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# Pesticides and toxic chemicals

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'Contamination' is a comparative term. In Britain at least, contaminants are trace substances; in the context of food they are distinguished from additives by whether or not there is an intention that the substances should be present when the food is consumed or prepared for consumption. Contaminants may be of natural or of technological origin: and technological contaminants may be direct or indirectly derived from additives. Contaminants occurring naturally in food may include alkaloids and cyanogenic glycosides: they may also arise from the natural action of micro-organisms as with certain fungal toxins or they may come about by direct environmental cross-contamination as with certain trace metals, allergens and polynuclear aromatic hydrocarbons. Technological contaminants can arise from deliberate treatment during the course of production as with agricultural or veterinary pesticides or other biocides. They may also arise from incidental treatment during processing or distribution, as residues from extraction solvent, trace metals from processing equipment, extractives or additives from plastics packaging materials, or residues from detergent, sterilants or disinfectants. Or they may arise from trace substances deliberately added during the course of the preparation and processing of food – food additives – residues of solvents used for the dispersal of colours and flavours, or nitrosamine compounds from nitrites for example.

What constitutes contamination is a matter of opinion—enlightened professional toxicological opinion for preference, although this may be crystallized in the law of the land to remove toxicological discretion and leave room only for legal opinion. Golberg (1971) has recently reviewed toxicological aspects of the potential harm of trace chemical contaminants in food; organochlorine pesticides and human health in particular have been considered by Deichmann & MacDonald (1971). Both the toxicological and the legal areas of opinion fall back on the analytical chemist. In considering trace contaminants in foods, I will indicate briefly the analytical principles concerned and then outline some of the particular areas of interest in this field. All trace analyses are characterized by sensitivity and specificity, both of which broadly follow the indications and requirements of the toxicologist. Looking first at the general principles of trace analysis, we can accept that the sensitivity of the analytical method used should match the requirements of the toxicological considerations. The general pattern in fact has been for the development of methods sensitive either to about 0·1 mg/kg (0·1 parts/$10^6$) or, in more recent years, and where the circumstance called for greater sensitivity, to about 0·1 parts/$10^9$. The basic operations, illustrated by pesticide residue analysis but common to virtually all methods of trace analysis, except that some elements of the sequence may be varied, are sampling, laboratory subsampling, extraction of the residue, clean-up of the extract from co-extracted interfering substances, detection, preliminary identification and estimation of the residue in the cleaned-up extract and, finally (although this may not be part of the same sequence of operations) where the identity of the residue is not known in advance of the analysis, confirmation of the preliminary identification using one or more independent methods of analysis. This last process is often a distinct operation and may be difficult for residues present in foods at levels of 1 part/$10^6$ and is exceedingly difficult at the level of 1 part/$10^6$. Apart from not always being easy, it is seldom cheap in terms of either manpower or equipment to obtain an unambiguous positive identification at a level of 1 part/$10^6$. The exact application of general principles of residue analysis will vary according to individual circumstances; on whether, for example, the analysis relates to a field-experiment research evaluation, to routine screening or regulatory screening purposes, or to a strict referee legal enforcement. Broadly speaking, the analyst knows in advance the identity of an additive but needs to involve special, and sometimes expensive, methods to establish the identity of contaminants.

## *Pesticide residues*

Pesticide residues in food are basically of technological origin, the pesticide chemicals in the first place having been deliberately used by the farmer. The situation is less clear insofar as some of the substances, such as lead or arsenic, can be of natural origin and it may be difficult or impossible (not to say unnecessary) to distinguish in the final product between the possible sources. Some of the purely synthetic organic pesticide compounds are characterized by a persistence to chemical and biological degradation; and, whereas their application to the original crop was entirely intentional, by virtue of this persistence their residue subsequently appear in other foods. This is of particular importance where there is a concentration of the residue in passing from one environment to another. Minute concentrations of persistent organochlorine compounds in the air and sea can pass, eventually, through plankton and other smaller marine organisms, to commercial fish, tending to be concentrated in the fatty tissues: average residues of DDT and its relatively stable metabolite DDE of the order of 0·5 mg/kg have been found in refined cod-liver oil by Ruzicka, Thomson & Tatton (1967).

This is not the occasion to review mammalian biotransformations illustrated by the conversion of DDT to DDE or of aldrin to dieldrin; this has in fact been done recently in the first of a new series of Specialist Periodical Reports prepared by Hathway (1970).

Data on residues of organochlorine pesticide residues in foods in Britain have been summarized by the Advisory Committee on Pesticides and Other Toxic Chemicals (1969*a*). Holmes, Simmons & Tatton (1969) examined the organochlorine insecticide residue contents of hens' eggs from battery, deep-litter and free-range systems of poultry husbandry, and from poultry houses containing insecticide thermal vaporizers. In general, they found the levels of all the residues to be low. DDT levels in free-range eggs were higher than in battery or deep-litter eggs in farms not using thermal vaporizers; γ-BHC residues were clearly greater where thermal vaporizers were used (Table 1). The pattern of pesticide residue levels in foods in Britain which has emerged over the years is largely reassuring, the mean dieldrin and total DDT levels in total diet now being approximately one-half (or less) of the values found 10 or 15 years ago (Egan, 1969). The levels of persistent residues found in milk and other dairy produce clearly indicate a tendency of progressive reduction of even the lowest levels (Egan, 1970). Mutton kidney-fat levels have been of special interest. The decline of dieldrin levels after the voluntary withdrawal by industry in 1966 of sheep dips containing dieldrin is shown in Table 2. The organophosphorus pesticide residues found by Abbott, Crisp, Tarrant & Tatton (1970) in total diet studies are summarized in Table 3. The number of positive findings shown must be related to sixty-six total diet samples taken over a period of 12 months, each consisting of the seven subsamples of cereals, meats, fats, fruits and preserves, root vegetables, green vegetables and milk. The residue most commonly found was malathion, being detected in twelve of the sixteen samples of the

Table 1. *Organochlorine pesticide residues (parts/*$10^6$*)* in hens' eggs from farms not using and those using thermal vaporizers*

| Mode of production | No. of samples | γ-BHC Range | γ-BHC Mean | *pp*′-DDE Range | *pp*′-DDE Mean | *pp*′-DDT Range | *pp*′-DDT Mean |
|---|---|---|---|---|---|---|---|
| Firms not using thermal vaporizers: | | | | | | | |
| Battery houses | 86 | 0–0·30 | 0·02 | 0–0·20 | 0·02 | 0–0·37 | 0·03 |
| Deep-litter houses | 54 | 0–0·33 | 0·04 | 0–0·13 | 0·02 | 0–0·31 | 0·04 |
| Free range | 33 | 0–0·40 | 0·04 | 0·01–2·8 | 0·36 | 0–3·8 | 0·54 |
| Firms using thermal vaporizers: | | | | | | | |
| Battery houses | 72 | 0–1·3 | 0·19 | 0·01–0·16 | 0·04 | 0·01–0·45 | 0·09 |
| Deep-litter houses | 75 | 0·03–2·1 | 0·70 | 0·02–0·50 | 0·13 | 0·03–0·75 | 0·21 |

*Equivalent to mg/kg.

Table 2. *Dieldrin content of kidney fats of home-killed sheep* (1964–70)

| Year | No. of samples | Dieldrin (HEOD) (parts/$10^6$)* Range | Dieldrin (HEOD) (parts/$10^6$)* Mean |
|---|---|---|---|
| 1964 | 128 | 0–12·4 | 0·84 |
| 1965 | 107 | 0– 8·2 | 1·1 |
| 1966 | 101 | 0– 5·3 | 0·44 |
| 1967 | 76 | 0– 8·0 | 0·24 |
| 1968 | 77 | 0–10·4 | 0·21 |
| 1969 | 53 | 0– 0·60 | 0·04 |
| 1970 | 35 | 0– 0·02 | 0·01 |

HEOD, active constituent of dieldrin. *Equivalent to mg/kg.

Table 3. *Organophosphorus pesticide residues detected in the total diet*

| Pesticide | Food group in which detected | No. of positive findings (66 samples of each group) | Amount found (parts/$10^6$)* |
|---|---|---|---|
| Demeton-S | Group 6–green vegetables | 1 | 0·13 |
| Disulfoton | Group 6–green vegetables | 1 | 0·02 |
| Fenchlorphos | Group 2–meats | 1 | 0·09 |
| Fenitrothion | Group 2–meats | 1 | 0·03 |
| Malathion | Group 1–cereals | 12 | 0·01 to 0·04<br>(mean 0·02) |
| | Group 4–fruits and preserves | 1 | 0·01 |
| | Group 6–green vegetables | 2 | 0·01 and 0·03 |
| Parathion | Group 3–fats | 1 | 0·01 |

*Equivalent to mg/kg.

cereals food group, with a mean value of 0·07 parts/$10^6$ eleven samples of apples showed a mean level of less than 0·01 parts/$10^6$ of organophosphorus compounds. For the most part the studies of residues in food in Britain by government departments has been confined to those foods which are at the greatest risk of exposure, coupled with an over-all 'total diet' study. To supplement this, local authorities throughout Britain have conducted a complementary study of all retail produce. In the first report the Association of Public Analysts (1968) found no evidence of any gross contaminations nor did the second report (Association of Public Analysts, 1971), which related to the period 1967–8, warrant any vigorous follow-up action. There was a small increase in the number of samples showing a positive response for organochlorine residues, but a true comparison is not possible because some different foods were involved.

All of these results are very similar to those obtained in similar studies in Canada, reported by Smith (1971), and in the USA (Corneliussen, 1969, 1970) where malathion has also been found to be the commonest pesticide residue and to occur mainly in the cereals section of the diet. Small amounts of other organophosphorus pesticides occurred, in a similar random fashion, in other food groups. It is also of interest to note that Durham, Armstrong & Quinby (1965) found no appreciable difference in the levels of residues in foods purchased at ordinary grocery stores and similar items purchased at a health food centre.

Residues of pesticides such as $\gamma$-BHC, DDT or dieldrin appear to be of no direct nutritional significance. A converse effect, that of dietary protein level on the toxicity of dieldrin to the rat, has however been described by Lee, Harris & Trowbridge (1964), who showed that the mortality when 150 parts/$10^6$ dieldrin were added to the diet was greater for low-(10%) than for high-(25%) protein diets. An interest has developed in recent years in polychlorbiphenyl compounds which in their response to routine analytical procedures behave similarly to persistent organochlorine pesticide compounds. These compounds are not pesticides but they have been widely used in industry, for example as transformer oils, and as plasticizers for paints, lacquers and resins. Since, analytically, they may behave similarly to organochlorine insecticide, they may present something of a special problem to the analyst. Traces can derive even from simple packaging materials such as cardboard, as found by Bailey, Bunyan & Fishwick (1970) who examined samples of ground cashew nuts, one of which appeared to contain about 10 parts $10/^6$ polychlorbiphenyl; the same sample on closer examination was found to be the only one packed in a lacquered cardboard box. Polychlorbiphenyl residues, where found, mainly occur in marine wildlife and do not feature largely in human dietary residues in Britain.

### *Residues from veterinary practice*

Antibiotic residues arising from the treatment of farm animals have been considered by Lucas (1972) at the present meeting. He has referred to the Swann Committee (Swann, 1969), which was of the opinion that any residues in food would present no danger where recommendations of dose and withdrawal time agreed by manufacturers under the Veterinary Products Safety Precautions Scheme were complied with. Where, occasionally, milk might be found to contain antibiotic residues, in most instances this was due to failure to observe the recommended withdrawal periods between treatment of the cow and resumption of marketing her milk. Concern has been expressed from time to time at the possibility that hormone implants used to facilitate poultry meat production could lead to undesirable residues in food. An analytical method for detecting small traces of hexoestrol was specially developed at the Laboratory of the Government Chemist by Cooper, de Faubert Maunder & McCutcheon (1967) to look into this problem. Meat from commercially caponized birds 12 weeks after implant was shown to contain less than 0·1 mg/kg of hexoestrol. In later experiments, birds were given double the commercial dose and killed at intervals of 1, 2 and 3 weeks after implantation; after 3 weeks there was less than 0·01 mg/kg of hexoestrol present in all the tissues examined.

### *Radioactive nuclides*

The need to say something about the contamination of food by radioactive substances arises mainly for the sake of presenting a complete picture. The surveillance of dietary contamination with fall-out in Britain from nuclear explosions is part of a national programme under the guidance of a joint committee of the Agricultural Research Council and the Medical Research Council. This committee has previously established that measurements of radioactivity in milk from throughout the United Kingdom provide a good guide to the contamination of the average diet with radioactivity deposited as fall-out from nuclear explosions and give sufficient information for assessing its medical significance. The ratio of strontium 90 to calcium in milk differs little from that in the mixed diet, and measurements in milk can also indicate the trends in contamination of the diet with caesium 137. Milk is also the appropriate food to analyse for the short-lived nuclide iodine 131 after nuclear explosions. The average levels of strontium 90 and caesium 137 found in milk in 1970 differed little from those found in 1969: 6·1 pCi of strontium 90/g of calcium and 17 pCi of caesium 137/l. These values are about one-quarter of those found in 1964 for strontium 90, the time of the peak levels following large-scale nuclear tests in 1961 and 1962. The reduction in caesium 137 during the same period was even greater. Iodine 131 levels remain below the limit of detection of about 15 pCi/l. Full details of these results are published in the annual report of the Agricultural Research Council's Letcombe Laboratory (Agricultural Research Council, 1971).

## *Trace metals*

Arsenic and lead have long been a subject of concern in relation to food, residues arising from both natural and other causes. Both have been used for crop protection for over 100 years and the need to limit trace levels in materials used in the food industry was recognized over 50 years ago. Lead is ubiquitous; traces can derive from cigarette smoke or from the atmosphere in general, as discussed by A. E. Martin (1971). The general position for both lead and arsenic has improved considerably in recent decades but a fuller understanding of the significence of the persistence of residue of some of the synthetic insecticides has stimulated a need to be aware of the possible build-up of inorganic residues where these materials are in regular use for pesticide, herbicide or defoliant purposes. The interest has extended to some other elements such as copper, cadmium and mercury; and the fact that certain of these now feature in organometallic combination has also meant that part of the interest may relate to the form in which the residue is present. The number of samples examined for arsenic, copper, mercury and lead by Public Analysts in Britain in 1961–6 was summarized by the Advisory Committee on Pesticide and Other Toxic Chemicals (1969*b*) and for later years by the Association of Public Analysts (1968, 1971). In 1967–8 none of the samples of bread, cheese, pork, lard, dripping, poultry, milk, eggs, butter, grapes, plums, sausage, canned meats, lettuce, potatoes, tomatoes or cucumbers contained more than the permitted levels of arsenic (1 mg/kg) or lead (2 mg/kg). Peden (1970) in Britain, in a direct survey of 120 pig and other livers, found less than 0·1 parts/$10^6$ arsenic in all of the lamb, ox and calf livers and in some 85% of the pig livers examined, with up to 1·0 parts/$10^6$ arsenic in about 10% and over 1·0 parts/$10^6$ in the remaining 5% of the pig livers. Some work has been done on chromatographic methods for separating organically-bound from inorganic arsenic, but such methods have not been widely employed. Unlike the position with mercury the general indication seems to be that organically bound arsenic is less toxic, at least to avian and mammalian species.

Trace mercury analysis has also long been a subject of interest in view of the toxic nature of this metal although, somewhat surprisingly, it has in former times featured in pharmacopoeia preparations. The interest in mercury has increased sharply in recent years, initially as a result of uses of organomercurial compounds as fungicides in agriculture and the timber industry; and more recently by the recognition of its long-established use in the plastics and chlor-alkali industries (Somers & Smith, 1971). Mercury residues have been studied in the total diet in Britain by Abbott & Tatton (1970), who showed the amounts to be generally below the level of analytical detection of 0·01 mg/kg; similar results were found in Canada by Smith (1971). The main interest is in aquatic organisms and arises from the circumstance that inorganic mercury residues can be biologically transformed by micro-organisms to much more toxic methylmercury compounds as shown by Wood, Kennedy & Rosen (1968). After reports from the USA in December 1970, several samples of canned tuna fish on the retail market in Britain were examined, both for total mercury content and for organically-bound mercury. The mercury levels found, calculated as Hg, ranged from 0·1 to 0·8 mg/kg, with a mean value of between 0·3 and 0·4 mg/kg, most of the mercury present being in the form of methylmercury compounds. These are similar to the values found in the USA, where the average consumption per head of tuna fish is some ten times the corresponding value in Britain. Since then many other foods have been examined for mercury content, and for other metals including cadmium and chromium. Other foods examined show much lower residues. Organomercury fungicides are used on rice as seed dressings and for the control of rice blast. Smart & Hill (1968) have reviewed levels found on rice in Japan and have examined samples of rice imported into the United Kingdom and have found that most do not contain significant traces of mercury. A few contained a detectable amount, up to 0·015 parts/$10^6$. Similar fungicides have also been used on seed potatoes: Lee & Roughan (1970) examined samples from eighty-seven commercial crops in England and found levels mainly in the range 0·01–0·04 mg/kg.

Pocklington & Tatton (1966) examined imported apples for traces of arsenic and lead, elements for which there are statutory limits in Britain of 1 and 3 mg/kg respectively. Few samples were found to exceed these limits, either for the whole fruit or for the peel and core, the mean levels being well within the limits. As indicated earlier, lead is ubiquitous. Jaworowski (1968) has shown that human bones in Poland contained as much or more lead in the eleventh to thirteenth centuries as today, although those from the third century (when the local populace probably had no contact with metallic lead) had much lower levels. One modern source of interest at the present time is that derived from leaded road fuel, petrol treated with lead tetra-ethyl as an anti-knock agent. Several workers have measured the lead content of roadside vegetation and shown this to be higher than crops or other vegetation growing at a distance of 50 m or more from the road. Bovay (1970) in Switzerland, for example, found up to 100 mg/kg or more of lead (calculated on a dry basis) in plants growing by the roadside: some 35–65% of this could be removed by simple washing, supporting the view that the contamination was of aerial origin. Such levels are some ten times greater than 'normal' lead levels. Table 4 gives values for lettuce and cabbage growing alongside the Great North Road in Britain. Cows fed with fodder contaminated in this way gave milk with four times the lead content of 'normal' milk.

Murphy & Rhea (1968) have reported levels of cadmium in milk of between 0·017 and 0·03 mg/l. Total diet studies in the USA suggest total levels of less than 0·02 mg/kg (Corneliussen, 1970), when analytical methods sensitive to 0·01 mg/kg were used (Table 5).

The use of triphenyltin fungicides in potatoes has increased in recent years. Thomas & Tann (1971) examined forty-four samples grown in Britain and found

Table 4. *Lead content (mg/kg of oven-dried material) of the inner and outer leaves of lettuce and cabbage (Agricultural Research Council,* 1967)

| Distance from road (m) | 10 | 15 | 20 | 50 | 150 |
|---|---|---|---|---|---|
| Lettuce: | | | | | |
| late August, | | | | | |
| inner | — | 3·1 | 2·8 | 1·5 | 0·5 |
| outer | — | 19·4 | 15·8 | 6·4 | 3·8 |
| early October, | | | | | |
| inner | — | 1·8 | 1·1 | 1·3 | 1·0 |
| outer | — | 19·8 | 26·6 | 13·9 | 11·2 |
| Cabbage: | | | | | |
| mid-July, | | | | | |
| inner | 1·0 | — | 0·4 | 0·5 | 0·4 |
| outer | 5·0 | — | 3·0 | 2·6 | 1·0 |

Table 5. *Summary of cadmium content of total diet samples in the USA (Corneliussen,* 1970)

| | No. of composite samples in which Cd detected (out of 30) | Maximum Cd level found (mg/kg) |
|---|---|---|
| Dairy products | 10 | 0·09 |
| Meat, fish, poultry | 21 | 0·06 |
| Grain and cereal products | 27 | 0·08 |
| Potatoes | 26 | 0·13 |
| Leafy vegetables | 27 | 0·23 |
| Legumes | 16 | 0·03 |
| Root vegetables | 24 | 0·08 |
| Fruits | 15 | 0·38 |
| Garden fruits | 25 | 0·07 |
| Oils, fats | 27 | 0·13 |
| Sugar | 18 | 0·07 |
| Beverages | 8 | 0·04 |

residues of 0·001 parts/$10^6$ or less in thirty-five of them: residues in six other samples were in the range 0·002–0·005 parts/$10^6$ and in three samples 0·006–0·008 parts/$10^6$.

### *Nitrosamines*

An interest in nitrosamines arises from their powerful carcinogenic character and the possibility that traces can occur in foods treated with nitrites or nitrates. The conditions necessary for the formation of nitrosamines from traces of nitrite and secondary amine have been discussed by Foreman (1971). Levels of interest are substantially below 1 mg/kg, ranging down to 0·01 mg/kg or less. The analytical approach, which calls for advanced instrumentation and substantial expertise, is basically classical and starts with extraction, clean-up of the extract by steam-distillation, ion-exchange chromatography and solvent partition followed by separation, detection, estimation and provisional identification by gas–liquid chromatography or polarography. This is a difficult area of trace analysis in which from 1 to 10 parts/$10^9$ of specific but not easily identifiable substances are of interest when present in a very large excess of complex organic substrate which itself may include very many other largely unrelated trace as well as principal constituents. Gas–liquid chromatography is in general more specific than polarography: the method of Sen (1970) in which advantage is taken of the great sensitivity to the electron capture detector of dimethylnitramine, the oxidation product of dimethylnitrosamine, is a typical example. Results to date, obtained by using an analytical method sensitive to 0·005 mg/kg, show that processed foods and, in particular, meats cured with nitrates or nitrites do not contain traces of volatile aromatic nitrosamines.

### *Polynuclear aromatic hydrocarbons*

Howard & Fazio (1969) have reviewed the occurrence of polynuclear aromatic hydrocarbons in foods, the results indicating that various smoked products, edible vegetable oils, and total diet samples contained trace amount of benzo(a)pyrene and other similar compounds. Levels in thirty-two products ranged up to 7 $\mu$g/kg. Cahnmann & Kuratsune (1957) studied the uptake from polluted surroundings by barnacles and oysters of polynuclear aromatic hydrocarbons, levels of up to 1 mg/kg being found to occur in these circumstances. Fisher, Cooper & Bell (1971) have discussed the possible contamination of wheat and baked products with benzo(a)-pyrene and found no justification in singling out any one type of oven as being particularly likely to lead to this. Levels of the order of 3 $\mu$g/kg in the crumb and 6 $\mu$g/kg in the crust were observed.

### *Other contaminants*

Other toxic chemicals of interest in relation to their trace occurrence in food include fluorides and bacterial toxins. The important microbiological organisms which cause food poisoning by the toxins they produce are beyond the scope of the present discussion but have been recently reviewed by C. H. A. Martin (1971).

### *Conclusion*

By way of conclusion it can be said that a number of contaminant possibilities exist for food, many but not all of them being technological in character. Methods for measuring all of these are available and have been used to show that the levels of contamination are normally very low—indeed, 'contamination' may not be the correct word. There is very little if any evidence that, except (for example antibiotics) where this was the original intention, any of the substances are of direct nutritional significance.

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