7. ANALYTICAL METHODS

The purpose of this chapter is to describe the analytical methods that are available for detecting, measuring, and/or monitoring zinc, its metabolites, and other biomarkers of exposure and effect to zinc. The intent is not to provide an exhaustive list of analytical methods. Rather, the intention is to identify well-established methods that are used as the standard methods of analysis. Many of the analytical methods used for environmental samples are the methods approved by federal agencies and organizations such as EPA and the National Institute for Occupational Safety and Health (NIOSH). Other methods presented in this chapter are those that are approved by groups such as the Association of Official Analytical Chemists (AOAC) and the American Public Health Association (APHA). Additionally, analytical methods are included that modify previously used methods to obtain lower detection limits and/or to improve accuracy and precision.

Zinc is ubiquitous in both the environment and the laboratory. Since many biological and environmental samples contain low levels of zinc, it is easy to contaminate samples. Thus, it is imperative that special precautions be taken to avoid sample contamination in order to obtain accurate results and ensure the integrity of samples. Precautions must be taken to avoid contamination during sample collection and analysis from sources such as sampling and filtration equipment, inadequate reagent purity, and atmospheric deposition. For ultratrace analysis, the use of a clean-room laboratory with a laminar flow work station is highly recommended to avoid contamination of samples and standards with airborne particulates. In blood analysis, collection tubes are potential sources of zinc contamination (Delves 1981). An example of failure to institute proper measures to control sample contamination, which led to inaccuracies in reported data, was described by Windom et al. (1991). Methods that can be used to avoid reporting erroneous results include interlaboratory data comparison (Galloway et al. 1983) or use of standard reference materials, such as certified SRM 1549 (nonfat powdered milk) available from the National Institute of Standards and Technology (Perry 1990).

Zinc concentrations are typically quantified using instrumental methods such as atomic absorption, emission, or mass spectroscopies; x-ray fluorescence; electro-analytical techniques (e.g., stripping voltammetry); and neutron activation analysis.

7.1 BIOLOGICAL MATERIALS

Table 7-1 lists the applicable analytical methods used for determining zinc in biological fluids and tissues.

Inductively coupled plasma-atomic emission spectroscopy (ICP-AES) is used for zinc determinations in blood and tissue samples (NIOSH Method 8005) and in urine (NIOSH Method 8310). Detection limits in blood and tissue are 1 µg/100 g and 0.2 µg/g, respectively, with recoveries of 100% (NIOSH 1994). Sample preparation involves acid digestion with concentrated acids. Detection of zinc in urine samples requires extraction of the metals with a polydithiocarbamate resin prior to digestion and analysis (NIOSH 1984). Detection limits in urine are 0.1 µg/sample. Inductively coupled plasma-mass spectroscopy (ICP-MS) has been used to determine the concentration of zinc in milk samples and brain tissue (Panayi et al. 2002; Patterson et al. 1992). Detection limits are 0.06 µg/sample for milk and 10.7 ng/g (for a 150 mg sample) for brain tissue samples. Recoveries ranged from 99–111% for brain tissue samples (Panayi et al. 2002).

Atomic absorption spectrometry (AAS) is a common and simple laboratory technique capable of routine zinc analysis of biological samples including bone, liver, hair, blood, and urine. Graphite furnace AAS (GF-AAS) is more sensitive than flame AAS and has been used to determine very low levels of zinc (detection limit, 0.052 µmol/L) in human milk (Arnaud et al. 1991). GF-AAS has been used to determine zinc in human semen. Recovery (96–104%) was good, and preparation by microwave wet acid dissolution was more accurate than the standard water dilution method (Alvarado et al. 1991). Zinc concentrations in liver have been accurately quantified by flame AAS. Homogenization of tissue samples coupled with flame AAS resulted in 100% recoveries, accuracies of 0–3%, and a detection limit of 0.04 mg/L (Luterotti et al. 1992). AAS has also been used to determine zinc in bloodstains on filter paper. This method is accurate, reproducible, and acceptable for routine clinical testing using both dry ashing and direct extraction sample preparation (Fan et al. 1991).

The use of stable isotopes or tracers to study zinc absorption in humans with subsequent analysis by mass spectrometry has been reported in the literature. Analysis of fecal samples obtained 3 and 6 days after the administration of zinc-65 isotope in food showed that between 45 and 75% of zinc isotope was absorbed (Johnson 1982). The results indicated satisfactory detection of the zinc-67 isotope in human feces, while the zinc-70 isotope was not as detectable. Better precision and recovery were obtained for the zinc-67 isotope (2.4% CV [coefficient of variation]; >95% recovery) than for the zinc-70 isotope (38%

Table 7-1. Analytical Methods for Determining Zinc in Biological Materials

Sample matrix	Preparation method	Analytical method	Sample detection limit	Percent recovery	Reference
Blood or tissue	Acid digestion with $HNO_3/HClO_4$, H_2SO_4, measure at 213.9 nm	ICP-AES	1 µg/100 g (blood); 0.2 µg/g (tissue)	103	NIOSH 1994 (method 8005)
Urine	Acid digestion of oxygen plasma ashing; extract with polydithiocarbamate resin; measure at 213.9 nm	ICP-AES	0.1 µg/sample	100	NIOSH 1994 (method 8310)
Semen	Microwave wet acid digestion	GF-AAS	400 µg/L	96–104	Alvarado et al. 1991
Fingernails	Digest nail samples with concentrated nitric acid; heat at 65 °C for 1 hour; cool and dilute with deionized water	GF-AAS	No data	No data	Sohler et al. 1976
Liver	Acid digestion with mixtures of different acids; distill volatile elements	Radio-chemical NAA	No data	98	Lievens et al. 1977
Liver	Homogenize sample with water; add HCl; shake; centrifuge; dilute	Flame AAS	40 µg/L	100	Luterotti et al. 1992
Muscle tissue	Mineralize sample in muffle furnace; dissolve in HNO_3	FIA	3 µg/L	No data	Fernandez et al. 1992b
Blood	Separate serum from blood by centrifugation; transfer a portion of serum into an ampule of highly pure silica and dry; irradiate capsules at a thermal neutron density of $5x10^3 n/cm^{-2}/second^{-1}$	Instrumental NAA	No data	>100	Jurgensen and Behne 1977
Blood	Feed radiotracer ^{65}zinc; measure zinc activity in blood at 14 days	Tracer technique	No data	88	Watson et al. 1987
Blood serum and red blood cells	Feed ^{68}zinc and ^{70}zinc and measure blood levels in a 24-hour sample and a sample taken immediately after zinc administration; wet ash sample; add APDC precipitant; dissolve precipitate in HNO_3 irradiate	Isotope tracer technique	No data	No data	Janghorbani et al. 1981
Blood	Feed $^{65}ZnCl_2$ orally; measure zinc blood levels and whole blood count	Radiotracer technique–whole blood count and blood level measurement	No data	88	Watson et al. 1987

Table 7-1. Analytical Methods for Determining Zinc in Biological Materials

Sample matrix	Preparation method	Analytical method	Sample detection limit	Percent recovery	Reference
Bloodstain	Place drop of blood on filter paper; cut away excess paper; optional dry ash; add HCl; shake	Flame AAS	No data	No data	Fan et al. 1991
Thoracic aorta, lung, myocardium, spleen	Homogenize sample; complete wet ashing with HNO_3	Flame AAS	No data	No data	Marks et al. 1972
Brain tissue	Digest with HNO_3 using microwave digestion; dilute	ICP-MS	32 mg/L (10.7 ng/g for 150 mg sample)	99–111	Panayi et al. 2002
Feces	Give ^{67}Zn through diet; treat fecal samples with H_2O_2; prepare chelates	Isotope tracer technique	No data	>95 (^{67}Zn); 71 (^{70}Zn)	Johnson 1982
Feces	Feed ^{70}Zn, ^{68}Zn, and ^{64}Zn orally; homogenize sample; evaporate; ash; HNO_3 digestion; boil; evaporate; add HCl; transfer to anion exchange column; prepare eluate; irradiate	Isotope tracer technique; NAA	No data	No data	Ni et al. 1991
Bone	Acid digestion of dried bone ash with concentrated HNO_3; evaporate to dryness and add more concentrated HNO_3; remove silica residue by filtration; transfer samples to polyethylene bottles	Flame AAS	No data	No data	Szpunar et al. 1978
Hair	Digest clean sample in acid mixture	Flame AAS	20 µg/g	No data	Wilhelm et al. 1991
Hair	Rinse sample with hexane; wet or dry ash with HNO_3	EDXRF	0.001 µg/L	No data	Folin et al. 1991
Hair	Rinse sample with hexane; wet or dry ash with HNO_3	Flame AAS	0.001 µg/L	No data	Folin et al. 1991
Hair	Digest clean sample in acid mixture	ICP-AES	No data	81–102	Takagi et al. 1988
Serum (animal)	Add Brij 35 to sample; mix	Flame AAS	~0.6 µg/mL	No data	AOAC 1990 (method 991.11)
Serum and plasma	Separate serum and plasma by centrifugation; keep stored in glass tubes at -20 °C until analysis; thaw to room temperature prior to analysis	Flame AAS	No data	No data	Shaw et al. 1982

Table 7-1. Analytical Methods for Determining Zinc in Biological Materials

Sample matrix	Preparation method	Analytical method	Sample detection limit	Percent recovery	Reference
Milk	Ash; lyophilize; wet-ash with HNO_3; add H_2O_2; dry; dissolve in HCl and NH_4Cl; extract with DDDC	ICP-MS	0.06 µg/sample	No data	Patterson et al. 1992
Milk	Dilute sample with Triton X-100	GF-AAS	0.052 µmol/L	86–106	Arnaud et al. 1991
Saliva	Lashley cup place over one of the Stenson's ducts; secretion stimulated with lemon candies; discard first 5–10 mL; collect ≈120 mL	GF-AAS	No data	No data	Langmyhr et al. 1979

AAS = atomic absorption spectroscopy; AES = atomic emission spectroscopy; APDC = ammonium pyrolidine dithiocarbamate; Brij 35 = polyoxyethylene (35) lauryl ether; DDDC = diethylammonium diethyldithiocarbamate; EDXRF = energy dispersive x-ray fluorescence; FIA = flow injection analysis; GF = graphite furnace; HCl = hydrochloric acid; $HClO_4$ = perchloric acid; HNO_3 = nitric acid; H_2O_2 = hydrogen peroxide; H_2SO_4 = sulfuric acid; ICP = inductively coupled plasma spectroscopy; MS = mass spectrometry; NAA = neutron activation analysis; NH_4Cl = ammonium chloride; Zn = zinc; $ZnCl_2$ = zinc chloride

CV; 71% recovery). Sample detection limits were not reported. Total reported sample preparation time was <2 hours, and it took only 5–10 minutes to analyze each sample on the mass spectrometer.

Multi-elemental analysis has been used to detect zinc and other trace metals in biological fluids and tissues. For determination of metallic constituents in biological samples, such as liver, samples were digested with mixtures of different acids, volatile elements were distilled by selective distillation, and a cleanup step was performed using ion exchange chromatography prior to assay by neutron activation analysis (NAA) (Lievens et al. 1977). Recovery (98%) and precision (<10% CV) were excellent. Although the limit of detection for zinc was not reported, based on the reported results, this method can detect levels ranging from the low- to the sub-ppm range (Lievens et al. 1977). The NAA technique has also been used to detect zinc in urine and blood samples. Jurgensen and Behne (1977) used the technique to measure human serum levels of trace elements including zinc. Recovery and precision for this method are very good. Sensitivity was not reported.

A practical method, based on NAA, was developed for accurate measurement of the stable isotopes zinc-68 and zinc-70 in human plasma and red blood cells (Janghorbani et al. 1981). This method can provide an alternative to the use of radiolabeled zinc. It is more complex and time consuming than those used to measure radiolabeled zinc levels. As with any isotopic method, isotope exchange may invalidate calculation of net absorption, but this potential problem was not investigated. Precision was very good (<10%). Sensitivity and accuracy were not reported.

Radionuclide studies offer an additional method to investigate the factors that affect trace element absorption. Radioactivity emitted by the radionuclide was measured in blood 14 days after the oral ingestion of zinc-65 and compared with the amount of radioactivity emission determined by whole-body counting (Watson et al. 1987). The results indicated that, where whole-body counting facilities were not available, measurement of radioactivity emitted in blood was a reasonable alternative for the prediction of zinc absorption. Recovery for this method was adequate (88%); precision was acceptable (<17% CV). The limit of detection for zinc was not reported.

Other analytical methods include flow injection analysis (FIA). FIA has been used to determine very low levels of zinc in muscle tissue. This method provides very high sensitivity, low detection limits (3 ng/mL), good precision, and high selectivity at trace levels (Fernandez et al. 1992b).

Animal and human tissues samples are usually analyzed without drying and concentrations are reported as wet weight. For some samples, freeze-drying has been used. Care should be taken during the acid dissolution of blood and urine samples as frothing of natural surfactants during digestion can lead to losses. This problem can be prevented by allowing the sample to stand overnight after the addition of acid (WHO 2001).

7.2 ENVIRONMENTAL SAMPLES

Table 7-2 lists the methods used for analyzing zinc in environmental samples.

ICP-AES is used to determine concentrations of zinc in air (NIOSH method 7300), water (EPA methods 3120 B, 6010 C, 200.7; APHA methods 3120B, 3125B, 3130B), solid wastes (AOAC method 990.08), and soil (EPA methods 6010, 3050) (AOAC 1998; APHA 1998; EPA 1986a, 1994; NIOSH 1994). Detection limits in air, water, and solid wastes are 0.6, 2, and, 2 µg/L, respectively (AOAC 1998; EPA 1994; NIOSH 1994). Preparation for water samples typically involves acid digestion with concentrated acids. The concentration of zinc in soil was determined by ICP-AES coupled with an ammonium bicarbonate-diethylenetriaminepentaacetic acid (NH4HCO3-DTPA) extraction procedure. This method can be used to screen soils for zinc (Boon and Soltanpour 1991). ICP-MS has been used to determine the concentration of zinc in water (EPA methods 200.8, 1638; APHA method 3125 B), (APHA 1998; EPA 1994, 1996). Detection limits have been reported to be as low as 0.017 µg/L using 66Zn isotope. Recoveries range from 99 to 117% (APHA 1998).

Flame AAS has been used to determine zinc concentrations in natural waters (Fishman 1966). AAS is a rapid method of measuring zinc, with a detection limit of 0.005 ppm. Brooks et al. (1967) demonstrated a simple extraction system consisting of two reagents, ammonium pyrollidine dithiocarbamate (APDC) and methyl isobutylketone (MIBK), with subsequent analysis by flame AAS to measure particulate and "soluble" zinc in seawater. Sensitivity was in the sub-ppm range, and precision was good (3% CV). Flame AAS, coupled with microwave digestion and GF-AAS, has been used to determine the concentration of zinc in food and shellfish samples. Limits of detection ranged from 0.12 to 0.24 ppm, with recoveries ranging from 80 to 113%. Precision and recovery using microwave digestion were comparable to traditional wet ashing and superior to dry ashing in shellfish samples (AOAC 1984; McCarthy and Ellis 1991; Morales-Rubio et al. 1992). GF-AAS was also used to determine low levels of zinc in beer. Recovery (94–106%) and precision (4.2% CV) were excellent. Sensitivity was not reported (Wagner et al. 1991). Flame AAS has been used to measure heavy metals, including zinc, in various oil

Table 7-2. Analytical Methods for Determining Zinc in Environmental Samples

Sample matrix	Preparation method	Analytical method	Sample detection limit	Percent recovery	Reference
Air	Collect air particulates on Teflon filters; digest with HNO_3	NAA (non-destructive)	No data	No data	Zoller et al. 1974
Air	Collect sample on cellulose filter; wet ash filter with $HNO_3/HClO_4$; dilute	ICP-AES	0.6 ng/mL	94–101	NIOSH 1994 (method 7300)
Air	Collect sample on cellulose filter; wet ash with HNO_3; dilute	Flame AAS	3 µg/sample	No data	NIOSH 1994 (method 7030)
Air (as zinc oxide)	Collect sample on PVC-acrylonitrile filter	XRD	5 µg/sample	No data	NIOSH 1994 (method 7502)
Atmospheric aerosols	Collect sample on cellulose filter; digest with HNO_3; filter; dry; add HNO_3; adjust pH; add KNO_3	Anodic stripping voltammetry	13.7 µg/L	No data	Casassas et al. 1991
Water	Acidify; dilute	ICP-MS	0.14 µg/L	No data	EPA 1996 (method 1638)
Water	Reflux with HNO_3/HCl; dilute	GF-AAS	0.14 µg/L	No data	EPA 1996 (method 1639)
Water	Acidify (digest if necessary); dilute	ICP-AES	2 µg/L	No data	EPA 1994 (method 200.7)
Water	Acidify (digest if necessary); dilute	ICP-MS	1.8 µg/L	No data	EPA 1994 (method 200.8)
Water	Acid digestion; dilute	ICP-AES	1.2 µg/L	No data	EPA 2000 (method 6010 C)
Water	Dissolve in HCl; dilute	Flame AAS	5 µg/L	No data	APHA 1998 (method 3111 B)
Water	Chelation with ammonium pyrrolidine dithiocarbamate and extraction into MIBK	Flame AAS	No data	No data	APHA 1998 (method 3111C)
Water	Acidify; dilute	ICP-AES	2 µg/L	No data	APHA 1998 (method 3120 B)
Water	Acidify; dilute	ICP-MS	0.017 µg/L (^{66}Zn) 0.020 µg/L (^{68}Zn)	99–117 (^{66}Zn) 98–116 (^{66}Zn)	APHA 1998 (method 3125 B)
Water	Dilute with HNO_3	Anodic stripping voltammetry	<1 µg/L	No data	APHA 1998 (method 3130 B)
Water	Add sodium ascorbate; KCN; zircon (2-carboxy-2'-hydroxy-5'-sulfoformazyl benzene)	Colormetry	No data	No data	APHA 1998 (method 3500-Zn B)
Water and waste water	Acid digestion	Flame AAS	5 µg/L	No data	EPA 1979 (method 289.1)

Table 7-2. Analytical Methods for Determining Zinc in Environmental Samples

Sample matrix	Preparation method	Analytical method	Sample detection limit	Percent recovery	Reference
Water and waste water	Acidify; dilute	GF-AAS	0.05 µg/L	No data	EPA 1979 (method 289.2)
Water	Mineralize sample in muffle furnace; dissolve in HNO_3	FIA	3 µg/L	No data	Fernandez et al. 1992b
Seawater	APDC-MIBK extraction	Flame AAS	0.05 ppb	No data	Brooks et al. 1967
Seawater	Take a sample digest in the electrochemical cell; adjust pH; add chelating agent and aerate	Cathodic stripping voltammetry	$7x10^{-11}$ M	No data	van den Berg 1986
Crude oil	Digest sample with HNO_3; extract with MIBK or dilute with MIBK	Flame AAS	0.8 µg/g	No data	Elson et al. 1981
Soil, solid waste, sludges	Acid digestion	ICP-AES or flame AAS	2 µg/L (in solution)	102.5 at 80 µg/L	EPA 1986a (methods 6010 and 3050)
Soil, solid waste and sludges	None	Flame AAS	0.005 µg/L	No data	EPA 1986a (method 7950)
Solid wastes	No data	ICP-AES	2 µg/L	No data	AOAC 1998 (method 990.08)
Soil	Extract with DTPA and NH_4HCO_3-DTPA	ICP-AES	No data	No data	Boon and Soltanpour 1991
Plants	Digest samples with acids	Flame AAS	No data	No data	AOAC 1984 (method 3.013)
Plants	Digest samples with acid; extract with dithiozone reagent and CCl_4; add HCl and CCl_4; read at 525 nm for mixed-color method and at 535 nm for single-color method	Mixed and single color methods – spectrophoto-metric analysis	No data	No data	AOAC 1984 (methods 3.054 and 3.061)
Food	Digest sample with acid mixtures; remove sulfide, nickel, and cobalt; add dithioxone and CCl_4; measure transmission at 540 nm	Colorimetry	No data	No data	AOAC 1984 (method 25.168)
Food	Wet ash using Kjeldahl digestion HNO_3/H_2SO_4 with heat; dilute; alternatively, dry ash; dissolve in HCl with heat	Flame AAS	No data	No data	AOAC 1990 (method 969.32)
Food	Digest samples with acid mixtures; dilute	Flame AAS	No data	No data	AOAC 1990 (method 986.15)
Food	Dry ash sample in muffle oven; dilute with HNO_3	Flame AAS; Flame AES	0.24 µg/g	97–100	Morales-Rubio et al. 1992

Table 7-2. Analytical Methods for Determining Zinc in Environmental Samples

Sample matrix	Preparation method	Analytical method	Sample detection limit	Percent recovery	Reference
Food	Clarify; de-gas; dilute with deionized water; add HNO_3 to solid samples	GF-AAS	No data	90–113	Wagner et al. 1991
Food	Blend; lyophilize; grind; oven-dry; press into pellets	EDXRF	0.8 ppm	No data	Nielson et al. 1991
Shellfish	HNO_3 digestion in microwave; dilute	Flame AAS	0.12 ppm	80	McCarthy and Ellis 1991

AAS = atomic absorption spectroscopy; AES = atomic emission spectrometry; APDC = ammonium pyrolidine dithiocarbamate; CCl_4 = carbon tetrachloride; DTPA = diethylenetriaminepentaacetic acid; EDXRF = energy dispersive x-ray fluorescence; FIA = flow-injection analysis; GF = graphite furnace; HCl = hydrochloric acid; $HClO_4$ = perchloric acid; HNO_3 = nitric acid; H_2SO_4 = sulfuric acid; ICP = inductively coupled plasma spectroscopy; KCN = potassium cyanide; KNO_3 = potassium nitrite; MIBK = methyl isobutyl ketone; NAA = neutron activation analysis; NH_4HCO_3-DTPA = ammonium bicarbonate-diethlyenetriaminepentaacetic acid; PVC = polyvinyl chloride; XRD = x-ray diffraction; Zn = zinc

samples collected at different stages of oil refining (Elson et al. 1981). These samples were prepared using three techniques (digestion, extraction, and dilution) prior to AAS analysis; recovery from crude oil was higher with wet digestion. Sensitivity for zinc was in the low-ppm range.

Cathodic stripping voltammetry, also known as adsorption voltammetry, has been used to detect various metal ions in a 10-10–10-11 M range in seawater (van den Berg 1986). APDC was used as a chelating agent for zinc. Because of the great sensitivity and specificity of APDC for zinc, it can be detected directly in the unaltered sample. Similarly, differential pulse cathodic stripping voltammetry (DPCSV) and differential pulse anodic stripping voltammetry (DPASV) after complexation with APDC have been used for determining zinc speciation at nanomolar concentrations in ocean waters (Donat and Bruland 1990). Anodic stripping voltammetry (ASV) has been used to detect zinc and other metal ions simultaneously at trace levels in atmospheric aerosols. This method is primarily used for small samples with very low concentrations of zinc. The limit of detection was 13.7 ng/L (Casassas et al. 1991).

An ion chromatographic method has been proposed for simultaneous determination of several elements including zinc in soil (Basta and Tabatabai 1990). In this method, after preliminary sample treatment, the metals are separated by ion chromatography, and the separated elements are quantified by ultraviolet-visible detection of zinc-PAR (4-[2-pyridylazo] resorcinol) colored complexes. The limit of detection for zinc by this method was 5 ppb in soil extract. Precision was ≤2.5% CV.

Other analytical methods include energy dispersive x-ray fluorescence (EDXRF). This technique has been used to detect zinc in dried food samples with better precision (e.g., detection limit, 0.8 ppm) than AAS methods (Nielson et al. 1991).

7.3 ADEQUACY OF THE DATABASE

Section 104(i)(5) of CERCLA, as amended, directs the Administrator of ATSDR (in consultation with the Administrator of EPA and agencies and programs of the Public Health Service) to assess whether adequate information on the health effects of zinc is available. Where adequate information is not available, ATSDR, in conjunction with NTP, is required to assure the initiation of a program of research designed to determine the health effects (and techniques for developing methods to determine such health effects) of zinc.

The following categories of possible data needs have been identified by a joint team of scientists from ATSDR, NTP, and EPA. They are defined as substance-specific informational needs that if met would reduce the uncertainties of human health assessment. This definition should not be interpreted to mean that all data needs discussed in this section must be filled. In the future, the identified data needs will be evaluated and prioritized, and a substance-specific research agenda will be proposed.

7.3.1 Identification of Data Needs

Methods for Determining Biomarkers of Exposure and Effect.

Exposure. ICP-AES, ICP-MS, and AAS are the most commonly used analytical methods to determine zinc levels in plasma, bone, fingernails, hair, and other biological tissues and body fluids (Alvarado et al. 1991; AOAC 1990; Arnaud et al. 1991; Fan et al. 1991; Folin et al. 1991; Langmyhr et al. 1979; Luterotti et al. 1992; Marks et al. 1972; NIOSH 1984a, 1994; Panayi et al. 2002; Patterson et al. 1992; Shaw et al. 1982; Sohler et al. 1976; Szpunar et al. 1978; Takagi et al. 1988; Wilhelm et al. 1991). These methods generally are sensitive enough to measure background levels in the population and levels at which biological effects occur. However, improved sensitivity and recovery data are needed in order to better evaluate the relationship between body and environmental exposure levels of zinc. Other methods that are specific for measuring zinc in biological fluids and tissues include NAA, FIA, and isotope tracers techniques (Fernandez et al. 1992b; Janghorbani et al. 1981; Johnson 1982; Lievens et al. 1977; NIOSH 1984a; Watson et al. 1987). Sensitivity and/or recovery data for these methods are needed to more fully evaluate the reliability of these methods as predictors of environmental exposure.

Effect. Although several biomarkers for the effects of zinc have been identified (increased levels of serum amylases and lipase, noniron responsive anemia, and decreased HDL cholesterol levels), these biomarkers of effect are not specific for zinc (Cotran et al. 1989; Suber 1989). Standard laboratory tests are available that can measure these biomarkers (Henry 1984). These methods are sensitive, accurate, and reliable enough to measure background levels in the population and levels at which biological effects occur. The development of methods for determining biomarkers of effect specific for zinc would be beneficial in assessing whether an individual has been exposed to elevated levels of zinc.

Methods for Determining Parent Compounds and Degradation Products in Environmental Media. Methods of adequate sensitivity and specificity are available for determining levels of zinc in

environmental media (AOAC 1984; APHA 1998; Basta and Tabatabai 1990; Brooks et al. 1967; Casassas et al. 1991; Donat and Bruland 1990; Elson et al. 1981; EPA 1979c, 1986a, 1994, 1996, 2000; Fishman 1966; McCarthy and Ellis 1991; Morales-Rubio et al. 1992; Nielson et al. 1991; NIOSH 1994; van den Berg 1986; Wagner et al. 1991; Zoller et al. 1974). Most of these methods are precise and sensitive enough to measure background levels in the environment and levels at which health effects occur. Some methods can distinguish between soluble zinc, insoluble zinc, and chelated zinc in water (Donat and Bruland 1990).

7.3.2 Ongoing Studies

The information in Table 7-3 was found as a result of a search of the Federal Research in Progress database (FEDRIP 2004)

Table 7-3. Ongoing Studies on Analytical Methods for Zinc[a]

Investigator	Affiliation	Study	Sponsor
Michel RG, Freake HC, Zinn SA et al.	University of Connecticut	Capillary electrophoresis to enable zinc speciation for studies of zinc homeostasis	USDA
Panemangalore M	Kentucky State University, Human Nutrition Research Program	Evaluation of biomarkers of zinc and copper status in animals and humans	USDA

[a]Source: FEDRIP 2004

FEDRIP = Federal Research in Progress Database; USDA = United States Department of Agriculture