Medical Screening and Biological Monitoring

A Guide to the Literature for Physicians

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The use of medical screening and biological monitoring has seen substantial changes in the past two decades specifically in the provision of occupational medical services. For example, national surveys of workplaces conducted by the National Institute for Occupational Safety and Health (NIOSH) showed that the provision of off-site medical care to workers increased from 19.6% in 1972–1974 to 57.8% in 1981–1983, although the percent of workers receiving on-site services remained stable during the same period. After a recent survey in 1990–1991, the Occupational Safety and Health Administration (OSHA) estimated that 6.3% of US industries have a medical surveillance program at their individual establishment. We reviewed NIOSH documents, OSHA's Code of Federal Regulations, and texts on biological monitoring and medical screening for recommendations on medical surveillance of workers. This report summarizes the medical tests (including biologic monitoring) recommended or used by independent investigators and by the government for OSHA-regulated substances to provide guidance to physicians and occupational health professionals in accessing the pertinent literature; the utility of the recommendations is not evaluated.

In the continuum of measures for the prevention of occupational disease, substantial changes have occurred in the past two decades in the provision of occupational medical services. One trend evident in national surveys of workplaces conducted by the National Institute for Occupational Safety and Health (NIOSH) has been an increase in the provision of off-site medical care of workers from 19.6% in the 1972–1974 National Occupational Hazard Survey to 57.8% in the National Occupational Exposure Survey conducted in 1981–1983.[1] The percent of workers receiving on-site services remained stable, however: 20.8% in the National Occupational Hazard Survey and 19.1% in the National Occupational Exposure Survey.[1] Currently, there is no information on the training of the physicians providing these services.

A recent survey conducted in 1990–1991 by the Occupational Safety and Health Administration (OSHA) estimated that 6.3% of all US industries currently have a medical surveillance program at the individual establishment.[2,3]

A concurrent trend shows an increased interest in academic training for occupational medicine.[4] However, although there has been a growth in the number of accredited occupational medicine residencies from 10 in 1976 to 36 at present, only 150 residents are now being trained (NJ Berberich, personal communication, 1992). The inevitable conclusion is that many workers are receiving occupational medical services from physicians with at most a modicum, if any, training in occupa-

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tional medicine and who are practicing off-site, away from their on-site industrial hygienist and occupational nurse colleagues, who are more familiar with the specific hazards of the worksite.

This scenario suggests that information, if appropriately formatted, may help the practicing off-site generalist in providing appropriate occupational medical services to the workers. Two approaches that are useful in the prevention of occupational disease are medical screening and biological monitoring.[5] Medical screening is the search for early signs or symptoms of disease before the patient is symptomatic. Biological monitoring is the testing of a specimen from the patient for the presence of a hazardous intoxicant or its metabolite. To effectively and appropriately utilize these techniques, the physician delivering occupational medical services must (1) understand the role of medical screening and biological monitoring in the full spectrum of approaches to occupational disease prevention, (2) be knowledgeable of the chemical and physical hazards to which the workers are exposed, and (3) have access to scientific and regulatory literature.

Current health practices have shown some problems in the provision of medical services: (1) Few physicians are trained in occupational medicine, (2) the off-site physician may have very little information regarding specific hazards in the worksite, and (3) there are numerous tests recommended in the literature for the various substances. A simple guide with specific medical tests for specific substances would be helpful to both the occupational physician and the general practitioner.

This report summarizes the medical tests recommended by the federal government and by independent individuals for substances regulated by OSHA in 1989[6] and revised on June 30, 1993.[7] The goal of this report is to provide the practicing physician with a roadmap to the literature of the available recommendations for medical screening and biological monitoring of the regulated substances; its intent is not to provide an evaluation of the amassed recommendations or a validation of the medical tests for use in surveillance.

Materials and Methods

The June 1993 revised list of substances regulated by OSHA, ie, substances in Table Z-1 of the OSHA standard,[7] was used to create the accompanying medical surveillance recommendations table. The OSHA list includes isomers of substances as well as compounds of individual substances.

For this report, recommendations for medical surveillance, ie, medical screening or biological monitoring, made jointly by OSHA and NIOSH, and by various individuals for the 1993 OSHA-regulated substances were reviewed and tabulated.

Literature Review and Selection Criteria

A literature search was conducted for medical screening requirements or biological monitoring techniques described by various individuals for the OSHA-regulated substances. Only those data sources that discussed or recommended medical tests for most OSHA-regulated substances have been included in the accompanying table. This type of selection criteria will have eliminated individual studies published on a particular chemical or improved screening methods for a specific chemical. It will also have excluded medical tests recommended only for a few specific chemicals, eg, heavy metals, specific pesticides, etc. This selection method has been followed because it is not the intent of this report to include every article or book that describes a medical screening test or a biological monitoring method. At the same time, the more recent books, eg, Lauwerys and Hoet,[8] and LaDou,[9] have discussed these methods in their review sections, and subsequently have included them in their recommendations. The medical tests, including biological monitoring techniques, are included in the accompanying table. An exhaustive list of references on biological monitoring methods will be made available upon request.

Second, it is not the intent of this report to describe the detailed procedure of each method recommended or every determinant of the biological material described in the open literature. It must be mentioned that many of the data sources available also include information on nonoccupational exposure levels, ie, reference values, for the specific determinants. In such cases, only the media, ie, biological materials, for which a clinical effect level has been identified during occupational exposure, are included in this report. However, many determinants and media are not included in our table if the authors found insufficient data or large individual variability. For example, mandelic acid levels are determined in the urine because of occupational exposure to styrene as well as nonoccupational exposure; styrene itself is noted in mixed-exhaled air and in blood at specific times (occupational); because there were insufficient data on the clinical effects level due to occupational exposure,[9] these tests are not included in our report.

Third, the recommended medical tests provided in our table may be for the chemical in question, its metabolite, or several metabolites of the chemical. For example, exposure to the chemical trichloroethylene can be determined by urinalysis using the determinants trichloroacetic acid and trichloroethanol. In addition, free trichloroethanol as well as trichloroethylene can be determined in the blood; the latter can also be determined in end-exhaled air.

Fourth, in the case of biologic monitoring, the sampling time is very critical in many instances and must be adhered to particularly when the level of the determinant changes rapidly or accumulation occurs because of continued exposure to the chemical. Hence, depending upon

the uptake and elimination rates of the chemicals and their metabolites, the sampling time will be different. For example, "end of shift" usually means the sampling can be done during the last 2 hours of exposure because the chemical or metabolite is eliminated rapidly with a half-life of less than 5 hours. The "end of workweek" notation usually means that exposure to the chemical is for 4 or 5 consecutive days and that elimination of the chemical or its metabolite has a half-life longer than 5 hours. When "end of shift at end of workweek" is mentioned, exposure to the chemical on the 5th day is also to be taken into consideration and the sample should be taken at the end of the shift at the end of the workweek. For other definitions, the original reference provided in the table should be scrutinized by the general practitioner or occupational health professional.

The following are the data sources that discussed or recommended medical tests or biological monitoring methods for the OSHA-regulated substances. The title of each data source, its availability, and a brief description of its contents, with emphasis on medical surveillance, ie, medical screening tests and/or biological monitoring methods, are provided below. Because this report deals basically with the OSHA-regulated substances, the OSHA references will be discussed first followed by other references.

Literature Review

1. *Air Contaminants. Final Rule. Department of Labor. Occupational Safety and Health Administration (OSHA). 29 CFR Part 1910.* Federal Register Volume 58, No. 124, pp 35337–35351. Wednesday, June 30, 1993.[7] The Federal Register is available from the Superintendent of Documents, P.O. Box 371954, Pittsburgh, PA 15250–7954.

The Federal Register is published Monday through Friday and makes available to the public any regulations and legal notices issued by federal agencies. These include Presidential proclamations and Executive Orders and federal agency documents.

The revised final rule published by OSHA on June 30, 1993 was the result of the revocation of the 1989 OSHA regulations by the 11th Circuit Court of Appeals. Although the final rule limits recommended by OSHA in 1989 were vacated, the permissible exposure limits specified in the "transitional limits" (29 CFR Part 1910) have remained in effect and are being enforced.

Details of the revised OSHA standard (1993) are presented below in the Code of Federal Regulations citation.

2. *Code of Federal Regulations, Title 29, Part 1910 (Section 1910.1000 to end); Revised as of July 1, 1993.*[10] This document is available from the Superintendent of Documents, US Government Printing Office, Washington, DC 20402.

The Code of Federal Regulations (CFR) is a compilation of the regulations of the executive departments and agencies of the Federal Government and is published in the Federal Register. Each volume of the CFR is revised at least once each calendar year and issued on a quarterly basis. Regulations relating to the air contaminants were revised by the Department of Labor as of July 1, 1993 and made available in January 1994. As mentioned above, the "Final Rule Limits" aspect of the 1989 regulations were vacated by the 11th Circuit Court of Appeals and the permissible exposure limits specified in the "Transitional Limits" are being enforced.

The regulations relating to air contaminants, ie, OSHA-regulated toxic and hazardous substances, are presented in Title 29, Part 1910, Subpart Z, Section 1910.1000 of the Code of Federal Regulations, 1993. Detailed regulations including the medical surveillance requirements (ie, recordkeeping, medical removal requirements, etc) for the substances are further discussed in Part 1910, Subpart Z, Sections 1910.1001 to 1910.1050.[10] For example, a detailed discussion of the standard for lead starts on page 139.[10] Requirements for medical surveillance for lead, which includes biological monitoring, medical examinations and consultations, and chelation, are discussed on pages 144–149. Medical removal protection requirements for lead are presented on pages 148–149. Medical surveillance and medical removals for lead are also discussed under "Recordkeeping" requirements on pages 150–151, and under Appendix B of the Standard, which provides the "Employee Standard Summary" (pp 157–160).[10] The complete medical surveillance guidelines for lead are discussed in Appendix C of the Standard on pages 167–171; this appendix provides an introduction, medical surveillance requirements, and monitoring requirements for workers exposed to inorganic lead, adverse health effects of inorganic lead, medical evaluation, and laboratory evaluation.[10]

3. *NIOSH/OSHA Occupational Health Guidelines for Chemical Hazards.* Mackison FW, Stricoff RS, Partridge LJ, Jr, Little AD, Inc, eds. US Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health, and US Department of Labor, Occupational Safety and Health Administration. DHHS (NIOSH) Publication Nos. 81-123, 88-118, and 89-104. Supplements I-OHG and II-OHG.[11] The three-volume set and its supplements are available from NIOSH Publications, 4676 Columbia Parkway, Cincinnati, OH 45226. Tel: 1-800-356-4674

Following the 1970 Occupational Safety and Health Act,[12] NIOSH and OSHA jointly developed a series of complete occupational health guidelines for substances with existing permissible exposure limits. These guidelines contain technical information and recommendations to provide a basis for the promulgation of new occupational health guidelines and are intended primarily for the industrial hygienist and medical service personnel responsible for initiating and maintaining an occupational health program. The medical surveillance aspect of the occupational health guidelines is placed under the heading "Health Hazard Information" and contains recommendations

for pre-employment and periodic medical examinations and other relevant tests depending upon the individual substance.

This document will be useful to the occupational physician because it is chemical-specific and thus serves as an index to chemical hazards. It not only provides information on medical surveillance requirements but also provides the physician with information on the toxicity of the substance including effects of overexposure. The document is up-dated periodically as more information becomes available on the substances.

The 1988 and 1989 supplements of the Guidelines[11] contain a detailed description of the toxicological and medical aspect of each substance. For example, the "Recommended Medical Practices" includes Medical Surveillance Program, Preplacement Medical Examination, Periodic Medical Screening and/or Biologic Monitoring, Medical Practices Recommended at the time of Job Transfer or Termination, and Sentinel Health Events.

4. *1994–1995 Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices.* American Conference of Governmental Industrial Hygienists (ACGIH).[13] This booklet is published annually and is available from ACGIH, Technical Affairs Office, Kemper Woods Center, 1330 Kemper Meadow Drive, Cincinnati, OH 45240

The American Conference of Governmental Industrial Hygienists (ACGIH) is an organization devoted to the administrative and technical aspects of occupational and environmental health. The ACGIH is a professional society, not a government agency. Threshold limit values (TLVs) for toxic substances have been recommended by this conference since 1950; as toxicity studies on a chemical are completed, the TLVs are appropriately recommended by the TLV committee. In the past few years, TLVs for physical agents as well as biological exposure indices for specific substances have been included in the TLV booklet.

In our report, the TLVs are not discussed but the sampling time for determining the biologic exposure indices of regulated substances are provided in the accompanying table. More details on the determinants, sampling time, etc, are provided in the companion publication *Documentation of TLVs and BEIs—Sixth Edition.*[14]

5. LaDou J, editor. *Occupational Medicine.* East Norwalk, CT: Appleton & Lange; 1990.[9] This book is available from Appleton & Lange, 25 Van Zant Street, East Norwalk, CT 06855.

This book provides a guide to common occupational injuries and illnesses, their diagnosis and treatment, and preventive and remedial measures in the workplace and is a useful resource for health care professionals as well as for students and residents.

Medical surveillance recommendations are provided for metals, inorganic and organic chemicals, solvents, pesticides, etc, in separate sections by different authors. In addition, Rempel et al[15] have summarized, in tabular format, the recommendations for medical monitoring of the various substances discussed in the book. Care should be exercised in using the table for occupational exposure situations because nonoccupational reference levels and levels at which no adverse effects noted among workers are also provided. Our report includes only those chemicals for which clinical effect levels were provided by Rempel et al[15] in this book.[9] Our report does not include the substances for which there was insufficient data on clinical effects among workers. Also, no distinction has been made between the biological monitoring recommendations made for the regulated substance or its metabolite(s).

6. Baselt RC. *Biological Monitoring Methods for Industrial Chemicals*, 2nd ed. Chicago: Year-Book Medical Publishers; 1988.[16] This book is available from Year Book Medical Publishers, Inc, 200 N. LaSalle Street, Chicago, IL 60601. Baselt RC. *Biological Monitoring Methods for Industrial Chemicals.* Davis, CA: Biomedical Publications; 1980.[17] This book may be available only through the library services.

The second edition of the book by Baselt[16] is valuable to the investigator who needs detailed methodology for conducting biological monitoring of specific substances. This book apprises the occupational physician of more than 90 substances for which methodology for biologic monitoring is available; the first edition recommended methods for biologic monitoring for 80 substances.[17] Some of the substances can be determined in more than one specimen, eg, blood, urine, etc. The choice of specimen depends upon its routine availability, the metabolic profile of the specific substance, route of exposure, time of sampling, and characteristics of the analytical method to be used. The specimens most often used are urine, blood, plasma, and serum; wet and dry ashing of the biologic specimen is also conducted with some substances, eg, arsenic. Biopsy fat, saliva, hair, breast milk, nails, and feces have been used in specific instances.

7. Kneip TJ, Crable JV, eds. *Methods For Biological Monitoring—A Manual for Assessing Human Exposure to Hazardous Substances.* Washington, DC: American Public Health Association; 1988.[18] This book is available from the American Public Health Association, 1015 Fifteenth Street, NW, Washington, DC 20005.

This manual provides methods for the analysis of body fluids, breath, hair, nail, and other tissues from human subjects in a step-by-step manner. It describes many of the currently used laboratory methods for biological monitoring in a uniform and readily usable manner. Part 1 provides basic information on the principles of biologic monitoring and Part 2 describes, in detail, methods for measurement of each substance. According to the authors, analytical methods were developed primarily to assess toxic exposures in the workplace, but these methods can be used in situations of suspected contamination, fugitive emissions, or other potential human exposures with hazardous materials.

8. Clarkson TW, Friberg L, Nordberg GF, Sager PR, eds. *Biological Monitoring of Toxic Metals.* Rochester Series on Envi-

ronmental Toxicity. New York: Plenum Press; 1988.[19] This book is available from Plenum Press, Division of Plenum Publishing Corporation, 233 Spring Street, New York, NY 10013.

This document is the result of a conference held in Rochester, June 2–6, 1986 on "Biological Monitoring of Metals." The conference was organized jointly by the Environmental Health Sciences Center of the School of Medicine and Dentistry of the University of Rochester, New York, and the Scientific Committee on the Toxicology of Metals within the International Commission on Occupational Health at the Karolinska Institute and the National (Swedish) Institute of Environmental Medicine and the University of Umea, Sweden. The aim of the conference was to define and evaluate the scientific basis for the biological monitoring of metals.

The overview of the biological monitoring of toxic metals is quite exhaustive and includes invited papers by individuals. The occurrence, metabolic model, toxicity, and biologic monitoring analysis of the metals and an evaluation of the procedures used is helpful to the health professional. For our report, the individual authors are not referenced but the book itself is.

9. Ho MH, Dillon HK, eds. *Biological Monitoring of Exposure to Chemicals. Organic Compounds.* 1987[20] and Dillon HK, Ho MH, eds. *Biological Monitoring of Exposure to Chemicals. Metals.* 1991[21] Both books are available from John Wiley & Sons, Inc, Eastern Distribution Center, 1 Wiley Drive, Somerset, NJ 08873-1272.

The primary goal of these publications is to provide an assessment of current applications and future directions of the biological monitoring of occupational exposure to chemicals. The first book deals with exposure of workers to organic chemicals and the second book deals with their exposure to metals. After an introduction to general and theoretical aspects of biological monitoring, reviews and recent investigations of applications of biological monitoring to specific substances are provided. Some of the investigations in both books deal with nonoccupational exposures including animal experiments; hence it is important to separate the determinants and media in the biologic monitoring of nonoccupational subjects from those in occupational settings. This is particularly true in the case of biologic monitoring of metals, eg, lead, mercury, etc, which has been extensively studied among the general population and in animals.

10. Aitio A, Riihimaki V, Vainio H, eds. *Biological Monitoring and Surveillance of Workers Exposed to Chemicals.* 1984. Hemisphere Publishing Corporation, 79 Madison Ave, Suite 1110, New York, NY 10016.[22]

This book contains the proceedings of the International Course on Biological Monitoring of Exposures to Industrial Chemicals held in Hanasaari Cultural Centre, Espoo, Finland, Aug 4–9, 1980. It contains general views on both theoretical and practical aspects of the performance of biological monitoring. In addition, it includes discussions on health surveillance of certain chemicals which are of major interest in occupational health and toxicology. For this report, the biological monitoring techniques discussed throughout the book are collated and the book is referenced instead of the individual authors.

11. Lauwerys RR, ed. *Industrial Chemical Exposure: Guidelines for Biological Monitoring.* Davis, CA: Biomedical Publications; 1983,[23] and Lauwerys RR and Hoet P, eds. *Industrial Chemical Exposure: Guidelines for Biological Monitoring,* 2nd ed. Lewis Publishers, 1993.[8]

The first edition of the book[23] summarizes the practical applications of toxicokinetic studies scattered throughout the open literature. The author's aim was to offer a practical guide to occupational physicians, industrial hygienists, and clinical chemists in assessing the exposure of workers to industrial chemicals.

The second edition, published in 1993,[8] provides further clarification of toxicokinetics of substances in humans. A few more biomarkers of exposure have been included in this edition and attempts have been made to better assess the relationship between the biomarker of exposure and the risk of adverse effects. For example, the estimation of total arsenic in workers exposed to inorganic arsenic depends upon the levels of seafood content (organic arsenic) in their diet and in drinking water; thus, both organic and inorganic arsenic levels are obtained if serum and urine levels of workers are used as biomarkers, unless workers have been instructed to refrain from eating fish or shellfish for 2–3 days before urine collection.[8] Another indicator for assessing inorganic arsenic content is the use of hair and fingernail analyses because of their high content of keratin. However, according to Yamauchi et al,[24] there is presently no reliable method available to remove exogenous arsenic. Lauwerys and Hoet[8] thus conclude that the determination of arsenic in hair and nail is more useful for evaluating the environmental exposure of the general population to inorganic arsenic than for estimating the exposure of workers.

A summary of the principal biological monitoring methods have been provided in tabular form in the last chapter of the 1993 edition of the book. It must be pointed out that the table includes the biological material for nonoccupationally exposed subjects (as reference values) as well as for occupationally exposed workers (as tentative maximum permissible concentrations). For our report, biomarkers recommended for occupationally exposed workers only have been included from the Lauwerys and Hoet 1993 table.[8] Also, no distinction has been made between the parameters used for any given biological material.

12. Proctor NH, Hughes JP, eds. *Chemical Hazards of the Workplace.* 1978[25]; Proctor NH, Hughes JP, Fischman ML, eds. *Chemical Hazards of the Workplace,* 2nd ed. 1988,[26] Philadelphia: J.B. Lippincott. Hathaway GJ, Proctor NH, Hughes JP, Fischman ML, eds. *Chemical Hazards of the Workplace,* 3rd ed. New York: Van Nostrand Reinhold Publishers; 1991.[27]

This book is in its third edition and is intended primarily for the health professional who needs toxicological

information on most chemicals used in the workplace. The first edition[25] provides the medical surveillance requirements for over 400 substances most likely to be encountered at work; many of these substances have been regulated by OSHA. The substances chosen for this Part are mainly from the Standard Completion Program, which was a joint effort by NIOSH and OSHA to develop supplemental requirements for the 386 workplace environmental exposure standards adopted by OSHA in 1971. Subsequently, these requirements were published as NIOSH/OSHA occupational health guidelines for chemical hazards[11] which have been described earlier in this report. The medical surveillance requirements include preplacement examinations, questionnaires with emphasis on the specific disorder, periodic examinations, and specific tests. This edition of the book may not be available with the publishers but may be loaned from the library.

More recent information on the toxicology of the substances or the permissible exposure levels mandated by OSHA are provided in the second and third editions of the book.[26,27] The monographs are arranged in alphabetical order with a description of the chief signs and symptoms caused by overexposure to the substance. The clinical manifestations, diagnostic tests, treatment, etc, for each substance are not discussed per se in these two editions but they are discussed in a general chapter in Part One of the book. The clinical effects seen in humans relative to exposure levels and the various doses reported in the literature allow for the consideration of a dose-response relationship. If sufficient human data are not available to illustrate the human effects, data from animal tests are provided in the third edition to depict the target organs that should be monitored closely in exposed workers.

The second and third editions of the book[26,27] are divided into two parts and an appendix. Part One provides "Guidelines in Occupational Health Practice." Part Two provides, in monograph format, a brief toxicologic review of each substance chosen from the NIOSH/OSHA occupational health guidelines.[11] The chapter "Some Clinical Manifestations of Occupational Chemical Exposure Seen in Emergency Medical Situations" includes appropriate tables of various toxicants causing specific signs or symptoms or specific disorders. Such information would be helpful to the practitioner to determine the occupational relatedness of the emergency medical situation.

13. Linch AL. *Biologic Monitoring for Industrial Chemical Exposure Control.* 1974.[28] This book may be available from CRC Press, 18901 Cranwood Parkway, Cleveland, OH 44128.

This is one of the first few books that discussed biological monitoring methods for industrial chemicals regulated by OSHA in 1974. Included in this book are various indicators used for biologic monitoring and some interesting methods described for the media chosen. A table is also provided with the appropriate indicator recommended for each chemical on the 1974 regulated list. In addition, the book provides a discussion on tissue systems other than the usual ones, eg, skin monitoring, hair, other body fluids and tissues, and physiological monitoring.

Two data sources that discuss biological monitoring strategies and their implementation are presented below; the information from these data sources will be helpful to the general practitioner or health professional although it does not contain specific medical surveillance requirements.

14. Fiserova-Bergerova V, Ogata M, eds. *Biological Monitoring of Exposure to Industrial Chemicals. Proceedings of the United States-Japan Cooperative Seminar on Biological Monitoring.* American Conference of Governmental Industrial Hygienists, Inc, 1990.[29] This book is available from the American Conference of Governmental Industrial Hygienists, Inc, Kemper Woods Center, 1330 Kemper Meadow Drive, Cincinnati, OH 45240

This is a monograph of papers presented at the Proceedings of the US-Japan Cooperative Seminar on Biological Monitoring of Exposure to Industrial Chemicals held Aug 22–25, 1989 at the East-West Center, University of Hawaii. Scientists and occupational health practitioners from both countries exchanged views on information and implementation of biological monitoring of occupational exposures to industrial chemicals in their respective countries.

Some salient features of interest of this publication to public health officials include a number of solvents with their respective urinary metabolites. Another feature is the discussion of "Biological Tolerance Values for Working Materials," which was first published in 1981. The book presents the appropriate parameters to be used in biological monitoring for numerous substances including organic solvents and metals. However, no specific medical tests are provided for individual chemicals as noted in the above literature sources and hence the data from this literature source are not included in the accompanying table.

15. Droz PO, Wu MM. In: Rappaport SM, Smith TJ, eds. *Exposure Assessment for Epidemiology and Hazard Control.* American Conference of Governmental Industrial Hygienists; 1991.[30] This book is available from Lewis Publishers, Inc, 121 South Main Street, PO Drawer 519, Chelsea, MI 48118.

This chapter was one of the papers presented at the proceedings of an international workshop held at Woods Hole, Massachusetts on April 18–19, 1988. It deals with strategies used for biological monitoring of workers and the sampling strategy includes not only the biological indicator to be used but also the time scale. Examples of biological indicators, ie, determinants in specific media and their half-lives ($T_{1/2}$ hours), are presented in tabular format, which is helpful to the health professional. Because variability is inherent in biological monitoring, the authors provide a good discussion on identifying the main categories of variability before strategic implica-

TABLE 1
Location of Medical Screening Requirements for Substances in 29 CFR Part 1910*

Name of Substance	Page Number(s) (July 1, 1993)
Asbestos	26–27, 42–54, 58–60
Actinolite asbestos	
Amosite	
Anthophyllite asbestos	
Chrysotile	
Crocidolite	
Tremolite asbestos	
Coal tar pitch volatiles	–
Coal tar	
Phenanthrene	
Pyrene	
4-Nitrobiphenyl	64–65
α-Naphthylamine	69–70
Methyl chloromethyl ether	74
3,3'-Dichlorobenzidine/salts	79
bis-Chloromethyl ether	83
β-Naphthylamine	88
Benzidine	92–93
4-Aminodiphenyl	97
Ethyleneimine	101–102
β-Propiolactone	106
2-Acetylaminofluorene	110–111
4-Dimethylaminoazobenzene	115–116
N-Nitrosodimethylamine	120
Vinyl chloride	124
Inorganic arsenic	131–132
Lead	144–151,157–160,162–171
Cadmium	182–190,197–198,200–201
Benzene	284–287, 291–294
Coke oven emissions	311–312
Cotton dust	333–334, 340–357
1,2-Dibromo-3-chloropropane	363–364
Acrylonitrile	375–376, 383–384
Ethylene oxide	393–394, 402–404
Formaldehyde	414–418, 432–434
Methylenedianiline	448–452, 457–458

* Title 29, Code of Federal Regulations, Part 1910.1001–1050, July 1, 1993.[10]

tions are considered. Some of the topics helpful to the health professional are (1) individual sources of variability, (2) choice of a biological indicator, (3) biological monitoring results as a time series, (4) the contribution of individual variability, etc.

Results

Table 1 presents a listing of the substances regulated by OSHA along with the pages where medical surveillance requirements are discussed in the Code of Federal Regulations.[10] Depending upon the individual substance, requirements for medical surveillance, medical removal, recordkeeping, etc, are discussed in separate parts of the standard; the pages on which these are found are also specified in Table 1. In some cases, details of medical questionnaires are also provided in the Code of Federal Regulations and these are enumerated in Table 1. The page numbers shown in Table 1 pertain only to the July 1993 issue of the CFR and are likely to change in subsequent versions.

Table 2 presents the medical tests recommended by NIOSH/OSHA and by individual investigators for the OSHA-regulated substances using the literature sources just described. This table does not reflect appropriate diagnostic tests for symptomatic patients, but are screening tests for asymptomatic patients.

The Chemical Abstracts Service Registry Number (CAS Number) for each substance is included in Table 2 and serves the following purpose: (1) it identifies the specific substance; (2) it differentiates one isomer of a substance from another, ie, ortho- versus para-isomer; and (3) in the case of metals and their compounds, only the CAS number of the metal is provided for simplicity, eg, "antimony and compounds" has been given the CAS number allotted to "antimony." Table 2 presents both medical surveillance and biological monitoring tests for the substances; in some cases, further detail is provided, eg, a "24-hour urine specimen," or "last 2 hours of exposure," etc.

Conclusion

The primary prevention strategy for occupational diseases should be to prevent exposure of workers to substances associated with toxic effects. When such exposures cannot be prevented through the substitution or elimination of hazardous substances, the appropriate strategy is to limit exposure through the use of engineering controls and work practices, or less ideally by the use of personal protective devices. Secondary prevention is the detection of the disease process at an early stage before the process is irreversible; biological monitoring and medical screening fall into the secondary prevention strategy of occupational diseases. Biological monitoring, coupled with environmental monitoring, is a valuable tool that can assess the exposure of workers to substances, and is a measure of the adequacy of engineering controls, before any significant adverse health effect has occurred. The goal of medical screening is the early detection of the disease when it is reversible or more easily treatable. Medical screening is less desirable than the more primary means of prevention.[31]

TABLE 2

OSHA REGULATED SUBSTANCES -- SPECIFIC MEDICAL TESTS RECOMMENDED BY NIOSH/OSHA AND BY VARIOUS INDIVIDUALS

NAME OF SUBSTANCE	CAS NUMBER	NIOSH/OSHA	OTHER INDIVIDUALS
Acetaldehyde	00075-07-0	-	Bl[16] ExA[16,28] Ua[16]
Acetone	00067-64-1	PFT	Bl[8,16] ExA[16,28] Ua(EOS)[16] Ua[8] Ua(DE)[9]
Acetonitrile	00075-05-8	-	BlC[16] BlP[16] Ua[16] ExA[28]
Acetylaminofluorene, 2-	00053-96-3	RIC	-
Acetylene tetrabromide	00079-27-6	LFT	LFT[25] ExA[27]
Acrolein	00107-02-8	CXr PFT	CXr[25] PFT[25] ExA[27]
Acrylamide	00079-06-1	-	NCS[9]
Acrylonitrile	00107-13-1	CXr FOB PFT	BlC[16] BlP[16] Ua[9,16] BlS[9] ExA[28]
Aldrin	00309-00-2	-	Ua[25] BlP[16]
Allyl chloride	00107-05-1	CXr LFT PFT Ua CBC	CXr[25] PFT[25] ExA[27]
Aluminum metal	07429-90-5	-	CXr[25] BlS[18] Ua[8,18,20]
Aminodiphenyl, 4-	00092-67-1	RIC	-
Ammonia	07664-41-7	CXr PFT	PFT[25] CXr[25] ExA[28]
Aniline	00062-53-3	CBC Bl(MHgb)	Bl[8,25] Hgb[25] Bl(MHgb)[8,13,16,28] Bl(COHb)[28] Bl(DE)[13] Ua[8,16,22] Ua(EOS)[13]
Anisidine (o-isomer)	00090-04-0	CBC Bl(MHgb)	Bl[25] Bl(MHgb)[13] CBC[25]
Antimony & compounds	07440-36-0	PFT	Cxr[25] PFT[9,25] Ua[8,16,18,19,28] Bl[18] BT[18]
Arsenic, inorganic	07440-38-2	CXr SpC PFT	Ua[8,16,18,19,20,21,22,28] Ua(EWW)[9,13] BT[9] NCS1[21]
Arsine	07784-42-1	PFT	Bl[19,25] Ua[18,20,25] Ua(EWW)[13] LFT[25]
Asbestos	Varies	CXr PFT	-
Azinphos-methyl (Guthion®)	00086-50-0	CH(BlS RBC)	CH[9,25] CH(RBC)[13] BlS[18]
Barium and compounds	07440-39-3	CXr PFT Ecg	Ua[18]
Benzene	00071-43-2	CBC PFT	Ua[8,16,18,20,22,28] Ua(EOS)[13] ExA[8,16,22,28] ExA(PNS)[13] Bl[8,9,16,22]
Benzidine	00092-87-5	RIC PFT	Ua[9,16]
Benzyl chloride	00100-44-7	PFT.CXr	ExA[28]
Beryllium and compounds	07440-41-7	PFT CXr	CXr[9,25] PFT[9,25] Ua[9,16,20,28] BT[18]
Bis(chloromethyl) ether	00542-88-1	RIC PFT	SpC[9]
Boron trifluoride	07637-07-2	CXr PFT	CXr[25] PFT[25]
Bromine	07726-95-6	CXr PFT	CXr[25] PFT[25] ExA[27]
Butoxyethanol, 2-	00111-76-2	CBC	Bl[25] CBC[25]
Butyl alcohol, n-	00071-36-3	-	Bl[16]
Butyl chromate, tert-	01189-85-1	CXr	-
Butyl glycidyl ether (BGE)	02426-08-6	PFT	ExA[28]
Butyl mercaptan, n-	00109-79-5	PFT	ExA[28]
Butyltoluene, p-tert-	00098-51-1	Ecg CXr	ExA[28]
Cadmium dust and fume	07440-43-9	CXr LFT PFT Ua	PFT[25] Ua[8,9,13,16,18,19,21,25,28] CXr[28] Bl[8,9,13,16,18,19] BT[18] UCy[9]
Camphor, synthetic	00076-22-2	-	BlP[16] Ua[16]
Carbaryl (Sevin®)	00063-25-2	Ua Rep	CH[25] CH(EOS)[9] CH(PPS)[16] Ua[8,16,28] BlS[18]
Carbon black	01333-86-4	PFT	-
Carbon disulfide	00075-15-0	Ua LFT Ecg Oph	LFT[25] Ua[8,25,28] Oph[25] Ecg[25] Bl[16] ExA[16] Ua(EOS)[9,13,16]
Carbon monoxide	00630-08-0	CBC COHb	ExA[8,16,28] ExA(EOS)[13] Bl(COHb)[8,9,16,22,25,27] Bl(COHB EOS)[13] Bl[8] Bl(EOS)[9]
Carbon tetrachloride	00056-23-5	LFT Ua	LFT[25] KFT[25] Ua[25] Bl[9,16] ExA[9,16,28] Ua(24H)[9]
Chlordane	00057-74-9	Ua	Ua[25] Bl[9,16] BT[16] BlS[18]
Chlorinated diphenyl oxide	55720-99-5	LFT	-
Chlorine	07782-50-5	CXr PFT	CXr[25] PFT[25] ExA[27]
Chlorine dioxide	10049-04-4	CXr PFT	CXr[25] PFT[25]

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Chlorine trifluoride	07790-91-2	CXr PFT	CXr[25] PFT[25]
Chloroform	00067-66-3	LFT Ua	LFT[25] Ua[25] ExA[16,28]
Chloromethyl methyl ether	00107-30-2	RIC PFT	SpC[9]
Chloropicrin	00076-06-2	CXr PFT	CXr[25] PFT[25] ExA[28]
Chloroprene, beta-	00126-99-8	CXr PFT	CXr[25]
Chromic acid and chromates	07738-94-5	Ua CXr PFT LFT CBC	Ua[25] CXr[25] PFT[25]
Chromium, Metal and Insoluble salts	07440-47-3	CXr PFT	CXr[18,25] Ua(EOS)[16] Ua[6,13,18,19,22,28] Ua(ESW)[13] Bl[18,22] BT[18]
Coal dust	68131-74-8	-	PFT[25] CXr[25]
Coal tar pitch volatiles	65996-93-2	CXr PFT SpC Ua UCy CBC PpT	CXr[25] PFT[25] SpC[25]
Cobalt metal, dust, and fume	07440-48-4	CXr PFT	CXr[25] PFT[25] Ua(EOS)[16] Ua[6,18,19,28] Bl[18,19] BT[18]
Coke oven emissions	-	CXr Ua SpC PFT UCy	-
Copper dusts and mists	07440-50-8	-	BlS[16] Ua(24H)[16] Ua[18] Bl[9,18] BT[9,18]
Cotton dust	-	PFT CXr	-
Cresol, p-isomer	00106-44-5	PFT	Ua[16,18]
Cumene	00098-82-8	-	Ua(L2H)[6,16]
Cyanide	00057-12-5	CXr PFT	Bl[16] BlP[16] Ua[6,16] UaBL[8]
Cyclohexane	00110-82-7	-	Bl[8,16] ExA[8,16,28] Ua(EOS)[16] Ua[8,20]
Cyclohexanone	00108-94-1	PFT	Ua[8] ExA[28]
DBCP(1,2-Dibromo-3-chloropropane	00096-12-8	PFT	-
DDT (Dichlorodiphenyltrichloroethane)	00050-29-3	-	AdT[16] BlS[16,18] Bl[22] BF[16] Ua[16,28]
Demeton (Systox®)	08065-48-3	CH	CH[20,25] CH(RBC Bl BlP)[8] CH(RBC)[13]
Diacetone alcohol	00123-42-2	PFT	ExA[28]
Diazomethane	00334-88-3	CXr PFT	CXr[25] PFT[25]
Diborane	19287-45-7	CXr PFT	CXr[25] PFT[25]
Dibutyl phosphate	00107-66-4	-	Ecg[25] WBC[25] SpC[25]
Dibutyl phthalate	00084-74-2	-	-
Dichloro-5,5-dimethyl hydantoin, 1,3-	00118-52-5	-	Ecg[25] WBC[25] SpC[25]
Dichlorobenzene, p-	00106-46-7	LFT Ua	LFT[25] Ua[6,16,28] Bl(MHgb)[9] ExA[28]
Dichlorobenzidine, 3,3'-	00091-94-1	RIC PFT	-
Dichloroethyl ether	00111-44-4	CXr PFT	PFT[25] CXr[25] ExA[27]
Dichlorvos (DDVP)	00062-73-7	CH	CH[9,16,20,25] CH(RBC)[13] Ua[16] BlS[18]
Dieldrin	00060-57-1	-	BF[16] Bl[8,9,16] BlS[18]
Diglycidyl ether (DGE)	02238-07-5	PFT	CBC[25] CXr[25] PFT[25]
Diisobutyl ketone	00108-83-8	PFT	-
Dimethyl acetamide	00127-19-5	LFT	LFT[25]
Dimethylaminoazobenzene, 4-	00060-11-7	RIC	-
Dimethyl-1,2-dibromo-2,2-dichloroethyl phosphate (Naled)	00300-76-5	CH	CH[9,25] CH(RBC)[13] BlS[18]
Dimethylhydrazine, 1,1-	00057-14-7	PFT	Bl[25] LFT[25] CBC[25]
Dimethyl sulfate	00077-78-1	Ua PFT LFT CXr	Ua[25] CXr[25] PFT[25] LFT[25]
Dimethylaniline	00121-69-7	CBC Bl(MHgb)	Bl(MHgb)[13]
Dimethylphthalate	00131-11-3	-	Preg[25]
Dinitro-o-cresol	00534-52-1	-	BlW[6,16]
Dinitrobenzene, (all isomers)	Varies	CBC Bl(MHgb) LFT	Bl[25] CBC[25] Bl(MHgb)[13] LFT[25]
Dinitrotoluene, 2,4-	00121-14-2	CBC Bl(MHgb) LFT	CBC[25] Bl(MHgb)[13] LFT[25]
Dioxane (Diethylene dioxide)	00123-91-1	LFT Ua CXr PFT	LFT[25] KFT[25] BlP[16] Ua(EOS)[16] ExA[28]
DMF (Dimethylformamide)	00068-12-2	LFT	Ua(24H)[16] Ua[8,20,22] Ua(EOS)[13] Bl[8] ExA[8,28]
Endrin	00072-20-8	-	BlP[16] Ua[8,16] BlS[16] Bl[8]
Epichlorohydrin	00106-89-8	CXr PFT Ua LFT Rep	CXr[25] PFT[25] ExA[28]
EPN	02104-64-5	CH	BlS[16] CH[9] CH(RBC)[13] Ua[20]
Ether (Ethyl ether)	00060-29-7	-	Bl[16] ExA[28]

Ethoxyethanol, 2-	00110-80-5	-	-
Ethyl alcohol (Ethanol)	00064-17-5	-	Bl[16] ExA[16,28] Ua(EOS)[16] BlS[16]
Ethyl benzene	00100-41-4	-	Ua(L2H)[16] Ua[8,18,20] Ua(ESW)[13] ExA[8,13,28] Bl[8]
Ethyl mercaptan	00075-08-1	PFT	ExA[28]
Ethyl silicate	00078-10-4	-	Bl[25]
Ethylene chlorohydrin	00107-07-3	LFT Ua	LFT[25] Ua[25] ExA[28]
Ethyleneimine	00151-56-4	RIC PFT	ExA[28]
Ethylene dibromide	00106-93-4	CXr PFT LFT Ecg40 Rep	ExA[28]
Ethylene dichloride	00107-06-2	PFT	LFT[25] ExA[28]
Ethylene glycol dinitrate	00628-96-6	-	Bl[16,22,25] CBC[25] Ecg[25] Ua[16,22] Bl(DE)[8] ExA(DE)[8]
Ethylene oxide	00075-21-8	CBC PFT	CBC[9] ExA[28]
Ferrovanadium (and dust)	12604-58-9	CXr PFT	-
Fluorides, Inorganic	16984-48-8	Ua CXr PFT PXr	CXr[25] PXr[25] PFT[25] BlP[16,22] Ua(PTS)[13] Ua(EOS)[13,15] Ua[8,18,20,22,28]
Fluorine	07782-41-4	CXr PFT	CXr[25] PFT[25]
Formaldehyde	00050-00-0	PFT(PPS)	Bl[16,18] Ua[16,18] PFT[9]
Furfuryl alcohol	00098-00-0	PFT	ExA[28]
Graphite, natural	07782-42-5	CXr PFT	CXr[25] PFT[25]
Hexachloronaphthalene (Halowax 1014)	01335-87-1	LFT	LFT[16]
Hexane, n-	00110-54-3	-	Bl[8,16] ExA[8,13,16,28] Ua[8,16,20] Ua(EOS)[13]
Hydrazine	00302-01-2	PFT	CXr[25] PFT[25]
Hydrogen chloride (Hydrochloric acid)	07647-01-0	CXr PFT	CXr[25] PFT[25]
Hydrogen cyanide	00074-90-8	Ecg40	Bl(COHb)[28] ExA[28]
Hydrogen fluoride (Hydrofluoric acid)	07664-39-3	Ua PXr CXr PFT	CXr[25] PXr[25] PFT[25] Ua[20] Ua(PPS)[9] LFT[9] KFT[9]
Hydrogen sulfide	07783-06-4	CXr PFT	CXr[25] PFT[25] Bl[16] BlP[16] Bl(COHb)[28]
Hydroquinone	00123-31-9	PFT	-
Iodine	07553-56-2	CXr PFT	CXr[25] PFT[25]
Iron oxide fume	01309-37-1	CXr PFT	CXr[25] PFT[25] Ua[18] Bl[18] BT[18]
Isophorone	00078-59-1	PFT CXr	ExA[28]
Isopropyl alcohol (Isopropanol)	00067-63-0	-	Bl[16] Ua[16] ExA[8]
Isopropyl glycidyl ether (IGE)	04016-14-2	PFT	-
Ketene	00463-51-4	CXr PFT	CXr[25] PFT[25]
Lead, inorganic	07439-92-1	BlL ZPP Hgb BUN SCr Ua CBC	Bl[8,9,13,16,18,19,22] Ua[8,13,16,18,19,21,22,28] BT[18] BlL[9,21] Hgb[9] RBC[8] ZPP21[19] ZPP(1M)[13]
Lindane	00058-89-9	CBC	Bl[8,16,22,25] BlS[9,16] CBC[25] Ua[28]
Lithium hydride	07580-67-8	-	BlS[16] Ua[16] Bl[18] BT[18]
Malathion	00121-75-5	CH CXr PFT LFT	CH[9,16,20,25] CH(RBC)[13] Ua[16,28] BlS[18]
Manganese and compounds	07439-96-5	CXr PFT CBC Ua	Ua[9,16,18,19,28] Bl[18,19] BT[18] Neur[9]
MBK (Methyl n-butyl ketone)	00591-78-6	PFT	Bl[16] ExA[16] Ua(EWW)[8]
MEK (Methyl ethyl ketone)	00078-93-3	PFT	Bl[16,18,20] ExA[16,20,28] Ua[8,16,20] Ua(EOS)[13]
MIBK (Methyl isobutyl ketone)	00108-10-1	PFT	Ua[8] Ua(EOS)[13] ExA[28]
Mercury (organo) alkyl compounds	07439-97-6	Bl Ua	Ua[9,18,25] Bl[16,18]
Mercury, inorganic	07439-97-6	Ua	Ua[8,9,16,18,19,20,21,22,28] Ua(PTS)[13] Bl(ESW)[13] Bl[8,16,21,22] BT[18] NCS[21]
Methyl alcohol (Methanol)	00067-56-1	LFT	Ua[8,16,20] Ua(EOS)[13] Ua(PWW)[13] ExA[28]
Methyl bromide	00074-83-9	CXr PFT	BlS[16] Bl[9] ExA[28]
Methyl cellosolve	00109-86-4	CBC Ua	Ua[18,28]
Methyl chloride	00074-87-3	-	Bl[16] ExA[16,28]
Methyl chloroform	00071-55-6	Rep	LFT[25] Bl[8,16,20,22] Bl(EWW)[20] Bl(ESW)[13] ExA[16,20,22,28] ExA(PWW)[13] ExA(16H)[8] ExA(EWW)[20] Ua[8,16,22] Ua(ESW)[13] Ua(EWW)[8,13]
Methyl hydrazine	00060-34-4	PFT	-
Methyl isocyanate	00624-83-9	CXr PFT	CXr[25] PFT[25]
Methyl mercaptan	00074-93-1	PFT	Bl[25] CXr[25] PFT[25] ExA[28]
Methyl n-amyl ketone	00110-43-0	PFT	-
Methyl propyl ketone	00107-87-9	PFT	-
Methylene bisphenyl isocyanate (MDI)	00101-68-8	CXr PFT	CXr[25] PFT[25]

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Methylene chloride	00075-09-2	LFT CBC COHb	CBC[25] Bl[8,16] Bl(EOS)[9] Bl(COHb)[8,16] Bl(COHb EOS)[9] ExA[8,16,28] ExA(EOS)[9] Ua[28]
Mica	12001-26-2	CXr PFT	-
Molybdenum	07439-98-7	-	Bl[18,25] BT[18] Ua[18,28]
Monomethyl aniline	00100-61-8	CBC Bl(MHgb)	Bl[25] Bl(MHgb)[13] CBC[25] Ua[25]
Naphthalene	00091-20-3	CBC Ua	Bl[25] CBC[25] Ua[25] LFT[25] Bl(MHgb)[9]
Naphthylamine, alpha-	00134-32-7	RIC	-
Naphthylamine, beta-	00091-59-8	RIC	-
Nickel carbonyl	13463-39-3	CXr PFT SpC Ua	CXr[25] PFT[9,25] BlP[16] ExA[16,18] Ua[9,16,22] Bl[9]
Nickel, metal and soluble compounds	07440-02-0	CXr PFT	CXr[25] BlP[16,18,22] BlS[19] Ua[8,16,18,19,22] BT[18] PPS21[19]
Nicotine	00054-11-5	-	BlP[16] Ua[16]
Nitric acid	07697-37-2	CXr PFT	CXr[25] PFT[25]
Nitric oxide	10102-43-9	CXr PFT Ecg40	CXr[25] PFT[25] ExA[28]
Nitroaniline, p-	00100-01-6	CBC Bl(MHgb) LFT	Bl[25] CBC[25] LFT[25] Bl(MHgb)[9,13]
Nitrobenzene	00098-95-3	CBC Bl(MHgb) Ua	Bl[25] CBC[25] Bl(MHgb)[8,16] Bl(MHgb)[13] Bl(COHb)[13,28] Ua[8,16] Ua(EWW)[22] Ua(ESW)[13]
Nitrobiphenyl, 4-	00092-93-3	RIC	-
Nitrochlorobenzene, p-	00100-00-5	CBC BlMHgb	Bl(MHgb)[13]
Nitrogen dioxide	10102-44-0	CXr PFT Ecg40	CXr[25] PFT[25] ExA[28]
Nitrogen trifluoride	07783-54-2	CBC BlMHgb	Bl[25] Bl(MHgb)[13] CBC[25]
Nitropropane, 2-	00079-46-9	PFT CXr	-
Nitrosodimethylamine, N-	00062-75-9	RIC PFT	-
Nitrotoluene (all isomers)	Varies	CBC BlMHgb	Bl[25] CBC[25] Bl(MHgb)[9,13]
Octachloronaphthalene	02234-13-1	LFT	LFT[25]
Oxalic acid	00144-62-7	-	Ua[16]
Oxygen difluoride	07783-41-7	CXr PFT	CXr[25] PFT[25]
Ozone	10028-15-6	CXr PFT	CXr[25] PFT[25]
Paraquat	04685-14-7	CXr PFT Ua LFT	CXr[25] PFT[25] Ua[16]
Parathion	00056-38-2	CH	CH[9,16,20,25] CH(RBC)[13] Ua[8,16,20,28] Ua(EOS)[9,13] BlS[18]
PCB (42% Chlorine)	53469-21-9	LFT	LFT[9,25] Bl[9,16] BlP[16] AdT[16] BlS[18]
PCB (54% Chlorine)	11097-69-1	LFT	LFT[9,25] Bl[9,16] BlP[16] AdT[16] BlS[18]
Pentachloronaphthalene	01321-64-8	LFT	LFT[25]
Pentachlorophenol	00087-86-5	Ua	BlP[8,9,16] BlP(EOS)[13] Bl[18] BlS[18] Ua[8,9,16,18,28] Ua(PWW)[13]
Perchloroethylene (Tetrachloroethylene)	00127-18-4	LFT Ua	LFT[25] ExA[16,20,22,28] ExA(EOS)[9] ExA(DE)[8] ExA(PWW)[13] ExA(16H)[8] Bl[9,16,22] Bl(PWW)[13] Bl(16H)[8] Ua(16H)[8,13] Ua(EWW)[8,13]
Perchloromethyl mercaptan	00594-42-3	CXr PFT LFT	CXr[25] PFT[25]
Perchloryl fluoride	07616-94-6	CBC Bl(MHgb) CXr PFT	Bl[25] Bl(MHgb)[13] CBC[25] CXr[25] PFT[25]
Phenol	00108-95-2	Ua LFT	Ua[8,16,22,25] Ua(L2H)[16] Ua(EOS)[13] LFT[25]
Phenyl glycidyl ether (PGE)	00122-60-1	PFT	-
Phenylhydrazine	00100-63-0	PFT	Bl[25] CBC[25] LFT[25] Ua[25]
Phosdrin (Mevinphos®)	07786-34-7	CH	CH[9,25] CH(RBC)[13] BlS[18]
Phosgene (Carbonyl chloride)	00075-44-5	CXr PFT	CXr[25] PFT[25] ExA[28]
Phosphine	07803-51-2	-	CXr[25] PFT[25]
Phosphorus (Yellow)	07723-14-0	De LFT CBC(Anm)	De[25] LFT[25] CXr[9] Ua[9] PFT[9]
Phosphorus pentachloride	10026-13-8	CXr PFT	CXr[25] PFT[25]
Phosphorus pentasulfide	01314-80-3	CXr PFT	CXr[25] PFT[25]
Phosphorus trichloride	07719-12-2	CXr PFT	CXr[25] PFT[25]
Phthalic anhydride	00085-44-9	-	CXr[25] PFT[25] Ua[8]
Picric acid	00088-89-1	Ua LFT	Ua[25] LFT[25]
Pindone (2-pivalyl-1,3-indandione)	00083-26-1	PTT	Bl[25] CBC[25] PTT[25] Ua[25]
Platinum, metal, soluble salts	07440-06-4	-	Bl[18] BT[18] Ua[18]
Portland Cement	65997-15-1	CXr PFT	CXr[25] PFT[25]
Propiolactone, beta-	00057-57-8	RIC PFT	-

Propyl nitrate, n-	00627-13-4	CBC Bl(MHgb)	Bl[25] Bl(MHgb)[13] CBC[25] Ua[25]
Propylene imine	00075-55-8	CBC(GL)	Bl[25] CBC[25]
Pyridine	00110-86-1	Ua LFT	ExA[28]
Quinone	00106-51-4	Oph	Oph[25]
Selenium compounds except SeF_6	07782-49-2	Ua LFT	Bl[16,19,25] BH[16] Ua[16,18] Ua(24H)[19]
Selenium hexafluoride (SeF_6)	07783-79-1	CXr PFT	CXr[25] PFT[25]
Silica, amorphous, diatomaceous earth	61790-53-2	CXr PFT	CXr[25] PFT[25]
Silica, crystalline cristobalite	14464-46-1	CXr PFT	CXr[25] PFT[25]
Silicates--Soapstone	-	CXr PFT	CXr[25] PFT[25]
Silicates--Talc (without asbestos)	14807-96-6	CXr PFT	CXr[25] PFT[25]
Silver, metal & soluble compounds	07440-22-4	Pgm	Bl[18] BT[18] Ua[18]
Sodium fluoroacetate	00062-74-8	Ua Ecg	Ua[25] Ecg[25]
Sodium hydroxide	01310-73-2	CXr PFT	-
Stibine	07803-52-3	CBC(Hem) Ua LFT	Bl[25] CBC[25] Ua[25] LFT[25]
Stoddard solvent	08052-41-3	LFT Ua CBC	ExA[28]
Strychnine	00057-24-9	Cnv	-
Styrene	00100-42-5	-	Ua[8,16,18,20,22] Ua(EOS)[13,20] Ua(PNS)[13] ExA[8,15,22,28] Bl(16H)[8] Bl(EOS)[13] Bl(PNS)[13]
Sulfur dioxide	07446-09-5	CXr PFT	CXr[25] PFT[25] ExA[28]
Sulfur monochloride	10025-67-9	CXr PFT	-
Sulfur pentafluoride	05714-22-7	CXr PFT	CXr[25] PFT[25]
Sulfuric acid	07664-93-9	CXr PFT	CXr[25] PFT[25] Ua[9] KFT[9] LFT[9]
TEDP (Sulfotep)	03689-24-5	CH	CH[25] CH(RBC)[13] BlS[18]
Tellurium hexafluoride	07783-80-4	(RIr)	CXr[25] PFT[25] Ua[9]
TEPP (Tetraethyl pyrophosphate)	00107-49-3	CH	CH[25] CH(RBC)[13] BlS[18]
Tetrachloroethane, 1,1,2,2-	00079-34-5	LFT Ua	LFT[25] Ua[25]
Tetrachloronaphthalene	01335-88-2	LFT	LFT[25]
Tetraethyl lead	00078-00-2	Ua BMU	Ua[16,25] Ua(EOS)[28] BMU[25] Bl[16]
Tetramethyl lead	00075-74-1	Ua BMU	Ua[25] Ua(EOS)[28] BMU[25]
Tetranitromethane	00509-14-8	CXr PFT CBC Bl(MHgb)	Bl[25] Bl(MHgb)[13] CBC[25] CXr[25] PFT[25]
Tetryl	00479-45-8	CBC(Anm)	CBC[25]
Thallium and compounds	07440-28-0	Ua	BH[25] Ua[9,16,25,28] Bl[16,18] BT[18] NCS[9]
Tin, inorganic compounds (exc oxide)	07440-31-5	-	Ua[16,18] CXr[9] Bl[19]
Tin, organic compounds	Varies	Ua CBC(Hem) Glau LFT Ecg40	Ua[9,16]
TNT (Trinitrotoluene, 2,4,6-)	00118-96-7	CBC(ApA) LFT Ua	Bl[25] CBC[25] LFT[25] Bl(MHgb)[9]
Toluene	00108-88-3	Ua	Ua[8,16,18,25,28] Ua(EOS)[13,20] Bl[8,9,16,18,20] Bl(EOS)[13] ExA[8,13,16,18,28] ExA(DE)20[18]
Toluene-2,4-diisocyanate (TDI)	00584-84-9	PFT CXr	CXr[25] PFT[25]
Toluidine, o-	00095-53-4	CBC Bl(MHgb) Ua	Bl[25] Bl(MHgb)[9,13]
Trichloroethane, 1,1,2-	00079-00-5	-	ExA[9,28] Bl[9] Ua[9]
Trichloroethylene	00079-01-6	PFT	Bl[16,22] Bl(ESW)[13] BlP[8] ExA[8,13,16,22,28] Ua[8,16,22,28] Ua(ESW)[13] Ua(EWW)[9,13]
Trichloronaphthalene	01321-65-9	LFT	LFT[25]
Trichloropropane, 1,2,3-	00096-18-4	-	ExA[28]
Uranium and compounds	07440-61-1	CBC CXr Ua	Bl[25] CXr[25] Ua[16,18,25,28] CBC[25]
Vanadium fume (pentoxide)	01314-62-1	CXr PFT Ua	CXr[25] PFT[25] Ua[8,9,19]
Vinyl chloride	00075-01-4	Br APh SGOT SGPT GGT PFT	ExA[16,28] Ua[9,16] APh[16] Usg[18] LFT[9]
Warfarin	00081-81-2	PTT CBC(Hyt) Ua	Bl[25] BlP[16] CBC[25] PTT[22,25] Ua[25]
Xylene, all isomers	01330-20-7	CBC(HeD) LFT Ua	Bl[16,22,25] Bl(DE)[8] BL(EOS)[9] CBC[25] LFT[25] Ua[8,16,18,20,22,25] Ua(EOS)[13] ExA[16,20,28]
Xylidine	01300-73-8	CBC Bl(MHgb)	Bl[25] Bl(MHgb)[13] CBC[25]
Zinc chloride fume	07646-85-7	CXr PFT	CXr[25] PFT[25] Ua[9,16,18] Bl[18] BT[18]
Zinc oxide fume	01314-13-2	CXr PFT	Ua[9,16,18] Bl[18] BT[18]
Zirconium and compounds, except ZrCl4	07440-67-7	(GraS)	Bl[18] BT[18]
2,4-D (Dichlorophenoxyacetic acid,2,4-)	00094-75-7	-	BlP[16] Ua[16,28] Ua(24H)[22]
2,4,5-T (Trichlorophenoxyacetic acid)	00093-76-5	-	BlP[16] Ua[16,28] Ua(24H)[22]

Glossary of Terms used in Table 2

- = No Data
1M = After 1 month exposure
16H = 16 hours after exposure
24H = 24-Hour Specimen
AdT = Adipose Tissue
Anm = Anemia
ApA = Aplastic Anemia
Aph = Alkaline Phosphatase
BF = Biopsy Fat
BH/N = Body Hair/Nail
Bl = Whole Blood
BlC = Blood cyanaide
BlL = Blood Lead
BlM = Metabolite in Blood
BlP = Blood Plasma
BlS = Blood Serum
BlW = Blood Analyzed Weekly
BMU = Biologic Monitoring of Urine every 3 mos.
Br = Bilirubin
BT = Biologic Tissue/Biopsy
BUN = Blood Urea Nitrogen
CBC = Complete Blood Count
CH = Blood Cholinesterase
CXr = Chest X-ray
Cnv = Convulsions
COHb = Carboxyhemoglobin
DE = During exposure
De = Dental Examination
Ecg = Electrocardiogram
Ecg40 = Electrocardiogram on Workers over 40 years
EOS = End-Of-Shift
ESW = End of Shift at End of Workweek
EWW = End of workweek
ExA = Expired Air
FOB = Fecal Occult Blood Screening
GGT = Gamma Glutamyl Transpeptidase
GL = Granulocytic Leukemia
Glau = Glaucoma
GraS = Granuloma of the Skin
GUT = Genital Urinary Tract
Hem = RBC Hemolysis
HeD = Hematopoietic Depression
Hyt = Hypoprothrombinemia
Hgb = Hemoglobin
KFT = Kidney Function Tests
L2H = Last 2 hours of 8-hour exposure
LFT = Liver Function Tests
MHgb = Methemoglobin
NCS = Nerve Conduction Studies
Neur = Neurologic Examination
Oph = Ophthalmic Examination
PFT = Pulmonary Function Tests
Pgm = Pigmentation evidence
PNS = Prior to next shift
PPS = Pre- & Post-Shift
PpT = Photopatch Testing
Preg = Pregnant Women: Danger to Fetus
PTS = Prior to shift
PTT = Prothrombin Time
PWW = Prior to last shift of workweek
PXr = Pelvic Roentgenogram with proper gonadal shielding (male)
RBC = Red Blood Cells
ReC = Reticulocyte Count
Rep = Reproductive Effects
Ria = Radioimmunoassay
RIC = Reduced Immunologic Competence
RIr = Respiratory Irritation
SCr = Serum Creatinine
SCt = Sperm Count
SGOT = Serum Glutamic Oxalacetic Transaminase
SGPT = Serum Glutamic Pyruvic Transaminase
SpC = Sputum Cytology
Ua = Urinalysis
UaBl = Urine+Blood (smokers)
UCy = Urine Cytology
Usg = Ultrasonography of the Liver
WBC = White Blood Cell Count (differential)
ZPP = Zinc Protoporphyrin

The criteria for an effective screening test are safety, reliability, validity, likelihood of positive results in the presymptomatic period, and good positive predictive value. The appropriate choice of medical screening and biological monitoring tests depends upon a thorough knowledge of the workplace, the toxicity of each substance in use, and the efficacy of the medical screening and biological monitoring tests, which is a sizable task for the practicing physician.

This report only tabulates medical screening data recommended by NIOSH/OSHA and by the individual investigators; it does not attempt the onerous task of evaluating the efficacy of these tests for screening workers exposed to the specific substances.

Trends in the provision of occupational medical services suggest that the utilization of tests for medical screening and biological monitoring will continue to be performed by off-site physicians without substantial formal training in occupational medicine. This is also attested by the results of the recent survey conducted by OSHA which estimated that 6.3% of US industries had a medical surveillance program.[2]

It is hoped that the information provided in our tables and the attached references will provide a starting point for the practicing off-site physician to design an appropriate screening and monitoring program. However, it is to be remembered that just knowing the medical tests recommended for a substance is not sufficient; there are ethical, social, and legal issues that should be considered prior to establishing a medical screening or biological monitoring program. Such issues are adequately discussed by Ashford et al.[32] In addition, the occupational health program should be a team effort, ie, using the services of the industrial hygienist, safety officer, occupational health nurse, and the practicing physician.

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The History of Aspirin

In purses and backpacks, in briefcases and medicine chests the world over, millions of people keep close at hand a drug that has both a long past and a fascinating future. Its past reaches at least to the fifth century B.C. when Hippocrates used a bitter powder obtained from willow bark to ease aches and pains and reduce fevers. . . . The substance in willow bark that made ancient Greeks feel better, salicin, is the pharmacological ancestor of a family of drugs called salicylates, the best known of which is the world's most widely used drug—aspirin. . . .

Yet aspirin's beginnings were rather unspectacular. Nearly 100 years ago a German industrial chemist, Felix Hoffmann, set about to find a drug to ease his father's arthritis without causing the severe stomach irritation associated with sodium salicylate, the standard anti-arthritis drug of the time. In the forms then available the large doses of salicylates used to treat arthritis—6 to 8 grams a day—commonly irritated the stomach lining, and many patients, like Hoffmann's father, simply could not tolerate them.

Figuring that acidity made salicylates hard on the stomach, Hoffmann started looking for a less acidic formulation. His search led him to synthesize acetylsalicylic acid (ASA), a compound that appeared to share the therapeutic properties of other salicylates and might cause less stomach irritation. ASA reduced fever, relieved moderate pain, and, at substantially higher doses, alleviated rheumatic and arthritic conditions. Hoffmann was confident that ASA would prove more effective than salicylates then in use. His superiors, however, did not share his enthusiasm. They doubted that ASA would ever become a valuable, commercially successful drug because at large doses salicylates commonly produced shortness of breath and an alarmingly rapid heart rate. It was taken for granted—incorrectly as it turns out—that ASA would weaken the heart and that physicians would be reluctant to prescribe it in preference to sodium salicylate, a drug they at least knew. Hoffmann's employer, Friedrich Bayer & Company, gave ASA the now familiar name *aspirin,* but in 1897 Bayer did not think that aspirin had much of a future. It could not have foreseen that almost a century after its development aspirin would be the focus of extensive laboratory research and some of the largest clinical trials ever carried out in conditions ranging from cardiovascular disease and cancer to migraine headache and high blood pressure in pregnancy. . . .

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