7. ANALYTICAL METHODS

The purpose of this chapter is to describe the analytical methods that are available for detecting, measuring, and/or monitoring chromium compounds, their metabolites, and other biomarkers of exposure to chromium compounds. The intent is not to provide an exhaustive list of analytical methods, but to identify well-established methods that are used as the standard methods of analysis. Many of the analytical methods used for environmental samples are 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 lower detection limits and/or to improve accuracy and precision in detection.

7.1 BIOLOGICAL MATERIALS

Several methods are available for the analysis of chromium in different biological media, with some methods of chromium determination summarized in Table 7-1. Multiple reviews on the subject provide more detailed descriptions of the available analytical methods (EPA 1984a; Fishbein 1984; IARC 1986a, 1990; Torgrimsen 1982; WHO 1988). Frequently used techniques for determining low levels of chromium in biological samples include neutron activation analysis (NAA) (Cornelis 1985; Greenberg and Zeisler 1988); inductively-coupled plasma-mass spectrometry (ICP-MS) (Bonnefoy et al. 2005; D'illio et al. 2011; McShane et al. 2007); graphite furnace atomic absorption spectrometry (GFAAS) (Dube 1988; Randall and Gibson 1987)); and electrothermal atomization-atomic absorption spectrometry (ET-AAS) (Olmedo et al. 2010).

There are numerous issues and considerations in collecting and analyzing the chromium content in presented samples. Some of these issues include problems with collection, contamination, and determining accurate concentration levels of the chromium content in the samples. The determination of trace quantities of chromium in biological materials requires special precautionary measures, from the initial sample collection process to the final analytical manipulations of the samples. The sample collection and handling of human blood and urine samples as it pertains to the analysis of trace metals including chromium has been discussed elsewhere (Cornelis et al. 1996). For chromium, a stainless steel needle should not be used for blood collection due to possible contamination of the sample, and it is advised that any anti-coagulants used be analyzed for the presence of chromium. In addition, acid-

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

Sample matrix	Preparation method	Analytical method	Sample detection limit	Percent recovery	Reference
Plasma	Wet ashing with $HNO_3/HClO_4/H_2SO_4$; residue complexed with APDC and extracted with MIBK; evaporated residue dissolved deposited in HNO_3/HCE, and solution on a polycarbonate foil	PIXE	0.3 µg/L	87% at 4.5 µg/g	Simonoff et al. 1984
Blood, serum	Sample after wet digestion converted to a volatile chelate usually with fluorinated acetylacetone	GC/ECD	0.03 pg 0.5 pg 1.0 ng	No data	Fishbein 1984
Serum	$Mg(NO_3)_3$ added to serum, dried by Lyophilization, ashed, and dissolved in 0.1 N HCl	GFAAS	0.005 µg/L	103% at 0.30 µg/L	Randall and Gibson 1987
Blood	Diluted with 0.1% EDTA and 5% isopropanol	GFAAS-Zeeman-effect background correction	0.09 µg/L	No data	Dube 1988
Blood	Collect blood samples in glass tubes containing sodium heparinate to prevent coagulation and store at 4 °C	ICP-MS	2.5 µg/L	No data	Bonnefoy et al. 2005
Blood	Collection and storage at 4 °C	ET-AAS	0.19 µg/L	99.15%	Olmedo et al. 2010
Blood or tissue	Wet ashing with $HNO_3/HClO_4/H_2SO_4$	ICP-AES	1 µg/100 g blood 0.2 µg/g tissue	114% recovery at 10 µg/sample	NIOSH 1994a (Method No. 8005)
Erythrocytes	Dilution with Triton X100	GFAAS	No data	No data	Lewalter et al. 1985
Serum and urine	HNO_3 de-proteinization	ET-AAS	0.02 µg/L (serum) 0.1 µg/L (urine)	No data	Sunderman et al. 1989

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

Sample matrix	Preparation method	Analytical method	Sample detection limit	Percent recovery	Reference
Body fluids (milk, urine, etc.)	Dried sample ashed by oxygen plasma, H_2O_2 addition, drying, dilution in 1N HCl	GFAAS with tungsten iodide or deuterium arc or CEWM background correction	<0.25 µg/L	91% at 0.55 µg/L	Kumpulainen 1984
Urine	None	GFAAS	0.05 µg/L	91% at 0.22 µg/L	Randall and Gibson 1987
Urine	None	GFAAS with CEWM background correction and WM-AES	0.09 µg/L (CEWM-AAS) 0.02 µg/L (WM-AES)	No data	Harnly et al. 1983
Urine	No sample preparation other than addition of yttrium internal standard	ICP-AES	12 µg/L	77% at 13 µg/L	Kimberly and Paschal 1985
Urine	Sorption onto polydithiocarbonate resin, ash sorbate in low temperature oxygen plasma and dissolve in $HNO_3/HClO_4$	ICP-AES	0.1 µg/sample	100% recovery at 1 µg/50mL urine	NIOSH 1994b (Method 8310)
Urine	None	GFAAS	0.0052 µg/L	No data	Kiilunen et al. 1987
Urine	Sample spiked with standard chromium (standard addition)	GFAAS	0.03–0.04 µg/L	No data	Veillon et al. 1982
Urine	Diluted with water	GFAAS-Zeeman-effect-background correction	0.09 µg/kg	No data	Dube 1988
Urine	Samples collected and diluted for analysis with 2% (v/v) double-distilled grade ultrapure nitric acid (and 0.002% Triton X-100 (diluent)	ICP-MS	0.26 µg/L	No data	McShane et al. 2007
Urine	Collection and storage at 4 °C with or without dilute nitric acid solution.	ET-AAS	0.19 µg/L	101.74%	Olmedo et al. 2010
Milk powder	Mixed with water	GFAAS	5 µg/kg	134–141% at 17.7 µg/kg	Wagley et al. 1989

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

Sample matrix	Preparation method	Analytical method	Sample detection limit	Percent recovery	Reference
Tissue(Chromium(V))	Injection of sodium dichromate	EPR	0.1 mmol/kg	No data	Liu et al. 1994
Hair	Wash with double-distilled water and neutral soap followed by acid digestion	ETAAS	0.19 µg/L	103.00%	Olmedo et al. 2010

AAS = atomic absorption spectrometry; APDC = ammonium pyrrolidine dithiocarbonate; CEWM = continuum source echelle monochromator wavelength-modulated; ECD = electron capture detector; EDTA = ethylenediaminetetra-acetic acid; EPR = electron paramagnetic resonance spectroscopy; ET-AAS = electrothermal-atomic absorption spectrometry GC = gas chromatography; GFAS = graphite furnace AAS; H_2O_2 = hydrogen peroxide; H_2SO_4 = sulfuric acid; HCI = hydrochloric acid; $HClO_4$ = perchloric acid; HNO_3 = nitric acid; ICP-AES = inductively coupled plasma-atomic emission spectrometry; ICP-MS = inductively coupled plasma-mass spectrometry; $Mg(NO_3)_3$ = magnesium nitrate; MIBK = methylisobutyl ketone; MS = mass spectrometry; PIXE = proton-induced X-ray emission spectrometry; XRF = X-ray fluorescence analysis; WM-AES = wavelength-modulated atomic emission spectrometry

washed plastic tubes are required for blood collection. Unwashed commercially available tubes were found to contain trace amounts of chromium in blank samples (Cornelis et al. 1996).

Contaminates including dust contamination or losses of the samples during collection, transportation, and storage should be avoided (EPA 1984a). Chromium-containing grinding and homogenizing equipment should not be used for preparation of biological samples. Reagents of the highest purity should be used to avoid contamination, and the potential loss of chromium due to volatilization during wet and dry ashing should be minimized (EPA 1984a).

The determination of chromium in most biological samples is difficult because of the matrix interference and the very low concentrations present in these samples. Prior to 1978, numerous erroneous results were reported for the chromium level in urine using electrothermal atomic absorption spectrometry (EAAS) because of the inability of conventional atomic absorption spectrometry systems to correct for the high nonspecific background absorption. Similarly, the reported serum and plasma chromium concentrations of normal subjects have varied more than 5,000-fold since the early 1950s. A limitation of ICP-MS is the presence of other elements that may combine with plasma argon ions to form polyatomic ions. The main polyatomic ions that interfere with the analysis of chromium are $^{40}Ar^{12}C^{+}$, $^{36}Ar^{16}O^{+}$, $^{38}Ar^{14}N^{+}$, $^{35}Cl^{16}O^{1}H^{+}$, and $^{37}Cl^{15}O^{+}$ because they have similar mass-to-charge ratios as the most abundant isotope of chromium, $^{52}Cr^{+}$ (D'illio et al. 2011). Matrix interference problems have been improved by using ICP-MS equipped with a dynamic reaction cell (DRC) (Bonnefoy et al. 2005; D'illio et al. 2011; McShane et al. 2007). The DRC contains a gas such as ammonia, which can react with polyatomic ions such as $^{40}Ar^{12}C^{+}$ resulting in a new species with a different mass-to-charge ratio.

The chromium levels in human serum or plasma as reported in the mid-1980s ranged from 0.01 to 0.3 μg/L (Anderson 1987) and the daily urinary excretion rate of chromium in healthy and nonoccupationally exposed humans range from approximately 0.24 to 1.8 μg/L; however, these levels are greatly influenced by food and beverage intake, smoking, and exercise (Paustenbach et al. 1997).

The problem with generating accurate data for chromium in biological materials in the past was associated with the lack of Standard Reference Materials (SRM). Recently, the National Institute of Standards and Technology (NIST) with collaboration of Centers for Disease Control and Prevention (CDC) released a new reference material (SRM 2668), toxic elements in frozen human urine, which contains chromium among other elements (DOC 2012). This will significantly improve the precision and accuracy of the analytical measurements of chromium in clinical samples. However, due to the previous

lack of SRMs, older data should be interpreted with caution (EPA 1984a), unless the data are verified by interlaboratory studies (WHO 1988).

In addition to the consideration of contamination and potential loss of sample, it should be noted that chromium may exist as several different oxidation states in biological media. Two of the most common oxidation states are chromium(III) and chromium(VI). Each of these oxidation states displays very different physical and biological properties. In biological samples where chromium is generally present as chromium(III), the choice of a particular method is dictated by several factors, including the type of sample, its chromium level, and the scope of the analysis (Kumpulainen 1984).

7.2 ENVIRONMENTAL SAMPLES

Analytical methods for determining chromium in environmental samples are reported in Table 7-2. Many of the issues that affect the measurement of chromium in biological samples are also present in environmental analysis, including issues of collection, contamination, and detection. Chromium may be present in both the trivalent and hexavalent oxidation states in most ambient environmental and occupational samples, as well as existing in soluble and insoluble forms. Soluble chromium(VI) may be reduced to chromium(III) on some filtering media, particularly at low concentrations, and under acidic conditions. Teflon® filter and alkaline solution are most suitable to prevent this reduction (Sawatari 1986). As in the case of biological samples, contamination and chromium loss in environmental samples during sample collection, storage, and pretreatment should be avoided. Chromium loss from aqueous samples due to adsorption on storage containers should be avoided by using polyethylene or similar containers and adjusting the solution to the proper pH.

Methods are available for the detection of hexavalent chromium in airborne particulate matter based on ion chromatography followed by UV-VIS spectroscopy (Ashley et al. 2003; ASTM 2008 [Method D6832]; CARB 1990; ISO 2005 [Method 16740]; NIOSH 2003a [Method 7605]; Sheehan et al. 1992). In general, a known volume of air is drawn through a filter to collect particulate chromium in workplace air and these samples are dissolved to extract hexavalent chromium. Following dissolution and treatment with ion chromatography in order to separate the extracted hexavalent chromium from trivalent chromium and other metal cations, the solutions are derivitized with 1,5-diphenylcarbazide to form a chromium diphenylcarbazone complex, which has a characteristic absorption band at approximately 540 nm. Field-portable instruments that can be employed to rapidly measure chromium(VI) levels in workplace air have been developed based upon these methods (NIOSH 2003b [Method 7703]; Wang et al. 1999). Different

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

Sample matrix	Preparation method	Analytical method	Sample detection limit	Percent recovery	Reference
Air (total chromium)	Air particulate matter collected on filter is cut out and irradiated with X-ray photons	XRF	0.017 µg/m^3	No data	Wiersema et al. 1984
Air (total chromium)	The collected particulates in filter dissolved in HNO_3, dried and redissolved in acidified water	ICP-AES	0.05–0.2 ng/m^3	No data	Barrie and Hoff 1985
Air (total chromium)	Particulate matter collected on cellulose ester filter, digested with aqua regia	ICP-AES	1 µg/m^3	87–102% at 0.5–100 µg	Lo and Arai 1988
Air (total chromium)	Air particulate collected on cellulose ester filter, wet wash with HCI/HNO_3	Flame atomic absorption	0.06 µg/sample	98% at 45–90 µg/sample	NIOSH 1994c (Method 7024)
Air (total chromium)	Sample collected on cellulose ester membrane filter dissolved in acid mixtures	ICP-AES	1 µg/sample	98% at 2.5 µg/filter	NIOSH 1994d (Method 7300)
Air(total chromium)	Collect 80 m^3 air using polystyrene filters	NAA	0.25 ng/m^3	No data	Schroeder et al. 1987
Air (chromium(VI))	Sample collected on sodium carbonate-impregnated cellulose filter and extracted with sodium bicarbonate followed by separation and derivatization with diphenylcarbazide solution	Ion chromato-graphy with post-column derivati-zation and UV-VIS detection	0.1 ng/m^3 for 20 m^3 sample	89–99% at 100 ng	CARB 1990
Air (chromium(VI))	Sample collected on sodium carbonate-impregnated cellulose filter and extracted with sodium bicarbonate followed by separation and derivatization with diphenylcarbazide solution	Ion chromato-graphy with post-column derivati-zation and UV-VIS detection	0.1 ng/m^3 for 20 m^3 sample	87–101 % (94% mean)	Sheehan et al. 1992

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

Sample matrix	Preparation method	Analytical method	Sample detection limit	Percent recovery	Reference
Air (chromium(VI))	Sample collected on PVC filter followed by extraction, separation and derivatization with diphenylcarbazide solution	Ion chromato-graphy with post-column derivatizatio n and UV-VIS detection	0.25 µg/m^3 for 200 L samples	94.8%	NIOSH 2003a (Method 7605)
Occupational air (chromium VI)	A known volume of air is drawn through a filter to collect particulate hexavalent chromium and then dissolved; following separation, derivatization with diphenylcarbazide solution	Ion chromato-graphy with post-column derivati-zation and UV-VIS detection	0.1–100 µg/m^3 for 1 m^3 air	96%	ASTM 2008 (Method D6832)
Occupational air (chromium VI)	A known volume of air is drawn through a filter to collect particulate hexavalent chromium and then dissolved; following separation, derivatization with diphenylcarbazide solution	Ion chromato-graphy with post-column derivati-zation and UV-VIS detection	0.01–10 µg/m^3 for 1 m^3 air	96%	ISO 2005 (Method 16740)
Occupational air (welding fumes)	Particulate matter captured on the filter was dissolved with hot H_2SO_4 and chromium(III) was oxidized to chromium(VI) by addition of Na_2O_2; iron and other metals that form insoluble hydroxides were removed by centrifugation; the centrifuged solution was acidified with HCl and reduced to chromium(III) by SO_2; the solution was complexed with β-isoproyl tropolone in $CHCl_3$	HPLC-UV	10 pg	No data	Maiti and Desai 1986
Occupational air (chromium (VI))	Extract with 0.05 M $(NH_4)_2SO_4$–0.5 M $(NH_4)_2SO_4$.1 M NH_3.	FIA-UV/VIS	0.11 ng	>90%	Wang et al. 1997a

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

Sample matrix	Preparation method	Analytical method	Sample detection limit	Percent recovery	Reference
Simultaneous determination of chromium(III) and chromium(VI) in water extract from metal fumes	Sample solution at pH 5 reacted with disodium ethylenediamine tetraacetic acid at 50 °C for 1 hour	HPLC on anion exchange column with Na_2CO_3 eluting solution and simultan-eous UV and AAS detection	0.2 ng by UV for chromium(VI) 2.0 ng by UV 5.0 ng by AAS for chromium (IV) 5 ng by AAS for chromium (III)	95–105% at 0.002–2.0 µg	Suzuki and Serita 1985
Atmospheric deposition (snow)	The melted snow filtered through Nucleopore filter; the filtrate acidified with HNO_3; and dried by freeze-drier; residue dissolved in HNO_3; this preconcentrated solution placed in plastic tubes; both plastic tube and Nucleopore filter irradiated with protons	PIXE	2 µg/L (soluble portion) 26 µg/L (snow particle)	No data	Jervis et al. 1983; Landsberger et al. 1983
	Either the above Nucleopore filter or the preconcentrated liquid placed in plastic vial is irradiated by thermal neutron	NAA	5 µg/L (soluble portion) 115 µg/g (snow particle)	No data	Jervis et al. 1983; Landsberger et al. 1983
Drinking water (dissolved chromium(VI)	The sample is introduced directly into the ion chromatograph and Cr(VI) is separated from the other matrix components by an anion exchange column followed by derivatization with diphenylcarbazide	Ion chromato-graphy with post-column derivatizatio n and UV-VIS detection	0.0044–0.015 µg/L	87.1–103% (results for different types of water and preservatives used)	EPA 2011 (Method 218.7)
Drinking water, surface water, and certain domestic and industrial effluents (dissolved chromium(VI))	Complex chromium(VI) in water with APDC at pH 2.4 and extracted with MIBK	AAS	2.3 µg/L	No data	EPA 1983b (Method 218.4)

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

Sample matrix	Preparation method	Analytical method	Sample detection limit	Percent recovery	Reference
Drinking water, groundwater and water effluents (chromium(VI))	Buffer solution introduced into ion chromatograph. Derivitized with diphenylcarbazide	Ion chromato-graphy with post-column derivati-zation and UV-VIS detection	0.3 µg/L	100% at 100 µg/L	EPA 1996a (Method 7199)
Waste water and industrial effluent for chromium(VI) only	Buffered sample mixed with $AlCl_3$ and the precipitate separated by centrifugation or filtration	DPPA at pH 10–12	30 µg/L	90% at 0.2 mg/L	Harzdorf and Janser 1984
Waste water 1986 (chromium(VI))	Derivatization with o-nitrophenylfluorone	UV-VIS spectro-metry at 582 nm	Lower than diphenyl-carbazone method	No data	Qi and Zhu 1986
Water (total chromium)	Calcium nitrate added to water and chromium is converted to chromium(III) by acidified H_2O_2	GFAAS or ICP/AES	1.0 µg/L (GFAAS) 7.0 µg/L	97–101% at 19–77 µg/L	EPA 1983a, 1986a (Method 218.2 and 7191)
Water (chromium(III) and chromium (VI))	Solid-phase extraction using anion exchange resins for Cr(VI) adsorption and chelating resins for Cr(III) adsorption	ICP-MS	0.009 µg/L (chromium VI); 0.03 µg/L (chromium III)	86–113%	Guerrero et al. 2012
Seawater (total chromium)	Derivatization with trifluoroacetylacetonate and solid-phase microextraction	ICP-MS	9.1–20 pg/L	No data	Yang et al. 2004
Industrial wastes, soils, sludges, sediments, and other solid wastes (total chromium)	Digest with nitric acid/hydrogen peroxide	ICP-AES	4.7 µg/L	101% at 3.75 mg/L	EPA 1996b (Method 6010b)
Oil wastes, oils, greases, waxes, crude oil (soluble chromium)	Dissolve in xylene or methyl isobutyl ketone	AAS or GFAAS	0.05 mg/L	107% at 15 µg/L	EPA 1986b (Method 7190)

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

Sample matrix	Preparation method	Analytical method	Sample detection limit	Percent recovery	Reference
Groundwater, domestic and industrial waste (chromium[VI])	Chromium(VI) is coprecipitated with lead sulfate, reduced, and resolubilized in nitric acid	AAS or GFAAS	0.05 mg/L (AAS) 2.3 µg/L (GFAAS)	93–96% at 40 µg/L	EPA 1986c (Method 7195)
Groundwater-EP extract, domestic, and industrial waste (chromium[VI])	Chelation with ammonium pyrrolidine dithiocarbamate and extraction with methyl isobutyl ketone	AAS	No data	96% at 50 µg/L	EPA 1983b, 1986d (Method 218.4 and 7197)
Water, waste water, and EP extracts (chromium(VI))	Direct	DPPA	10 µg/L	93% at 5 mg/L	EPA 1986e (Method 7198)
Soil, sediment and sludges (chromium(VI))	Acid digestion extraction using hot HNO_3	GFAAS	No data	No data	Oygard et al. 2004
Sediment (total chromium)	Samples digested with HNO_3 and HF and dried	XRF	No data	No data	Adekola and Eletta (2007)
Sediment	Acid digestion using 0.5N HCl followed by filtration	AAS	No data	94.88%	Ayyamperumal 2006

AAS = atomic absorption spectrophotometry; $AlCl_3$ = aluminum chloride; APDC = ammonium pyrrolidine dithiocarbamate; $CHCl_3$ = chloroform; DPPA = differential pulse polarographic analysis; EAAS = electrothermal atomic absorption spectrometry; EP = extraction procedure (for toxicity testing); FIA/uv/vis = flow injection analysis-ultraviolet/visible spectroscopy; GFAAS = graphite furnace atomic absorption spectrometry; H_2SO_4 = sulfuric acid; HCl = hydrochloric acid; HF = hydrofluoric acid; HNO_3 = nitric acid; HPLC = high pressure liquid chromatography; ICP-AES = inductively coupled plasma-atomic emission spectrometry; NAA = neutron activation analysis; MIBK = methylisobutyl ketone; Na_2O_2 = sodium peroxide; NaOH = sodium hydroxide; Na_2CO_3 = sodium carbonate; $(NH_4)_2SO_4$ = ammonium sulfate; NH_3 = ammonia; PIXE = proton-induced X-ray emission spectrometry; SO_2 = sulfur dioxide; UV = ultraviolet; XRF = X-ray fluorescence analysis

procedures may be employed for the extraction of soluble versus insoluble hexavalent chromium compounds and the various sequential extraction procedures described in standardized methods ASTM D6832 and ISO 16740 have been compared for their effectiveness for recovering hexavalent chromium from workplace air (Ashley et al. 2009). A three-step sequential extraction procedure was outlined that employed deionized water to dissolve soluble chromium compounds such as potassium chromate, an ammonium sulfate buffer for sparingly soluble species, and a sodium carbonate buffer to dissolve insoluble chromium complexes such as lead chromate. Recovery data for chromium compounds spiked onto PVC filters suggested that the three-step procedure may result in excessively high recoveries of soluble chromium species. A two-step extraction process using either water or sulfate buffer to dissolve soluble hexavalent chromium compounds followed by sonication in a carbonate buffer to obtain insoluble species yielded acceptable results when applied to the analysis of hexavalent chromium in paint pigments and stainless steel welding fumes (Ashley et al. 2009).

Measurements of low levels of chromium concentrations in water have been made by methods, such as ICP-MS (Guerrero et al. 2012; Henshaw et al. 1989; Parks et al. 2004; Yang et al. 2004), GFAAS (Gonzalez et al. 2005), ICP-AES (Malinski et al. 1988), and high resolution capillary column gas chromatography (HRGC) with ECD (Schaller and Neeb 1987). EPA Method 218.7 uses ion chromatography followed by derivatization with 1,5-diphenylcarbazide and UV-VIS analysis for the detection of hexavalent chromium in drinking water (EPA 2011). Proper storage and maintenance of water samples is critical since chromium(III) can be oxidized to chromium(VI) especially in the presence of free chlorine. Samples are typically stored at pH 8 or above and with buffers containing ammonium ions to complex free chlorine. Methods using high performance liquid chromatography (HPLC) interfaced with a direct current plasma emission spectrometer have also been used for the determination of chromium(III) and chromium(VI) in water samples (Krull et al. 1983). Abranko et al. (2004) employed GC-ECD, electron impact-mass spectrometry (EI-MS) and ICP-MS to the quantification of chromium in seawater following derivatization with trifluoroacetylacetone and solid phase microextraction (SPME). Detection limits ranging from 0.011 to 0.015 ng/mL were reported for all three techniques. Acid leachable and digestion procedures followed by AAS have been developed that can quantify chromium(VI) and total chromium in soil, sediment, and sludge (Ayyamperumal 2006; Oygard et al. 2004). The preferred methods for digestion of environmental samples have been discussed by Griepink and Tolg (1989) and Parks et al. (2004).

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 chromium compounds 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 chromium compounds.

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. There are studies correlating chromium in urine (Cocker et al. 2007; Gylseth et al. 1977; Kilburn et al. 1990; Lindberg and Vesterberg 1983a; McAughey et al. 1988; Minoia and Cavalleri 1988; Mutti et al. 1985b; Sjogren et al. 1983; Tola et al. 1977), blood (Kilburn et al. 1990; Lewalter et al. 1985; McAughey et al. 1988; Wiegand et al. 1988), hair (Randall and Gibson 1987, 1989; Takagi et al. 1986), hair in children (Chiba et al. 2004), nails (Takagi et al. 1988), and erythrocytes (Lukanova et al. 1996) to occupational exposure levels. Since chromium is an essential element, levels of chromium compounds have to be relatively high in humans before they signify an increase due to exposure. Hair has been useful in determining chronic occupational exposure to chromium in high concentrations (Randall and Gibson 1989), although the utility of this method for detecting prior exposures has a limited timespan of months (Simpson and Gibson 1992). Analytical methods to detect chromium concentrations in urine (Randall and Gibson 1987), whole blood (Case et al. 2001; Dube 1988; Fahrni 2007), serum/plasma (Simonoff et al. 1984), and tissue (Fahrni 2007; Liu et al. 1994) have been reported. Generally, the detection limits are in the sub ppb to ppb range, and recoveries are good (>70%).

Chromium induced DNA-protein complexes were prepared as a biomarker of exposure, as discussed in Section 3.12.2. These complexes can be detected by potassium chloride-sodium dodecyl sulfate mediated precipitation. These methods have a number of inherent limitations including tedious methodology and

being subject to considerable interindividual and interlaboratory variations (Singh et al. 1998b). Only one study has attempted to utilize this biomarker, and it was found that volunteers exposed to chromium in drinking water showed no increase in protein-DNA crosslinking in blood cells (Kuykendall et al. 1996). This suggests that this procedure may not be sensitive enough for use in environmental monitoring unless an individual has received a potentially toxic level of exposure. In addition, chromium forms chromium-DNA complexes inside of cells, and these complexes constitute a potential biomarker for the assessment of environmental or occupational exposure. A novel method has been described for the sensitive detection of chromium-DNA adducts using inductively coupled plasma mass spectrometry (Singh et al. 1998b). The detection limits of this method are in the parts per trillion range and allow for the detection of as few as 2 chromium adducts per 10,000 bases, which coupled with the low DNA sample requirements, make this method sensitive enough to measure background levels in the population. There are no data to determine whether there are age-specific biomarkers of exposure or effects or any interactions with other chemicals that would be specific for children.

Methods for Determining Parent Compounds and Degradation Products in Environmental Media. Methods are available and in use for detecting chromium in air, water, and soil environments. Methods have been developed that can determine low levels of total chromium and chromium(VI) in the air, with detection limits in the ng/m^3 range and excellent recoveries (90% or better) (Ashley et al. 2003; Barrie and Hoff 1985; CARB 1990; NIOSH 2003a; Sheehan et al. 1992). These methods are sufficient to determine background chromium levels in the environment and levels at which health effects may occur. There are also field-portable instruments that can be employed to rapidly measure chromium(VI) levels in workplace air (NIOSH 2003b; Wang et al. 1999). Chromium can be detected in water at concentrations in the ppb range (Abu-Saba and Flegal 1997; EPA 1983a, 1996a; Harzdorf and Janser 1984 Parks et al. 2004) and household and bottled drinking water (Al-Saleh and Al-Doush 1998), with recoveries of ≥90% being reported in some studies. In addition, there are also methods that can differentiate chromium(VI) from chromium(III) in water samples (EPA 1986c, 2011). A reliable analytical method for extracting and quantifying chromium from soil surfaces has also been reported (Ayyamperumal et al. 2006; Oygard et al. 2004). Analytical methods exist that are sufficient for measuring background levels of chromium in soil (Ayyamperumal et al. 2006; EPA 1996b; Finley and Paustenbach 1997; Oygard et al. 2004) and water (EPA 1983a, 1983b, 1983c, 1986a, 1996a; Finley and Paustenbach 1997) and also water samples collected from various geological sites of interest (Gonzalez et al. 2005; Parks et al. 2004).

7.3.2 Ongoing Studies

Analytical methods for the detection of chromium compounds at increasingly lower concentrations are currently under development. Targeted areas of interest include air, water, and soil monitoring, with special emphasis being placed on populations considered vulnerable or potentially at risk, such as children and occupational workers. Additionally, more reliable methods to separate chromium(III) analysis from chromium(VI) analysis in collected samples is a source of interest and active research.