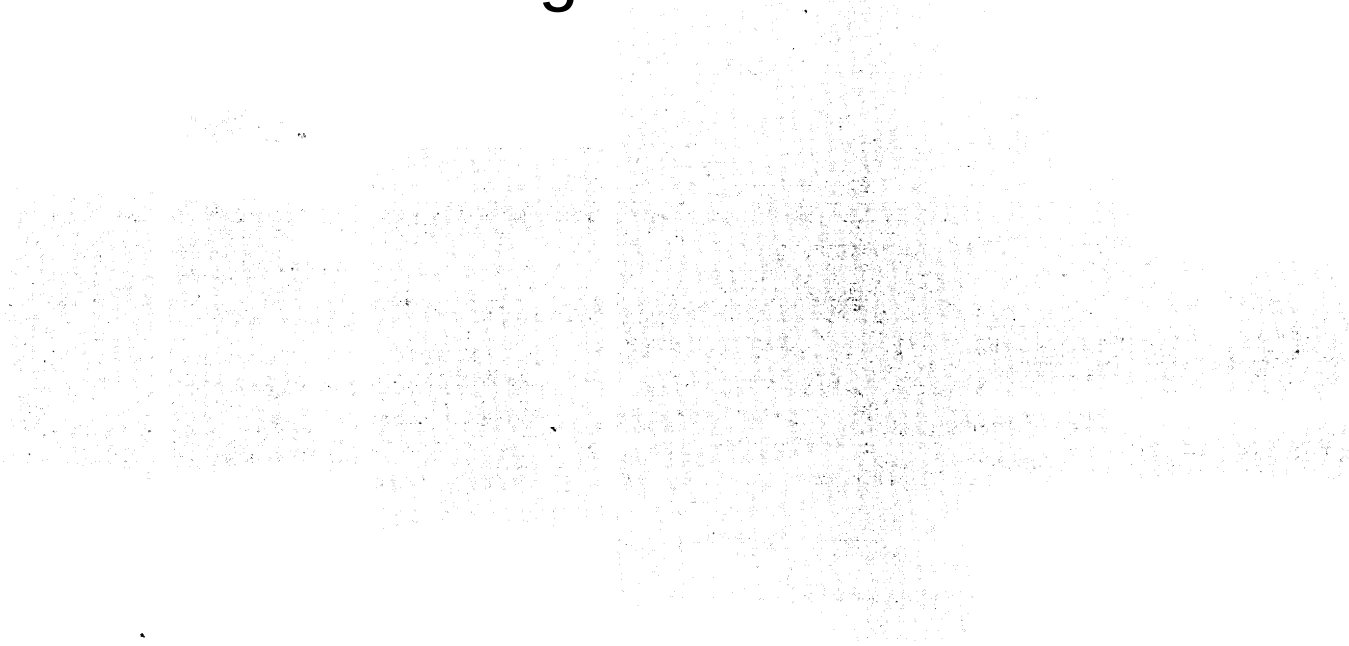
Chapter VIII

Monitoring Instrumentation



Chapter VIII

Monitoring Instrumentation

Various instruments have been designed to detect and quantify organic chemicals, trace metals, and radioactivity in foods. This chapter focuses on not only the technological state of this analytical art but also how such instrumentation could be applied in an investigatory monitoring program.

ORGANIC ENVIRONMENTAL CONTAMINANTS

Analysis

The vast number and wide diversity of natural and synthetic organic chemicals pose difficult analytical problems. Many methods and instruments have been developed to detect and quantify specific environmental contaminants in foods. There are generally three steps required for each type of analysis: extraction, cleanup, and detection and quantification. Figure 6 is a flow chart depicting how these steps would be applied to the analysis of the Environmental Protection Agency priority pollutants in food.

Extraction usually involves mixing the food sample with a selected solvent. In this step, the chemical is removed from the food and dissolved in the solvent. The time required for this step depends on the physical and chemical characteristics of the food sample and the substances. In some cases, the process may take 24 hours or more. The initial extract contains not only the substance of interest but possibly other organic compounds of similar volubility that must be removed before analysis.

The second step is known as the cleanup or isolation stage. The complexity and time required for this procedure depends on the food sample and the number of substances to be removed. In many cases multiple cleanup steps are necessary. The end products of cleanup procedures are fractions containing different classes of organic compounds.

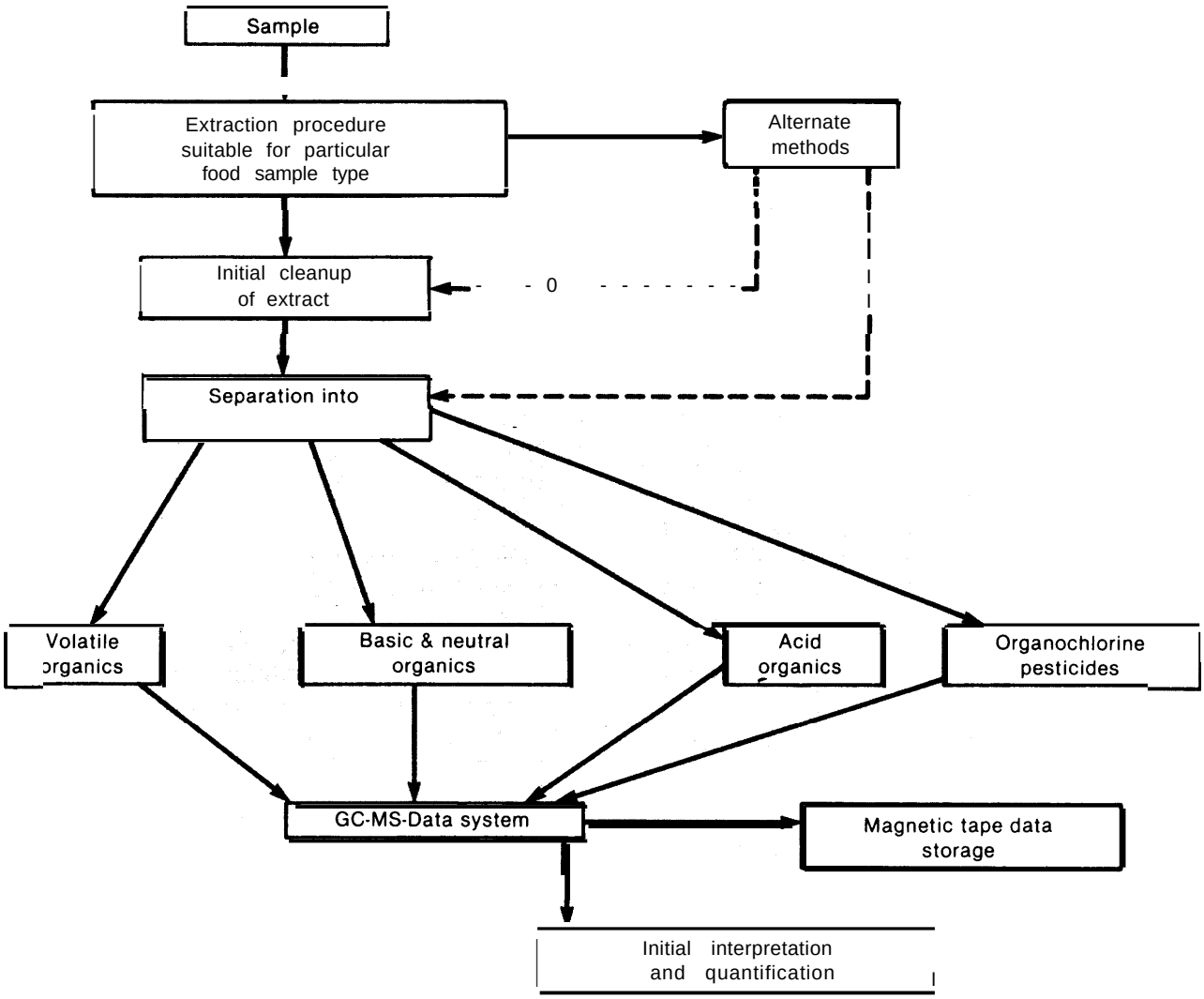
The final step, detection and quantification, requires the use of highly sophisticated instruments and techniques. Among the most frequently used methods are mass spectrometry, gas chromatography, and liquid chromatography. Table 18 summarizes the techniques available for qualitative and quantitative organic analysis. More information can be found in appendix G.

The gas chromatography is an instrument designed to separate, identify, and quantify organic compounds. In simplified terms it consists of four components: an injection port, a column, a detector, and a recorder. There are many types of injection chambers, columns, and detectors, but the principles of operation are similar.

Gas chromatography involves vaporization of the sample to be analyzed. The gaseous sample then passes through a long tube or column packed with a solid matrix which is coated with an organic compound. This is called the “liquid phase. ” The rate at which various organic compounds in the sample pass through this column is a function of various chemical and physical properties, notably molecular weight. polarity, and geometric structure. The time of passage through the column is called the “retention time. ” Each compound has a characteristic retention time in the column.

To determine when and how much of each substance leaves the column, a detector is placed at the end of the column. The retention time can be used to identify each compound, while the strength of the electrical signal from the detector indicates the quantity. The

Figure 6.— A General Scheme for the Qualitative and Quantitative Analysis of the Organic EPA Priority Pollutants in Semisolid Foods



[a] Identification is based on the presence of characteristic ion fragments and associated chromatographic retention time data. Absolute identification would require a detailed interpretation of the complete mass spectrum of the organic compound of interest.

SOURCE John L Laseter Approaches to Monitoring Environmental Contaminants in Food OTA Working Paper 1978

identity of the compound is confirmed by comparing its retention time to that of a series of standard solutions (of known composition) injected into the gas chromatography under the same conditions. The areas under the graphed peaks of a sample readout or "fingerprint" are compared to a standard "fingerprint" to determine how much of each substance is present in the sample, If a peak in the sample fingerprint, for example, has the same retention time but twice the area as one in the standard fingerprint, it is assumed

Table 18.—Techniques Available for Qualitative and Quantitative Organic Analysis

Method	Approximate detection limit, gm	Specificity or common uses
Gas chromatography		
Retention Indices. .,	10^{-10} (H_2 flame)	Detects most compounds
Electron capture	10^{-12}	Halides, conjugated carbonyls, nit riles, di- and trisulfides
Flame photometer.	10^{-9} (S), 10^{-11} (P)	Phosphorus, sulfur
Nitrogen/phosphorus	10^{-12}	Nitrogen, phosphorus
Chemical methods		
Pyrolysis	10^{-9}	Compound-type determinant ion
Chemical reagents. .,	10^{-6}	Classical-functionality determination
Electrolytic systems .	10^{-8}	Sulfur, nitrogen, halogens
Instrumentation		
infrared-grating	10^{-6}	Compound-category-type identification
Infrared-interferometer	10^{-7}	Compound-category-type identification
Ultraviolet	Variable to 10^{-10}	Aromatics conjugated carbonyls
Proton magnetic resonance	10^{-5}	Excellent for function, some molecular weight data.
Mass spectrometer		
Batch inlet .	10^{-7}	Best for complete identification,
GC-MS mode	10^{-11}	molecular weight structure, and
Multiple-ion detection	10^{-12}	function. Confirm any compound.

SOURCES Adapted from W McFadden *Techniques of Combined* Gas *Chromatography/Mass Spectrometry* Wiley-Interscience New York N Y 1973, p 4, and "Trace Organic Analysis ' *Environmental Science and Technology 12757* (1978)

that the identity of the sample peak is the same as that of the known standard but that twice as much is present.

Recent developments in analytical organic chemistry promise new, more sensitive techniques for monitoring of synthetic organic chemicals in foods. These developments include high-resolution glass capillary columns for gas chromatography, and the linking of gas chromatography to mass spectrometers.

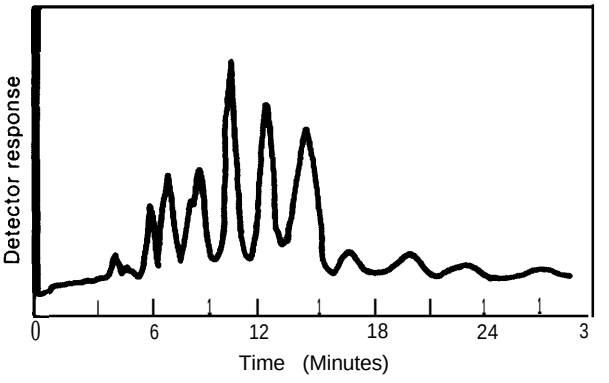
The glass capillary column is much more efficient in separating compounds than the older "packed" columns (figure 7). The gas chromatograph's packed column separates the individual components so that they exit the column and enter the detector one at a time. Some of the early data on the pesticide family DDT-DDE-DDD were incorrect because polychlorinated biphenyls (PCBs) had similar retention times in packed columns. As a result, reported concentrations of DDT, DDE, and DDD were often too high because the peak areas were really reflecting a combination of pesticides plus PCBs (l). Because of their superior resolution power, glass capillary columns avoid some of these problems. Also because less cleanup is required, their use reduces the possibility that an important environmental contaminant may be removed in the process of preparing a sample for analysis.

Although the capillary column offers a number of advantages, it is more expensive and difficult to use than the standard packed column. More highly trained personnel are required to operate capillary columns and interpret results. However, many chemists feel that the advantages far outweigh any difficulties. Glass capillary columns are not now widely used for monitoring synthetic organics in foods. Packed columns continue to play an important role in the organic chemistry monitoring laboratory, but their future use may be restricted to more specific analyses.

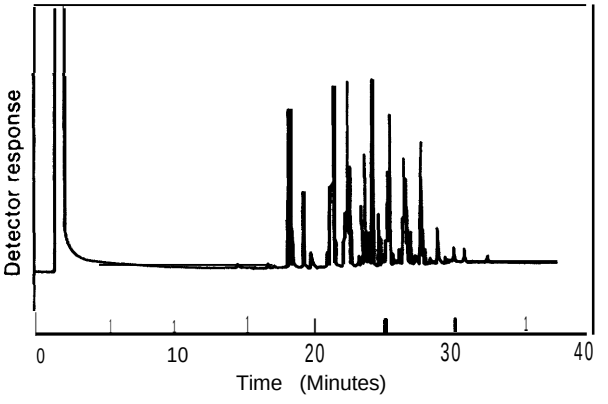
Gas chromatography are currently the primary means by which laboratories monitor for organic chemicals. Some chemists, though, prefer mass spectrometers because of their high sensitivity and flexibility (z). The coupling of a gas chromatography to a mass spectrometer introduces a new dimension that allows a chemist to identify compounds

Figure 7. —Comparison of the Gas Chromatographic Analysis of a Standard Mixture of Polychlorinated Biphenyls (Aroclor 1254) on Two Types of Gas Chromatographic Columns

A: **Analysis** Using a Conventional Packed Column



B: Analysis Using a High-Resolution Glass Capillary Column



SOURCE John L Laseter II Approaches to Monitoring Environmental Contaminants in Food OTA Working Paper 1978

classed as uncharacterized (3). Moreover, results from a mass spectrometer can confirm the identity of known chemicals whose presence (as indicated by gas chromatography alone) is in doubt because of sample contamination or other factors. Mass spectrometers are expensive and in addition require computerized data management systems.

Because of their physical and chemical characteristics. many organic compounds cannot be analyzed by gas chromatography. Therefore, instruments such as infrared spectrophotometers and high-pressure liquid chromatography are necessary. These instruments add many thousands of dollars to the costs of setting up and equipping an up-to-date organic chemical-monitoring laboratory.

Application to Investigatory Monitoring

Although the instrumentation described above has been available for several years, it has only recently been utilized for investigatory monitoring. Experimental projects incorporating computer analyses are now under study in at least three research facilities: the Bodega Marine Laboratory, the University of New Orleans, and the Virginia Institute of Marine Science, These projects employ high-resolution glass capillary gas chromatographs coupled to mass spectrometers and sophisticated computer analyses, The resulting "fingerprints" or readouts from a sample extract are highly complex and show the presence of not only known or suspected environmental contaminants but also many organic compounds that must be classified as uncharacterized.

The three research groups are now testing an approach to determine which compounds deserve further testing. The gas chromatographic fingerprints are computerized so that information on retention times and peak intensities are stored. Subsequent samples are collected and analyzed and the data are computerized in the same manner. By comparing results from the same location over time (or with samples taken from other locations), one can determine whether peaks are increasing or decreasing, whether new peaks have appeared or old ones have disappeared, or whether some peaks occur only in some locations.

With appropriate computer programs or "soft ware, " the data bank could be asked if there is a peak that occurs in samples from only one area or location. If so, the investigator can assume that the compound is anthropogenic, or man-induced, The compound could then be identified and its source con-

trolled before the concentration increased to the point that a major contamination episode occurred. This type of monitoring could have detected kepone in the James River, Va., long before thousands of pounds of the pesticide entered the river.

Another question which could he asked of the data bank is whether there is a peak that is increasing with time. In other words, does sampling over time indicate that a compound is becoming more concentrated? Such a finding would flag the compound as one which merits attention, Had this type of monitoring program been in effect and this question been asked earlier, widespread pollutants such as PCBs could have been detected long before they were,

Other information from the chemical labora tory car-r draw attention to an uncharacterized substance deserving attention. For example, gas chromatographic detectors exist that respond mainly to organic compounds containing halogens such as chlorine or bromine. Because naturally occurring halogen-containing organic chemicals are rare and are far outnumbered by manmade ones, an uncharacterized peak from a halogen-specific detector may represent a manmade compound, Historically, halogen-containing organics such as DDT, PCBs, polybrominated biphenyls (PBBs), and kepone have caused major pollution crises. Therefore, such information may be sufficient to focus attention on a given peak from a halogen-specific detector.

Uncharacterized substances may or may not be dangerous to human health if consumed. But no assessment of toxicity can be made until the compounds are identified. To perform the chemical and physical tests necessary to identify even one uncharacterized peak may cost from $10,000 to $100,000, and in some cases even more.

DETECTING AND QUANTIFYING TRACE METAL CONTAMINANTS

Trace metals pose many of the same problems that plague the analyst monitoring for organic chemicals. However, the number of trace metals is much smaller. If only the total concentration of a metal is sought, more rigorous extraction procedures can be employed. But some metals, such as mercury, form organic complexes--for instance, methylmercury--which give rise to a subset called metallo-organics. These metallo-organics are not stable under harsh conditions and are often changed during rigorous extraction procedures.

Analysis

Analysis for trace metals usually requires extraction and cleanup before the quantitative analysis can be performed. Extraction often involves destruction of the sample's organic structure to release the metals from the solid or liquid food. There are a few analytical instruments such as X-ray emission spectrographs that can accept solid or liquid samples, thus eliminating the extraction step (4). But these instruments cannot detect all metals at environmental concentrations.

Depending on what instrumentation is used in the final analysis, some cleanup of the extract may be required. The cleanup step is not nearly as frequent with trace metals, however, as with organic chemicals except if a metal lo-organic complex is sought. For metallo-organic compounds cleanup and separation procedures may be similar to those for organic compounds. After extraction and possibly cleanup, the sample is ready to be analyzed by an instrument to determine which metals, and how much, are present. There are a variety of instruments available for the determinations.

Probably the most commonly used instrument is the atomic absorption spectrophotometer (AA). The cost of this instrument is nominal ($ 15,000 to $25,000), and i t can be operated by a well-trained, motivated technician

with a high school chemistry and physics background working under the supervision of a chemist. One drawback of this instrument is that only one metal can be analyzed at a time.

In contrast, more sophisticated instrumentation such as X-ray emission, proton-induced X-ray emission, or plasma emission spectrometers can cost in excess of $100,000. With these instruments, 20 to 60 elements can be determined simultaneously. These more sophisticated instruments require more highly trained personnel to operate and maintain. Table 19 summarizes the techniques available for qualitative and quantitative analysis of trace metals. More information can be found in appendix H.

Application to Investigatory Monitoring

It is important to note that most AA units can detect only the specific element (metal) that they are set up to analyze. By contrast, the gas chromatography may sometimes detect the presence of organics other than those being sought. As a result, metals are more likely than synthetic organics to escape detection simply because they are not programed for analysis.

With the rapid development of lower cost techniques for detecting more than one element at a time, it would be possible to obtain data on trace metals in foods that were previously not sought and therefore not obtained. This is analogous to uncharacterized organic monitoring where many unsought compounds can be found in the analysis of a food extract. Given the proper data systems, these "other" metals can be tracked, and perhaps pollution crises can be averted by detecting anomalous concentrations early enough.

Speciation of Trace Metals

Often the active or functioning forms of elements must be identified and measured. The need for the development of analytical methodology to identify and quantify the chemical form of metals found in the environment—i.e., chemical speciation—is pointed up by the following examples.

- Although arsenic is toxic, the plus three oxidation state, As (III), is more toxic than the plus five state, As (V). The compound arsine, AsH_3, is perhaps the most toxic chemical form of arsenic.
- Alkyl (organic) mercury compounds pose greater propensities for bioaccumulation and the associated health effects than do the more common inorganic forms of mercury (but these also can vary greatly in toxicity).

Chemical forms or states are an important determinant of a trace metal's toxicity in biological systems. The selection of elemental analysis techniques capable of specifically measuring those chemical forms most important from a biological-effects viewpoint

Table 19.—Techniques Available for Qualitative and Quantitative Trace Metal Analysis

Technique	Approximate detection limit	Specificity or common uses
Atomic absorption		
Flame	0.005 μg/ml	Single element analysis, but multielement
Furnace	0.00002 μg/ml	prototypes are under development
Atomic emission	0.02 μg/ml	Single element capabilities
Neutron activation analysis	0.03×10^{-9} g	Multielement capabilities
Plasma emission		
Inductively coupled plasma	0.002 μg/ml	Multielement capabilities
Direct current plasma	0.01 μg/ml	Multielement capabilities
Proton-induced X-ray emission	0.02 μg/gm	Multielement capabilities

SOURCE: Adapted from R. K. Skogerboe, Analytical Systems for the Determination of Metals in Food and Water Supplies, OTA Working Paper, 1978.

should be a primary objective of any environmental monitoring program.

The status of the present analytical technology is inadequate for this purpose in most routine monitoring programs. As a result, the functioning forms of most elements cannot be adequately studied. Thus the determination of the important (threshold) concentration levels for various elements typically has been rather crude. The most important current research need related to trace metal monitoring is the development of methods to measure the species rather than the total amount of trace metals.

ANALYSIS OF FOODS FOR RADIOACTIVITY

Analysis

Measuring radioactivity in foods is a physical process. It is most efficient when the radioactivity from a relatively large sample can be placed close to a detector. This means that direct measurements of radioactivity in bulk samples are only useful when levels of contamination are relatively high. Most measurements are preceded by preparation and possibly chemical separation to reduce the bulk of the material and to improve the efficiency of the measurement.

Foods generally have a high water content. The primary method of reducing bulk is freeze-drying or drying at room or at elevated temperatures. Most of the radionuclides of interest are not volatile under these conditions. Only elements such as tritium or iodine may experience losses. The dried materials can be reduced further by ashing at elevated temperatures, by cold-ashing with oxygen, or by wet-ashing with oxidizing acids. Dry-ashing is the simplest process, but it is most likely to lead to loss of volatile elements. With care even cesium, polonium, or lead can be retained. The other processes should not result in losses of elements of interest, except for iodine, tritium, and carbon.

Another way to reduce bulk is to treat either the original sample or the dried or ashed material with acids or other solvents and thus remove the desired elements from the bulk of the sample. This requires considerable testing beforehand to be certain that the process operates in the desired manner. The radionuclides of interest in ashed foods should be soluble in strong acids if ashing temperatures have not been excessive. If there is concern that insoluble particulate may be present, it is necessary to use more drastic methods such as fusion to bring the entire sample into solution.

In addition to bulk reduction, radiochemical separations are required to isolate the desired radionuclide both from the remaining bulk constituents and from other radionuclides that would interfere in the measurement. It is also necessary to convert the final product to a form suitable for presentation to the counter. This may involve electrodeposition, precipitation, or other processes.

The actual mass of radionuclide that is measured is almost always extremely small. As a result, many of the normal chemical reactions used in analytical chemistry to isolate an element are not appropriate. For instance, precipitates may not form. Therefore, it is common to add a few milligrams of a carrier material, preferably the inert form of the same element. When such an inert form does not exist, it is frequently possible to use similar elements as a carrier (for example, substituting barium for radium). The inert form then follows normal chemistry, carrying the radionuclide with it. It is also worth noting that even when the separation technique does not depend on the mass of element present, a carrier may still be useful in preventing unwanted coprecipitation or absorption on glassware.

In the chemical separations there is considerable use of classical analytical chemistry based on precipitation. In most cases, precipitation will be the final collection step in

preparing the desired radionuclide for counting. In other cases the techniques of ion exchange, liquid extraction, distillation, and electrolysis may be required to prepare the sample for counting.

In certain cases, the total amount of a sample may be limited, and analysis for several radionuclides may be required. Procedures should be available for the sequential analysis of single samples, even though separate samples are used for routine work.

The measurement method used depends on the type of radiation, the form of the sample, and (to some extent) the amount of radioactivity. The selected analytical procedure should be designed so that the sample is brought to a suitable form for the equipment and conditions that exist.

The major emitted radiations are generally grouped as alpha, beta, and gamma. Alpha radiation is characteristic of the natural and artificial radionuclides of high atomic weight and consists of energetic particles with very low penetrating power. Its hazard is significant only within the body, where alpha-emitting nuclides can irradiate specific sensitive tissues. Beta radiation appears in both natural and manmade radionuclides, and consists of electrons possessing kinetic energy and modest penetrating power. Gamma radiation is pure electromagnetic radiation and is extremely penetrating. Thus, it is hazardous externally as well as when it is present in the body. Gamma radiation can be directly measured in foodstuffs, while alpha and beta emitters generally must be separated from the bulk constituents of the sample before they can be measured.

It is possible to measure the total gamma, total beta, or even the total alpha activity in a sample of food. Unfortunately, such data are valueless in estimating human exposure. The accuracy of such estimates is very poor because natural potassium usually interferes, and the chemical and radiation characteristics needed to evaluate possible hazards are not known.

It is possible, however, to set a particular total activity level as a screening level for a specific food, If the measured value is below the screening level, no analyses for individual radionuclides are performed. In such a case, the measurements should be considered internal data and the numerical results should not be published, Any report should merely list the samples as having activities below the stated screening level. Table 20 summarizes the typical limits of detection for radionuclide measurement.

Alpha Emitters.—The measurement of alpha activity is best carried out on a very thin sample to avoid self-absorption of the alpha particles. Most metals are electro-deposited onto small smooth discs of stainless steel, nickel, or platinum. Evaporation of pure solutions is used in some cases. The measurement of the total alpha activity can be conducted either in thin-window counters or by scintillation counting with zinc sulfide phosphor. Both techniques are highly efficient, but the scintillation method can give a considerably lower background with a consequently lower limit of detection.

A somewhat less-sensitive technique is the liquid scintillation spectrometer described in the next section.

Alpha spectroscopy provides two other alternatives: the Frisch grid ionization chamber or the silicon diode solid-state detector. The Frisch grid unit can handle large area samples but is slightly poorer in resolving closely separated energies. On the other hand, the silicon diodes available are all quite small and can only count samples of about 1-cm diameter with high efficiency.

Beta Emitters.—Beta counting is a little more flexible in the mass of material that can be present at the time of counting. This is true for higher energy beta emitters but carbon-14 and tritium present a problem. Since each individual beta emitter gives off particles with a range of energies from zero to a characteristic maximum, beta spectrometry is not possible for food samples.

Table 20.—Typical Limits of Detection for Radionuclide Measurement

Nuclide	Counter efficiency %	Counter background cpm	Chemical yield %	LLD (dpm) per sample for various counting times: 10 min	40 min	400 min	1,000 min	
Amerlclum.241	25	0.001	60	03	015	0.05	003	Chemistry, α spectrometry
Ceslum-144	22	04	75	6	3	09	06	Chemistry, β counting
Cesium-137	30	04	75	4	2	06	04	Chemistry, β counting
	2	006	75	30	14	45	3	Chemistry, γ Spectrometry (Ge)
Cobalt-60, other activated products	1	005	—	100	50	15	10	γ Spectrometry (Ge)
Tritium	30	5	75	15	6	2	1.5	β Scintillation, can be enriched electrolytically by 10-25 times
Iodine- 131	25	0.4	80	5	2	0.7	0.5	Chemistry, β counting
	4	03	80	25	13	4	25	Chemistry, γ spectrometry(NaI)
Phosphorus-32	45	03	60	3	1.5	0.5	0.3	Chemistry, β counting
Plutonium-239. -240	25	0005	85	06	0.3	0.09	0.06	Chemistry, α spectrometry
Radium-226	56	02	90	1	0.6	0.2	0.1	Chemistry, emanation, ^{222}Rn counting
	40	0.001	85	1	0.5	0.15	0.1	Chemistry, α counting
Strontium-90	45	0.3	80	2	1	0,4	0.2	Chemistry, β counting
Thor! urn-230, -232	25	0001	70	0.3	0.1	0.04	0.03	Chemistry, α spectrometry
U-Isotopic	25	0.005	75	0.7	0.3	0.1	0.07	Chemistry, α spectrometry

SOURCE N H Harley Analysts of Foods for Radioactivity OTA Work ing Paper 1979

The available counting equipment for quantitative measurement includes geiger counters, proportional counters, and scintillation counters. The geiger counter is relatively inexpensive and requires only simple electronics but is not popular and is generally not available as a counting system. The thin-window proportional counter is used widely and has both reasonably high efficiency and low background. For low-level samples the background can be further reduced by anti-coincidence techniques. These add to the complexity and cost of the system but are sometimes necessary.

Scintillation counting can be performed in two ways. Solid scintillators can be used for counting chemical precipitates collected on filter papers, and liquid scintillators can be used whenever the sample can be made miscible with the scintillating solution itself. This can even be done with solids by suspending them in a scintillating gel. The advantage of liquid scintillators is their high efficiency, even for the low-energy emitters carbon-14 and tritium. Scintillation systems for counting precipitates are not commercially available at present. There are, however, many liquid scintillation systems on the market, most of them with automatic sample changers. These use high levels of activity and short counting times. The better systems also have a provision for rather crude spectrometry. They can distinguish qualitatively and quantitatively among carbon-14, tritium, alpha emitters, and higher energy beta emitters.

Gamma Emitters.—Gamma rays are so penetrating that the detector must have a

considerable mass to absorb enough energy to produce a response. Since energy absorption is required for spectrometry, solid detectors are most useful, Sodium iodide is a popular detector because crystals can be fabricated in large sizes and are transparent to the scintillations produced by radiation. Sodium iodide has high efficiency but poor energy resolution and is now applied to samples where some separation has taken place. The advantages are that samples of food can often be counted directly without chemical preparation. Milk is a good natural example, as the metabolism of the cow removes most gamma emitters other than isotopes of cesium, iodine, and naturally radioactive potassium.

More complex spectra can be resolved with the solid-state germanium diode detector. Interferences from radionuclide impurities are greatly reduced compared to spectra from sodium iodide detectors. The efficiency of the diode is low and, for many analyses, a spectrometer can only be used for one measurement a day, Another disadvantage is that the detector must be kept at liquid nitrogen temperature to maintain its detection capability.

Diode spectrometers may also be used to measure the low-energy gamma-rays that accompany alpha emission. This allows direct measurement in some environmental samples, but the levels in foods have not been high enough for this technique.

General Requirements.—The choice of a counting procedure depends on the precision required. The relative precision of a quantitative counting measurement, in turn, is inversely proportional to the square root of the number of counts obtained. Thus any improvement in precision must be obtained by increasing the number of counts. This can be done by using larger samples, by counting for longer times, or by using counters with higher efficiency, A secondary improvement is possible for low-activity samples by decreasing the background, Each of these improvements has some drawback, and selection of the optimum balance requires a weighing of cost, manpower, and quality.

Applications to Investigatory Monitoring

The monitoring of foods for radioactivity should not be considered a primary defense against human exposure. The first indication of hazards should always come from information on releases or from measurements of radioactivity in air or water. Once the existence of contamination has been established, foods can be analyzed to evaluate the potential hazard to man.

Knowledge of the source of radioactive contamination gives a good indication of the nuclides that can be expected in the sample. This information helps in planning the analysis, since requesting a complete analysis for all radionuclides or even for all types of radioactivity in a single sample would lead to a lengthy and expensive operation. Indeed, monitoring for suspected contaminants is more applicable than the uncharacterized monitoring.

The general groups of nuclides that maybe encountered include those that occur naturally such as radioactive potassium and members of the uranium and thorium series, artificial fission products such as transuranic elements, and other activation products that result from nuclear weapon explosions and nuclear reactor operations.

Fission products are a very complex mixture when they are formed, but the short-lived radionuclides die out rapidly and the mixture becomes simpler within a few days. The transuranics (plutonium, americium, etc. formed by activation of the basic fissionable material) are of some interest because of their high toxicity when incorporated into the body. Present evidence, however, indicates that their uptake through the gut is relatively small and that dietary intake is not a significant problem. The other activation products are frequently elements that make up steel or other metal containers or structural ele-

ments. Radioactive manganese, chromium, cobalt, zinc, and iron are particularly common and result from interactions of the materials with neutrons released in the nuclear reaction, Contamination of foodstuffs with single nuclides is extremely unlikely, and more than one member of any group will probably be present in any sample.

In contrast to most other pollutants, the effects of radiation are considered to have a linear response regardless of the level, Thus there is no threshold and no absolutely safe limit. The analytical significance of this is that the lower limits of detection for radioactive substances have been brought down to very low levels. The simple yes-or-no testing for acceptability that satisfies regulators for many other pollutants in foods cannot be used.

Almost all radionuclides of interest in cases of contaminating events now exist in foods in small but measurable quantities. Short-lived nuclides are the exception and the transuranic elements are only present at levels that require considerable effort in analysis. Since most of the radionuclides are already present in foods, measurements made for background information should produce a numerical answer, not merely an indication that the amount is less than some pre-set value. This accumulation of background data provides a valuable baseline for evaluating hazardous levels following a contaminating event. The natural activity data are equally valuable, since the amount of information on food concentrations is presently insufficient for valid comparisons with man-made radioactivity.

ESTIMATED COST TO EQUIP A LABORATORY TO CONDUCT INVESTIGATORY MONITORING

Table 21 illustrates estimated costs, required space, and estimated downtime for a laboratory designed to conduct investigatory monitoring. In addition, the number of samples the system would be able to analyze in a year are estimated.

These figures do not reflect the total costs for establishing a national system of investigatory monitoring. Such a cost estimate would require information on the total number of samples to be collected and analyzed. Information of this sort could be obtained through a pilot project to investigate the feasibility of the two investigatory monitoring approaches. This would determine the number of laboratories, the number of people and their salaries, and costs of equipment maintenance, supplies, and training. Once the system is setup and running, some savings might be realized through automation.

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Table 21.—Estimated Costs to Equip a Laboratory to Conduct Uncharacterized Monitoring

Analytical instrumentation	Approximate capital cost	Required space	Samples per year	Estimated down time
Synthetic organics				
1. Small, high throughput, GC-MS-data system with automated liquid Injection device.	$100,000	5,000-6,000 ft. ' laboratory supporting facilities and equipment are required,	200-300 for uncharacterized environmental contaminants as well as known environmental contaminants	20- 50%
2. Electron impact/chemical Ionlzatlon-equipped high-resolution mass spectrometer data system with automated injection device	$200,000-$300.000			20- 50%
3. Gas chromotographic flame ionization detector, electron capture detectors (additional chromotographic systems may be required).	$15,000			20-50 %
4 Liquid chromotograph interfaced to mass spectrometer system	$20,000			20- 50%
5. Central data management system	$75,000-$1,000,000			20- 50%
6. Cold storage and processing facilities	$500! 000			
Synthetic organics subtotal	$1,585,000-$1,935,000			
Trace metals				
1. Inductively coupled plasma Multielement atomic emission system	$100,000	Approximately 2,500 ft.' of laboratory equipped with supporting facilities and equipment are required for items 1-4	3,000-5,000	3-15%
2. Flame and furnace atomic absorption spectrophotometer (single element mode)	$25.000			3- 15°/0
3. Electrochemical instrumentation	$25,000			3-15%
4. Central data management system.	$50.000 - $75,000			3-15%
Trace metals subtotal.	$200.000 - $225,000			
Radionuclides				
1. Four position alpha spectrometer and detectors, multichannel analyzer and output	$21,000	Approximately 1,500 ft. ' laboratories equipped with supporting facilities and equipment are required	1,000-4,000	5%
2. Germanium diode gamma spectrometer wit h detector, shield, electronics, PDP-11 computer and output	$100,000			5 %
3. Four general purpose proportional counters,	$10,000			5 %
4. Liquid scintillation spectrometer, automatic sample. or alpha-counting capabilities	$18.000			5%
Radionuclides subtotal	$149,000			
Total.	$1,934,000. $2,309,000			

SOURCES Adapted from J L Laseter Approaches to Monitoring Environmental Contaminants in Food OTA Working Paper 1978 R K Skogerboe Analytical Systerns for the Determination of Metals in Food and Water Supplies OTA Working Paper 1978 and N H Harley Analysis of Foods for Radioactivity OTA Working Paper 1979

CHAPTER VIII REFERENCES

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