penetration through the skin is relatively slow, and although the different layers of the skin do present a barrier to absorption, it is evident that ignorance and negligence when handling the many different potent chemicals used in agriculture, constitute a real threat to the health of pesticide applicators, farmers, labourers and laymen alike.

1.2.3 Translocation

It is not possible to discuss fully the theories of translocation in a few paragraphs. However, referring to pesticides, three factors should be mentioned: (1) enterohepatic circulation; (2) mechanisms for a chemical

to cross membranes; and (3) ionisation, as a factor in translocation of chemicals.

Once a chemical is absorbed, translocation has to follow, either to the lymphatic system or to portal circulation. Portal circulation leads to enterohepatic circulation, a cycle which involves a chemical having to "travel" the following route:

intestine → liver → bile → intestine

Such a circulation results in three possible actions: (1) termination of the compound through excretion; (2) absorption of the compound throughout the circulatory process; and (3) after possible biotransformation of the compound by for instance the liver, excretion in the intestine where it becomes available for recirculation. The latter action is important due to the fact that many chemicals - including pesticides - are metabolised by the liver to more potent and toxic compounds, thus generating toxic compounds available to the system, from a relatively harmless parent compound.

Before a chemical can be absorbed, it must cross permeable or semi-permeable membranes. Membranes are essentially lipoproteins with pores through which water-soluble molecules can pass. The pore sizes vary from 4Å (intestinal epithelium, most cells) to 30Å (capillaries) allowing the passage of molecules with molecular weights of 100 to approximately 60 000. The fact that many of these membranes have an electrical potential which will to a great extent preclude penetration of particles in the ionised form is very important.

There are essentially three mechanisms for a chemical to pass a cell membrane (WHO, 1978):

- (1) Passive diffusion through the membrane, which is regarded as the principle mechanism. Factors which will influence the rate of passive diffusion are concentration gradient across a membrane, area available for diffusion, the thickness of a membrane and the lipid and water solubility of the chemical;
- (2) Filtration, a natural process during which a chemical will pass through the aqueous pores in the membrane where the size of the molecule could be decisive; and

(3) transport processes by which large molecules which are water soluble, cross the membrane by using a carrier. Usually such a carrier is part of the membrane, which combines with the molecule to facilitate transportation across the membrane. The ratio, and therefore the degree of effectiveness, of translocation between any two systems can be calculated by the equation

$$R_T = \frac{T_C}{B_C}$$

where R_T is the translocation ratio and T_C and B_C the concentration of the agent in each of the two systems (those of the tissue and blood in the presented example) respectively. It is important to realise that many different steps or factors could influence transformation of a compound between the point of intake and the final penetration of the chemical into the intracellular fluid of a cell. One such an example is proteins - which are endogenous molecules - which can bind, or react with, or absorb xenobiotic chemicals and therefore either totally remove the chemical, or at least lower the concentration to a level which could be non-effective. Another example is the possibility of a foreign chemical, on its way to a specific cell within an organ, coming into contact with nonspecific binding sites which again might remove or lower the concentration of the specific chemical.

Chemicals are also eliminated from the body by various means. Removing a cell contaminated with a foreign chemical to an environment not contaminated with the specific chemical, would, in time, free the cell of the chemical due to reversal of the concentration gradient. Literature is replete with data where oysters, more specifically *Crassostrea gigas*, are used as indicator organisms for metal pollution; such an organism, which has a metal 1 000 to 10 000 fold the concentration in its metal containing environment, can be freed from the chemical by leaving it in "clean" water for some time.

In mammals elimination could be via the urinary system, sweat, saliva or the lungs. The rate of such elimination will depend on the nature of the chemical (Loomis, 1978). Usually metabolites have relatively short half lives in the body e.g. ethyl alcohol which is metabolised at a rate of approximately 200mg/Kg/hr (Loomis, 1978). Similarly a metabolite which is

deposited in fat has a short life in the blood and non-fatty tissues. Thiopental (Loomis, 1978) has a brief anaesthetic action of 15 minutes or less (Loomis, 1978). The drug undergoes rapid metabolism in the blood to a nonanaesthetic form, while some of the drug is deposited in fat. As the deposited thiopental rediffuses from fat to blood, it again undergoes conversion to a nonanaesthetic form at concentrations which are noneffective.

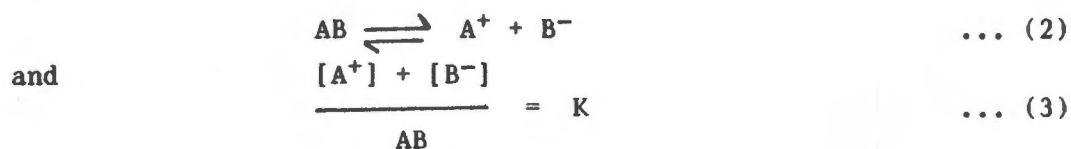
However, chemicals can be selectively absorbed, which limits their excretion by the body. DDT is an example and the inhibition of the cholinesterase enzyme by organophosphates is another. Thus, the deposition of such chemicals, or their effective binding to proteins creates storage depots so that the chemical and its effect could remain in the body for a long time.

A chemical must be in its free form to be able to exert a toxic effect. For example, once it is bound to a protein, it is unavailable for further reactions. A toxic reaction depends, however, not only on the free form of a chemical but also on the important phenomenon of ionisation.

The degree of ionisation, that is the ionisation constant or the dissociation constant (pKa), depends on the hydrogen ion concentration (pH) of an electrolyte in an aqueous solution. Arrhenius suggested in his Ionic Dissociation Hypothesis that an electrolyte will partially dissociate into positive and negative ions when dissolved in water, and that the degree of ionisation (α) depends on the concentration of the electrolyte. In such a solution an equilibrium will exist between dissociated ions and undissociated molecules and the degree of dissociation will be equal to the ratio of conductivity at a concentration (c), to the conductance at infinite dilution:

$$\alpha = \frac{\Lambda_c}{\Lambda_\infty} \quad \dots (1)$$

where Λ_c = the conductivity of the electrolyte at concentration c, and Λ_∞ = the conductivity of the electrolyte at infinite solution. The law of mass action may be applied to this equilibrium (Oswald's dilution law):



where K = dissociation constant of electrolyte. If the concentration of AB is $cg\text{-mol/l}$ and if the degree of dissociation is α , then $AB = (1 - \alpha)cg\text{-mol}$ and A^+ and $B^- = \alpha c$ $g\text{-ions per liter}$.

Substitute in (3), then

$$\frac{(\alpha c)^2}{(1 - \alpha)c} = K \quad \dots (4)$$

and since will be small compared to unity,

$$\alpha^2 c = K \quad \dots (5)$$

therefore

$$\alpha = \sqrt{\frac{K}{c}} \quad \dots (6)$$

The degree of dissociation is therefore proportional to the square root of the dissociation constant.

A weak acid HA dissociates reversibly to produce H^+ and A^- as in equation (2).



In equation (3):

$$\frac{[H^+] [A^-]}{HA} = K_a \quad \dots (8)$$

or

$$H^+ = K_a \frac{[HA]}{[A^-]}$$

Taking logarithms:

$$-\log H^+ = -\log K_a - \log [HA] + \log [A^-] \quad \dots (10)$$

The term $-\log H^+ = pH$ (Sorenson) and $-\log K_a = pK_a$

therefore
$$\text{pH} = \text{pK}_a + \log \frac{[\text{A}^-]}{[\text{HA}]} \quad \dots (11)$$

If a weak acid and its salts (BA) are taken, then (BA) will exist in solution completely dissociated as B^+ and A^- . In such a buffer action the contribution of the A^- by the acid will be negligible compared with that of the salt BA, therefore equation (9) could be expressed as

$$\text{H}^+ = K_a \frac{[\text{HA}]}{[\text{BA}]} \quad \dots (12)$$

Substituted in equation (11):

$$\text{pH} = \text{pK}_a + \log \frac{[\text{BA}]}{[\text{HA}]} \quad \dots (13)$$

which is known as the Henderson-Hasselbach equation:

$$\text{pH} = \text{pK}_a + \log \frac{[\text{salt}]}{[\text{acid}]} \quad \dots (14)$$

Hence for acids :
$$\text{pK}_a = \text{pH} + \log \frac{\text{non-ionised form}}{\text{ionised form}}$$

and for bases :
$$\text{pK}_a = \text{pH} + \log \frac{\text{ionised form}}{\text{non-ionised form}}$$

The very important role of the ionisation of a compound is thus very clear. If the pK_a of a compound is known and the pH of the aqueous solution (e.g. body fluids) is known, then it is possible to calculate the ratio of the ionised and non-ionised forms of the chemical and thereby predict the possible behaviour of the chemical. For example: The pH on both sides of membranes in most organs is more or less the same. If a compound which is highly ionised is introduced to one side of the membrane, such a compound would have difficulty in passing through the membrane. On the other hand, a poorly ionised compound which is lipid soluble will diffuse through the membrane according to the concentration gradient until equilibrium is reached.

However, should a pH difference exist between the two sides of the

membrane, there will also be a concentration gradient regarding the non-ionised part of the electrolyte, and once equilibrium is reached, the total quantity of the electrolyte will be much greater on one side of the membrane than on the other. Thus the pH and therefore the ionisation of a chemical controls the diffusion and absorption of chemicals across membranes. In Fig.1.1 Loomis (1978) illustrates in theory the absorption of acetylsalicylic acid ($pK_a = 3.5$) across different membranes in biological fluids.

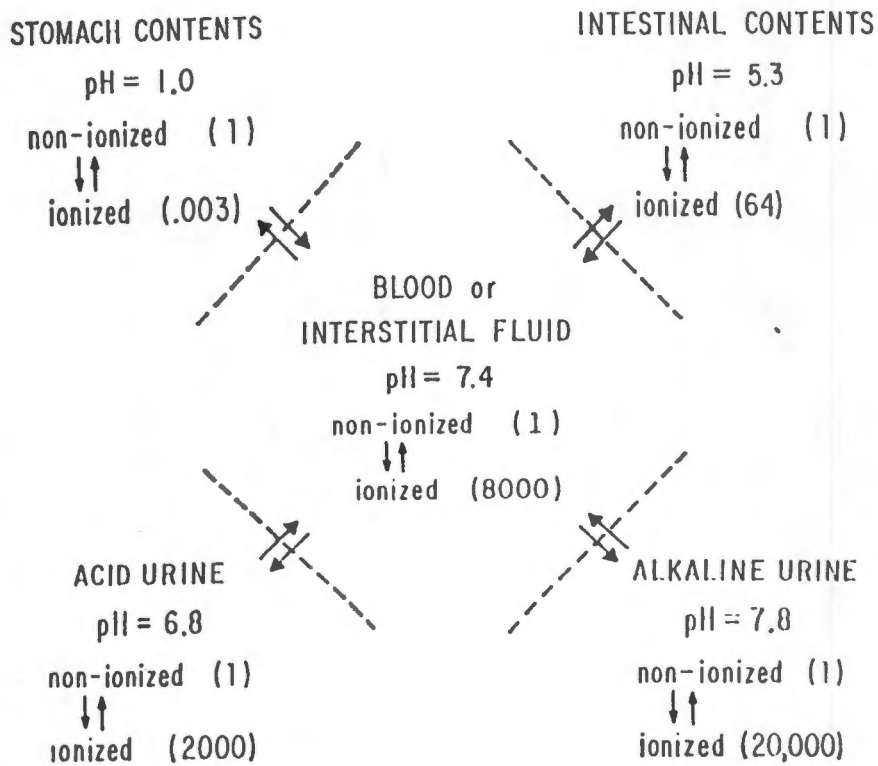


FIG. 1.1 Proportions of non-ionized and ionized forms of acetylsalicylic acid ($pK_a = 3.5$) in biologic fluids

1.2.4 Biotransformation

When a chemical is converted *in vivo* to a derivative or metabolite, the process is called biotransformation or metabolic transformation. These processes are enzymatically mediated and the result is usually a more polar and water soluble product which can be more readily excreted. Thus biotransformation does contribute to the termination of a biological action. However, biotransformation may also lead to conversion of a chemical to a more or less toxic compound than the parent compound. Biotransformation, therefore, could not only terminate an action but also act as a metabolic intoxicator as well as a metabolic detoxicator. An example of metabolic intoxication is the *in vivo* conversion of parathion to paraoxon and an interesting example of detoxification is that of detoxifying enzymes in the liver which prevent phosphates from inhibiting cholinesterase in nerve target tissue (WHO, 1978). It is well known that the route of exposure influences biotransformation. When absorbed through the gastrointestinal route, chemicals are transported via the portal circulation to the liver where detoxification takes place. Should absorption from the oral route be in small quantities, detoxification may proceed faster than the rate of absorption and the detoxification process would be totally effective. The same quantity of chemical absorbed via the lungs or the skin, which have fewer detoxification properties but also biotransformation actions, could result in a toxic action.

The different mechanisms of metabolic transformation have been well reviewed by the World Health Organization (WHO, 1978). These include oxidation, reduction, hydrolysis and conjugation reactions by means of single or multiple reactions, as well as enzyme induction and inhibition and metabolic saturation. Other factors such as malfunction of mechanisms, action on the wrong target and toxicity due to synergism have been reviewed by Loomis (1978).

In practice one dare not underestimate the importance of biotransformation. Animal studies (rat, mouse, dog, etc.) are used to predict toxicological consequences in man, a very common practice worldwide in the evaluation of, for example, pesticides. The problem man is confronted with is whether or not the metabolic pathway in the animal species used, coincides with that in man. There is no doubt that biotransformation influences the toxicity of a compound and should the metabolic pathway

differ between animal species and man, it could lead to very serious consequences in risk assessment.

1.3 Environmental Toxicology

In 1975 W.J. Hayes wrote in his book Toxicology of Pesticides: "The term environmental toxicology is relatively new and its exact usage is not established fully. The term ought to be reserved for all applications of toxicology to organisms other than man and his domestic animals." Since 1975 a decade has passed during which this relatively "new term" has not only been well-defined, but has also dissociated itself from the restriction that it should be totally separated from classical toxicology and therefore from man.

By the term "environment" is meant all those factors or entities, which surround a specific living entity (Van der Ploeg, 1982). It therefore denotes all of an individual's surroundings, inanimate components such as water, soil and air, as well as all other living matter such as plants, animals and members of its own species.

Man is an organism and has a relationship with his environment and problems associated with his environment. Non-desired changes in the environment are by definition (1) changes caused by human activities and (2) changes in the environment of human beings. The activities could be described as (Van der Ploeg, 1982):

- (1) pollution - addition of matter or energy to the environment;
- (2) exploitation - extraction of matter or energy from the environment;
- (3) destruction and disturbance of processes in the environment; and
- (4) population growth - addition of more human beings to the environment.

These human activities and their effects on the environment are studied by the discipline Environmental Sciences and it is important to realise that they are factors in the environment pertaining to the health of the individual organism: Homo sapiens.

The term "Environmental toxicology" should therefore present no problem as being the science concerned with the harmful effects encountered by man in his environment. Thus it is a branch of classical toxicology which deals with the incidental exposure of human life to agents that are basically contaminants of the environment and which studies the causes, conditions, effects and limits of safety to man in such an environment (Loomis, 1978). It is a natural consequence that environmental health standards should exist to protect human individuals from the adverse effects of hazardous environmental factors and contaminants and therefore also natural to view the environment anthropocentrically - that is, almost exclusively in relation to man and his activities (Metcalf, 1974).

Although it is a natural tendency in Environmental toxicology to define limits primarily in relation to direct risk to human beings, environmental toxicology should also be defined to include (1) the toxic effects to man by naturally occurring substances in the environment (Duffus, 1980), as well as (2) the environmental risk to any other individual organism (in the sense of classical toxicology), provided such a living entity is clearly defined i.e. for a grazing rabbit the environment includes factors such as the weather, other rabbits, grass and soil. Duffus is therefore correct in also including the toxic effects to man by naturally occurring substances because they do exist (toxic plants, snake venom, etc.). The important factor to remember is once again: the toxic effects ~~are~~ related to man.

In the previous section it was stated that toxicology refers to man, the individual and the effects once an agent has been absorbed and that the term toxicology could be used with any other form of life (rabbit), on condition that such other forms of life are clearly defined and adhere to the same principles stated above. These same principles hold true for environmental toxicology, except that cognisance is taken of the presence of anthropogenic (and natural) toxicants and their effects on man.

1.4 Ecotoxicology

1.4.1 General considerations and definitions

In 1978 a report Principles of ecotoxicology (SCOPE 12), edited by G.C. Butler was published by the Scientific Committee on Problems of the Environment. The report, devoted to "the new science of ecotoxicology" was prepared by about 20 specialists in different aspects of the subject and it was intended to be a "source of ideas and principles rather than that of data". Since 1978 another excellent publication: Ecotoxicology, the study of Pollutants in Ecosystems by F. Moriarty (1983) has emerged. Numerous papers in the international literature have in the meantime also been published, addressing toxicology and/or environmental problems, many of which used the term ecotoxicology out of context. It is clear that the term ecotoxicology remains confusing to the scientific community, not only in the Republic of South Africa but also in some other countries of the world. It would therefore be expedient to include in this study - even if only theoretically - an effort to clarify the terms of reference used in the subject of ecotoxicology.

"Ecotoxicology is concerned with the toxic effects of chemical and physical agents on living organisms, especially on populations and communities within defined ecosystems; it includes the transfer pathways of those agents and their interactions with the environment"
(Butler, 1978).

From the above definition two very important points are evident: (1) it does not contain the word human or man and (2) it not only does not refer to the individual, but it explicitly refers to populations, communities and ecosystems.

Because populations, communities and ecosystems play such a vital role in this subject, some definitions are appropriate.

Groups of natural productively isolated populations of organisms form a species. The populations of different species that exist in the same area form a community. An individual, a population or a community with its

abiotic environment constitute a habitat, and a community with its habitat is an ecosystem. Thus, the toxic effects of chemical or physical agents on ecosystems form the subject ecotoxicology or, the effects of pollutants on ecosystems form the subject ecotoxicology (Moriarty, 1983).

Ecotoxicology forms a four-part subject (Miller, 1978) which has to be taken into account before any effects can be assessed:

- (1) Chemical form, amount and site of release of a pollutant must be known;
- (2) The processes by which a pollutant may be transported geographically, chemically transformed as well as availability for uptake by biota must be known;
- (3) Target organisms must be identified; and
- (4) In many systems it might be necessary to assess the response of the population or community as well as that of the individual organism.

In section 1.1 the vast volume of chemical compounds manufactured annually was discussed as well as factors such as waste disposal and possible pollution of the environment through bad management, accidents, ignorance and many other reasons. It is obvious that the assessment of (i) the actual amounts manufactured, (ii) the volume accidentally or deliberately released to the environment, (iii) chemical transformation and the various pathways that could be followed, and (iv) possible exposure, target organisms and ultimate effects on ecosystems, is an almost impossible task. None the less, this kind of information is essential to make assessments on which policy decisions may be based. This delicate situation has been perfectly summarised by Miller (1978): "Thus we have an obviously impossible problem, namely that scientists must accurately predict the probability and the nature of an event that has never occurred".

One of the main problems other than rate of pollutant released, pathways and exposure, is the speciation of chemicals or pollutants, i.e. the different forms in a physico-chemical state in which a chemical could exist. It has been established that these different chemical forms of a

compound can effect all the aspects of a metal's behaviour and its biological effects in different natural systems (Burton, 1979). One example is the analyses of heavy metals in water and biota which give little or no information on these aspects because the metals are analysed and expressed as total metal content. Another good example is that of polychlorinated biphenyls (PCBs). Commercial PCBs are mixtures of individual compounds which differ by the number and the position of the chlorine atoms on the biphenyl molecule. The number of chlorine atoms influences metabolism and excretion, while the position of the atoms has an effect on degradability. Thus, for ecotoxicology it is necessary not only to consider a parent compound but also to take into consideration the configuration of a molecule, isomersim, metabolites and all other possible conversion products.

1.4.2 Populations and Communities

The complexity of ecotoxicology becomes apparent when it is realised that different species and their populations in the same area, thus a part of the same community, react differently to the same pollutant. Species differ in their life cycles, have different resource needs and survive in different ways. Thus the populations of two different species differ in the net effect, even when affected to the same extent by a pollutant. Even more complicating is the fact that pollution, or rather the presence of a xenobiotic in a community, is only one factor influencing population sizes. Birth rates, death rates, immigration and emigration naturally influence population sizes. It is even possible that a xenobiotic which is detrimental to one species in a community, might be advantageous to another. Thus competition for resources, interactions between species, effects of the abiotic environment and the effects of xenobiotics are all factors which determine population trends, acting at any time or stage of the life cycle. Thus population dynamics cannot be predicted from simple assumptions. On the contrary, changes in population sizes could be as misleading as using toxicity data from one species to predict the toxicological effects of a chemical on another. With reference to communities, it might be easier, more appropriate and more meaningful to concentrate on the effects of a xenobiotic on populations of individual species, than on communities.

The effects of a xenobiotic on an individual have been discussed in section 1.1. However, it should be pointed out that the principles of ecotoxicology do not exclude the fundamental issues of toxicology such as dose, response, effect, acute, subacute, etc. This is understandable because both the individual and the population have something in common and that is an agent which exerts an effect which is unfamiliar both to the individual and to the population. Similarly sublethal exposures to individual organisms can affect them without any obvious signs of injury and without any apparent effect to the population (Moriarty, 1983).

It has to be realised, however, that the principles of ecotoxicology include not only those of toxicology but go beyond those of classical toxicology. The quantitative assessment of the amount (dose) of an agent which detrimentally affects an organism, is much more problematic than in toxicology where the primary concern is the action on receptors. The interaction between a host of environmental variables - which will determine biological response - is not easy to assess but it is necessary to relate degree of exposure to degree of effect. The measurements of a pollutant in any one of the components of the abiotic environment is thus

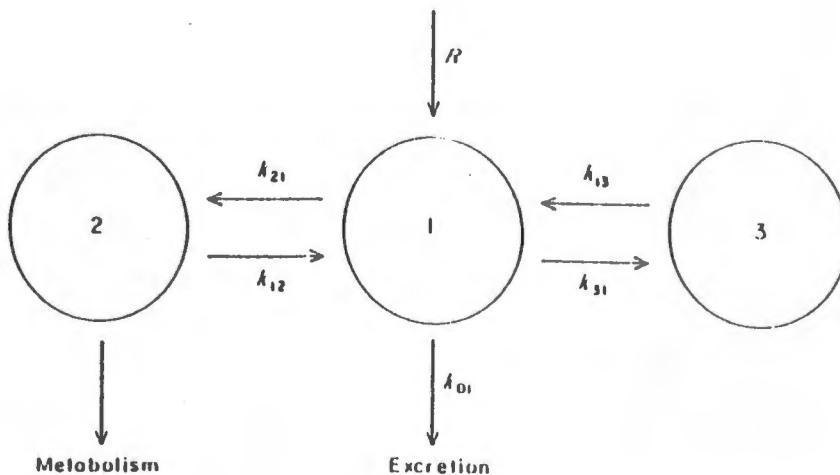


Fig. 1.2: A three-compartment model for the distribution of a pollutant within a vertebrate. Pollutant is absorbed into the blood (compartment 1) at a rate R , most metabolism occurs in the liver (compartment 2), and rates of transfer between compartments are indicated by the rate constant K

(from Moriarty, 1983)

of limited value because it can not readily be related to exposure in real terms. Similarly, the concentration of a pollutant in an animal or plant can only give some indication as to past exposure and such analyses are not indicative of amounts present at the site of action.

The compartmental method (Atkins, 1969; Moriarty, 1983) is being used extensively to quantify exposure and to relate exposure to effect (Fig. 1.2). A compartment is defined as a mass of pollutant that has uniform kinetics of transformation and transport. Generally four assumptions are made in using these models (Moriarty, 1983):

- (1) Compartment one, the only compartment to receive a pollutant, represents the blood, extracellular fluid or transport system.
- (2) The model assumes that the rate (rate constant = K) at which pollutants leave a compartment is directly proportional to the amount of pollutant in the compartment.
- (3) Retention or loss is difficult to estimate for a model with more than 3 compartments.
- (4) Compartments are defined in terms of mass of pollutant rather than concentration, assuming that the volume of the tissue in which the mass occurs is not directly relevant.

Equations in exponential terms are derived from these models for pollutants present before and after exposure. It would perhaps be more relevant (and accurate) to use concentration instead of mass but this could only be done if changes in the volume of a compartment are well known. If not, it would seldom be possible to relate the concentration in the tissue of one compartment with the concentration in another. Be that as it may, this kind of approach is necessary instead of just measuring the concentration of an agent present in an organism, if exposure is to be related to effect.

For ecotoxicology this is easier said than done. It is not possible to predict (section 1.5) the effect of a pollutant in the environment without monitoring the distribution of such an agent in the abiotic and biotic environments. Unfortunately, monitoring is that part of an investigation

which is regarded as the easiest and therefore does not usually receive the proper planning and designing it needs. Scientists do not always realise that it is of no value to employ sophisticated and sensitive analytical methodology when the monitoring scheme itself fails to match these techniques in sensitivity, accuracy and precision. It would not be exaggerating to claim that the success of the analytical project, which includes or is based on a monitoring programme, stands or fails by the preciseness of the execution of the monitoring programme.

To date most monitoring programmes in the environment or in an ecosystem have been executed mainly to measure the quantities of a specific agent present, not to detect the effects of the presence of the agent. This attitude is fundamentally wrong because concern about a pollutant is derived from the effect it causes and not from its presence. Therefore a successful monitoring system assesses the effects, amounts and distribution of a pollutant by measuring:

- (1) rate of release of pollutant;
- (2) degree of contamination; and
- (3) biological effects.

It is important to note that measurements taken without monitoring discharges make it impossible to sensibly relate observed levels to the rates at which pollutants are released (Preston, 1979). With reference to biological effects in ecotoxicology it is necessary to emphasise that although pollutants can readily be measured within organisms, the effects may be indirect, i.e. through another species or the abiotic environment. However, this does not change the essence of the subject: to measure the impact of a pollutant and observe the effect on structure, size and distribution of populations.

Man is not excluded from ecotoxicology but unlike classical toxicology and environmental toxicology, where man is of primary importance, he is an equal partner in ecotoxicology. Furthermore toxicology is concerned with the effects on individuals (more specifically the human individual), whereas ecotoxicology is concerned with the effects on populations. Thus, as in toxicology, the underlying principles for ecotoxicology are that effects depend on exposure and dose but unlike toxicology, the effect is measured on the population (Moriarty, 1983).

1.5 Regulatory Toxicology

1.5.1 Introduction

Regulatory toxicology is not a formal subject. It is briefly discussed here because it is in this capacity that toxicology is practised. Every form of life is subjected to all kinds of chemicals, most of them to date with unknown structures. It could be argued that the introduction in the environment of more chemicals with known or unknown structures would make no difference. This of course is not true due to the fact that present life-forms have had many thousands of years to adapt to existing chemicals through evolution and that the lifetime of man or any other organism is too short to develop a mechanism for survival while alive on the planet earth. Thus, the possibility of injury must be dealt with prior to introduction into the environment.

Assessment of possible hazards once a compound has been released can be a very complicated matter. Acute toxicity, which occurs rapidly often from a single dose, is of relatively little concern. Such an effect is cognizable in a short time after introduction and can be dealt with accordingly. Repeated small doses of a chemical can, however, lead to chronic effects which are usually more difficult to identify. Such effects, to make any assessments more difficult, can have one of the following characteristics (Bedding, 1983): (1) it might disturb metabolic systems in the long term, which could have important effects on disease patterns or susceptibility to diseases, or (2) it could have irreversible damage to deoxyribonucleic acid (DNA), an effect which may not be manifested within a human life span.

Health risk evaluation is the evaluation of the biological changes which are caused by chemicals. Risk is a statistical concept which measures the frequency of such undesirable effects and it forms the basis of regulatory control of exposure to such substances. However, risk as an absolute measure could never be the only criterion in the regulatory process. The beneficial qualities of a compound are as important and therefore risk assessment involves a risk/benefit ratio. In toxicology the risk/benefit ratio is not a controversial matter but is associated with conflicts of interest or even perhaps conflicts of necessity. In risk/benefit the people who enjoy the benefits are not always those that run the risks; for

example the eskimos in Alaska are exposed to Strontium-90 fallout through food chains but do not gain anything by nuclear explosions.

1.5.2 Toxicity and safety

Toxicity is widely accepted to be a relative term and is used to study and compare the harmful effect on a biological system, being man, on individuals or an ecosystem. There is no shortage of definitions in the literature describing toxic(ity) or harmful(ness); the same does not, however, apply to the concept of safety. Perhaps the reason for this ~~(lack)~~ must not be sought scientifically but rather from a human point of view. All life, no matter the stage of development, possesses defence mechanisms, mechanisms which subtend survival. Thus, from such a point of view, safety is not to be questioned, it is taken for granted, hence, for the same reason we do not write books on the fact that one must be born to be able to live, for the same reason safety is part of life.

Absolute safety however, does not exist.

Assessing the magnitude of risk from a chemical, supplies the information needed for the estimation of the order of safety. In practice toxicity studies are performed (Table 1.9), involving laboratory animals and the results extrapolated to man. The methods for testing, using laboratory animals are well documented in the literature, while the procedure for the evaluation of an agricultural chemical is described in Chapter II.

Essentially, two different approaches are used to estimate acceptable levels of exposure (Bedding, 1983). These are discussed in Chapter II. One of the main concepts in toxicological testing however, is that of a threshold i.e. some level of concentration of the chemical below which there will be no biological effect. Although there does exist controversy as to the presence or absence of such a non-effect level, it is generally accepted that such a level does exist for all chemicals except carcinogens. In fact such a no-effect dose can be proved in theory (Loomis, 1978): the chemical-receptor interaction is a biomolecular equilibrium reaction

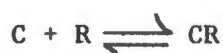


TABLE 1.9AN OUTLINE OF TYPES OF ANIMAL TOXICOLOGIC TESTSI. Acute Tests (single dose)

- A. LD₅₀ determination (24-hour test and survivors followed for 7 days)
 - 1. Two species (usually rats and mice)
 - 2. Two routes of administration (one by intended route of use)
- B. Topical effects on rabbit skin (if intended route of use is topical; evaluated at 24 hours and at 7 days)

II. Prolonged Tests (daily doses)

- A. Duration - three months
- B. Two species (usually rats and dogs)
- C. Three dose levels
- D. Route of administration according to intended route of use
- E. Evaluation of state of health
 - 1. All animals weighed weekly
 - 2. Complete physical examination weekly
 - 3. Blood chemistry, urinalysis, hematology, and function tests performed on all ill animals
- F. All animals subjected to complete autopsy including histology of all organ systems

III. Chronic Tests (daily doses)

- A. Duration - 2 to 7 years depending on species
- B. Species - selected from results of prior prolonged tests, pharmacodynamic studies on several species of animals, possible single dose human trial studies. Otherwise use two species.
- C. Minimum of two dose levels
- D. Route of administration according to intended route of use
- E. Evaluation of state of health
 - 1. All animals weighed weekly
 - 2. Complete physical examination weekly
 - 3. Blood chemistry, urinalysis, hematologic examination and function tests on all animals at 3- to 6-month intervals and on all ill or abnormal animals
- F. All animals subjected to complete autopsy including histologic examination of all organ systems

IV. Special Tests

- A. For potentiation with other chemicals
- B. For effects on reproduction
- C. For teratogenicity
- D. For carcinogenicity
- E. For mutagenicity
- F. For skin and eye effects
- G. For behavioral effects

where C = chemical and R = receptor. As described in an earlier section, this reaction obeys the Mass Law, i.e. the free and combined chemical is in equilibrium and is equal to a constant K

$$\frac{[C] + [R]}{[CR]} = K$$

The complex [CR] is responsible for an effect, therefore the quantity of [CR] determines the quantity of effect. The quantity of receptor could be seen as a constant and therefore the concentration of the compound [C] is directly related to the concentration [CR]. Thus a concentration of the chemical below which a no-effect level does exist is possible. The threshold dose would in principle not be such a controversial matter if this principle was only to be used to demonstrate the existence of toxic effects. The threshold concept, however, is not only used to demonstrate the existence of a toxic effect but is widely applied to estimate the limits of safety by relying on laboratory experiments conducted on a limited number of animals over a relatively short period of time, and the results then extrapolated to man. Although these problems are dealt with statistically to be acceptable, it has to be admitted that in tests large doses are administered over a short period of time which is in direct contrast to the real life situation, where usually small amounts of a contaminant are ingested over a human lifetime. Loomis (1978) therefore concluded: "When safety to man is the objective, the only rational approach to the problem is through a consideration of the nature of the toxicity in question and the application of an acceptable interpretation of benefits versus potential hazards under the condition of intended use of the compound."

It has to be pointed out that the majority of tests examine an individual compound and that mixtures of compounds probably react differently. Relative toxicities for a range of compounds can be compared by calculating a toxicity index:

$$\frac{\text{LD}_{50} \text{ of most toxic compound}}{\text{LD}_{50} \text{ of less toxic compound}} \times 100$$

and a joint acute toxicity of different compounds can be calculated if the chemicals act on the same site and if their regression lines on the probit

against log doses graph is parallel to each other (WHO, 1978):

$$\frac{1}{LD_{50}(A,B,C)} = \frac{f_A}{LD_{50}(A)} + \frac{f_B}{LD_{50}(B)} + \frac{f_C}{LD_{50}(C)}$$

where f_A , f_B and f_C are the fractions of the different compounds A, B and C in the mixture. Synergism, however, can pose a real problem when a mixture contains different unknown compounds. It has been proved with agricultural pesticides that synergists may increase the activity of insecticides by inhibiting the enzymes responsible for detoxification (EL-Guindy, 1983). The factor for synergism could be calculated:

$$\frac{\text{LD}_{50} \text{ of insecticide}}{\text{LD}_{50} \text{ of synergized insecticide}}$$

These calculated factors demonstrate the problems associated with risk estimation when ignorant about their presence.

However, it is recognised that animal studies permit the prediction of effects in man based on selective toxicity of chemicals, and a common physiologic mechanism present in man and the test animal. In fact, it is due to such selectivity of biological action on biochemical and physiological mechanisms, common to the cells of different species, that permit the predicting of effects in man.

1.5.3 Dose-response relationships

It is not possible to draw a line between safe chemicals and toxic chemicals. Toxicity is relative and is described as a relationship between dose and effect. Primarily an amount (dose) of a chemical is able to respond to some or other effect, an effect which could be either harmful or beneficial. What is important is that the effect is directly related to the dose and that the response to such a dose is a graded one i.e. related to progressive changes in dose and ultimately to a frequency distribution for the individual responders as a function of dose. Figure 1.3 shows such a frequency distribution as well as the dose-response relationship which is observed from a cumulative frequency distribution.

In practice, when a number of animals of the same species are each given a dose adequate to produce an identical response, the data plotted will form

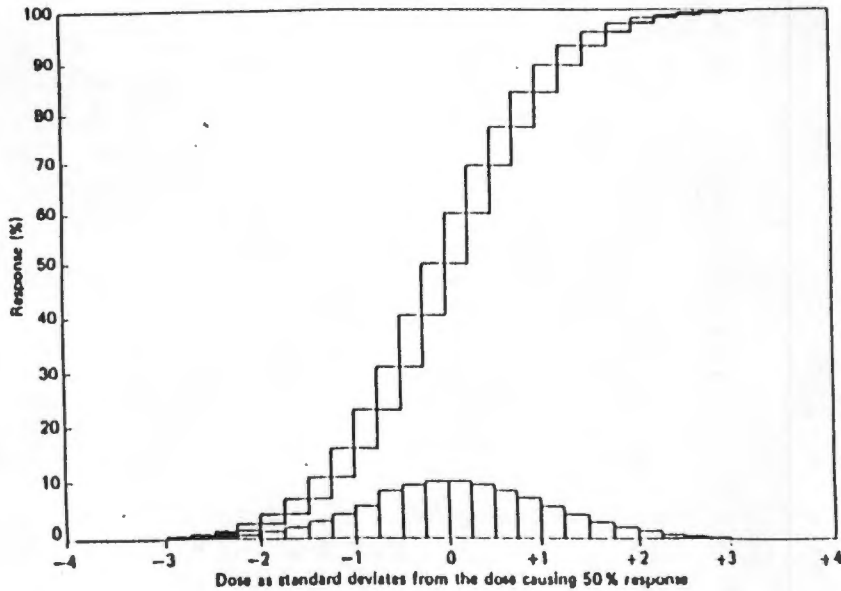


Fig. 1.3: A hypothetical dose-response relationship as a frequency distribution and as a cumulative frequency distribution.

From WHO, 1978.

the distribution curve shown in Figure 1.3 which follows the pattern of the normal Gaussian distribution as indicated in Figure 1.4. When data of

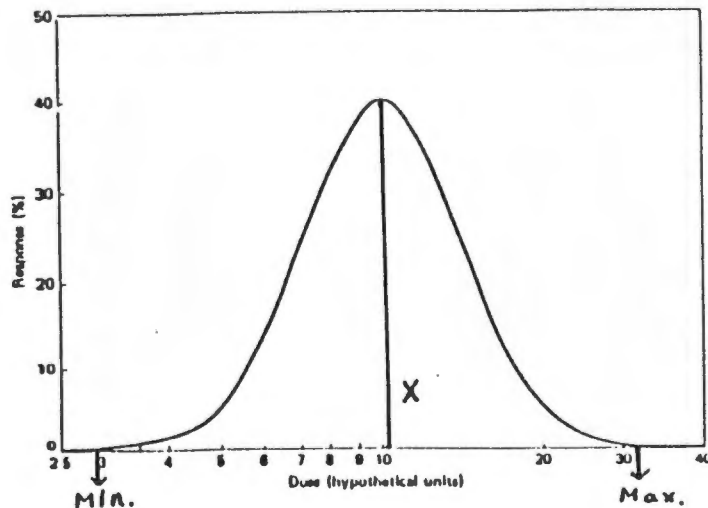


Fig. 1.4: Normal frequency distribution when dose is plotted on log scale

increased doses (for instance on a logarithm basis) to groups of animals are plotted (1) on normal graph paper and (2) plotted by conversion of the percent mortality figures to a probit scale, then the typical S-shaped curve is obtained by (1) and a straight line is obtained by (2) as shown in Figure 1.5.

The dose-response relationship is not only a method of obtaining the effect of a dose by means of a graded response but also of determining the safeness (relative), or margin of safety of a compound. In drug therapy the margin of safety, which is referred to as the therapeutic index, is the dosage range between the effective dose (ED₅₀) and the lethal dose (LD₅₀) and is calculated by the ratio

$$\frac{LD_{50}}{ED_{50}}$$

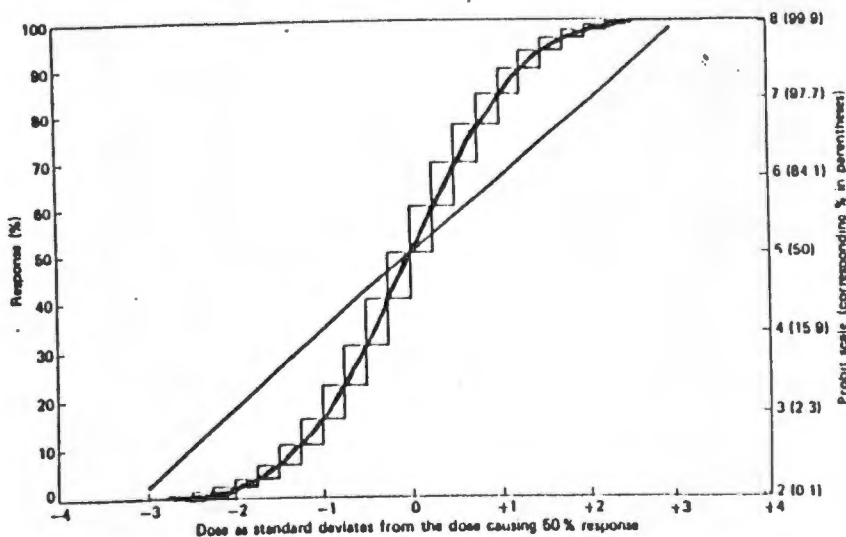


Fig. 1.5: Transformation of the normal sigmoid curve (%) to a straight line (probit)

This margin of safety for a drug is shown graphically in Figure 1.6.

The therapeutic index principle does not apply to xenobiotics. However, the dose-response relationship concept can also be used to estimate the relative safeness of such compounds:

- (1) Figure 1.7 illustrates the dose-response curves for 4 chemicals C, D, E and F. Chemicals C and D can only be compared to one another

at the particular dose Z. At higher doses chemical C will be more effective than D and at lower doses chemical D will be more effective than C. In contrast to C and D, chemicals E and F show equal effects over the dose range from 1 to 10. This figure illustrates that to compare xenobiotics, (1) their dose-response curves must be available; and (2) comparisons between chemicals are only possible when their dose-response curves are parallel to one another. Needless to say, the comparison between chemicals E and F is only possible for one specific effect under the same experimental conditions.

- (2) In Figure 1.8 the dose-response curves for two chemicals A and B are illustrated. It is evident that the two chemicals responded totally differently, accentuated by the different slopes. The greater the slope (chemical B = 5,0) the more hazardous the compound and the smaller the slope (chemical A = 1,0), the greater the margin of safety of the compound. Flat slopes (chemical A) are therefore indicative of factors such as poor absorption and rapid excretion or detoxification, while steep slopes (chemical B) indicate rapid absorption and rapid onset of toxic effects (WHO, 1978).

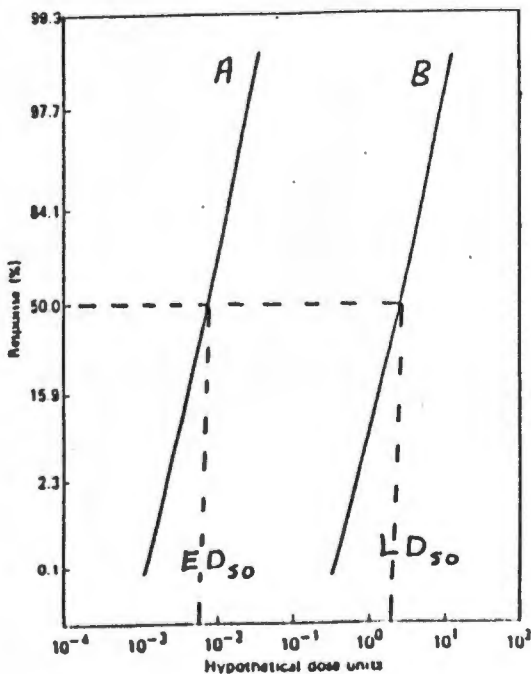


Fig. 1.6: Dose-response curves for two chemicals

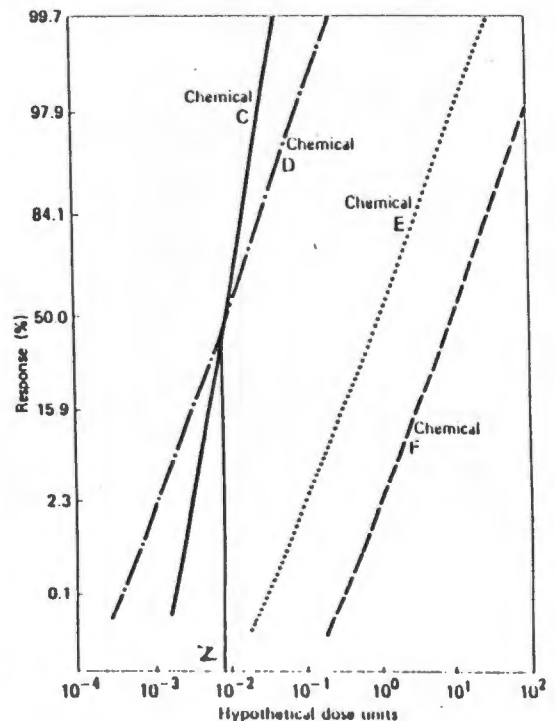


Fig. 1.7: Dose-response curves for four chemicals

Figure 1.9 illustrates two compounds A and B with the same LD₅₀ value but two totally different slopes. Although both compounds have the same LD₅₀, compound B, slope = 1,7, is the safer compound and any assessment of these chemicals, without knowledge of the slopes of their curves would be incorrect.

Many books have been published to serve as reference material and to assist in toxicity evaluation by regulatory bodies. However, very little is known of the toxicity of most of the thousands of compounds used daily. The best known property of these compounds is their LD₅₀ and it is this that is usually published as an index of toxicity. Without exception, slope values are omitted, which not only nullifies the data but leads to the misuse of data by scientists, medically trained personnel and regulatory bodies not properly trained in toxicology.

A final word of caution with the use of LD₅₀ figures. It has to be realised that the LD₅₀ test centres around lethal effects of compounds. Results of these tests will always depend on the animals used and on the experimental conditions. It does not take sublethal effects into consideration, or any variables due to environmental conditions. If used with caution though and if the slope values are available with each LD₅₀ value, then this data - especially in the absence of any other toxicological data - could well be of assistance in regulatory toxicology.

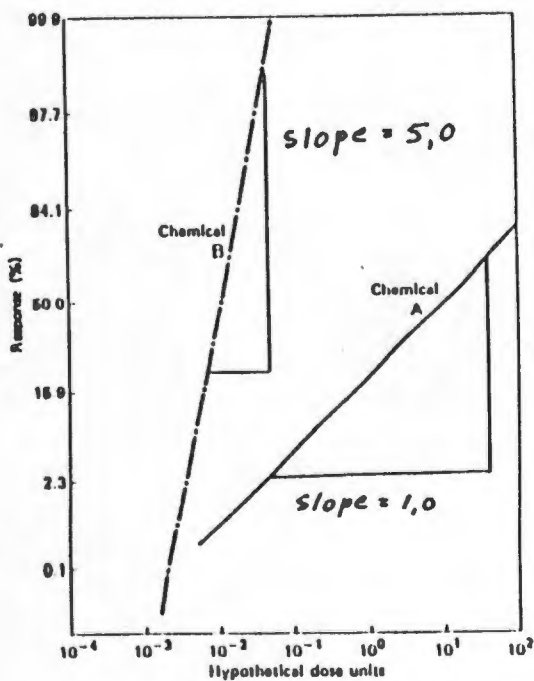


Fig. 1.8: Dose-response curves for two chemicals

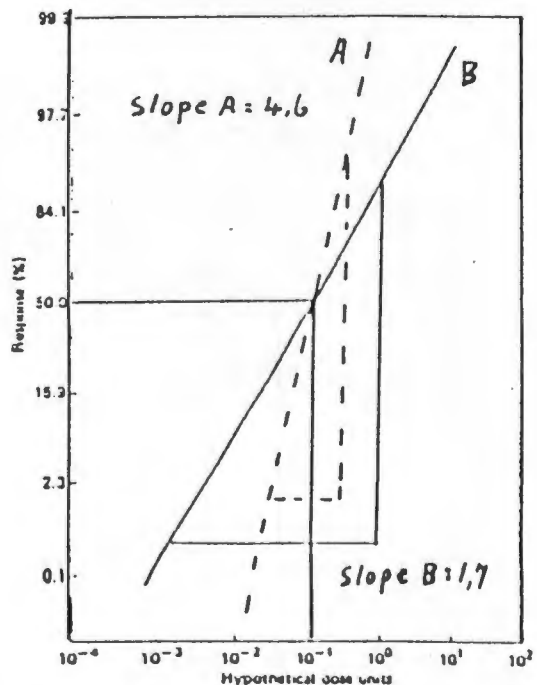


Fig. 1.9: Dose-response curves for two chemicals

1.5.4 Regulatory principles in Ecotoxicology

To man, man is the most important living organism, but its quality of life and welfare undoubtedly depend on many fauna and flora species. To neglect or allow the effacement of such species, will only be to his own disadvantage and could very well in extreme cases lead to an abnormal way of living if not perhaps cause its own effacement.

To predict the behaviour of a chemical compound in the biotic and abiotic environment, is a much more complicated matter than the assessment of effects on an individual. Moriarty (1983) summarised the problems as follows:

- (1) Mixture of compounds are involved or their active impurities, metabolites or breakdown products have biological effects.
- (2) Distribution effects exposure. However distribution is never uniform which hampers assessment of exposure.
- (3) Exposure, amount of pollutant and effects are complex.
- (4) Species, and groups within species reacts differently to the same exposure.
- (5) Consequences of interactions between individuals within a population and between species within a community is a complex matter and little understood.

These problems have to be solved as meaningfully as possible to enable a prediction of the possible behaviour of a compound, which essentially implies the following questions:

- (1) What is the relationship between exposure and the amount of pollutant in the organism?
- (2) What are the biological effects of the compound in question?
- (3) What are the effects on ecosystems?

It is understandable that bioconcentration, bioaccumulation and biomagnification will be of major importance in, for instance, establishing the amounts of a substance within the organism.

The accumulation of a pollutant through the food chain (biomagnification) is to some extent controversial and could briefly be summarised from the literature as follows (Moriarty, 1983):

- (1) From experiments with DDT available to biota in ponds, Hamelink (1971) concluded that the accumulation of DDT and its metabolites depended on partition coefficients and other physical parameters and not on transfer along a food chain.
- (2) Hunt(1960) concluded, among others, that mortalities due to DDT in Aechmophorus occidentalis in a lake in California were due to accumulation and concentration along the food chain.
- (3) In an experiment with a food chain of an algae, a crustacean and a fish when exposed separately to dieldrin in water, the concentration of dieldrin kept on increasing in the food chain even when the crustacean and fish were given uncontaminated food. These results were confirmed by additional tests which showed contaminated food not to be an important source of dieldrin (Reunert, 1972).
- (4) A similar experiment by Chadwick (1967) confirmed that only 16% of the total body burden of dieldrin in fish was due to their food source.
- (5) On a study on the intake of leptophos by bluegill sunfish, Macek (1979) proved a bioconcentration for intake from water, with negligible intake form the diet.
- (6) Similar other studies to reach the same conclusions are: ten Berge (1974); Harvey (1974); Elder (1978); Rosenberg (1975a,b); Bryan (1979); Prosi (1979); and Preston (1972).

It was concluded by Moriarty (1983) that the available experimental data suggests that intake from food is not likely to be the major source of

pollutants in aquatic species and that generally speaking bioconcentration along the food chain is of secondary importance. Such a conclusion could make it easier to predict the behaviour of a chemical. Attention should then be focussed on predicting a pollutant pathway as well as the rates at which pollutants enter and leave organisms, instead of locating their positions in the food chain.

Many organisms possess the ability to bioaccumulate compounds. Geyer (1982) investigated the relevance of water solubility (WS) and n-octanol/water partition coefficient (K_{ow}) for predicting the possibility of bioaccumulation. By using the bioaccumulation factor (BF) and water solubility data from the literature, a linear inverse relationship between log WS and log BF was demonstrated (Figure 1.10). They also demonstrated a linear relationship between log BF and log K_{ow} (Figure 1.11).

They then concluded from this study that for the evaluation of a chemicals' behaviour in the environment, the n-octanol/water partition coefficient and water solubility estimations of the bioaccumulation factor could and should be used. They also concluded that if $K_{ow} > 1\ 000$ for organic chemicals then laboratory bioaccumulation studies would not be necessary. Similarly they concluded that if $WS > 2\ 000\ \text{mg/l}$ then bioaccumulation studies with mussels would not be necessary. Although these analyses do not take into account the size of the dose, or the difference between species in rates of uptake, metabolism and excretion, factors such as WS and K_{ow} are useful for the screening of organic compounds in ecotoxicology regulatory procedures.

In addition to the above analyses, Freitag (1982) developed a screening system: ecotoxicologic profile analysis. The system comprises of five tests:

- (1) bioaccumulation in algae;
- (2) bioaccumulation in fish;
- (3) retention, dispersion and excretion in rats;
- (4) degradation, transformation and accumulation in activated sludge;
and
- (5) photomineralisation (abiotic process).

This profile analysis test system, also called environmental hazard

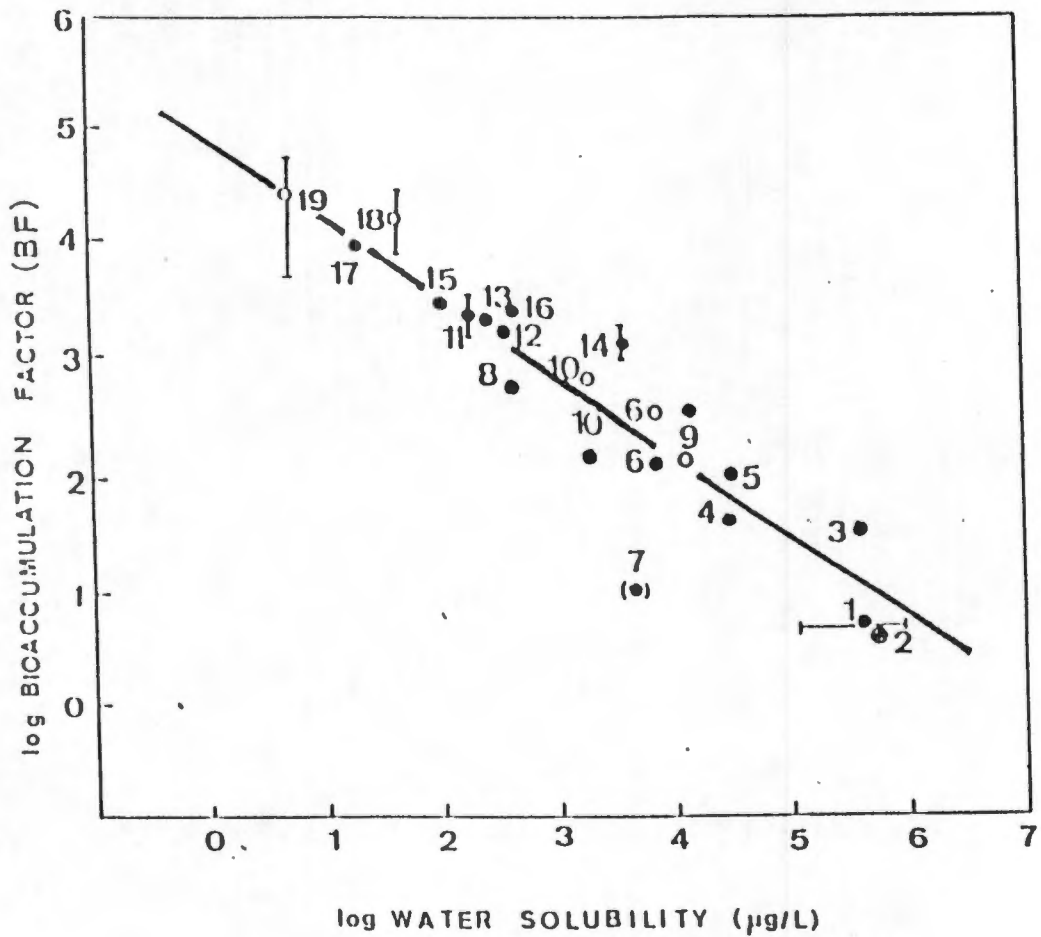


Fig. 1.10 Correlation of log bioaccumulation factor in the mussel *Mytilus edulis* with the log water solubility for various organic chemicals. (Solid circles (•) designate laboratory experiments; open circles (o) indicate data from environmental analysis).

From Geyer, 1982.

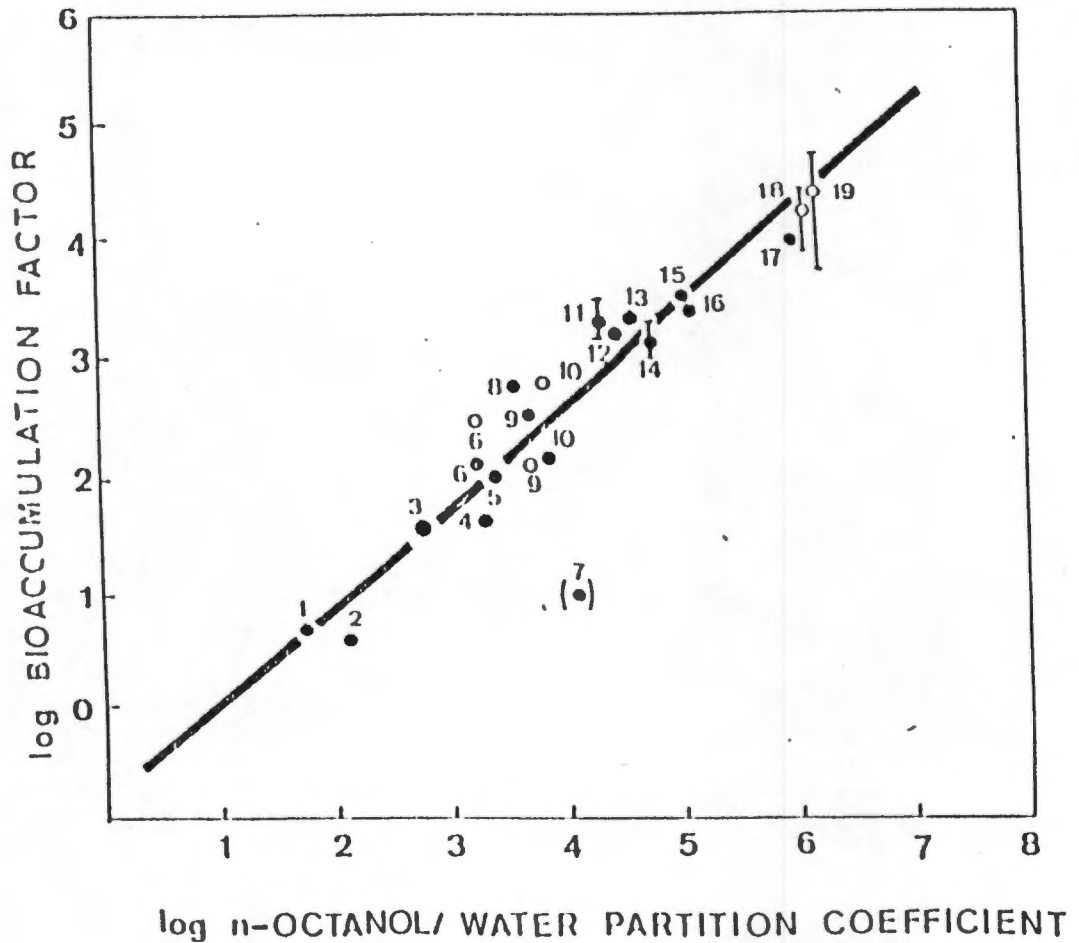


Fig. 1.11: Correlation of log bioaccumulation factor in the mussel *Mytilus edulis* with log n-octanol/water partition coefficient for organic chemicals. (Solid circles (●) designate laboratory experiments; open circles (○) indicate data from environmental analysis).

From Geyer, 1982.

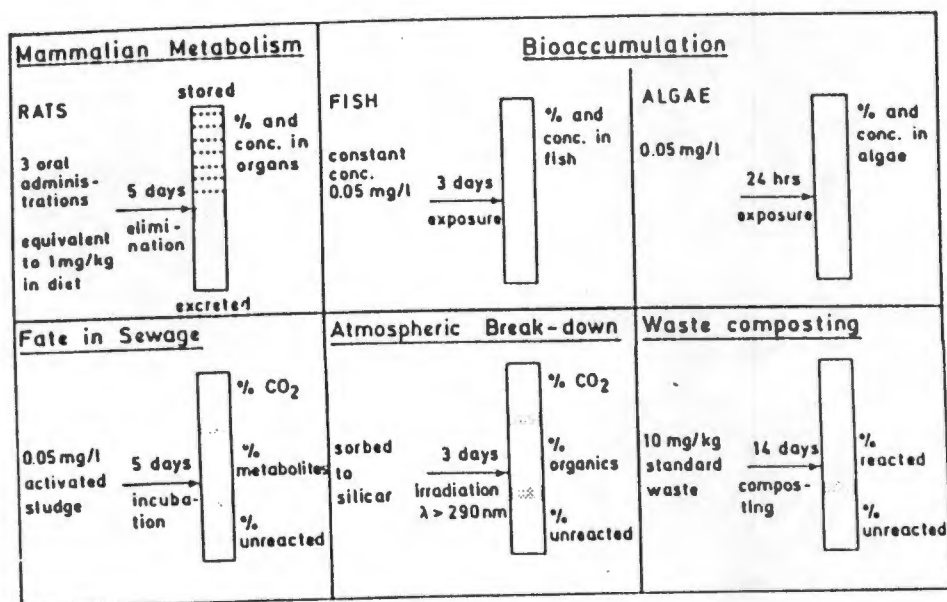


Fig 1.12: Environmental hazard profile: test system.

From Freitag, 1982.

profile (Figure 1.12) can be used to identify chemicals which could be potential pollutants in the environment. Should a compound prove to be of any significance, then further toxicological tests should be performed. Thus, although this profile analysis does not provide the ultimate answer, it can be used by regulatory bodies to evaluate by means of a short, relatively non-expensive method, the possible behaviour in the environment.

Ecosystems usually contain a number of species which make it difficult, even if some effects on a species are known, to predict the effect of a compound on the ecosystem as a whole. The problem is the shortage of data on a pollutants' impact on competitive ability, as toxicological data in a species are usually obtained under specified static conditions. It has therefore been proposed (Moriarty, 1983) that the most effective prediction would be to establish the least exposure likely to produce a deleterious response and then to examine the extent to which different environmental conditions could alter such a response.

1.6 Aim of this study

Chemicals used in agricultural activities, could possibly be the most potent group of compounds used on a regular basis by employees representing a significant fraction of the unskilled, economically active, labour market of a country. Certainly such a statement will hold true for South Africa and probably for most Third World and developing states. It is therefore the aim of this study to investigate the following:

- (1) Acute intoxication due to chemicals used in the agricultural industry will be investigated. A compendium - the first of its kind in South Africa - for use by hospitals and clinical practitioners, and containing trade names, chemical classification of active ingredients, toxicology, symptomatology and proposed treatment procedures for each product, is presented as an Appendix.
- (2) Chronic exposure to residues of agricultural products in the diet of South Africans will be investigated. Although some surveillance data of these chemicals in raw agricultural produce are available, such data are inadequate to evaluate chronic exposure and thus a total diet (Market Basket) study will be presented. Although this study reports only on contaminants from pesticides, polychlorinated biphenyls, cadmium and lead will also be included.
- (3) Factors contributing to acute intoxication by pesticides will be determined. It is not believed that the toxicity of a compound is the only reason for acute poisoning. Therefore a 400 case study will be investigated by an epidemiological investigation to obtain the contribution from occupational, environmental, cultural and socio-economic variables. It is believed that the South African agricultural industry represents both the First and Third World and thus should be ideally suited for this kind of investigation.

CHAPTER II

ACUTE EXPOSURE TO PESTICIDES IN THE REPUBLIC OF SOUTH AFRICA

2.1 Introduction

The object of agriculture is primarily to provide in the food requirements of a community. In a crop situation this normally results in monoculture, the reduction to a single plant species over a given land area. Maximum production is vital if not critical; the world's population is multiplying while the agricultural area remains static. One of several factors in achieving maximum productivity, is to prevent any stress intolerable to a specific crop. Such simplified ecosystems are vulnerable to disease and pests, and therefore pesticides will always be needed. The challenge in employing pesticides is to use the minimum effective dosage to achieve the desired results, without adverse effects to the environment or hazard to man.

Pesticides can be categorised into three main groups: (1) insecticides, (2) herbicides and (3) fungicides. In Africa and other countries of the Third World, the damage to crops is mainly caused by insects, despite the fact that only 5 000 of the million plus insect species are recorded as being pests (Madeley, 1984). It is thus not surprising that at a major food conference - Advancing Agricultural Production in Africa, 1984 - it was widely agreed to investigate alternative methods to remedy the situation. I do not myself believe it possible (~~fully~~) to replace insecticidal use ^{totally,} nor that pesticides should be blamed for the failure of control (Madeley, 1984). What is of the utmost importance is that chemicals of this nature should be used correctly, only when necessary and strictly according to the prescribed conditions. The number of pests resistant to pesticides has escalated from 137 to 432 between 1960 and 1980 (Madeley, 1984) and the consequent loss of production due to insect activity is alarming. A report by the FAO as early as 1947 recorded the loss of world production of cereal grains at 5%. "In 29 countries the loss of cereals was 23 355 000 tons of which 50% was attributed to insects" (Plimmer, 1982).

Pesticides are not only a necessity in agriculture; they are vital in containing infectious diseases. A few examples should suffice (De Foliart, 1982):

- * Prior to 1953 India had 750 million cases of malaria and 750 000 deaths annually from this cause.
- * The 750 million cases in India were reduced to 100 000 annually in the mid-1960's, resurged to 5 million in 1976 and to 10 million in 1977.
- * In 1981 Japanese encephalitis resulted in 5 359 cases with 1 869 deaths.
- * The United States has more than 1 000 cases of Rocky Mountain fever annually and Texas had an epidemic of Venezuelan equine encephalitis in 1971 which resulted in 1 500 equine deaths and 110 human cases, while 3 million horses were vaccinated and more than 8 million acres were sprayed with insecticides to bring the situation under control.
- * Between 1896 and 1948, 12,5 million people died in India due to bubonic plague.

Thus chemicals are used in agriculture and in public health because no viable immediate alternatives exist. Another approach is integrated pest management, in which biological control is the most important component. Such an approach might prove viable in future and should therefore receive attention. However, a statement such as "the aim of biological control is to establish a once-and-for-all self-regulatory system" by the Commonwealth Agricultural Bureau (Madeley, 1984), is an over-simplification of the "problem", simply because (1) to re-establish ecosystems to achieve such a goal might take centuries; and (2) it could well be that a point of no return has already been reached.

Korte (1974) estimated a world production of 1 000 million Kg of pesticides annually. An indication and typical example of the kind as well as the quantities of insecticides involved in forest insect control in the USA, is shown in Tables 2.1 (Page 56) and 2.2 (Page 57). Table 2.1

also includes as an example the approximate oral LD₅₀ (rat) values of the active ingredients used.

These Tables indicate no obvious differences between the RSA and the most developed countries in the use of particular generic group of chemicals or in the avoidance of chemicals with an LD₅₀ below any specified value. Thus, they are probably representative of any other country, enabling meaningful comparisons as to quantities used and statistics on morbidity and mortality data.

2.2 Poisoning by pesticides

Poisoning of man by pesticides is recognised by mortality and morbid effects and could be described as being endemic (as opposed to epidemic) due to its constant presence in a community. Death, as opposed to illness, is the more drastic condition and therefore information on morbidity is expected to be neglected. Thus, in the event of a special study such as poisoning by pesticides, morbidity is more often estimated from the ratio of nonfatal to fatal cases (Hayes, 1975). Epidemics of accidental poisoning, on the other hand, happen in isolation, are more noticeable and therefore usually recorded with greater accuracy. In both circumstances the compound dose, routes of exposure as well as more local factors such as accessibility, sex and age, contribute to pesticidal poisoning in man. Referring to the safe use of pesticides, the WHO Expert Committee on Vector Biology and Control (1979) is of the opinion that the use of chemical pesticides remains indispensable at the present time but that "the large number of cases of poisoning reported from certain countries indicates clearly that the technology of pesticides has outstripped the social and legislative development needed for their proper control" (WHO, 1979). They recognised an increasing use of pesticides for crop protection and control of vector-borne disease, unfortunately to the expense of increased hazards for the local population and thus more poisoning cases.

In industrialised (developed) countries, statistics on the incidence of

Table 2.1

INSECTICIDES USED BY THE FOREST SERVICE, U.S. DEPARTMENT OF AGRICULTURE,
IN FOREST INSECT CONTROL PROGRAMS, 1975 - 1977, BY POUNDS USED

Insecticide	Pounds used	LD50 mg/Kg
Carbaryl	4 180 878	850
Fenitrothion	387 852	250
Trichlorfon	270 074	630
Malathion	82 912	2 800
Acephate	38 036	945
DDT *	37 202	113
Mexacarbate	35 688	-
Crotoxyphos	19 576	52
Azinphosmethyl	8 633	16
Carbofuran	6 485	8
Lindane	5 677	88
Mirex	3 936	306
BHC	3 296	88
Dichlorphos	2 420	80
Dimethoate	1 766	500
Aminocarb	1 332	50
Chlordane	877	457
Disulfoton	855	8
Dimilin	592	4 640
Disyston	525	8
Toxaphene	500	90
Diazinon	394	300
Methomyl	263	17
Phorate	134	3
Tetrachlorvinphos	134	4 000
Chlorpyrifos	116	163
Pyrethrins	114	586
Dieldrin	50	46
Oxydemetonmethyl	50	65
Chlorpyrifos methyl	44	2 140
Dicofol	42	809
Methoxychlor	35	600

* Used to control plague fleas, a use permitted by law.
 From Crisp (1982)

TABLE 2.2

INSECTICIDES USED IN FOREST SPRAY PROGRAMS FOR CONTROL OF INSECT PESTS
BY THE FOREST SERVICE, U.S. DEPARTMENT OF AGRICULTURE, 1975 - 1977
BY ACREAGE TREATED

Insecticide	Acres sprayed or treated
Carbaryl	5 240 063
Fenitrothion	1 521 074
Trichlorfon	294 642
Mexacarbate	237 784
Malathion	116 820
Lindane	86 936
Acephate	73 289
DDT *	34 979
Toxaphene	21 241
Methoxychlor	16 000
Dimilin	14 602
Carbofuran	13 288
Aminocarb	5 910
BHC	5 688
Phorate	4 807
Dibrom	3 000
Mirex	2 226
Phosmet	1 802
Dimethoate	1 115
Crotoxyphos	900
Methomyl	450
Abate	361
Azinphosmethyl	300
Disulfoton	207
Diazinon	143

* Used to control plague fleas, a use permitted by law.
 From Crisp (1982)

poisoning are both readily obtainable and relatively low (Tincknell, 1982), which means that by analysing the contribution of poisoning cases in developed countries in comparison with an estimated global total, some indication as to the position in developing countries is possible. Table 2.3 is a summary of poisoning cases by pesticides, taken from what is available in literature. Table 2.4 is a breakdown of such cases in the USA and in Table 2.5 population figures are used to derive the poisoning ratio per 100 000 of the population for not only poisonings due to pesticides but also for the total number of poisonings.

In the United States of America case reports to the National Clearinghouse for Poison Control Centers are submitted voluntarily and may therefore not reflect an accurate rate of poisoning. In fact, the national incidence of poisoning episodes has been estimated to be between 2 and 10 million cases per annum (FDA, 1980), while in the county of Denver the rate of poisoning contacts is reported to be as much as 1 000 - 1 200 cases per 100 000 population annually (Barry, 1978). A global estimate of poisoning by pesticides by the World Health Organisation is reported by the British Food Journal (1982) to be 500 000 cases with 5 000 deaths annually. The credibility of such an estimate will be reflected by poisoning cases in developing countries. The number of pesticide intoxications in Hungary (Table 2.5), of 1 700 cases annually, results in a ratio of 58,6 per 100 000 population in comparison with the average of 7,5 per 100 000 in developed countries. The position is even worse in Sri Lanka (Jeyaratnam, 1982). The author reports 15 504 poisoning cases due to pesticides in 1978, resulting in more than 1 000 deaths and a morbidity rate of 100 cases per 100 000 population. The total annual number of cases of all poisonings reported in 1978 was 19 682, thus a contribution of 79% by pesticides poisoning. There can be little doubt that developing countries of the Third World are the most prone to pesticidal poisoning and that each of these countries will have to deal with the problem as a matter of urgency.

2.3 Classification of Pesticides

In Chapter I it was discussed that all chemical compounds contain the

TABLE 2.3INTOXICATION BY PESTICIDE CHEMICALS 1-6

Country	Date	Number of cases	Number of fatalities	Reference
Tunisia	1977	100	4	3
New Zealand	1978	124	0	3
Indonesia (Djakarta)	1976	105	8	3
Austria	1978	443	0	3
Sweden	1977	735	0	3
Canada	1975	1 317	1	3
Norway	1976	200	0	3
Switzerland	1978	510	0	3
Belgium		720	12	3
Australia	1976	399	2	3
USA	1978	9 271	4	4
Italy	1978	102	3	3
Japan	1978	145	18	3
UK	1978	51	1	3
France (Paris)	1976	878	4	3
Germany	1978	200	1	3
Algeria	1976	367	7	3
Egypt (Cairo)	1975	3 255	129	3
Uruguay	1975	1 700	-	5
Brazil	1978	819	11	6

1. In some instances a figure is the mean of figures of consecutive years.
2. Number of fatalities does not include suicides.
3. Groupement International Des Associations Nationales De Fabricant De Pesticides, Bruxelles - Belgique, 1980.
4. National Cleaninghouse for Poison Control Centers, 24, 1980.
5. Pronczuk de Gorbino, J. (1982): Safe use of pesticides in Uruguay. Education and safe handling in pesticide application, Elsevier, Amsterdam.
6. Almeida, W.F. (1982) Agromedicine and pesticide management. Education and safe handling in pesticide application, Elsevier, Amsterdam.

TABLE 2.4PESTICIDE POISONING IN THE UNITED STATES OF AMERICA, 1978¹

Pesticide group	Total cases	Fatal	Accidental	Suicide	Other
Insecticides	5 304	3	4 223	142	938
Rodenticides	1 710	1	1 568	53	89
Fungicides	207	0	176	2	29
Herbicides	457	0	260	13	184
Pesticide combinations	92	0	66	1	25
Moth balls	996	0	956	3	37
Animal repellants	233	0	104	0	129
Insect repellants	272	0	218	0	54
Total	9 271	4	7 571	215	1 485

1. National Clearinghouse for Poison Control Centers, 24, 1980.

inherent property of being toxic and/or hazardous and that the toxicity of a compound could be expressed as a numeric value to facilitate comparison and to enable us to distinguish between compounds. It could be argued that such an awareness is sufficient to allow man to avoid these chemicals and therefore safeguard himself and his environment against detrimental effects and pollution. Such an argument would certainly include pesticides. However, pesticides are chemicals intentionally used to kill. They are therefore not avoidable and in contrast to other chemicals, are used only because of their ability to kill.

In 1975 the 28th World Health Assembly approved the WHO recommended classification of pesticides by Hazard (WHO, 1984). The classification is based on acute oral and dermal toxicity to the rat and distinguishes between the more and less hazardous forms of a technical compound and their formulations.

"The hazard referred to in this Recommendation is the acute risk to health (that is, the risk of single or multiple exposures over a relatively short

TABLE 2.5POISONING CASES PER 100 000 OF POPULATION

Country	Population million	Total poisoning cases	Total poisoning ratio per 100 000	Pesticide poisoning cases	Pesticide poisoning ratio per 100 000
New Zealand	3,1	2 044	65,9	124	4,0
Austria	7,5	-	-	443	5,9
Sweden	8,3	32 612	393	735	8,9
Canada	23,7	53 955	228	1 317	5,6
Norway	4,1	-	-	200	4,9
Switzerland	6,3	12 743	202	510	8,1
Belgium	9,9	118 849	1 200	720	7,3
Australia	14,6	6,320	43,3	399	2,7
Italy	57	142 764	250	102	0,2
Japan	115,9	-	-	145	0,13
United Kingdom	56	-	-	51	0,1
Germany	61,5	-	-	200	0,3
Egypt	41,6	12 450	29,9	3 235	7,8
USA	220,6	152 433	69,1	9 271	4,2
Uruguay	2,9	-	-	1 700	58,6
Brazil	122	-	-	819	0,7
X			276		7,5
Republic of S.A. calculated from					
1. Total population					
2. 276 cases per 100 000					
3. 7,5 cases per 100 000					
	25	69 000	(276)	1 875	(7,5)

period of time) that might be encountered accidentally by any person handling the product in accordance with the directions for handling by the manufacturer or in accordance with the rules laid down for storage and transportation by competent international bodies" (WHO, 1984). In this classification allowance was made for the lesser hazards ^{formulations.} ~~from~~, for example, solids as compared with liquids. The different groupings of this classification are given in Table 2.6, while Figure 2.1 also indicates into what classes the different generic groups of pesticides are classified.

TABLE 2.6

WHO CLASSIFICATION OF PESTICIDES

Class	LD ₅₀ for the rat (mg/kg body weight)			
	Oral		Dermal	
	Solids *	Liquids *	Solids *	Liquids *
1a Extremely hazardous	5 or less	20 or less	10 or less	40 or less
1b Highly hazardous	5 - 50	20 - 200	10 - 100	40 - 400
II Moderately hazardous	50 - 500	200 - 2 000	100 - 1 000	400 - 4 000
III Slightly hazardous	Over 500	Over 2 000	Over 1 000	Over 4 000

* The terms "solids" and "liquids" refer to the physical state of the product or formulation being classified.

It is important to note that:

- (1) the hazard concerned is the acute risk to human health;
- (2) adjustments to the classification can be made should it be warranted due to specific damage or effects by a compound; and
- (3) pesticides are also classified on the basis of the physical state of a product.

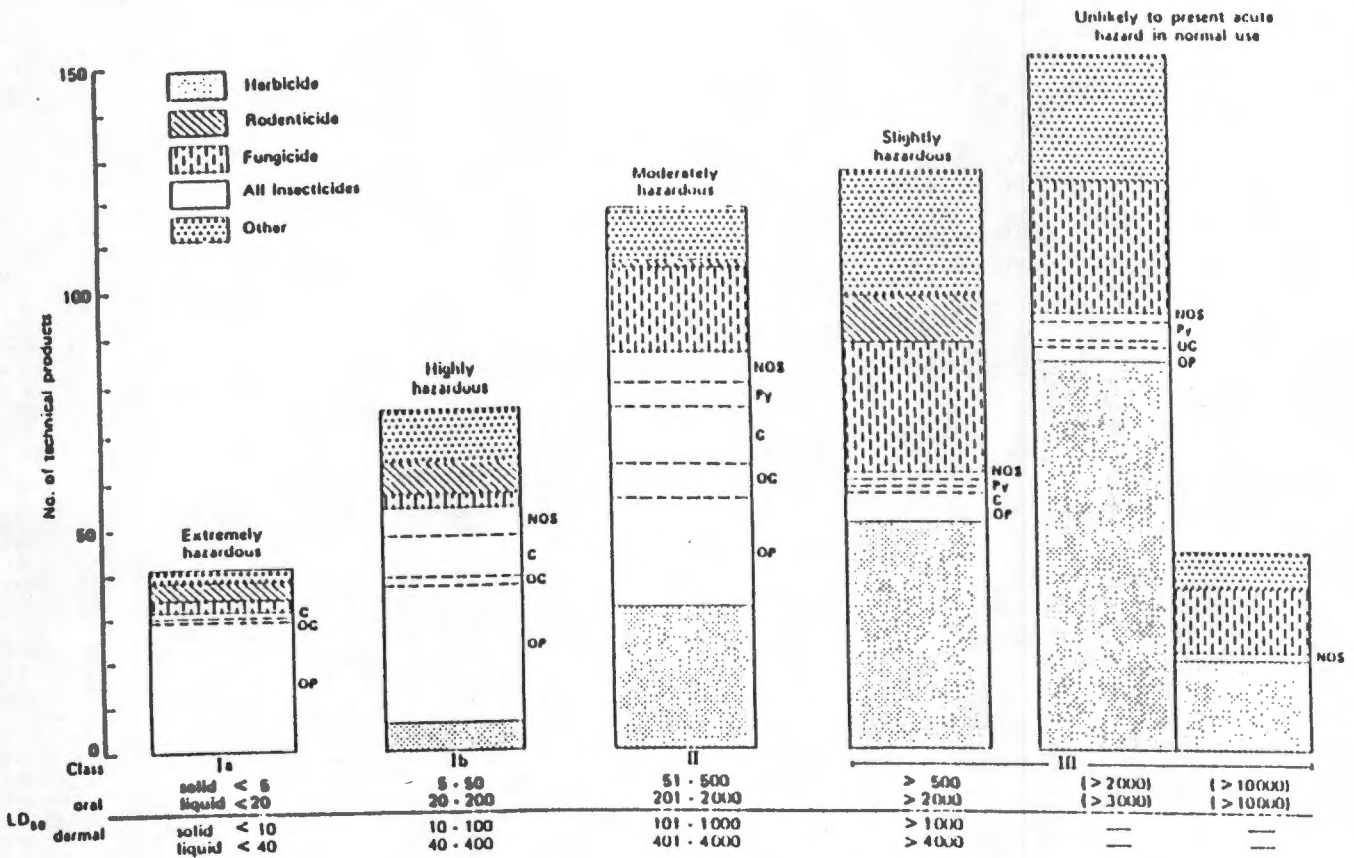


Fig. 2.1: WHO Recommended Classification of Pesticides by Hazard: Distribution of technical products among hazard classes for insecticides:
 OP = organophosphorus Py = pyrethroid
 OC = organochloride NOS = not otherwise specified
 C = carbamate

from Copplestone, 1982.

2.4 The South African Situation

2.4.1 Agricultural and pastoral activities

The Republic of South Africa is situated at the southern tip of the African continent. It has a total area of 112 405 000 hectare with a population of 25 million, constituted by the following groups:

Blacks	17 022 248	(68%)
Whites	4 551 068	(18,2%)
Coloureds	2 624 007	(10,5%)
Asians	819 202	(3,3%)
	<hr/>	
Total	25 016 525	
	<hr/>	

According to the Census of Agriculture; and Pastoral production (1980) the country constitutes 75,562 farming units with an area of 85 447 000 ha, thus 76% of the total land area. Agricultural land is cultivated for the following annual and perennial crops:

	<u>hectares</u>
Wheat	1 544 790
Seed cotton	58 552
Edible dry beans	60 875
Millet and manna	11 945
Grain sorghum	229 940
Groundnuts	215 163
Sunflower seed	323 082
Maize	4 350 864
Vegetables	100 005
Nuts	1 193
Flowers, bulbs & shrubs	13 252
	<hr/>
	6 909 661
	<hr/>

In a developing country such as the Republic of South Africa, employment opportunities are of utmost importance. The agricultural sector makes the following contribution:

	<u>Regular employees</u>	<u>%</u>
Blacks	547 886	81,9
Coloureds	104 644	15,6
Whites	13 720	2,1
Asians	2,836	0,4
	<hr/>	<hr/>
	669 086	100,0
	<hr/>	<hr/>

The Republic of South Africa is, with regard to agriculture, not only self-supporting but the export of agricultural goods is important in earning foreign exchange. The Republic also depends on the agricultural sector for creating employment opportunities.

2.4.2 Registration of agricultural chemicals

The aim of environmental health standards is to protect individuals, human populations, and their progeny from the adverse effects of hazardous environmental factors, including chemicals. A sound principle of health protection is to keep all exposures as low as reasonably achievable, subject to the condition that the appropriate exposure limits are not exceeded.

Environmental health standards for chemicals may be formulated either in terms of concentrations in environmental components (eg. air, water, consumer products) or in terms of amounts of substances that may be taken into the body. These concentrations and amounts should be sufficiently low so that the threshold dose will not be reached, or that the population will not be subject to unacceptable risk, even following lifetime or working lifetime exposure. The setting of standards however, is no easy task. This process of necessity involves many considerations beside toxicology. It may differ from country to country and even from society to society. In general, however, it involves appraisal of toxicological data, particularly of dose-response relationships, including the effects on non-human targets (plants, animals), social and economic analysis, policy analysis and review of experience elsewhere, leading eventually to an administrative or policy decision concerning the standard. Such a standard is an acceptable level of risk, which means accepting a level of

risk at which it is unlikely that anybody will become chronically ill, but at which 100% safety could not be guaranteed. It means living with reasonable assurance of safety and an acceptable uncertainty.

In the Republic of South Africa, as in all developed countries, an agricultural and stock remedy has to obtain official registration in order to be available to commerce. Such registration is provided by the Fertilizers, Farm Feeds, Agricultural Remedies and Stock Remedies Act (Act 36 of 1947), which includes the registration of fertilizers, farm feeds, agricultural remedies, stock remedies, sterilizing plants and pest control operators; to regulate or prohibit the importation, sale, acquisition, disposal or use of fertilizers, farm feeds, agricultural remedies and stock remedies; to provide for the designation of technical advisers and analysts; and to provide for matters incidental thereto. In the registration procedure this act is assisted by the Hazardous Substances Act (Act 15 of 1973) by which the State Department of Health and Welfare provides for the importation, sale, use, application, disposal, etc. of any substance which may cause ill-health or death to human beings. By regulation under Act 15 of 1973, chemicals are grouped to control the conditions of sale, supply, transportation, labelling, disposal, etc., of specific chemicals or chemical compounds.

All insecticides, herbicides or "poisons" used as agricultural remedies are registered for a specific use, prescribing the crop or plant to be treated, formulation, dosage, withdrawal period and the maximum residue limit allowed on the commodity at harvest. By legislation these measures therefore assure that controls are "tight enough", although misuse or abuse by the end user could and does occur and is not easy to control.

Most countries call upon pesticide manufacturers to submit information on the effect and safe use of their products. International organisations such as WHO, FAO and the Council of Europe have encouraged a uniform approach to the questions and problems surrounding the registration and use of these chemicals. This uniform approach has to a large extent been accepted by the world as guidelines and codes of practices and is therefore also applied in the RSA.

A uniform approach has also been adopted as a guideline on environmental phenomena and wildlife data. The risk to the environment could be of a

very complex nature and depends on many factors such as toxic properties, persistence in the environment, extent of use, method of application, etc. Nevertheless experience has shown that predictions can be made from the results of residue studies, toxicity tests and field trials and surveys. Experience has also shown that birds, fish and insects may differ widely from mammals in response to pesticides and therefore tests are carried out on more than one avian, fish and insect species. Usually these tests are done on bird species such as pigeons, quails, pheasants and ducks, fish species such as trout and bluegill, and insects, particularly honey bees.

It has to be emphasised that although legislation is needed to prevent poisoning, such a goal can hardly be achieved without educating those who handle the compounds. Dr. J.F. Copplestone (1982) of WHO, summarised it as follows: "It is a truism to say that the surest way of preventing accidental poisoning by pesticides is by educating those who handle the compounds at all stages from manufacture to final use. While legislation is effective in achieving part of this goal if it is efficiently enforced, education is essential in even the most well regulated countries. However, the fact that, after more than 30 years of widespread use of pesticides, the subject of mode of education is still being discussed, shows that not as much has been achieved in this respect of prevention as might have been expected."

In section 2.3 the classification of pesticides by the World Health Organization and the way in which it distinguishes between the more and less hazardous forms of each pesticide, was discussed. It is based on hazard rather than toxicity and it recognises the greater hazards that may arise when a pesticide or formulation is in a liquid state. Thus it is true that the proposal distinguishes between the different risks of handling the different physical forms and concentrations of pesticides and formulations.

Scientifically speaking, I agree with the philosophy and theory of the World Health Organization's proposal.

However, I cannot agree with its practical implementation. One of the objects of the proposal is to offer maximal protection to all classes of persons subject to risk from the use of these chemicals and secondly the

World Health Organization themselves admit that dilution of some of the formulations will not alter their hazard and that it could appear to the handlers that fewer precautions are required using diluted formulations than in the handling of concentrates.

In the handling of pesticides, statistics show South Africa to be vulnerable to an appreciable number of deaths and poisoning cases. There could be a number of reasons for this phenomenon, two of them probably being:

- (1) ignorance and negligence on the part of officers in charge of handling pesticides; and
- (2) perhaps the most important, the exploitation of unskilled labour in applying and handling pesticides.

In South Africa therefore, pesticides are classified into four groups according to their oral and dermal LD₅₀'s. It does not take the formulation into consideration except when the LD₅₀ of the formulation is lower than the LD₅₀ of the active ingredient. It is therefore not based on hazard and does not recognise the less hazardous nature of a diluted formulation or even any other physical state for that matter.

Classifying an active ingredient into a specific group (according to LD₅₀), means that no product with such a specific active ingredient could appear in any other group, no matter the nature of the formulation. It is proposed that this way of classification counteracts confusion amongst unskilled workers, should contribute to fewer accidental poisonings and should in fact be recommended to developing countries until such time as the country has developed sufficiently to implement the system proposed by WHO.

In the South African situation we also have to keep the political situation in mind, where we have several relatively speaking undeveloped nations becoming independent within the borders of Southern Africa. Agriculture will probably play a major role in their economy and thus pesticides will be used. The question arises that if we have difficulty educating the users of pesticides in a relatively developed country, using a straight forward classification according to toxicity, what problems are we going to encounter when we use a classification - which we believe

could lead to a fair extent of confusion - amongst the unskilled in undeveloped states?

It is therefore believed that the World Health Organization's proposals could not be applied generally and that social and political factors have to be considered.

Ironically, the philosophy of classifying according to toxicity and not hazard, is advocated by WHO when dealing with education. Coppelstone (1982), chief of pesticide development and safe use of WHO comments: "If all pesticides are treated the same way educationally, there seems to be real danger that precautions which are necessary for the higher hazard classes will be neglected with impunity when compounds in the lower hazard classes are used. Precautions may then not be taken when later needed for the application of a more hazardous compound." It is believed that the classification of pesticides is not only a regulatory process but also an educational one and that such an inconsistency must be deplored - at least as far as developing countries are concerned.

2.4.3 Poisoning by chemicals in agriculture and public health

As in most other countries in the world, poisoning in the Republic of South Africa is to be expected due to the use of pesticides. In Tables 2.3 and 2.5 poisoning incidences as well as the ratio of insecticides per 100 000 population according to available literature has been reproduced. Most, if not all, of these cases were voluntarily reported to either poison centers at hospitals, or the numbers were calculated from positively diagnosed cases admitted to hospitals. It was also stated (FDA, 1980) that such reported cases may only represent 1,5% - 7,6% of all poisoning episodes.

In the Republic of South Africa poisoning due to any agricultural or stock remedy registered in terms of the fertilizers, Farm Feeds, Agricultural Remedies and Stock Remedies Act (Act 36 of 1947), is declared a notifiable medical condition in terms of section 45 of the Health Act (Act 63 of 1977) (Government gazette, 1979). Cases reported, mortality and ratio per 100 000 population for the years 1979 to 1982 are given in Table 2.7.

2.5 Results and Discussions

A synopsis of all pesticide products used in South Africa is given in Appendix I (Fourie, 1984). It contains in tabulated format the trade names of products in alphabetical order, including the names and addresses of manufacturers. Swimming pool chemicals are also included because they too are regulated by the same Act (Act 36 of 1947). All active

TABLE 2.7

REPORTED CASES OF PESTICIDE POISONING TO THE DEPARTMENT OF HEALTH
AND WELFARE (1983)

	1979	1980	1981	1982
Poisoning cases reported	77	113	98	166
Morbidity per 100 000 population	0,33	0,48	0,40	0,65
Reported deaths	17	6	9	10
Mortality per 100 000 population	0,07	0,03	0,04	0,04

ingredients used in the formulation of a product are classified into chemical groups. These groups need some clarification. When a compound is not classified strictly according to chemical structure, such classification must be open to criticism. However, the ultimate objective for the classification must not be overlooked. In the present classification the object is to assist hospitals and health officials in the identification of the active ingredient responsible for intoxication and hence, the treatment of such patients. To illustrate this ^{point} the following examples should suffice: Fenchlorphos ($C_8H_8Cl_3O_3PS$) and dichlorphos ($C_4H_7Cl_2O_4P$) are halogenated organic pesticides and could strictly speaking be classified as organochlorines. In fact, if environmental pollution and the fate of these chemicals in ecology were under discussion, cognizance would have to be taken of the chlorine atoms attached to these molecules. However, the biological effects of these chemicals are those typical of organophosphate compounds - which differ totally from organochlorines - and a classification as organochlorines would not only

be misleading but could also be fatal.

For each group of chemicals a monograph has been drawn up which includes information on toxicity, symptomatology and recommended treatment procedures (Appendix I).

An analysis of the products registered indicates a total of 1 211 products available and classified into the groups as shown in Table 2.8. Of the 1 211 products, 359 different active ingredients are used 1 530 times. It is not possible to compare these figures with the official poisoning notifications (Table 2.7) because very little is known about these cases. However from the epidemiology survey (Chapter 4), Figure 2.2 indicates the contribution to poisoning cases by the different chemical groups. It is noticeable that the three chemical groups responsible for 73% of the poisoning cases (organophosphates 55%; carbamates 14%; organochlorines 4%) are also with the exception of pyrethroids, the chemicals most frequently formulated (Table 2.8). When it is realised that products containing these three chemical groups constitute only 41% (n = 495) of all formulated products, but are responsible for 73% of all intoxications, and that the balance consisting of 59% (n = 716) is only responsible for 27% of the intoxications, then it seems to indicate no relation between the number of products available and poisonings occurring but rather some relationship between type of chemical and poisonings occurring. Therefore Appendix I has to be analysed in greater detail.

Tables 2.9 to 2.11 represent the three main chemical groups containing each individual active ingredient as formulated. Not only is the number of products representing the active ingredients tabled, but also the calculated number of possible uses of the formulations containing a specific ingredient. The LD₅₀ of each active ingredient is also tabled.

With reference to organophosphates (Table 2.9) the order of active ingredients (a.i.) responsible for intoxications is:

a.i.	: parathion>Mevinphos>Fenthion>diazinon>mercaptotion>bromophos					
% intox.	: 19,8	14,9	8,6	7,7	6,7	5,4
No. prod.	: 6	2	2	30	39	1
No. uses	: 51	15	18	32	143	2
LD ₅₀	: 3	3	200	108	1 375	15

TABLE 2.8GROUP CLASSIFICATION OF PESTICIDAL COMPOUNDS USED IN SOUTH AFRICA

Pesticide group	Number of products	% of total
Organophosphate	304	25,1
Pyrethroid	145	12,0
Organochlorine	97	8,0
Carbamate	94	7,8
Organonitrogen	93	7,7
Fumigant	72	6,0
Dithiocarbamate	52	4,3
Chlorophenoxy	43	3,6
Anticoagulant	23	1,9
Nitrophenolic	18	1,5
Dipyridyl	14	1,2
Arsenical	12	1,0
Others	244 *	20,1
Total	1 211	100,0

* Other: mostly swimming pool products with active ingredients which can not be sensibly classified in any group and are generally of very low toxicity.

In organophosphates it is obvious that the relative toxicity is a major factor in poisoning; in parathion (3mg/Kg) and mevinphos (3mg/Kg) it is substantially lower than in other compounds and contributes to poisoning by 19,8% and 14,9% respectively. Relative toxicity is however, not the only factor. Bromophos, also with a relatively low LD₅₀ of 15mg/Kg, is only no.6 on the list, preceded by three compounds (Fenthion, diazinon and mercaptothion) which are much less potent but with the possibility of being used much more frequently. Thus it is not only the inherent toxicity of a compound that can be blamed but also the way in which a compound is managed and used in operation.

Poisoning by organochlorines (Table 2.10) and carbamates (Table 2.11) leads to the same conclusion. The organochlorines gamma-BHC and endosulfan, which are responsible for all the intoxications in this category, are the most potent and are also used more frequently than the other compounds. Aldrin which also has a low LD₅₀ (39mg/Kg) and is not responsible for any poisonings, is only used to a very limited extent against wood-destroying termites and serves to emphasise that frequency of use is a major factor in poisoning by pesticides.

Carbamates (Table 2.11) show the same results. The compounds aldicarb, methomyl and carbaryl are either the most potent or the most frequently used or both, and this endorses the conclusions drawn with organophosphates and organochlorines.

a.i.	:	aldicarb	>	methomyl	>	carbaryl	>	carbofuron	>	pirimicarb
% intox.	:	54		23,7		12,7		5,5		1,8
No. uses	:	16		30		55		16		15
LD ₅₀	:	1		17		400		8		147

Most alarming is the erratic notification of intoxications and hence the statistics published by the Department of Health and Welfare. Hayes (1975) discusses this problem at great length and reaches the conclusion that nonfatal poisonings must be estimated from the ratio of nonfatal to fatal cases in special studies. Analysing the available statistics through the years 1958 - 1970 in the United States of America, Hayes reports nonfatal to fatal ratios such as 25:1, 115:1, 50:1, 750:1, 65:1 and concludes that a ratio of 100:1 for the entire population to probably be the most accurate estimate.

Fig. 2.2 CLASSIFICATION OF POISONS WHICH CAUSED POISONING

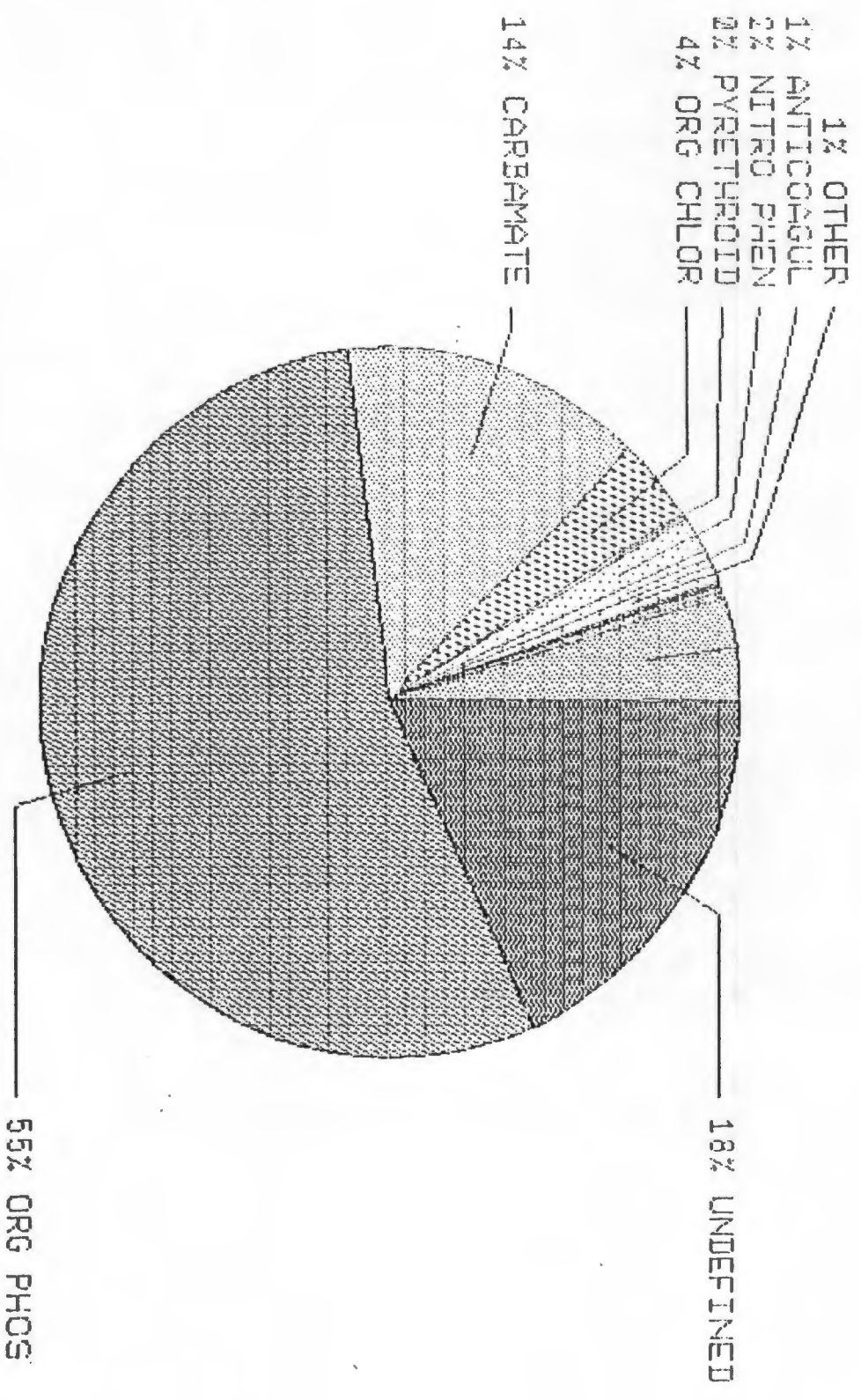


TABLE 2.9ORGANOPHOSPHATE ACTIVE INGREDIENTS

	Number of products in which a.i. appear	Number of uses *	Intoxication %	LD ₅₀ mg/Kg
Mercaptothion	39	143	6,7	1 370
Dichlorvos	39	37	1,8	80
Diazinon	30	32	7,7	108
Clorfenvinphos	19	1	1,8	10
Dimethoate	17	70	2,3	200
Chlorpyrifos	14	55	2,7	135
Trichlorphon	12	22	1,4	450
Fenitrothion	9	28	0,5	250
Bromophos-ethyl	9	1	0	52
Tetrachlorvinphos	9	14	0	400
Propetamphos	6	10	0	82
Phoxim	6	10	0	1 680
Parathion	6	51	19,8	3
Disulfoton				
Bromophos	6	22	0	2 900
Fenamiphos	1	2	5,4	15
Mevinphos	2	15	14,9	3
Monocrotophos	2	21	2,3	17
Acephate	1	26	2,7	866
Fenthion	2	18	8,6	200
Methamidophos	3	9	1,8	13
Dioxathion	4	-	0,9	

* calculated from Bot (1986)

TABLE 2.10ORGANOCHLORINE ACTIVE INGREDIENTS

	Number of products in which a.i. appear	Number of uses *	Intoxication %	LD ₅₀ mg/Kg
Gamma-BHC	33	72	60	88
Endosulfan	18	115	40	35
Chlorbenzilate	3	12	0	700
Quintozene	3	6	0	12 000
Chlordane	2	4	0	283
HHDN	2	1	0	39

* calculated from Bot (1986)

In the RSA the average fatalities reported between 1979 to 1982 was 11 cases per annum (Table 2.7). Should the ratio of 100:1 be applied, morbidity should be 1 100 cases - in comparison with a reported mean of 114 cases - per annum. However, Hayes (1975) also implies that the ratio could vary between 25 and 750, which means the morbidity figure in the Republic could vary between 275 and 8 250 cases per annum.

In Table 2.5 the ratio per 100 000 population of total and pesticide poisoning from 16 countries has been calculated. The arithmetic mean was 276 per 100 000 for total poisonings and 7,5 per 100 000 for pesticide poisonings. These two figures were then applied to the South African situation, resulting in 69 000 total poisonings and 1 878 agricultural poisonings per annum.

However, unpublished data (Stokhol, personal communication) has revealed an average death rate from pesticides of approximately 103 cases annually. This is based on inquests in which pesticides were involved, although it was not possible to establish beyond doubt that pesticides were responsible for all deaths. If these cases were in fact accidental poisonings by agricultural chemicals and the factor of Hayes (1975) is applied, then at least 10 000 poisonings by agricultural products annually could be a possibility in South Africa. Be that as it may, reporting of

TABLE 2.11CARBAMATE ACTIVE INGREDIENTS

	Number of products in which a.i. appear	Number of uses *	Intoxication %	LD ₅₀ mg/Kg
Carbaryl	54	55	12,7	400
Carbofuran	3	16	55	8
Methiocarb	3	14	0	100
Methomyl	3	30	23,7	17
Carbendazim	2	4	0	15 000
Pirimicarb	2	15	1,8	147
Aldicarb	1	16	54	1

* calculated from Bot (1986)

poisonings by pesticides in South Africa is unreliable, which emphasises an attitudinal problem by those responsible for reporting such cases, as well as the inability to enforce the legislation concerned. It is concluded that in the Republic of South Africa, agriculture is a prominent activity, employing a significant amount of unskilled labour for the production of a variety of annual and perennial crops. Farming activities are distributed over a wide rural area where medical facilities with regard to poisonings and intensive care units are limited. It was therefore vital to produce a compendium such as Appendix I in order to (1) aid local medical officials in the rural areas to identify agricultural poisoning cases and to be of assistance in the treatment thereof; and (2) to create an awareness of the safe use of these chemicals which hopefully will also have an effect on notification, to enable legislators to take appropriate measures.

Thirdly this chapter emphasises the necessity for an in depth study to determine the reasons, other than toxicity, responsible for agricultural intoxications in the South African situation. Such a study had been undertaken and is reported in detail in Chapter 4.

CHAPTER III

SUBACUTE AND CHRONIC EXPOSURE TO PESTICIDES IN SOUTH AFRICA

3.1 Introduction

Toxicological tests for the determination of the toxicology of chemicals fall mainly into 3 categories, namely acute toxicity, subacute toxicity and chronic toxicity. Subacute tests, usually using animals of two species, and being continued for about 3 months by exposure on a daily basis, provides information on the toxic effects of the compound and the target organs affected. In Chronic toxicity tests, the test animals are usually exposed for their entire lifetime to repeated doses, to establish the long term toxicological effect of the chemical. One of the main aims of these tests is to establish a no-effect level used in setting acceptable daily intakes for man (refer Chapter I). It has to be appreciated that generally speaking, man is exposed most of his lifetime to low levels of many different chemicals. Usually these exposures occur at such low doses that signs of toxicity and dose-effect relationships are not easily established, and although epidemiological studies do assist in this respect, the degree of hazard due to low level exposure in man is not easy to assess. Thus subacute and chronic testing of chemicals by using animals to assess long term effects is unavoidable.

Pesticides in agriculture and public health are used to control insects harmful to man and animals. The problem of malnutrition in an evergrowing world population, which necessitates the use of pesticides to maintain food production at an adequate level, was discussed in Chapters I and II and should be regarded to be beyond dispute. Simultaneously however, it has to be fully acknowledged - also beyond dispute - that the many pesticidal chemicals used daily give rise to metabolites and degradation products with similar toxicological properties to the parent compounds. These residues are xenobiotics which can be more potent than the majority of chemicals encountered daily, and the fact that such a chemical is deliberately used to "contaminate" foodstuffs and animal feeds, is relevant to the concern expressed by the general public on the possible

presence of such chemicals in foods. The general public is not wrong in regarding pesticides as a specific group of chemicals which they call poisons and they should not be blamed for being suspicious about possible detrimental effects ^{to} ~~on~~ their health. After all, as man is not infallible, history and literature is replete with morbidity and mortality statistics due to agricultural chemicals, in one way or another.

It is therefore the obligation of a national authority to ensure that contaminants such as pesticide residues are not present in food at levels which may adversely affect the health of consumers. In the registration procedure of such a chemical, two parties are involved, i.e. the manufacturer and the government.

The contribution of the manufacturer is twofold: (1) Experiments are to be carried out to assess the safety of the compound. Such experiments could involve several years of work and may involve 80 separate parameters in heamatology, clinical chemistry, urine analysis, electrocardiography, ophthalmoscopy, organ weighing at death and extensive histopathology (Turnbull, 1984). A chronic study in rats, for example, will involve about 130 000 separate measurements and will comprise several volumes (Turnbull, 1984); and (2) experiments are to be carried out to determine the residues which may occur in crops when the product is used as recommended.

The contribution of the government is also twofold: (i) The toxicity and residue data must be evaluated and reviewed in depth, to ascertain that the product will not be a health hazard when approved. A statutory maximum residue limit, determined by Good Agricultural Practice for a specific food commodity, has to be established and be used to establish an Acceptable Daily Intake (ADI), which is defined as the amount of a chemical which can be consumed daily for an individual's entire lifetime with the practical certainty, on the basis of all known facts, that no harm will result. (ii) It is also the responsibility of government to instigate residue monitoring programmes to determine whether the approved residue levels in commodities are not being exceeded in practice.

Some perspective, however, has to be given to the intake of residue contaminants as a measure of exposure. When a maximum residue level is established by government, the established level is kept at the minimum

and consistent with the use by good agricultural practice, which in most cases is far below the level considered to possibly give rise to toxicological effects. Thus a large margin of safety exists between level of consumption and a hazardous level. In contrast to this highly geared mechanism to nullify any possible detrimental effects due to consuming pesticide residues, two examples could be mentioned to illustrate the possibility of similar, if not much more serious, risks by chemicals commonly used. One such example is the use of chlorinated hydrocarbons. Most of these compounds, such as DDT and Dieldrin, have been prohibited for use in agriculture. However, many commercial halogenated derivatives are being extensively utilised as solvents, aerosol propellants, degreasing agents, dry-cleaning agents and in the production of plastics (British, 1984). Secondly, although natural, large numbers of mutagens and carcinogens are available in every meal and it has been emphasised that no human diet can be entirely free of such natural substances (Ames, 1983).

In many countries, governments have programmes for the analysis of residues in crop (Duggan, 1983; GEMS, 1982; GEMS 1983; GIFAP 1984). In the Republic of South Africa residue determinations in raw agricultural commodities, are also being executed on a regular basis by health officials ~~from~~^{from} local authorities, municipalities and State Departments. However, these studies are mostly done for surveillance purposes, samples being selected for infringement purposes, so that they are not representative of total food supply or dietary habits of the general public. Generally, where diet studies have been carried out, the level of ingestion of residues has been lower than the recommended acceptable daily intakes (GIFAP, 1984), which emphasises that caution must be taken in the interpretation of such data for any purpose other than those necessary for infringement studies.

In conclusion it is important to bear in mind that an individual is not only exposed to contaminants by food consumption. Exposure to heavy metals for example could be via ingestion or inhalation, and should such a contaminant be the object of concern, then the total risk in comparison to the ADI must take into account both sources of exposure.

3.2 Objectives of study

The assessment of toxicological consequences of pesticidal use in South Africa would be incomplete without a study on possible subacute exposure to these chemicals. For this specific study - toxicological consequences of pesticidal use in South Africa - the main objective is to obtain estimates of the intake of pesticide residues via food and to correlate such data with acceptable daily intakes. Comparison of such results with the legal limits set per food contaminant, will disclose whether the individual or population is exposed to chronic exposure and therefore indicate whether current regulatory practices are adequate to protect all consumers. It is also of importance to realise that the Republic of South Africa exports foodstuffs which have to comply with the regulatory pesticidal residue limits of the importing countries. It is also believed that initiating such a project would stimulate regulatory authorities to adopt a co-ordinated official food safety programme from which the monitoring data could be effectively utilised to (1) evaluate the current situation of dietary intakes of contaminants; (2) predict potential exposures to residue contaminants; and (3) create an awareness of responsibility to utilise the existing resources of manpower, facilities and finance to maximum advantage of the population as a whole.

3.3 Methods and design of study

It is not the object of this study to make food intake assessments. It is the aim of this project to derive intakes of contaminants, and therefore all available data on food consumption patterns in the Republic of South Africa have been used to develop a sampling programme. In fact not much consumption data representative of an entire ethnic population in the RSA is available, nor is it possible to determine the absolute validity of such dietary survey data. It is also realised that existing surveillance data, accumulated for infringement purposes, is inadequate for the current objectives and that the daily intake of a contaminant must be based on available food consumption data.

Food intake data was calculated from 24-hour dietary recall studies which were undertaken in the Cape Peninsula and three rural towns (Rossouw, 1983; Steyn, 1985). Although these studies by Rossouw and Steyn were

undertaken for totally different objectives, the data presented could be used for the present study. The interviewers used in their study were graduated dieticians familiar with such techniques and therefore the data is regarded as reliable.

Normally, the 24-hour recall method is only suitable when several 24-hour recalls per person are undertaken (GEMS, 1983). However, it has been established that a single 24-hour recall within a large population does reflect reliable average long-term intakes since the group mean values obtained by this approach do not vary significantly on a day-to-day basis (GEMS, 1983).

Three approaches (GEMS, 1983), based on food consumption data, are available for the estimation of the daily intake of a contaminant: (1) Total diet ("Market Basket") studies; (2) selective studies of individual foodstuffs; and (3) duplication portion studies. Normally only one of these approaches is used, but because this study had not been done before in South Africa and because a single study to reflect the average intake of a contaminant for the population as a whole is not feasible due to the diversity of ethnic groups in South Africa, it was decided to use the total diet as well as the selective studies of individual foodstuffs approaches.

The market basket approach entails table-ready prepared foods of a defined total diet consumption. Food commodities are combined in food group composites in proportions based on consumption data, and each group analysed separately for the different contaminants selected. Such analyses allow calculations for each composite group - which will reflect the distribution of contaminants amongst composite groups - as well as for the diet as a whole.

The individual foodstuffs approach involves the separate analysis of each food component of a food group in its unprocessed state. This method will not only allow daily intakes to be calculated, but will also (1) allow the calculation of daily intakes for any ethnic group if consumption data are available; and (2) allow assessment of possible contamination of foods as well as possible losses of contaminants due to the table-ready preparation of commodities. If no consumption data is available for a particular ethnic group, theoretical consumption data could be used in combination

with those from the individual foodstuffs approach to calculate the probable daily intake of contaminants.

Sampling sites chosen were representative of all the geographically important cultural regions within the country. These were the major cities from the four provinces including six rural towns:

Cities

Cape Town plus one rural town
 Port Elizabeth plus one rural town
 Durban plus one rural town
 Kimberley plus one rural town
 Bloemfontein plus one rural town
 Johannesburg
 Pietersburg plus one rural town

Sampling was performed during the months of July, October and January/February, from supermarkets and butcheries normally available to the public.

A standard shopping list was developed describing the food item and quantity to be supplied. The 142 food items were arranged according to the 11 food classes:

	<u>Food class</u>	<u>Number of items</u>
1.	Vegetables	13
2.	Fruit	8
3.	Meat, meat products and poultry	24
4.	Cereals	33
5.	Eggs	1
6.	Fish	6
7.	Soup	7
8.	Fat and oils	3
9.	Milk and milk products	18
10.	Sugars and sweets	12
11.	Beverages	17

	Total	142

Sampling was done on the same day at the 13 locations during summer, spring, winter/autumn and transported by air, under refrigerated

conditions to the analysing laboratories in Cape Town. Thus for each sampling, 1 846 food items from the 13 locations were sampled, which totalled 5 538 food items for the three calendar periods.

One of the laboratories was established as a kitchen facility. On receipt of each batch of 1 846 samples, samples were categorised and prepared according to flow-diagrams I - XI. Samples to be prepared as ready-to-consume foods, were processed according to pre-prepared cookbook to standardise all methods used, which consisted of typical, normal household recipes consistent with cultural habits. Mixing, blending and homogenisation of samples were done carefully to obtain representative samples. Although all possible care was taken not to contaminate any samples, equipment and containers used were those typical of a South African kitchen so that normal contamination or loss of contaminants, if any, would be reflected in the analytical results. Prepared samples were frozen in large mouth glass containers until analysis could be performed.

Analyses were performed at the Chemical Health Laboratories of the Department of Health and Welfare in Cape Town. After food preparation and compositing into the 11 groups, each group was analysed separately by multiresidue procedures, covering a wide range of contaminants. All samples, composite and individual, were analysed for organochlorine, organophosphate and polychlorinated biphenyl (PCB) residues, cadmium and lead. For this specific study, however, only the results of organochlorine and organophosphate residues on the composite samples of the market basket study will be reported on, being those residues from pesticides to indicate possible chronic exposure of the population at large. Results reported here, together with those on PCB residues, cadmium and lead will be reported in a comprehensive report: "Risk assessment and the estimation of possible health threats to populations by the intake of chemical contaminants present in food and water at levels which may adversely effect the health of the consumers", to the Water Research Commission of South Africa (H.O. Fourie, in prep.).

Analyses of organochlorine and organophosphate residues were done by gas/liquid chromatography after extraction and cleanup procedures. Because diet samples contain fat, fat assays of each food or food group were performed in advance to facilitate calculations of results and to ensure compatibility with established analytical methods. For the

determination of organochlorine compounds, two gas/liquid chromatography systems were used employing stationary phases of different polarities and fitted with electron-capture detectors. Residues were separated from fat extracts by gel permeation chromatography. For the determination of organophosphate residues, two gas/liquid chromatography systems with columns of different polarities were used. Instruments used were equipped with flame-photometric detectors operating in the phosphorous mode. Confirmations were carried out on a third gas chromatograph with different columns.

3.4 Results and discussion

Most countries where maximum pesticide residues are regulated in food commodities, routinely use quantitative, multiresidue, gas-liquid chromatographic methods in either surveillance or total diet monitoring programmes. More than 300 pesticide residues are being analysed using these methods, although their limits of detection could differ substantially due to matrixes (fatty and non-fatty foods), recoveries and analytical capabilities. The limits of quantification for the residues determined in this study (Table 13) typically varied between 0,01 - 0,03 ppm and may even be better using larger sample aliquots after cleanup procedures.

The distribution of items in the food consumption survey are given in Tables 1 - 11, while the total diet consumption for the white population is given in Table 12. Tables 1 - 11 also include the daily consumption of each food item, the amounts purchased, and whether cooking preparation was required or not. In order to obtain a large enough sample for duplicate analysis, a seven day sample was composited from each food group. The schematic sequences of the preparation of the different food groups are given in the flow-diagrams I - XI.

The eleven food groups contained 142 food items sampled at 13 locations country wide. The total diet of the white population compared favourably with those from other countries (GEMS, 1982; GEMS, 1983):

	Austria	Canada	Guatemala	Japan	New Zealand	U.K.	U.S.A.	South Africa
Consumption g/day	1 650	1 034	1 553	1 400	3 310	1 500	2 900	1 995
Population group	Adult	Average person	-	Average Male	Young Man	Average Person	Teenage Male	Adult
Number of food items	-	120	41	90	-	78	117	142
Beverages:								
alcoholic drinking water	Yes	-	No	Yes	Yes	No	No	Yes
	Yes	No	No	Yes	-	No	Yes	No
Number of composites	8	11	12	14	8	9	12	11

Residues were found in 8 (73%) of the diet groups (Table 14), with no residues found in soups, sugars and beverages. DDT, Dieldrin and dicloran were present in seven groups, while the organophosphate mercaptothion was only present in cereals. It is somewhat surprising to find residues of mercaptothion in grains and not in fruits and vegetables as this compound is extensively used in the latter, although the maximum residue levels allowed in fruits and vegetables are much lower (2 - 4 mg/Kg) than in grain (8 mg/Kg). It is also surprising to find mercaptothion residues at a concentration of 0,05 mg/Kg in ready-to-eat cereals. Duggan (1983) reported malathion residue levels of 0,234 - 0,790 mg/Kg in grain for human consumption for the years 1970 - 1976 in the U.S.A., but also reported the concentration to be only 0,020 mg/Kg in their cereal products. However, although 0,05 mg/Kg mercaptothion in the R.S.A. cereals seems to be at a marginally higher level than in the U.S.A., the daily intake of 11,1 µg/day due to this compound (Table 14) results in only 0,000 19 mg/Kg body weight/day, which is only 0,9% of the acceptable daily intake (Table 15).

Tables 14 and 15 also indicate the levels of DDT, dieldrin and dichloran found in the diet study. DDT and dieldrin are persistent organochlorines and occur at very low levels, i.e. 0,6% and 6% of the acceptable daily intakes, respectively. Although total dichloran results in only 0,5% of the acceptable daily intake, it should be noted that residues of this

compound should not be present in the vegetable group (Table 14), being only permitted for use on peaches (Bot, 1986).

Summary

Residues of only 4 compounds were present in 33 composite, ready-to-eat foods, consisting of 5 538 foodstuffs sampled over a period of one year country wide, and representing 142 different food items categorised into 11 food groups. The residues found were well within acceptable levels and compare very favourably with those found in the diets of developed countries. It has to be concluded that possible chronic exposure due to agricultural chemical contaminants, to the white population at least, does not exist, and implies a sound regulatory policy towards the use of these chemicals in South Africa.

The community in South Africa consists of Black, Coloured and White population groups with different cultures and socio-economic standards. Therefore, this market basket study was duplicated to include ready-to-eat foods as well as selective studies of individual foodstuffs which, due to the analysis of each unprocessed individual food component, will allow the calculation of daily intake for any ethnic group, if consumption data are available. The individual food components are currently being analysed and the results will be used to calculate daily intakes of contaminants for all population groups concerned (H.O. Fourie, in prep.).

TABLE ITOTAL DIET STUDIES - ADULT

GROUP I : VEGETABLES					
Food item	Purchase	24-hour consumption	Cooking required		7-day composite
			gram	Yes	
Beans fresh	200 gram	20,5	x		143,5
Beetroot fresh	100 gram	5	x		35
Beetroot bottled	1 bottle	2,8		x	19,6
Cabbage fresh	100 gram	0,51		x	3,6
Cabbage fresh	-	4,4	x		30,6
Carrot fresh	1 bunch	7,3		x	51
Carrot fresh	-	8,3	x		57,9
Peas canned	250 gram	9,1	x		63,8
Lettuce fresh	1 head	1,9		x	13,3
Pumpkin fresh	100 gram	8,9	x		62,6
Squash fresh	100 gram	8,9	x		62,6
Sweet potato fresh	100 gram	8,2	x		57,7
Potato fresh:	1 000 gram				
roasted		25,4	x		177,8
chips		7,3	x		51,1
mashed		19,8	x		138,9
peeled		41,2	x		289,1
Tomato fresh	500 gram	31		x	217,2
Tomato canned	250 gram	2,6		x	18,2

TABLE IITOTAL DIET STUDIES - ADULT

GROUP II : FRUIT

Food item	Purchase	24-hour consumption	Cooking required		7-day composite
			gram	Yes	
Apple fresh	500 gram	29,9		x	419,3
Pear fresh	200 gram	19,7		x	137,9
Pear canned	250 gram	0,72		x	5,04
Grapes fresh	500 gram	59,6		x	417,2
Orange fresh	100 gram	4		x	28
Peach fresh	300 gram	38,2		x	267,4
Peach canned	250 gram	3,8		x	26,3
Peach dried	100 gram	6,2		x	43,5

TABLE IIITOTAL DIET STUDIES - ADULT

GROUP III : MEAT					
Food item	Purchase	24-hour	Cooking		7-day
		consumption	required	required	composite
		gram	Yes	No	gram
Bacon	100 gram	0,46	x		3,2
Ham smoked	100 gram	0,37		x	2,6
Brawn	100 gram	0,36		x	2,5
Polony	100 gram	3,1		x	21,7
Pork sausage	100 gram	0,59	x		4,1
Pork chops	100 gram	4,5	x		31,2
Mutton stew	100 gram	5,9	x		41,3
Mutton chops	100 gram	8,9	x		62,2
Mutton leg chops	400 gram	38,2	x		267,6
Beef sirloin	100 gram	11	x		76,9
Beef rump steak	200 gram	11,1	x		77,7
Beef stew meat	100 gram	4,9	x		34
Beef mince meat	500 gram	18,7	x		130,7
Beef liver	100 gram	2,6	x		18,5
Beef sausage	200 gram	11,7	x		81,9
Vienna sausage canned	250 gram	1,4		x	9,8
Frankfurters	100 gram	1,2	x		8,4
Sausage roll/meat pie	1	1,2		x	8,4
Beef patties	100 gram	0,86	x		6,0
Steak and kidney pie	1	0,71		x	5,0
Corned beef canned	250 gram	1,2	x		8,4
Chicken	100 gram	11,0	x		76,7
Chicken pie	1	0,36		x	2,5

TABLE IVTOTAL DIET STUDIES - ADULT

GROUP IV : CEREALS					
Food item	Purchase	24-hour consumption	Cooking required		7-day composite gram
			Yes	No	
		gram			
Bread white	1 loaf	47,1		x	330
Bread brown	1 loaf	49,4		x	346
Bread whole wheat	1 loaf	17		x	119
Crisp bread whole wheat	1 pkt	0,59		x	4,1
Rusks whole wheat	1 pkt	3,4		x	23,8
Rusks white	1 pkt	9,1		x	63,8
Cookies commercial	1 pkt	2,3		x	16,4
Biscuits commercial	1 pkt	0,11		x	0,8
Cake homemade	1 cake	3,2		x	22,4
Cake chocolate	1 cake	1,1		x	7,9
Cake flour (vetkoek)	1 pkt	2	x		14
Swiss roll	1	0,24		x	1,7
Tart/pie: apple	1	1,4		x	9,8
jam	1	0,54		x	3,8
caramel	1	1		x	7,0
coconut	1	0,29		x	2,0
lemon	1	0,13		x	0,9
milk	1	2,7		x	18,9
savoury	1	1,2		x	8,4
fruit	1	0,59		x	4,1
Oats	500 gram	10,8	x		75,6
Tastee wheat	500 gram	0,19		x	1,3
Maltabella	1 tin	1,5	x		10,5
All-bran	1 pkt	0,51		x	3,6
Corn flakes	1 pkt	0,83		x	5,8
Wheatbix	1 pkt	2,1		x	14,7
Pro-nutro	1 pkt	2,2		x	15,4
Rice crispies	1 pkt	0,27		x	1,9
Rice white	500 gram	39,9	x		279,1
Rice brown	500 gram	0,07	x		0,49
Maize meal	1 000 gram	13,7	x		95,9
Mealie/samp	500 gram	1,7	x		11,9
Gravy (Bisto)	1 pkt	1,9	x		13,3
Gravy beef powder	1 pkt	2,1	x		14,7

TABLE VTOTAL DIET STUDIES - ADULT

GROUP V : EGGS					
Food item	Purchase	24-hour	Cooking		7-day
		consumption	required		composite
		gram	Yes	No	gram
eggs large	1 dozen	24,3	x		170

TABLE VITOTAL DIET STUDIES - ADULT

GROUP VI : FISH					
Food item	Purchase	24-hour	Cooking		7-day
		consumption	required		composite
		gram	Yes	No	gram
Pilchards	1 can	0,31		x	2,2
Tuna	1 can	0,96		x	6,7
Sardines	1 can	0,11		x	0,8
White fish fresh	200 gram	17,9	x		125,7
Fish fingers	1 pkt	0,09	x		0,6

TABLE VIITOTAL DIET STUDIES - ADULT

GROUP VII : SOUP					
Food item	Purchase	24-hour	Cooking		7-day
		consumption	required		composite
		gram	Yes	No	gram
Bean	2 pkts	18,5	x		129,5
Pea	1 pkt	10,1	x		70,7
Lentil	100 gram	0,59	x		4,1
Vegetable	1 pkt	10,6	x		74,2
Tomato	1 pkt	0,21	x		1,5
Chicken	1 pkt	0,27	x		1,9
Asparagus	1 pkt	0,23	x		1,6

TABLE VIIITOTAL DIET STUDIES - ADULT

GROUP VIII : FATS AND OILS					
Food item	Purchase	24-hour	Cooking		7-day
		consumption	required		composite
		gram	Yes	No	gram
Oil vegetable	750 ml	0,24		x	1,7
Mayonaise	120 ml	1,2		x	8,4
Orley whip	1 pkt	0,09		x	0,6

TABLE IXTOTAL DIET STUDIES - ADULT

GROUP IX : MILK AND MILK PRODUCTS					
Food item	Purchase	24-hour	Cooking		7-day
		consumption	required		composite
		gram	Yes	No	gram
Whole milk	2 liters	236		x	1 652
Skim milk	1 liter	18,5		x	129,5
Evaporated milk	1 can	0,31		x	2,2
Skim milk powder	100 gram	0,89		x	6,2
Whole milk powder	100 gram	0,26		x	1,8
Melkkos/snysels	100 gram	0,21		x	1,5
Malted milk powder	100 gram	0,04		x	0,3
Cheddar cheese	100 gram	8,5		x	59,5
Sweetmilk cheese	100 gram	3,7		x	25,9
Cheese spread	1 bottle	0,21		x	1,5
Non-dairy creamers	1 bottle	0,59		x	4,1
Butter	100 gram	2,2		x	15,4
Cream fresh	125 ml	0,34		x	2,4
Margarine hard	250 gram	10,2		x	71,4
Margarine poly- unsaturated	250 gram	7,3		x	51,1
Ice cream	100 gram	2,6		x	18,2
Ice cream (sorbet)	100 gram	1,7		x	11,9
Custard	500 gram	9,7		x	68,2

TABLE XTOTAL DIET STUDIES - ADULT

GROUP X : SUGARS AND SWEETS					
Food item	Purchase	24-hour	Cooking		7-day
		consumption	required	required	composite
		gram	Yes	No	gram
Jelly dessert	1 pkt	4,1	x		28,7
Honey	1 bottle	1,6		x	11,2
Jam	1 bottle	9,9		x	69,3
Sweets, jelly	1 pkt	1,1		x	7,7
Milk chocolate plain	1 pkt	0,27		x	1,9
Fudge/caramel/toffee	1 pkt	0,83		x	5,8
Chocolate assorted	1 pkt	0,53		x	3,7
Chocolate sauce	1 pkt	0,16		x	1,1
Chocolate coated nuts	1 pkt	0,21		x	1,5
Chocolate coated bar	1	0,63		x	4,4
Peppermints	1 pkt	0,10		x	0,7
White sugar	500 gram	41		x	287

TABLE XITOTAL DIET STUDIES - ADULT

GROUP XI : BEVERAGES					
Food item	Purchase	24-hour	Cooking		7-day
		consumption	required		composite
		gram	Yes	No	gram
Beer	1 can	14,9		x	104,3
Sherry	50 ml	0,84		x	5,9
White wine	750 ml	20,4		x	142,7
Spirits	2 x 50 ml	6,6		x	46,2
Coffee instant	1 tin	412		x	2 884
Tea	1 box	230		x	1 610
Soft drink carbonated	2 tins	61,6		x	431,2
Soft drink non- carbonated	1 bottle	23,2		x	162,4
Grapefruit juice	1 can	1,3		x	9,0
Guava juice	1 can	0,61		x	4,3
Orange juice	1 can	0,39		x	2,7
Apple juice	1 can	0,61		x	4,3
Apple juice fresh	1 pkt	0,40		x	2,8
Orange juice fresh	2 pkts	6,3		x	44,1

TABLE XIIFOOD GROUPS AND CONSUMPTION DATA OF TOTAL DIET STUDY

COMPOSITION (DAILY BASIS) FOR ADULT DIET			
Food Group	Average grams/day	% by weight of Total Diet	
I	Vegetables	213,2	10,7
II	Fruit	192,1	9,6
III	Meat	140,3	7,0
IV	Cereals	221,1	11,1
V	Eggs	24,3	1,2
VI	Fish	19,4	0,97
VII	Soup	40,5	2,0
VIII	Fats and oils	1,53	0,08
IX	Milk	303,2	15,2
X	Sugars	60,4	3,0
XI	Beverages *	779,2	39,1
		1 995,2	100,0

* excluding drinking water

TABLE XIIIACCEPTABLE DAILY INTAKE FOR COMPOUNDS ANALYSED

Compound	WHO/FAO mg/Kg/day	Codex Alimentarius mg/Kg/day
Cabtab	0,1	0,01
Captofol	-	0,01
Chlorobenzilate	-	0,02
Chlorothalonil	-	0,005
Chlorpyriphos	-	0,01
DDT	0,005	0,005
Diazinon	0,002	0,002
Dicofol	0,025	0,025
Dichloran	0,03	0,03
Dieldrin	0,000 1	-
Endosulfan	0,007 5	0,008
Fenitrothion	-	-
Fenthion	-	0,001
Gamma-BHC	-	0,01
Mercaptothion	0,02	0,02
Parathion	0,005	0,005
Phosalone	0,006	0,006
Pirimiphos-Ethyl	-	-
Pirimiphos-Methyl	-	0,01
Procymidone	-	0,05
Prothiophos	-	-
Triazophos	-	0,000 2
Vinclozolin	-	-

TABLE XIVPOSITIVE RESULTS OF RESIDUES AMONG FOOD GROUPS OF TOTAL DIET SAMPLES

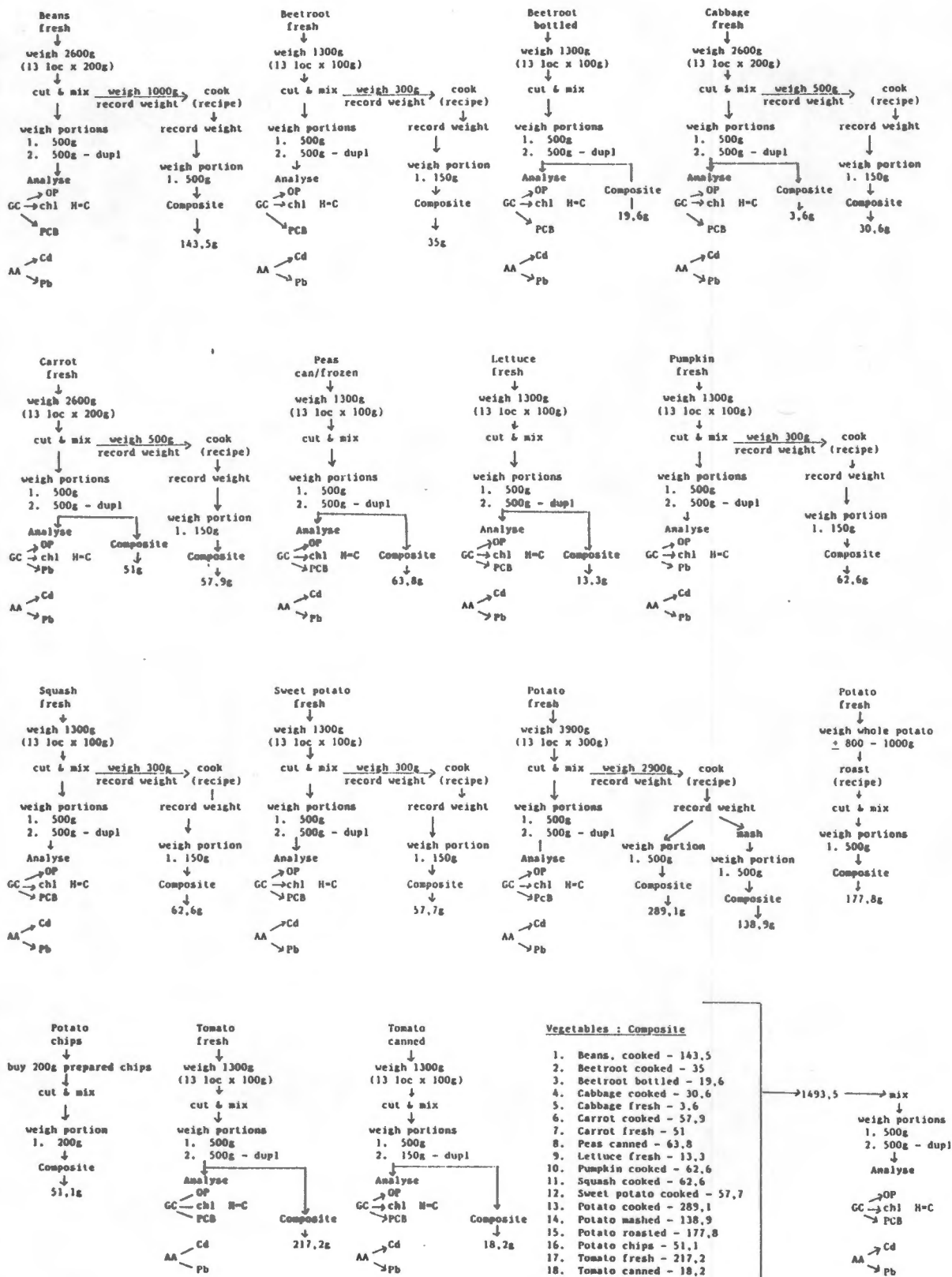
Food Group	Compound	Residues mg/Kg			Mean mg/Kg	Daily Intake µg/day
		July 1985	November 1985	February 1986		
Vegetables	Dichloran	- *	0,03	-	0,03	6,3
Fruit	Dichloran	0,02	-	0,01	0,015	2,9
Meat	DDT (total)	0,006	0,005	-	0,005 5	0,77
	Dieldrin	-	0,000 7	-	0,000 7	0,098
Cereals	Mercaptothion (Malathion)	0,05	0,05	-	0,05	11,1
Eggs	DDT (total)	0,002	0,003 4	0,003 4	0,002 9	0,07
	Dieldrin	-	0,000 3	0,000 3	0,000 3	0,007
Fish	DDT (total)	0,002	0,008	0,003	0,004 3	0,08
	Dieldrin	0,000 9	-	0,001	0,000 95	0,017
Fats & Oils	DDT (total)	-	0,007	-	0,007	0,011
Milk	DDT (total)	-	0,002 4	0,002 8	0,002 6	0,788
	Dieldrin	0,001	0,000 7	0,000 7	0,000 8	0,243

* means not found

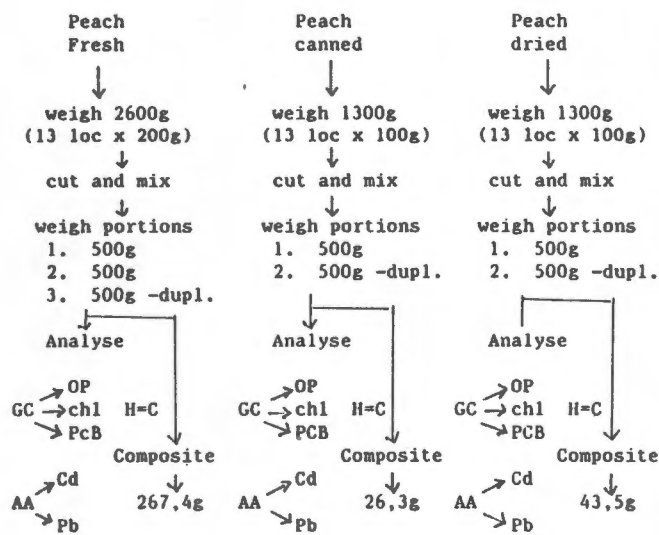
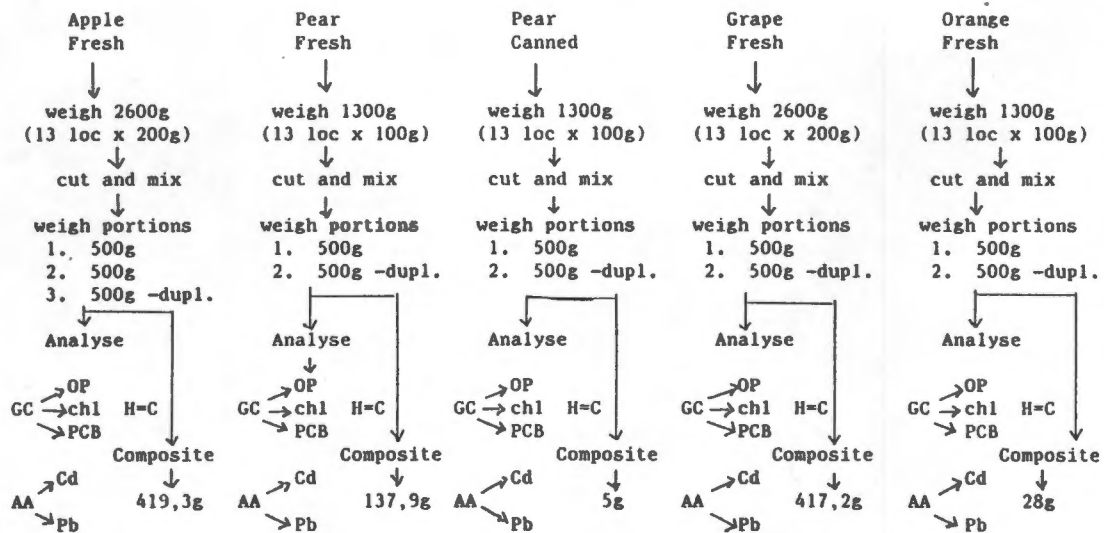
TABLE XVDIETARY INTAKE OF PESTICIDE CHEMICALS IN READY-TO-EAT FOODS

Compound	Total Daily Intake		Acceptable Daily Intake WHO/FAO/Codex mg/Kg/day	% of ADI %
	µg	mg/Kg/day		
DDT	1,72	0,000 029	0,005	0,6
Dieldrin	0,365	0,000 006	0,000 1	6,0
Dichloran	9,2	0,000 15	0,03	0,5
Mercaptothion (Malathion)	11,1	0,000 19	0,02	0,9

GROUP 1 : VEGETABLES

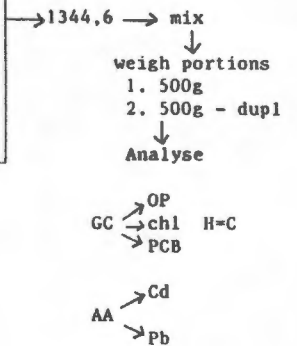


GROUP 2 : FRUIT

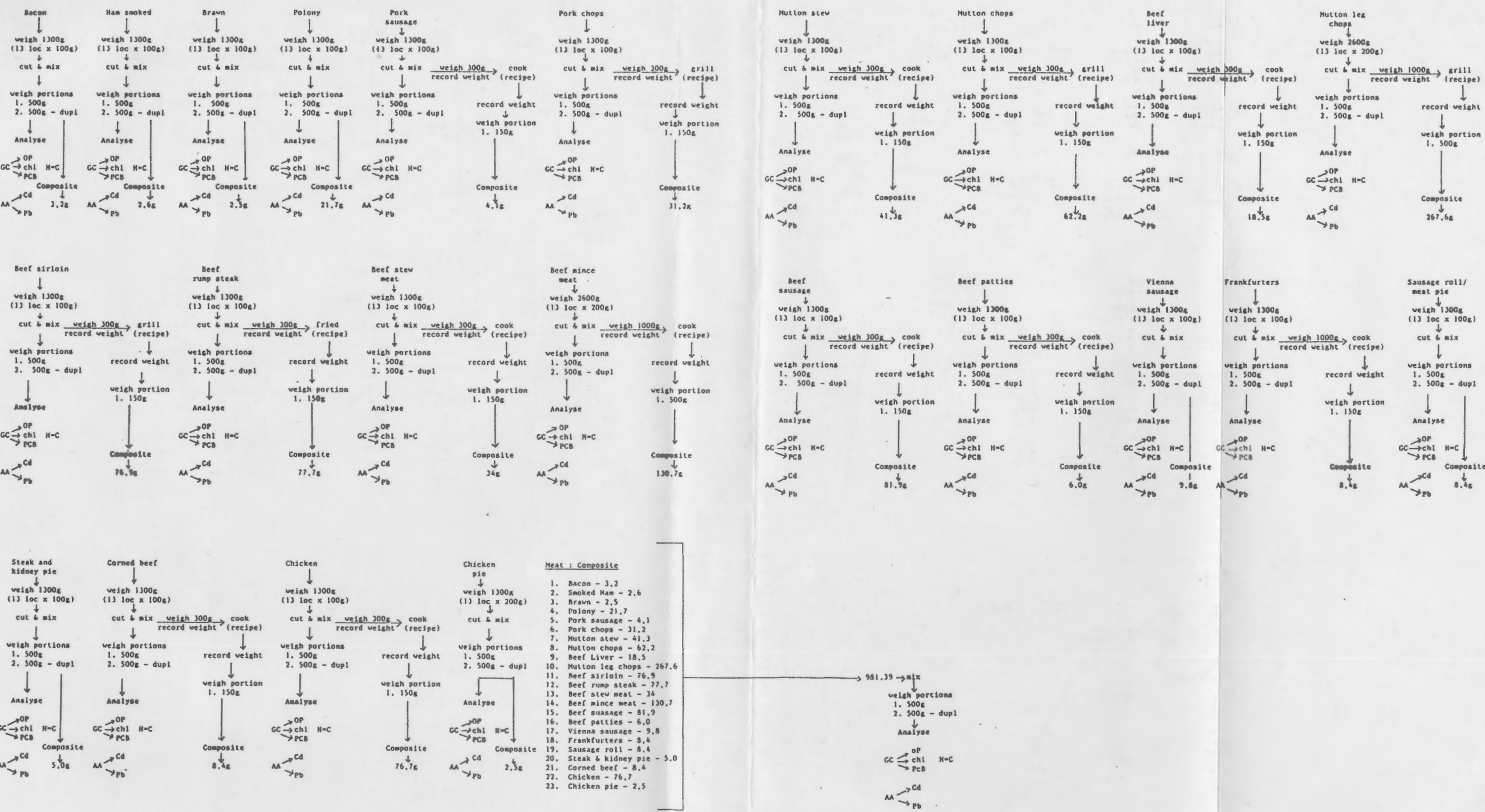


Fruit : Composite

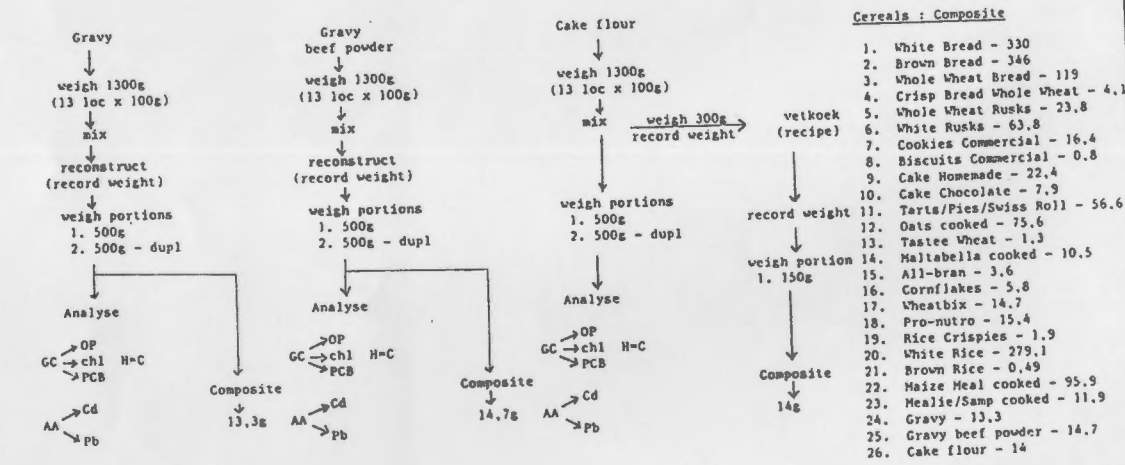
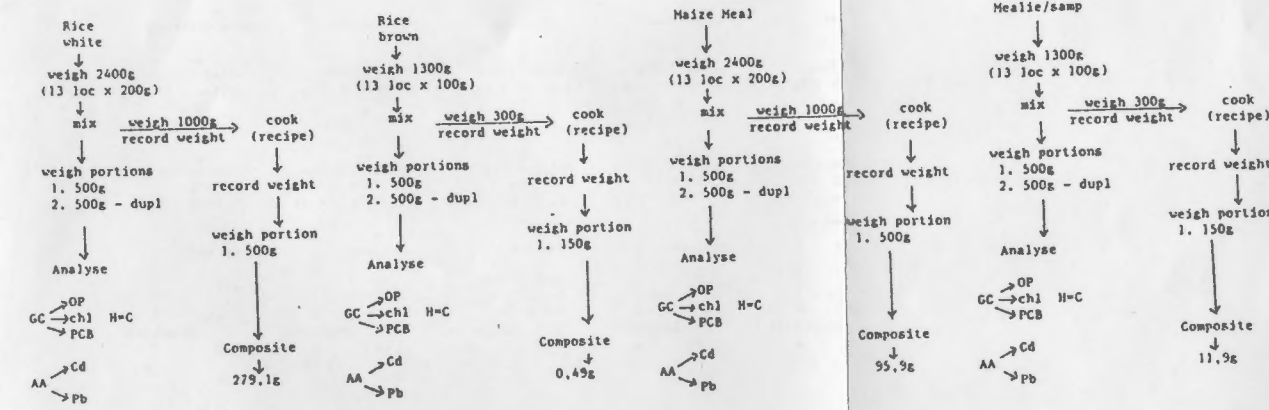
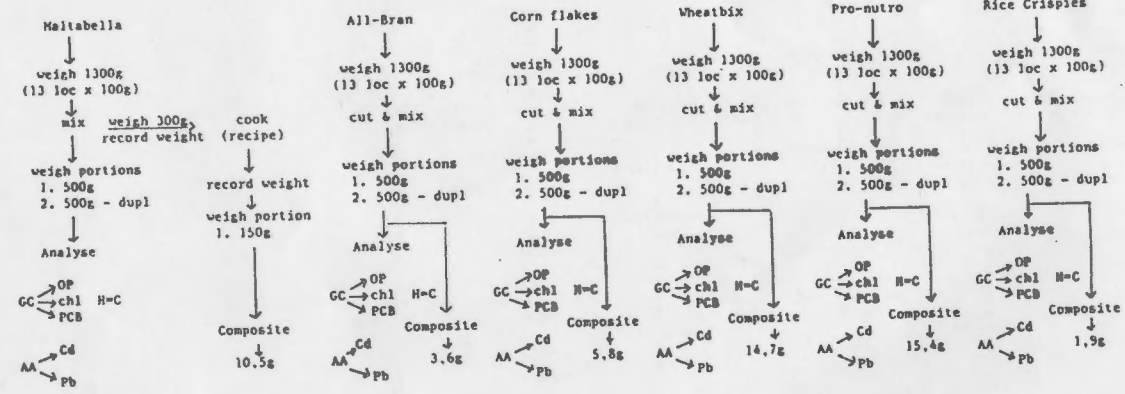
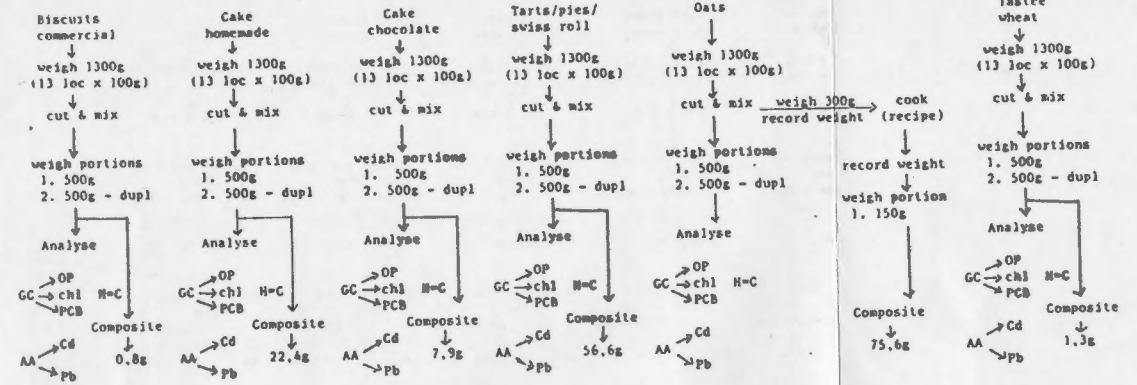
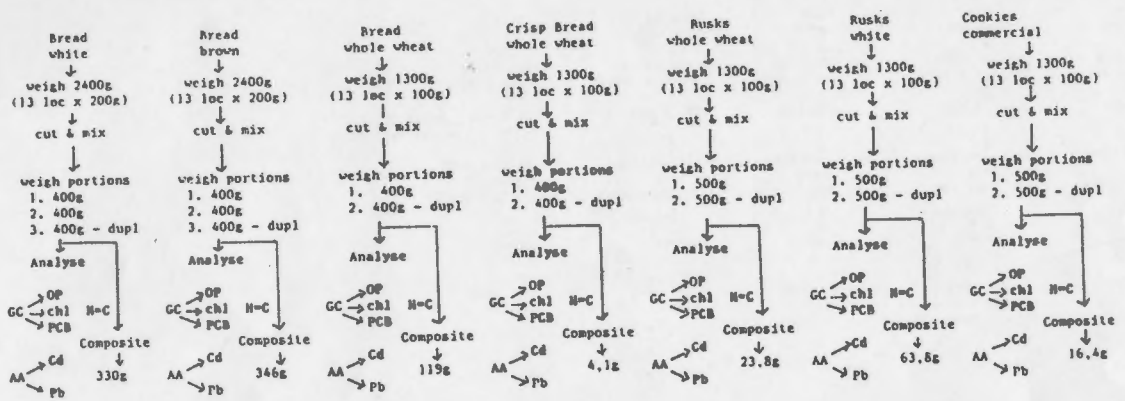
1. Apple fresh - 419,3
2. Pear fresh - 137,9
3. Pear canned - 5,0
4. Grapes fresh - 417,2
5. Orange fresh - 28,0
6. Peach fresh - 267,4
7. Peach canned - 26,3
8. Peach dried - 43,5

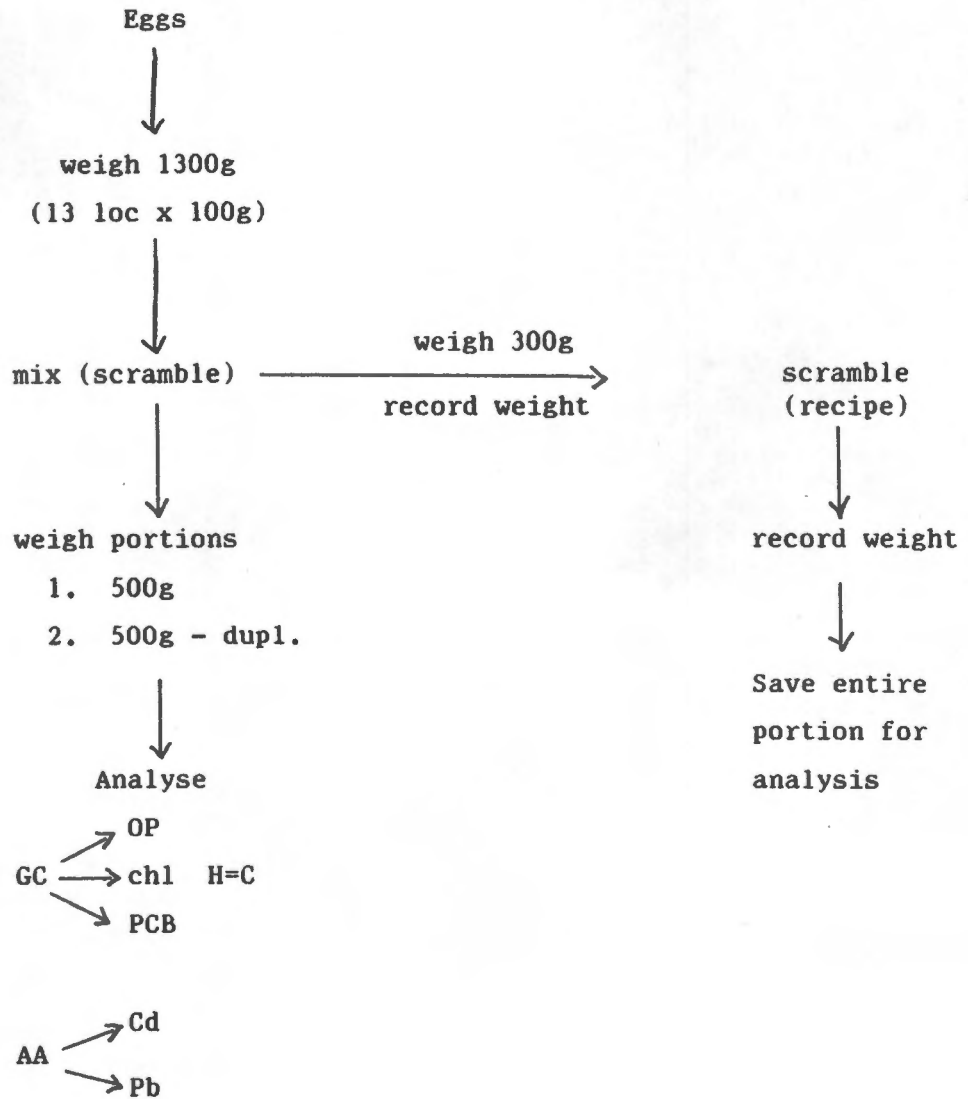


GROUP 3 : MEAT

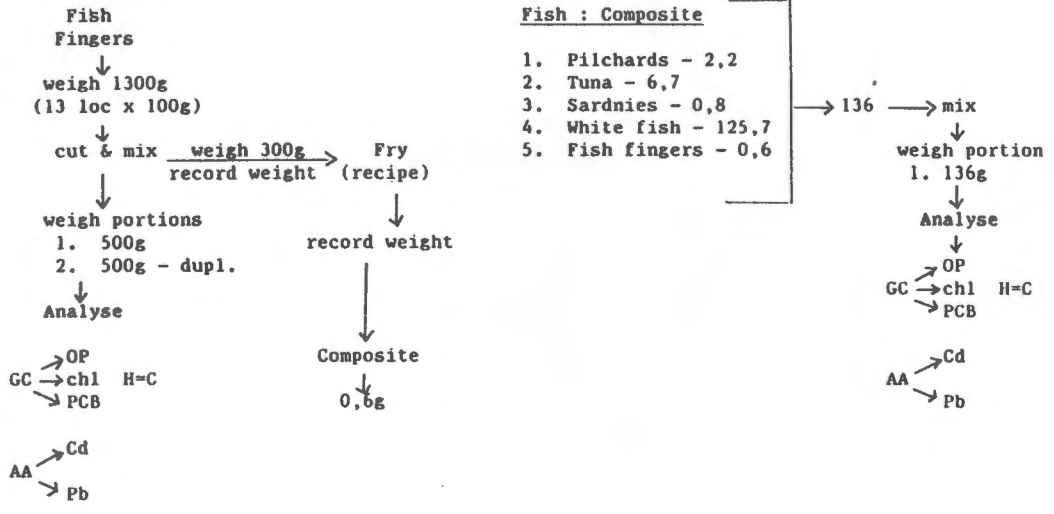
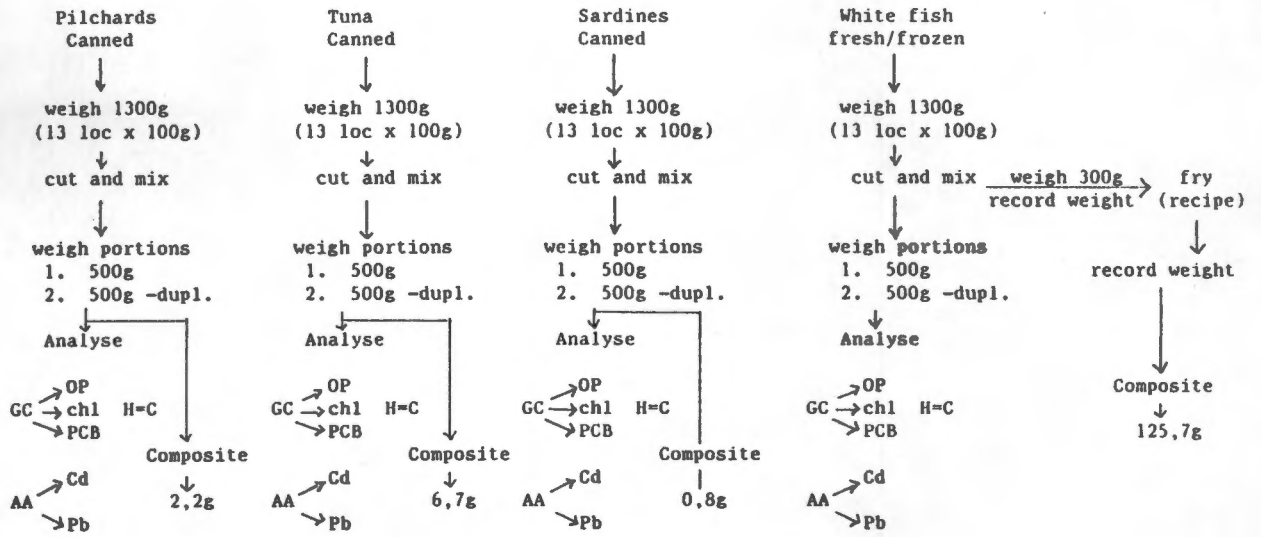


GROUP 4 : CEREALS

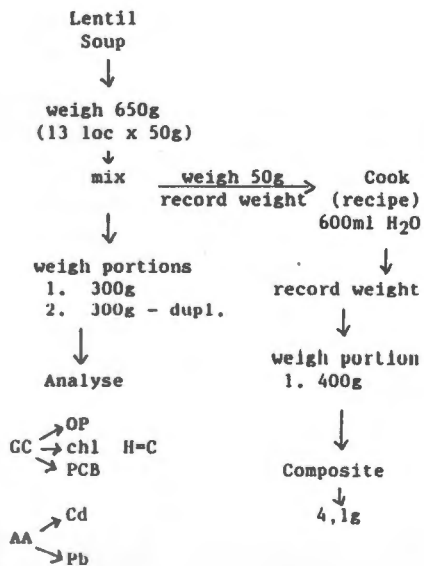
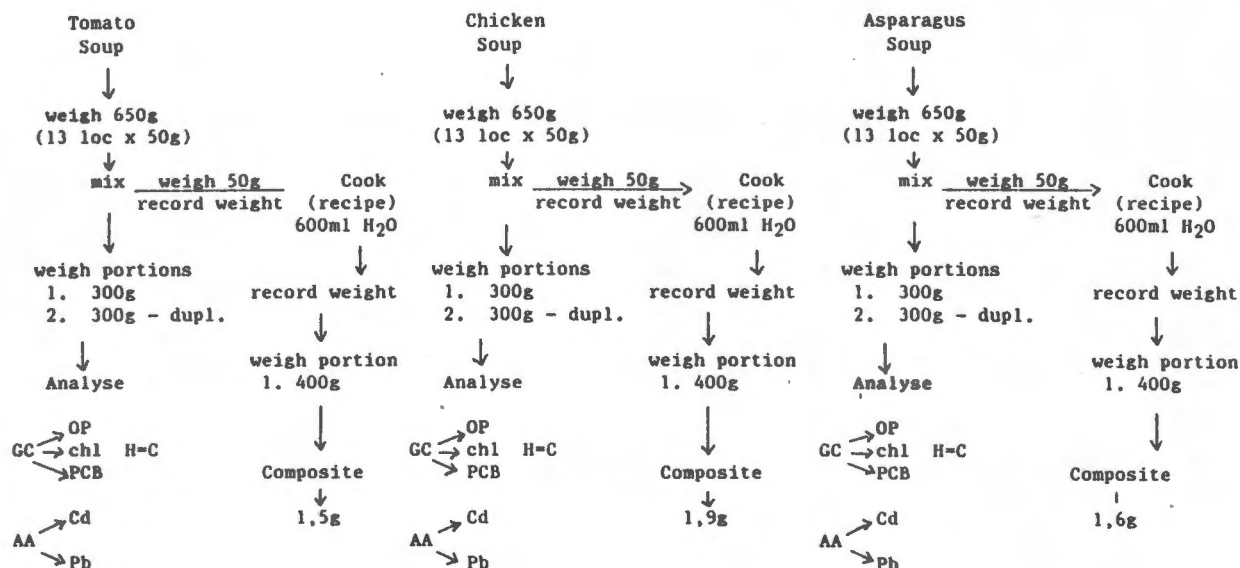
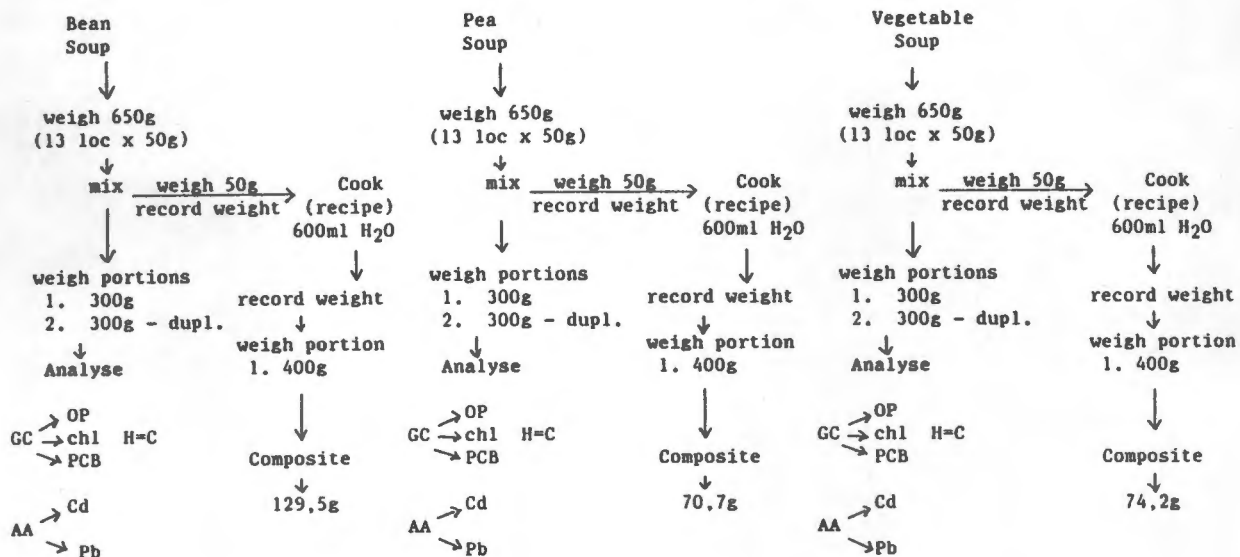


GROUP 5 : EGGS

GROUP 6 : FISH

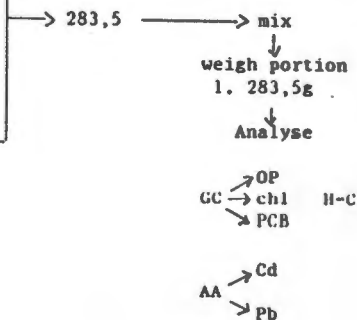


GROUP 7 : SOUP

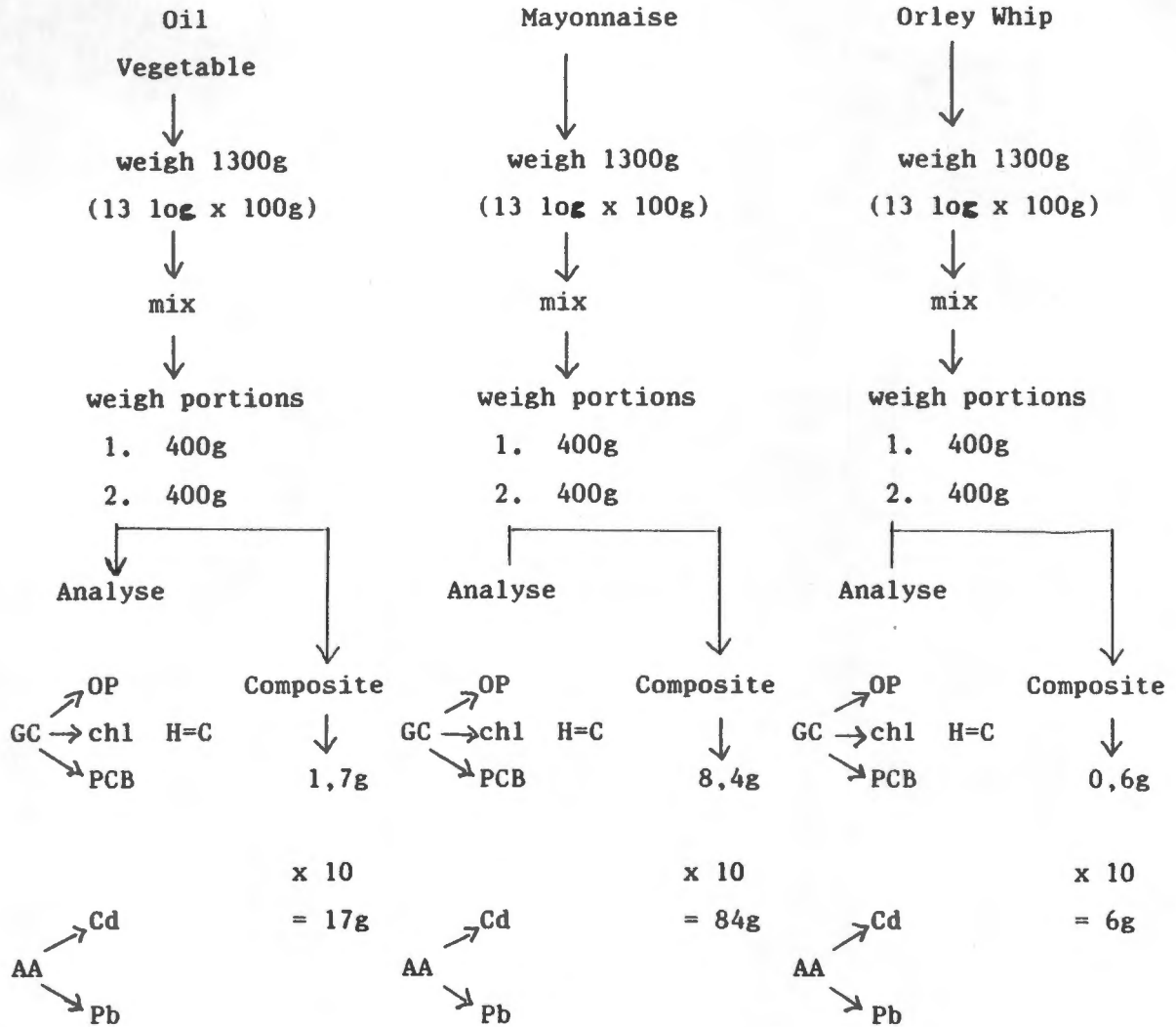


Soup : Composite

1. Bean soup - 129,5
2. Pea soup - 70,7
3. Vegetable soup - 74,2
4. Tomato soup - 1,5
5. Chicken soup - 1,9
6. Asparagus soup - 1,6
7. Lentil soup - 4,1



GROUP 8 : FATS AND OILS

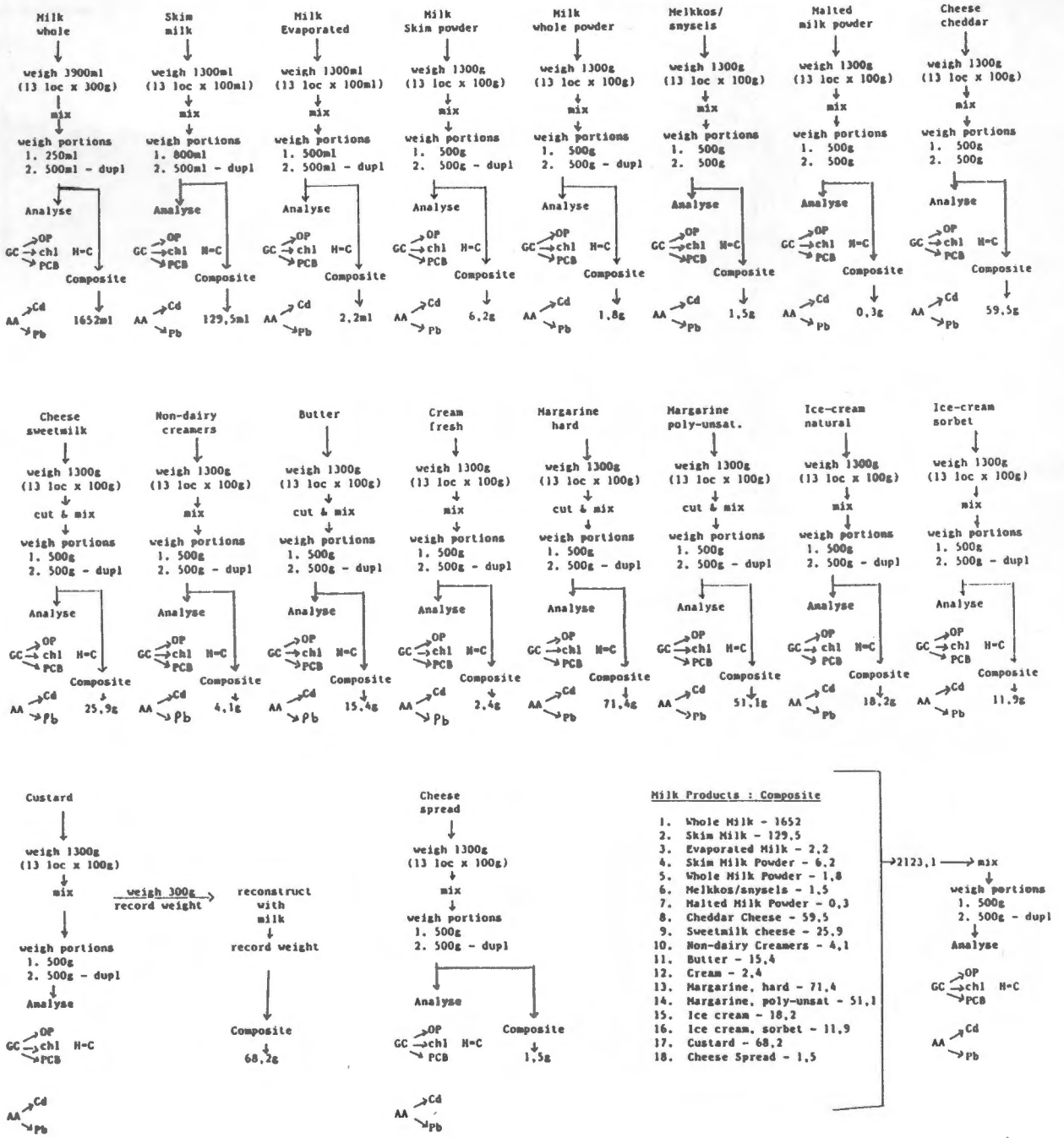


Fats and Oils : Composite

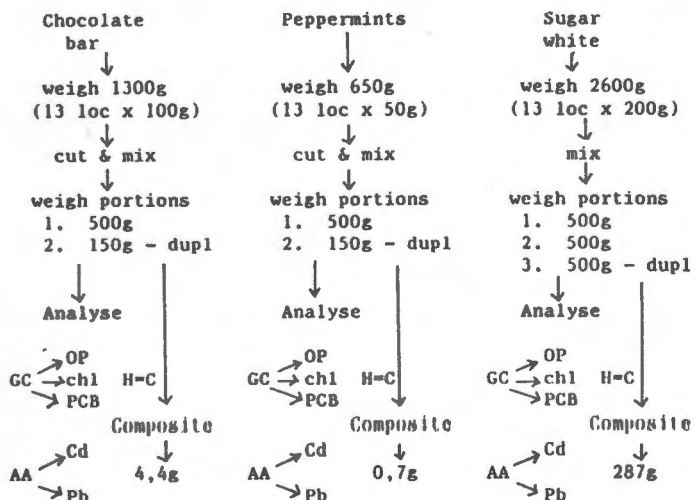
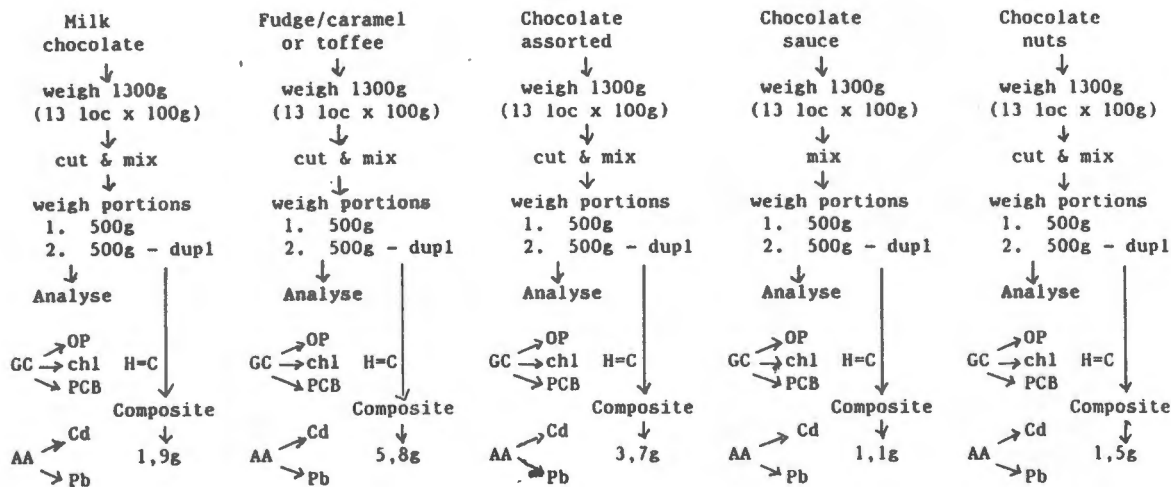
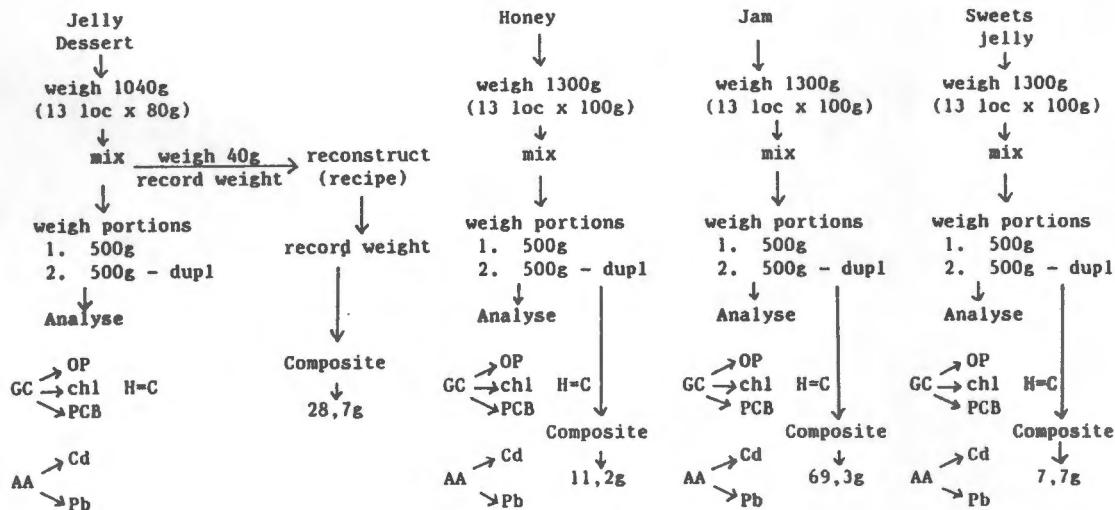
- 1. Vegetable oil - $1,7 \times 10 = 17g$
- 2. Mayonnaise - $8,4 \times 10 = 84g$
- 3. Orley whip - $0,6 \times 10 = 6g$

→ mix
↓
Keep entire weight for analysis
(107g)

GROUP 9 : MILK PRODUCTS

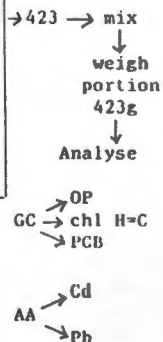


GROUP 10 : SUGAR AND SWEETS

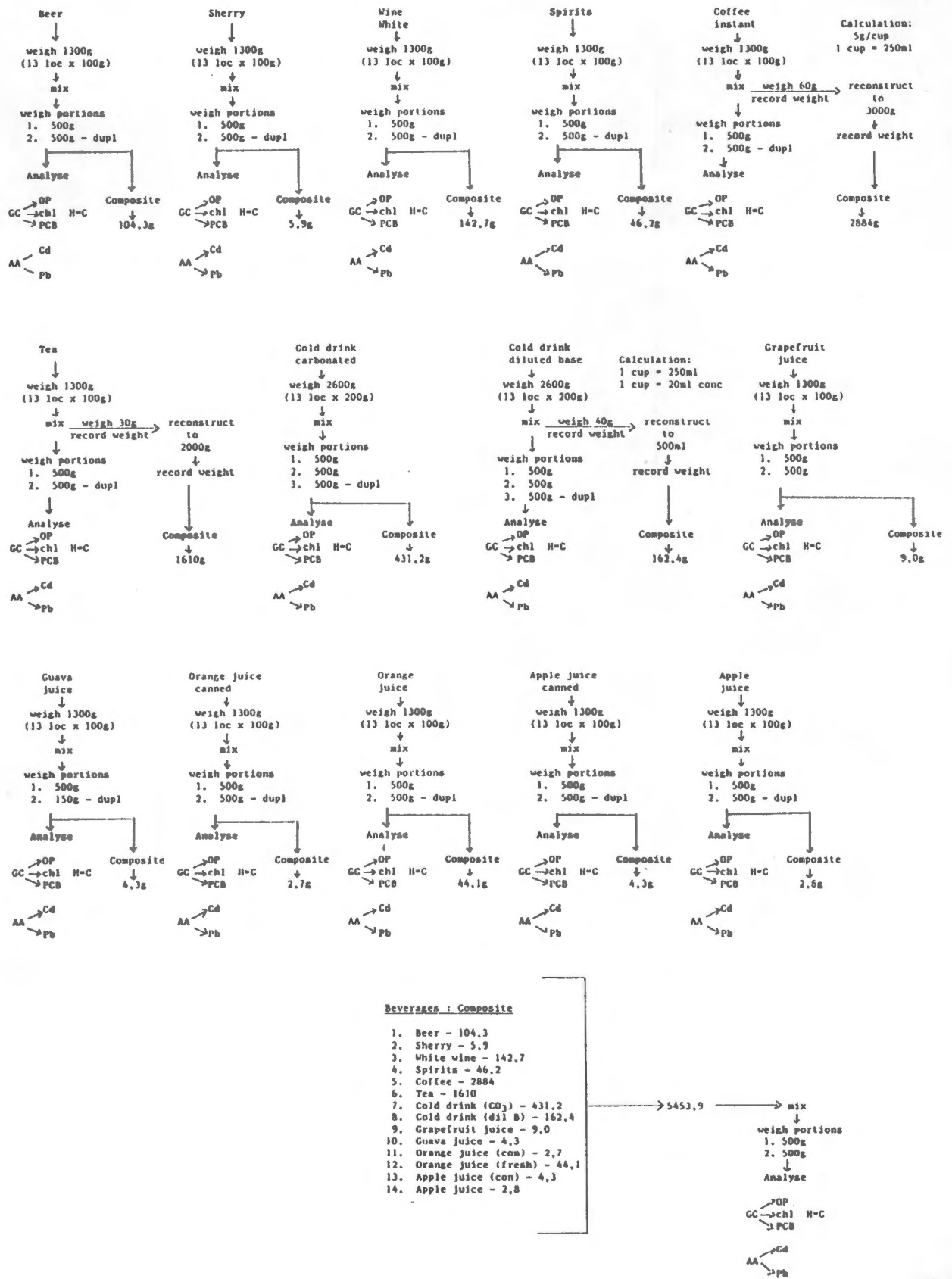


Sugar and Sweets : Composite

1. Jelly dessert - 28,7
2. Honey - 11,2
3. Jam - 69,3
4. Sweets Jelly - 7,7
5. Milk chocolate - 1,9
6. Fudge/caramel/toffee - 5,8
7. Chocolate assorted - 3,7
8. Chocolate sauce - 1,1
9. Chocolate nuts - 1,5
10. Chocolate bar - 4,4g
11. Peppermints - 0,7
12. Sugar white - 287



GROUP 11 : BEVERAGES



CHAPTER IV

EPIDEMIOLOGY OF PESTICIDAL USE IN SOUTH AFRICA

4.1 Introduction

Classical epidemiology has developed through the years as a reliable tool in health sciences to investigate the spread of infectious diseases through a community. Primarily it was used to identify effects introduced by biological agents, but fortunately, due to many such successfully completed surveys, it was adopted by the environmental sciences for studying the effects of non-biological agents present in the environment. Thus, the subject classical epidemiology - effects by biological agents, has developed to include environmental epidemiology - effects by non-biological agents.

It is important though, to note beyond any doubt, that epidemiological investigations cannot and are not meant to replace toxicological studies. The object of both these sciences is to study the possible harmful effects of agents and substances on the human population. Broadly speaking, toxicological investigations have the advantage of employing animals under laboratory conditions to evaluate exposure and effects, but have the disadvantage of usually using high doses which are unrealistic in the actual situation. An even more serious disadvantage is the extrapolation of results from laboratory animals to human beings. Epidemiology, on the other hand, has the advantage of studying effects in the human under real life conditions, but apart from many other disadvantages, epidemiology cannot prove that a particular agent caused a particular health effect. It is only possible to demonstrate the association between an observed effect and the presence of an agent (WHO, 1983). Thus epidemiology provides the evidence on health effects which, in combination with toxicological data, is the basis for establishing health criteria.

The information from epidemiology surveys must be used to analyse possible associations between some agents in general, different chemical, physical or toxicological properties of compounds, biotic and abiotic environmental factors as well as attitudinal deficiencies towards risk and safety on the

one hand, and the health of those exposed to them on the other hand. This is usually done by studies which aim to demonstrate a relationship between exposure and effect. It is important to note though, that unlike toxicology experiments, it is not possible in epidemiology to measure a concentration or a dose of a compound present at a target organism or receptor, and therefore it is more correct in epidemiology to use the terminology exposure/effect relationship, rather than dose/effect relationship. A very interesting and well-executed monograph (WHO, 1983) "to provide guidelines on epidemiology methods for assessing the effects of environmental agents on human life" was published by the World health Organization in 1983 and should be studied comprehensively by those concerned with environmental epidemiology.

Once the relationship of a biological effect to a quantum of exposure has been established, it becomes necessary to proceed to those epidemiological studies - referred to as descriptive studies - which usually have the object of searching for common factors causing the observed exposure and ultimately the resultant effects.

4.2 Hypothesis and design of study

4.2.1 Introduction

Exposure to pesticides and resultant poisoning is a well known phenomenon, as are the detrimental effects to human life when these chemicals are abused. Pesticides must certainly be the group of chemicals whose toxicology, symptomatology and treatment procedures are the best documented. Thus, it enables the epidemiologist to study the pesticidal poisoning situation in any country or community without tedious and difficult surveys to investigate factors such as exposure, effects and physiological functions. However, while the association between exposure and effect are very well documented, the possible contribution to such poisonings of environmental and human factors has been largely neglected. While the literature is replete with data of poisoning by agricultural chemicals (refer to chapters I and II), most of the morbidity and mortality data have only been analysed for one or two obvious factors such as age of patient, reason for poisoning and the compounds responsible for intoxication.

There must be more to it. The question arises why WHO (refer chapter II), still estimates poisoning by pesticides to be 500 000 cases per annum, decades after these chemicals - with well-known toxicology - have been in use and why such enormous contrasts in poisoning incidences exist between developed countries and developing countries. This study hopes to clarify these questions.

4.2.2 Hypothesis

It is postulated in the present study that neither the inherent toxicities of pesticidal compounds, nor a paucity of knowledge about the toxicological, chemical and physical properties of these compounds could be mainly responsible for the numerous intoxications recorded annually. The object of this study is therefore to identify and determine those environmental, domestic, behavioural and probably attitudinal factors commonly related to pesticidal poisoning. Ultimately the object is to recommend corrective measures and to assess whether the incidence of poisoning can effectively be reduced. Although the labourer working with pesticides is the most likely to be detrimentally effected, this study includes the whole population, women, children, the elderly and everybody who could come into contact directly or indirectly with these chemicals.

4.2.3 Design of study

In this investigation the epidemiology design used is referred to as "descriptive studies", i.e. describing the situation as it exists in the community, and therefore observations based on these existing situations as opposed to, for example, the case-control type of study, in which the prime concern, by using cases and controls, is to prove by means of statistical analyses that an exposure/effect does exist.

A questionnaire consisting of 58 questions was designed, consisting mostly of objective questions relating to those factors which could possibly give rise to accidents, misuse, abuse and ultimately intoxication. The study sample consisted of 400 intoxications during 1983 - 1984 by agricultural chemicals country-wide and reported to the Department of Health as a notifiable disease. All the questionnaires were completed by graduated Health Inspectors employed by the Department of Health at its seven regional offices throughout the Republic of South Africa. Possible

observer biases and intra-observer variations were minimised by:

- (1) the limited number of questions (7%) which could be regarded as subjective and therefore possibly give rise to differences in observation and interpretation; and
- (2) by employing graduated officers who are familiar with hazardous chemicals, the community and its culture, for completion of the questionnaires.

The layout of the questionnaires was arranged to address mainly the following topics (examples of some variables included):

- (1) The owner, who by definition is not necessarily the person who physically handles these chemicals, but who is in all respects responsible for their use, safekeeping and management.
- (2) The patient, being the person detrimentally effected, directly or indirectly. All variables such as age, sex, ethnic origin, occupation, family, home, children and many more which could possibly generate information, were included.
- (3) The poison, which refers not only to the chemical which primarily caused the intoxication, but also to physical and chemical properties, uses, application methods etc. of the specific chemical in question, as well as other similar chemicals which might be relevant.
- (4) Socio-economic status, which includes variables such as housing, eating and drinking habits.
- (5) Clinical aspects, with variables such as morbidity, mortality, hospitalisation, first aid, reference to a doctor and symptomatology.
- (6) Region, which refers to the seven geographical regions where regional officers of the Department of Health operate, and thus geographically representing the total population of South Africa.

The Republic of South Africa may be regarded as an ideal community for such a study, as it is representative of both the First and Third Worlds. The regulatory and commercial management of agricultural chemicals is typical of the First World; the regulatory procedure according to good agricultural practice and toxicological appraisal, while commercially these products are marketed and distributed within a code of conduct which characterise responsibility. However, although the average South African farmer is responsible and well-educated, the farming community depends to a very large extent on unskilled labourers which are representative of the Third World. Thus, this study will not only be of importance to developing countries, but should also be of value to developed countries - where most of these chemicals are formulated - to understand the problems of the Third World and to help them to act in a responsible way in the usage and application of these chemicals.

4.3 Results and Discussion

During the course of the study, data were generated from a variety of geographically distant places, through the 7 regional offices of the Department of Health. Data received was inspected for completeness to ensure that no material was lost and subsequently the data were entered into a computer for analyses. The results are mainly analysed in a pie-diagram format in Appendix III. When in the following discussions of the results reference is made to a diagram in Appendix III, the reference is a number typed bold in brackets and refers to the page number of the specific diagram or diagrams. Thus the page number in Appendix III is also the number of the diagram and facilitates reference to a particular diagram or diagrams.

4.3.1 Owner

The general poison knowledge of the owners where intoxication took place was found to be only 44% good, 42% fair and 7% poor (1). This is alarming if one considers that the owner is the person responsible for the management of these chemicals as well as being the person who should instruct the actual user in their use. The low percentage of owners with a good poison knowledge is also reflected in the way these chemicals were stored: 17% of the owners isolated the chemicals while 23% kept them

locked up without isolating them from other goods and only 46% had these poisons both isolated and locked (2). It is important to realise that only isolated and locked could be regarded as good enough. Free access is possible when only isolated and even when these chemicals are locked up but not separated from other goods, access to poisons is possible when not needed. The importance of the owners' knowledge is illustrated by analysing owners' knowledge against:

(i) storage of poisons:

	Isolated	Isolated and locked	Locked but not isolated	
	%	%	%	
storage of poisons by owner	17	46	23	(2)
storage when owners' know- ledge = good	18	63	13	(3)
storage when owners' know- ledge = poor	46	11	11	(4)

Poisons isolated and locked drop from 63% to 11% between good and poor.

(ii) protective clothing used:

	General poison knowledge	
	Good (5)	Poor (6)
	%	%
overalls	38	14
gloves	2	0
other	2	0
overalls and gloves	9	32
overalls and masks	8	0
gloves and masks	1	0
overalls, gloves and masks	23	0
overalls, gloves, masks and other	4	0

When poison knowledge is good, much more use is made of protective clothing.

(iii) hospitalisation of intoxications:

	<u>Hospitalised</u>		
	<u>Yes</u>	<u>No</u>	
	<u>%</u>	<u>%</u>	
Poison knowledge = good	94	6	(7)
Poison knowledge = poor	86	11	(8)

More patients are hospitalised when knowledge is good.

(iv) fatalities:

	<u>Fatal</u>		
	<u>Yes</u>	<u>No</u>	
	<u>%</u>	<u>%</u>	
Poison knowledge = good	10	90	(10)
Poison knowledge = poor	14	82	(11)

Fatalities are fewer when knowledge is good.

(v) and when:

	<u>Poison knowledge</u>	
	<u>Good</u>	<u>Poor</u>
	<u>%</u>	<u>%</u>
Fatal = yes (12)	37	8
Fatal = No (13)	45	7

When fatalities occurred, only 37% of owners had a good knowledge, while 45% of owners had a good knowledge where poisoning was non-fatal.

(vi) first aid applied:

	Yes %	No %	
	—	—	
Poison knowledge = good	20	71	(169)
Poison knowledge = poor	14	82	(171)

First aid per se will be discussed in the clinical section (4.3.4). In relation to the knowledge of the owner, however, the incidence of first aid applied was higher where the knowledge was good than where the knowledge was poor.

Two other important factors are whether the owner received any guidance in managing poisons and whether the owner gave guidance to the labourers handling the poisons. Diagram (14) indicates that 75% of owners did receive guidance. When this 75% was analysed according to poison knowledge, then 54% (15) in comparison to the 44% (1) of the average number had a good knowledge. Similarly when the 75% of owners who did receive guidance was analysed according to poison storage, then 55% (16) in comparison to the 46% (2) of the average owners had their chemicals isolated and locked. It is thus evident that guidance to owners had a positive influence on the management of poisons. With reference to guidance given to labourers, 78% (17) supplied guidance, while 94% (19) of the owners that received guidance did supply guidance, and only 47% (20) of the owners who did not receive guidance [16% (14)], supplied guidance to labourers. These results are similar to those between guidance received and supplied when working with specific chemicals. Of the 75% (150) of the owners who received guidance when working with organophosphates, 77% (152) supplied guidance to workers. Similarly, of the 94% (151) of the owners who received guidance to apply carbamates, 96% (153) supplied guidance to workers. It emphasises again that owners who received guidance respond favourably in comparison to those who did not receive any guidance at all. The guidance provided to labourers was, however, regarded (18) to be only 28% intensive and 49% superficial. This is reflected in the small differences in protective clothing used (21 - 22) between guidance provided and guidance provided intensively:

	<u>Comparison of protection used</u>	
	<u>Yes (21)</u>	<u>Intensive (22)</u>
	<u>%</u>	<u>%</u>
overalls	42	32
gloves	2	1
masks	1	0
other	3	3
overalls and gloves	7	7
overalls and masks	10	15
overalls and other	2	4
gloves and masks	0	1
overalls, gloves and masks	20	27
overalls, gloves, masks and other	4	4

Actual control of poisons by owners is shocking; 71% (23) did not apply any system of bookkeeping. Owners therefore have no specific control over pesticides. Guidance received does not change the situation, in that 73% (24) still applied no control. The level of guidance received is also reflected in the limited, 36% (25), washing facilities available to labourers after handling pesticides. Not even the possibility of contact with potent poisons such as organophosphates and carbamates changed the situation; washing facilities for labourers working with organophosphates were also only 36% (155) and those for carbamates 35% (156).

When possible accessibility to poisons by unauthorised persons was tested, 70% (26) of the owners claimed no accessibility. When, however, this 70% is analysed according to poison storage (27), only 59% of the chemicals were isolated and locked. This is of course not possible. It is concluded that the owners regard locked but not isolated - which is 25% (27) - as also being correct and sufficient, and therefore 70% of owners claim no unauthorised accessibility to pesticides.

In conclusion the very important matter of labelling containers in which dilution, mixing or distribution of pesticides takes place, should be considered. Only 37% (28) of owners are responsible enough to apply labelling to such empty containers used for the above-mentioned purposes.

Summary

The owners' general knowledge of pesticides is insufficient. It has

been illustrated that when the owners' knowledge is good, it is reflected positively in the management and uses of pesticides as well as a higher incidence of hospitalisation of poisoning cases, as well as indicating a lower incidence of fatalities. Similarly, guidance to owners does promote better management of poisons, but only superficial guidance is passed on to the labourer. Serious shortages as regards owners are:

- (1) inefficient storage of pesticides;
- (2) superficial conveyance of guidance;
- (3) total lack of control (bookkeeping);
- (4) lack of special washing facilities; and
- (5) irresponsibility in not labelling pesticide containers used for diluting and other purposes.

4.3.2 Patient

In section 2.4.1 of Chapter II, the ratio of permanent labourers in the farming community in South Africa was indicated to be Blacks [81,9%], Coloureds [15,6%] and Whites [2,1%]. Intoxications by agricultural chemicals over a given period was, with reference to ethnic groups, similar to these employment figures. However, there was a distinct difference in the ratios between employment and intoxication (29):

	Black > %	Coloured > %	White > %
Regular employment	81,9	15,6	2,1
employment ratio	39	: 5,3	: 1
Intoxication	61	25	13
intoxication ratio	4,7	: 2,3	: 1

The incidence of total intoxication is thus proportional to that of total employment. The intoxication/employment ratio for each ethnic group is however inversely proportional:

	White >	Coloured >	Black
ratio intoxication/employment	6,2 >	1,6 >	0,7

which indicates that although Blacks are the main contributors to total intoxications, Whites and Coloureds are detrimentally affected to a higher degree within each specific group.

Poisoning by pesticides occurred mainly in males 76% than females 24% (30), and this should be expected due to occupational exposure.

The location of poisoning furnishes some alarming results:

	House or yard of Owner %	Patient %	Cultivated land %	Orchard %	Elsewhere %
Total poisonings (31)	15	39	25	4	12
Male poisonings (32)	16	33	32	4	12
Female poisonings (33)	12	59	5	1	15

The relative high rate of 39% (31) poisoning at the house of the patient, in comparison with only 25% (31) on the cultivated land - which is occupational - points to the availability of these chemicals and therefore inefficient control (see 4.3.1). The 39% (31) at patients' house is also clarified by the high incidence of males 33% (32) and the almost dominant rate of female poisoning 59% (33) at this location. The very low contribution [5% (33)] of females to poisoning at cultivated land is in comparison with males [32% (32)] due to male's occupational exposure, but stresses again that the 59% (33) of female poisoning at patients' house is due to inefficient control.

Most pesticidal poisonings take place during off-duty; 62% (34) in relation to the 34% (34) when on duty. This is very clearly illustrated by analysing the poisonings during on and off duty by location:

	House or yard of Owner %	Patient %	Cultivated land %	Orchard %	Elsewhere %
Poisoning on duty (35)	11	5	58	7	17
Poisoning off duty (36)	16	59	8	2	10

Thus of the 62% of poisonings during on duty, a total of 82% (58% + 7% +

17%) happened on cultivated land, orchard and elsewhere, while of the 34% of poisonings during off duty, a total of 75% (16% + 59%) happened at either the owner's or the patient's house - once again illustrating the availability of these chemicals. The storage of pesticides during on and off duty proves the same point:

	Isolated	Isolated and locked	Locked but not isolated
	_____ % _____	_____ % _____	_____ % _____
Poisoning during on duty (37)	16	53	21
Poisoning during off duty (38)	18	41	25

These results are also in agreement with those discussed in section 4.3.1; that during off duty these chemicals are also accessible.

The reasons for poisoning were mainly attempted suicide, attempted murder, accident or ignorance, the differences between the latter being accidental poisoning occurring due to negligence by somebody acquainted with the presence of the chemical, while poisoning due to ignorance occurs to someone unfamiliar with the chemical and unaware of its presence. The reason's distribution of total poisonings as well as the reason's ratio in each ethnic group were:

	Suicide %	Murder %	Ignorance %	Accident %
	_____ % _____	_____ % _____	_____ % _____	_____ % _____
Ratio of total poisonings (39)	15	8	27	33
Ratio in White group (40)	36	2	15	34
Ratio in Coloured group (41)	25	1	30	36
Ratio in Black group (42)	7	12	28	32

while the contribution to these causes by males and females were:

	Males %	Females %
Suicide (47)	60	40
Murder (48)	43	53
Ignorance (49)	79	21
Accident (50)	83	17

Poisoning due to accidents and ignorance totals 60% (39) and those due to suicide and murder 23% (39). The difference between these two groups of reasons is understandable and is due to the male dominance [76% (30)] in poisoning cases, and poisoning due to accidents and ignorance in males being 83% (50) and 79% (49) respectively. It is possible to postulate that because due to (1) the relatively low incidence [24% (30)] of female poisoning, mainly due to suicide [40% (47)] and murder [53% (48)]; (2) female poisoning taking place at mainly patient house/yard [59% (33)]; (3) all poisonings being mainly off duty [62% (34)]; and (4) at patients' house/yard [59% (36)] when off duty, that suicide and murder must take place in non-working hours, mainly at the residence of the patient. This is confirmed by suicide 58% (56) and murder 93% (57) taking place at patients' house/yard during non-working hours - suicide being 93% (64) and murder 100% (65).

The analyses of each reason's contribution to total poisonings i.e.

	Suicide %	Murder %	Ignorance %	Accident %
Total poisonings (39)	15	8	27	33

is very interesting when each such reason is analysed for the three ethnic groups:

	Black %	Coloured %	White %
Suicide (43)	27	42	32
Murder (44)	93	3	3
Ignorance (45)	64	28	8
Accident (46)	59	27	14

The 15% (39) suicidal poisonings were attempted by Coloureds 42% > Whites 32% > Blacks 27% (43), although suicide was the most important reason among Whites 36% (40) > Coloureds 25% (41) and the least important among Blacks being only 7% (42). Males contributed 60% (47) to the attempted suicide mainly at patient's house/yard [58% (56)] after working hours [93% (64)].

The 8% (39) murder poisonings were attempted by the almost total dominance of Blacks 93% (44) > Whites 3% (44) = Coloureds 3% (44), but other than suicides, murder was the most important reason among Blacks 12% (42) > Whites 2% (40) > Coloureds 1% (41). Also different from suicides, murder attempts were contributed mainly by females [53% (48)] but similar to suicides at patient's house/yard [93% (57)] and all cases [100% (65)] after working hours.

The 27% (39) poisoning cases due to ignorance were mostly dominated by Blacks 64% > Coloured 28% > Whites 8% (45) and once again, totally different from suicide and murder, ignorance was the most important reason among Coloureds 30% (41) > Blacks 28% (42) > Whites 15% (40). Males were the main contributors [79% (49)] again at patient's house/yard [36% (58)] mainly after hours [62% (66)].

Accidents accounted for the most poisonings [33% (39)] and similar to ignorance was mostly dominated by Blacks 59% > Coloureds 27% > Whites 14% (46) and unlike all the other causes, accidents were the most important reason among Coloureds 36% (41) > Whites 34% (40) > Blacks 32% (42). Similar to suicides and ignorance (but different from murders), males had the main contribution [83% (50)] but unlike all the other reasons, 31% (59) at cultivated land and 49% (67) within working hours.

In section 4.3.1 it was described that a substantial percentage of owners supplied guidance to labourers, although most of the guidance supplied was of a superficial nature. From diagram (51) it is concluded that guidance provided to labourers do not alter the incidences of reasons for poisoning dramatically. Similar to the results in section 4.3.1, guidance was also provided extensively where incidences of poisonings occurred. However when guidance was not provided, no poisonings occurred due to suicide and murder:

	Suicide %	Murder %	Ignorance %	Accident %
Guidance provided to labourers (51)	8	10	30	34
Guidance not provided to labourers (52)	0	0	35	35

	Guidance given to labourers	
	Yes %	No %
Suicide (53)	40	18
Murder (54)	100	0
Ignorance (55)	86	12

It may be concluded that when no guidance is provided at all then poisonings due to ignorance and accidents could still occur. However, it must be assumed if no information on the possible detrimental effects is provided, then there will be no reason for anybody to choose such a chemical to commit suicide or murder.

Diagrams (56) and (59) indicate the different location ratios for each reason of poisoning:

	House or yard of Owner %	or yard of Patient %	Cultivated land %	Orchard %	Elsewhere %
Suicide (56)	25	58	3	0	3
Murder (57)	3	93	0	0	0
Ignorance (58)	13	36	28	5	13
Accident (59)	19	27	31	6	15

Poisonings due to ignorance and accident takes place at all possible locations. Suicide and murder however, only occur at the residences of owner and patient.

Diagrams (60) to (63) illustrate the different ratios of each reason for a specific locality:

	Suicide %	Murder %	Ignorance %	Accident %
Poisoning at owners house/yard (60)	26	2	24	43
Poisonings at patients house/yard (61)	23	18	25	23
Poisoning at cultivated land (62)	2	0	30	40
Poisoning at orchard (63)	0	0	36	57

All poisonings occurred mainly outside working hours:

murder 100% (65) > suicide 93% (64) > ignorance 62% (66)

However, accidents were 49% outside and 48% inside working hours (67).

Educational levels differ largely between race groups and so do the intoxication patterns (results are expressed according to the American system i.e. grade 1 to grade 12):

Educational level (grade)	< 5 %	6 - 7 %	8 - 10 %	11 - 12 %
Total intoxications (68)	72	5	9	5
Whites	1	5	56	95
Coloureds	26	43	24	5
Blacks	73	52	21	0
	(69)	(70)	(71)	(72)

Total poisoning by Whites are proportional to level of education, just the opposite from Blacks, where the contribution to total poisoning is inversely proportional to level of education. Up to grade seven the contribution to poisoning by the different races is: Black > Coloured > White, while from grade 8 - 12 the sequence is just the opposite: White > Coloured > Black.

Incidences of poisoning within a race group follow the same pattern as the contribution to total poisoning by the different race groups i.e. Whites being mostly proportional to educational level:

Grades:	< 5 %	6 - 7 %	8 - 10 %	11 - 12 %
Whites (73)	6	2	36	38

and Coloureds and Blacks being inversely proportional to educational level:

Grades:	< 5 %	6 - 7 %	8 - 10 %	11 - 12 %
Coloureds (74)	74	9	8	0
Blacks (75)	85	5	3	0

It should be expected that if the educational level is relatively low, that

(i) the abilities to read Afrikaans and English will also not be good:

	<u>Ability to read</u>		
	Good %	Fair %	Poor %
Afrikaans (78)	18	10	63
English (84)	10	8	71

(ii) Ability to read Afrikaans per race group:

	<u>Afrikaans reading ability</u>	
	Good (79) %	Poor (80) %
White	58	0
Coloured	26	22
Blacks	16	78

(iii) Ability to read English per race group:

	<u>English reading ability</u>	
	Good (85) %	Poor (86) %
White	80	1
Coloured	10	25
Blacks	10	74

(iv) Influences of guidance on reading ability:

	<u>Guidance to labourers</u>	
	Yes %	No %
Ability to read Afrikaans good (81)	43	17
Ability to read Afrikaans poor (82)	88	9
Ability to read English good (87)	33	20
Ability to read English poor (116)	88	9

The majority of the poisoning victims [72% (68)] only read Afrikaans [63% (78)] and English [71% (84)] poorly. Generally, patients could read Afrikaans, if only marginally, better than English:

Afrikaans good = 18% (78)	English good = 10% (84)
Afrikaans fair = 10% (78)	English fair = 8% (84)

When the majority of labourers are only educated to grade 5 and their ability to read Afrikaans and English is poor, then labelling of pesticides has little real function, which is a very serious matter. It is interesting though to note that guidance was particularly given to those with an ability to read only poorly. This indicates some responsibility by those (owners) in charge of pesticide application operations.

The importance to be able to read labels is also demonstrated in the relationships between ability to read and reasons for poisoning:

	Suicide %	Murder %	Ignorance %	Accident %
Ability to read Afrikaans good/fair	62 (88)	96 (89)	16 (90)	29 (91)
Ability to read Afrikaans poor	37 (88)	0 (89)	65 (90)	62 (91)
Ability to read English good/fair	51 (92)	97 (93)	9 (94)	20 (95)
Ability to read English poor	47 (92)	0 (93)	74 (94)	72 (95)

For both Afrikaans and English reading ability, those who attempted suicide or murder, were able to read both languages while those who were only able to read both languages poorly, were victims to ignorance or accidental poisoning. With reference to ignorance and accidental poisoning these results are a serious accusation against government and

industry alike, while suicides and murders emphasise the responsibility to control and keep these chemicals isolated and locked because those who want to commit suicide and murder can read and therefore choose what chemicals to use.

Diagram (96) indicates the poisoning incidences by different age groups:

Age groups in years:	1-10	11-20	21-30	31-40	41-50	51-60	61-99
Poisoning incidences % (96)	23	< 28	> 19	> 14	> 8	> 5	> 2

Except for the youngest group, the results indicate an inverse relationship between poisoning and age.

No apparent relationship exists between the storage of poisons and age groups (98 - 104). However, there is an obvious relationship between location of poisoning and age group:

Age groups in years:	1-10	11-20	21-30	31-40	41-50	51-60	61-99
	%	%	%	%	%	%	%
Total poisonings at workplace	26	46	52	51	41	32	20
	(105)	(106)	(107)	(108)	(109)	(110)	(111)
Total poisonings at residence	70	52	43	43	50	63	70

* elsewhere = workplace

Between 0 - 20 years most of the poisonings occur at the residence, from 21 - 40 years at the workplace and from 41 - 99 again at the residence. Thus these results directly relate to labourers being economically active.

The reasons for poisoning as per age group are given in diagrams (112 - 115):

Age groups in years:	1-10	11-20	21-30	31-40	41-50	51-60	61-99
	%	%	%	%	%	%	%
Suicides (112)	0	27	37	22	5	3	7
Murder (113)	37	47	0	7	3	3	3
Ignorance (114)	38	22	22	8	4	5	2
Accident (115)	22	28	14	14	14	7	1

There are no suicide cases between 1 - 10 years of age, the majority of

cases being between 11 - 40 (86%) years of age. The majority of attempted murders are within the two youngest groups (84%), 1 - 20 years of age, possibly due to unstable socio-economic conditions in those age groups (husband, wife and child). The greatest problem of ignorance is between 0 - 30 years, with the main contribution (38%) in the 0 - 10 year range. Accidents are also more frequent in the two younger groups, with a lower but more evenly spread contribution up to 50 years of age.

Summary

1. Incidence of total poisoning is proportional to total employment, however intoxication/employment ratio for each ethnic group is inversely proportional.
2. High rate of poisoning at patient's house/yard indicates inefficient control of chemicals.
3. Most poisonings occur during off duty at patient's house/yard; poisonings on duty mainly occur on cultivated land i.e. being of occupational nature.
4. Poisonings mainly due to ignorance and accident.
5. Murders and suicides take place during non-working hours mainly at patient's house.
6. Suicides most important reason among Whites, males, at patient's house, during non-working hours.
7. Murders most important reason among Blacks, females, at patient's house, during non-working hours.
8. Ignorance most important reason among Coloureds, males, at patient house, during non-working hours.
9. Accidents most important reason among Coloureds, males, on cultivated land, during working hours.
10. Poisoning among Whites is proportional to level of education.

11. Poisoning among Coloureds and Blacks is inversely proportional to level of education.
12. Majority of labourers only educated to grade 5, their ability to read is poor and therefore labelling of poisons with reference to labourer is of no use.
13. Labourers with poisoning due to suicide and murder, however, are able to read and therefore choose the chemical they use.
14. Inverse relationships exist between poisoning and age.
15. Poisonings relate directly to being economically active.

4.3.3 Poisons

The chemicals mainly responsible for acute intoxications (116), are those classified as organophosphates 55%, carbamates 14%, organochlorines 4%, nitrophenolic compounds 2% and anticoagulants 1%. The nature of the formulations (117) of these chemicals involved in poisoning is diluted liquids 36%, concentrated liquids 31%, solids 19%, gas 1% and aerosol 1%. The formulations of the three main groups responsible, however, not only differ between groups but, except for organophosphates, also deviate from the general pattern of total chemicals:

	Liquids		Solids	Gas	Aerosol
	diluted %	concentrated %			
Total chemicals (117)	36	31	19	1	1
Organophosphates (118)	49	40	7	0	1
Carbamates (119)	2	6	93	0	0
Organochlorines (120)	13	80	7	0	0

The chemicals involved in the four different reasons for poisoning are:

	Suicide % (121)	Murder % (122)	Ignorance % (123)	Accident % (124)
Organophosphates	67	0	63	57
Carbamates	3	93	7	11
Organochlorines	10	0	4	3
Nitrophenolic	2	0	0	1
Anticoagulants	2	0	0	1
Organonitrogen compounds	0	0	1	0
Pyrethroids	0	0	4	2
Dithiocarbamates	0	0	1	2
Dipyridyl compounds	0	0	1	0

Organophosphates are the dominating chemicals in all the reasons but attempted murder. The reason why carbamates were chosen for the latter cause is difficult to assess. A possible factor could be the difference in storage conditions between organophosphates and carbamates:

	<u>Storage of poisons</u>		
	Isolated %	Isolated and locked %	Locked but not isolated %
Organophosphates (145)	19	60	12
Carbamates (146)	0	31	65

A substantial percentage of organophosphates 60% were isolated and locked in contrast to carbamates 31%. Thus access to carbamates was easier than organophosphates, once again emphasising the importance of storage.

When no particular motive for poisoning existed, the formulation responsible was similar to the formulation responsible for total poisonings:

	Pesticide formulation				
	Liquid diluted		Liquid concentrated		Solids
	%		%		%
Total chemicals (117)	36	>	31	>	19
Ignorance (127)	47	>	29	>	12
Accident (128)	37	>	31	>	18

However, when a motive existed, the formulation responsible changed:

	Pesticide formulation				
	Liquid diluted		Liquid concentrated		Solids
	%		%		%
Suicide (125)	20	>	60	>	8
Murder (126)	0		0		93

These results correlate with the patient's ability to read (page 18), ignorance and accident being poor, and suicide and murder being good or fair. It thus suggests that where a motive existed, the responsible chemical and formulation was selectively used.

Diagrams (129 - 133) indicate at which location the different formulated pesticides were responsible for intoxication:

	Owners house	Patients house	Cultivated land	Orchard	Elsewhere
	%	%	%	%	%
Liquid concentrated (129)	24	33	20	2	0
Liquid diluted (130)	13	27	39	6	0
Solids (131)	3	64	23	3	0
Gas (132)	0	0	0	0	100
Aerosol (133)	0	75	0	0	0

These results confirm those previously described. Ignorance and accidents are mainly due to liquids diluted (127) and liquids concentrated (128) and mainly at owners house (60), patients house (61) and cultivated land (62). Therefore it is expected that liquids concentrated (129) and diluted (130) will mainly be responsible at owners and patients' house as

well as on cultivated land. The same argument is valid for attempted murder, this taking place mainly at the patients' house. It is also to be expected, due to the nature of the products, that poisonings due to aerosols would be at the residences of the patients (133). Once again, aerosol poisoning not occurring at the house of the owner but at the house of the patient, suggests socio-economic factors influencing this type of intoxication.

Results on the location of poisonings by the different chemicals (134 - 136) also confirm results already described:

	Owners house %	Patients house %	Cultivated land %	Orchard %	Elsewhere %
Organophosphates (134)	15	29	35	6	14
Carbamates (135)	4	76	19	0	2
Organochlorines (136)	47	13	13	0	13

Organophosphates are mainly responsible for suicides 67% (121), ignorance 63% (123) and accidents 57% (124) and overall 55% (116) for all poisonings, being nearly equally responsible in the concentrated 40% (118) and diluted 49% (118) formulations. Furthermore they are extensively and frequently used; 40% of all organophosphates are used more than 6 times annually (138) and by all methods of application (142). It is thus obvious that organophosphates must be mainly responsible for occupational poisoning, i.e. at cultivated land.

Carbamates make a small contribution to suicides [3% (121)], ignorance [7% (123)] and accidents [11% (124)] being the main contributor to attempted murder poisonings [93% (122)] which predominantly take place at patients house/yard [93% (57)]. It is also frequently applied, 61% of carbamates four times annually (139) by mainly aerial and mechanical surface methods 59% (143). However, being responsible for almost all attempted murders, carbamate poisoning occurs predominantly at patients house or yard.

Organochlorines contributed only 4% to poisonings by pesticides, mainly by concentrated formulations [80% (120)]. Of all uses, [27% (140)] of organochlorines are applied more than six times annually, mostly by mechanical surface methods [47% (144)]. Unlike organophosphates and

carbamates, organochlorine poisoning predominantly took place at the house or yard of the owner (136).

The frequency with which pesticide chemicals are applied, can only enhance the incidence of poisoning, 34% being applied more than six times annually:

Annual frequency of use:	>6	6	5	4	3	2	1	
	%	%	%	%	%	%	%	
	—	—	—	—	—	—	—	
Total poisons	34	1	1	18	6	11	13	(137)
Organophosphates	40	1	1	9	4	15	16	(138)
Carbamates	15	0	0	61	9	0	11	(139)
Organochlorines	27	0	0	0	7	20	13	(140)

Nearly half - 40% - of organophosphates are being physically handled every second month of the year, while 61% of carbamates are handled every third month of the year. Thus, the application of pesticides is not a rare, once-in-a-while phenomenon but is rather integrated as normal procedures in the day to day activities of agriculture and public health.

The physical method of pesticide application must certainly be a factor in the incidence of poisoning. In the attempt to assess the method of application as a factor in poisoning, this investigation distinguishes three basic methods: (1) aerial application; (2) mechanical surface application; and (3) hand application. By "mechanical surface" is meant the spraying or soil application of a pesticide by means of primarily a mechanical device handling the chemicals - such as a machine towed by a tractor - opposed to hand application in which an operator - labourer, housewife, etc. - handles the device personally, such as knapsack kits and pressurised cannisters. The contribution to poisoning by application methods is as follows:

	Mechanical surface	Hand application	Mechanical surface and aerial	Mechanical surface and hand application
	%	%	%	%
	—	—	—	—
Total pesticides (141)	27	23	17	15
Organophosphates (142)	28	25	13	19
Carbamates (143)	9	9	59	13
Organochlorines (144)	47	20	7	0

	aerial %	aerial and hand application %
	_____	_____
Total pesticides (141)	4	2
Organophosphates (142)	5	1
Carbamates (143)	4	2
Organochlorines (144)	0	0

In total pesticides, organophosphates and organochlorines, the methods mainly used are mechanical surface > hand application > mechanical surface and aerial, while with carbamates mechanical surface and aerial methods predominate. Surprising is the relatively low contribution by aerial spraying per se or in combination with other methods.

Carbamate's much lower incidence of poisoning when applying pesticides by mechanical surface and hand application methods could be attributable to differences in protective clothing used:

	Organophosphates % (157)	Carbamates % (158)
	_____	_____
Overalls	30	69
Gloves	1	0
Masks	1	0
Other	4	0
Overalls and gloves	6	4
Overalls and masks	6	4
Overalls and other	3	0
Gloves and masks	1	0
Overalls, gloves and masks	16	13
Overalls, gloves, masks and other	3	7

Overalls are being used in carbamate applications to a much greater extent, whether alone or in combination with gloves and masks, than when applying organophosphates. Despite all other reasons already described for the differences between organophosphates and carbamate poisonings, (Organophosphates: ignorance 63% (123), accidents 57% (124), concentrated liquid 40% (118), diluted liquid 49% (118), cultivated land 35% (134). Carbamates: ignorance 7% (123), accidents 11% (124), cultivated land 19% (135)), differences in poisonings due to organophosphates and carbamates could also be ascribed to overalls or overalls, gloves and masks being used to a greater extent when applying carbamates than organophosphates.

Results already reported, on carbamate poisoning contributing mainly to attempted murder and not ignorance or accidents, strengthens this argument. The results on guidance given to labourers however, indicate that those poisoned due to murder (54), received guidance to a very large extent and therefore it is not surprising (1) that protective clothing is used to a larger extent when applying carbamates, but could (2) also be the reason for so relatively few poisonings by carbamates due to ignorance and accidents.

An analysis of the protective clothing used when working with the different formulations of products is rather surprising:

	Concentrated liquids % (159)	Diluted liquids % (160)	Solids % (161)
Overalls	28	35	57
Gloves	1	3	3
Masks	0	1	0
Other	2	3	1
Overalls and gloves	8	6	4
Overalls and masks	2	11	5
Overalls and other	1	4	1
Gloves and masks	2	0	0
Overalls, gloves and masks	15	18	17
Overalls, gloves, masks and other	2	4	5

It is surprising because normally protective clothing such as gloves and masks should be used to a much greater extent working with concentrated and diluted liquids. However, not only are these devices neglected, but there is little difference between liquids and solids regarding wearing of gloves and masks. The 57% (161) overalls used when applying solids, refers once again to carbamates.

Summary

The results in this section could be summarised as follows:

	Suicide %	Murder %	Ignorance %	Accident %
Chemical group	organo-phosphates	Carbamates	Organo-phosphates	Organo-phosphates
Poison storage	60% iso and lock	31% iso and lock	60% iso and lock	60% iso and lock
Application	Mechanical surface & hand appl	Mechanical surface/aerial	Mechanical surface/hand appl	Mechanical surface & hand appl
Formulation	Liquid concentrate	Solids	Liquid diluted	Liquid diluted
Protective clothing	overalls 33%	overalls 69%	overalls 33%	overalls 33%
Location of poisoning	patient house/yard	patient house/yard	patient house/yard	cultivated land
Race	Coloureds	Blacks	Blacks	Blacks
Sex	males	female	males	males
Time of poisoning	off duty	off duty	off duty	on duty
Afrikaans reading	good/fair	good/fair	poor	poor
English reading	good/fair	good/fair	poor	poor
Age, years	21 - 30	11 -20	1 - 10	11 -20

4.3.4 Clinical

Although symptomatology was recorded in all the poisoning cases, it will, due to its familiar nature, not be discussed in this section. The validity of the poisoning cases identified is reflected by the confirmation thereof (165):

	<u>Confirmation of Intoxications</u> %
Clinical	69
Laboratory	9
Evidence of patient	11
Evidence of relatives/friends	10

The application of first aid to patients before a medical doctor or

hospital was reached, was very unsatisfactory (166), although with reference to fatalities, the application of first aid was insignificant.

	<u>First aid applied</u>	
	Yes %	No %
First aid applied (166)	18	76

	<u>Fatalities</u>	
	Yes %	No %
When first aid was applied (167)	15	85
When first aid was not applied (168)	10	89

	<u>First aid applied</u>	
	Yes %	No %
General poison knowledge = good (169)	20	71
General poison knowledge = poor (170)	14	82

Although not very significant, there seems to be some indication that first aid was applied to a greater extent when the owner's poison knowledge was good. Unlike first aid, patients were referred for medical assistance to a significant degree with positive results regarding fatalities.

	<u>Medical aid</u>	
	Yes %	No %
Patients referred to a doctor (171)	95	4
Fatalities when referred to doctor (172)	11	88
Fatalities when not referred to doctor (173)	40	60

The poison knowledge of the owner had no influence on whether a patient was referred to a doctor or not. When the poison knowledge of owner was good (174), 97% of intoxications were referred to a doctor, whilst 96%

(175) were referred when poison knowledge was poor.

Mortality in the 400 cases investigated was 12% (179), while intoxications were hospitalised to a significant degree (176). The importance of hospitalisation of intoxications is reflected by mortality statistics:

	<u>Hospitalisation</u>	
	Yes %	No %
Intoxications hospitalised (176)	93	7

	<u>Fatalities</u>	
	Yes %	No %
Patients hospitalised (177)	11	88
Patients not hospitalised (178)	25	75

Thus, of the 93% of patients hospitalised, only 11% were fatal, while 25% of the 7% intoxications not hospitalised were fatal.

Hospitalisation (180) of the intoxications from the four different reasons for poisoning, was virtually identical to the incidence of total poisoning, which implies that reason for poisoning had no direct influence on hospitalisation. A very distinct difference however, existed between the different reasons for poisoning of the 7% (176) intoxications not hospitalised:

	<u>Not hospitalised</u> (181)
	%
Attempted suicide	11
Attempted murder	0
Ignorance	18
Accident	43

Thus, when reasons of intoxications are expressed as a fraction of total

intoxications not hospitalised, then the dominant contribution is made by those due to accidents, while all those due to murder are hospitalised. Similarly, but perhaps more significantly, are the intoxications by the different reasons not hospitalised, but expressed as a fraction of the intoxications by each reason:

	<u>Not hospitalised</u>
	<u>%</u>
Attempted suicide (182)	5
Attempted murder (183)	0
Ignorance (184)	5
Accidental poisoning (185)	9

Once again, those poisonings due to accidents contribute mainly to being not hospitalised. This must be regarded as a serious matter because most of the accidental poisonings are of an occupational nature - at cultivated land during working hours.

Contribution to total fatalities [12% (179)] by the four different reasons were (186):

suicide	>	ignorance	>	accident	>	murder
33%		22%		20%		2%

while fatalities expressed as a proportion of each reason are:

suicide	>	ignorance	>	accident	>	murder
27%		10%		8%		3%
(188)		(190)		(191)		(189)

In total fatalities as well as within a reason per se, suicide was the main contributor to mortality and being an intoxication with a motive, these patients were quite successful, with 27% fatalities using mainly concentrated liquid (125) organophosphates (121). Attempted murder intoxication was the smallest contributor [2% (186)] and being a reason with a motive, the patients were unsuccessful [3% (189)] using mainly solids (136) of carbamate formulations (132).

The hospitalised intoxications analysed per poison group is reflected in diagram (192) and conveys essentially the same ratio as those

The sequence of the groups responsible for total poisoning, hospitalisation and fatalities is thus essentially the same for the main groups, differing only to a small extent in the minority groups. These minority groups contributing to fatalities (197), also contributes a small percentage to the total poisonings not hospitalised (193).

When fatalities within a poison group were analysed, the sequence - similar to no hospitalisation (194 - 196) - changed to:

Fatalities: organochlorines > organophosphates > carbamates
 20% > 9% > 7%
 (201) (199) (200)

Not hospitalised: organochlorines > organophosphates > carbamates
 13% > 8% > 0%
 (196) (194) (195)

These results lead to three important conclusions:

- (i) A direct relationship exists between cases not hospitalised and fatalities within a poison group.
- (ii) Although organophosphates and carbamates contribute to a larger extent to total fatalities, organochlorines recorded a substantial larger mortality rate when fatalities are expressed as a proportion of the intoxications of the same group.
- (iii) These results serve as a reminder that a specific antidote is available to organophosphate and carbamate poisonings, whilst such an antidote does not exist for organochlorine poisonings.

The different formulations of pesticide proved similar differences between hospitalisation and fatality patterns:

	<u>Liquids</u> diluted %	concentrate %	<u>Solids</u> %
Total cases hospitalised (202)	36	30	20
Total cases not hospitalised (206)	36	43	11

Hospitalisation within a formulation:

	<u>Hospitalised</u>	
	Yes %	No %
Liquid concentrated (203)	89	10
Liquid diluted (204)	93	7
Solid matter (205)	96	4

The sequences of hospitalisation differ between total cases hospitalised, total cases not hospitalised and hospitalisation within a specific formulation:

Total cases hospitalised: liquids dilutes > liquids concentrated > solids
 Total cases not hospitalised: liquids concentrated > liquids dilutes > solids
 Hospitalisation within a formulation: solids > liquids dilutes > liquids concentrated

Fatalities for the different formulations of total poisonings were (207):

liquid concentrate > liquid diluted > solids
 37% > 29% > 12%

which was also the sequence for fatalities within a formulation:

liquid concentrate > liquid diluted > solids
 15% > 10% > 8%
 (208) (209) (210)

and which is the same sequence for total cases not hospitalised:

liquid concentrate > liquid diluted > solids
 43% > 36% > 11%
 (206) (206) (206)

Thus, unlike hospitalisation, fatalities from total poisoning and fatalities within a specific formulation are essentially similar, liquid concentrate being the main contributor to fatalities. It is also noticeable that a direct relationship exists between the sequence of formulations responsible for fatalities and the sequence for total cases

not hospitalised. Summarising the preceding results, organochlorines and liquid concentrate feature very prominently: liquid concentrate was mainly used in attempted suicides 67% (125) being also the main contributing formulation 80% (120) in organochlorine poisoning. Organochlorine poisoning mainly took place at owners' house/yard 47% (136), had the largest contribution to unhospitalised patients 13% (196), and within a chemical group organochlorines were responsible for the main contribution 20% (201) to fatalities. Moreover, liquid concentrate was the main contributor to total fatalities 37% (207), also recording the largest fatality rate 15% (208) within a formulation. Thus organochlorines, concentrated liquid, suicides, not hospitalised, fatality rate and owner's house/yard forms a formidable combination in pesticidal poisoning.

In hospitalisation per race group, the tendency not to hospitalise poisoning cases is highest among whites:

	<u>Hospitalisation</u>	
	Yes %	No %
	—	—
Whites (212)	81	19
Coloureds (213)	94	6
Blacks (214)	95	5

This tendency could be explained as follows:

From the preceding results it has been established that

- (1) organochlorines main contributor to not hospitalising;
- (2) per poison group, organochlorines contribute most to fatalities;
- (3) suicide main reason for poisoning among Whites; and
- (4) organochlorines main contributor to attempted suicides.

A positive relationship therefore exists between not hospitalising, organochlorines, suicides and Whites.

The contribution to total fatalities by race, follows the same pattern as total poisoning by race:

		Black %		Race Coloured %		White %
		_____		_____		_____
Total poisoning	(29)	61	>	25	>	13
Total fatalities	(215)	51	>	31	>	18

However, fatalities within a population group is

White > Coloured > Black
 17% > 15% > 10%
 (217) (218) (219)

which is inversely proportional to total poisoning and fatalities. This could be explained by total fatalities per reason for poisoning being (186):

suicide > ignorance > accident > murder
 33% > 22% > 20% > 2%

and within a population group, the contribution to poisoning due to suicides by race group being

White > Coloured > Black
 36% > 25% > 7%
 (40) (41) (42)

Thus although fatalities in total poisoning is Black > Coloured > White, fatalities within a population group will be proportionally higher in Whites due to the contribution by suicides.

The significance of ignorance and accidental poisoning contributing to fatalities, is illustrated in the fatality ratio in the youngest age group, 1 - 10 years of age.

	<u>Age group (years)</u>						
	0-10 %	11-20 %	21-30 %	31-40 %	41-50 %	51-60 %	61-90 %
Total poisonings (96)	23	< 28 >	19	> 14 >	8	> 5 >	2
Total fatalities (220)	27	> 20 >	10	< 20 >	12	> 6 >	4

The main contributor to fatalities is the age group 1 - 10 years. This age group made no contributions to poisoning due to suicide 0% (112) and although it contributed 37% (113) of attempted murders, the latter contributed only 2% (186) to total fatalities. Thus, the age group 1 - 10 years was the main contributor to fatalities due to ignorance and accidents, accentuating the importance of proper control of these chemicals.

Hospitalisation of poisoning cases were mainly during off duty, which is in agreement with most poisoning occurring during non-working hours.

	<u>Working hours</u>	
	on duty %	off duty %
Total poisoning (34)	34	62
Hospitalisation (222)	33	63
Suicide (64)	2	93
Murder (65)	0	100
Ignorance (66)	36	62
Accident (67)	49	48

Patients were hospitalised to a significant degree:

	<u>Hospitalisation</u>	
	Yes %	No %
Total poisonings (176)	93	7
During normal duty (223)	90	10
During off duty (224)	94	5

Fatalities analysed by during normal duties were an insignificant 14% during normal duties in comparison with fatalities due to poisoning during off duty [82% (226)]. This is in perfect agreement with the causes for

fatalities: suicide > ignorance > accident >. murder of which poisonings were mainly off duty (64 - 67).

Fatalities analysed by time of poisoning, again shows most fatalities to be due to poisoning during off duty:

	On duty %	Off duty %
	-----	-----
Total poisonings (34)	34	62
Total fatalities (227-228)	5	16

The relation between protection used and hospitalisation and fatalities is depicted in diagrams (231 - 232). No obvious relationship is cognisable between these variables.

The contribution to hospitalisation by the different application activities is very much in agreement with the general pattern by which these chemicals are applied:

	<u>Methods of chemical application</u>	
	General pattern % (141)	Hospitalisation % (233)
	-----	-----
Mechanical surface	27	27
Hand application	23	23
Aerial and mechanical surface	17	18
Mechanical surface and hand application	15	15
Aerial	4	5
Aerial and hand application	2	2

It is surprising that mechanical surface spraying, although being used only marginally more extensively, contributes more to poisoning than does hand application. Hospitalisation expressed as a percentage of the total poisonings due to a method of application, differs totally from the general pattern of use as well as the contribution to hospitalisation by the different methods:

90% and 89% of poisonings of the mechanical surface and hand application is hospitalised, therefore the relative high percentages not hospitalised.

Fatalities in relation to method of poison application, differ from the ratio hospitalised:

	Hospitalisation ratio of poisonings % (233)	Fatality ratio of poisonings % (240)	Fatalities by specific chemical method %	Non-fatality ratio per poison application % (246)
Mechanical surface	27	20	9 (242)	28
Hand application	23	22	12 (243)	24
Aerial and mech- anical surface	18	8	6 (244)	16
Mechanical surface and hand appl.	15	27	22 (245)	13
Aerial and hand application	2	2	-	1
Aerial	5	4	12 (241)	4

Although mechanical surface and hand application are the two main methods contributing to hospitalisation, the fatality ratio of poisonings as well as fatalities by specific chemical methods, indicates [mechanical surface and hand application] plus [hand application] to be mainly responsible for fatalities. Should it be noted that the general pattern (141) of the ratio of chemical application is virtually identical to the ratio of hospitalisation (233), then the contribution to fatalities by hand application associated methods is that much more important. Even more important is the fact that poisoning due to aerial spraying is much more severe than generally indicated; although it only contributes 4% (141) to total poisonings, it is responsible for 12% (241) of fatalities. The non-fatal poisoning cases (246) differ totally from the fatality pattern (240), but being non-fatalities the pattern agrees with those of (1) methods used (141) and (2) hospitalisation (233), as should be expected.

The relationship between hospitalisation, fatalities and non-fatal cases and the annual frequency of chemicals used is:

	<u>Annual frequency of poisons used</u>						
	>6 %	6 %	5 %	4 %	3 %	2 %	1 %
Hospitalisation (247)	33	1	1	18	6	12	13
Fatality ratio (248)	27	6	0	14	4	12	14
Non-fatality ratio (249)	35	1	1	18	6	11	13
Annual frequency of use (137)	34	1	1	18	6	11	13

Hospitalisation of poisonings cases and ratio of fatalities are of the same order and proportional to annual frequency of use, and therefore hospitalisation and fatalities are directly related to frequency of use.

Poisonings from the different locations where poisonings occurred, were hospitalised in the same ratio as location of poisonings:

	<u>Location of poisonings</u>				
	House/yard owner %	House/yard patient %	Cultivated land %	Orchard %	Elsewhere %
Total poisonings (31)	15	39	25	4	12
Hospitalisation (250)	15	40	25	4	11
Not hospitalised (255)	14	25	29	4	25

Thus, location of poisoning did not have any significant influence on hospitalisation. Poisonings from the different locations were hospitalised to a high degree:

Patient house/yard > owners house/yard = orchard > cultivated land
 95% > 93% = 93% > 92%
 (252) (251) (254) (253)

However, of the cases not hospitalised the main contribution came from cultivated land [29% (255)]. This figure is complemented by the actual poisonings from the locations not hospitalised:

cultivated land > owners house/yard = orchards > patients house/yard
 8% > 7% = 7% > 5%
 (253) (251) (254) (252)

These results are not surprising because all the poisonings occurring on cultivated land were due to ignorance and accidents (62), and most of the patients not hospitalised were poisonings due to ignorance and accidents (181). Therefore patients not hospitalised must be mainly from cultivated land.

Fatalities overwhelmingly occurred due to poisoning in the house/yard of the patient:

	Fatalities (256) %
Patient house/yard	57
Owner house/yard	20
Cultivated land	8
Elsewhere	8
Orchard	0

This is not surprising. Suicides were responsible [33% (186)] for most of the fatalities and 58% (56) of all suicides took place at the house/yard of the patient. Furthermore, ignorance [22% (186)] and accidents were the next most important causes responsible for fatalities, ignorance also occurring mainly at the patient's house/yard [36% (58)] and accidents contributing 27% (59) occurrence at patient's house/yard. Therefore most fatalities would occur at the house/yard of the patient.

Summary

- (1) First aid is virtually not applied, although with reference to fatalities first aid is an insignificant variable.
- (2) Intoxications are hospitalised and referred to a doctor to a very high degree; when not hospitalised or referred, the mortality rate significantly increased.
- (3) Reason for poisoning had no direct influence on hospitalisation. All attempted murder cases were hospitalised while of those intoxications not hospitalised, accidental poisoning was the main contributor - a serious matter being of occupational nature.

- (4) Attempted suicide poisoning was mainly responsible for fatalities, attempted murder poisoning being mostly unsuccessful.
- (5) Total poisoning, hospitalisation and fatalities were mainly due to organophosphates > carbamates > organochlorines, but for those cases not hospitalised the sequence changed to organochlorines > organophosphates > carbamates. A direct relation exists between failure to hospitalise and fatalities, and although organophosphates are the main contributors to total fatalities, the fatality rate was higher among organochlorine poisonings.
- (6) Total cases hospitalised were due to diluted liquid formulations, while total cases not hospitalised were due to poisoning by concentrated liquid formulations. Among specific formulations responsible for intoxication, solids (granules, etc.) have the highest rate of hospitalisation.
- (7) Concentrated liquid formulations were responsible for most fatalities.
- (8) Tendency not to hospitalise was highest among Whites, unlike total poisoning and total fatalities (being Black > Coloured > White), fatality rate was highest among the White population.
- (9) Total fatalities were highest between 1 - 10 years of age due to ignorance and accidental poisoning.
- (10) Total poisoning, hospitalisation and fatalities mainly occurred during non-working hours.
- (11) Mechanical surface application of chemicals recorded most intoxications, poisonings due to aerial spraying are hospitalised to highest degree (100%) and the application methods of hand application and hand application and mechanical surface combined, were responsible for most of the fatalities.
- (12) Hospitalisation and fatality rate are directly related to frequency of chemical usage.

- (13) Fatalities are overwhelming due to poisoning at the house of the patient, being of a non-occupational nature.

4.3.5 Socio-economic conditions

In this epidemiology survey, questions on socio-economic conditions were considered simply to allow the investigator to decide whether this aspect should be included in future studies of this nature. The few variables reported on are thus by no means adequate to evaluate the socio-economic status of those involved in poisoning by pesticides, nor was it the intention adequately to analyse possible relationships between socio-economic variables and intoxication. The results however do point to some conditions relevant to those involved in poisoning.

Families of the labourers with pesticide intoxications were mostly composed of husband, wife and children:

	<u>Composition of families</u>			
	Single %	Husband and wife %	Husband, wife and children %	Husband, wife, children and others %
Total families (262)	24	8	48	11
White (263)	21	15	58	4
Coloured (264)	23	9	55	12
Blacks (265)	25	6	44	12

The composition of families of all three race groups were predominantly similar, being husband, wife and children. This should be expected because poisoning occurred mainly between 1 - 20 years of age (96); 1 - 10yr = 23%, 11 - 20yr = 28%, while most fatalities [27% (220)] occurred under 10 years of age due to accidents and ignorance. Thus those families with children contributed most to poisoning and fatalities.

A distinct difference in accommodation between the race groups exists:

	<u>Housing</u>			
	Very favourable %	Favourable %	Unfavourable %	Very unfavourable %
All races (266)	13	68	12	3
Whites (267)	57	42	0	0
Coloureds (268)	9	73	16	2
Blacks (268)	5	71	14	4

Although the vast majority of all three race groups had at least favourable accommodation, a very high percentage of Whites 57% (267) lived under very favourable conditions with none being unfavourable or worse, while very few Coloureds and Blacks (268, 269) boasted the same luxury 9% (268) and 5% (269) respectively. Both Coloureds and Blacks had a moderate percentage of families living under unfavourable or worse conditions and this must be attributed to families of these races sharing accommodation with others. A direct relationship exists, between sharing accommodation by coloureds 12% (264) and Blacks 12% (265) and favourable plus very unfavourable conditions for Coloureds 18% (268) and Blacks 18% (269). A direct relationship being of the same order of magnitude, also exists between the normal composition of families (single & husband and wife & husband, wife and children) and very favourable plus favourable accommodation:

	<u>Race</u>		
	White %	Coloured %	Black %
Single, husband and wife, husband, wife and children	94	87	75
Very favourable and favourable housing	99	82	76

However, not only is there a relationship between family composition and accommodation, but both these variables are inversely proportional to total poisoning (29): Black > Coloured > White, thus an association between unfavourable accommodation and poisoning, and between composition of family and poisoning.

The validity of the assessment of accommodation is reflected in the

availability of toilets, as well as by analysing toilet availability against accommodation:

	Flush %	Prewit %	Toilet Bucket %	None %
All races (270)	23	49	4	20
Whites (271)	92	2	0	0
Coloureds (272)	13	61	8	17
Blacks (273)	12	54	3	26
<u>Accommodation</u>				
Very favourable (274)	69	21	2	2
Favourable (275)	18	62	5	13
Unfavourable (276)	2	27	2	69
Very unfavourable (277)	0	8	17	75

On average a very high percentage of labourers had no toilets in their accommodation. Almost all Whites 92% (271) had flush lavatories while all Whites had this necessity to their disposal. Most Coloureds [61% (272)] and Blacks [54% (273)] had prewit facilities available but all facilities without toilet accommodation existed in the Coloured [17% (272)] and Black [26% (273)] races. Very favourable accommodation had mainly flushing facilities [69% (274)], with only 2% (274) no facilities available, favourable had mainly prewit facilities [62% (275)] while 13% (275) had no facilities to their disposal. Unfavourable and worse accommodation ranged from as low as only 17% (277) bucket facilities to 75% (277) accommodation with no toilet facilities at all.

From the Census of Agricultural and Pastoral production (1980), it was noticeable that use is made of a substantial number of casual (migratory) employees in the farming community:

	<u>Employees</u>			
	<u>Regular</u>	<u>%</u>	<u>Casual</u>	<u>%</u>
Blacks	547 886	81,9	392 353	81,1
Coloureds	104 644	15,6	90 725	18,8
Whites	13 720	2,1	472	0,1
Asians	2 836	0,4	129	0,03
Total	669 086	100,0	483 679	100,00

The overwhelming contribution to migratory labour is by Blacks (81%) with a small contribution by Coloureds (18,8%). These statistics coincide with those of migratory labourers as assessed by this study (285):

Blacks > Coloureds > Whites		
72%	23%	5%

Employees, regular and migratory are also directly proportional to intoxications:

	Blacks > Coloureds > Whites		
	%	%	%
Regular employees	82	> 16	> 2
Migratory employees (285)	72	> 23	> 5
total poisonings (29)	61	> 25	> 13

The situation of Blacks being mainly responsible for migratory labour as well as for total poisonings, could very well be problematic in that the contribution to poisoning by migratory labourers is not known, but could possibly be of the same order as those by regular employees whilst going unnoticed and therefore not recorded. It is also possible that migratory labourers could be responsible for the relatively high percentage [12% (265)] sharing accommodation and living under unfavourable [18% (269)] conditions. These variables could also possibly facilitate poisoning at the house or yard of the patient and is it obvious that socio-economic conditions, with reference to intoxications, needs urgent attention.

In this epidemiology study the descriptive approach used is normally included amongst exploratory investigations. Such studies aim to seek

indications of the possible role played by environmental factors and not to assess relationships between exposure and effect in a quantitative statistical manner (WHO, 1983). Thus descriptive studies primarily describe the situation as it exists in the community without paying special attention to physiological functions (WHO, 1983) and are of an exploratory nature to possibly identify common factors - such as those achieved by the present study - to be followed up by further and additional epidemiological investigations if necessary. From a statistical point of view it is the relative frequencies of observations, rather than absolute numbers which assimilate a picture of distribution and is conventionally expressed in percentages. In some situations (WHO, 1983), such as the present one, the results expressed as the prevalence rate satisfies the research object, but in others much more sophisticated statistical analyses may be required. For the purpose of data description however, the essence of effective data presentation is to reveal the presence or absence of associations that are pertinent to the research questions (WHO, 1983).

A second cogent reason for not undertaking statistical analyses in the data presented is that such procedures might well be very misleading. This arises from the fact that each set of data is skewed to an unknown extent and almost certainly to a different extent in each set. The chief reason for this is that only the reported data can be assessed. It would appear likely that serious cases of intoxication are more likely to be reported than mild cases, while death is almost certain to be reported. There may also be differences in reporting according to race and other factors.

In conclusion it should be noted that only part of the data by this investigation are included in this presentation. Almost all data presented here are applicable to regional differences and therefore currently being analysed for the seven geographical different regions in South Africa (Fourie, in preparation) and will be disseminated to them for their perusal.

CONCLUSIONS

AND

RECOMMENDATIONS

The annual consumption of pesticides in the Republic of South Africa results in a dose of approximately 250 mg/m² and compares very favourably with consumption rates of developed countries which vary between 81 mg/m² (India) and 1 200 mg/m² (Japan). Chemicals in South Africa are used in agriculture and public health - as in developed countries - because no viable alternatives exist to provide for the production of sufficient food and the prevention of infectious diseases. No obvious differences exist between South Africa and the rest of the world regarding the use of any particular compound or generic group of chemicals, and it is concluded that the country applies a sound, firm and objective regulatory policy towards the use of pesticides.

Pesticides theoretically do not pose a serious waste disposal problem when used according to prescribed conditions. Many of the more persistent compounds have been phased out of agricultural applications, leaving chemicals to be used which degrade relatively easily under normal environmental conditions. However very little research of an ecotoxicological nature has been done in South Africa to support such a statement and some research of this nature should be considered.

It is believed that the former statement would not hold true for chemicals other than pesticides. If at least a 5 % growth rate in the South African economy is needed to attain prosperity for all its peoples, the chemical and chemical engineering industries will mainly have to supply the employment opportunities needed. Such developments will, however, generate considerable volumes of chemical wastes which will have to be dealt with in a responsible way. It is therefore recommended:

- (1) to be able to avoid the enormous waste and health problems developed countries have encountered (Chapter I), to formulate well in advance a firm national policy on waste disposal; and

- (2) as a matter of urgency to provide university trained toxicologists by the establishment of formal Chairs in toxicology at South African universities.

Unlike most other countries, poisoning by pesticides is a notifiable condition in South Africa. However, notification virtually does not exist. The average poisoning ratio for all poisonings in developed countries is about 276 cases per 100 000 population and for pesticides, 7,5 cases per 100 000 population. If these figures are applied to South Africa, they imply 69 000 total poisoning cases and 1 875 cases due to pesticide poisonings - in contrast with a mean of 113 cases reported annually between 1979 and 1982. It is concluded that the poisoning rate by pesticides, is appreciably higher than officially notified, and that the fatality rate could well be two orders of magnitude higher than developed countries. Acute intoxication by pesticides therefore does occur, and a compendium has been drafted for use by those concerned in the treatment of such cases. It is recommended that the Department of Health and Population Development take the necessary action to enforce the existing legislation in notification of pesticidal poisoning and to simultaneously initiate the keeping of reliable statistics on an annual basis of all poisonings that occur. It is not possible for the Department to adequately administer the Hazardous Substances Act when unfamiliar with the nature and extent of such problems associated with this Act.

Dietary intake of the white population in South Africa has been calculated from 24-hour dietary recall studies. The total average diet per individual amounted to 1 995 grams/day (excluding drinking water) and compares favourably with developed countries. Residues of only four compounds were found in 8 of the 11 food groups, at levels well below the acceptable daily intake standards, which indicates that the inhabitants of South Africa are not subjected to chronic exposure to contaminants introduced by the use of pesticides.

Existing surveillance data for infringement purposes are inadequate to estimate the daily intake of contaminants. It is recommended that a co-ordinated food safety programme, such as the total diet studies initiated in this project, be implemented as an ongoing programme. Because of the different ethnic communities in South Africa detailed food intake studies should be executed to be able to evaluate effectively

residue intake for all communities.

The many different variables and their contribution to acute poisoning has been summarised in Chapter IV. It is concluded that developing and Third World countries using agricultural chemicals, need a better understanding from First World countries trading in these products, in order to prevent accidents as well as the abuse of these chemicals for such purposes as attempted murder and suicides. It has been proved that in a Third World situation, an official regulatory mechanism similar to developed countries, is of the utmost importance to specifically control the commercial concerns of pesticides. Unlike developed countries, however, almost all possible occupational, environmental, cultural and sosio-economic variables affect the possibility of acute intoxication. It is important that the Department of Health should take cognisance of the impact on poisoning by these variables in its current and future population development programmes. With reference to pesticidal use in developing countries, three important matters arising from the study should be considered.

Firstly the World Health Organisation (WHO) should reconsider their unconditional recommendation to classify pesticides according to hazard. The scientific merits of such a classification are not questioned when applied by developed countries. However, the difference in the hazard of a product due to being a solid or liquid, or being either a concentrated or diluted formulation, can only be confusing to illiterate and semi-educated users. It is recommended that classification strictly according to toxicity of active ingredients be used by developing countries until the local regulatory authorities are convinced that changing the method of classification will not adversely affect intended users.

Secondly, a code of conduct with which all companies trading in pesticides must comply, should be formulated. Such a code is needed to safeguard developing countries against "fly by nights" and to aid regulatory authorities in the Third World, which lacks the necessary expertise to evaluate thoroughly complicated toxicity data.

Thirdly, the importance of education cannot be over accentuated. Education with regard to pesticides is not a matter which can be dealt

with by either local authorities or industry alone. It is a venture in which both parties have equal responsibility, neglect of which would be a disservice to the community. In South Africa the Agricultural and Veterinary Chemicals Association of South Africa (AVCA) represents the industry active in the pesticidal chemical field. It is recommended that the AVCA in collaboration with the Departments of Agriculture and Health considers membership to the AVCA to be compulsory in order to be able to register a product under Act 36 of 1947. A nominal fee should be paid annually to the AVCA by every firm for each product registered to enable this association to appoint staff with the fulltime reference to educate and advise users in the safe use of pesticidal chemicals.

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