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# **Study Designs for Pilot Testing and a Multimedia, Total Exposure Study in Delaware**

**Draft**

Prepared for

State of Delaware  
DNREC OTS  
89 Kings Highway  
Dover, DE 19901

Prepared by

RTI International  
3040 Cornwallis Road  
Research Triangle Park, NC 27709

RTI Project Number 0211670.001



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Dover, DE 19901  
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## **Preface**

This report was prepared in support of the State of Delaware's Department of Natural Resources and Environmental Conservation (DNREC) to serve as an update of a 1996 proposal prepared by RTI International\* (RTI), DNREC, and Department of Health and Social Services (DHSS) to characterize Delaware residents' exposures to pollutants in the environment. That proposal was subsequently revised in collaboration between the Delaware DNREC and RTI to become the exposure component of Senate-House Joint Resolution No. 11. Since 1996, advances in the science have changed what pollutants are considered important, how samples are collected, and how the collected samples are analyzed. Some of the most significant changes have occurred in the characterization and knowledge of particulate matter toxicology. Chemical usage patterns have changed, with production and usage decreasing for many chemicals and increasing for others and with concurrent concerns for new impacts on human health. Methods for the collection of environmental samples have improved over the years to result in fewer burdens on study participants. Analytical chemistry methods have also improved to permit the expanded characterization of a wider array of pollutants, often with great improvements in sensitivity and selectivity.

This report presents background and introductory information, the objectives of the revised monitoring program desired by the State of Delaware, the recommended approach to acquire the desired data, and an estimate of costs to aid the budgetary process as the State of Delaware moves such an exposure study forward. During planning discussions between DNREC and RTI, it was decided that two study designs would best serve the program. A pilot study (DESIGN I) would aid in the acquisition of information to inform and optimize a population-based probability design (DESIGN II). Testing of new collection and analysis methods or survey instruments is anticipated to provide information to show that either 1) the method or instrument performed acceptably, or 2) the method or instrument requires modification or should not be used in the implementation of DESIGN II. DESIGN I would also provide some data to provide a potential range of exposures across the State of Delaware and to provide some additional data relevant to the concerns related to emissions from the Indian River Power Plant. In Section 3 of this report, considerations relevant to both DESIGN I and DESIGN II are discussed, followed by details of both designs. Such information includes the key design considerations, the selection of participants, sample collection methods, the selection of target pollutants, and analytical chemistry approaches to the measurements of those pollutants. The specific details of DESIGN I and DESIGN II are then described separately in Appendices B and C, respectively. So that DESIGN I and DESIGN II might be used as stand alone documents, there is considerable redundancy, both between the two designs and with the overlay text.

It is critically important for the data produced by all facets of DESIGN I to be both defensible and, when possible, relate to national and international standards. The necessary levels of defensibility must be specifically identified in the detailed study workplan (to follow from this design) and would be established collaboratively with Delaware DNREC technical staff. From the outset, these levels will be guided by the Data Quality Objectives (DQOs) needed to test the hypotheses. Carefully defined standard operating procedures (SOPs) and validation

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\* RTI is a trade name of Research Triangle Institute.

under actual Delaware conditions help assure that the selected methods provide the required data and data quality.

## Executive Summary

In 1996, a proposal was jointly prepared by the State of Delaware's Department of Natural Resources and Environmental Conservation (DNREC) and RTI International (RTI) that was designed to characterize Delaware residents' exposures to pollutants in the environment. This proposal was subsequently revised to become the exposure component of Senate–House Joint Resolution No. 11 (SJR-11). Since 1996, advances in the science have changed which pollutants are considered important, how samples are collected, and how the collected samples are analyzed. Some of the most significant changes have occurred in the characterization and knowledge of particulate matter (PM) toxicology. Chemical usage patterns have changed, with production and usage decreasing for many chemicals and increasing for others and with concurrent concerns for new impacts on human health. Methods for the collection of environmental samples have improved over the years to result in fewer burdens on study participants. Analytical chemistry methods have also improved to permit the expanded characterization of a wider array of pollutants, often with great improvements in sensitivity and selectivity. This document provides an update on the state of the science and folds this new information into an overarching study design.

The underlying goals of the study described herein are to execute robust study designs that reflect clear relevance to the State of Delaware's environmental and health requirements, as well as apply defensible methodologies and defined DQOs that produce databases that are scientifically credible and stand up to national review. Study data will be used to

The most current thinking and practice will enable the State of Delaware to bring the latest science to environmental characterization and personal exposure science for the protection of public health.

- Characterize human exposure representative of the people of Delaware. A probability-based human exposure study conducted within Delaware will provide a statistically defensible representation of the exposures experienced by the people of Delaware. A combination of indoor, outdoor, and personal environmental samples (e.g., air, drinking water, food, dust) will be used, along with biological samples, to help characterize human exposure.
- Serve as a baseline for future trends monitoring. Trends data are critical to understanding the environmental factors associated with changes in disease incidence and to help assess the effectiveness of the policy/regulatory changes designed to reduce human exposure to pollutants. Key uses of study data are risk assessments and source identifications.
- Validate models that have been developed to predict human exposures. One of the logical applications of data from area monitors is the prediction of local pollutant concentrations that can then be used to inform about risk estimations. An exposure study that includes outdoor, indoor, and personal measurements will provide data that can be used to validate the transport models in use (outdoor measurements) and to estimate the extent to which personal exposure can be predicted, given additional information of housing characteristics, personal and household behaviors, and individual mobility. Exposure models under development at EPA incorporate media other than air to provide a multimedia estimation.

Discussions held among DNREC, the Delaware Health and Social Services's (DHSS's) Division of Public Health, RTI, and The Delaware Cancer Consortium suggested that two study designs would best serve the program. DESIGN I will address three objectives over a 12-month

DESIGN I provides for statewide multimedia pollutant range finding, protocol testing, and refined data on emissions from the Indian River Power Plant.

period, ahead of the probability-based Multimedia Exposure Study (MMES) proposed in DESIGN II. The design of the National Human Exposure Assessment Survey (NHEXAS) MMES (Pellizzari et al., 2000; Whitmore et al., 1999) provides an underlying framework for the current, updated designs. DESIGN I is a pilot effort with three objectives to complete the study design for the MMES and provide initial exposure data for targeted areas within the state. First, the pilot study will determine the range of contaminant concentrations across all of Delaware that are expected in all media planned to be investigated during the MMES of DESIGN II. Three areas with presumed low, medium, and high pollutant concentration will be targeted. Second, a study of experimental and analytical methods will be simultaneously implemented for specific metrics to identify the best methods for DESIGN II. Methods for survey selection, recruitment/enrollment, sample collection, analysis, archival, and database management will be evaluated and refined, as needed. Although many accepted and proven methods are proposed, the testing of new or Delaware-specific collection and analysis methods or survey instruments is anticipated to provide information to show that either 1) the method or instrument performed acceptably, or 2) the method or instrument requires modification or should not be used in the implementation of DESIGN II. Lastly, an intensive exposure characterization study will be conducted in the Millsboro Census County Division (CCD), as one of the three locations for statewide range finding, to provide additional data relevant to the concerns related to emissions from the Indian River Power Plant.

Measurement of contaminant concentration ranges in all media (e.g., air, water, food, soil, and house dust) across Delaware will be made as part of DESIGN I. Air samples will be collected inside and outside of participants' residences. Personal air samples and other environmental samples that impact personal exposure will also be collected. Biological samples will help to define pollutant doses experienced by participants. The data will identify whether concentrations are spatially homogeneous or heterogeneous for classes of air pollutants and specific air pollutant species. The influence of local point and area sources (primarily for air) will be factored into the experimental design, especially when accounting for specific particle or gas-phase species. Food and water media contaminant ranges are not expected to be large across the state, except for those citizens electing to use specialty foods and waters (e.g., organic food, homegrown vegetables, self-caught fish, and bottled water). The preliminary selection of analytes and biomarkers addresses adverse cancer, cardiovascular, and pulmonary outcomes and was developed from many sources. Among these sources are recent Delaware-specific reports (DNREC/DAWM, 2005; DNREC/DWR, 2007b; DNREC/DAWM, 2007; DNREC/DAWM, 2006) on the spatial distributions of a wide range of contaminants, as well as the most recent U.S. Environmental Protection Agency (EPA) PM criteria document (U.S. EPA, 2004). These sources, along with input from Delaware DNREC and DHSS technical staff, will be used to guide the final design.

A variety of pollutants will be measured, including PM, volatile organic compounds (VOCs) (including reactive aldehyde [carbonyl] chemicals), polynuclear aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), persistent organochlorine pesticides, environmentally non-persistent pesticides (organophosphates and pyrethroids), polybrominated

diphenyl ethers (a class of brominated flame retardants), polyfluorinated acids, and reactive gases and ions. Air  $PM_{2.5}$  and  $PM_{10}$  mass concentrations will be characterized. Also, the concentrations of chemical species adsorbed to PM that are known source apportionment markers, inflammatory agents, and/or carcinogens will be measured (U.S. EPA, 2004).

For the air route, it is expected that  $PM_{10}$  concentrations may be more variable than  $PM_{2.5}$ , especially if the coarse PM component ( $PM_{2.5-10}$ ) is the major contributor to  $PM_{10}$ . However, it is also known that the chemical species that comprise  $PM_{2.5}$  may vary spatially due to the impact of local sources before atmospheric mixing distributes the species uniformly. Similarly, VOC and carbonyl concentrations may be greater near point and area sources. VOCs and carbonyls may show less spatial variability due to their greater diffusivity and photochemical degradation.

Source, meteorological, and geographical influences will also impact the (air) PM and gas/vapor concentrations. Point sources, such as the Indian River Power Plant and the Valero refinery, will generate high-concentration hotspots, where their emission plumes reach ground level. The hotspot locations will vary between sources because of emission rates and release heights. Area sources, such as highways, will have a more localized impact on pollutant concentrations. PM concentration gradients reach a background level within 500 m of the road, whereas VOC and carbonyl gradients quickly reach equilibrium in <200 m. Meteorology is another factor because wind speed, wind direction, and atmospheric stability determine the direction and rate of pollutant dispersion from any source. Geographic influences include primarily population density and source-to-receptor proximity, as influenced by the meteorology. Pollutant concentrations in urban, suburban, and rural areas are expected to vary, especially for specific species, due to the impact of local sources. Also, the Delaware coast will have its own wind speed and direction micrometeorology that may differ substantially from weather conditions at interior locations.

The communities around the Indian River Power Plant have been identified as a high-priority area for addressing the third objective for DESIGN I. Neighborhoods expected to have low, medium, and high PM concentrations caused by Indian River Power Plant emissions and not impacted by other point sources will be identified in conjunction with DNREC. It is especially important to additionally characterize the (upwind, depending on the meteorology) regional background coming into Delaware from the surrounding areas during the sampling to support Objective 3. The predominant seasonal meteorology and distance from the source will be determining factors that define the low-, medium-, and high-concentration areas resulting specifically from the Indian River Power Plant as compared to any other source category.

Provision is made in DESIGN I (and in DESIGN II) to archive samples for later analyses. This provision allows full use of the value of the field efforts that led to the collected samples and permits after the fact prioritization of analyte class/matrix combinations for chemical analysis to meet the needs at hand within the resources available. A well-designed archival plan can also allow the later chemical analyses of pollutants outside the current project's scope, perhaps to even include emerging future pollutants.

In DESIGN II, the MMES will collect data to monitor participants at multiple points in time, and it proposes using a moving panel strategy to collect multimedia exposures measurements for major pollutants in separate calendar years. This approach, termed a hopscotch design, enables the acquisition of human exposure data to particular pollutants in a systematic,

periodic manner so that costs of the program can be spread across years. Consistent implementation of annual DESIGN II monitoring phases over time provides the basis for baseline exposure characterization and for the identification of exposure trends. These data will support linkages between exposure and chronic disease outcomes and can help assess the impact of pollution-control regulations. The inclusion of longer sampling intervals (i.e., the number of days for which exposures are measured for each person) and seasonal variations will provide better estimates of the yearly exposure. This will improve not only the utility of the data for the study of chronic diseases, such as cancer, but the increased time resolution will also provide better a linkage between exposures and acute disease outcomes, including pulmonary and cardiovascular diseases.

The Multimedia Total Exposure Study of DESIGN II builds on the lessons and data from DESIGN I to provide an optimized probability-based study to characterize human exposures for all residents of Delaware.

The DESIGN II plan will, for the first time, allow statistically valid inferences concerning statewide contaminant exposures that represent and apply to all Delaware residents. The expected participant selection of 400 Delawareans will be made randomly across the state to reflect the population densities in each of the 27 Delaware CCDs. Collection and contaminant analysis of air, water, food, house dust, backyard soil, and biospecimen samples over a planned 9-year period at the personal, residence level in each selected Delaware household will add enormously to our understanding of who in Delaware is most/least exposed to toxic components during their daily activities. This understanding of resident exposures by all pathways will facilitate the most robust assessments possible for health risks in Delaware from a comprehensive list of acute and chronic environmental stressors. Ambient (air) monitoring data from existing DNREC sites will allow the DESIGN II data to be related to separate Delaware data collection efforts and the development, testing, and validation of human exposure models.

Defensible statistical inferences about Delaware's population require a sample survey in which all household residents of the state (the members of the DESIGN II survey population) have a positive probability of selection. Important factors include an operational definition of the population, a mechanism for selecting subjects from the population with known probabilities, specific hypotheses to be tested or population parameters to be estimated, and precision requirements. The overview of the DESIGN II approach is provided in Table ES-1, which presents the key elements that have been incorporated into the design. To meet the study objectives and the specific hypotheses proposed, it is important that subpopulations are adequately represented in the survey. These subpopulations include the residents of each county, the residents of each CCD of Delaware who have cancer incidence rates higher than the corresponding state incidence rates, the urban/suburban residents of Delaware; the rural residents of Delaware; the residents of CCDs along the Interstate-95 corridor through Wilmington; and the residents of CCDs near the Indian River Power Plant and the Valero refinery.

A population sample, based on equal distribution among New Castle, Kent, and Sussex counties, is inadequate for state-level inferences because the population of the state is not evenly distributed among these counties. The 2000 census data show that the mean population densities for New Castle, Kent, and Sussex counties are 1,174; 215; and 167 persons per square mile, respectively, which highlights the more rural characteristics of Kent and Sussex counties. The CCDs' spatial distribution of combined cancer incidence rates suggests a gradient of cancer incidence that moves from north to south and calls for a study of the possible correlation between

pollutant exposures and cancer rates. Since 1996, census data show a slight shift in population toward the less dense Kent and Sussex counties.

As a result, the sample will be equally allocated between New Castle, Kent, and Sussex counties. This allocation will result in slight oversampling of the southern two-thirds of the state, which is appropriate for addressing the unusually high cancer prevalence there, as well as for highlighting the importance of pollutant emissions from the Indian River Power Plant on exposures that may have led to the high cancer rate. Limiting the geographic comparisons to these areas reduces sample size requirements and is efficient for establishing statewide estimates. Moreover, the sample size requirements for the CCD-level and urban/rural comparisons will then be comparable, thus efficiently using resources. Each monitoring cycle in the hopscotch design will consist of approximately 400 total observations—either 400 unique sample persons or 300 unique persons with repeat observations in different seasons for 100 of them.

Establishing clearly defined Data Quality Objectives, using tested and standardized approaches to field sample collection and chemical analysis, and constructing databases that contain data of defined quality will help provide information that can be defensibly related to national and international studies.

It is critically important that the data produced by all facets of DESIGN II are defensible in all respects and, where possible, can be referenced to national and international methods and standards. The necessary levels of defensibility are established collaboratively with DNREC

technical staff, and, from the outset, are guided by the DQOs necessary to test the hypotheses and the soundness of the fundamental design, which is based heavily on the original SJR-11 plan. Carefully defined protocols and SOPs with validation under actual Delaware conditions will help ensure that the selected methods provide the required data and data quality to achieve the study objectives.

**Table ES-1. Overview of DESIGN II**

Design Element	Description
Design basis	Multimedia, multipathway exposure study
Cohort selection	Stratified random sample of Delaware adults (ages 18 years or older)
Spatial stratification levels	Personal, household, census tract, CCD
General hypothesis	Delaware residents do or do not have excessive health risks from a comprehensive suite of environmental pollutants via all pathways and relevant media
Pathways	Inhalation, ingestion, dermal exposure
Media	Air, water, food, house dust
Contaminant phases	Particles (PM <sub>10</sub> and PM <sub>2.5</sub> ) and vapor /liquid
Contaminant chemical class targets	Metals, diesel PM chemicals, pesticides, VOCs, PAHs, PCBs, dioxins, furans, carbonyls, perfluorinated acids, PBDEs, environmental tobacco smoke
Supporting metrics	Meteorological variables, air receptor modeling chemicals, residence air exchange
Dose media	Blood, urine, hair
Health risk basis	Cancer, cardiovascular disease, pulmonary disease, asthma
Source categories	Power generation, mobile source combustion, chemical production, refineries, (non-Delaware) regional background
Model development	Total exposure prediction by pathway, media, and stratification level; prediction of the residents' personal exposures from fixed-location measurements

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## 1. Background and Introduction

### 1.1 Cancer and Delaware

In April 2008, the Delaware Health and Social Services's (DHSS's) Division of Public Health released a report on annual age-adjusted cancer incidence rates from 2000–2004 at the Delaware sub-county level (DHSS, 2008). This report identifies eight Census County Divisions (CCDs) with cancer rates higher than the state as a whole. The CCDs are Central Pencader, Kenton, Lower Christiana, Middletown-Odessa, Millsboro, New Castle, Upper Christiana, and Wilmington. Statistically elevated incidence rates in these CCDs include lung cancer, prostate cancer, colorectal cancer, and all cancers combined.

Cancer, unlike many other diseases, has a wide-ranging latency period (the time between the occurrence of insult, which initiates the disease and its final symptomatic expression, terminating with death) that can span anywhere from a few years to 20 to 30 years. This phenomenon complicates attempts to discover a cause-and-effect relationship between environmental contamination and mortality. The ability to establish a relationship between environmental contamination and a health outcome requires establishing that contact has occurred between a person and a pollutant. Exposure is defined scientifically as the contact between a pollutant and an exchange membrane (e.g., lung, gut, skin). Unfortunately, longitudinal exposure data for pollutants that parallel the latency period for cancer and that might explain the elevated cancer rates in Delaware do not exist. For this reason, attempting to discover the basis for the elevated rates in Delaware has been extremely difficult using a retrospective approach. During the past 10 years, Delaware's Department of Natural Resources and Environmental Control (DNREC) has greatly expanded its air monitoring network and has conducted many other studies to address potential sources of exposure, including fish, and has used modeling to study the transport of pollutants to Delaware residents. However, there has been no systematic multipathway human exposure monitoring program conducted that can estimate, on a probability basis, the exposure of Delaware residents. The types of cancers that have been identified suggest the importance of carcinogens that are inhaled or ingested (DHSS, 2008).

### 1.2 Pollution and Exposure

Environmental Awareness. The environmental movement began at the grassroots level in the 1960s, and subsequent to this groundswell, U.S. President Richard Nixon established the U.S. Environmental Protection Agency (EPA) in 1972. The formation of the EPA galvanized research programs on air and water quality, and Congress subsequently passed the Clean Air Act and the Clean Water Act in the 1970s. These Acts have been reauthorized since their initial passage. The predominant research conducted throughout the 1970s and 1980s was to determine the occurrence of pollutants in specific media (i.e., in air, water, sediments). However, beginning in the late 1970s, scientists recognized that people's exposure to pollutants stemmed from multiple media and pathways; therefore, pollutant exposure was determined to be a multi-route phenomenon. As a result, a new vista of research programs was initiated to develop the ability to measure people's exposure to pollutants by monitoring relevant pathways (aggregate exposure). As the field of exposure research matured over the next 10 years, research methods and concepts became available, which enabled the measurement of exposures in populations through the use

of probability-based sampling techniques. The paucity of exposure data for populations to date has hampered the examination of today's cancer incidences throughout the United States.

In addition to cancer, there are other adverse effects that can manifest as a result of exposure to pollutants. Gases (e.g., ozone and nitrogen and sulfur oxides [NO<sub>x</sub>, SO<sub>x</sub>]), particulate matter (PM), and metals have been shown to impact pulmonary disease, including asthma, chronic obstructive pulmonary disease (COPD), and cardiovascular disease. Mercury, lead, brominated flame retardants, and non-persistent pesticides, impact neurological development and function. Organochlorine (OC) pesticides, phthalates, and perfluorinated chemicals may impact endocrine function and reproductive ability. Pollutants can enter the body by inhalation, ingestion (e.g., food, water, non-dietary), and by dermal routes. Thus, both cancer and non-cancer endpoints (e.g., asthma, cardiovascular disease, and endocrine disturbances) can be induced or exacerbated by exposure to pollutants, suggesting that a broad array of chemicals be monitored in a variety of matrices to provide the most complete environmental data.

Environmental Monitoring and Exposure. Regional monitoring networks provide a great deal of information about air pollutants in areas surrounding monitoring stations, and transport models can predict potential exposures downwind of the monitoring stations. Although there is great appeal to using models to predict exposure, the activities of individual persons, including movements into and out of micro-environments and the use of various consumer products, can impact indoor concentrations of modeled pollutants. Volatile pollutants from the outdoors penetrate the indoor environment, and their concentrations can be modulated by indoor sources and sinks. Similarly, outdoor PM penetrates the indoor environment, depending on PM size and the air exchange rate of the given structure. Indoor sources, such as cooking, surface shedding, and re-suspension of previously deposited particulate matter, also contribute to changes in PM predicted from outdoor measures. Thus, it is only through the measurement of exposure at the individual level (personal exposure) that accurate depictions of potential exposure can be made. The absorbed fraction (dose) of the aggregate potential exposure is the factor that is most directly linked to adverse health outcomes. From a health perspective, it is most desirable to know this dose, generally reflected by measurements in biological media, yet the relationship of the biological concentrations to the measured environmental concentrations is extremely important as well. Through appropriate study designs, measures in biological media can be linked to measures in environmental media. It is the environmental concentration that can be regulated in an attempt to protect public health.

Biomonitoring and Exposure. Advances in analytical chemistry methods have improved the analysis of biological specimens and data from such analyses that have been used to gain an understanding of the total (cumulative) exposures experienced by individuals. Cumulative exposure refers to past and/or present exposure (including relevant background exposure) of an individual or subpopulation to multiple environmental stressors that occur by all pertinent routes, pathways, and sources (Sexton and Hattis, 2007). The accurate application of data from biological specimens, commonly blood (or plasma or serum), urine, hair, and saliva, to assess exposure requires an understanding of the physiological kinetics of the individual pollutants and the time relationships between the occurrence of the exposure and the collection of the biological medium. These temporal relationships are less important for highly persistent and lipophilic compounds (e.g., polychlorinated biphenyls [PCBs], OC pesticides, polybrominated diphenyl ethers [PBDEs], perfluorinated acids, and bioaccumulative metals [e.g., lead, cadmium]), than for non-persistent compounds, such as the pyrethroid pesticides or volatile organic compounds

(VOCs). For example, the measurement of urinary 3-phenoxybenzoic acid (3-PBA) provides an instantaneous view of recent exposure to permethrin and related pyrethroid pesticides. Following an acute exposure, 3-PBA concentrations in urine increase, and then decrease rapidly, to non-detectable concentrations within a couple of days. By contrast, a measureable concentration of an OC pesticide in the blood can reflect past exposures because such compounds partition into body fat following an exposure and are released into the blood, metabolized, and then excreted slowly over time. Although biological samples provide information about cumulative exposures, only concurrent measures of environmental media that are relevant to a given exposure pathway can provide information about contemporary exposures.

If the desired study outcome is a valid interpretation of the importance of a particular pathway or route of exposure on the absorbed dose, then the biological half-life of the pollutant must be considered. The timing of biological sample collection relative to environmental sample collection is important. Referring back to the 3-PBA example previously mentioned, consider the collection of food and urine samples on the same day. If the urine sample is taken shortly after the food was consumed, chemical analysis of the food for pyrethroids and the urine for 3-PBA might result in measurable values in both media. However, any urinary 3-PBA that was measured cannot be related to the pyrethroid concentration in the collected food because insufficient time had passed to permit absorption of the pyrethroid, its metabolism to 3-PBA, and its urinary excretion. In other words, any urinary 3-PBA arose from an earlier, unmeasured ingestion. Similarly, the measurement of urinary 3-PBA in a sample collected 1 week following the food collection also cannot be related to the pyrethroid concentrations in the food because any 3-PBA formed as a result of the ingestion has long since been excreted.

Multimedia Exposure Studies. The National Human Exposure Assessment Survey (NHEXAS) was conducted in EPA Region 5 (Great Lakes area) in the mid-1990s for EPA's National Exposure Assessment Research Laboratory (Lioy and Pellizzari, 1995; Pellizzari et al., 1995). The NHEXAS procedures addressed all phases of the design, implementation, and reporting processes, focusing on chronic, longer term exposure periods. An important element of the NHEXAS design approach was the application of personal-level exposure sampling procedures, along with parallel residence- and neighborhood-scale sampling to provide the most accurate and representative estimates of the extremes (e.g., upper and lower 10 percentiles) of the exposure distributions. The NHEXAS program developed the basic suite of methodologies for describing exposure distributions for key environmental contaminants (those identified as environmentally important in the mid-1990s) in all media and exposure routes, with a random, probability basis that was applied for the cohort selection process. The basic NHEXAS design approach is still considered the "gold standard" by which exposure studies attempt to provide the most robust estimates of distributional exposures for a spatially defined cohort (Whitmore et al., 1999). Periodic re-sampling in subsequent years would allow for the longitudinal assessment of temporal trends, as well as for defining the impacts of mitigation programs to address exposures that were deemed to be excessive.

The high cost of implementing the NHEXAS design in Delaware subsequently suggested that a more manageable parsing strategy by contaminant category for the technical elements was appropriate. Major individual contaminant categories (e.g., sized PM, pesticides, polycyclic aromatic hydrocarbons [PAHs]) would be addressed in separate calendar years to reduce the funding levels required annually. This "hopscotch" design (i.e., the collection of selected media across Delaware each year), which was applied across several years, defined the overall exposure

program and was applicable for addressing adverse health outcomes, such as cancer, in which long latency periods often exist between the contaminant exposures and the adverse outcomes.

In response to the 1994 Governor's Task Force on Cancer report, the Governor of Delaware signed on June 23, 1995, the Senate–House Joint Resolution No. 11 (SJR-11) “requiring the Department of Natural Resources and Environmental Control and the Department of Health and Social Services to prepare and submit a plan and an estimate of associated costs to expand existing monitoring and analysis programs and to develop new programs to monitor and analyze the environment and the population to better understand the interaction between environmental toxicants and public health.” The resolution called for acquiring information that will 1) provide a better understanding of the interaction between the environment and the population and 2) permit health risk assessments to be performed for Delaware's population.

As part of a response to SJR-11, a Delaware-specific version of the NHEXAS design was developed in 1996 that consisted of three selectable study designs, focusing on the same integration periods and a suite of environmental contaminant exposures. The design levels, which were designated as A, B, and C, were intended to be applied entirely within the State of Delaware and each level represented a different intensity level regarding the proportion of personal-level exposures. For example, Level A consisted of ambient (outdoor) sampling, but no personal-level sampling, whereas Level C incorporated personal sampling for every study participant, along with indoor and outdoor metrics. An update of the Level C plan is the focus of this document.

## 2. Overall Objectives

The underlying goals of the study described herein are to execute robust study designs that reflect clear relevance to the State of Delaware's environmental and health requirements, as well as apply defensible methodologies and DQOs that produce databases that are scientifically credible and stand up to national review. Study data will be used to

- Characterize human exposure representative of the people of Delaware. A probability-based human exposure study conducted within Delaware will provide a statistically defensible representation of the exposures experienced by the people of Delaware. A combination of indoor air, outdoor air, and personal environmental samples (i.e., air, drinking water, food, house dust) will be used, along with biological samples (i.e., blood, urine, hair), to help characterize human exposure.
- Serve as a baseline for future trends monitoring. Trends data are critical to understanding the environmental factors associated with changes in disease incidence and to help assess the effectiveness of the policy/regulatory changes designed to reduce human exposure to pollutants. Key uses of study data are risk assessments and source identifications.
- Validate models that have been developed to predict human exposures. One of the logical applications of data from area monitors is the prediction of local pollutant concentrations that can then be used as input for risk estimations. An exposure study that includes outdoor, indoor, and personal measurements will provide data that can be used to validate the transport models in use (outdoor measurements) and to estimate the extent to which personal exposure can be predicted, given additional information of housing characteristics, personal and household behaviors, and individual mobility.

### **3. Approach**

#### **3.1 Introduction**

During April 2008, a joint meeting was held among DNREC, DHSS, RTI, and The Delaware Cancer Consortium to discuss how the science of exposure had changed since 1996 and how a study conducted in 2008 might be different. A Delaware citizens' group, the Delaware Citizens for Clean Power, also attended the public portion of the meeting. Discussions before and after the public meeting focused on those elements that would best meet both the long-term and short-term needs of the state.

Recent cancer cluster health concerns that were summarized by DHSS (2008), along with parallel concerns expressed by Delaware citizens' groups, including the Delaware Citizens for Clean Power, provide a basis to more closely study the link between excessive exposures and potential offending adverse health consequences. These consequences include cancer risks and potentially increased cardiovascular and pulmonary health risks. Supporting data to assist in assessments that link causes and effects are now needed in a timely manner—specifically, in no more than a 12-month period beginning in late 2008. This time requirement suggests that a stand-alone pilot study (DESIGN I) is needed ahead of the full study (DESIGN II) to conduct three hypothesis-driven sub-studies. In DESIGN I, the first sub-study will collect limited data at three locations in Delaware for a wide range of contaminants to define the expected ranges that would be encountered in a large-scale effort. The second sub-study, which will be conducted concurrently, will provide for the basis of the methodology selection (i.e., those that best meet the study Data Quality Objectives [DQOs]), for DESIGN II, having tested them under Delaware conditions and within the Delaware boundaries in DESIGN I prior to DESIGN II implementation. A third sub-study would focus on collecting exposure data for a range of contaminants, including potential carcinogens and cardiopulmonary stressor exposures in the proximity of the Indian River Power Plant that may (over short or long periods) have contributed to the observed excess cancer frequency or other more acute health indicators of citizens living in the vicinity (primarily the Millsboro CCD in Sussex County).

The study designs being put forward reflect the population assumed in SJR-11 (i.e., adults over the age of 18 years). It should be noted that children, especially younger children, experience different exposures than adults because of their behaviors (e.g., mouthing and the resultant increase in non-dietary ingestion exposure, and their physiology). With regard to the latter, the volume of air breathed per kg body weight is higher than adults; the properties of their skin are different, which could result in different rates of dermal uptake compared to adults; and their metabolic capabilities are immature (especially true for very young children). These factors can combine to result in substantially increased doses (i.e., increased exposure and slowed elimination) relative to adults, for a given pollutant. In addition, children are in a stage of development that might render them more susceptible to a health outcome (e.g., neurological decrement), than an adult, even at the same dose. The inclusion of children creates an additional dimension of complexity, especially with regard to the approaches used for sample collection. Although feasible, those unique attributes and consequent budgetary impacts have not been included at this stage.

## 3.2 Contaminants for Study

Samples collected during the study will be analyzed for substances with known associations with cancer, asthma and other respiratory indications, or cardiovascular disease. A variety of analytes will be measured that may provide information about the origins of related pollutants (source apportionment markers). In addition, analyses will be performed to determine the concentrations of emerging pollutants of concern, most of whose effects are endocrinological or neurological, including effects on reproduction and childhood development.

In considering the contaminants for study, thought must be given to the sources of the contaminants, the media that might contain those contaminants (environmental matrices), as well as to the routes of exposure (i.e., inhalation, ingestion, dermal). Outdoor sources can include point sources (e.g., power plants and industrial operations), mobile sources (e.g., gasoline- and diesel-powered vehicles), and area sources (e.g., agricultural operations), where chemicals are applied to large areas. Depending on the source of a pollutant, various pathways can be important in transporting the pollutant through the environment. For example, a point source (e.g., a coal-fired power plant) will release volatile compounds (e.g., benzene and some inorganics), semi-volatile compounds (e.g., two- to three-ringed PAHs), and PM into the air. The PM will contain elemental carbon, inorganic elements and compounds, and various types of organic matter, including non-volatile PAHs and other organic compounds of low volatility. Chemicals of low, but finite, volatility can exist both as vapors and as adsorbed onto PM. Chemicals present as vapors under ambient conditions and fine and ultra-fine PM can be transported long distances. Some portion of the pollutants can be deposited from the air into other areas of the environment (e.g., soil and water), depending on their physical properties. For example, mercury emitted from coal combustion can end up in streams and ultimately accumulate into fish. It can also be inhaled by people downwind. Another point source, such as a manufacturing facility, might discharge waste into a stream where it can bioaccumulate into aquatic life or contaminate a source of drinking water for a downstream community. Thus, people can become exposed to pollutants through different pathways, and a given pollutant will be present to differing extents in the media of those pathways. When these pathway options are considered along with the relative magnitudes of the route-dependent potential exposures (e.g., the volume of air inhaled, the volume of water ingested, or the amount of fish eaten), it becomes clear that some media will be more important than others with regard to their impact on human exposure. These differences provide for a basis for prioritizing which pollutants are analyzed in which media.

A complete listing of analytes and matrices of potential interest in the study is shown in Table 1. Pollutants of concern can be measured in a variety of matrices (e.g., air, house dust, water, and food) that are important in exposure. This table indicates the primary matrices of importance for each pollutant or pollutant class, including both indoor and outdoor sources. In addition, this table includes biological matrices that will be used to provide information about the overall doses experienced, given the caveats previously discussed. The following information provides an overview of the chemical classes, the primary medium with which they are associated, and their importance to human health.

### 3.2.1 Carcinogens

Combustion from mobile and stationary sources generates a variety of pollutants that have been intensively investigated in toxicological and epidemiological studies. These pollutants

include PM (from soot and diesel exhaust), PAHs, metals, and gases. PM, PAHs, and metals all include pollutants that appear in the National Toxicology Program's Report on Carcinogens (NTP's ROC). These analytes are to be measured in air samples collected from environmental and personal monitors and in dust samples collected from the homes of study participants. PM will be speciated by PM<sub>2.5</sub>, PM<sub>10</sub>, and PM<sub>coarse</sub>. PAHs to be analyzed will include all 14 compounds included in the NTP's ROC, as well as all of the PAHs included on EPA's Priority Pollutants list. Significant amounts of PAHs can also be formed during high-temperature cooking of foods (when charring occurs). Metals will include arsenic (i.e., speciated by organic, inorganic trivalent, and inorganic pentavalent), chromium (VI), cadmium, lead, selenium, nickel, mercury, manganese, and beryllium.

Commercial and industrial sources contribute a wide variety of VOCs and other organic compounds to the environment. They may derive from fuels, dry-cleaning operations, manufacturing operations, leaching from commercial products, or water disinfection processes. The use of consumer products and off-gassing from construction materials and furnishings in the indoor environment also contribute to the total exposure. Many of these VOCs are included in the NTP's ROC; others may be associated with exacerbation of respiratory diseases or other toxicological sequelae. Compounds from the NTP ROC list include carbonyls (formaldehyde and acetaldehyde); benzene; butadiene; isoprene; vinyl chloride; chloroform; bromodichloromethane; carbon tetrachloride; 1,2-dibromoethane; *p*-dichlorobenzene; trichloroethylene; and tetrachloroethylene. VOCs will be measured in air samples (indoors and outdoors) that were collected from environmental and personal monitors. In addition, drinking water samples (i.e., treated municipal water and well water) will be collected for measuring a subset of carcinogenic VOCs that occur frequently in those matrices. Those analytes include chloroform and bromoform (disinfection by-products), as well as dibromoethane, trichloroethylene, and tetrachloroethylene.

In addition to the airborne pollutants previously mentioned, two other pollutants are well-known environmental hazards: environmental tobacco smoke (ETS) and radon. ETS can be a confounder in epidemiological studies of the impact of environmental toxins on human health. ETS can also comprise a significant portion of the PM mass measured in personal or indoor air samples; therefore, it is important to estimate its contributions to calculate an accurate non-ETS PM exposure. Because ETS exposure is lifestyle dependent, the use of personal exposure monitors to determine exposure to ETS is critical. Airborne nicotine will be used as a marker of ETS exposure in this study (Lawless et al., 2004). Radon exposure depends not only on the underlying geology, but also on the age and construction of the home, as well as whether any remedial measures (e.g., sub-basement ventilation) have been taken. Radiation monitors will be used as markers of radon exposure.

Despite having been banned from commerce for decades, a large number of OC chemicals, and their precursors or combustion products, persist in the environment. These include PCBs, chlorinated dibenzodioxins and dibenzofurans, and OC pesticides. These chemicals are transported into the environment primarily via adhesion to surface particles, which may be distributed by wind or by surface runoff into waterways, and by ingestion by animals, which can carry the adsorbed chemicals far from the original source. However, some of these chemicals, such as DDT, possess significant volatility and can be measured in the air as vapors. All of these chemicals accumulate in adipose tissues, with half-lives measured in years. On-going exposures may be assessed by measuring environmental samples, such as household dust.

Life-long exposures may be more relevant for assessing health effects. Such exposures are best measured using biological samples; the partitioning of OC chemicals into lipoproteins makes plasma (or serum) ideal matrices for providing the required data. Of the 209 PCB congeners, emphasis will be placed on measuring 12 dioxin-like congeners that were identified by the World Health Organization. Selected food samples (especially fish and fatty foods) that originate from local producers will be tested for all 209 congeners. Of the 75 dioxin congeners and 135 dibenzofuran congeners, emphasis will be placed on measurement of those that have chlorine atoms at each of the 2, 3, 7, and 8 positions, which have been shown to have the greatest affinity for the aryl hydrocarbon receptor (AhR), which is intimately associated with human toxicological outcomes, including carcinogenesis. OC pesticides to be measured will include those in the NTP ROC: dichloro diphenyl trichloroethane (DDT) and degradation products (six compounds), lindane (a mixture of compounds), hexachlorobenzene, mirex, and kepone. Commonly encountered OC pesticides to be measured that are not in the NTP ROC include chlordane, toxaphene, dieldrin, endrin, and aldrin.

### **3.2.2 Source Apportionment Markers**

PM samples will also be analyzed for markers used in source apportionment. The presence of metals helps distinguish pollution that originates from coal-fired power plants from other sources. Determination of elemental carbon and organic carbon helps distinguish between particulates that are derived from combustion of coal or of petroleum products. Further resolution of sources is obtained from measuring semi-volatile organic compounds (SVOCs) in air samples. These include many intermediate molecular weight aliphatic hydrocarbons, phenolic compounds, and carboxylic acids. Specific SVOCs to be analyzed may include hopanes (from mobile sources), fatty acids, and levoglucosan (from wood burning). However, exposure to these and other SVOCs is not currently associated with toxic outcomes, although research is ongoing.

VOC analyses provide additional information that is useful in source apportionment for a variety of pollutants. Aromatic hydrocarbons, including benzene, toluene, ethylbenzene, and xylenes (BTEX), are common markers for source apportionment for fuels. Chlorinated benzenes, including chlorobenzene, *o*-dichlorobenzene, and *m*-dichlorobenzene, are included as relevant source markers for known, Delaware-specific industrial activity. Other compounds of interest include acrolein; 1,3,5- and 1,2,4-trimethylbenzene; methyl *t*-butyl ether; styrene; *cis*- and *trans*-dichloroethylene; 1,1,1- and 1,1,2-trichloroethane; and 1,1,1,2- and 1,1,2,2-tetrachloroethane.

### **3.2.3 Pollutants Impacting Other Health Endpoints**

Endotoxins are associated with PM collected from many environments and are found in soil, water, and air. The bacteria that produce endotoxins can grow in a great diversity of situations, and the endotoxins remain intact following the death and disruption of their cells of origin. Because they are widely produced, are highly stable, and are water soluble and amphiphilic, they are commonly found in other indoor and outdoor samples and routinely contaminate other materials. Exposure is associated with respiratory symptoms and pulmonary inflammation and, as such, can exacerbate the effects of other respiratory and pulmonary irritants.  $\beta$ 1,3 glucans are multi-unit carbohydrates that are in the cell walls of many organisms, including some bacteria, fungi, and plants. The glucans have been recognized as potent inducers of non-specific inflammatory reactions.  $\beta$ 1,3 glucans have been suggested as a causative entity in the production of respiratory symptoms from bioaerosol exposures. The determination of  $\beta$ 1,3

glucan is also useful in estimating total mass of the PM, which can be attributed to biological sources in house dust or on air collection filters. As with the endotoxin analysis, the sensitivity is such that we can provide meaningful data with lightly loaded filters.

Gaseous pollutants formed during combustion processes include ozone and NO<sub>x</sub> and SO<sub>x</sub>. These gases (also known as criteria gases) are associated with exacerbation of asthma, COPD, and cardiovascular disease. They will be analyzed in air samples and from personal exposure monitors.

Non-persistent pesticides were developed in response to the phase out of the persistent OC pesticides, the first of which were the organophosphate pesticides, which were subsequently withdrawn from commerce due to concerns about their causing potential neurologic effects. Currently, carbamate and pyrethroid pesticides are the major pesticide classes in wide application. Humans may be exposed from pesticide applications in the home or from consuming contaminated food; therefore, house dust and food samples may be evaluated for evidence of human exposure. (All classes of these pesticides are metabolized rapidly in vivo, so that biological samples reflect recent exposures.) A large number of pesticides from this category are candidates for measurement in the collected samples. They can be found as residues in food and in dust in the indoor environment. Given their water solubility, these compounds can also permeate into groundwater where they can enter into drinking water, although in those cases, hydrolysis products are often more likely to be measured.

PBDEs are flame retardant chemicals that can slowly volatilize in the home. PBDEs have been widely used in consumer electronics and home furnishings, and can also mobilize in fragments of materials (foams). Structurally, they are kin to PCBs, and congeners are identified using the same numbering system. Similar to PCBs, they concentrate in adipose tissue, including mammary tissues, and are of concern because of their potential to induce breast tumors, as well as their potential to influence the development of newborns. Four congeners have been found to be dominant in most environmental samples: BDE-47 (2,2',4,4'-tetrabromodiphenyl ether), BDE-99 (2,2',4,4',5-pentabromodiphenyl ether), BDE-100 (2,2',4,4',6-pentabromodiphenyl ether), and BDE-209 (decachlorodiphenyl ether). Human exposure may result from inhaling house dust, directly contacting contaminated surfaces with skin, and ingesting food that has come into contact with PBDE-contaminated house dust or surfaces. The chemicals also bioaccumulate and have been found in fish from the Delaware River drainage basin (Green, 2007). House dust, food, and plasma samples will be analyzed for these compounds.

Many chemicals that have been widely used in commerce in the last 20 years are emerging as new subjects of toxicological interest because of their ubiquity or persistence. They also represent a shift from the historical focus on health effects related to respiratory and inflammatory diseases, cardiovascular disease, and cancer. These chemicals are of concern because they structurally mimic many hormones, enabling them to interfere with normal endocrine function. Such “estrogen mimics” or “endocrine disrupting (active) compounds” may affect metabolism, behavior, reproduction, or development.

Three types of compounds are of emerging interest due to their potential for disturbing childhood development: dialkylphthalates, alkylphenol ethoxylates, and bisphenol A. Dialkylphthalates are plasticizers that are added to polyvinyl chloride used in consumer products. From those products, they may leach into liquids and foods that are ingested or volatilize where they may adsorb to dust and surfaces. Bisphenol A is a monomer that is used in a variety of

polyester formulations and enters the environment in the same way. Alkylphenol ethoxylates are a class of surfactants that enter the environment via direct application in the home and the workplace, as well as via wastewater. Environmentally, the long polyethoxylate chains that provide water solubility are progressively cleaved, so that the most persistent and toxicologically relevant substances are the parent alkylphenols and their derivatives with one to three ethoxy substituents. As with PBDEs, humans may be exposed to all three categories of compounds via inhalation, skin absorption, or ingestion, so that dust and food samples are useful targets for analysis. As with non-persistent pesticides, a large number of dialkylphthalates are potential candidates for analysis. Bis-2-ethylhexylphthalate should be included in any method of analysis of the targeted sample set. Octyl- and nonyl-phenol (the nonyl-phenol mono-, di-, and tri-ethoxylates) are the most commonly investigated members of this class of analytes. Given their chemical similarity, the alkylphenols and bisphenol A are frequently measured using the same method.

Measurement of metabolites of these compounds provides an additional means of assessing exposure. Phthalates are metabolized and excreted as monoalkyl phthalates. Alkylphenols and their ethoxylates and bisphenol A are directly converted to glucuronide conjugates and are excreted as such. Measurement of the metabolites of the parent compounds in urine will provide complementary evidence of exposure to these compounds.

Perfluorinated alkyl compounds have been used to manufacture many industrial and consumer products, such as repellent coatings for paper, fabric, and carpets; in heat-resistant or impermeable materials; and in insecticides. Perfluoroalkyl acids have been recently shown to have relatively long elimination half-lives in humans, and due to their widespread environmental distribution and persistence, their toxicology is of increasing concern. Analyses of archived and contemporary blood samples have demonstrated detectable concentrations in all samples collected, following the introduction of products that contain perfluorinated chemicals. Perfluorooctanoic acid (PFOA) and perfluorooctanesulfonic acid (PFOS) are the most commonly identified members of this class from environmental studies. In addition, the Delaware River Basin Commission has identified perfluorononanoic acid (PFNA) as a significant contaminant in environmental samples in the Delaware region. As with the phthalates and phenols, exposure to these compounds will be monitored by analysis of dust and food samples, as well as plasma and urine, in which they are eliminated unchanged.

### **3.3 Participant Surveys and Questionnaires**

Multiple surveys and questionnaires will be collected to document neighborhood, residence, and participant characteristics. This type of information provides insights into the range of pollutant concentrations measured during the study. The surveys and questionnaires currently used by RTI will be modified, as appropriate, to reflect the goals of DESIGN II. The updated assessment instruments will be tested during DESIGN I data collection and will be revised if needed.

Local sources of PM and VOCs will be recorded on the Neighborhood Source Survey, which records the global positioning system coordinates of all potential sources within a defined distance from the monitoring location, usually a 2-mile radius.

The Residence Survey will provide a central location for information that may influence ambient pollutant infiltration into the home, indoor sources of pollution, and general residence characteristics.

Four surveys capture participant characteristics. The Participant Survey will document the participant's general lifestyle and activities that may influence his or her chronic exposure to pollutants. A daily Time Activity Diary will provide a detailed record of the participant's activities during the 24-hour sampling period to assess his or her acute exposure. This diary will be supplemented with a Nutrition Diary to document the liquids and foods ingested by the participant during the 24-hour period. Of particular interest will be the sources of local fish consumed and food preparation methods. Both diaries are supplemented with a computer-based Follow-Up Questionnaire, which provides a detailed series of cued questions to confirm and expand the information recorded in the diaries. This questionnaire will be administered daily by a field technician.

### **3.4 Sample Collection and Analysis**

The selection of sampling methods and analytical methods are interdependent. Analytical methods are sought that yield the best quality data (measured by parameters, such as sensitivity, precision, and bias). Sensitivity may be constrained by sampling times or volumes. Precision may be influenced by the effectiveness of the sampling device, whereas bias may be influenced by the efficiency of analyte recovery from the sampling media. In addition, given the scope of the study being proposed, many different analytes and procedures may be proposed for one sampling medium, so that either a large sample must be collected to accommodate the proposed analyses or replicate samples must be obtained.

Ideally, some of these challenges may be met by using non-destructive test methods (e.g., gravimetric determination of PM, and phase contrast microscopy for determination of asbestos), whenever applicable. However, it is usually necessary to separate the analyte from the matrix, using techniques, including acid digestion (for metals), thermal desorption (for VOCs in air), purge and trap (for VOCs in water), and solvent or solid-phase extraction (for SVOCs and nonvolatile organic compounds) prior to quantitative analysis. In some cases, it may be practical to combine multiple analyte groups into a single separation and analysis. More commonly, tradeoffs will have to be evaluated, with respect to the number of analytical results desired from each matrix, as well as the limitations imposed by the requisite sampling methods and the potential costs imposed by additional sampling and multiple analyses.

For many of the matrix-analyte combinations that are proposed, already well-established methods will be used for sample analyses. These encompass the extraction methods previously described, as well as extract cleanup methods and quantitative techniques. These techniques include inductively coupled plasma mass spectrometry (ICP-MS) and ion chromatography mass spectrometry (IC-MS) for metals, and gas chromatography (GC) and high-performance liquid chromatography (HPLC) for organic compounds. GC and HPLC are used with a variety of detection modes, such as electron capture, flame ionization, nitrogen-phosphorus, and photoelectron detectors for GC. Common HPLC detection methods include fluorescence and absorbance (visible and ultraviolet) detection, sometimes in conjunction with post-column derivitization methods. The gold standard detection modes for GC and HPLC are mass-selective detection (or more commonly GC-MS) and tandem mass spectrometry (HPLC-MS/MS), which provide qualitative confirmation of the analytes, as well as quantitative measurements.

For some classes of analytes, using GC-MS may provide qualitative information about the presence of specific compounds. A sample may be “scanned” by injecting an aliquot of the sample or sample extract into the instrument and acquiring a mass spectrum of each compound as it elutes. The mass spectrum may then be compared to a library of spectra of compounds, which were acquired using the same ionization technique. Although this approach is less sensitive than quantitative methods, where the instrument only looks for specific ions within a reference time window, it can be used to identify whether any of a large number of different analytes is present, and to inform about whether discussions of more sensitive, quantitative methods are required.

Data contained in Appendix A summarize the concentrations of analytes relevant to this study that have been measured in previous studies. This information defines the minimal required method sensitivities for this study. Although any method that can meet the performance parameters required (see Appendix A and Study DESIGNS I and II) is a candidate for use in the study, methods selected must be sufficiently accepted and validated to provide data that defensibly support the program.

Also included in the Appendix A tables is information about the potential to archive samples for later analysis. For example, VOCs in water must be analyzed within a week or two following collection, whereas pollutants on house dust tend to be very stable as long as the sample is kept dry and, for some analytes, cold. This will be an important consideration in the final selection of analytes and media to maximize information gained while minimizing cost.

Table 1. Contaminants and Matrices Proposed for Study

Analyte Class	Primary Toxicology <sup>a</sup>	Analyte <sup>b</sup>	Potential Matrices <sup>c</sup>	Analytical Method <sup>d</sup>
Soot; diesel exhaust	C, A	PM <sub>2.5</sub>	Air	Gravimetric
	C, A	PM <sub>10</sub>	Air	Gravimetric
	C, A	PM <sub>coarse</sub>	Air	Gravimetric
	M	Elemental carbon	Air, dust	Thermal and optical
	M	Organic carbon	Air, dust	Thermal and optical
Minerals	C	Silica	Air	XRD
	C	Asbestos	Air	PCM
Metals	C	Arsenic, inorganic (+3 and +5), organic	Air, dust, food, water, plasma, urine, hair	IC-ICP-MS
	C	Cadmium	Air, dust, food, water, plasma, urine, hair	ICP-MS
	C	Lead	Air, dust, food, water, plasma, urine, hair	ICPMS
	C	Nickel, total	Air, dust, food, water, plasma, urine	ICP-MS
	C	Beryllium	Air, dust, food, water, plasma, urine	ICP-MS
	C	Chromium (VI) (Information on trivalent Cr can be obtained with special precautions)	Air, dust, food, water, plasma, urine, hair	IC
	C	Selenium	Air, dust, food, water, plasma, urine	ICP-MS
	E	Mercury	Air, dust, food, water, plasma, urine, hair	CVAA or AF
	O	Manganese	Air, dust, food, water, plasma, urine, hair	ICP-MS
PAHs	C	EPA priority PAHs	Air (with PM), dust, food	GC-MS
Carbonyls	C	Formaldehyde	Air	HPLC
	C	Acetaldehyde	Air	HPLC
	O	Acrolein	Air	HPLC
Volatile organic compounds	C	Benzene	Air	GC-MS
	C	1,3-butadiene	Air	GC-MS
	C	Isoprene	Air	GC-MS
	C	Vinyl chloride	Air	GC-MS
	C	Bromodichloromethane	Air, water	GC-MS
	C	Chloroform	Air, water	GC-MS
	C	Carbon tetrachloride	Air	GC-MS
	C	1,2-dibromoethane	Air, water	GC-MS
	C	1,4-dichlorobenzene	Air	GC-MS
	C	Trichloroethylene	Air, water	GC-MS

Analyte Class	Primary Toxicology <sup>a</sup>	Analyte <sup>b</sup>	Potential Matrices <sup>c</sup>	Analytical Method <sup>d</sup>
Volatile organic compounds (continued)	C	Tetrachloroethylene	Air, water	GC-MS
	O	Toluene	Air	GC-MS
	O	o-xylene	Air	GC-MS
	O	m,p-xylene	Air	GC-MS
	O	Ethylbenzene	Air	GC-MS
	O	1,2,4-trimethylbenzene	Air	GC-MS
	O	1,3,5-trimethylbenzene	Air	GC-MS
	O	Methyl <i>t</i> -butyl ether	Air	GC-MS
	O	Styrene	Air	GC-MS
	O	1,2-dichlorobenzene	Air	GC-MS
	O	1,3-dichlorobenzene	Air	GC-MS
	O	1,1-dichloroethene	Air	GC-MS
	O	<i>cis</i> -dichloroethene	Air	GC-MS
	O	1,1-dichloroethane	Air	GC-MS
	O	1,2-dichloroethane	Air	GC-MS
	O	1,1,1-trichloroethane	Air	GC-MS
	O	1,1,2-trichloroethane	Air	GC-MS
	O	1,1,2,2-tetrachloroethane	Air	GC-MS
O	Chlorobenzene	Air	GC-MS	
Semi-volatile organic compounds	M	Levogluconan	Air, dust	GC-MS
	M	Hopanes (4 compounds)	Air, dust	GC-MS
	M	Fatty acids (4 compounds)	Air, dust	GC-MS
Gases	A, V	Ozone	Air	IC
	A, V	SO <sub>x</sub>	Air	IC
	A, V	NO <sub>x</sub>	Air	IC
Environmental tobacco smoke	C, A, V	Nicotine	Air	Optical method
Radiation	C	Radon	Air	Scintillation
PCBs and dioxin	C	PCBs, 12 dioxin-like congeners	Air, dust, plasma, food (fish)	GC-HRMS
	C	PCBs, all congeners (select samples)	Fatty food	GC-HRMS
	C	Tetrachlorodibenzodioxins	Air, dust, plasma, food	GC-HRMS
	O	Tetrachlorodibenzofurans	Air, dust, plasma, food	GC-HRMS
	M	Lipids	Plasma	Clinical
Organochlorine pesticides	C	DDT (6 compounds)	Air, dust, plasma, food	GC-MS
	C	Hexachlorobenzene	Air, dust, plasma, food	GC-MS
	C	Lindane (multiple compounds)	Air, dust, plasma, food	GC-MS
	C	Mirex	Air, dust, plasma, food	GC-MS
	C	Kepone (chlordecone)	Air, dust, plasma, food	GC-MS

Analyte Class	Primary Toxicology <sup>a</sup>	Analyte <sup>b</sup>	Potential Matrices <sup>c</sup>	Analytical Method <sup>d</sup>
Organochlorine pesticides (continued)	O	Chlordane	Air, dust, plasma, food	GC-MS
	O	Oxychlordane	Air, dust, plasma, food	GC-MS
	O	Heptachlor	Air, dust, plasma, food	GC-MS
	O	Heptachlor expoxide	Air, dust, plasma, food	GC-MS
	O	Endosulfan	Air, dust, plasma, food	GC-MS
	O	Toxaphene	Air, dust, plasma, food	GC-MS
	O	Dieldrin	Air, dust, plasma, food	GC-MS
	O	Endrin	Air, dust, plasma, food	GC-MS
	O	Aldrin	Air, dust, plasma, food	GC-MS
Non-persistent pesticides	O	Organophosphate scan	Air, dust, plasma, food	GC-MS
	O	Pyrethroid scan	Air, dust, plasma, food	GC-MS
Microbiological	A, O	Endotoxin and $\beta$ 1,3-glucan	Air, dust	Limulus amoebocyte lysate
PBDEs	E	BDE 47	Air, dust, plasma, food	GC-MS
	E	BDE 99	Air, dust, plasma, food	GC-MS
	E	BDE 153	Air, dust, plasma, food	GC-MS
	E	DecabromoDE	Air, dust, plasma, food	GC-MS
Perfluorinated acids	E	PFOA	Air, dust, food, plasma, urine	HPLC-MS/MS
	E	PFOS	Air, dust, food, plasma, urine	HPLC-MS/MS
	E	PFNA	Air, dust, food, plasma, urine	HPLC-MS/MS
Other chemicals	E	Dialkylphthalates	Air, dust, food	GC-MS scan
	E	Alkyl phthalates	Plasma, urine	GC-MS scan
	E	Bisphenol A and alkylphenols	Air, dust, food, plasma, urine	GC-MS (with alkylphenols)

<sup>a</sup> A = asthma, C = cancer, E = endocrine active, M = source marker, O = other, V = cardiovascular

<sup>b</sup> Additional analyte descriptions are provided in the text. Speciation of metals (i.e., inorganic/organic, valence state) is possible for some metals in some media. Method development and validation would be required in many cases.

<sup>c</sup> Matrices represent both environmental media that impact exposure and biological media of use in documenting exposure.

<sup>d</sup> Analysis methods abbreviations as follow: XRD = X-ray diffraction; IC = ion chromatography; PCM = phase contrast microscopy; GC/MS = gas chromatography/mass spectrometry; TOC/TOR = thermal and optical method for total organic, elemental carbon; ICP/MS = inductively coupled plasma/mass spectrometry; CVAA = cold vapor atomic absorption; AF = atomic fluorescence; HPLC = high performance liquid chromatography; HRMS = high resolution mass spectrometry.

### 3.5 DESIGN I

Provided in Appendix B.

### 3.6 DESIGN II

Provided in Appendix C.

## 4. Resource Estimates

In this section, initial estimates of costs are provided for planning purposes. For this purpose, decisions were made to propose some degree of sample archiving and to project labor costs and sample analysis costs at usual and customary commercial rates. The costs associated with sample analyses are a major driver of study costs. It is assumed that alternate strategies will be implemented that would reduce these costs, especially for DESIGN II. Included among such strategies would be proven approaches in the use of temporary, but well-trained, labor for select non-supervisory field collection roles, modifications of the analyte priority, changes to the archival plans, and partnerships with universities. Although it will be very important to keep costs as low as possible, the manner in which this is accomplished will be critical to protect the quality of the samples collected, the quality of the data generated, the defensibility of the data analysis, and the objectivity of results presentation. An additional concern for DESIGN II is the continuity of field staff proficiency and the use of SOPs for chemical analysis so that data are comparable for the duration of the study. It is envisioned that these factors will be optimized, with substantial input from DNREC/DHSS, during the preparation of more detailed work plans.

The cost of implementing DESIGN I is estimated to **range from \$926,000** for core, high-priority analytes (80% of the collected water VOCs, metals in media, and pesticides in media samples will be archived) to **\$1.37 million with an archival rate of 50%**.

The adoption of DESIGN II will provide for the detailed probability-based collection and analysis of personal, indoor, and ambient air concentrations, drinking water, food and house dust for agreed upon core target list of contaminants analyzed. As for DESIGN I, selected categories for each study year were considered as the core, with 0% of these categories archived (i.e., 100% are proposed for analysis). The sample analyses costs drive the overall study cost, nominally ranging from 40 to 70% of the totals. Sample collection (only) costs for the core are highest during Year 1 (~35% of the total) to allow for purchase of special samplers and preparation for the full QAPP. In subsequent years, the percentage would be closer to 25%.

Additionally, collection and analysis of biospecimen samples for each participant are included. The original SJR-11 plan included biospecimen collection and analysis as an optional category. DESIGN II considers biospecimen collections as critical to compare Delawarean doses to national levels (NHANES). The core analytes include full blood, urine, and hair collections and analyses to support determination of both exposure and dose components for the totals. The same archival percentages for exposure samples were applied to the analyses of biospecimens.

Given these assumptions, the costs range from **\$1.7 million to \$3.1 million** for Year 1, **\$1.3 million to \$2.1 million** for Year 2, **\$1.7 million to \$5.1 million** for Year 3, and **\$1.3 million to \$2.3 million** for Year 4. A rotating repeat of Years 1 thru 4 would be started in Year 5 to allow estimation of long-term trends. These longitudinal data would greatly assist DNREC and DHHS in future health cluster reports, including future updates in 5 and 10 years for cancer.

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## **Appendix A**

# **Reported Concentrations of Proposed Analytes in Relevant Media**

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Table A-1. Indoor-Outdoor Air

Analyte Class	Analyte	Analytical Method	MDL/MQL	Occurrence—Mean	Occurrence—Median	Occurrence—Maximum	Reference (Study)
Soot; diesel exhaust	PM <sub>2.5</sub>	Gravimetric	1.0/3.0 µg/m <sup>3</sup>				U.S. EPA, 2008a (DEARS)
	PM <sub>10</sub>	Gravimetric		31–42 µg/m <sup>3</sup>	38–31 µg/m <sup>3</sup>	260 µg/m <sup>3</sup>	U.S. EPA, 2008b (NHEXAS Arizona)
			1.0/3.0 µg/m <sup>3</sup>				U.S. EPA, 2008a (DEARS)
	PM <sub>coarse</sub>	Gravimetric					
	Elemental carbon	TOC/TOR	0.2/0.6 µg/m <sup>3</sup>				U.S. EPA, 2008a (DEARS)
	Organic carbon	TOC/TOR	0.2/0.6 µg/m <sup>3</sup>				U.S. EPA, 2008a (DEARS)
Minerals*	Silica	XRD	5 µg/sample				
	Asbestos	PCM	7 fibers/mm <sup>3</sup>				
Metals *	Arsenic, inorganic (+3 and +5), organic	IC-ICP-MS	0.2 ng/m <sup>3</sup> (total)	0.67–0.83 ng/m <sup>3</sup>	0.50–0.69 ng/m <sup>3</sup>	7.2 ng/m <sup>3</sup>	U.S. EPA, 2008b (NHEXAS Region 5)
			0.036 ng/m <sup>3</sup> (total)	0.88–1.1 ng/m <sup>3</sup>			DNREC, 2005
	Beryllium	ICP-MS	0.002 ng/m <sup>3</sup>	0.008–0.017 ng/m <sup>3</sup>			DNREC, 2005
	Cadmium	ICP-MS	0.9 ng/m <sup>3</sup>	1.2 ng/m <sup>3</sup>	0.53 ng/m <sup>3</sup>	31 ng/m <sup>3</sup>	U.S. EPA, 2008b (NHEXAS)
			0.024 ng/m <sup>3</sup>	0.20–0.28 ng/m <sup>3</sup>			DNREC, 2005
	Lead	ICP-MS	7.6–9.4 ng/m <sup>3</sup>	13–15 ng/m <sup>3</sup>	5.8–8.1 ng/m <sup>3</sup>	290 ng/m <sup>3</sup>	U.S. EPA, 2008b (NHEXAS Region 5)
			0.073 ng/m <sup>3</sup>	3.4–8 ng/m <sup>3</sup>			DNREC, 2005
	Manganese	ICP-MS	46 ng/m <sup>3</sup>	66–83 ng/m <sup>3</sup>	64–65 ng/m <sup>3</sup>	219 ng/m <sup>3</sup>	U.S. EPA, 2008b (NHEXAS Arizona)
			0.049 ng/m <sup>3</sup>	4.6–18 ng/m <sup>3</sup>			DNREC, 2005
	Mercury	CVAA					
	Nickel, total	ICP-MS	540 ng/m <sup>3</sup>				U.S. EPA, 2008b (NHEXAS Arizona)
			0.073 ng/m <sup>3</sup>	2.1–6.9 ng/m <sup>3</sup>			DNREC, 2005
	Selenium	ICP-MS	309 ng/m <sup>3</sup>	520–690 ng/m <sup>3</sup>	490–550 ng/m <sup>3</sup>	1,500 ng/m <sup>3</sup>	U.S. EPA, 2008b (NHEXAS Arizona)
	Chromium (VI)	IC	25–27 ng/m <sup>3</sup> (total)	9.1–18 ng/m <sup>3</sup>	3.3–4.0 ng/m <sup>3</sup>	1,700 ng/m <sup>3</sup>	U.S. EPA, 2008b (NHEXAS Region 5)
		0.049 ng/m <sup>3</sup> (total)	1.7–3.8 ng/m <sup>3</sup>			DNREC, 2005	

Analyte Class	Analyte	Analytical Method	MDL/MQL	Occurrence— Mean	Occurrence— Median	Occurrence— Maximum	Reference (Study)
PAHs*	EPA priority PAHs	GC-MS	0.02/0.06 ng/m <sup>3</sup>				U.S. EPA, 2008a (DEARS)
			0.3 ng/m <sup>3</sup>	ND–30 ng/m <sup>3</sup>			DNREC, 2005
			0.01–0.04 ng/m <sup>3</sup>	.03–400 ng/m <sup>3</sup>		1,200 ng/m <sup>3</sup>	Wilson et al., 2003
Aldehydes	Formaldehyde	HPLC	6.0/18.0 µg/m <sup>3</sup>				U.S. EPA, 2008a (DEARS)
			0.0002 µg/m <sup>3</sup>	0.0043 - 0.0051 µg/m <sup>3</sup>			DNREC, 2005
	Acetaldehyde	HPLC	5.0/15.0 µg/m <sup>3</sup>				U.S. EPA, 2008a (DEARS)
			0.0001 µg/m <sup>3</sup>	0.0013 - 0.0013 µg/m <sup>3</sup>			DNREC, 2005
	Acrolein	HPLC	0.5/1.5 µg/m <sup>3</sup>				U.S. EPA, 2008a (DEARS)
Volatile organic compounds	Benzene	GC-MS	0.04 µg/m <sup>3</sup>	5.1 µg/m <sup>3</sup>	2.8 µg/m <sup>3</sup>	119 µg/m <sup>3</sup>	NCHS, 2007 (NHANES)
			0.73–0.91 ng/m <sup>3</sup>	3.7–7.7 ng/m <sup>3</sup>	2.9–4.7 ng/m <sup>3</sup>	156 µg/m <sup>3</sup>	U.S. EPA, 2008b (NHEXAS Region 5)
			99 pptv				U.S. EPA, 2008a (DEARS)
			0.035 µg/m <sup>3</sup>	0.46–1.37 µg/m <sup>3</sup>			DNREC, 2005
	1,3-butadiene	GC-MS	0.4 µg/m <sup>3</sup>				U.S. EPA, 2008b (NHEXAS Arizona)
			234 pptv				U.S. EPA, 2008a (DEARS)
			0.12 µg/m <sup>3</sup>	0.04–0.30 µg/m <sup>3</sup>			DNREC, 2005
	Isoprene	GC-MS					
	Vinyl chloride	GC-MS					
			0.067 µg/m <sup>3</sup>	0.02–0.22 µg/m <sup>3</sup>			DNREC, 2005
	Bromodichloromethane	GC-MS					
	Chloroform	GC-MS	0.011 µg/m <sup>3</sup>	2.7 µg/m <sup>3</sup>	1.1 µg/m <sup>3</sup>	54 µg/m <sup>3</sup>	NCHS, 2007 (NHANES)
			1.1 µg/m <sup>3</sup>	1.5–2.6 µg/m <sup>3</sup>	0.86–1.6 µg/m <sup>3</sup>	31 µg/m <sup>3</sup>	U.S. EPA, 2008b (NHEXAS Region 5)
		0.13 µg/m <sup>3</sup>	0.08–0.13 µg/m <sup>3</sup>			DNREC, 2005	

Analyte Class	Analyte	Analytical Method	MDL/MQL	Occurrence— Mean	Occurrence— Median	Occurrence— Maximum	Reference (Study)
Volatile organic compounds (continued)	Carbon tetrachloride	GC-MS	0.74 $\mu\text{g}/\text{m}^3$	1.0–1.1 $\mu\text{g}/\text{m}^3$	0.78–1.2 $\mu\text{g}/\text{m}^3$	1.75 $\mu\text{g}/\text{m}^3$	U.S. EPA, 2008b (NHEXAS Arizona)
			252 pptv				U.S. EPA, 2008a (DEARS)
			0.30 $\mu\text{g}/\text{m}^3$	0.54–0.56 $\mu\text{g}/\text{m}^3$			DNREC, 2005
	1,2-dibromoethane	GC-MS					
			0.17 $\mu\text{g}/\text{m}^3$	ND–0.01 $\mu\text{g}/\text{m}^3$			DNREC, 2005
	1,4-dichlorobenzene	GC-MS	0.02 $\mu\text{g}/\text{m}^3$	46 $\mu\text{g}/\text{m}^3$	2.2 $\mu\text{g}/\text{m}^3$	2200 $\mu\text{g}/\text{m}^3$	NCHS, 2007 (NHANES)
			0.77 $\mu\text{g}/\text{m}^3$	0.54–4.0 $\mu\text{g}/\text{m}^3$	0.39–0.57 $\mu\text{g}/\text{m}^3$	120 $\mu\text{g}/\text{m}^3$	U.S. EPA, 2008b (NHEXAS Region 5)
			70 pptv				U.S. EPA, 2008a (DEARS)
			0.066 $\mu\text{g}/\text{m}^3$	0.08–0.22 $\mu\text{g}/\text{m}^3$			DNREC, 2005
	Trichloroethylene	GC-MS	0.0099 $\mu\text{g}/\text{m}^3$	4.16 $\mu\text{g}/\text{m}^3$	0.006 $\mu\text{g}/\text{m}^3$	330 $\mu\text{g}/\text{m}^3$	NCHS, 2007 (NHANES)
			1.0 $\mu\text{g}/\text{m}^3$	1.6–2.0 $\mu\text{g}/\text{m}^3$	0.54–0.64 $\mu\text{g}/\text{m}^3$	77 $\mu\text{g}/\text{m}^3$	U.S. EPA, 2008b (NHEXAS Region 5)
			1,540 pptv				U.S. EPA, 2008a (DEARS)
			0.12 $\mu\text{g}/\text{m}^3$	0.06–0.11 $\mu\text{g}/\text{m}^3$			DNREC, 2005
	Tetrachloroethylene	GC-MS	0.0095 $\mu\text{g}/\text{m}^3$	5.2 $\mu\text{g}/\text{m}^3$	0.78 $\mu\text{g}/\text{m}^3$	659 $\mu\text{g}/\text{m}^3$	NCHS, 2007 (NHANES)
			1.6 $\mu\text{g}/\text{m}^3$	2.8–7.4 $\mu\text{g}/\text{m}^3$	1.9–2.4 $\mu\text{g}/\text{m}^3$	660 $\mu\text{g}/\text{m}^3$	
			57 pptv				U.S. EPA, 2008a (DEARS)
			0.21 $\mu\text{g}/\text{m}^3$	0.11–0.53 $\mu\text{g}/\text{m}^3$			DNREC, 2005
	Toluene	GC-MS	0.11 $\mu\text{g}/\text{m}^3$	49 $\mu\text{g}/\text{m}^3$	16 $\mu\text{g}/\text{m}^3$	6,300 $\mu\text{g}/\text{m}^3$	NCNH, 2007 (NHANES)
			3.5 $\mu\text{g}/\text{m}^3$	11–41 $\mu\text{g}/\text{m}^3$	10–25 $\mu\text{g}/\text{m}^3$	750 $\mu\text{g}/\text{m}^3$	U.S. EPA, 2008b (NHEXAS Region 5)
			81 pptv				U.S. EPA, 2008a (DEARS)
		0.083 $\mu\text{g}/\text{m}^3$	1.38–1.49 $\mu\text{g}/\text{m}^3$			DNREC, 2005	

Analyte Class	Analyte	Analytical Method	MDL/MQL	Occurrence— Mean	Occurrence— Median	Occurrence— Maximum	Reference (Study)
Volatile organic compounds (continued)	o-xylene	GC-MS	0.017 $\mu\text{g}/\text{m}^3$	9.6 $\mu\text{g}/\text{m}^3$	2.2 $\mu\text{g}/\text{m}^3$	2,300 $\mu\text{g}/\text{m}^3$	NCHS, 2007 (NHANES)
			0.86–1.2 $\mu\text{g}/\text{m}^3$	3.3–9.2 $\mu\text{g}/\text{m}^3$	2.7–3.9 $\mu\text{g}/\text{m}^3$	940 $\mu\text{g}/\text{m}^3$	U.S. EPA, 2008b (NHEXAS Region 5)
			74 pptv				U.S. EPA, 2008a (DEARS)
			0.067 $\mu\text{g}/\text{m}^3$				
	m,p-xylene	GC-MS	0.024 $\mu\text{g}/\text{m}^3$	30 $\mu\text{g}/\text{m}^3$	6.0 $\mu\text{g}/\text{m}^3$	8,400 $\mu\text{g}/\text{m}^3$	NCHS, 2007 (NHANES)
			0.92 $\mu\text{g}/\text{m}^3$	4.1–21 $\mu\text{g}/\text{m}^3$	3.7–6.6 $\mu\text{g}/\text{m}^3$	2,800 $\mu\text{g}/\text{m}^3$	U.S. EPA, 2008b (NHEXAS Region 5)
			157 pptv				U.S. EPA, 2008a (DEARS)
			0.14 $\mu\text{g}/\text{m}^3$	0.21–2.25 $\mu\text{g}/\text{m}^3$			DNREC, 2005
	Ethylbenzene	GC-MS	0.016 $\mu\text{g}/\text{m}^3$	11 $\mu\text{g}/\text{m}^3$	2.3 $\mu\text{g}/\text{m}^3$	2,200 $\mu\text{g}/\text{m}^3$	NCHS, 2007 (NHANES)
			0.22 $\mu\text{g}/\text{m}^3$	1.3–5.1 $\mu\text{g}/\text{m}^3$	0.91–2.3 $\mu\text{g}/\text{m}^3$	27 $\mu\text{g}/\text{m}^3$	U.S. EPA, 2008b (NHEXAS Arizona)
			99 pptv				U.S. EPA, 2008a (DEARS)
			0.048 $\mu\text{g}/\text{m}^3$	0.098–0.66 $\mu\text{g}/\text{m}^3$			DNREC, 2005
	1,2,4-trimethylbenzene	GC-MS					
			0.076 $\mu\text{g}/\text{m}^3$	0.12–0.78 $\mu\text{g}/\text{m}^3$			DNREC, 2005
	1,3,5-trimethylbenzene	GC-MS	0.32 $\mu\text{g}/\text{m}^3$	1.1–2.5 $\mu\text{g}/\text{m}^3$	1.0–2.0 $\mu\text{g}/\text{m}^3$	7 $\mu\text{g}/\text{m}^3$	U.S. EPA, 2008b (NHEXAS Arizona)
			374 pptv				U.S. EPA, 2008a (DEARS)
	Methyl <i>t</i> -butyl ether	GC-MS	0.039 $\mu\text{g}/\text{m}^3$	5.1 $\mu\text{g}/\text{m}^3$	0.01 $\mu\text{g}/\text{m}^3$	180 $\mu\text{g}/\text{m}^3$	NCHS, 2007 (NHANES)
	Styrene	GC-MS	0.83 $\mu\text{g}/\text{m}^3$	1.6–2.1 $\mu\text{g}/\text{m}^3$	1.4–1.9 $\mu\text{g}/\text{m}^3$	15 $\mu\text{g}/\text{m}^3$	U.S. EPA, 2008b (NHEXAS Region 5)
			201 pptv				U.S. EPA, 2008a (DEARS)
		0.14 $\mu\text{g}/\text{m}^3$	0.09–0.17 $\mu\text{g}/\text{m}^3$			DNREC, 2005	

Analyte Class	Analyte	Analytical Method	MDL/MQL	Occurrence— Mean	Occurrence— Median	Occurrence— Maximum	Reference (Study)
Volatile organic compounds (continued)	<i>o</i> -dichlorobenzene	GC-MS	0.51 $\mu\text{g}/\text{m}^3$				U.S. EPA, 2008b (NHEXAS Arizona)
			76 pptv				U.S. EPA, 2008 (DEARS)
			0.13 $\mu\text{g}/\text{m}^3$	0.06–0.07 $\mu\text{g}/\text{m}^3$			DNREC, 2005
	<i>m</i> -dichlorobenzene	GC-MS	0.58 $\mu\text{g}/\text{m}^3$				U.S. EPA, 2008b (NHEXAS Arizona)
			70 pptv				U.S. EPA, 2008a (DEARS)
			0.066 $\mu\text{g}/\text{m}^3$	0.06–0.07 $\mu\text{g}/\text{m}^3$			DNREC, 2005
	1,1-dichloroethene	GC-MS	0.49 $\mu\text{g}/\text{m}^3$				U.S. EPA, 2008b (NHEXAS Arizona)
			67 pptv				U.S. EPA, 2008a (DEARS)
			0.19 $\mu\text{g}/\text{m}^3$	0.00–0.01 $\mu\text{g}/\text{m}^3$			DNREC, 2005
	<i>cis</i> -dichloroethene	GC-MS	1.1 $\mu\text{g}/\text{m}^3$				U.S. EPA, 2008b (NHEXAS Arizona)
			385 pptv				U.S. EPA, 2008a (DEARS)
			0.14 $\mu\text{g}/\text{m}^3$	ND–0.01 $\mu\text{g}/\text{m}^3$			DNREC, 2005
	1,1-dichloroethane	GC-MS	0.49 $\mu\text{g}/\text{m}^3$				U.S. EPA, 2008b (NHEXAS Arizona)
			177 pptv				U.S. EPA, 2008a (DEARS)
			0.089 $\mu\text{g}/\text{m}^3$	ND–0.02 $\mu\text{g}/\text{m}^3$			DNREC, 2005
	1,2-dichloroethane	GC-MS	0.54 $\mu\text{g}/\text{m}^3$				U.S. EPA, 2008b (NHEXAS Arizona)
			275 pptv				U.S. EPA, 2008a (DEARS)
			0.063 $\mu\text{g}/\text{m}^3$	0.04–0.05 $\mu\text{g}/\text{m}^3$			DNREC, 2005
	1,1,1-trichloroethane	GC-MS	1.4 $\mu\text{g}/\text{m}^3$	2.5–6.6 $\mu\text{g}/\text{m}^3$	1.5–3.0 $\mu\text{g}/\text{m}^3$	186 $\mu\text{g}/\text{m}^3$	U.S. EPA, 2008b (NHEXAS Region 5)
			0.6 $\mu\text{g}/\text{m}^3$	2.6–5.4 $\mu\text{g}/\text{m}^3$	1.8–3.2 $\mu\text{g}/\text{m}^3$	23 $\mu\text{g}/\text{m}^3$	U.S. EPA, 2008b (NHEXAS Arizona)
		153 pptv				U.S. EPA, 2008a (DEARS)	
		0.17 $\mu\text{g}/\text{m}^3$	0.15–0.17 $\mu\text{g}/\text{m}^3$			DNREC, 2005	

Analyte Class	Analyte	Analytical Method	MDL/MQL	Occurrence— Mean	Occurrence— Median	Occurrence— Maximum	Reference (Study)
Volatile organic compounds (continued)	1,1,2-trichloroethane	GC-MS	0.9 $\mu\text{g}/\text{m}^3$				U.S. EPA, 2008b (NHEXAS Arizona)
			153 pptv				U.S. EPA, 2008a (DEARS)
			0.20 $\mu\text{g}/\text{m}^3$	ND			DNREC, 2005
	1,1,,2,2-tetrachloroethane	GC-MS	0.50 $\mu\text{g}/\text{m}^3$				U.S. EPA, 2008b (NHEXAS Arizona)
			0.15 $\mu\text{g}/\text{m}^3$	0.10 $\mu\text{g}/\text{m}^3$			DNREC, 2005
	Chlorobenzene	GC-MS	0.39 $\mu\text{g}/\text{m}^3$				U.S. EPA, 2008b (NHEXAS Arizona)
			62 pptv				U.S. EPA, 2008a (DEARS)
			0.13 $\mu\text{g}/\text{m}^3$	0.05–0.10 $\mu\text{g}/\text{m}^3$			DNREC, 2005
Semivolatile organic compounds*	Levogluconan	GC-MS	0.2/0.6 $\text{ng}/\text{m}^3$				U.S. EPA, 2008a (DEARS)
	Hopanes (4 compounds)	GC-MS	0.02/0.06 $\text{ng}/\text{m}^3$				U.S. EPA, 2008a (DEARS)
	Fatty acids (4 compounds)	GC-MS	0.2/0.6 $\text{ng}/\text{m}^3$				U.S. EPA, 2008a (DEARS)
Gases	Ozone	IC Passive	3/9 ppb				U.S. EPA, 2008a (DEARS)
	SOx	IC Passive	8/24 ppb				U.S. EPA, 2008a (DEARS)
	NOx	IC Passive	3/9 ppb				U.S. EPA, 2008a (DEARS)
Radiation	Radon	Scintillation					
PCBs and dioxin*	PCBs, 12 dioxin-like congeners	GC-MS	.04 $\text{ng}/\text{m}^3$	ND–6.7 $\text{ng}/\text{m}^3$		51 $\text{ng}/\text{m}^3$	Wilson et al., 2003
	2,3,7,8-dibenzodioxins	GC-HRMS	2–19 $\text{fg}/\text{m}^3$	1–830 $\text{fg}/\text{m}^3$			DNREC, 2005
	2,3,7,8-dibenzofurans	GC-HRMS	2–19 $\text{fg}/\text{m}^3$	1–90 $\text{fg}/\text{m}^3$			DNREC, 2005
Organochlorine pesticides*	DDT (6 compounds)	GC-MS	0.1 $\text{ng}/\text{m}^3$	0.06–0.12 $\text{ng}/\text{m}^3$		0.31 $\text{ng}/\text{m}^3$	Wilson et al., 2003
	Hexachlorobenzene	GC-MS					
	Lindane (BHC) (multiple compounds)	GC-MS	0.1 $\text{ng}/\text{m}^3$	0.25–7.4 $\text{ng}/\text{m}^3$		10.8 $\text{ng}/\text{m}^3$	Wilson et al., 2003
	Mirex	GC-MS					
	Kepone (chlordecone)	GC-MS					
	Chlordane	GC-MS	0.1 $\text{ng}/\text{m}^3$	0.57–7.7 $\text{ng}/\text{m}^3$		28 $\text{ng}/\text{m}^3$	Wilson et al., 2003

Analyte Class	Analyte	Analytical Method	MDL/MQL	Occurrence— Mean	Occurrence— Median	Occurrence— Maximum	Reference (Study)
Organochlorine pesticides* (continued)	Oxychlorane	GC-MS					
	Heptachlor	GC-MS	0.1 ng/m <sup>3</sup>	0.9–34 ng/m <sup>3</sup>		133 ng/m <sup>3</sup>	Wilson et al., 2003
	Heptachlor epoxide	GC-MS					
	Endosulfan	GC-MS					
	Toxaphene	GC-MS					
	Dieldrin	GC-MS	0.1 ng/m <sup>3</sup>	0.06–0.18 ng/m <sup>3</sup>		0.78 ng/m <sup>3</sup>	Wilson et al., 2003
	Endrin	GC-MS	0.1 ng/m <sup>3</sup>	0.09–0.25 ng/m <sup>3</sup>		0.69 ng/m <sup>3</sup>	Wilson et al., 2003
	Aldrin	GC-MS	0.1 ng/m <sup>3</sup>	0.08–2.74 ng/m <sup>3</sup>		4.7 ng/m <sup>3</sup>	Wilson et al., 2003
Non-persistent pesticides*	Organophosphate scan	GC-MS	0.1 ng/m <sup>3</sup>	0.6–160 ng/m <sup>3</sup>		1,100 ng/m <sup>3</sup>	Wilson et al., 2003
	Pyrethroid scan	GC-MS					
Microbiologicals*	Endotoxin and $\beta$ 1,3 glucan	Limulus amoebocyte lysate					
PBDEs*	BDE 47	GC-MS or GC-ECD		53–107 pg/m <sup>3</sup>			Lorber, 2008
	BDE 99	GC-MS or GC-ECD		51–79 pg/m <sup>3</sup>			Lorber, 2008
	BDE 153	GC-MS or GC-ECD		3.9–5 pg/m <sup>3</sup>			Lorber, 2008
	DecabromoDE	GC-MS or GC-ECD		25–121 pg/m <sup>3</sup>			Lorber, 2008
Perfluorinated acids*	PFOA	HPLC-MS/MS					
	PFOS	HPLC-MS/MS					
	PFNA	HPLC-MS/MS					
Other chemicals*	Dialkylphthalate scan, including DEHP	GC-MS	0.04 ng/m <sup>3</sup>	31–288 ng/m <sup>3</sup>		474 ng/m <sup>3</sup>	Wilson et al., 2003
	Bisphenol A/Alkylphenol scan	GC-MS	0.1 ng/m <sup>3</sup>	1.3–169 ng/m <sup>3</sup>		402 ng/m <sup>3</sup>	Wilson et al., 2003

\*This matrix-analyte class may be archived for later analysis.

Table A-2. Personal Air

Analyte Class	Analyte	Analytical Method	MDL/MQL	Occurrence— Mean	Occurrence— Median	Occurrence— Maximum	Reference (Study)
Soot; diesel exhaust	PM <sub>2.5</sub>	Gravimetric					
	PM <sub>10</sub>	Gravimetric					
	PM <sub>coarse</sub>	Gravimetric					
	Elemental carbon	TOC/TOR					
	Organic carbon	TOC/TOR					
Minerals*	Silica	XRD					
	Asbestos	PCM					
Metals*	Arsenic, inorganic (+3 and +5)	ICP-MS	0.19 ng/m <sup>3</sup> (total As)	1.2 ng/m <sup>3</sup>	0.79 ng/m <sup>3</sup>	14 ng/m <sup>3</sup>	U.S. EPA, 2008b (NHEXAS Region 5)
	Arsenic, organic	IC					
	Beryllium	ICP-MS					
	Cadmium	ICP-MS	0.64 ng/m <sup>3</sup>	2.1 ng/m <sup>3</sup>	1.2 ng/m <sup>3</sup>	29 ng/m <sup>3</sup>	U.S. EPA, 2008b (NHEXAS Region 5)
	Lead	ICP-MS	6.7 ng/m <sup>3</sup>	25 ng/m <sup>3</sup>	13 ng/m <sup>3</sup>	250 ng/m <sup>3</sup>	U.S. EPA, 2008b (NHEXAS Region 5)
	Mercury	CVAA					
	Manganese	ICP-MS					
	Nickel, total	ICP-MS					
	Selenium	ICP-MS					
	Chromium (VI)	IC	29 ng/m <sup>3</sup> (total Cr)	12 ng/m <sup>3</sup>	7 ng/m <sup>3</sup>	102 ng/m <sup>3</sup>	U.S. EPA, 2008b (NHEXAS Region 5)
PAHs*	EPA Priority PAHs	GC-MS					
Aldehydes	Formaldehyde	HPLC-fluorescence					
	Acetaldehyde	HPLC-fluorescence					
	Acrolein	HPLC-fluorescence					
Volatile organic compounds	Benzene	GC-MS		8.3 ng/m <sup>3</sup>	5.5 ng/m <sup>3</sup>	120 ng/m <sup>3</sup>	U.S. EPA, 2008b (NHEXAS Region 5)
	1,3-butadiene	GC-MS					
	Isoprene	GC-MS					
	Vinyl chloride	GC-MS					
	Bromodichloromethane	GC-MS					

Analyte Class	Analyte	Analytical Method	MDL/MQL	Occurrence— Mean	Occurrence— Median	Occurrence— Maximum	Reference (Study)
Volatile organic compounds (continued)	Chloroform	GC-MS	1.1 $\mu\text{g}/\text{m}^3$	2.4 $\mu\text{g}/\text{m}^3$	1.5 $\mu\text{g}/\text{m}^3$	26 $\mu\text{g}/\text{m}^3$	U.S. EPA, 2008b (NHEXAS Region 5)
	Carbon tetrachloride	GC-MS					
	1,2-dibromoethane	GC-MS					
	1,4-dichlorobenzene	GC-MS	0.76 $\mu\text{g}/\text{m}^3$	4.8 $\mu\text{g}/\text{m}^3$	1.0 $\mu\text{g}/\text{m}^3$	120 $\mu\text{g}/\text{m}^3$	U.S. EPA, 2008b (NHEXAS Region 5)
	Trichloroethylene	GC-MS	1.0 $\mu\text{g}/\text{m}^3$	3.6 $\mu\text{g}/\text{m}^3$	0.64 $\mu\text{g}/\text{m}^3$	170 $\mu\text{g}/\text{m}^3$	U.S. EPA, 2008b (NHEXAS Region 5)
	Tetrachloroethylene	GC-MS	1.6 $\mu\text{g}/\text{m}^3$	18 $\mu\text{g}/\text{m}^3$	2.4 $\mu\text{g}/\text{m}^3$	990 $\mu\text{g}/\text{m}^3$	U.S. EPA, 2008b (NHEXAS Region 5)
	Toluene	GC-MS	3.2 $\mu\text{g}/\text{m}^3$	72 $\mu\text{g}/\text{m}^3$	28 $\mu\text{g}/\text{m}^3$	3,500 $\mu\text{g}/\text{m}^3$	U.S. EPA, 2008b (NHEXAS Region 5)
	o-xylene	GC-MS		13 $\mu\text{g}/\text{m}^3$	4.6 $\mu\text{g}/\text{m}^3$	1,765 $\mu\text{g}/\text{m}^3$	U.S. EPA, 2008b (NHEXAS Region 5)
	m,p-Xylene	GC-MS		34 $\mu\text{g}/\text{m}^3$	8.6 $\mu\text{g}/\text{m}^3$	5,300 $\mu\text{g}/\text{m}^3$	U.S. EPA, 2008b (NHEXAS Region 5)
	Ethylbenzene	GC-MS					
	1,2,4-trimethylbenzene	GC-MS					
	1,3,5-trimethylbenzene	GC-MS					
	Methyl <i>t</i> -butyl ether	GC-MS					
	Styrene	GC-MS	0.82 $\mu\text{g}/\text{m}^3$	2.7 $\mu\text{g}/\text{m}^3$	1.9 $\mu\text{g}/\text{m}^3$	79 $\mu\text{g}/\text{m}^3$	U.S. EPA, 2008b (NHEXAS Region 5)
	o-dichlorobenzene	GC-MS					
	<i>m</i> -dichlorobenzene	GC-MS					
	1,1-dichloroethene	GC-MS					
	<i>cis</i> -dichloroethene	GC-MS					
	1,1-dichloroethane	GC-MS					
	1,2-dichloroethane	GC-MS					
1,1,1-trichloroethane	GC-MS	1.4 $\mu\text{g}/\text{m}^3$	11 $\mu\text{g}/\text{m}^3$	3.8 $\mu\text{g}/\text{m}^3$	540 $\mu\text{g}/\text{m}^3$	U.S. EPA, 2008b (NHEXAS Region 5)	
1,1,2-trichloroethane	GC-MS						
1,1,2,2-tetrachloroethane	GC-MS						
Chlorobenzene	GC-MS						

Analyte Class	Analyte	Analytical Method	MDL/MQL	Occurrence— Mean	Occurrence— Median	Occurrence— Maximum	Reference (Study)
Semi-volatile organic compounds*	Levoglucosan	GC-MS					
	Hopanes (4 compounds)	GC-MS					
	Fatty acids (4 compounds)	GC-MS					
Gases	Ozone	IC passive					
	SOx	IC passive					
	NOx	IC passive					
Environmental tobacco smoke	Nicotine	Mass/EC/ETS					
Microbiologicals*	Endotoxin and $\beta$ 1,3 glucan	Limulus amoebocyte lysate					
Other chemicals*	Dialkylphthalate panel, including DEHP	GC-MS					
	Bisphenol A/Alkylphenol scan	GC-MS					

\*This matrix-analyte class may be archived for later analysis.

Table A-3. Dust

Analyte Class	Analyte	Analytical Method	MDL/MQL	Occurrence—Mean	Occurrence—Median	Occurrence—Maximum	Reference (Study)
Minerals*	Silica	XRD	5 µg/sample				
	Asbestos	PLM	7 fibers/mm <sup>2</sup>				
Metals*	Arsenic, inorganic (+3 and +5)	ICP-MS	48 µg/g (total As)	100 µg/g	95 µg/g	250 µg/g	U.S. EPA, 2008b (NHEXAS Arizona)
	Arsenic, organic	IC					
	Beryllium	ICP-MS					
	Cadmium	ICP-MS		7.1 µg/g	6.2 µg/g	17 µg/g	U.S. EPA, 2008b (NHEXAS Arizona)
	Lead	ICP-MS	3.3 µg/g	95 µg/g	57 µg/g	930 µg/g	U.S. EPA, 2008b (NHEXAS Arizona)
	Mercury	CVAA					
	Manganese	ICP-MS	5.2 - 230 µg/g	320–740 µg/g	310–650 µg/g	2,800 µg/g	U.S. EPA, 2008b (NHEXAS Arizona)
	Nickel, total	ICP-MS	1.1 µg/g	39 µg/g	36 µg/g	170 µg/g	U.S. EPA, 2008b (NHEXAS Arizona)
	Selenium	ICP-MS					
Chromium (VI)	IC	16 µg/g (total Cr)	46–870 µg/g	41–720 µg/g	1,400 µg/g	U.S. EPA, 2008b (NHEXAS Arizona)	
PAHs*	EPA Priority PAHs	GC-MS	.001 µg/g	.006–.297 µg/g		1.6 µg/g	Wilson et al., 2003
PCBs and dioxin*	PCBs, 12 dioxin-like congeners	GC-MS	.001 µg/g	ND–14 ng/g		44 ng/g	Wilson et al., 2003
	2,3,7,8-dibenzodioxins	GC-HRMS	8–150 pg/sample				
	2,3,7,8-dibenzofurans	GC-HRMS	6–45 pg/sample				
Organochlorine pesticides*	DDT (6 compounds)	GC-MS	.001 µg/g	.059 µg/g		.047 µg/g	Wilson et al., 2003
	Hexachlorobenzene	GC-MS					
	Lindane (BHC) (multiple compounds)	GC-MS	.001 µg/g	.033 µg/g		.046 µg/g	Wilson et al., 2003
	Mirex	GC-MS					
	Kepone (chlordecone)	GC-MS					
	Chlordane	GC-MS	.001 µg/g	.15 µg/g		.63 µg/g	Wilson et al., 2003
	Oxychlordane	GCMS					
	Heptachlor	GC-MS	.001 µg/g	.119 µg/g		.335 µg/g	Wilson et al., 2003
Heptachlor epoxide	GC-MS						

Analyte Class	Analyte	Analytical Method	MDL/MQL	Occurrence—Mean	Occurrence—Median	Occurrence—Maximum	Reference (Study)
Organochlorine pesticides* (continued)	Endosulfan	GC-MS					
	Toxaphene	GC-MS					
	Dieldrin	GC-MS	.001 µg/g	.018 µg/g		50 µg/g	Wilson et al., 2003
Non-persistent pesticides*	Endrin	GC-MS	.001 µg/g	ND			Wilson et al., 2003
	Aldrin	GC-MS	.001 µg/g	.006 µg/g		.051 µg/g	Wilson et al., 2003
	Organophosphate scan	GC-MS	.001 µg/g	0.04–1.0 µg/g		6.5 µg/g	Wilson et al., 2003
	Pyrethroid scan	GC-MS					
Microbiologicals*	Endotoxin and β1,3 glucan	Limulus amoebocyte lysate					
PBDEs*	BDE 47	GC-MS or GC-ECD	1–5 ng/g	1,900 ng/g			Lorber, 2008
	BDE 99	GC-MS or GC-ECD	1–5 ng/g	2,400 ng/g			Lorber, 2008
	BDE 153	GC-MS or GC-ECD	1–5 ng/g	243 ng/g			Lorber, 2008
	DecabromoDE	GC-MS or GC-ECD	1–5 ng/g	2,400 ng/g			Lorber, 2008
Perfluorinated acids*	PFOA	HPLC-MS/MS	1 ng/sample				
	PFOS	HPLC-MS/MS	0.1 ng/sample				
	PFNA	HPLC-MS/MS					
Other chemicals*	Dialkylphthalate scan, including DEHP	GC-MS	.001 µg/g	1.2–5.9 µg/g		15.6 µg/g	Wilson et al., 2003
	Bisphenol A/Alkylphenol scan	GC-MS	.001 µg/g	1.5 µg/g / 7.2 µg/g		1.9 µg/g / 9.6 µg/g	Wilson et al., 2003

\*This matrix-analyte class may be archived for later analysis.

Table A-4. Water

Analyte Class	Analyte	Analytical Method	MDL/MQL	Occurrence— Mean	Occurrence— Median	Occurrence— Maximum	Reference (Study)
Metals*	Arsenic, inorganic (+3 and +5)	ICP-MS	0.075 µg/L (total As)	4.9–6.7 µg/L	2.4–5.0 µg/L	36.7 µg/L	U.S. EPA, 2008b (NHEXAS Arizona)
	Arsenic, organic	IC					
	Beryllium	ICP-MS					
	Cadmium	ICP-MS	0.21–0.29 µg/L	0.17–1.2 µg/L	0.16–0.17 µg/L	8.3 µg/L	U.S. EPA, 2008a (NHEXAS Arizona)
	Lead	ICP-MS	0.05–0.08 µg/L	0.69–1.9 µg/L	0.36–0.46 µg/L	28.4 µg/L	U.S. EPA, 2008b (NHEXAS Arizona)
	Manganese	ICP-MS	0.06–0.10 µg/L	1.3–3.2 µg/L	0.36 µg/L	110 µg/L	U.S. EPA, 2008b (NHEXAS Arizona)
	Mercury	CVAA					
	Nickel, total	ICP-MS	0.13–0.13 µg/L	5.1–9.7 µg/L	2.6–3.7 µg/L	200 µg/L	U.S. EPA, 2008b (NHEXAS Arizona)
	Selenium	ICP-MS	0.25–0.31 µg/L	1.3–1.7 µg/L	1.0–1.1 µg/L	8.1 µg/L	U.S. EPA, 2008b (NHEXAS Arizona)
	Chromium (VI)	IC-ICP-MS	0.11–0.15 µg/L (total Cr)	7.2–7.3 µg/L	0.67–1.6 µg/L	140 µg/L	U.S. EPA, 2008b (NHEXAS Arizona)
Volatile organic compounds	Bromodichloromethane	GC-MS	0.34 ng/mL	0.02 ng/mL	0.007 ng/mL	0.92 ng/mL	NCHS, 2007 (NHANES)
	Chloroform	GC-MS	0.66 ng/mL	7.4 ng/mL	5.1 ng/mL	39.3 ng/mL	NCHS, 2007 (NHANES)
	1,2-dibromoethane	GC-MS					
	Trichloroethylene	GC-MS	0.03 µg/L	0.01 µg/L	0.006 µg/L	0.09 µg/L	U.S. EPA, 2008b (NHEXAS Region 5)
	Tetrachloroethylene	GC-MS	0.015 µg/L	0.002 µg/L	0.00 µg/L	0.032 µg/L	U.S. EPA, 2008b (NHEXAS Region 5)
	MTBE	GC-MS	0.29 ng/mL	0.46 ng/mL	0.24 ng/mL	10 ng/mL	NCHS, 2007 (NHANES)

Analyte Class	Analyte	Analytical Method	MDL/MQL	Occurrence— Mean	Occurrence— Median	Occurrence— Maximum	Reference (Study)
Non-persistent pesticides	Organophosphate panel	GC-MS					
	Pyrethroid panel	GC-MS					
Perfluorinated acids	PFOA	LC-MS/MS	10 ng/L	ND–520 ng/L			Hölzer et al., 2008
			50–1000 µg/L	<100–4800 ng/L			Paustenbach, 2007
	PFOS	LC-MS/MS	10 ng/L	ND–5 ng/L			Hölzer et al., 2008
	PFNA	LC-MS/MS					
Other chemicals	Dialkylphthalate scan, including DEHP	GC-MS					
	Bisphenol A/Alkylphenol scan	GC-MS					

\*This matrix-analyte class may be archived for later analysis.

Table A-5. Food

Analyte Class	Analyte	Analytical Method	MDL/MQL	Occurrence —Mean	Occurrence —Median	Occurrence —Maximum	Reference (Study)
Metals*	Arsenic, inorganic (+3 and +5)	ICP-MS	0.40 µg/kg (total As)	8.6 µg/kg	2.8 µg/kg	326 µg/kg	U.S. EPA, 2008b (NHEXAS Region 5)
			0.29 µg/kg (total As)	3.1 µg/kg	2.1 µg/kg	20 µg/kg	U.S. EPA, 2008b (NHEXAS Arizona)
	Arsenic, organic	IC					
	Beryllium	ICP-MS					
	Cadmium	ICP-MS	0.27 µg/kg	8.1 µg/kg	5.4 µg/kg	61 µg/kg	U.S. EPA, 2008b (NHEXAS Region 5)
	Lead	ICP-MS	0.38 µg/kg	5.1 µg/kg	3.0 µg/kg	195 µg/kg	U.S. EPA, 2008b (NHEXAS Region 5)
			0.20 µg/kg	3.6 µg/kg	2.0 µg/kg	32 µg/kg	U.S. EPA, 2008b (NHEXAS Arizona)
	Manganese	ICP-MS		1,600 µg/kg	890 µg/kg	17,000 µg/kg	U.S. EPA, 2008b (NHEXAS Region 5)
	Mercury	CVAA					
	Nickel, total	ICP-MS	2.0 µg/kg	79 µg/kg	42 µg/kg	7,700 µg/kg	U.S. EPA, 2008b (NHEXAS Region 5)
	Selenium	ICP-MS	1.2 µg/kg	50 µg/kg	34 µg/kg	360 µg/kg	U.S. EPA, 2008b (NHEXAS Region 5)
	Chromium (VI)	IC-ICP-MS	16 µg/kg (Total Cr)	39 µg/kg	21 µg/kg	530 µg/kg	U.S. EPA, 2008b (NHEXAS Region 5)
		14 µg/kg (Total Cr)	84 µg/kg	66 µg/kg	462 µg/kg	U.S. EPA, 2008b (NHEXAS Arizona)	
PAHs*	EPA Priority PAHs	GC-MS	.04 ng/g	ND–1.8 ng/g		2.8 ng/g	Wilson et al., 2003
PCBs and dioxin*	PCBs, 12 dioxin-like congeners	GC-MS	0.04 ng/g	ND–0.05 ng/g		0.17 ng/g	Wilson et al., 2003
	PCBs, all congeners (select samples)	GC-HRMS	80–1,900 pg/sample				
	2,3,7,8-dibenzodioxins	GC-HRMS	8–150 pg/sample				
	2,3,7,8-dibenzofurans	GC-HRMS	6–45 pg/sample				
Organochlorine pesticides*	DDT (6 compounds)	GC-MS	.04 ng/g	.27 ng/g		1.3 ng/g	Wilson et al., 2003
	Hexachlorobenzene	GC-MS					
	Lindane (BHC) (multiple compounds)	GC-MS	.04 ng/g	ND			Wilson et al., 2003
	Mirex	GC-MS					

Analyte Class	Analyte	Analytical Method	MDL/MQL	Occurrence —Mean	Occurrence —Median	Occurrence —Maximum	Reference (Study)
Organochlorine pesticides* (continued)	Kepone (chlordecone)	GC-MS					
	Chlordane	GC-MS	.04 ng/g	.06 ng/g		.14 ng/g	Wilson et al., 2003
	Oxychlordane	GCMS					
	Heptachlor	GC-MS	.04 ng/g	.30 ng/g		.82 ng/g	Wilson et al., 2003
	Heptachlor epoxide	GC-MS					
	Endosulfan	GC-MS					
	Toxaphene	GC-MS					
	Dieldrin	GC-MS	.04 ng/g	ND			Wilson et al., 2003
	Endrin	GC-MS	.04 ng/g	ND			Wilson et al., 2003
Aldrin	GC-MS	.04 ng/g	ND			Wilson et al., 2003	
Non-persistent pesticides*	Organophosphate scan	GC-MS		ND–0.82 ng/g		2.3 ng/g	Wilson et al., 2003
	Pyrethroid scan	GC-MS					
PBDEs*	BDE 47	GC-MS or GC-ECD		0.02–3.6 µg/g			Lorber, 2008
	BDE 99	GC-MS or GC-ECD		0.03–1.2 µg/g			Lorber, 2008
	BDE 153	GC-MS or GC-ECD		ND–0.02 µg/g			Lorber, 2008
	DecabromoDE	GC-MS or GC-ECD		0.08–5.7 µg/g			Lorber, 2008
Perfluorinated acids*	PFOA	LC-MS	0.1 ng/g	0.69 ng/g	<MDL	120 ng/g	Fromme et al., 2007
	PFOS	LC-MS	0.05 ng/g	0.06 ng/g	<MDL	1.0 ng/g	Fromme et al., 2007
	PFNA	LC-MS					
Other chemicals*	Dialkylphthalate scan, including DEHP	GC-MS	.04 ng/g	20–100 ng/g		400 ng/g	Wilson et al., 2003
	Bisphenol A/Alkylphenol scan	GC-MS	.04 ng/g	1.3 ng/g / 33 ng/g		4.2 ng/g / 76 ng/g	Wilson et al., 2003

\*This matrix-analyte class may be archived for later analysis.

Table A-6. Hair

Analyte Class	Analyte	Analytical Method	MDL/MQL	Occurrence— Mean	Occurrence— Median	Occurrence— Maximum	Reference (Study)	
Metals*	Arsenic, inorganic (+3 and +5)	ICP-MS						
	Arsenic, organic	IC						
	Beryllium	ICP-MS	N/A	N/A	N/A	N/A		
	Cadmium	ICP-MS						
	Lead	ICP-MS						
	Nickel, total	ICP-MS	N/A	N/A	N/A	N/A		
	Mercury	CVAA		0.11 ppm	1.0 ppm	0.19 ppm	849 ppm	NCHS, 2007 (NHANES)
				0.04 µg/g	0.37 µg/g	0.26 µg/g	3.5 µg/g	U.S. EPA, 2008b (NHEXAS Region 5)
	Manganese	ICP-MS						
	Selenium	ICP-MS	N/A	N/A	N/A	N/A		
Chromium (VI)	IC							

\*This matrix-analyte class may be archived for later analysis.

Note: N/A = Hair not a suitable matrix for this analyte.

Table A-7. Blood, Plasma, and Serum

Analyte Class	Analyte	Analytical Method	MDL/MQL	Occurrence— Mean	Occurrence— Median	Occurrence— Maximum	Reference (Study)
Metals*	Arsenic, inorganic (+3 and +5)	ICP-MS	0.20 µg/L (total As)	0.92 µg/L	0.60 µg/L	14 µg/L	U.S. EPA, 2008b (NHEXAS Baltimore)
	Arsenic, organic	IC					
	Beryllium	ICP-MS					
	Cadmium	ICP-MS	0.30 µg/L	0.83 µg/L	0.41 µg/L	8.6 µg/L	U.S. EPA, 2008b (NHEXAS Baltimore)
	Lead	ICP-MS	0.3 µg/dL	2.2 µg/dL	1.7 µg/dL	54 µg/dL	NCHS, 2007 (NHANES)
			0.6 µg/dL	2.2 µg/dL	1.7 µg/dL	18 µg/dL	U.S. EPA, 2008b (NHEXAS Arizona)
			0.6 µg/dL	2.3 µg/dL	1.8 µg/dL	13 µg/dL	U.S. EPA, 2008b (NHEXAS Region 5)
			0.10 µg/L	0.86 µg/L	0.40 µg/L	13.4 µg/L	U.S. EPA, 2008b (NHEXAS Baltimore)
	Manganese	ICP-MS	0.005 µg/L	5.8 µg/L	3.88 µg/L	86.4 µg/L	U.S. EPA, 2008b (NHEXAS Baltimore)
	Mercury	CVAA	0.14 µg/L (total Hg)	1.6 µg/L	0.9 µg/L	39 µg/L	U.S. EPA, 2008b (NHEXAS Baltimore)
	Nickel, total	ICP-MS	0.017 µg/L	3.0 µg/L	2.6 µg/L	11.7 µg/L	U.S. EPA, 2008b (NHEXAS Baltimore)
	Selenium	ICP-MS	0.54 µg/L	0.36 µg/L	0.3 µg/L	1.8 µg/L	U.S. EPA, 2008b (NHEXAS Baltimore)
Chromium (VI)	IC	0.21 µg/L (total Cr)	2.8 µg/L	0.43 µg/L	44.6 µg/L	U.S. EPA, 2008b (NHEXAS Baltimore)	
PCBs and dioxin*	PCBs, 12 dioxin-like congeners	GC-HRMS	69–160 fg/g	82–250 fg/g	77–140 fg/g	15,000 fg/g	NCHS, 2007 (NHANES)
	Octachlorodibenzodioxin	GC-HRMS	1,400 fg/g	3,000 fg/g	2,000 fg/g	54,600 fg/g	NCHS, 2007 (NHANES)
	Octachlorodibenzofuran	GC-HRMS	100 fg/g	51 fg/g	47 fg/g	490 fg/g	NCHS, 2007 (NHANES)
	Heptachlorodibenzodioxin	GC-HRMS	190 fg/g	370 fg/g	260 fg/g	5,400 fg/g	NCHS, 2007 (NHANES)
	2,3,7,8 -dioxins, other	GC-HRMS	32–59 fg/g	18–250 fg/g	15–170 fg/g	4,100 fg/g	NCHS, 2007 (NHANES)
	2,3,7,8-dibenzofurans, other	GC-HRMS	30–38 fg/g	15–45 fg/g	14–32 fg/g	640 fg/g	NCHS, 2007 (NHANES)
	Lipids	Clinical					

Analyte Class	Analyte	Analytical Method	MDL/MQL	Occurrence— Mean	Occurrence— Median	Occurrence— Maximum	Reference (Study)
Organochlorine pesticides*	DDT (6 compounds)	GC-MS	0.08 ng/g	0.04–6.2 ng/g	0.04–2.38 ng/g	170 ng/g	NCHS, 2007 (NHANES)
	Hexachlorobenzene	GC-MS	0.28 ng/g	0.15 ng/g	0.06 ng/g	2.0 ng/g	NCHS, 2007 (NHANES)
	Lindane (BHC) (multiple compounds)	GC-MS	0.04 ng/g	0.03–0.2 ng/g	0.02–0.07 ng/g	25 ng/g	NCHS, 2007 (NHANES)
	Mirex	GC-MS	0.05 ng/g	0.09 ng/g	0.03 ng/g	19 ng/g	NCHS, 2007 (NHANES)
	Kepone (chlordecone)	GC-MS					
	Chlordane	GC-MS	0.013 µg/L	0.0067 µg/L	0.007 µg/L	0.007 µg/L	U.S. EPA, 2008b (NHEXAS Baltimore)
	Oxychlordane	GC-MS	0.05 ng/g	0.14 ng/g	0.08 ng/g	3.2 ng/g	NCHS, 2007 (NHANES)
	Heptachlor	GC-MS	0.22 µg/L				U.S. EPA, 2008b (NHEXAS Baltimore)
	Heptachlor epoxide	GC-MS	0.05 ng/g	0.07 ng/g	0.04 ng/g	6.0 ng/g	NCHS, 2007 (NHANES)
	Endosulfan	GC-MS					
	Toxaphene	GC-MS					
	Dieldrin	GC-MS	0.04 ng/g	0.06 ng/g	0.04 ng/g	4.13 ng/g	NCHS, 2007 (NHANES)
	Endrin	GC-MS	0.04 ng/g	0.02 ng/g	0.02 ng/g	0.08 ng/g	NCHS, 2007 (NHANES)
	Aldrin	GC-MS	0.04 ng/g	0.02 ng/g	0.02 ng/g	0.05 ng/g	NCHS, 2007 (NHANES)
PBDEs*	BDE 47	GC-MS or GC-ECD	1–5 ng/g	0.63–130 ng/g lipid			Sjödin et al., 2003
	BDE 99	GC-MS or GC-ECD	1–5 ng/g	0.32–30 ng/g lipid			Sjödin et al., 2003
	BDE 153	GC-MS or GC-ECD	1–5 ng/g	0.96–16 ng/g lipid			Sjödin et al., 2003
	DecabromoDE	GC-MS or GC-ECD	1–5 ng/g				
Perfluorinated acids*	PFOA	HPLC-MS/MS	1.0 ng/mL	7.8 ng/mL	7.1 ng/mL	22 ng/mL	Longnecker et al., 2008
	PFOS	HPLC-MS/MS	0.1 ng/mL	33 ng/mL	27 ng/mL	95 ng/mL	Longnecker et al., 2008
	PFNA	HPLC-MS/MS					

Analyte Class	Analyte	Analytical Method	MDL/MQL	Occurrence— Mean	Occurrence— Median	Occurrence— Maximum	Reference (Study)
Other chemicals*	Dialkylphthalate scan, including DEHP	GC-MS					
	Bisphenol A/Alkylphenol scan	GC-MS					

\*This matrix-analyte class may be archived for later analysis.

Table A-8. Urine

Analyte Class	Analyte	Analytical Method	MDL/MQL	Occurrence— Mean	Occurrence— Median	Occurrence— Maximum	Reference (Study)
Metals*	Arsenic, inorganic (+3 and +5)	ICP-MS	4 µg/L (total As)	23 µg/L	4 µg/L	1,644 µg/L	U.S. EPA, 2008b (NHEXAS Region 5)
			4 µg/L (total As)	31 µg/L	18 µg/L	430 µg/L	U.S. EPA, 2008b (NHEXAS Arizona)
	Arsenic, organic	IC					
	Beryllium	ICP-MS					
	Cadmium	ICP-MS	0.06 ng/mL	0.48 ng/mL	0.30 ng/mL	37 ng/mL	NCHS, 2007 (NHANES)
			0.1 µg/L	0.71 µg/L	0.40 µg/L	5.5 µg/L	U.S. EPA, 2008b (NHEXAS Region 5)
	Lead	ICP-MS	0.1 ng/mL	1.22 ng/mL	0.9 ng/mL	31 ng/mL	NCHS, 2007 (NHANES)
	Mercury	CVAA	0.14–0.3 ng/mL	0.56–1.3 ng/mL	0.4–0.6 ng/mL	61 ng/mL	NCHS, 2007 (NHANES)
	Manganese	ICP-MS	0.1 µg/L	2.9 µg/L	2.6 µg/L	8.3 µg/L	U.S. EPA, 2008b (NHEXAS Arizona)
	Nickel, total	ICP-MS		4.5 µg/L	3.9 µg/L	21 µg/L	U.S. EPA, 2008b (NHEXAS Arizona)
	Selenium	ICP-MS					
	Chromium (VI)	IC	0.4 µg/L (total Cr)	0.69 µg/L	0.4 µg/L	7.6 µg/L	U.S. EPA, 2008b (NHEXAS Region 5)
Perfluorinated acids*	PFOA	HPLC-MS/MS					
	PFOS	HPLC-MS/MS					
	PFNA	HPLC-MS/MS					
Other chemicals*	Alkyl phthalate panel, including MEHP	GC-MS			< 0.1–>100 ng/mL		NCHS, 2007 (NHANES)
	Bisphenol A/Alkylphenol scan	GC-MS	0.1 ng/mL				Kuklenyik et al., 2003

\*This matrix-analyte class may be archived for later analysis.

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## **Appendix B**

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## DESIGN I—PLAN

### 1. Goals and Objectives

DESIGN I will address three objectives over a 12-month period ahead of the Multimedia Exposure Study (MMES) proposed in DESIGN II. The design of the National Human Exposure Assessment Survey (NHEXAS) MMES (see Pellizzari et al., 2000; Whitmore et al., 1999) provides an underlying framework for the current, updated designs. DESIGN I is planned to include objectives to address the following:

- A range-finding study for a targeted suite of contaminant exposure levels that are generally applicable to all of Delaware
- A methodological evaluation pilot to test methods proposed for the first year of the MMES under Delaware conditions
- A focused study in Sussex County to characterize the impact of the Indian River Power Plant's source emissions on contaminant exposure levels for residences living nearby.

All objectives are unique, but they are also linked because the same data will be used to satisfy all DESIGN I objectives. First, the pilot study will determine the range of contaminant concentrations across Delaware that are expected in all media to be investigated during the MMES of DESIGN II. Samples will be intentionally collected at Delaware locations selected jointly with DNREC that are expected to bracket low, medium, and high concentrations for contaminants in air, water, food, and dust media. These data will provide a reasonable understanding of the ranges of contaminants that affect Delawareans during the subsequent MMES effort. They will also provide a first-cut assessment of the spatial variability among Delaware Census County Divisions (CCDs) for the target contaminants. Second, a study of experimental and analytical methods will be implemented simultaneously for specific metrics for all media to identify the best methods for the MMES. Methods for survey selection, recruitment/enrollment, sample collection, analysis, archival, and database management will be evaluated and refined. Lastly, an intensive exposure characterization study will be conducted in the Millsboro CCD to assess the ground-level impacts of the Indian River Power Plant's air contaminant emissions on personal, indoor, and backyard exposure scenarios. Note that the source and impacted area selections for this objective were made separately by DNREC, and no other rationales for these selections are provided in this document.

The specific objectives to be addressed during the 12-month DESIGN I period are the following:

- **Objective 1.** Conduct a limited, range-finding pilot study for air, water, food, and dust across Delaware on high-priority contaminants to nominally define the ranges for low, medium, and high concentration exposure levels that are expected to be encountered by Delawareans, including personal, indoor, and outdoor air samples during the DESIGN II effort.
- **Objective 2.** Conduct methodology testing for all proposed DESIGN II activities to take advantage of the concentration ranges monitored in Objective 1. Of particular concern is whether the minimum detection limits of the analytical methods are low enough to capture the lowest concentrations of target analytes in Delaware. Methods and procedures

accepted by the scientific community will be customized specifically for Delaware to maximize the data quality. Multiple sample collection and analysis techniques will be evaluated if an accepted standard method is not available.

- **Objective 3.** Conduct a source impact study that focuses on multimedia exposures to carcinogens in the Millsboro CCD. The data will provide the Delaware Department of Natural Resources and Environmental Control (DNREC) and the Delaware Division of Public Health (DDPH) timely, targeted data to assess the impact of the Indian River Power Plant on the local population's exposure concentrations to carcinogens. The exposure media studied will be air, water, food, house dust, and biomarkers.

Activities and sampling would be conducted entirely within Delaware, with a concerted effort made to collect samples and data throughout the CCDs identified in the Delaware Department of Health and Social Services (DHSS) report, *Average Annual Age-Adjusted Cancer Incidence Rates 2000–2004, at the Delaware Sub-County Level* (2008). For completeness, the air impacts from regional background contributions (in adjacent states and the United States) will also be assessed by collecting some samples at representative “upwind” locations. These contributions from outside Delaware are surmised to be substantial at times for some contaminants.

The spatial representativeness for DESIGN I locations relative to a specific CCD will be subjectively defined by exposure assessment experts (within RTI and DNREC/DHSS). An associated source survey questionnaire will be completed for each location to support the experts' assessments. Note that temporal representativeness of the DESIGN I study periods will be heavily dependent upon the prevailing meteorology and the presence/absence of strong nearby sources during the period. It is also important to recognize that the range-finding data collected in Objective 1 will be valuable and provide Delaware with timely exposure assessment data within a nominal calendar year period, but it will not have the same statistical power to make inferences about the population planned for the probability-based study in DESIGN II. Delaware DNREC assistance will be required to help define the level of expected temporal representativeness to prior or future time periods. Ideally, the DESIGN I study would be conducted during portions (e.g., seasons) of the 12-month period that will maximize the probability that the data collected will be optimally useful to DNREC and the DESIGN II effort.

DESIGN I will not include a risk analysis to place the collected exposure data into perspective. This would be the obvious next step after completing DESIGN I (in addition to folding “lessons learned” into DESIGN II), and RTI could certainly assist DNREC/DHSS in such an effort if requested to do so.

Some activities, samples, and analyses would serve only one objective, whereas others would provide input for two or all three objectives. Matrix tables are provided in this plan to identify how each activity and data point supports each objective. Although the DESIGN I procedures will be validated and part of the Quality Assurance Project Plan (QAPP) for DESIGN II, none of the samples or data collected during DESIGN I are expected to satisfy the (completely separate) sampling matrix requirements for DESIGN II in support of the probability-based MMES hypotheses. It is unlikely that any households selected for DESIGN I sampling would also overlap with the random selection to be used in DESIGN II. The same locations previously sampled by DNREC (air and water) used in DESIGN I would also be used in DESIGN II for consistency.

It is critically important for the data produced by all facets of DESIGN I to be both defensible and, when possible, relate to national and international standards. The necessary levels of defensibility must be specifically identified in the detailed study workplan (to follow from this design) and would be established collaboratively with Delaware DNREC technical staff. From the outset, they will be guided by the Data Quality Objectives (DQOs) needed to test the hypotheses. Carefully defined standard operating procedures (SOPs) and validation under actual Delaware conditions help assure that the selected methods provide the required data and data quality.

### **1.1 Data for Objective 1—Contaminant Range Finding**

Measurement of contaminant concentration ranges in all media—specifically, air, water, food, and house dust—across Delaware will be made as part of Objective 1 in DESIGN I. The data will identify whether concentrations are spatially homogeneous or heterogeneous for classes of air pollutants and specific air pollutant species. The influence of local point and area sources (primarily for air) will be factored into the experimental design, especially when accounting for specific particle or gas species. Food and water media contaminant ranges are not expected to be large across the state, except for those electing to use specialty foods and waters (e.g., organic food, homegrown vegetables, self-caught fish, and bottled water). An important aspect of such studies is to identify whether inferences can be made about differences that exist across the CCDs to understand spatially varying adverse health outcomes. The preliminary selection of analytes and biomarkers addresses adverse cancer, cardiovascular, and pulmonary outcomes and was developed from many sources. Recent Delaware-specific reports (see all Delaware-specific references, including DNREC, 2005; DNREC/DWR, 2007b; DNREC, 2007; DNREC, 2006; Greene, 2008; and MacGillivray, 2008) on the spatial distributions of a wide range of air and water contaminants, as well as the most recent U.S. Environmental Protection Agency (EPA) particulate matter (PM) criteria document (U.S. EPA, 2004), will be used for guidance, along with input from Delaware DNREC and DHSS technical staff.

PM, volatile organic compounds (VOCs), and carbonyl samples will be collected, and PM<sub>2.5</sub> and PM<sub>10</sub> mass concentrations will be characterized. Also, the concentrations of particulate chemical species that are known source apportionment markers, inflammatory agents, and/or carcinogens will be measured (U.S. EPA, 2004).

For the air route, it is expected that PM<sub>10</sub> concentrations may be more variable than PM<sub>2.5</sub>, especially if the coarse PM component (PM<sub>10-2.5</sub>) is the major contributor to PM<sub>10</sub>. However, it is also known that the chemical species that comprise PM<sub>2.5</sub> may vary spatially due to the impact of local sources before atmospheric mixing distributes the species uniformly. Similarly, VOC and aldehyde concentrations may be greater near point and area sources. VOCs and carbonyls may show less spatial variability due to their greater diffusivity and photochemical degradation.

Source, meteorological, and geographical influences will also impact the (air) PM and gas concentrations. Point sources, such as the Indian River Power Plant and the Valero refinery, will generate high-concentration hotspots, where their emission plumes reach ground level. The hotspot locations will vary between sources because of emission rates and release heights. Area sources, such as highways, will have a more localized impact on pollutant concentrations. PM concentration gradients reach a background level within 500 m of the road, whereas VOC and carbonyl gradients quickly reach equilibrium in <200 m. Meteorology is another factor because

wind speed, wind direction, and atmospheric stability determine the direction and rate of pollutant dispersion from any source. Geographic influences include primarily population density and source-to-receptor proximity, as influenced by the meteorology. Pollutant concentrations in urban, suburban, and rural areas are expected to vary, especially for specific species, due to the impact of local sources. Also, the Delaware coast will have its own wind speed and direction micrometeorology that may differ substantially from weather conditions at interior locations.

## **1.2 Data for Objective 2—Study Method Testing**

The purpose of the method testing is to develop and finalize the sample collection methods and intervals to be used in DESIGN II that will provide the necessary data quality to meet the DESIGN II goals. Multiple methods for sample collection, analysis, and archival procedures of certain pollutants and media combinations exist. An integrated test matrix at locations covering low, medium, and high concentrations will provide the requisite data to identify the best procedures. Primary considerations are minimum detection limits, accuracy, and precision of the method. A secondary consideration is cost. Already established methods and procedures will be finalized as part of the study method testing. These procedures may need to be customized for situations unique to Delaware.

An appropriate sample collection interval is required to characterize chronic, long-term exposures versus acute, intermittent exposures to carcinogens and cardiopulmonary inflammatory agents. In some instances, the sample collection interval for chronic and acute exposure assessment is contradictory. On one hand, chronic carcinogen exposures may occur at low concentrations that require a multi-day sample integration time to obtain a measurable sample. On the other hand, acute exposures are often at high concentrations to produce an immediate cardiopulmonary effect. The DESIGN I workplan will include a discussion of the most appropriate sample integration intervals and sample collection designs to provide data to assess chronic and acute exposures. The default times for planning purposes are assumed to be 24-hour collections for acute and 72-hour collections for chronic assessment active (pumped) sampling. However, the low effective collection rates of passive sampling devices (e.g., for VOCs) may supercede these defaults and demand the longer term collections to meet detection limit goals.

## **1.3 Data for Objective 3—Source Impact Assessment**

A source impact assessment that focuses on the Indian River Power Plant will be implemented to provide credible and timely exposure data to the Delaware DNREC. Carcinogens and cardiopulmonary inflammatory agents from Indian River or other sources that impact the health of residents in the Millsboro CCD will be the focus. A convenience cohort of homes will be recruited for conducting outdoor residential air sampling. A subset of homes will have indoor and personal air samples collected. Although inhalation exposure will be the primary route studied, dietary and dermal exposure routes will also be investigated for a subset of homes. Biospecimens from residents will be collected to potentially characterize exposure from other microenvironments outside the home and to possibly assess chronic exposure levels.

## 2. Hypotheses

The hypotheses designed to meet the DESIGN I objectives are listed below. Each hypothesis links the study objectives defined in Section 1 with the sample collection and analysis strategy, appropriate statistical models, and expected outcomes. The general approaches for testing each specific hypothesis should be apparent from this design, but the detailed data analyses and modeling steps to do so will be provided subsequently in the associated workplan for DESIGN I.

### 2.1 Objective 1

- **H1:** Spatial concentration gradients for PM and toxic gases exist across Delaware that may be below or above the nominal sampling and analytical ranges of selected methods.
- **H2:** Coal-fired power plant emission marker concentrations exhibit a spatial concentration gradient that is influenced by meteorology, residence characteristics, personal activities, and other sources.

### 2.2 Objective 2

- **H3:** All methodologies used in Year 1 of DESIGN II under conditions and at locations unique to Delaware are optimal to achieve acceptable Data Quality Objectives (DQOs) in the most cost-effective manner.

### 2.3 Objective 3

- **H4:** Targeted air route (primarily) contaminants inside and outside of residences near the Indian River Power Plant are higher than concentrations in other urban and rural areas in the state.
- **H5:** The range of carcinogen concentrations in (primarily) air, drinking water, and house dust media will vary depending on residence proximity to the Indian River Power Plant, residence characteristics, and resident lifestyle choices.

## 3. DESIGN I Plan

The DESIGN I Monitoring Plan integrates the data requirements for all three objectives to maximize resource utilization. If properly planned and structured, the experimental design will provide the requisite pollutant concentration data to test each hypothesis from the same group of samples. In the instances where data that are specific to a single hypothesis is required, the simultaneous collection and analysis of the special samples will provide economies of scale that increase the overall cost effectiveness of the study.

The rationales for DESIGN I (e.g., exposure routes, scenarios, analytes) draw heavily from the entire list of Delaware-specific reports, presentations, and environmental alerts cited in the Reference section. Rationales for particle phase contaminants and regional air pollutant concerns are provided by EPA (2004).

### 3.1 Study Areas

DESIGN I is meant to provide data in a timely manner (Year 1 of the composite DESIGN I and DESIGN II plans) to identify differences in pollutant concentrations between and among geographical areas and microenvironments across Delaware. These areas are shown in the

overall map of Delaware (Figure A-1) and map for Sussex County (Figure A-2), in the attachments. The modest range-finding efforts by media of Objective 1 are recognized not to provide supporting data, but will not replace, the defensible statistical inferences regarding the residential population of Delaware to be obtained through the probability sampling design implemented in DESIGN II. The range finding nature of these measurements allows selection of specific study areas based on expected concentrations that might be influenced by point and area sources, meteorology, and geography. Population density by CCD is another consideration in selecting a study area. High population densities increase the probability of achieving the desired number of recruited participants within the designated area. Densely populated areas also increase the efficiency of sample collection.

DNREC/DHSS specifically identified the communities around the Indian River Power Plant as a high priority area for conducting Objective 3 and addressing Hypotheses 4 and 5. Neighborhoods expected to have low, medium, and high PM concentrations caused by Indian River Power Plant emissions and not impacted by other point sources will be identified in conjunction with DNREC. It is especially important to additionally characterize the (upwind, depending on the meteorology) regional background coming into Delaware from the surrounding areas during the sampling to support Objective 3. The predominant seasonal meteorology and distance from the source will be determining factors defining the low, medium, and high concentration areas resulting specifically from the Indian River Power Plant as compared to any other source category.

Additional monitoring areas in other parts of Delaware, in combination with the nearby Indian River Power Plant monitoring sites, will provide the large-scale spatial distribution necessary to answer Hypotheses 1 and 2. A site along the Delaware coast will capture concentration data influenced by the Indian River Power Plant and other major sources covering a wide angle of vectors. A rural location more than 50 km from known point sources will be selected as a regional background site. Because a majority of the population is found in suburban areas, a representative suburban community that is not directly impacted by a point or area source will be selected as the sixth monitoring site. The final site will be an urban site, preferably impacted by mobile source emissions and will be selected in a Wilmington area CCD to provide the highest concentrations. The carcinogenic metals and certain polycyclic aromatic hydrocarbons (PAHs) in the PM attributed to mobile sources are also found in coal combustion emissions. In all cases, final site selection will require additional information and input from DNREC.

### **3.2 Study Population**

The eased requirement for study population selection, relative to DESIGN II, allows a convenience cohort to be recruited for DESIGN I. DESIGN I will use a small, purposive (rather than random) sample approach to help ensure that the sample of residences and participants will experience the environmental exposures of interest in the pilot studies. A convenience sample is especially important for characterizing influence of personal preferences on exposure to carcinogens. Residents with individually unique, but fairly common, lifestyle choices must be sampled to bracket the range of carcinogen concentration in their food, water, and homes. Residences selected only for outdoor monitoring will not have any participation restrictions, and any residence within the selected neighborhoods will be allowed to participate. Smokers confound our ability to identify the exposure contributions from semi-volatile organic

compounds (SVOCs), VOCs, and carbonyls so smokers and smoking households will be excluded when personal and indoor sample collection are collected. Participants selected for personal exposure monitoring will be adults 18 years or older who are able to comprehend English, understand and agree to the study Consent Form, and assist study technicians in the completion of study questionnaire material.

Because the study includes human participants, an Institutional Review Board (IRB) must review and approve the study before participant enrollment. Delaware agencies may also require separate IRB approval for human studies. The study participants are not expected to be at significant risk for physical or psychological harm, although they may experience occasional challenges and burdens associated with having the field staff enter their homes and interfere with their regular activities. In some instances, the participants may be asked to record their activities, prepare additional meals, allow biological samples to be collected, wear personal air pollutant monitoring vests, or have air monitoring devices in their homes.

The study will also collect biological samples, including blood, urine, or hair, from select participants. Blood collection would likely be the riskiest procedure for this study. Although IRBs usually consider blood collection to be minimal risk. Because the blood samples include genetic material, and the protection of study participants and their data is paramount, participants will be given the choice of how their blood and other biological samples will be used. For example, blood could be collected and stored for future analyses, and the participants may want their blood destroyed after a specific number of years. The study's Consent Form will provide options that will allow participants to choose how their blood is used. Hair samples are simple to collect and can provide confirming dose data for metals, but can also be confounded (e.g., by constituents in hair care products). Hair analyses will only be completed to confirm high doses in other biomedica.

### **3.3 Recruitment/Retention Considerations**

Recruitment methods for DESIGN I will be selected to efficiently provide the needed convenience sample. The ability to use a convenience sample of the population relaxes the strictness of the recruitment requirements and procedures, thereby reducing cost. Informational pamphlet mailings and door-to-door recruitment are the two primary techniques for enrolling participants. Brochures that describe the study will be mailed to every residence in a study area and will yield an initial number of positive responses to satisfy the number of participants needed in that area. Residents who indicate an interest in the study will be contacted for a follow-up conversation by locally hired recruiters who know about neighborhood concerns and are trained in recruitment techniques. From this discussion, the resident will either enroll in the study or will decline to participate. If this recruitment campaign does not yield the desired number of participants in the area, then door-to-door recruitment may also be conducted.

A significant challenge of this type of study is to maintain the participants' interest in the study without being obtrusive. For this reason, retention techniques will be necessary if return visits to a participant's home are planned. Considerate and polite field technicians are the best retention technique, especially if personal and indoor samples are collected. Participants are often self-motivated at the start of a study, and polite field technicians can maintain their interest by minimizing the burden of the study, promptly addressing any participant concerns. In addition, properly designed and planned follow-up calls, summary reports, and reminder letters are effective retention devices and will be used for the study.

### 3.4 Temporal Sampling Considerations

Daily variability in pollutant concentrations is to be expected and should be accounted for in the study design. Meteorology and variation in source strengths are the primary contributors to inter-day variability. Continental meteorology affects the long-range transport of PM and gases from the Ohio River Valley or the Washington, DC, Baltimore, and Philadelphia metropolitan areas into Delaware. Hysplit back trajectories will provide important information on potential sources that may affect the measured concentrations. Weekday versus weekend changes in source strengths also need to be considered in the data analysis and source apportionment models, when appropriate. For example, lower traffic counts on weekends decrease mobile source emissions dramatically. Conversely, personal activity patterns may change on weekends and either increase or decrease the indoor and personal exposure concentrations.

Seasonal variability in pollutant concentrations also should be considered when characterizing pollutant concentration ranges. The concentration and composition of PM changes between summer and winter, and criteria gas concentrations also exhibit seasonal variability due to the reduction in photochemical reaction rates and lack of vegetation. Increased atmospheric stability also intensifies the magnitude of the spatial concentration gradients produced by specific sources.

### 3.5 Statistical Design

The statistical design of the study must provide an adequate number of samples to achieve the anticipated power of the hypothesis tests. Sample size will depend on the natural variability in the observations, expected difference in the means, and sensitivity in the data to minimize the possibility of a false positive. For DESIGN I, classical statistical formulas based on quasi-random sampling are applicable for Objectives 1 and 3. Data for Objective 2 do not require a separate statistical design. Method evaluation data will be obtained from the samples collected for addressing Objectives 1 and 3.

The variability in the observations is dominated by the daily fluctuations in the expected contaminant concentrations, and two approaches are available to account for this variability. The first approach will use a larger number of samples to provide sufficient data to estimate the concentration variability. For this approach, 24-hour samples for “day” will be included as a variable in the statistical analyses. This approach typically requires that the larger sample size be collected in a brief, intensive field campaign for all target contaminants; therefore, more participants will need to be recruited or multiple visits to the same participants will be required. In contrast, the second approach uses a longer sample-collection periods of 3 to 7 days to effectively “average out” the daily variability. The additional contaminant mass collected (especially for lower flow-rate air samplers) increases the accuracy and precision of the analytical data, thereby increasing the sensitivity of the statistical tests. However, because of the multi-day collection periods, this approach requires that samples be collected over an extended period of months to minimize participant burden (consecutive weeks of wearing sampling equipment).

The expected difference in mean concentrations is inversely proportional to the sample size. A larger concentration difference decreases the required number of samples. Historical pollutant concentration data and modeled concentrations will be invaluable for selecting the study areas to maximize the mean differences in the low-, medium-, and high-concentration

areas. DNREC and DHSS data on air pollutant concentrations and dietary exposures will aid in study area selection. When available, DNREC–modeled pollutant concentration distributions will be used. An important consideration is that not all pollutants will exhibit the same magnitude of concentration differences. For these pollutants, a larger sample size may be required to definitively prove the DESIGN I hypotheses.

The accuracy, precision, and detection limits for the sample collection and analysis methods determine the data sensitivity. Methods with high accuracy, high precision, and low detection limits minimize the experimental error associated with each datum and increase the probability that a statistically significant difference will be detected with the fewest number of samples. For these reasons, Objective 2 (Section 1.2) was included in DESIGN I to provide these data for proper selection of methods in DESIGN II.

### **3.5.1 Study Design Issues—Objective 1**

The spatial and seasonal variabilities in the selected contaminant concentrations across the selected areas can be determined with an estimated minimum of 280 samples. These samples would be equally divided among the areas (40 samples per area). The seasonal influence on concentrations would further divide the number of samples to 20 per area per season.

### **3.5.2 Study Design Issues—Objective 2**

Multiple, collocated samples will be collected simultaneously during assessments in Objectives 1 and 3 to address Objective 2. These samples will employ different integration times, collection methods, and analysis methods. The number of samples required for these assessments is highly variable and subjective. A final determination of the metrics and the number of samples to collect will be detailed in the DESIGN I QAPP.

### **3.5.3 Study Design Issues—Objective 3**

The statistical design to investigate the impact of the Indian River Power Plant on the Millsboro CCD cancer cluster will be based on the expected PM and gas pollutant concentrations. Areas categorically described as being impacted low, medium, and high by the Indian River Power Plant will be identified through existing DNREC data and modeling. A tentative design requires 12 samples per area (36 samples total) per metric to test Hypotheses 4 and 5. Spatial and temporal variability in media contaminant and biomarker concentrations will require that all samples be analyzed; however, it is likely that carcinogen concentrations in food, water, and dust samples will be more homogeneous across the areas. Therefore, only a limited 50% subset of the collected samples will be analyzed for the “base” effort to bracket the concentrations and test Hypotheses 4 and 5 for these matrices. All samples would be analyzed optionally, if resources were available. A more comprehensive assessment would be accomplished in DESIGN II.

## **3.6 Contaminants for Study**

The proposed summary list of contaminants by DESIGN I objective is shown in Tables 3-1 and 3-2. Objectives 1 (range-finding) and 2 (method-testing) will also support DESIGN II, and all contaminants are proposed initially for these objectives in that separate study design. After Delaware’s initial review of the contaminant list, some of these contaminants might be deleted or others might be added (see Appendix C: DESIGN II).

Also included in Table 3-1 is the proposed DESIGN I priority for each contaminant to (specifically) support only Objective 3, which is the Indian River Power Plant source impact study. This priority listing is based on a composite of 1) the key contaminants that may potentially have contributed to the observed cancer clustering (DHSS/DPH, 2008), 2) key contaminants that have been identified in recent toxicology and epidemiologic studies as important for either cardiovascular and pulmonary adverse endpoints (e.g., DHSS, 2005, focusing on asthma), and 3) contaminants and constituent markers needed to link expected Indian River Power Plant source “signatures” to personal, indoor, and outdoor air route receptor samples collected in the vicinity of Indian River Power Plant. This source impact effort is primarily an air route study with limited other route collections/analyses (carcinogens in drinking water and house dust) for the residences selected for personal and indoor monitoring. No household-level food collections/analyses are proposed to specifically support Objective 3 because this route is unlikely to have influenced the cancer clustering observed in Sussex County near the Indian River Power Plant, as compared with the rest of Delaware.

**Table 3-1. Contaminants Proposed to Be Measured for DESIGN I**

Priority ranking indicates the probability that data for the listed analytes will be collected. High-priority contaminants constitute the core (base) study, whereas medium- and low-priority analytes will be collected, archived, and analyzed optionally in limited percentages if optional funds are available. Priority rankings are subject to change following review by DNREC and DDPH.

Class (Media)	Analyte Category (Species)	Objective	Objective 3 Priority
Particulate matter, soot, diesel exhaust (air)	<b>PM<sub>2.5</sub> mass</b>	1, 2, 3	<b>High</b>
	<b>PM<sub>10</sub> mass</b>	1, 2, 3	<b>High</b>
	<b>Elemental carbon (e.g., soot, diesel exhaust)</b>	1, 3	<b>High</b>
	<b>Total organic carbon</b>	1, 3	<b>High</b>
	<b>Semi-volatile organic compounds (SVOCs) (e.g., PAHs, hopanes, fatty acids, alkanes)</b>	1, 2, 3	<b>High</b>
	<b>Metals (e.g., arsenic, beryllium, cadmium, chromium, mercury, manganese, lead, nickel, selenium, plus 39 more)</b>	1, 3	<b>High</b>
	<b>Environmental tobacco smoke</b>	3	<b>High</b>
	<b>PM<sub>coarse</sub> mass (by difference)</b>	1, 3	<b>High</b>
	<b>PM ions (e.g., sulfate, nitrate, carbonate)</b>	1, 2, 3	<b>High</b>
	Minerals (e.g., crystalline silica, asbestos)	1, 3	Low
	Microbiologicals (e.g., endotoxins, β-glucan)	1, 3	Low
Organic gases (air)	<b>Volatile organic compounds, VOCs (10 National Toxicology Program [NTP] Report on Carcinogens [ROC] listed; includes benzene, toluene, ethylbenzene, and xylenes [BTEX], 1,3-butadiene, carbon tetrachloride, tetrachloroethene, trichloroethene; organochlorines; polychlorinated biphenyls [PCBs]/dioxins/furans)</b>	1, 3	<b>High</b>
	<b>Carbonyls (e.g., acrolein, acetaldehyde, formaldehyde)</b>	1, 2, 3	<b>High</b>
	<b>Vapor phase PAHs</b>	1, 2, 3	<b>High</b>
Criteria gases (air)	<b>Ozone</b>	1, 3	<b>High</b>
	Nitrogen oxides	1, 3	Medium
	Sulfur dioxide	1, 3	Medium
Radiation (air)	Radon	1	Low

**Table 3-2. Specific Carcinogens Proposed to Be Measured in Water, Food, Dust, and Biological Samples Collected for Objective 3 in DESIGN I**

High-priority contaminants constitute the core (base) study, whereas medium- and low-priority analytes will be collected, archived, and analyzed optionally in limited percentages if optional funds are available. Priority rankings are subject to change following review by Delaware DNREC and DDPH.

Class (Media)	Analyte Category (Species)	Objective	Objective 3 Priority
VOCs (air)	<b>BTEX, MTBE, chlorodibromomethane, organochlorines</b>	1,3	<b>High</b>
Metals (all)	<b>Speciated arsenic, including (As)(III), As(V), arsenobetaine, arsenocholine, selected organic As acid, and oxides; chromium (Cr)(VI); U.S. Environmental Protection Agency (EPA) priority metals</b>	1,3	<b>High</b>
Organochlorine pesticides (in blood)	Dichloro diphenyl trichloroethane (DDT) (6 compounds)	1	Low
	Hexachlorobenzene		Low
	<b>Lindane (multiple compounds)</b>		<b>High</b>
	<b>Mirex</b>		<b>High</b>
	<b>Kepone (chlordecone)</b>		<b>High</b>
	<b>Chlordane</b>		<b>High</b>
	<b>Toxaphene</b>		<b>High</b>
	<b>Dieldrin</b>		<b>High</b>
	<b>Endrin</b>		<b>High</b>
Non-persistent pesticides	<b>Carbamate panel</b>	1	<b>High</b>
	<b>Organophosphate panel</b>		<b>High</b>
	<b>Pyrethroid panel</b>		<b>High</b>
Polybrominated diphenyl ethers (PBDEs) (blood and dust)	BDE 47	1	Medium
	BDE 99		Medium
	BDE 153		Medium
	DecabromoDE		Medium
Perfluorinated acids (td)	Perfluorooctanoic acid (PFOA)	1	Medium
	Perfluorooctanesulfonate (PFOS)		Medium
	Perfluorononanoic acid (PFNA)		Medium
Other chemicals	Dialkylphthalate panel, including DEHP	1	Medium
	Bisphenol A	1	Medium
	Alkylphenol panel	1	Medium

### 3.7 Sample Collection

Each air pollution sample will be collected over a 24-hour sample collection interval. A longitudinal component can be added by collecting samples over several days. The entire study design is insufficient for assessment of chronic exposure to carcinogens. Instead, the limited data collection will bracket the range of carcinogen concentrations near the Indian River Power Plant and across Delaware.

Two field teams will be sufficient to perform sample collection. One field team would service the Indian River Power Plant area, and the other field team would handle the remaining locations. The size of the field teams depends on the number of samples to be collected at each site. Two-person teams will be sufficient to simultaneously perform the study designs in Objectives 1 and 2. When all three study designs are simultaneously implemented, three-person

teams or the addition of a third two-person team will be required to collect the samples in a reasonable time period. Each field team will have a designated leader to supervise the work of the other technician(s) and to perform his or her own duties. The field teams will consist of locally hired, properly trained temporary contractors, which will provide a cost-effective means to collect high-quality samples. Mini-vans will be required to transport field staff and their equipment.

A central office will be required for conducting base operations for DESIGN I. All samples will be processed and stored in the office until they are shipped to the laboratory. The ideal office would have separate rooms for processing filter-based samples and all other samples, a large staging area, and an office for data entry and validation. A technician to process samples and a field manager to supervise all activities during all phases of DESIGN I will work out of the central office each day of sample collection. The Field Leader or Manager will have extensive field study experience in leading complex environmental exposure studies. The office technician will be a locally hired, temporary contractor who is trained in the appropriate SOPs.

Samples will be collected over 4 to 5 weeks in summer 2009 and winter 2009. Each week will have 3 or 4 days of weekday samples and 1 day of weekend samples to characterize the expected changes in air pollutant sources and strengths. Final field study preparations and temporary contractor training would occur the week before the first week of sample collection. All sampling equipment and ancillary supplies required for the field study will be transported to Delaware, checked for proper performance, and organized. A 3-day training program will provide the temporary contractors with practical experience on how to properly collect samples, use all equipment, and process samples in the laboratory.

### **3.7.1 *Prioritization for Sample Collections, Archival, and Analyses***

After defining the hypotheses for each objective, the full suite of potential analytes, and the sample size needed to test the hypotheses, all elements must be combined into the integrated plan for that objective and the associated costing defined.

However, the constant concern over resource restraints requires that an intervening determination of the level of importance (short- and long-term) for each sample and analyte be defined to guide field implementation and funding options. Priority importance is established based on straightforward technical requirements to link cause and effect in an epidemiological sense, combined with the overarching policy importance placed on these aspects by Delaware. A preliminary prioritization plan is suggested here that attempts to broadly categorize each sample and analyte across objectives and to also simplify the cost-estimation framework. This approach provides Delaware with the greatest clarity and flexibility in defining essential versus optional sampling and analyses choices and in optimizing the application of available funding now and in the future.

A key distinction between sampling and analyses costs is the aspect of opportunity. The substantial combined costs of planning and implementing the field efforts diminish the impact of including additional metrics to the sample suite, as long as the added burdens to the residents and/or field sampling teams are manageable. Sample metric types that offer reasonable archival flexibility provide a range of post-analyses options that allow for the utilization of available funds in either the short term or long term (e.g., now versus delaying until the next funding cycle). Not taking advantage of sample collection options when the opportunities exist results in

lost opportunities that can only be rectified with the significant cost increments of additional field deployments. Note that an option to simply collect additional duplicate substrates and archiving some of these duplicates to provide the greatest range of analytical possibilities in subsequent years may be useful.

A straightforward approach from the outset is defining core standard- and optional-level sampling and analysis suites for each objective that most clearly address evaluating hypotheses. Sampling examples might include 1) the core PM<sub>2.5</sub> sample collection would be a single Teflon filter that can be readily analyzed for a wide array of analytes, or 2) separately collecting both particle and vapor-phase SVOCs, instead of just a single phase. One or more option-level PM<sub>2.5</sub> sample collections might include alternate substrates, such as pre-fired quartz or polycarbonate materials, or more simply, duplicate samples planned for as-yet-undefined characterization at a later date. Comparable core versus option-level analysis examples might be 1) analyzing for total arsenic as the core metric and selected arsenic ions as the option levels to better understand relative toxicity impacts, and 2) including supplemental (sampling and) inductively coupled plasma mass spectroscopy (ICP-MS) analyses of selected elements to improve minimum detection levels over X-ray fluorescence (XRF) for key constituents, or simply going well beyond the standard XRF suite normally defined by routine analyses, e.g., the element beryllium that cannot be measured by XRF.

Tables 3-1 and 3-2 show the proposed priorities by DESIGN I objective for analytes by all routes. Note that the air route includes personal, indoor, and outdoor scenarios. The personal scenario is a necessarily abbreviated version of the air table shown for Objective 3 because only a limited number of analytes can be applied per participant to minimize the burden level. Similarly, the indoor scenario is abbreviated, but, to a lesser degree, is based on the total metrics that can be serviced by a field team in a reasonable period of time (e.g., 1 hour) to limit participant burden. The outdoor sampling scenario is not necessarily limited.

Objectives 1 (range finding) and 2 (method evaluation) will address all analyte categories finally elected by Delaware, and include all priority levels (core and optional). Objective 3 (source impact) will address only the high-priority analytes in bold. The specific constituents in each suite (core or optional) are defined in separate tables.

The collection of air samples will apply a range of measurement technologies that must be in some manner referencable to standard procedures. This will be accomplished and described more fully in the workplan discussions by selecting methods that meet acceptable performance requirements and conducting limited collocated testing to demonstrate comparability. This approach has always been considered in RTI research studies conducted for EPA. A recent paper by Chow and Watson (2008) also fully supports this approach. Using a range of sampler types for the same collections also provides the opportunity to collect parallel samples in more cost-effective manners.

### **3.7.2 Particulate Matter**

PM sample collection instrumentation should meet several basic criteria. Most importantly, the instrument must provide sufficient analyte mass to exceed the minimum detection limit of the chosen analytical method. In addition, the instrument must be able to collect a sufficient air volume during the sample collection interval so that sufficient mass is deposited. The sample collection media must also be conducive to the analytical method. When

performing residential sampling, the instruments should be small, quiet, and (preferably) battery powered to reduce the burden on residents.

The PM instrumentation characteristics suggested for DESIGN I fully consider the data quality necessary to prove the hypotheses. Residential outdoor, indoor, and personal samples should provide PM<sub>2.5</sub> and PM<sub>10</sub> concentrations with minimal burden to the study participants. The low-burden, low-flow samplers should be collocated with EPA Federal Reference Method (FRM) samplers at a DNREC central monitoring site to provide a comparison with a standard method in case a bias in the data needs to be corrected. RTI will not be providing any FRM samplers for this effort. Duplicate samplers for each size fraction are needed for Teflo media (e.g., mass, optically determined black carbon (BC), environmental tobacco smoke [ETS] by using the method from Lawless and colleagues [2004], SVOCs) and quartz media (elemental carbon/organic carbon [EC/OC] organic PM).

### **3.7.3 VOCs and Carbonyls**

As with PM samples, instrumentation selected to collect VOC and carbonyl samples must consider minimum sample volume and sample media requirements. The sorbent media is also of critical importance. The sorbent media must remain stable to prevent degradation of the analytes before extraction, especially after sample collection. The media also must allow >95% desorption of the analytes. Use of passive dosimeters is preferred for both metrics.

Collection of personal, indoor, outdoor, and ambient VOC samples is proposed using PerkinElmer diffusion sampling tubes, and the adsorption media is Carbo-pack. This method has been extensively used for 24-hour collection of the target VOCs in sufficient quantity and yields high recovery rates so that instrumentation detection limits are exceeded.

The proper sorbent for the collection of carbonyls will be studied during Phase I. Commercially manufactured passive dosimeters with dansylhydrazine (DNSH) and dinitrophenylhydrazine (DNPH) sorbent media are available; however, there is not a clear consensus in the scientific community on whether DNSH or DNPH is the better media.

### **3.7.4 Auxiliary Air Data**

Auxiliary air data will be required to provide additional information for understanding the range of exposures to air pollutants measured during DESIGN I. Local meteorology is important to capture the small-scale fluctuations in wind speed and direction that are not captured by the centrally located stations. Trees and buildings can impact the meteorology at heights that determine exposure concentrations; therefore, Davis Weather Wizard stations (or equivalent) should be used at every outdoor monitoring location.

Indoor residential air exchange rate data also are needed. Air exchange rate is an important predictor of ambient pollution infiltration into residences when combined with the indoor-outdoor ratio of sulfur concentrations. Daily air exchange rate measurements will be conducted using perfluorotoluene (PFT) permeation emitters and capillary adsorbent tube samplers (CATS). PFT emitters will be placed throughout each residence 24 hours before monitoring. CATS in the central living area will absorb the diffused PFT within the residence. The PFT concentration collected on the CATS is inversely proportional to the air exchange rate of the residence.

### **3.7.5 Participant Surveys and Questionnaires**

Multiple surveys and questionnaires will provide insights into the range of air pollutant concentrations measured during the study and help to determine the validity of data outside the expected concentration distribution (e.g., outliers). The surveys will also document whether the characteristics and activities of Delaware residents are comparable to the rest of the United States. Existing surveys and questionnaires will be used, as appropriate, to reflect the goals of DESIGN II. Note that many current questionnaires reflect only a single medium and will need to be upgraded as appropriate for the media and pathways proposed. The updated assessment instruments will be tested during DESIGN I data collection and will be revised if needed.

The survey and questionnaires used for this study will document neighborhood, residence, and participant characteristics. Local sources of PM and VOCs will be recorded on the Neighborhood Source Survey, which records the global positioning system coordinates of all potential sources within a defined distance from the monitoring location, usually a 2-mile radius. The Residence Survey will provide a central location for information that may influence ambient pollutant infiltration into the home, indoor sources of pollution, and general residence characteristics.

Four surveys will capture participant characteristics. The Participant Survey will document the participant's general lifestyle and activities that may influence his or her chronic exposure to pollutants. A daily Time Activity Diary will provide a detailed record of the participant's activities during the 24-hour sampling period to assess his or her acute exposure. This diary will be supplemented with a Nutrition Diary to document the liquids and food ingested by the participant during the 24-hour period. Both diaries will be supplemented with a computer-based Follow-Up Questionnaire, which will provide a detailed series of cued questions to confirm and expand the information recorded in the diaries. This questionnaire will be administered daily by a field technician.

### **3.7.6 Drinking Water**

Drinking water is a major potential exposure pathway for many contaminants, including carcinogens and pesticides. Residences with well water have the highest probability of elevated concentrations, whereas residences supplied by municipal water systems or that exclusively use bottled water are expected to have lower exposures. The same subset of homes near the Indian River Power Plant that were selected for indoor sampling will have water samples collected for VOCs and metals analysis.

### **3.7.7 House Dust**

House dust contains a mixture of soil tracked inside by residents and settled PM of ambient and indoor origin. The soil surrounding a residence may contain high concentrations of carcinogenic metals and pesticides. These concentrations are influenced by a residence's proximity to major roads or industrial sources, which can determine the loading of lead, arsenic, platinum group metals, and other heavy metals, and the frequency of pesticide and herbicide spraying by residents, which can affect the loading in the soil and levels inside the home. In addition, arsenic may be tracked inside a home if the porch or deck is manufactured with treated lumber. Residence age and cleaning frequency are other variables that can influence exposure levels.

The common exposure routes are ingestion following dermal contact and inhalation of resuspended dust. Contaminant loadings will vary spatially within the house, with the highest levels found on the floor near entrances and most commonly occupied rooms. A representative assessment of carcinogen levels inside a home can be obtained from the dust collected by the resident's vacuum. If available, vacuum bags from homes near the Indian River Power Plant that are selected for indoor assessment will be collected. The dust from the vacuum bags will be sieved and homogenized prior to analysis.

Tracked-in soil comprises the major component by mass for house dust. Soil concentration levels by themselves are not useful exposure metrics, but they can provide indications about where contaminants are originating for subsequent mitigation planning. Delaware-specific data suggest that agricultural (Sparks et al., 2006), but perhaps not residential, soils may provide significant levels of contaminants, such as As, into the environment through multiple pathways. Representative backyard soil samples will be collected from each sampled residence for archival (only). If excessively elevated contaminant levels are apparent from the vacuum cleaner dust samples, the companion soil samples could then be analyzed for confirmation purposes.

This approach to characterizing exposures by the house dust route for adults is assumed to contribute to the primary dermal exposures in residences and is recognized to be only a crude surrogate for this exposure route. Prior efforts to use sampling devices that more closely mimic dermal contact (e.g., the Lioy, Wainmann, and Wiesel [LWW] surface sampler) add little to the accurate representation of dermal exposure, given that there is still no direct confirmation that a specific adult actually came in contact with, or was exposed to, the surface dust. This technological weakness in the NHEXAS approach exists today because no better means of providing mass closure for the dermal component of total exposure has been devised. Thus, the vacuum cleaner bag surrogate is a reasonable, but not ideal, approach to estimating this component for DESIGN I. These data will be carefully reviewed before DESIGN II to determine whether this approach should be continued as part of that design.

### **3.7.8 Food**

Ingestion of hormones or pesticides in food is another exposure route for carcinogens. Carcinogen levels found in food have been summarized by the U.S. Food and Drug Administration; however, cooking methods and sanitary conditions may alter the resident's exposure to PAHs and metals. Also, the increased prevalence of vegan/vegetarian diets and the number of residences where residents prepare meals with organic ingredients has changed the potential range of exposures.

The study population near the Indian River Power Plant will be used to bracket the range of potential dietary exposure to carcinogens. Due to the expense of processing and analyzing food samples, a limited sample of food will be collected. Residences will be categorized as standard diet, organic, vegetarian or vegan, or a combination of standard-organic and organic-vegetarian. Food from one residence in each category will be collected and analyzed. This will help to define the exposure ranges, but will not provide statistically defensible comparisons among the diet types. As part of this process, more economical methods for food processing, sample preparation, and storage will be explored as a method development effort. Innovative techniques for collecting electronic nutrition diaries will be implemented.

### **3.7.9 Biological Specimens**

Biological specimens provide valuable information that allows the linkage of exposure to dose. Biological samples also provide an indication of non-residential (occupational) or unnoticed (incidental) exposures. Blood, urine, and in some cases, hair are excellent media for identifying exposure to metals (hair), PAHs (blood or urine), PCBs, PBDEs, PFOA, organochlorine pesticides (blood), and non-persistent pesticides (urine). In most cases, the metabolic products are the analytes identified during urinary analysis, e.g., hydroxy-PAHs. Because metabolic products are the analytes of interest, the half-life of the chemical in the body is important. The half-life determines the sample volume (slow excretion could correlate with lower urinary concentration, for example), collection frequency (kinetics), and type of biological specimen collected. A reasonable biospecimen collection plan would be a single blood draw and hair sample at the completion of the sampling period for each participant, plus a first-void urine sample at both the beginning and the end of sampling. This places minimal burden on the study participants and minimizes the incentive costs.

As with the other secondary media, biological specimens will be collected only from the participants recruited near the Indian River Power Plant. The results from DESIGN I will be used to select one or two biological media for DESIGN II. Additionally, a reduced list of metabolites that contain only those with levels above analytical detection limits will be developed.

### **3.7.10 Archival**

Some proportions of both environmental and biospecimen samples are proposed to be archived after collections to minimize the immediate cost impacts from the associated analyses and provide a wide time window to secure funding, if necessary. This pre-supposes that samples and/or their extracts can reasonably be archived with minimal loss of data quality. Preliminary assessments of the archival options have been made to support the suggested plan in Table 5-1B, but a detailed assessment in the subsequent workplan must be made to fully cross-walk the archival planning with the impacts on the data quality and the QAPP. Extended archival is not desirable in any case, considering the long-term costs.

## **3.8 QA/QC requirements**

### **3.8.1 Data Quality Objectives**

The DQOs for each metric for DESIGN I will be defined at the outset jointly with the Delaware DNREC. The overarching rationale for the DQOs will be the minimally acceptable quality of the data required to statistically test the stated hypotheses. Key DQOs expected to be defined by objective in the QAPP for DESIGN I include at least accuracy, precision, representativeness, and data capture rate. The data quality required for Objectives 1 and 2 might be expected to be somewhat less demanding than that required for Objective 3; however, the robustness of the data necessary to evaluate Hypotheses 3 and 4 are far more influenced by the power calculations to define the amount of data necessary to statistically demonstrate that gradients can be observed. Linking the exposure sample collections specifically to the emissions from the Indian River Power Plant will require the additional application of receptor modeling. The collection of data of acceptable quality to allow this is part of DESIGN I approach, but DESIGN I does not include the actual application of the receptor modeling.

### **3.8.2 Quality Control Samples**

A series of quality control (QC) samples will be implemented to assess the precision and accuracy of the collection and analysis methods. Blank, duplicate, and reference samples should be collected for each metric at a rate of 5% to 10% of the total collected. Field and laboratory blanks assess potential contamination during the normal handling of the samples. Duplicate samples or analyses are standard for confirming the precision of the procedures. Reference samples, such as spiked standards, are necessary to confirm the accuracy of the analytical methods.

### **3.8.3 Standard Operating Procedures**

All processes used in DESIGN I will be described in SOPs. Those SOPs that are determined to be critical (at least those that produce data used to test hypotheses) will be evaluated under Delaware conditions as described in Objective 2. The applicability of all SOPs to national and international standards, as applicable, or scrutiny will be included. Any procedural changes suggested by Objective 2 testing prior to their application in DESIGN II will be identified as part of the documentation process.

### **3.8.4 Database**

Contaminant concentrations in air measured during DESIGN I will bracket the range of expected concentrations spatially across Delaware. PM chemistry will allow application of receptor modeling to attribute the PM to specific upwind sources using such methods as chemical mass balance (CMB) or positive matrix factorization (PMF). Although the conduct of a full receptor modeling effort by RTI was not planned and costed here, RTI will work with DNREC to at least apply preliminary CMB8 modeling by appropriately structuring the DESIGN I data files and by assisting in the selection of the most representative source signatures representing the expected Indian River Power Plant emission profiles.

## **4. Expected Outcomes**

### **4.1 Contaminant Range Finding**

Sufficiently robust experimental data are required for all DESIGN objectives, statistically proving that PM and gaseous pollutant concentrations are spatially variable (or not) across Delaware and between CCDs. At a minimum, the data will identify whether specific contaminant concentration levels (Tables 3-1 and 3-2) are low, medium, or high across Delaware in Objective 1, and whether the selected target contaminants and/or source apportionment markers for Objective 3 are spatially heterogeneous. The methods testing in Objective 2 will select samples from these contaminant concentration ranges to demonstrate the applicability of the methods to Delaware scenarios.

The final methodology selections (e.g., sampling, analyses, survey selection, questionnaires) will be proposed in the DESIGN I workplan to meet the performance requirements of DESIGN I, DESIGN II, or both. Demonstrated comparability with referee methods is a requirement, but the actual use of referee methods is not (necessarily) a requirement. DNREC/DHSS will provide final method selection approvals.

A robust database that encompasses fall/winter and spring/summer meteorology and source signatures will allow the Delaware DNREC to refine its computer modeling. Air dispersion and deposition models (AERMOD) for specific point sources can be refined. Higher resolution Community Multi-Scale Air Quality (CMAQ) modeling can be performed. Preliminary source apportionment will identify the impact of local sources and long-range transport on local air quality.

The ranges of contaminants determined from this design will be stratified by CCD, and thus will provide estimates of the expected exposure levels for each contaminant as input to the DESIGN II workplan. These range-finding data will also be useful because they can be cross-walked against adverse-health clustering reports that are based at the CCD level (e.g., DHSS/DPH, 2008).

#### **4.2 Method Testing/Development**

A test report that identifies the final set of participant selection techniques, participant recruitment/retention methods, sample collection and analysis Research Operating Protocols (ROPs), and statistical analysis models for implementation of DESIGN II as SOPs will be prepared. This test report will validate the key DQOs necessary to conduct testing for both DESIGN I and Year 1 of DESIGN II. Method testing for DESIGN II years beyond Year 1 will be included at the outset of each year to allow new technologies to be considered that may provide higher quality data. The full suite of validated ROPs and SOPs will be prepared to accompany the test report.

#### **4.3 Source Impact Assessments**

An Indian River Power Plant source impact assessment report will be prepared jointly with the Delaware DNREC following the data analyses and hypothesis testing Objective 3. The validated database from DESIGN I will allow for final refinement of the goals, objectives, and methods applicable to the MMES, which will be conducted in DESIGN II. An initial assessment of carcinogen exposures at each level (i.e., personal, indoor, and outdoor) in the Millsboro CCD will provide insights into the potential causes of the cancer clustering in that area, presuming these measurements represented prior year exposures and the assessed residences existed for sufficient periods (years) to have caused the measured cancer increases.

Once the data collected are combined with AERMOD results, the Delaware DNREC and DHSS will have an improved comprehension of the range and magnitude of the emissions from the Indian River Power Plant that impact the surrounding communities. RTI will work with DNREC to apply the DESIGN I data to this model. The collected data will also be placed into database files that are amenable to both CMB and PMF receptor modeling.

A priority list of exposure routes for contaminants that may affect the health of Delaware's residents will be prepared and submitted to allow for existing Delaware summaries, such as the *Delaware Air Quality Management 2007 Air Toxics Strategic Plan* (DNREC, 2007), to be updated.

The priority ranking of the likely sources of these pollutants (primarily air route) will be identified, as well as whether the likely sources are the Indian River Power Plant, other local Delaware sources, or regional background levels transported to Delaware from other states. A final assessment of the spatial impact of the Indian River Power Plant on the nearby CCDs will

require supporting data from DESIGN II. Because other southern Delaware air route source categories also contribute some of the same contaminants, specific source marker chemistries will be need to be defined. Two key categories are emissions from gasoline, as opposed to light- and heavy-duty diesel vehicles, plus the regional upwind background contributions from areas outside of Delaware. Diesel (and gasoline) vehicle emission chemistry is discussed fully by EPA (2002) with sufficient information on constituent differences (e.g., 1,3-butadiene and BTEX) between fuels to make distinctions in receptor modeling. The E-DATAS report (DNREC, 2006) provides a comprehensive list of contaminants identified as “regional background” during sampling in Wilmington, and these same constituents can reasonable be expected to comprise the regional air background for all of Delaware.

A summary risk analysis assessment for each contaminant suite will be made to identify the routes that are the most likely contributors for that category to the total primary exposures in each studied CCD. The key CCD for Objective 3 contains the Indian River Power Plant (Millsboro). The limited collections of DESIGN I will not allow these risk assessments to be completely definitive, but would provide supporting data for the subsequent DESIGN II assessment.

The limited multipathway collections in DESIGN I will not readily support total exposure modeling. This activity is planned for DESIGN II.

## **5. Resources**

### **5.1 Schedule**

DESIGN I is scheduled to last for 1 year. Assuming a start date in fall 2008, sample collection for Objectives 1 and 2 could begin as early as January 2009. An initial summary of findings from the winter study would be delivered in June 2009. The second sample collection campaign, which would provide the longitudinal component to Objective 1, would start in summer 2009. Objective 3 would start simultaneously to provide a logical lead into the implementation of DESIGN II. All analyses would be completed by early fall 2009, and the final report would be delivered by December 2009. A detailed schedule is provided as Table 6-1 in Section 6.

### **5.2 Personnel**

The Principal Investigator’s (PI’s) role in this study is to provide global oversight over all technical and administrative aspects of DESIGN I. To successfully lead this project, the PI must have experience conducting large, complex MMESs. This individual’s primary role will be to implement the study efficiently to provide the high-quality data needed to answer the study hypotheses. A critical skill of the PI is the ability to identify and resolve major obstacles that may interfere with key project milestones. As the point of contact with the Delaware DNREC and DHSS, the PI will be responsible for the preparation and submission of all reports or deliverables and for the overall oversight of associated statistical analyses. The PI will also handle any coordination of activities with the Delaware DNREC or DHSS.

An advisory group of senior Subject Matter Experts also will be assembled to provide guidance to the PI. The members of the expert panel will possess specific expertise in survey design, statistics, human exposure, epidemiology, toxicology, and environmental and biospecimen sample collections.

The PI will delegate daily management tasks regarding technical details of the study to two deputies who will be responsible for the field and laboratory aspects. The Field Manager will have responsibility for all DESIGN I field aspects, including monitoring locations, participant recruitment and retention, field personnel, equipment, and sample collection. The Analytical Manager will have responsibility for all DESIGN I laboratory aspects, including the management of the required multiple analytical laboratories, database assembly, and database validation.

The Quality Assurance Manager (QAM) is the final project management role. The QAM will operate independently to provide an unbiased assessment of the project. The QAM will focus on data quality and whether it is sufficient to meet the study's objectives. This may require the QAM to conduct independent audits of all field and laboratory activities. The results of these audits will be provided to the PI, who will implement any corrective actions.

## 6. Proposed DESIGN I Structure

### 6.1 Workplan Preparation

Before any study of this nature can be undertaken, it is necessary for the eventual implementer of this design to carefully plan out all of the details and to document these details so that high-quality data will be collected to meet the DESIGN I. This is accomplished by preparing a detailed Work Plan that reaches a consensus with Delaware on each design element. The Work Plan consists of three volumes: Volume 1 is the detailed study design, Volume 2 is the QA/QC document, and Volume 3 contains all the field and laboratory protocols and SOPs.

### 6.2 DNREC and DHSS Roles

DESIGN I is expected to require input or assistance from DNREC and DHSS in several areas. These roles have not been completely defined, but will become clearer during the workplan preparation. At a minimum, input will be needed with the selection of locations within Delaware expected to provide low, medium, and high concentrations by contaminant type, as well as locations expected to provide samples that best represent (regional) background levels for contaminant coming into the state.

### 6.3 Implementation

The implementation of DESIGN I will require close coordination of concurrent activities to fit this design into one calendar year. Failure to meet a milestone will have repercussions on subsequent tasks that will cause a delay in the overall project schedule. The milestone chart (Table 6-1) illustrates the links between the most critical tasks (shown in bold text). All elements on this table are considered critical for the successful implementation of this study design.

**Table 6-1. Proposed Project Schedule for Core Program to Achieve Critical Milestones**

Category	Element	Month											
		1	2	3	4	5	6	7	8	9	10	11	12
Pre-sample collection planning	<b>QAPP development</b>	X					X						
	SOP preparation	X					X						
	Sample location selection		X	X				X					
	Delaware central office selection and lease		X										

Category	Element	Month											
		1	2	3	4	5	6	7	8	9	10	11	12
Equipment	Meteorology stations		X										
	PM samplers		X										
Participant recruitment and retention	<b>IRB approval</b>			X									X
	Census tract selection		X										
	Recruitment and retention materials preparation		X	X									
	<b>Recruitment and enrollment activities</b>				X	X			X	X	X		
	Retention activities						X	X					
Sample collection	Field staff selection			X					X				
	Field staff training				X					X			
	Equipment preparation and setup			X	X				X	X			
	<b>Sample collection—8 weeks</b>				X	X				X	X		
	QA audit				X					X			
Sample analysis	PM samples—gravimetric, ETS, EC				X	X	X			X	X	X	
	PM samples—XRF (or ICP/MS)					X	X				X	X	
	PM samples—EC/OC				X	X	X			X	X	X	
	PM samples—SVOC					X	X				X	X	
	Carbonyl samples				X	X	X			X	X	X	
	Air—VOC samples				X	X	X			X	X	X	
	Air—criteria gases				X	X	X			X	X	X	
	Air exchange rate						X					X	
	Meteorology data				X	X	X			X	X	X	
	Water—VOCs (organic carcinogens)				X	X	X			X	X	X	
	Metals—water, dust, food, biological					X	X				X	X	
	Pesticides and emerging pollutants—water, dust, food, biological				X	X	X			X	X	X	
	Surveys/questionnaires				X	X	X			X	X	X	
QA audit				X					X				
Data analysis and reporting	<b>Database assembly</b>				X	X	X	X		X	X	X	
	Data validation				X	X	X	X		X	X	X	X
	Statistical analysis						X	X				X	X
	Data interpretation and limited modeling					X	X	X			X	X	X
	Hypotheses testing							X	X	X	X	X	
	Report preparation					X	X	X	X	X	X	X	X
	Administrative reporting	X	X	X	X	X	X	X	X	X	X	X	X

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## **Attachments**

1. Delaware map showing counties, CCDs, cancer cluster data by CCD, and key features.
2. Delaware map of Sussex County, showing CCDs, cancer cluster data by CCD, and key features.

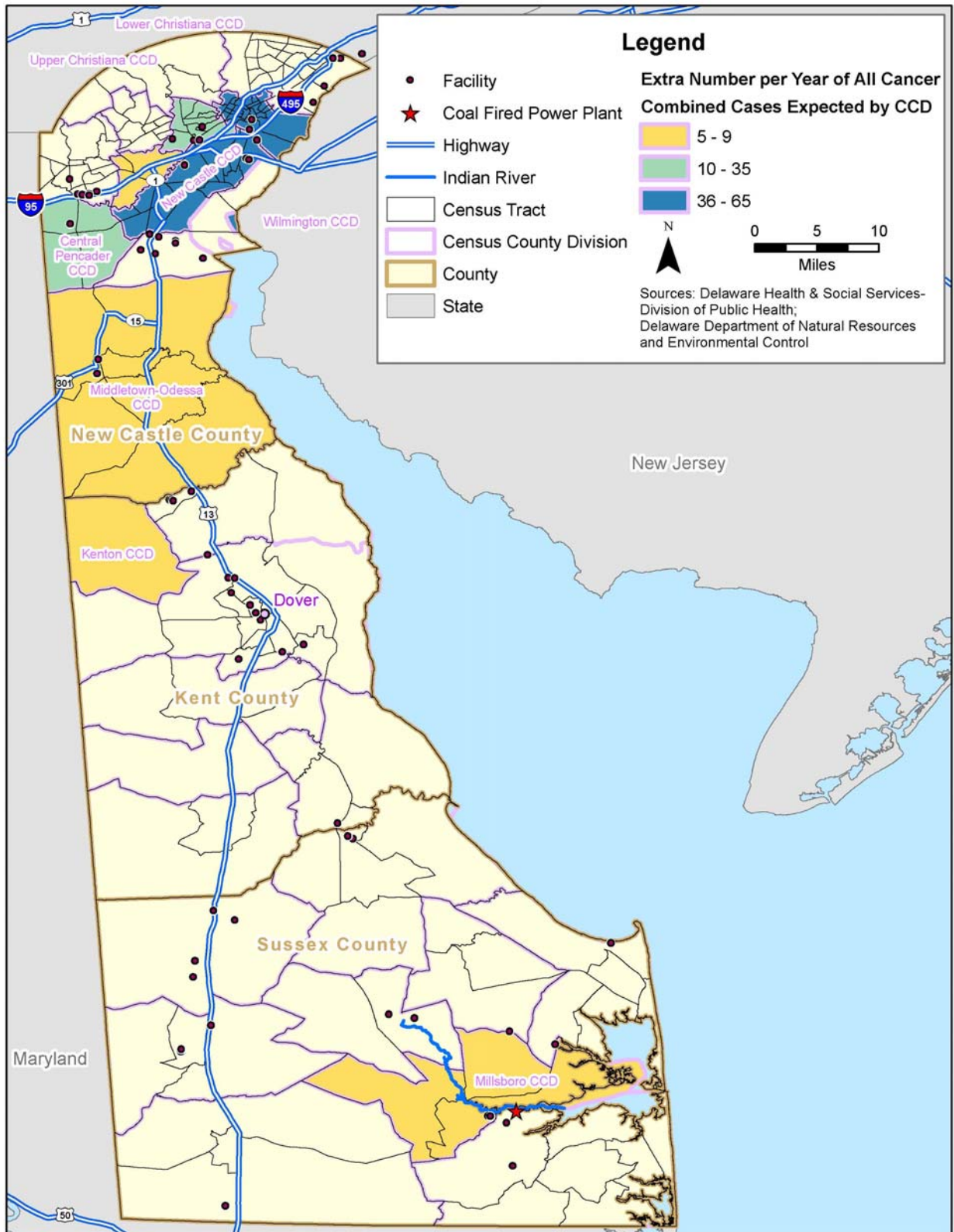


Figure A-1. Delaware map showing CCDs, cancer cluster data, and major contaminant sources.

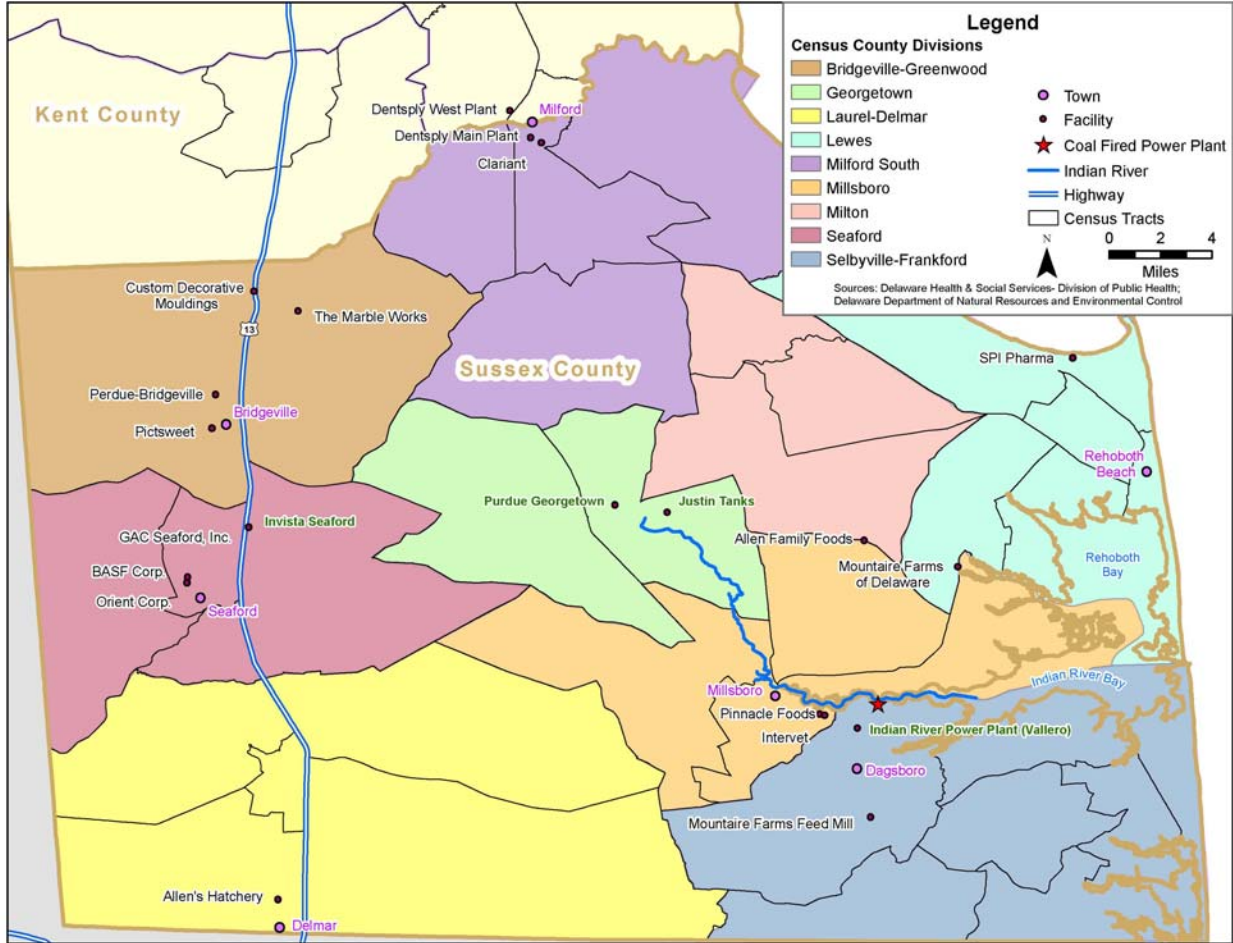


Figure A-2. Delaware map focusing on Sussex County, showing CCDs, cancer cluster data, and major contaminant sources.

## **Appendix C**

### **DESIGN II**

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## DESIGN II—PLAN

### 1. Goals and Objectives

This study plan designated as DESIGN II will apply a Multimedia Exposure Study (MMES) plan for air, water, food and house dust routes across multiple years entirely within the state of Delaware, targeting a different focus suite of contaminants each year in a “hopscotch” design. The study design is fundamentally the Plan C portion of the original (Senate-House Joint Resolution No. 11, or SJR-11) study design prepared by RTI International (RTI) in 1996. DESIGN II reflects an update in 2008 to target the latest set of contaminants of interest to the Delaware Department of Natural Resources and Environmental Control (DNREC) and the Delaware Health and Social Services (DHSS); adds a focus on cancer, cardiovascular disease, and pulmonary disease endpoints; and upgrades the proposed methodologies to those current used in multimedia studies.

The DESIGN II plan will, for the first time, allow statistically valid inferences concerning statewide contaminant exposures that represent and apply to all Delaware residents. The expected participant selection of 400 Delawareans will be made randomly across the state to reflect the population densities in each of the 27 Delaware County Census Divisions (CCDs). Collection and contaminant analysis of air, water, food, housedust, backyard soil, and biospecimen samples over a planned 9-year period at the personal residence level in each selected Delaware household will add enormously to our understanding of who in Delaware is most/least exposed to toxic components during their daily activities. This understanding of resident exposures by all pathways will facilitate the most robust assessments possible for health risks in Delaware from a comprehensive list of acute and chronic environmental stressors.

DESIGN II is not a research study, but will utilize existing, validated methodologies where possible that provide the data quality necessary to support the study objectives and hypotheses being evaluated. A presumption is that the DESIGN II method-evaluation pilot effort proposed as part of DESIGN I will have been funded and implemented prior to the commencement of the DESIGN II effort. Otherwise, the methods to be used and applied under Delaware-specific conditions would also need to be validated in Year 1, similar to the original National Human Exposure Assessment Survey (NHEXAS) study (Pellizzari et al., 1995).

The four objectives to be addressed during DESIGN II include the following (the underlined phrase generally characterizes the intent of each objective):

- **Objective 1.** Document the occurrences and distributions of exposures to hazardous environmental contaminants of concern within Delaware, including geographic trends across stratification levels and for a subset of the participants, during two seasons.
- **Objective 2.** Develop appropriate information to gain an understanding of the underlying point, line, and area sources and causes of exposure for populations potentially at risk for cancer, cardiovascular diseases, or pulmonary diseases. Such information is a key element in developing cost-effective intervention strategies that prevent or reduce exposures deemed to be unacceptable.
- **Objective 3.** Develop databases, which will include exposure and dose measurements, that can make multimedia, probability-based exposure assessments for Delaware

residents in the context of risk analyses and to serve as a baseline for future status and trends analysis over an extended study period exceeding at least 4 years.

- **Objective 4.** Develop and validate Delaware-specific total exposure models (by media) and spatial-to-fixed site exposure models at the residence, CCD, and county levels.

DESIGN II is a statewide, probability-based study of households and individuals that is aimed at providing multimedia exposure data on selected toxicants, along with related information (e.g., personal activity pattern data, indoor and outdoor source identification for air toxicants at each study residence, and residence air exchange rates [AERs] to allow for the prediction of indoor contaminant source strengths, as well as the penetration rates of outdoor contaminants into the residence). Ambient (air) monitoring collections from existing DNREC sites will allow the DESIGN II data to be related to Delaware referee site data collections.

Because it is impractical for most research organizations to have sufficient equipment and staff to address all contaminants in the same year, and it is unlikely that Delaware would have the financial resources to support all sampling and analyses categories in the same year, the “hopscotch” design proposed in SJR-11 is still reasonable. This approach will group contaminants in a logical manner and will allow Delaware (e.g., DNREC, DHHS) to determine which categories it needs data from the earliest in the study years (Years 1, 2, 3) to set the order of priorities. This approach is followed here, but the categories are updated based on considering both DESIGN I and DESIGN II objectives and the updated 2008 analyte target list.

It is critically important for the data produced by all facets of DESIGN II to be both defensible in all respects and, where possible, referenceable to national and international methods and standards. The necessary levels of defensibility are established collaboratively with DNREC technical staff, and, from the outset, are guided by the Data Quality Objectives (DQOs) necessary to test the hypotheses, as well as the soundness of the fundamental design (based heavily on the original SJR-11 plan). Carefully defined standard operating procedures (SOPs) and validation under actual Delaware conditions will help ensure that the selected methods provide the required data and data quality.

Following the completions of exposure/dose data validation and database development, statistical analyses and associated modeling to allow predictions of the total exposures and observed doses from the individual route exposures will be undertaken. The data and models will allow the inferences to be made that apply to all Delaware residents, as well as allow these data to be compared against nationwide data bases such as the National Health and Nutrition Examination Survey (NHANES). An upgrade in the DESIGN II plan compared with SJR-11 is the focus on providing additional source signature chemistry that will subsequently facilitate robust source apportionment studies that could follow the recent approach of Ito et al. (2006), which innovatively-linked source categories with adverse health effects. The DESIGN II data will be placed in compatible formats for apportionment studies to allow DNREC/DHSS to take this additional step. RTI could certainly assist DNREC/DHSS in this effort if requested.

The DESIGN II plan does not include a risk analysis to place the collected exposure and dose data into perspective for Delaware. This would be an obvious next step after completing each study year for the target contaminant suite, and RTI could certainly assist DNREC/DHSS in such an effort if requested to do so. The rationales for DESIGN II (exposure routes, scenarios, analytes) draw heavily from key DNREC and DHSS technical staff and the entire list of Delaware-specific reports, presentations, and environmental alerts cited in the Reference section.

Rationales for particle-phase contaminants and regional transport concerns that affect the background air coming into Delaware are provided by more nationwide focused reports, such as EPA's *Health Assessment Document for Diesel Engine Exhaust* (2002) and *Air Quality Criteria for Particulate Matter* (2004).

It is very important to recognize that DESIGN II was prepared as a study design and not as a detailed workplan. Specific details on aspects such as the exact sampling and analytical methods that will be employed and how the statistical analyses and modeling will be conducted to test each proposed hypotheses are assumed to be workplan elements and are only briefly highlighted here. A comprehensive, detailed workplan is the critical next step in the implementation of DESIGN II, after reaching DNREC/DHSS approval on the proposed design elements.

## **1.1 Background**

### **1.1.1 NHEXAS Design**

The probability-based NHEXAS was conducted in U.S. Environmental Protection Agency (EPA) Region 5 (Great Lakes area) in the mid-1990s for the EPA's National Exposure Assessment Research Laboratory (Pellizzari et al., 1995). The NHEXAS procedures addressed all phases of the design, implementation, and reporting processes, focusing on chronic, longer-term exposure periods. An important element of the NHEXAS design approach was the application of personal-level multimedia exposure sampling procedures, along with parallel residence- and neighborhood-scale sampling, to provide the most accurate and representative estimates of the extremes (e.g., upper and lower 10 percentiles) of the exposure distributions. The NHEXAS program developed the basic suite of methodologies for describing exposure distributions for key environmental contaminants (those identified as environmentally important in 1996) in all media and exposure routes, with a random, probability-basis that was applied for the cohort selection process. The basic NHEXAS design approach is still considered the "gold standard" by which exposure studies attempting to provide the most robust estimates of distributional exposures for a spatially defined cohort (Whitmore et al., 1999). Periodic re-sampling in subsequent years would allow for longitudinal assessment of temporal trends, as well as for defining the impacts of mitigation programs to address exposures that were deemed to be excessive.

The high cost of implementing the NHEXAS design in Delaware subsequently suggested that a more manageable parsing strategy by contaminant category for the technical elements was appropriate. Major individual contaminant categories (e.g., sized particulate matter [PM], pesticides, polynuclear aromatic hydrocarbons [PAHs]) would be addressed in separate calendar years to reduce the funding levels required on an annual basis. This "hopscotch" design, which was applied across several years, defined the overall exposure program and was applicable for addressing adverse health outcomes, such as cancer, in which long latency periods often exist between the contaminant exposures and the adverse outcomes. The 1996 SJR-11 hopscotch plan targeted the following:

- Year 1—Volatile organic compound (VOC) monitoring
- Year 2—Particulates and metals monitoring
- Years 3 and 4—Pesticides, polychlorinated biphenyls (PCBs), and PAHs monitoring

- Year 5 to 9—Repeat the cycle to obtain longitudinal and long-term exposure data.

The current DESIGN II plan would be preceded by DESIGN I, which currently includes a focused 12-month source impact study for the Indian River Power Plant (IRP) that focuses heavily on the air exposure route (e.g., particulates, PAHs, metals). Immediately continuing exposure assessments across Delaware in DESIGN II would supplement the just-collected DESIGN I data. Additionally, several new contaminant categories, including carbonyls (aldehydes) and polybrominated diphenyl ethers (PBDEs), have been elevated in importance in many health studies, and these are now appended to the 2008 target contaminant list. Although SJR-11 did not focus on a single adverse health outcome, it is now clear that cancer clustering has now been shown to exist in Delaware and that linking the DESIGN II plan to these localized areas (making exposure gradient inferences, where possible, on both temporal and spatial bases) is a critical priority. That potentially elevates the importance of the order for collecting specific PAH carcinogen categories that are known to have elevated exposure levels in Delaware residents. The SJR-11 plan also focused heavily on extended-interval chronic exposures rather than shorter-term intervals that are more appropriate for cardiovascular and pulmonary diseases. Developing databases that can provide inferences to potential Delaware linkages between selected more-acute exposure periods and these latter disease categories has been included in the DESIGN II plan.

A revised plan with updated integration intervals is proposed, with DNREC/DHSS to decide the final order. This revised target contaminant order takes advantage of the PM data focus of DESIGN I (essentially DESIGN II Year 0) and builds an even stronger database that includes probability-based sampling. The current DESIGN II draft plan also includes proposed core exposure collections (following the full probability-based selection), followed by full (100%) analyses. A subset of analyses are proposed for full categorical collections, but with a planned percentage archival (where analytically feasible and quality can be maintained) to produce limited data during the study year. The availability of subsequent additional funding would allow the balance of each category to be analyzed. The revised 2008 DESIGN II hopscotch plan includes the following timelines and analyses:

- Year 1—PM<sub>2.5</sub> and PM<sub>10</sub> (air, 1-day), metals (all media, 1-day), and particle-phase PAHs (3-day)
- Year 2—Carbonyls (air, 3-day), VOCs (air/water, 3-day), SVOCs (vapor-phase air/water, 3-day)
- Years 3—Pesticides (all media, 3-day), PCBs (all media, 3-day), dioxins/furans (all media, 3-day)
- Years 4—PBDEs (all media, 3-day), perfluorinated acids (all media, 3-day), other chemicals (all media, 3-day)
- Year 5 to 9—Repeat the cycle to obtain longitudinal and long-term exposure data.

The Delaware-specific version of the NHEXAS design was developed in 1996 to consist of three selectable study designs, focusing on the same integration periods and suite of environmental contaminant exposures. This Delaware-specific plan was designated as SJR-11. The design levels (designated as Levels A, B, and C) were intended to be applied entirely within the state of Delaware (unlike NHEXAS) and differed between levels by the intensity level of the proportion of personal-level exposures. For example, Level A consisted of ambient (outdoor) air,

but no personal-level sampling, whereas Level C incorporated 100% personal sampling along with indoor and outdoor metrics, along with multimedia sampling.

After the 1996 plans were prepared for Delaware, it became clear that neither the need nor the funding availability at the State level at that time merited proceeding with a study within the boundaries of Delaware. However, more recent State agency assessments by and in conjunction with the Delaware DNREC and the Delaware Division of Public Health (DPH) now suggest that a merging of levels B and C for the 1996 exposure study design be reconsidered in 2008 for potential funding by the State. This revised plan is designated as DESIGN II.

### **1.1.2 SJR-11 Changes Requested**

#### **1.1.2.1 Updated Delaware Requirements**

The key factors provided by DNREC and DHSS, now apparent in 2008, that should be taken into account by revising/updating SJR-11 into DESIGN II include factors (1) through (5) on the following list:

- (1) Consider how chemical usage patterns and environmental source emission rates in Delaware differ from 1996 and suggest revised lists and possible reordering of priorities of contaminants not on the 1996 list
- (2) Consider how more recent toxicological and epidemiologic data in the literature suggests shifting the importance of focus contaminants and integration intervals
- (3) Review and propose new, more robust and representative technologies for characterizing exposures to improve data quality and reducing participant personal burden, including better methods to identify environmental (rather than just biomarker) exposures to the critical confounder, environmental tobacco smoke (ETS)
- (4) Define more extensive collections of samples and analytical suites to allow for the application of receptor sample modeling to more closely link exposure distributions with potential offending sources, including non-Delaware contributions from the regional air background
- (5) Include significant communication action group participation in a public communications plan (jointly with the state) to minimize refusal rates during initial public contacts and enrollments
- (6) Collect limited data to establish the ranges of expected exposure levels in Delaware for a broad list of environmental toxicants
- (7) Define a robust methodological evaluation pilot study conducted within Delaware to demonstrate its applicability and cost-effectiveness in low, medium, and high concentration settings
- (8) Define limited sampling and analyses at three locations (that may be one of the low-, medium-, or high-range-defining locations) of specific importance to the State to assist in a specific environmental impact assessment focusing on the IRP project.

Items (1) through (5) are directly relevant to DESIGN II, whereas (6) through (8) will be implemented as part of DESIGN I.

### **1.1.3 DESIGN II Amendments**

Many elements of the SJR-11 design are still applicable to current Delaware requirements, including the underlying survey design process and the sample size considerations. The toxicological and epidemiologic bases described in 1996, are still valid today—updates are appropriate to bolster cases, especially for new contaminant categories. The longitudinal repeat design to assess long-term trends and potential impacts of intervening controls or usage pattern changes is still completely relevant. Key amendments to SJR-11 in DESIGN II include the following:

- Revision of the target analyte suites (see Table 1-1)
- Inclusion of pilot method testing consistent with NHEXAS (but not described in SJR-11)
- Inclusion of focuses on cardiovascular and pulmonary endpoints, in addition to cancer, mandating shifts for some metrics from longer (3-day) chronic exposure intervals to shorter (1-day) acute intervals
- Inclusion of a focus on collecting sufficient analyte chemistry to support potential receptor modeling to assist in linking exposures with source categories
- Inclusion of background air monitoring to identify regional contributions from non-Delaware sources
- Inclusion of the CCD stratification level in the survey design process to allow inferences for exposures to be made geographically that are more consistent with current Delaware adverse health cluster reporting
- Collection of additional probability-based data in selected Sussex County CCDs (i.e., survey over-sampling) to provide supplementary support for the DESIGN I source impact study focusing on the IRP
- The cost of collection using options, where archival is feasible, of a wider array of sampling substrates than could be analyzed for constituents in any single year to take advantage of the probability-based survey frame and the contaminant-exposure sampling process
- Inclusion of non-destructive ETS exposure characterization for all personal and indoor air samples to allow adjustment for the chemical confounding.

### **1.1.4 Key Delaware Reports and Studies**

A critically important report (DHHS, 2008) identified significant cancer clustering in several CCDs within Delaware (see Figure A-1 in the Attachments). Inadequate potential carcinogen exposure data for the Delaware population defining multimedia route (e.g., air, water, food, dermal dust) contributions are not available to allow a linkage between cause and effect. Additionally, population exposure data for environmental tobacco smoking are not available to allow adjustment for the substantial confounding in cancer rates that may have occurred. The DHSS report showed that the greatest numbers (36 to 65) of excess cases/year were located in the CCDs of Wilmington and New Castle (Wilmington metropolitan area). A range of contaminant source categories that would influence expected exposure levels are within and near these CCDs, including Delaware City refinery complex and the Interstate-95 (I-95) corridor. Lower Christiana and Central Pencader CCDs had rates of 10–35 excess cases per year and border (west and southwest) the Wilmington and New Castle CCDs. Upper Christiana, Middletown-Odessa, Kenton, and Millsboro CCDs have rates of 5–9 excess cases per year.

The largest single point source (by mass emission) in Delaware—IRP project (coal-fired power plant)—is in the Millsboro CCD. All other Delaware CCDs have rates < 5 excess cases per year. This report significantly elevated the interest in characterizing the potential for contaminant (carcinogen) sources in Delaware to have provided gradients during the past decade that may have contributed to the observed elevated cancer rates. Many source types in Delaware produce contaminant signatures containing known carcinogens. Whether these source emissions have actually translated into significant exposure contributions of carcinogens for CCD residents is not clear. An important consideration that cannot currently be decoupled from exposure estimates based on ambient air monitoring data is the confounding caused by tobacco smoking levels.

An important DNREC research study (DNREC/DAWM, 2006) was conducted entirely in the Wilmington metro area to examine the makeup of aerosols in the New Castle and Wilmington CCDs. This “E-DATAS” study examined a range of particle types and contaminants, but did not identify whether the contaminant levels in nearby CCDs were significantly different (presumably lower). The report did associate the levels with selected source categories (i.e., wood smoke, diesel PM, and potentially the Delaware City refinery area), the wind flow, and seasons. These source categories provide complex mixtures of contaminants that have individually been linked in a wide range of epidemiologic analyses to adverse cardiovascular disease and pulmonary disease outcomes, in addition to their carcinogen contributions.

An important finding in the E-DATAS study for PM<sub>1</sub> (PM < 1 μm) was that 38% of the aerosol was from regional background sources. Given the strong westerly air movements during the sampling periods, this suggests that ~40% of the PM<sub>2.5</sub> may have come from sources well upwind of Delaware. The map in Figure A-2 shows that a number of coal-fired power plants are west of Delaware, along with the metropolitan area emissions from both Baltimore, MD, and Washington, DC. Note that the Baltimore, MD, area is immediately due west of the Delaware Middletown-Odessa CCD. The latter potential regional contributions to Delaware must be characterized in an effort to understand the spatial contaminant gradients within the state, as well as the potential impacts of point, line, and area sources. Also note that the I-95 corridor is located west of northernmost Delaware CCDs.

Delaware-focused studies to date have not allowed inferences to be made about whether spatial exposure contaminant gradients for Delaware residents might be causal for important adverse health outcomes (cancer, cardiovascular, or pulmonary related). Both DHSS and DNREC staff have concluded that the focused robust studies proposed here (DESIGNS I and II) should dramatically assist them in identifying whether environmental factors play key roles in the health of Delaware residents.

Note that CCDs are county subdivisions that were delineated by the U.S. Census Bureau, in cooperation with State and local officials, for purposes of presenting statistical data. CCDs have been established in 21 states where there are no legally established Minor Civil Divisions (MCDs). These 21 states include the following: Alabama, Arizona, California, Colorado, Delaware, Florida, Georgia, Hawaii, Idaho, Kentucky, Montana, Nevada, New Mexico, Oklahoma, Oregon, South Carolina, Tennessee, Texas, Utah, Washington, and Wyoming. CCDs have also been established where the MCDs do not have governmental or administrative purposes, where the boundaries of the MCDs change frequently, and/or where the MCDs generally are not known to the public. CCDs have no legal functions and are not governmental

units. The boundaries of CCDs are usually delineated to follow visible features and coincide with census tracts, where applicable. (In rare instances, two CCDs may constitute a single census tract.) The name of each CCD is based on a place, county, or well-known local name that identifies its location.

### **1.1.5 Updated Analyte List**

The particle-phase analytes for the air route are listed in Table 1-1. The proposed target analytes by media and route to address Delaware priorities are suggested for the base effort, with the categories spread across the proposed study years in a hopscotch plan. This list for Year 1 is comparable to that proposed for DESIGN I to build on those data collected in the previous year and is subject to final approval from DNREC and DHSS. The analyte lists apply to both exposure and biological sample collections, as appropriate.

A limited suite of analytes is proposed as the fully collected and analyzed core each year, with other supporting analytes proposed for full collections, but only partial analyses for costing purposes, at 80% and 50% archival rates (20% and 50% analyses, respectively) to provide some data and keep the cost for each study year manageable. These core and percentage of archival levels greatly affects the yearly cost levels.

Similarly, the proposed vapor-phase analytes for all routes (e.g., air, water, food, and house dust), as well as blood, hair, and urine biospecimens, are provided in Table 1-2.

Table 1-1. Particle-Phase Analytes (Air Only)

ID #	Analyte Category	Matrices	Collection/Analysis Options by Hopscotch Plan Year	
			Description	DESIGN II Study Year
1	PM <sub>2.5</sub> (non-destructive)	Outdoor air, indoor air, personal air	Teflon collection mass	1
2	PM <sub>10</sub> (non-destructive)	Outdoor air, indoor air, personal air	Teflon collection mass	1
3	PM <sub>coarse</sub> (non-destructive)	Outdoor air, indoor air, personal air	Teflon collection mass	1
4	PM <sub>2.5/10/coarse</sub> black carbon (BC) (non-destructive)	Outdoor air, indoor air, personal air	Teflon collection optical absorbance	1
5	PM <sub>2.5/10/coarse</sub> silica (non-destructive)	Outdoor air, indoor air, personal air	XRD on polycarbonate	1
6	PM <sub>2.5/10/coarse</sub> asbestos (non-destructive)	Outdoor air, indoor air, personal air	PCM on polycarbonate	1
7	PM <sub>2.5/10/coarse</sub> ETS (non-destructive)	Indoor, personal air	Teflon collection optical absorbance	1
8	PM <sub>2.5/10/coarse</sub> ions	Outdoor air, indoor air, personal air	Sulfate, nitrate, carbonate	1
9	PM <sub>2.5/10/coarse</sub> elemental carbon	Outdoor air, indoor air, personal air	Pre-fired quartz collection	1
10	PM <sub>2.5/10/coarse</sub> organic carbon	Outdoor air, indoor air, personal air	Pre-fired quartz collection	1
11	PM <sub>2.5/10/coarse</sub> endotoxins and β1,3-glucan	Outdoor air, indoor air, personal air	standard analysis	1
12	PM <sub>2.5/10/coarse</sub> metals by XRF/ICP-MS combo	Outdoor air, indoor air, personal air	EPA priority Metals (13 analytes include As, Be, Cd, Hg, Mn, Ni, Se)	1
13	PM <sub>2.5/10/coarse</sub> metals by IC-ICP-MS	Outdoor air, indoor air, personal air	Cr(VI)	1
14	PM <sub>2.5/10/coarse</sub> arsenic speciation	Outdoor air, indoor air, personal air	As(III), As(V), organic As	1
15	PM <sub>2.5/10/coarse</sub> PAHs	Outdoor air, indoor air, personal air	EPA priority PAHs (includes 3 on NTP ROC list)	1
16	PM <sub>2.5/10/coarse</sub> other semi-volatiles	Outdoor air, indoor air, personal air	Levoglucosan	1
17	PM <sub>2.5/10/coarse</sub> PCBs, dioxins, furans	Outdoor air, indoor air, personal air	12 dioxin-like congeners and 2,3,7,8-substituted dioxins and furans	1, 3
18	PM <sub>2.5/10/coarse</sub> organochlorine pesticides	Outdoor air, indoor air, personal air	DDT, lindane, hexachlorobenzene, mirex, kepone	3
19	PM <sub>2.5/10/coarse</sub> GC-MS scan with library search	Outdoor air, indoor air, personal air	Organophosphates, pyrethroids, dialkylphthalates, PBDEs, alkylphenols, bisphenol A	3
20	PM <sub>2.5/10/coarse</sub> carbamate pesticides	Outdoor air, indoor air, personal air	21 EPA method 632 compounds	3

**Table 1-2. Vapor-Phase Analytes (Air, Water, Food, and House Dust Media; Blood, Plasma, Hair, and Urine Biospecimen)**

ID #	Analyte Category	Matrices	Collection / Analysis Options	
			Description	DESIGN II Study Year
21	Vapor phase PAHs	Outdoor air, indoor air, personal air	EPA priority PAHs (includes 3 on NTP ROC list)	2
22	Vapor phase other semi-volatiles	Outdoor air, indoor air, personal air	Hopanes, aliphatic acids	2
23	Vapor phase PCBs, dioxins, furans	Outdoor air, indoor air, personal air	12 dioxin-like congeners and 2,3,7,8-substituted dioxins and furans	3
24	Vapor phase organochlorine pesticides	Outdoor air, indoor air, personal air	DDT, lindane, hexachlorobenzene, mirex, kepone	3
25	Vapor phase GC-MS scan with library search	Outdoor air, indoor air, personal air	Organophosphates, pyrethroids, dialkylphthalates, PBDEs, alkylphenols, bisphenol A	4
26	Vapor phase carbamate pesticides	Outdoor air, indoor air, personal air	21 EPA method 632 compounds	3
27	Radon	Indoor air	Standard analysis (passive collection)	4
28	Criteria pollutant gases	Outdoor air, indoor air, personal air	Standard core suite (passive collections)	1
29	Carbonyls	Outdoor air, indoor air, personal air	DNSH standard suite on PAKS: Formaldehyde, acetaldehyde, acrolein	2
30	Airborne VOCs	Outdoor air, indoor air, personal air	10 NTP ROC listed VOCs	2
31	Water VOCs	Water	5 NTP ROC listed VOCs	2
32	Metals by ICP-MS	Dust, water, food, blood, urine, hair	EPA priority metals (13 analytes include As, Be, Cd, Hg, Mn, Ni, Se)	1
33	Metals by IC	Dust, water, food, plasma, urine, hair	Cr(VI)	1
34	Arsenic speciation	Dust, water, food, blood, urine, hair	As(III), As(V), organic As	1
35	Other semivolatiles	Dust, food	Levogluconan	
36	PCBs, dioxins, furans	Dust, food, blood	12 dioxin-like congeners and 2,3,7,8-substituted dioxins and furans	3
37	Organochlorine pesticides	Dust, food, blood	DDT, lindane, hexachlorobenzene, mirex, kepone	3
38	GC-MS scan with library search	Dust, food, blood	Organophosphates, pyrethroids, dialkylphthalates, PBDEs, alkylphenols, bisphenol A	4
39	Carbamate pesticides	Dust, food, blood	21 EPA method 632 compounds	3
40	Endotoxins and $\beta$ 1,3-glucan	Dust	standard analysis	
41	Perfluorinated acids	Dust, water, food, blood	PFOA, PFOS, PFNA, PFHxA, PFHpA, PFOS-amide	4
42	Urine metabolites GC-MS scan with library search	Urine	Monoalkylphthalates, alkylphenols, bisphenol A	4

The SJR-11 analyte list has been updated to add new contaminant categories now of health concern, to delete contaminants that are no longer of concern, to add contaminants of special Delaware interest, and/or to add contaminants that will facilitate receptor modeling of the air exposure route. Only summary information is provided in Tables 1-1 and 1-2, with more complete method performance data provided in the tables in the Attachments (Tables A-1 and A-2).

### **1.1.6 Exposure Interval Considerations**

#### **1.1.6.1 Environmental Samples**

The SJR-11 design was based primarily on supporting long-term, chronic exposure assessment consistent with linking carcinogen exposures to cancers. An additional emphasis, where possible, is now strongly suggested for DESIGN II for shorter-term intervals to examine more acute air exposures consistent with cardiovascular diseases (e.g., heart rate variability and reduced artery flow) and pulmonary diseases (e.g., chronic obstructive pulmonary disease [COPD] and asthma) (DHSS/DPH, 2005). Estimating annual average or lifetime exposures to support possible cancer-related inferences mandates sample collections that represent extended periods (e.g., 3 to 5 days of sampling) that also allow collection of sufficient sample to permit robust analyses with adequate detection limits. These extended 3- and 5-day exposures could alternatively consist of averaging consecutive 1-day sample analyses together, but the extra costs are not warranted for endpoints, such as cancer. Using random start day-of-the-week starts can provide reasonable longer-term averages that composite weekday and weekend days.

Acute-level sampling to support linkages to cardiovascular or pulmonary diseases, mandates at least a 1-day (24-hour) definition to provide reasonable temporal definitions of week-long exposures.

#### **1.1.6.2 Biomarker Samples**

Biomarkers in the body represent the true absorbed doses that result from the composited exposures in a time interval by all routes. Exposure data collected at the right times, accommodating biological lag periods, and with appropriate time resolution can be used in pharmacokinetic models to estimate body burdens (doses). Biomarker data allow direct referencability of the DESIGN II data to existing national databases, such as the NHANES. Collection of parallel multimedia exposure data, along with the appropriate biomarker collections, provides the most complete picture of how contaminant exposures are likely to result in uptakes in the body. This will allow the strongest linkages to be made between environmental concentrations and observed adverse health outcomes and will provide the most robust environmental risk estimates for Delaware residents. The biomarkers proposed for DESIGN II include blood, urine, and hair. One blood sample (last sampling day), two urine samples (first and last sampling day), and one hair sample will be collected.

The selection of biomarker collection frequencies are driven partly by the pharmacokinetics and partly by the levels of burden and invasiveness imposed on the participants. Blood levels for target biomarkers typically change more slowly than in urine, whereas hair samples obviously are relatively invariant at a specific location along the strand.

## **1.2 Data Needs**

### **1.2.1 Data for Exposure, Dose, and Risk Assessments**

Direct measurements of exposure to Delaware environmental contaminants, including PM, VOCs, metals, and pesticides, are to be made in ambient, indoor, personal (breathing zone), and occupational (also breathing zone) air. Other relevant environmental media, such as drinking water, food, and house dust, will be collected and analyzed. Consideration is given to all major known pathways of exposure to the different pollutant classes. The Delaware-focused reports listed in the citations provide the most definitive assessment available for contaminants of interest by media and route.

The study design is probability-based to allow making inferences to the population in general about exposures to toxic chemicals and potential excessive health risks. By including measurements of air and other relevant environmental media, this plan seeks to obtain pollutant exposure data that will allow for more accurate and comprehensive health risk assessments.

Biomonitoring in DESIGN II calls for measuring metals in blood or urine, pesticides in blood or urine, and metals in hair. This will provide the necessary information for estimating dose for these contaminant categories, which is a key input parameter in risk assessment.

The inferences for DESIGN II obviously apply only to short-term (i.e., 3-day or daily) exposures. The average of long-term exposures can be inferred directly from the estimated short-term average; however, the relationship of upper-end short-term exposures to longer-term (e.g., annual or lifetime) exposures will be less certain. The availability of actual air-exposure data will allow some validity checks to be made on modeling approaches that make use of microenvironmental concentrations with personal activity pattern data. Similarly, if the biomonitoring option is exercised, a better basis for determining the relative contributions of the various pathways may be available. Estimated exposures for certain subpopulations (e.g., different seasons, persons working outside the home) may also be useful. Associations of personal-air exposures with environmental concentrations and with the biomarkers (under the Plan C option) can also be generated for each measured chemical; moreover, inter-compound associations can be explored.

### **1.2.2 Chemical Occurrences in Environmental Media**

During each year of implementation, DESIGN II will result in multimedia exposure measurements (i.e., air, water, food, and house dust) for a probability-based sample of Delaware residents. Contaminants include primarily particle-phase PM contaminants (in Year 1); vapor-phase VOCs, carbonyls, and semi-volatile organics (SVOCs)(in Year 2); pesticides and PCBs (in Year 3), and other chemicals including PBDEs and perfluorinated acids (in Year 4). PM mass and metals that exhibit more acute effects will include three successive 1-day person-days, whereas PM PAHs that have more long-term chronic effects will be integrated over concurrent 3-day collections. Vapor-phase VOCs will be three 1-day collections, with SVOCs collected over 3 person-days. Contemporaneous information will be obtained on a subsample basis for residential ambient-air and indoor-air concentrations, for dust concentrations, and for occupationally related air exposures. Data analysis would consist of estimating parameters that characterize the population short-term exposure distribution of a given contaminant in a given medium (e.g., estimates of the population mean, of the population standard deviation, or of the

75<sup>th</sup> percentile of the person-3-day [or person-day] population distribution for air or food). Similar estimates would be determined for subpopulations of interest.

### **1.2.3 Exposure Levels and Long-Term Trends Assessment**

As the database on pollutants in air and drinking water, food, and house dust is compiled over a long period of time (e.g., a decade), it becomes possible to make an assessment of trends in pollutant levels. For example, questions may arise, such as 1) are the levels of pollutants in environmental media increasing or decreasing with time, 2) are regulations effective in reducing the levels of pollutants in each environmental medium, 3) are new regulations needed because pollutants are increasing, and 4) are the right regulations in place to control the actual exposure (as demonstrated by biomonitoring) experienced by people?

In addition to the summaries previously mentioned, DESIGN II will permit the exposures and pollutant concentration levels to be examined over time in two main ways: within years (e.g., to reveal seasonal trends) and across years (e.g., to reveal long-term [e.g., 4-year] trends). The latter can be addressed both for the state as a whole and on a regional basis (see H11, H12, and H13).

### **1.2.4 Multimedia Pollution Comparison of Counties and Urban and Rural Areas**

As noted in Section 1.2.2, the data analysis can include estimating parameters that characterize the exposure distributions of a given contaminant for each of several subpopulations (e.g., estimates of the county [or rural- and urban-area] means and percentiles of the person-3-day [or person-day] exposure distributions). Long-term trends for such regions can also be estimated and compared.

### **1.2.5 Emerging High Exposures**

The data obtained under this study design would permit the estimation and comparison of exposure distributions for persons with high and low exposures, 95<sup>th</sup> and 5<sup>th</sup> percentiles, and associated body burdens.

### **1.2.6 Chemical Occurrences in Human Biological Specimens**

These collections from the primary participant will allow for a summary to be created that details body burden distributions (i.e., population mean, population percentiles) by year for the overall population and relevant subpopulations by targeted stratification level, primarily CCDs. Biological specimens include one blood sample at the conclusion of the exposure periods, two urine samples (one pre- and one post-collection), and one hair sample at the end of the periods.

## **2. Hypotheses**

The hypotheses designed to meet the DESIGN II objectives provided in Section 1 are listed below. Each hypothesis links the study objective with the sample collection and analysis strategy, appropriate statistical models, and expected outcomes. The umbrella general hypothesis (H1) for DESIGN II to support Objective 1 is the following:

- **H1:** Delaware residents do or do not have higher health risks from a comprehensive suite of environmental contaminants via all pathways and relevant media compared, where possible, to national-level data.

The hypotheses to be addressed by study objectives (and general objective goal) are the following:

## **2.1 Objective 1 (Define Exposure Occurrences and Distributions)**

- **H1:** Delawareans do or do not have greater health risks from a comprehensive suite of environmental contaminants via all pathways and relevant media compared, where possible, to national-level data.
- **H2:** Delawareans living in each CCD do or do not have higher exposures to and doses of stressors from a comprehensive suite of environmental contaminants via all pathways and relevant media compared with the state as a whole.
- **H3:** Delawareans living in each CCD do or do not have higher exposures to and doses of stressors from a comprehensive suite of environmental contaminants via all pathways and relevant media than persons living in other CCDs.
- **H4:** Delawareans living in urban CCDs do or do not have higher exposures to and doses of stressors from a comprehensive suite of environmental contaminants via all pathways and relevant media compared with persons living in rural CCDs.

## **2.2 Objective 2 (Define Sources and Causes of Exposures)**

- **H5:** Delawareans do or do not have higher exposures to and doses of stressors from a comprehensive suite of environmental contaminants produced by sources within Delaware.
- **H6:** Delawareans do or do not have higher exposures to and doses of stressors from a comprehensive suite of environmental contaminants produced by (regional) sources outside Delaware.
- **H7:** Delawareans do or do not have higher exposures to and doses of stressors from a comprehensive suite of environmental contaminants produced by residential indoor sources compared to outdoor sources.

## **2.3 Objective 3 (Define Exposure and Dose Status and Trends)**

- **H8:** Delawareans' exposures to and doses of stressors from a comprehensive suite of environmental contaminants via all pathways and relevant media have or have not changed over 5 years.
- **H9:** Delawareans' exposures to and doses of stressors from a comprehensive suite of environmental contaminants via all pathways and relevant media in each CCD have or have not changed over 5 years.
- **H10:** Delawareans exposures to and doses of stressors from a comprehensive suite of environmental contaminants via all pathways and relevant media in urban versus rural areas have or have not changed over 5 years.

## 2.4 Objective 4 (Develop Delaware-Specific Exposure Models)

- **H11:** A model to predict contaminant exposure by all pathways and media can be developed and validated to predict and apportion the total exposures for Delawareans living in any CCD.
- **H12:** A model to predict personal contaminant exposures from fixed-location measurements by all pathways and media can be developed and validated for Delawareans living in any CCD.
- **H13:** A receptor model to apportion air route contaminant exposure contributions from selected Delaware point, area, and line sources can applied to Delawareans living in any CCD.
- **H14:** A receptor model to apportion air route contaminant exposure contributions from regional, non-Delaware point, area, and line sources can applied to exposures for Delawareans living in any CCD.

The general approaches for testing each specific hypothesis should be apparent from this design, but the detailed data analyses and modeling steps to do so will be provided subsequently in the associated workplan for DESIGN II.

## 3. Study Design

The Multimedia Exposure Study (MMES) will collect data to monitor participants at multiple points in time and proposes using a moving panel strategy to collect multimedia exposures measurements on major stressors in separate calendar years. The contaminant categories identified in the hopscotch plan described in Section 1.1.1 are of particular interest in 2008.

Designing a survey to provide statistical inferences about Delaware's population requires developing an operational definition of the population; a mechanism for selecting subjects from the population with known probabilities; specific hypotheses to be tested or population parameters to be estimated; and precision requirements. These specifications are developed in the sections that follow. The overview of the DESIGN II approach is provided in Table 3-1, which describes the key elements incorporated into the design. The conceptual framework for conducting the effort for each set of contaminant categories (all media, all routes) is shown in Figure 3-1.

**Table 3-1. Overview of DESIGN II**

Design Element	Description
Design basis	Multimedia, multipathway exposure study
Cohort selection	Stratified random sample of Delaware adults (ages 18 years or older)
Spatial stratification levels	Personal, household, census tract, CCD
General hypothesis	Delaware residents do or do not have excessive health risks from a comprehensive suite of environmental contaminants via all pathways and relevant media
Pathways	Inhalation, ingestion, dermal exposure
Media	Air, water, food, house dust
Contaminant phases	Particles (PM <sub>10</sub> and PM <sub>2.5</sub> ) and vapor /liquid

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<b>Design Element</b>	<b>Description</b>
Contaminant chemical class targets	Metals, diesel PM chemicals, pesticides, VOCs, PAHs, PCBs, dioxins, furans, carbonyls, perfluorinated acids, PBDEs, environmental tobacco smoke
Supporting metrics	Meteorological variables, air receptor modeling chemicals, residence air exchange
Dose media	Blood, urine, hair (confirmation only)
Health risk bases	Cancer, cardiovascular disease, pulmonary disease
Source categories	Power generation, mobile source combustion, chemical production, refineries, (non-Delaware) regional background
Model development	Total exposure prediction by pathway, media, and stratification level; prediction of the residents' personal exposures from fixed-location measurements

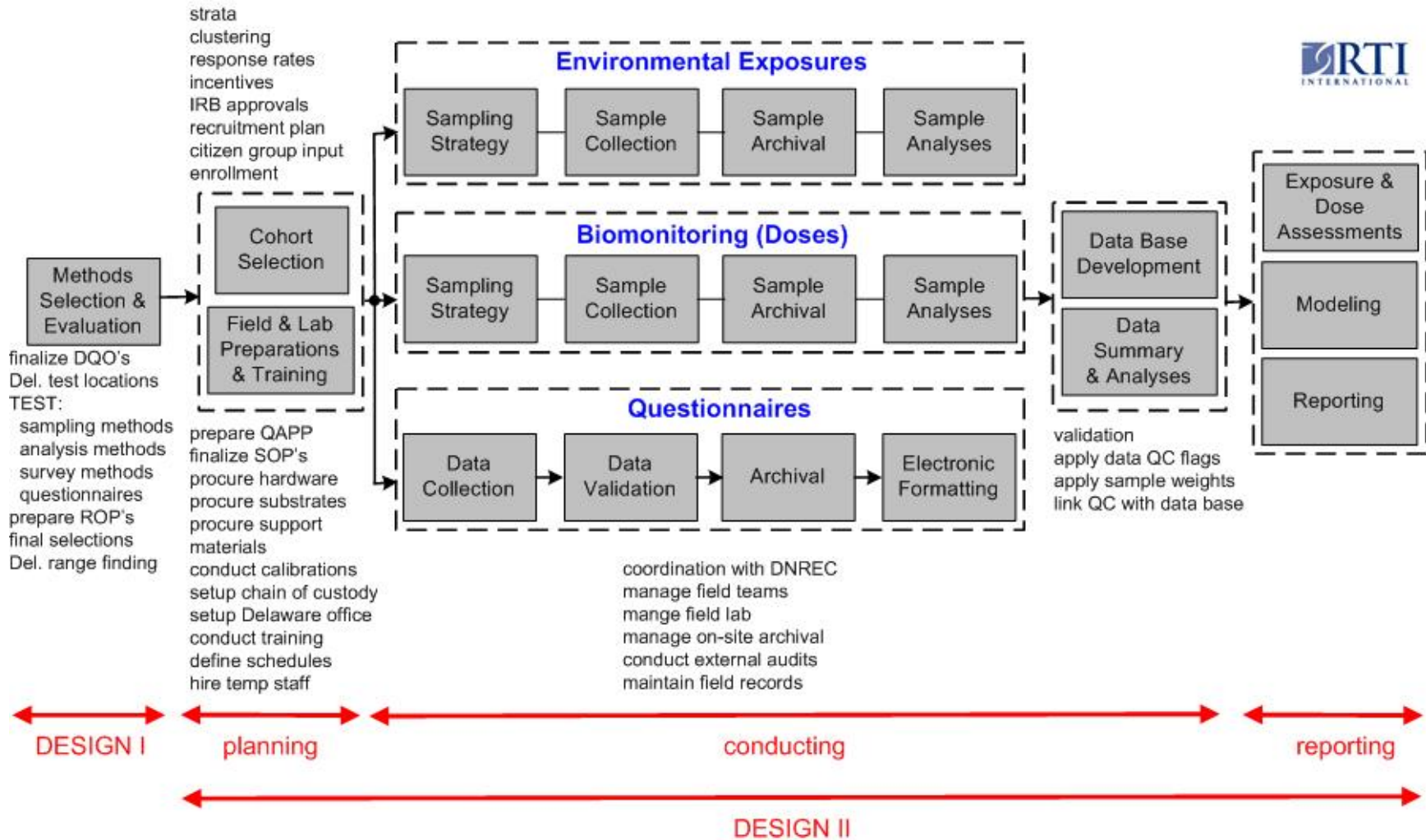


Figure 3-1. DESIGN II conceptual framework.

### 3.1 Study Area and Population

Defensible statistical inferences about Delaware's population will require conducting a sample survey in which all household residents of the state (the members of the DESIGN II survey population) have a positive probability of selection. This design will not include homeless and institutionalized populations because they are difficult and expensive to survey. Given the general hypotheses presented in Section 2.1, important subpopulations to be adequately represented in the survey include the following:

- The residents of each county
- Residents of Delaware CCDs who have cancer incidence rates higher than the corresponding State incidence rates
- The urban/suburban residents of Delaware
- The rural residents of Delaware
- The residents of CCDs along the I-95 corridor through Wilmington
- The residents of CCDs near the IRP project and the Valero refinery.

Comparisons among the three counties in the state of Delaware would be most efficient if the sample was equally allocated to the three counties. However, this allocation would be inefficient for state-level inferences because the population of the state is not evenly distributed among the three counties, as shown in Table 3-2. Figure A-1 in the Attachments presents a map of Delaware, counties, CCDs, and locations of main interstates and some pollution sources. The spatial distribution of CCDs of combined cancer-incidence rates suggests a gradient of cancer incidence that moves from north to south and calls for a study of the possible correlation between exposures and cancer rates. The extra number of cases per year refers to the expected cases to occur in the CCDs as a result of the CCDs having higher incidence rates compared to the state. Table 3-2 shows the Delaware census data since 1996 and indicates a slight shift in population toward the less dense Kent and Sussex counties. Table 3-3 shows demographic and socioeconomic summary statistics for the three counties from Census 2000 data.

**Table 3-2. Delaware Census by Counties Since SJR-11**

County	1990 Population (%)	2000 Population (%)	2006 Estimated Population (%)
New Castle	441,946 (66.3%)	500,265 (63.8%)	525,587 (61.6%)
Kent	110,993 (16.7%)	126,697 (16.2%)	147,601 (17.3%)
Sussex	113,229 (17.0%)	156,638 (20.0%)	180,288 (21.1%)
TOTALS	666,168	783,600	853,476

Source: U.S. Census Bureau

The Census 2000 data also show that the mean population densities for New Castle, Kent, and Sussex counties are 1,174; 215; and 167 persons per square mile, respectively, which highlights the much more rural characteristics of Kent and Sussex counties.

Therefore, the sample will be equally allocated between New Castle, Kent, and Sussex counties. This allocation results in slight over sampling of the southern two-thirds of the state, which is appropriate for addressing the unusually high cancer prevalence there, as well as for highlighting the importance of the IRP emissions on exposures that may have led to the high

cancer rate. Limiting the geographic comparison to these two geographic areas reduces sample size requirements and is efficient for statewide estimates. Moreover, the sample size requirements for the CCD-level and urban/rural comparisons are then comparable, conserving the resources required for sample collection.

**Table 3-3. Selected Demographic and Socioeconomic Characteristics of Study Area**

	Kent	Percentage	New Castle	Percentage	Sussex	Percentage	Delaware State	Percentage
Total population	126,697		500,265		156,638		783,600	
White	93,106	73.49%	365,810	73.12%	125,857	80.35%	584,773	74.63%
Black	26,180	20.66%	101,167	20.22%	23,319	14.89%	150,666	19.23%
Hispanic	4,069	3.21%	26,293	5.26%	6,915	4.41%	37,277	4.76%
American Indian and Alaska Native	806	0.64%	979	0.20%	946	0.60%	2,731	0.35%
Asian	2,137	1.69%	12,950	2.59%	1,172	0.75%	16,259	2.07%
Native Hawaiian and other Pacific Islander	50	0.04%	165	0.03%	68	0.04%	283	0.04%
Other	1,611	1.27%	11,087	2.22%	3,157	2.02%	15,855	2.02%
2+ races	2,807	2.22%	8,107	1.62%	2,119	1.35%	13,033	1.66%
<b>Housing</b>								
Total housing units	50,481		199,521		93,070		343,072	
Occupied	47,224	93.55%	188,935	94.69%	62,577	67.24%	298,736	87.08%
Vacant	3,257	6.45%	10,586	5.31%	30,493	32.76%	44,336	12.92%
<b>Occupancy</b>								
Owner occupied	33,040	69.96%	132,514	70.14%	50,484	80.68%	216,038	72.32%
Renter occupied	14,184	30.04%	56,421	29.86%	12,093	19.32%	82,698	27.68%
<b>Age</b>								
Median age	34.4		35		41.1		36	
18 years and older	92,164		375,516		121,333		589,013	
<b>Gender</b>								
Male	61,070	48.20%	242,943	48.56%	76,528	48.86%	380,541	48.56%
Female	65,627	51.80%	257,322	51.44%	80,110	51.14%	403,059	51.44%

Source: U.S. Census Bureau, 2000.

### 3.2 Population Sampling Design

This section discusses several aspects of the population sampling design. First, it addresses the mechanism for achieving positive probabilities of selection for all members of the

survey population in each year's cross-sectional survey of the state's population. Second, it addresses two aspects of temporal sampling: monitoring sample persons at multiple points in time and allocating each year's sample across time. Lastly, it addresses longitudinal sampling considerations for the recurring surveys every 5 years for the same classes of contaminants.

### **3.2.1 Cross-Sectional Population Sampling Considerations**

A multistage area household sampling design will be developed because analytical technicians must visit the sample homes to collect the environmental specimens (i.e., personal air samples and other optional media samples). Sample subjects will be selected using the following three stages of sampling:

- Geographic areas —CCDs, constructed from 2000 Census blocks
- Households within sample areas
- People within sample households.

As each stage of the sample is selected, the probabilities of selection will be recorded. The initial analysis weights will be computed as the reciprocals of the overall probabilities of selection. These probabilities of selection (and analysis weights) will be optimized for person-level analyses because personal exposure measurements are the primary focus of the study.

The primary sampling units (psu), or first-stage sample of geographic areas, will be stratified to ensure sufficient sample sizes for the northern, central, and southern portions, as well as for the urban/suburban and rural portions of the state. Stratification and cluster techniques will be used to produce a time and cost-effective sampling design that can reflect combinations of potential exposures that may be associated with the observed distribution of cancer incidence around the pollution sources. Each year's survey will also be optimized for the primary contaminants in that year's study by stratifying on population characteristics expected to be related to exposure measurements.

To perform a random selection of housing units in the selected sampling areas, a sampling frame, or a list, of residential addresses for each selected psu will be prepared. Previous studies conducted by RTI have shown that postal address lists purchased from reliable U.S. Postal Service vendors will provide residential addresses for nearly 98% of the occupied housing units when using similar sampling frame checks that are performed on the traditional counting and listing prepared sampling frames of housing units. The situations in which the postal address method falls short are in identifying residents in locations with college dormitories and in rural locations without home mail delivery. From these listings, households will be randomly selected. For the final stage, participants in the study population will be chosen from those selected households.

The population sampling activities during the year before DESIGN II (the DESIGN I study period) include developing a more detailed description of the sampling design, selecting the sample areas for the Year 1 survey, and sending field staff to the sample areas that will be visited during the first few months of the Year 1 study to verify the mailing list with current housing units. These lists will be needed to select the sample households for the Year 1 study.

### **3.2.2 Temporal Sampling Design Considerations**

Estimates of the risks resulting from exposures to substances with chronic health endpoints are based on the distribution of long-term exposures, typically cumulative lifetime exposures. Multiple observations of sample persons, preferably in different seasons, are valuable for estimating distributions of long-term exposures (e.g., the 75<sup>th</sup> or 90<sup>th</sup> percentile of annual or lifetime exposures). The number of points in time that need to be observed for each sample subject is directly proportional to the intra-person variability in exposures.

Given insufficient resources to develop sound estimates of long-term exposures, at most a portion of the survey observations (e.g., one-third) will be devoted to repeat observations. A small number of repeat observations could provide valuable information for designing future studies and for modeling long-term exposures. Resources will be concentrated primarily on achieving sound statistical estimates of average population exposure levels and on estimating the distribution of the actual exposures that are monitored (typically 1-day or 3-day integrated exposures, depending upon the media and compounds being measured).

If the sample geographic areas were assigned to months for data collection in a haphazard manner, temporal and spatial differences could be confounded and the ability to make annual estimates could be compromised. Therefore, the geographic areas selected at the first stage of sampling will be allocated to months and seasons for data collection in a manner that enables annual estimates and does not confound temporal and spatial differences. Ideally, this requirement would be satisfied by randomly allocating the sample areas to months for data collection. Because this type of randomization would probably result in very inefficient use of travel resources, a compromise plan that achieves the desired results will be developed.

### **3.2.3 Longitudinal Sampling Considerations**

Repetition of the cycle of monitored compounds begins in the Year 5 to detect long-term (5-year) temporal trends in exposure concentrations. This temporal repetition is important for determining if regulations are resulting in decreasing exposures and for identifying emerging problems where exposure concentrations are increasing. Revisiting some of the sample persons who were monitored 5 years before could increase the precision of longitudinal comparisons. However, approximately 20% of the U.S. population moves in any 1 year; therefore, many of the sample persons would have moved during the 5 years between cycles. A portion of the sample for Year 5 (e.g., half) may be selected from the same households that were monitored during Year 1. We may gain some precision for longitudinal comparisons by selecting the same sample persons whenever they have not moved, and we may slightly reduce costs by sampling from some of the same geographic areas. However, at least half of the sample should be devoted to a fresh sample of households, selected as described in the first subsection above to provide sample coverage of the current population for each cycle of the survey.

## **3.3 Sample Size Considerations**

The monitoring cycle for each suite of compounds (tentatively identified for particle and gas phases in Tables 1-1 and 1-2) will consist of approximately 400 total observations—either 400 unique sample persons or 300 unique persons with repeat observations in different seasons for 100 of them. The latter is more reasonable in providing an indication of the influence of seasonal factors (e.g., meteorology, source emission patterns, snow versus no-snow) on

Delaware exposures. This section addresses the precision with which important population parameters can be estimated and the anticipated power of important hypothesis tests.

The sampling variance of a survey statistic depends not only on the sample size and the natural variability of the observations in the population but also on the characteristics of the sampling design. Classical statistical formulae are based on simple random sampling, which is impractical for population surveys. Features of the sampling design that affect the sampling variances of survey statistics include stratification, multistage sampling, and unequal probabilities of selection. Moreover, adjustment of the analysis weights to reduce the potential for non-response bias also affects the precision of survey statistics. The cumulative effect of these factors is often modeled by the “survey design effect” (Deff), which is defined as the ratio of the sampling variance of a statistic under the actual sampling design divided by the variance that would be expected for a simple random sample (SRS) of the same size.

$$\text{Deff}(\hat{\theta}) = \frac{\text{Var}_{\text{actual\_sampling\_design}}(\hat{\theta})}{\text{Var}_{\text{SRS}}(\hat{\theta})}$$

where,

$\hat{\theta}$  represents a survey statistic (e.g., a sample mean or proportion).

Hence, the modeled precision for any survey statistic must account for the expected design effect for that statistic.

For the proposed survey, the design effects are expected to be approximately 1.25 to 1.50 for most person-level statistics. This assumes that the sampling rates are optimized for person-level estimates. The design effects will be larger for measurements that exhibit high intra-cluster correlations (e.g., lead [Pb] in drinking water) within the sampled geographic areas. The design effects will also be larger (e.g., 1.50 to 1.75) for household-level estimates (e.g., those for indoor air, outdoor air, or tap water concentrations).

Tables A-1 and A-2 in the Attachments can be used to determine the expected precision for survey statistics and the expected power of hypothesis tests for given sample sizes. These tables are presented for the planned sample sizes for important population domains, as shown below:

- 300 or 400 sample persons (depending on whether 100 are selected for monitoring in a second season) monitored in the state as a whole
- 150 or 200 sample persons monitored in each of the following domains:
  - New Castle County
  - Kent and Sussex counties
  - Urban/suburban areas of the state
  - Rural areas of the state.

Examples of the types of information provided by the precision and power tables are presented in terms of person-level estimates because they are the primary focus of the study. Therefore, we concentrate on the precision and power achieved when the survey design effect is in the range from 1.25 to 1.50, although higher design effects are possible for some types of person-level statistics, as previously mentioned.

The tables present expected precision and power for estimates of and hypothesis tests regarding population proportions because the random sampling variance of an estimated proportion depends only on the sample size and the true population proportion. These proportion estimates are most easily interpreted as estimates of the proportion of the population whose personal exposure measurements exceed a given regulatory or health-based threshold.

Table 3-4 presents standard errors (SEs) for estimates of population proportions, given the true population proportion,  $P$ , the domain sample size,  $n$ , and the survey design effect. One application of this table is to model expected confidence interval estimates, given the true population proportion,  $P$ . For statewide estimates ( $n = 300$  or  $400$ ), we see that the SE of the sample proportion will be about 1.35% (1.22% to 1.54% for  $Deff = 1.25$  to  $1.50$ ) when the true population proportion is 5%. Hence, the 95% confidence interval estimate of a 5% population proportion is expected to be approximately  $5\% \pm 2(1.35\%) = 2.3\%$  to  $7.7\%$  for statewide estimates.

Likewise, for the domains represented by a sample size of approximately 150 to 200 people (i.e., county and urban/rural domains), we see that the 95% confidence interval estimate of a true 5% population proportion would be approximately  $5\% \pm 2(2\%) = 1\%$  to  $9\%$ .

Finally for smaller geographic areas or sub-domains, such as census tracts, combinations of census tracts or CCDs where the sample size may be approximately 50 to 100, the 95% confidence estimate of a true 5% population proportion would be approximately  $5\% \pm 2(3.08\%) = 0\%$  to  $11\%$ .

Another useful measure of the precision of a survey statistic is its relative standard error (RSE), which is defined as the ratio of the SE of the survey statistic divided by the true value of the population parameter being estimated. That being

$$RSE(\hat{\theta}) = \frac{SE(\hat{\theta})}{\theta}.$$

This measure of precision is particularly useful for estimates of small population percentages (e.g., 1% to 5%), which are appropriate in the current application where the percentage estimates are being interpreted as percentage of the population exceeding a regulatory or health-based threshold. A common rule-of-thumb in this situation is that an estimate is reasonably precise if the RSE is between 20% and 50%. Estimates with RSEs exceeding 50% are usually considered unsatisfactory.

Table 3-5 presents relative SEs for the sample sizes and survey design effects under consideration. For statewide estimates ( $n = 300$  or  $400$ ), we see that we can expect reasonably precise estimates when the true population proportion is 5% (RSE = 24% to 31% for  $Deff = 1.25$  to  $1.50$ ), but we should not expect satisfactory estimates of population proportions as small as 1% (RSE = 56% to 70% for  $Deff = 1.25$  to  $1.50$ ). Likewise, for domains represented by a sample of approximately 150 to 200 persons, we should expect less precise, but acceptable, estimates when the population proportion is 5% (RSE = 34% to 44% for  $Deff = 1.25$  to  $1.50$ ). Lastly, for those small geographic areas, such as census tracts or combinations of CCDs, where the sample may vary between 50 to 100, we should expect satisfactory or acceptable estimates if the true proportion is 25% (RSE = 19% to 30% for  $Deff = 1.25$  to  $1.50$ ), less precise but acceptable for a true proportion of 10% (RSE = 27% to 37% for  $Deff = 1.25$  to  $1.50$ ), and unreliable, therefore not acceptable, for true proportions below 5% (RSE > 50 for  $Deff = 1.25$  to  $1.50$ ).

**Table 3-4. Standard Error of the Estimated Population Percentage, P, for Specified Sample Sizes and Design Effects**

Sample Size, n	Percentage, P	Design Effect				
		1	1.25	1.5	2	3
400	50%	2.50%	2.80%	3.06%	3.54%	4.33%
	25%	2.17%	2.42%	2.65%	3.06%	3.75%
	10%	1.50%	1.68%	1.84%	2.12%	2.60%
	5%	1.09%	1.22%	1.33%	1.54%	1.89%
	1%	0.50%	0.56%	0.61%	0.70%	0.86%
300	50%	2.89%	3.23%	3.54%	4.08%	5.00%
	25%	2.50%	2.80%	3.06%	3.54%	4.33%
	10%	1.73%	1.94%	2.12%	2.45%	3.00%
	5%	1.26%	1.41%	1.54%	1.78%	2.18%
	1%	0.57%	0.64%	0.70%	0.81%	0.99%
200	50%	3.54%	3.95%	4.33%	5.00%	6.12%
	25%	3.06%	3.42%	3.75%	4.33%	5.30%
	10%	2.12%	2.37%	2.60%	3.00%	3.67%
	5%	1.54%	1.72%	1.89%	2.18%	2.67%
	1%	0.70%	0.79%	0.86%	0.99%	1.22%
150	50%	4.08%	4.56%	5.00%	5.77%	7.07%
	25%	3.54%	3.95%	4.33%	5.00%	6.12%
	10%	2.45%	2.74%	3.00%	3.46%	4.24%
	5%	1.78%	1.99%	2.18%	2.52%	3.08%
	1%	0.81%	0.91%	0.99%	1.15%	1.41%
100	50%	5.00%	5.59%	6.12%	7.07%	8.66%
	25%	4.33%	4.84%	5.30%	6.12%	7.50%
	10%	3.00%	3.35%	3.67%	4.24%	5.20%
	5%	2.18%	2.44%	2.67%	3.08%	3.77%
	1%	0.99%	1.11%	1.22%	1.41%	1.72%
50	50%	7.07%	7.91%	8.66%	10.00%	12.25%
	25%	6.12%	6.85%	7.50%	8.66%	10.61%
	10%	4.24%	4.74%	5.20%	6.00%	7.35%
	5%	3.08%	3.45%	3.77%	4.36%	5.34%
	1%	1.41%	1.57%	1.72%	1.99%	2.44%

**Table 3-5. Percentage of Relative Standard Error for Estimates of Population Proportions for Various Design Options**

Sample Size, n	Percentage, P	Design Effect				
		1	1.25	1.5	2	3
400	50%	5	6	6	7	9
	25%	9	10	11	12	15
	10%	15	17	18	21	26
	5%	22	24	27	31	38
	1%	50	56	61	70	86
300	50%	6	6	7	8	10
	25%	10	11	12	14	17
	10%	17	19	21	24	30
	5%	25	28	31	36	44
	1%	57	64	70	81	99
200	50%	7	8	9	10	12
	25%	12	14	15	17	21
	10%	21	24	26	30	37
	5%	31	34	38	44	53
	1%	70	79	86	99	122
150	50%	8	9	6	12	14
	25%	14	16	11	20	24
	10%	24	27	18	35	42
	5%	36	40	27	50	62
	1%	81	91	61	115	141
100	50%	10	11	12	14	17
	25%	17	19	21	24	30
	10%	30	34	37	42	52
	5%	44	49	53	62	75
	1%	99	111	122	141	172
50	50%	14	16	17	20	24
	25%	24	27	30	35	42
	10%	42	47	52	60	73
	5%	62	69	75	87	107
	1%	141	157	172	199	244

Table 3-6 presents RSEs for the sample sizes and survey design effects under consideration. For statewide estimates ( $n = 300$  or  $400$ ), we see that we can expect reasonably precise estimates when the true population proportion is 5% (RSE = 24% to 31% for  $Deff = 1.25$  to  $1.50$ ), but we should not expect satisfactory estimates of population proportions as small as 1% (RSE = 56% to 70% for  $Deff = 1.25$  to  $1.50$ ). Likewise, for domains represented by a sample of approximately 150 to 200 persons, we should expect less precise, but acceptable, estimates when the population proportion is 5% (RSE = 34% to 44% for  $Deff = 1.25$  to  $1.50$ ).

Table 3-7 addresses the expected power for the primary hypothesis tests. It tabulates the probability of declaring specific differences in population proportions to be statistically significant using a two-tail test conducted at the 5% level of significance and assuming a common sample size,  $n$ , for the domains being compared. For example, for  $n = 300$  or  $400$ , the table presents the power expected for hypothesis tests that compare the statewide proportions exceeding various thresholds in one survey with the estimates of those same proportions in the survey conducted 5 years later.

For example, if we are comparing state-level statistics from surveys of 400 people conducted 5 years apart, we see that we have a 94% chance of detecting a significant decrease when the population proportion exceeding a threshold decreases from 50% to 35%, assuming a design effect of 1.50. However, we have only a 64% chance of declaring a decrease from 50% to 40% to be significant. Moreover, we are almost certain to declare a decrease from 25% to 10% to be significant, and have an 82% chance of declaring a decrease from 25% to 15% to be significant.

**Table 3-6. Probability of Detecting the Specified Difference in Population Proportions Using a Two-Tail Test at the 5% Level of Significance by Sample Size and Survey Design Effect (Power of the Test) for  $n = 300$  and  $n = 400$**

Sample Size, $n^a$	Larger Proportion, $P_1$	Decrease, $\Delta$	Survey Design Effect				
			1.00	1.25	1.50	2.00	3.00
N = 400	$P_1 = 50\%$	5%	0.29	0.24	0.21	0.17	0.13
		10%	0.81	0.72	0.64	0.52	0.38
		15%	0.99	0.97	0.94	0.86	0.70
		20%	>.99	>.99	>.99	0.98	0.92
	$P_1 = 25\%$	5%	0.40	0.33	0.28	0.22	0.17
		10%	0.94	0.89	0.82	0.71	0.53
		15%	>.99	>.99	>.99	0.98	0.90
		20%	>.99	>.99	>.99	>.99	>.99
N = 300	$P_1 = 50\%$	5%	0.23	0.20	0.17	0.14	0.11
		10%	0.69	0.60	0.52	0.41	0.30
		15%	0.96	0.91	0.86	0.75	0.57
		20%	>.99	0.99	0.98	0.94	0.82
	$P_1 = 25\%$	5%	0.31	0.26	0.22	0.18	0.14
		10%	0.86	0.78	0.71	0.58	0.42
		15%	>.99	0.99	0.98	0.93	0.80
		20%	>.99	>.99	>.99	>.99	0.98

**Table 3-7. Probability of Detecting the Specified Difference in Population Proportions Using a Two-Tail Test at the 10% Level of Significance by Sample Size and Survey Design Effect (Power of the Test) for n = 300 and n = 400**

Sample Size, n <sup>a</sup>	Larger Proportion, P <sub>1</sub>	Decrease, Δ	Survey Design Effect				
			1.00	1.25	1.50	2.00	3.00
N = 400	P <sub>1</sub> = 50%	5%	0.41	0.35	0.32	0.26	0.21
		10%	0.88	0.82	0.75	0.64	0.50
		15%	>.99	0.99	0.97	0.92	0.80
		20%	>.99	>.99	>.99	0.99	0.96
	P <sub>1</sub> = 25%	5%	0.52	0.45	0.40	0.33	0.26
		10%	0.97	0.94	0.89	0.80	0.66
		15%	>.99	>.99	>.99	0.99	0.94
		20%	>.99	>.99	>.99	>.99	>.99
N = 300	P <sub>1</sub> = 50%	5%	0.34	0.30	0.26	0.22	0.18
		10%	0.79	0.72	0.64	0.54	0.41
		15%	0.48	0.96	0.92	0.84	0.69
		20%	>.99	>.99	0.99	0.97	0.89
	P <sub>1</sub> = 25%	5%	0.43	0.37	0.33	0.28	0.22
		10%	0.92	0.86	0.80	0.70	0.55
		15%	>.99	>.99	0.99	0.96	0.87
		20%	>.99	>.99	>.99	>.99	0.99

Table 3-8 shows how the power of these hypothesis tests increases if we are willing to increase the significance level of the test from 5% to 10%. Thus, we see that we can improve the probability of detecting a significant change in exposure concentrations if we allow the probability of a false positive result to increase from 5% to 10%.

### 3.4 Contaminants for Study

Environmental exposures for Delawareans with the potential to have previously played or might in the future play roles in adverse cancers or cardiovascular and pulmonary diseases are of interest. Public health issues and environmental exposures for the broad range of potential contaminants listed in Tables 1-1 and 1-2 will be selected, based on final priorities set by Delaware, combined with the resources that become available to support the DESIGN II effort. The choice of contaminants and the geographical region for study considers toxicity, potential human exposure (i.e., the occurrence of the contaminant) and other factors (e.g., multipathway, multimedia routes of exposure). A brief discussion of these factors is provided in this section for each contaminant category. The final selection will be made jointly by DNREC and DHSS.

The rationales for DESIGN I (e.g., exposure routes, scenarios, analytes) draw heavily from the entire list of Delaware-specific reports, presentations, and environmental alerts cited in the Reference section. Rationales for particle-phase contaminants and regional air pollutant concerns are provided by the report *Air Quality Criteria for Particulate Matter* (2004).

The hopscotch design, spreading the contaminant categories across study years to provide more manageable (fundable and logistically possible) yearly targets results in the proposed analyte suites shown in Table 3-8. Year 1 groups the PM, particle-phase contaminant categories together, with acute- and chronic-level collections integrated over 24- and 72-hour periods, depending upon the contaminant category.

**Table 3-8. Proposed Key Analytes Categories for 2008 DESIGN II Hopscotch Plan**

Year	Categories
Year 1	PM <sub>2.5</sub> and PM <sub>10</sub> (air, 1-day), metals (all media, 1-day), and particle-phase PAHs (3-day)
Year 2	Carbonyls (air, 3-day), VOCs (air/water, 3-day), SVOCs (vapor-phase air/water, 3-day)
Year 3	Pesticides (all media, 3-day), PCBs (all media, 3-day), dioxins/furans (all media, 3-day)
Year 4	PBDEs (all media, 3-day), perfluorinated acids (all media, 3-day), other chemicals (all media, 3-day)
Years 5 to 9	Repeat the cycle to obtain longitudinal and long-term exposure data

The proposed selection of core and optional analyte categories for the collected environmental and biospecimen samples by study year are shown in Table 3-9. The probability basis would allow full inferences to be made. These proposed core analytes are subject to final approval from DNREC and DHSS.

**Table 3-9. Samples Collected for Analyses for All DESIGN II Study Years, Identifying Proposed Core and Optional Analytes**

Category	Category Element	Proposed Sample Collections for Analysis			
		Year 1	Year 2	Year 3	Year 4
<b>Sample Analyses</b>	PM samples (2.5 and 10) —gravimetric, ETS, BC	5,538	0	0	0
	PM samples (2.5 and 10) —XRF or ICP-MS	5,538	0	0	0
	PM samples (2.5 only)—EC/OC	2,490	0	0	0
	PM samples (2.5 only)—SVOC	930	0	0	0
	PM samples (2.5 and 10)—ions	5,538	3,090	0	0
	SVOCs—air, food, dust, biologicals	2,630	0	0	0
	PM (10 only) —endotoxin	258	5,890	0	0
	Carbonyl samples	0	0	0	0
	Air—asbestos	100	0	0	0
	Air—silica	100	0	0	0
			1290		
	Air—VOC samples	0	1,290	0	0
	Air—criteria gases	1,200	400	0	0
	Air exchange rate	400	400	400	400
	Meteorology data	yes	yes	yes	yes
Water, biospecimen—VOCs (organic carcinogens)	0	2,100	0	0	

Category	Category Element	Proposed Sample Collections for Analysis			
		Year 1	Year 2	Year 3	Year 4
Sample analysis	Metals—water, dust, food, biological	2,200	0	0	0
	Arsenic speciation	2,200	0	0	0
	Chromium (VI)	2,200	0	0	0
	Pesticides—water, dust, food, biological	0	0	3,490	0
	Dioxin/furans—air, dust, food, biological	0	0	3,490	0
	PCB 12 congeners—air, dust, food, biological	0	0	3,490	0
	PCB 209 congeners—food	0	0	1,290	0
	PBDEs—air, dust, food, biological	0	0	0	3,490
	Perfluorinated compounds—air, dust, food, biological	0	0	0	3,490
	GCMS scans/library search	0	0	0	3,490
<b>Total samples collected (core only)</b>		<b>13,276</b>	<b>1,290</b>	<b>3,490</b>	<b>3,490</b>
<b>Total samples collected (all types)</b>		<b>31,322</b>	<b>14,460</b>	<b>12,160</b>	<b>10,870</b>

Core collections:

Optional analysis rates:

### 3.4.1 Toxicity

The suspected carcinogens are found in both particle and vapor phases in the air, but from a public health perspective, more important exposures from these and other agents may occur through other sources. For example, the main exposure to inorganic arsenic generally occurs via ingestion, with drinking water and food potentially contributing approximately 30% and 50%, respectively. Pb can be found not only in airborne aerosols, but also in drinking water and food. Pesticides and PAHs also occur in several environmental media that ultimately are inhaled or ingested. Because there are several routes of exposure for these contaminant classes, the dosing regime to persons can vary; therefore, the endpoints of toxicity can also differ. These factors must be considered in devising a comprehensive strategy for assessing people's risk to contaminants.

A variety of contaminants in Delaware's ambient air, including VOCs, PM and metals can cause toxicity. For example, benzene is a widely used industrial solvent and a by-product from waste incineration and cigarette smoking. Several Delaware facilities reported on-site air releases of benzene under the EPA's Toxic Release Inventory for 1978–1992, and approximately 99% of benzene in the environment occurs in air (Hattemer-Frey et al., 1990). High doses of benzene affect the nervous system, and long-term exposure to low levels impairs blood cell formation and bone marrow function, damages the central nervous system, and causes some types of cancer (Foo, 1991). Exposure levels as low as 1 ppm are reported to have a relative risk of 1.7 for leukemia (Hattemer-Frey et al., 1990). The California Environmental Protection Agency (CAL-EPA) has estimated a risk factor of  $3.9 \times 10^{-4}$  for exposure to benzene ( $13.6 \mu\text{g}/\text{m}^3$ ) from indoor sources alone (Alexeef, 1993).

Measurement of trihalomethanes (THMs) and metals in drinking water provides an important addition to the monitoring of environmental exposures. Not only are many contaminants ingested through drinking water, VOCs can also be inhaled during bathing or absorbed through the skin. As summarized by McGeehin and colleagues (1993), an increasingly rigorous series of epidemiologic studies indicates that THMs, which are common by-products of water chlorination, increase the risk of bladder cancer. Moreover, a recent study in New Jersey suggested an association between ingestion of THM-contaminated drinking water and several types of birth defects (Bove et al., 1995). Arsenic in drinking water poses a potentially substantial risk of health problems. Ingestion is the main exposure route for inorganic As, and 30% of ingested As comes from drinking water for most people in the United States (Smith et al., 1992). These researchers concluded that increased cancer risks from As in drinking water may be comparable to those from exposure to radon (3/1000) and ETS (4-10/1000) in the United States.

Regarding metals, there are subtle effects associated with low exposures levels to Pb (Needleman and Bellinger, 1991). Metanalyses indicate that low-level exposure to Pb causes intelligence quotient deficits. Some studies of school age children with Pb exposure have shown problems with speech and language processing, attention, reading, spelling and mathematics scores, perceptual motor integration, and reaction time (Bellinger et al., 1991). These neurobehavioral problems may persist beyond childhood.

In addition to neurobehavioral effects of low Pb exposure, such exposures are also associated with a variety of other outcomes, including low birth weight, decreased postnatal growth, miscarriages, and premature birth (Saloum, 1993). Several studies have found minor hearing impairment associated with low-level Pb exposure (Schwartz, 1991). Although some studies suggest that Pb exposure can cause chronic renal disease, this putative association remains controversial (Nuyts et al., 1991).

Experimental and epidemiologic studies have indicated that blood Pb levels in the range of 10–15  $\mu\text{g}/\text{dL}$ , or possibly lower, are likely to produce subclinical toxicity (Landrigan, 1988). A discernible threshold has not been demonstrated. Therefore, an RfD for Pb has not been developed; instead probabilistic dose-response functions have been used (Whitfield and Wallsten, 1989). EPA has alternatively developed the uptake/biokinetic Pb model that provides a means for evaluating the relative contribution of various media to establishing blood Pb levels in children because abatement strategies will need to deal with potential multimedia, multipathway routes of exposures-air, diet, water, soil/dust (nondietary ingestion), and paint (Hoffnagle and DeCesar, 1987).

Chronic As poisoning leads to a variety of symptoms, including weakness and fatigue, hair loss, weight loss, and anemia (U.S. EPA, 1993). Kidneys, liver, and other organs can be damaged, along with causing peripheral vascular lesions and other cardiovascular diseases. Peripheral neuropathy, primarily in the arms and legs, can also occur (Hindmarsh and McCurdy, 1986). Ingested As causes a variety of benign and malignant skin lesions that are distributed in a characteristic pattern (Shannon and Strayer, 1989). Children may be especially susceptible to As toxicity from ingesting drinking water.

Animal studies indicate that As is a teratogen. Moreover, epidemiologic studies found an association between As exposure near a copper smelter and congenital malformations and spontaneous abortions (Hindmarsh and McCurdy, 1986). In a review of the literature that was

weighted heavily by drinking water studies, the authors found strong evidence that ingested inorganic As causes cancer of the bladder, kidney, lung, and liver (Bates et al., 1992). EPA classifies As a human carcinogen (U.S. EPA, 1998; International Agency for Research on Cancer, 1987).

The potency of As a human carcinogen is relatively high. Several estimates for lifetime risk of dying of cancer (liver, lung, bladder, kidney, and skin) from As ingestion exposure to 1  $\mu\text{g}/\text{kg}\text{-day}$  have been made. These risks range from 0.001 to 0.048 (U.S. EPA, 1993; Hindmarsh and McCurdy, 1986; Shannon and Strayer, 1989; Bates et al., 1992; U.S. EPA, 1998; International Agency for Research on Cancer, 1987). EPA's estimate for skin cancer is 0.002 (U.S. EPA, 1993).

Although there are no accurate data on the average As levels in drinking water for the United States, estimates range from 2.0–2.5  $\mu\text{g}/\text{L}$  (Smith et al., 1992). The lifetime risk of dying from liver, lung, bladder, or kidney cancer due to drinking 1.6 L per day of water containing 2.5  $\mu\text{g}/\text{L}$  of As has been estimated to be 1 in 1,000 (Smith et al., 1992). Based on these calculated risks, Smith and colleagues (Smith et al., 1992) concluded that increased cancer risks from As in drinking water may be comparable to those from exposure to radon (3 in 1,000,) and ETS (4–10 in 1,000,) in the United States. Comparable estimations are not available for Delaware.

Although particulate air pollution in Delaware is unlikely to substantially affect the state's cancer rates, studies in several U.S. cities show positive associations between particle levels and daily mortality from cardiovascular and respiratory causes (Health Effects Institute, 1995). Fossil fuel combustion accounts for most particulate air pollution.

In addition to VOCs, particles, and metals mentioned above, other contaminants in Delaware's air, such as pesticides, PCBs, and PAHs, could also pose potential health threats. For example, epidemiologic studies suggest that some organophosphate agricultural pesticides, such as diazinon and malathion, can cause non-Hodgkin's lymphoma (Cantor et al., 1992), and high exposures to organophosphate pesticides cause acute neurotoxicity. Chlorpyrifos, another organophosphate pesticide with neurotoxic properties (Hodgson et al., 1986), was ranked No. 4 in pounds applied out of 14 pesticides studied in a 1989 Delaware Pesticide Usage survey.

Reports suggest that chlorpyrifos use can cause headaches, allergic reactions (e.g., skin rash and asthma), and liver or kidney disease, and excess dizziness, malaise, and fatigue in exposed manufacturing workers (Brenner et al., 1989). High doses of chlorpyrifos cause acute organophosphate toxicity, and some evidence suggests that toxicity can occur from routine use for pest control in office buildings and homes (Fenske et al., 1990). Infants are especially susceptible to home exposures because they receive higher doses than adults and have lower body tolerances.

Studies of workers and others exposed to benzo[a]pyrene (BaP) and other PAHs (e.g., coke oven workers, foundry workers, and cigarette smokers) have found an increased risk of lung cancer (Perera et al., 1988). A review of studies of aluminum plant workers, who are exposed to BaP and other chemicals, found evidence of excess lung, bladder, kidney, brain, and pancreatic cancers and leukemia (Ronneberg and Langmark, 1992), but the specific etiologic agents are unclear. Additionally, Everson and colleagues (1988) found an inverse association between placental levels of a smoking-related (and presumably aromatic) DNA adduct and birth weight. Supporters of the monoclonal theory of atherogenesis propose that such mutagenic

chemicals as BaP cause atherosclerosis by transforming smooth muscle cells in the arterial intima (Penn, 1990).

As with many chemicals, a BaP metabolite (BPDE-1), rather than BaP itself, is the toxic agent. Because the human placenta and fetal liver can metabolically activate BaP and other PAHs, the fetus may suffer damage from reactive metabolites (Pelkonen, 1984). Animal studies indicate that genetic differences in fetal metabolism can influence the toxicity and teratogenicity of PAHs (Pelkonen, 1984). The induction of detoxification enzyme systems from such dietary components as cruciferous vegetables and from environmental chemical exposures also helps determine the metabolic fate of PAHs in exposed persons. Therefore, genetic, as well as environmental determinants, apparently influence the toxicity of BaP and other PAHs.

All of the contaminants selected for DESIGN II, including the examples previously mentioned, have been reported found in Delaware's ambient air. For chemicals such as benzene, indoor air levels exceed outdoor levels, and ETS is the largest anthropogenic source (Hattemer-Frey et al., 1990), so a total air monitoring plan captures important exposure information that would be missed by monitoring restricted to ambient air. Different lines of evidence indicate that the selected contaminants all can potentially lead to adverse health effects. Moreover, some of these ubiquitous contaminants are carcinogenic. Monitoring these agents will help to characterize the environmental exposures that may negatively affect Delaware's public health.

### **3.4.2 Occurrence**

A brief description of the chemicals' occurrence in media is presented based upon extant data. This information is important in assuring that the selected collection and analysis protocols have adequate sensitivity for making the desired measurements.

Benzene and other VOCs are widely used industrial solvents and are by-products of combustion processes, including forest fires, burning of wastes, and cigarette smoke. Although environmental exposure levels vary from place to place, they are typically very low. Gasoline station attendants, automobile mechanics, and drivers of tanker trucks experience modest VOC exposure levels that substantially exceed those in persons without occupational exposures (Foo, 1991). People who frequently fill their own automobile gas tanks, especially those in hot climates, probably have intermediate exposure levels. Because gasoline from leaking underground storage tanks can contaminate groundwater, some individuals using contaminated drinking water sources could have substantially higher VOC exposure levels, especially if they also bathe using contaminated water.

The occurrence of trihalomethanes (THMs) in drinking water was discussed in the previous section. Studies indicate that Pb exposures in industrialized countries are approximately 100 times the exposure levels found in pre-industrialized countries. This ubiquitous contaminant can be found in air, food, water, soil, and household products and exposure often occurs through complex interacting pathways (Grandjean, 1988). Lead-based paint is the primary cause of high exposure among U.S. children; among children without acute poisoning, Pb levels in household dust is a strong predictor of levels in blood (Needleman and Bellinger, 1991). There are an estimated 40 million homes in the United States with lead-based paint, and 12–13 million children exposed in these homes (Saloum, 1993). The lead exposures experienced in Delaware is not well known.

In uncontaminated soil, Pb concentrations typically range from 10–50 ppm. Soil concentrations near major roads can reach 2,000 ppm, and soil levels of 60,000 have been found near smelters (U.S. EPA, 1988). Some crops, especially root vegetables, take up Pb, but most food contamination occurs during processing or storage (e.g., from soldered cans). Exposure to Pb in food and beverages is believed to far exceed exposure to Pb in air, and gastrointestinal absorption is the major avenue of Pb uptake (Landrigan, 1988). Pb from household plumbing is the major source in drinking water, especially in corrosive or soft waters where the pH is acidic; the principal source is Pb solder (Landrigan, 1988). Another important source has been lead-based fuels that have led to multimedia contamination.

Arsenic (As) is ubiquitous in soil, water, air, plants, and animals. In addition to such natural emission sources as volcanoes and forest fires, major anthropogenic sources include metal production, fossil fuel combustion, and waste incineration. Inorganic As found widespread use as an agricultural pesticide; however, since the 1970s farmers have used only small amounts. Arsenic compounds are currently used in the glass and electronics industries, as wood preservatives, and as food additives for farm animals to promote growth (Hindmarsh and McCurdy, 1986).

Occurrence data for As in ambient air is sparse because it is not routinely measured in the National Air Sampling Network. The reported range is from non-detectable to 83 ng/m<sup>3</sup> (Sluta, 1980; Polissar et al., 1990). A limited study in Washington has reported personal and indoor air levels of 0.05–70.6 ng/m<sup>3</sup> and 0.8–34 ng/m<sup>3</sup>, respectively (Buchet et al., 1981). Arsenic is present in soil at levels ranging from 0.2–40 µg/g (Polissar et al., 1990).

The main exposure to inorganic As generally occurs via ingestion. Current dietary intake of total As in U.S. adults, excluding tap water, is estimated at approximately 45–50 µg per day (Smith et al., 1992). Approximately 80% of the As derives from seafood, meat, and poultry, and approximately 17% comes from grains and cereals.

Because sulfhydryl groups bind trivalent As, concentrations are high in nails and hair. A single dose of As appears at the nail tip in approximately 4 months. Arsenic deposited in nail roots migrates distally about 0.12 mm per day in growing nails and approximately 0.35 mm per day in growing hair. Both materials provide potential markers of exposure. Arsenic is cleared rapidly from the blood (within approximately 10 hours). Urine levels are often used for monitoring occupational 8-hour exposures (Buchet et al., 1981). Urine measurements of inorganic As and its metabolites (i.e., monomethyl arsenic and dimethylarsenic acids) are preferable to measurements of total As; the latter can include substantial amounts of organoarsenicals from seafood and other sources, which have low toxicity (Buchet et al., 1981).

Chlorpyrifos has broad-spectrum activity against several common pests (Hodgson et al., 1986; Fenske et al., 1990). It is used agriculturally in different countries on such crops as corn, cotton, and citrus; structural treatments are used to control termites. Of concern is the residential use of chlorpyrifos to control flea infestations and other applications leading to dermal contact with treated surfaces or inhalation exposures following product use. Infants could have substantial dermal and inhalational exposures. Chlorpyrifos was the second most frequently encountered pesticide residue found in food and feed samples in the Los Angeles District of the U.S. Food and Drug Administration (FDA) (Penn, 1990), and it was the ninth most frequently encountered residue in the FDA's Total Diet Study (Gunderson, 1988). Because plasma cholinesterase activity is more susceptible to inhibition from chlorpyrifos than is erythrocyte

cholinesterase, the former is more commonly used for biologically monitoring of exposed workers (Brenner et al., 1989). A chlorpyrifos metabolite is rapidly excreted in the urine.

BaP and other PAHs result from incomplete combustion of various organic materials, such as fossil fuels (especially diesels), and tobacco. These ubiquitous contaminants are found in virtually all environmental media and food. Hattemer-Frey and colleagues (1990) estimate that 82% of BaP is found in soil and 17% is found in sediment. Because of its lipophilic properties, BaP accumulates in the food chain, which accounts for approximately 97% of BaP intake by humans (Hattemer-Frey et al., 1990). It is abundantly produced during the frying/grilling of meats. Because BaP typically occurs in mixtures with other PAHs, its independent role in human disease is difficult to ascertain from epidemiologic studies. BaP is often used as a surrogate or index for all PAHs in a mixture.

### **3.5 Sampling Strategies**

#### **3.5.1 Probability-Based Sample**

The objectives of DESIGN II require a probability-based sample selection to allow the most robust statistical inferences to be made concerning exposures in the Delaware population. Within the probability selection framework, the ability to stratify at selected levels (participant, household, CCD, etc.) and along desired variables (e.g., location, socioeconomic status, smoking status) is not compromised. The overall cost of implementing a probability-based exposure study similar to the NHEXAS for a wide range of contaminants can be prohibitive, and the previously-described hopscotch plan conducting the sampling successively over several years is appropriate.

By selecting the hopscotch design of doing one contaminant group at a time, there are major dividends in terms of being able to focus our energies. For example, if particles and metals were the target in one year, then we could focus on the main pathways of exposure. If PAHs are the target, we can monitor during the winter when inversions are typically strongest and wood smoke or other combustion products are at their highest levels.

This plan considers interrelated host and environmental variables in the framework of a multidimensional paradigm that potentially leads to exposure through air (Lioy and Pellizzari, 1995). A linear conceptual framework that shows the important routes of exposure and environmental media is provided in Figure 3-1. There are several strategies that may be used to study the relationship among elements responsible for measuring airborne exposure. A set of strategies recommended under this plan accounts for air exposure encountered by a person for VOCs, PM, metals, pesticides, PCBs, and PAHs.

A primary goal is to estimate total human exposure to environmental contaminants that produce chronic health effects. Subsequently, these data can be used for making accurate risk assessments. A key factor is to estimate long-term (annual or lifetime) exposure. The sampling strategy of this plan covers all seasons. Another important factor in achieving this goal is to separately measure the PM<sub>10</sub> and PM<sub>2.5</sub> size fraction of aerosols.

Based upon the previously mentioned hypotheses, the key variables for DESIGN II are the direct physical measurements of air (e.g., personal, indoor, outdoor, and occupational), drinking water, food exposure, housedust, and potential dose (i.e., if the biomonitoring option is exercised). A central focus of this plan is to estimate regional distributions of these types of measurements. The contaminants (Tables 3-6 and 3-7) and questionnaire items needed to define

important analysis domains may also be regarded as key (Figure 3-1). These include variables such as age and education level used to identify susceptible subpopulations (e.g., children, elderly, low socioeconomic status). Questionnaire variables should be included that identify strong sources of contaminants that may dominate the high-end portion of the exposure distribution (e.g., personal air benzene exposures from combustion sources).

### **3.5.2 Base Sampling for Environmental Media**

#### **3.5.2.1 Air (Inhalation)**

PM, VOCs and other air contaminants have a multitude of emission sources and are important toxic chemicals. VOCs (e.g., benzene) are emitted from many commercial solvents and combustion sources (e.g., cigarette burning). Also, the prevalence of wood burning suggests the potential exists for exposure to high levels of benzene and other VOCs. Petroleum refineries, coking ovens, chemical plants, and motor fuel handling can also lead to significant VOC air exposures in the general population. Based on previous studies for VOCs, inhalation exposure is believed to be the major route of exposure; however, exposure can be nearly equivalent for the THMs chloroform that occur in air and drinking water.

The hypotheses require simultaneous residential indoor and outdoor measurements because it has previously been shown that indoor contributions to exposure for most prevalent VOCs outweigh outdoor concentrations. It has also been shown repeatedly that personal exposures to both VOCs and particles are greater than simultaneous indoor and outdoor ambient measurements at homes. In the case of some gasoline- and tobacco-related VOCs, this can be traced to higher exposures while driving or smoking. In the case of the particles, the reason for the higher personal exposures is unclear, but it appears to be related to personal activities in the home. Therefore, a fundamentally sound approach is to include all three types of air monitoring (i.e., personal, indoor, outdoor) in this plan. As an example from the TEAM study (Pellizzari et al., 1993), the mean personal, indoor, and outdoor concentrations of benzene for 50 Los Angeles residents were 15, 10, and  $6 \mu\text{g}/\text{m}^3$ , respectively. A study without personal monitoring would have greatly underestimated actual personal exposure to most of the VOCs.

Another advantage of personal monitoring is the ability to include measurement of occupational exposures to VOCs in a single study. In this approach, participants would wear two badges, one of which would be closed off while they are working. The difference in the measured exposures between total and non-occupational exposures would be the occupational exposure. The extra burden in wearing two badges instead of one is minimal. The extra analytical cost would not be significant when including occupational measurement. At present, it does not seem possible to add an occupational component to the study for particles and metals because the active personal monitor is too bulky to consider wearing two.

A good monitoring period for using badges for collecting VOCs might be 3 days. This time period is sufficient to collect enough material to provide reasonable detection limits and does not place too much burden on the participants.

Inhalation of Pb, As, cadmium (Cd), and chromium (Cr) in PM represents one of several exposure routes. Personal, residential indoor, and outdoor PM samples will be collected from the participants to obtain a 24-hour time-weighted average concentration measurement. Personal samples will provide exposure data obtained in the breathing zone of the participant. Indoor and

outdoor measurements for metals will provide data for use in models that attempt to calculate resident's exposure by linking personal activity patterns with environmental measurements.

The personal particle monitoring system proposed for PM<sub>2.5</sub> and PM<sub>10</sub> in 1996 was too heavy and bulky to consider monitoring both fractions simultaneously. That will not be the case for Year 1 of DESIGN II because the cell-phone-size personal MicroPEM developed at RTI for large-scale exposure studies will be available. This extremely low burden system not only facilitates collections of one or both size fractions, but it will also provide critical protocol compliance information, along with maximizing the participant burden levels. Burden levels contribute heavily to poor participant recruitment and retention in the NHEXAS, which significantly weakens the value of the probability selection.

As previously discussed, there is considerable evidence on the toxicity and occurrence of pesticides in air. Some pesticides are commonly used in residential environments to control many types of insects, with common ones being termites and fleas. The number of people exposed and the magnitude of exposure to pesticides is not well understood in either the United States or in Delaware, despite their widespread use. Pesticides have widespread agricultural uses, which complicates the exposure matrix for rural participants living on or near farms.

Another important contaminant class of particular concern because they contain many known carcinogens are PAHs (e.g., BaP), which are part of the broader class known as SVOCs. The widespread prevalence of wood-burning stoves and fireplaces are known to occur, where the levels of BaP have been reported to be elevated in both indoor and ambient air (Lioy et al., 1988; Sheldon et al., 1993; also see Section 2). PAHs are also emitted from a variety of other combustion sources, such as coking ovens, steel mills, internal combustion engines, power plants, kerosene space heaters, charcoal/wood cooking, candles and cigarette smoke. For these reasons, BaP and other PAHs occur in several media (e.g., PM, house dust, and food). Exposure primarily occurs through inhalation and ingestion pathways. A multiclass, multicontaminant method for collecting and analyzing pesticides and PAHs is suggested as part of this plan to achieve efficiency, and thus lower costs. The target pesticides, PCBs, and PAHs selected include only those that have been shown in previous studies their main route of exposure through air because other media are not being sampled.

### **3.5.2.2 Water (Ingestion)**

THMs are ubiquitous in chlorinated drinking water. Chloroform has been shown in TEAM studies to be one of the few true multimedia VOCs, with important routes of exposure in drinking water, soft drinks, and food, as well as from showers and baths (both inhalation and dermal exposure). For these reasons, tap water is potentially a significant pathway of exposure for VOCs. Lead and especially arsenic in drinking water and fish caught locally may be also a source of significant exposure in Delaware. Both chloroform and As have been associated with bladder cancer, and chloroform has been associated with colon cancer; these cancers are among the types shown to have elevated rates in Delaware.

From the same set of subjects monitored for exposure to airborne VOCs and metals, this plan calls for collecting and analyzing drinking water because they are considered to be a significant pathway of exposure for these contaminants. Water samples from the homes participating in the air exposure study would be collected for THMs and metals analyses.

### 3.5.2.3 Food (Ingestion)

The levels of toxic metals have been reported in FDA's total diet studies (Gunderson, 1988; Liroy et al., 1988). However, cooking practices and sanitary conditions in a home may yield a different exposure scenario than predicted from the Total Diet Study data alone (e.g., food may be contaminated by the cooking water used during its preparation). Also, homegrown items and fish or game caught/hunted locally may qualitatively and quantitatively differ in contaminant content than those purchased at markets. From selected study participants, food is collected over the course of 3 days; each day's collection is composited to obtain a 3-day exposure estimate to metals.

### 3.5.2.4 Dermal (House Dust Surrogate)

Because of the occurrence of metals in air, an important pathway is the penetration of aerosols into the home. Once inside, there are several routes of exposure: inhalation of suspended house dust, dermal exposure from direct contact with surfaces, and activities leading to non-dietary ingestion (e.g., hand-to-mouth or object-to-mouth activity). The effectiveness of home cleaning practices may inversely correlate with exposure levels.

Particles deposited on flat surfaces are of specific interest. Experience has suggested that the maximum concentrations ( $\mu\text{g-contaminant/g-medium}$ ) for dust generated outdoors and deposited indoors are found on the window sill and near entrances. However, the best locations for correlating dust levels and exposure are surfaces (e.g., rugs, furniture) that are commonly available for contact by an adult or child. These would include the family or living room floor or a bedroom/living room surface, where the highest frequency and size of contact are likely to occur.

As previously indicated there is some emerging evidence about the toxicity and occurrence of pesticides in house dust. Pesticides are commonly used in residential environments to control many types of insects, a common one being fleas. The number of people exposed and the magnitude of exposure to pesticides is not well understood despite their widespread use. Likewise, pesticide contaminated food eaten in the home have not been adequately examined.

As a compliment to indoor and outdoor PM samples collected for BaP and other PAHs, house dust provides a measure of the magnitude of BaP in this medium. House dust can be a significant medium, leading to exposure via ingestion in children. Similarly to metals, house dust can be resuspended into the air, leading to inhalation exposure. The sampling strategy will be the same as for metals described earlier.

### 3.5.2.5 Summary (All Routes)

For particles, depending on the contaminants of interest, a large number of environmental media may need to be sampled. For instance, Pb and As have important pathways, including air, tap water (if the plumbing uses lead solder), house dust, and food.

PAHs and pesticides have important pathways in air and food. PAHs can also exist in both particle and vapor phases, depending on the constituent. Therefore, both air and food must be sampled for PAHs in both phases and analyzed for the PAHs, as well as for the broader suite of SVOCs, including some pesticides. Water is probably not of interest for these chemicals.

For carbonyls, the air route is sufficient; for VOCs, air and drinking water measurements are sufficient. Regarding food, although interesting data on accumulation of VOCs by oily foods (e.g., potato chips) exist, it appears at this time that the food would be a heavy additional cost with little to add in the way of significant exposures for most VOCs.

### **3.5.3 Base Sampling for Biomonitoring**

#### **3.5.3.1 Sample Types and Pollutants**

Parallel collection of biological media bridge the gap between exposure and dose. If exposure measurements happen to miss media of importance, biological sampling can indicate this. A good example is the discovery that smoking was the major source of exposure to benzene and styrene; the factor of 5–10 observed in breath values was decisive, whereas the 50% increase observed in the personal air values (due to side stream smoke) greatly underestimate actual exposure. Because of the great contribution of active smoking to exposure to many VOCs (including benzene, styrene, and 1,3-butadiene), breath analysis is the only way to determine these exposures (the personal monitor does not sample mainstream smoke). Because some pregnant women smoke, only biological measurements can determine the exposure of the fetus.

Blood, urine, and possibly hair are likely media for sampling metals, PAHs, and pesticides or their metabolic products. A cost-effective alternative for an initial screening of exposure to metals, pesticides, and possible PAHs might be to measure only one or two biological media, selected from blood, urine, and hair. Depending on the results, it might then be possible to identify a sharply reduced list of target contaminants for sampling in a somewhat reduced set of relevant environmental media.

The potential for adverse health effects from environmental contaminants is most directly associated with biological effective dose (BED) to sensitive target organs because this is the most relevant parameter for evaluating dose-response relationships. One goal of exposure assessment is to make accurate inferences of BED from measurements of environmental and exposure media, via modeling. However, it is often not possible or practical to measure the active toxin at the target site. Nonetheless, it is possible in many cases to quantitate the presence of a contaminant in human tissue (i.e., a biological marker of internal dose). This provides the next step toward BED with which to evaluate measurements of external dose (Needham et al., 1992).

Although the biological marker is preferable, it is not always possible or practical for the larger populations needed for epidemiological studies or for risk assessments. We plan to use biological marker measurements to validate the external exposure data. This presupposes sufficient toxicological information (e.g., physiologically based pharmacokinetic [PBPK]) on the mechanism of action and fate. For example, it is imperative that metabolic interferences, which may occur, be identified and that the analytical technique has known sensitivity and specificity. Likewise, the biological (and sample) lifetimes must be sufficiently long (or known) to allow for quantification.

Arsenic is measured in a urine samples taken as first-morning voids. The biological half-life of As in urine after exposure is 1 to 2 days. When exposure is only to inorganic As, the excreted forms are principally the uncharged inorganic As plus methylated species (Buchet et al., 1981). However, organoarsenicals may be found in some marine fish or shellfish at high

concentrations, and they are rapidly excreted without substantial transformation (Hindmarsh and McCurdy, 1986). Therefore, measurement data as total As may be highly influenced by diet.

Hair is an easily accessible biological material for detecting As and mercury (Hg) because these elements are accumulated over the growth period and hair provides better indices of chronic exposure than urine. Because both elements are covalently bound to sulfhydryl groups in hair proteins, they biomagnify.

### **3.5.3.2 Monitoring Time Frame**

Because of the differing residential half-lives of VOCs, metals, and pesticides in the body, it is difficult to arrive at an optimal monitoring time. For example, the half-life of Pb in blood may be several weeks, but it may be several years in bone. The desirable approach in biological monitoring would be to measure a baseline level, and then measure the change in that level due to exposure during the environmental monitoring period. However, this is seldom possible, unless a single contaminant, or possibly a group of contaminants, is the target. This is one of the main arguments for the hopscotch design, focusing on one contaminant group each year over a 3- or 4-year cycle.

For VOCs, the monitoring time frame could be 1 to 3 days, with a breath sample collected at the end of the monitoring period. (There would be no need for a breath sample at the beginning of the period because the influence of the levels at the initial time would be nearly completely washed out after 24–72 hours.) Integration times approach a week would be of interest, but there is a possible problem with a decline in the quality of the data for the personal monitors as the study progresses and participants forget or choose not to wear the badge on certain days or to certain occasions. The shorter time period can actually contribute to determining weekend–weekday differences, although previous studies have not shown a large effect.

### **3.5.3.3 Hopscotch Design**

Establishing trends in exposures to determine the effects of environmental regulations and emerging or unsuspected environmental exposure problems requires conducting comparable exposure monitoring programs periodically. Repeat measures for the same participant could be made over short (e.g., between seasons) or long (years) periods. A 5-year rotation design is the approach used in DESIGN II to develop a database that allows for an investigation of long-term trends and emerging problems. Five year or longer replication periods also provide the strongest basis for supporting outcomes with potentially long latency periods such as many cancers. The full cycle is shown as follows:

The study design for each year (see Table 3-8) would be optimized for the chemical class scheduled for monitoring. For each year's study, the known information about potential for exposure (e.g., sales or use of the chemical of interest and toxic releases) to chemicals of interest is used to ensure that the study includes individuals who are likely to experience high exposures relative to the rest of the population. A subset of the cohort (100 of the 400) will be sampled in a different seasons to provide short-term trend information. Those participants who can be retained across years allow the most robust assessments, with a planned repeat of Years 1 to 4 beginning in Year 5.

The order of contaminants by year is electable by Delaware; however, those identified in the proposed Year 1 plan would follow immediately and bolster the data collected in DESIGN I, as well as take advantage of the method testing in DESIGN I just for these categories.

### 3.6 Prioritization for Sample Collections, Archival, and Analyses

After defining the hypotheses for each objective, the core and optional archival percentage suite of potential analytes, and the sample size needed to test the hypotheses, all elements must be combined into the integrated plan for that objective, and associated costing then defined.

However, the resource restraint typically requires that an intervening determination of the level of *importance* (short- and long-term) for each sample and analyte be defined to guide field implementation and funding options. Priority importance is established based on straightforward technical requirements to create a linkage between cause and effect in an epidemiological sense, combined with the overarching policy importance placed on these aspects by Delaware. A preliminary prioritization plan is suggested here that attempts to broadly categorize each sample and analyte across objectives and to simplify the cost-estimation framework. This approach provides Delaware the greatest clarity and flexibility in defining essential versus optional sampling and analyses choices and optimize the application of available funding now and in the future.

A key distinction between sampling and analyses costs is the aspect of *opportunity*. The substantial combined costs of planning and implementing the field efforts diminishes the impact of including additional metrics to the sample suite, as long as the added burdens to the residents and/or sampling teams are manageable. Sample metric types that provide reasonable archival flexibility provide a range of post-analyses options that allow for the utilization of available funds in either the short term or long term (e.g., now versus delaying till the next funding cycle). Not taking advantage of sample collection options when the opportunities exist could result in lost opportunities that can only be rectified with the significant cost increments of additional field deployments. Note that an option to simply collect additional duplicate substrates and archiving some of these duplicates to provide the greatest range of analytical possibilities in subsequent years may be useful.

A straightforward approach from the outset is defining *core standard* and *optional level* sampling and analysis suites for each objective that most clearly address evaluating hypotheses. Sampling examples might be: 1) the core PM<sub>2.5</sub> sample collection would be a single Teflo filter that can be readily analyzed for a wide array of analytes or 2) separately collecting both particle- and vapor-phase PAHs or SVOCs, instead of just a single phase. One or more option-level PM<sub>2.5</sub> sample collections might include alternate substrates, such as pre-fired quartz or polycarbonate materials, or more simply, duplicate samples planned for as-yet-undefined characterization at a later date. Comparable core versus option-level analysis examples might be: 1) analyzing for total arsenic as the core metric and selected As ions as the option levels to better understand relative toxicity impacts, and 2) including supplemental (sampling and) inductively coupled plasma atomic emission spectroscopy (ICP-AES) analyses of selected elements to improve minimum detection levels over X-ray fluorescence (XRF) for key constituents—or simply going well-beyond the standard XRF suite normally defined by routine analyses.

### **3.7 Incentive Structure**

The DESIGN II participant/residence incentive for total participation at all levels will vary by year, depending on the level of burden imposed on the participants. Year 1 is likely the most burdensome year, and the incentive level is expected to be at least \$250 per person per year, and \$500 per year for those being sampled for 2 seasons. Thus, the total incentive cost is then likely to be a substantial element of the total costing at ~\$100,000 for 400 participants. Given recent RTI experience in relatively high burden, general population studies, the incentive structure should provide for less than the full incentive for less than full participation and/or for violation of specific protocol compliance rules.

## **4. Media Sampling and Methods**

### **4.1 Core DESIGN II Environmental Exposure Samples**

A brief description of the sampling and analysis methods for ambient, residential and personal air, drinking water, house dust, and food will be presented for key contaminant categories, along with the suggested methods.

One criterion for qualifying a candidate measurement method for use in DESIGN II is its sensitivity for the contaminants of interest. Method sensitivity for each medium was compared to the previously reported occurrence data for the target contaminants. A method must have adequate sensitivity to ensure that measurable data will be obtained for at least the 25<sup>th</sup> percentile level, even though our primary interest is on the high end of the exposure distribution. Other performance criteria, including minimum detection levels for the proposed methods are shown in Table A-1 for indoor and outdoor air sampling.

The importance of arsenic and arsenic compounds in Delaware is very clear in many of the Delaware-specific references cited for both multi-media exposure (and biospecimen) samples. Full arsenic speciation is planned for a subset of these collected samples to include As, As(III), As(V), monomethylarsonic acid, and dimethylarsinic acid in environmental media, plus arsenobetaine and arsenocholine in biospecimens. Other key toxic metals (speciated Hg and Ni) are also included.

#### **4.1.1 Personal, Indoor, and Outdoor Air**

The air exposure route for each contaminant will be monitored using personal samplers and stationary samplers inside and outside 25% of the home. Personal samplers will be both active (using a pump) or passive (relying on diffusion for the collection substrate) (Pellizzari et al., 1995). The collection of air samples will apply a range of measurement technologies that must be in some manner be referencable to standard procedures. This will be accomplished and described more fully in the workplan discussions by selecting methods that meet acceptable performance requirements and conducting limited collocated testing to demonstrate comparability. This approach has always been considered in RTI research studies conducted for EPA. A very recent paper by Chow and Watson (2008) also fully supports this approach. Utilizing a range of sampler types for the same collections also provides the opportunity to collect parallel samples in more cost effective manners.

PM sample collection instrumentation should meet several basic criteria. Most importantly, the instrument must provide sufficient analyte mass to exceed the minimum

detection limit of the chosen analytical method. In addition, the instrument must be able to collect a sufficient air volume during the sample collection interval so that sufficient mass is deposited. The sample collection media must also be conducive to the analytical method. When performing residential sampling, the instruments should be small, quiet, and (preferably) battery powered to reduce the burden on residents.

The PM instrumentation characteristics suggested for both DESIGN I and DESIGN II must fully consider the data quality necessary to prove the hypotheses. Residential outdoor, indoor, and personal samples should provide PM<sub>2.5</sub> and PM<sub>10</sub> concentrations with minimal burden to the study participants. The low-burden, low-flow samplers should be collocated with EPA Federal Reference Method (FRM) samplers at a DNREC central monitoring site to provide a comparison with a standard method in case a bias in the data needs to be corrected. RTI will not be providing any FRM samplers for this effort. Duplicate samplers for each size fraction are needed for Teflon media (e.g., mass, optically-determined black carbon [BC], environmental tobacco smoke [ETS] by the method of Lawless et al. [2004], SVOCs) and quartz media (elemental carbon/organic carbon [EC/OC], organic PM).

#### **4.1.1.1 Metals and PM Mass**

Personal, indoor, and outdoor air samples are collected over a 24-hour period to measure inhalation exposure to mass and metals (Pellizzari et al., 1993, 1995). Collecting aerosols will be accomplished using active pumping with single-stage impactor inlets that size the particle range into PM<sub>10</sub> and PM<sub>2.5</sub> fractions. These particle size ranges are of interest because they represent those aerosols that are inspirable and inhalable. Personal samples will employ only PM<sub>10</sub> collection, whereas both PM<sub>10</sub> and PM<sub>2.5</sub> will be collected inside and outside for 25% of the homes. The ability to compare data from this monitoring effort with existing PM<sub>10</sub> databases (e.g., 24-hour average ambient air National Ambient Air Quality Standards and Particle Total Exposure Assessment Methodology data) will be important to assess whether Delaware residents have excess health risks relative to other U.S. populations.

A new-technology, RTI's MicroPEM battery-operated personal sampling system (the pump, flow controller, pressure sensing cell, thermistor, motion sensor, interval timer, data system, battery pack, and aerosol inlet), will be used to collect aerosols at 2.0 lpm through either a PM<sub>2.5</sub> or PM<sub>10</sub> size selective inlet with a 25-mm OD, 3  $\mu$ m porosity Teflon filters. The inlets collect the total sized aerosol fraction up to 10  $\mu$ m. The mass collected is computed to provide a minimum detection limit of 1  $\mu$ g/m<sup>3</sup> using a 7-place analytical balance with a resolution of 0.1  $\mu$ g. Filter samples are pre- and post-weighed to determine aerosol mass (Pellizzari et al., 1995).

#### **4.1.1.2 VOCs**

A personal sample is collected over a period of approximately 72 hours with a 3M model 3520 two-stage passive charcoal badge to measure VOC exposure. These badges provide acceptable accuracy, pose a minor subject burden, reduce data collection costs, and provide for flexible study designs (Pellizzari et al., 1995; Otson, 1990). If contaminant measurement methods have poor detection limits, relative to expected levels, a substantial undefined set of non-quantifiable values will be acquired. The performance of the passive badges over 3-day periods (compared to more typical 24-hour samples) has been previously validated, and this length of sampling will have sufficient sensitivity (Otson, 1990). A second badge is used for participants that have jobs to assess the contribution of occupational exposure to the total

exposure to selected VOCs. Occupational exposure is measured by difference; one badge is covered during working hours. Badges are also deployed inside (main living area) and outside for 25% of the homes to determine the contribution of these locations to exposure (Pellizzari et al., 1995). The analysis procedures (Pellizzari et al., 1995) are summarized in Table 5-8.

#### **4.1.1.3 Pesticides, PCBs, PBDEs, and PAHs**

A personal sample will be collected for selected pesticides, PCBs, and PAHs in air to assess exposure through the inhalation pathway (Sheldon, 1992; Sheldon et al., 1993). All contaminants will be collected on, and analyzed from, the same filter. A battery-operated pump will be used to pull air through a cartridge with a quartz fiber filter and bed of XAD-2 resin at 1 or 2 L/min. Pesticide and PAH samples will be collected inside and outside of the participant's home to assess sources of exposure. Samples will be shipped cold and stored at -20°C. Filters and the XAD-2 sorbent will be extracted with solvents. Extracts will be analyzed by using gas chromatography/mass spectrometry/secondary ion mass spectroscopy (GC/MS/SIMS). Collection and analysis protocols have been described in detail as outlined by Pellizzari and colleagues (1993).

#### **4.1.2 Drinking Water**

##### **4.1.2.1 VOCs**

Drinking water samples are collected from the primary drinking water source (Pellizzari et al., 1995). This is collected either from a flushed home piping system, when tap water is the source of drinking water, or from any other source such as bottled water. This sample assesses the contribution to exposure that results from the drinking water and permits inferring dermal and inhalation exposures from bathing and showering. Samples for VOCs are collected in 40 mL glass vials with acid preservative and ascorbic acid to quench residual chlorine. All samples are refrigerated in the field and shipped cold to the analysis laboratory. Table 5-8 summarizes the analysis procedures used by Pellizzari and colleagues (1995).

##### **4.1.2.2 Metals (Standing or Tap Water Flushed)**

Water samples are collected from the kitchen tap after water has been run through the pipes for 3 minutes (Pellizzari et al., 1995). This sample assesses potential contamination with metals from the water source or supply. Often, where tap water is also the primary drinking water source, the flushed sample is also used to assess exposure via the ingestion route. A sample is collected in a 250-mL polyethylene container. Samples are acidified upon receipt at the analysis laboratory. Metals analyses (Pellizzari et al., 1995) are accomplished as summarized in Table 5-8. Water samples for standing water are collected from the kitchen tap by the participant after the water in the pipes in the home has remained undisturbed for at least 4 hours (Pellizzari et al., 1995). Water is collected once in a 250-mL polyethylene container. Samples are refrigerated and shipped cold to the analysis laboratory, and they are acidified upon receipt at the laboratory. Metals analysis procedures (Pellizzari et al., 1995) are summarized in Table 5-8.

##### **4.1.2.3 Food**

Dietary samples are collected during 3 consecutive days using duplicate diet methodology (Pellizzari et al., 1995; Thomas et al., 1993a, 1993b). This method requires

participants to prepare or obtain and store duplicate portions of all foods and beverages they consume during the specified period. Drinking water is included in the dietary collection so that dietary ingestion of the target analytes from all sources is measured. Participants collect separate solid food and beverage samples in polyethylene containers. The solid foods and beverages collected for metals analyses during each of the four 1-day collection periods are refrigerated and shipped cold to the analytical laboratory, where they will be combined and homogenized. Beverage samples are also combined and homogenized. This method requires that participants prepare or obtain duplicate portions of all foods and beverages they consume during the specified period. Drinking water is included in the dietary collection so that dietary ingestion of the target analytes from all sources can be measured. Participants will collect separate solid food and beverage samples in polyethylene (metals) or glass (pesticides/PAHs) containers. Solid foods and beverages will be collected separately to reduce sample handling problems and to reduce analyte dilution effects. The solid foods and beverages collected for metals analysis during each of the three 1-day collection periods will be refrigerated and shipped cold to the analytical laboratory, where they will be combined and homogenized. Beverage samples will also be combined and homogenized.

#### **4.1.3 House Dust**

Dust samples will be collected from participants' vacuum cleaner bag samples. This collection is recognized not as a true exposure metric, but only a surrogate to indicate the levels of indoor contamination for each participant and study contaminant. Tracked-in soil comprises the major component by mass for house dust. Soil concentration levels by themselves are not useful exposure metrics, but they can provide indications as to where contaminants are originating for subsequent mitigation planning. Delaware-specific data does suggest that agricultural (Sparks et al., 2006), but perhaps not residential, soils may provide significant levels of contaminants such as As to the environment through multiple pathways. Representative backyard soil samples will be collected from each sampled residence for archival (only). If excessively elevated contaminant levels are apparent from the vacuum cleaner dust samples, the companion soil samples could then be analyzed for confirmation purposes.

## **4.2 Biomonitoring**

A reasonable biospecimen collection plan would be a single blood draw and hair sample at the completion of the sampling period for each participant, plus a first-void urine sample at both the beginning and the end of the sampling. This places minimal burden on the study participants and additionally minimizes the incentive costs.

### **4.2.1 Metals, Pesticides, PAHs, PBDEs, PFOAs, and PCBs in Blood**

Venous blood samples are collected by venipuncture by a local health care worker or project phlebotomist at one time using specially prepared Vacutainers (Pellizzari et al., 1995). Whole blood is collected in Vacutainers for metals (Year 2) and PCBs and pesticides (Years 3 and 4). Whole blood samples are refrigerated and shipped cold. The serum is centrifuged and frozen in glass bottles, and then the samples are returned frozen for analysis. Procedures (Pellizzari et al., 1995) are provided in Table 5-8.

#### **4.2.2 Metals, Non-Persistent Pesticides, and PAH Metabolites in Urine**

Urine samples for metals (Year 2) and PAH (Years 3 and 4) analyses are collected during the monitoring period (Pellizzari et al., 1995). Morning void urine samples are collected, and participants store the samples in their freezers or in coolers provided by the field staff. Samples are shipped frozen and analyzed (Pellizzari et al., 1995).

#### **4.2.3 Metals in Hair**

Because of the potential usefulness of hair to assess body burden to metals (e.g., As and mercury [Hg]) and the low burden of collection, hair samples will be collected and archived for future analysis (Pellizzari et al., 1995). Hair samples are simple to collect and can provide confirming dose data for metals, but can also be confounded, i.e., by constituents in hair care products. Hair analyses will only be completed to confirm high doses in other biomedica.

### **4.3 Ancillary Data**

#### **4.3.1 Questionnaires**

Questionnaire data will still be necessary; DESIGN II would have multiple questionnaires in addition to the time-activity diary. These questionnaires (i.e., personal, household, nearby source, and daily followup) would be modified for each target year to address the key sample types. Meteorological data, air exchange, and house volume measurements will be collected.

The most important ancillary data to be collected include data on household characteristics (e.g., heating type, ventilation habits) and personal activities (e.g., smoking, driving, visits to dry cleaners, hobbies, special diets). This is normally collected through the use of a set of questionnaires administered face to face by a technician. One questionnaire focuses on the fixed (unchanging) household characteristics, and the second questionnaire focuses on recalling events and activities during the monitoring period. Alternatively, the second (recall) questionnaire can be replaced by a diary or log that is kept by the participant, but this places extra burden on the respondents. It will be very important to review and update all questionnaires jointly with DNREC/DHSS to provide a consensus set of questions that most closely reflects lifestyles and daily activities in Delaware without overburdening the participant with excessive information requests. These joint questionnaire review activities are proposed as part of the pilot activities to be conducted at the outset of each study year.

#### **4.3.2 Meteorology**

The parallel collection of basic meteorological parameters—primarily wind speed, wind direction, temperature, and relative humidity—provide valuable supporting data to assist in explaining spatial and temporal variabilities. Micro-level meteorology will collect 10-m tower data at selected Delaware locations in selected counties and CCDs to assist in defining regional background contributions for contaminants entering Delaware from other states and regions. The micro-level meteorology can be compared with airport and DNREC monitoring locations to estimate spatial contaminant concentration difference influenced by meteorology.

### **4.3.3 Residence Air Exchange Rate**

An important ancillary measurement for particles and for reactive gases includes the AER of the home. Only in this way can the impact of outdoor air on indoor air be determined. For example, a tight house with no indoor sources of particles ( $AER = 0.2 \text{ h}^{-1}$ ) would be expected to have only approximately 25% of the outdoor  $PM_{10}$  concentration, whereas a house with higher ventilation (say  $1 \text{ h}^{-1}$ ) would have more than 60% of the outdoor concentration. If we restrict our attention to nonreactive gases, such as benzene, the need for AERs is lessened because we can assume that indoor levels due to outdoor sources will be approximately 100% of the outdoor levels. However, because the methodology for AER measurements is well developed and the cost is low, such measurements are recommended for any studies that involve particles or metals. The volume of the home must be measured or estimated in conjunction with the air exchange measurements.

Five questionnaire instruments will be used, but they must be tailored to be multimedia and multiroute, as well as specific to any Delaware scenarios. The questionnaires are descriptive because they enumerate individuals within a household, identify general characteristics of the living quarters and occupants, and provide a basis for assessing potential bias due to refusals in subsequent steps. The questionnaires are also baseline because they provide more detailed information on the characteristics of the sample individuals and housing and on the usual frequency of activities over a longer period (i.e., last month or year). They are designed to provide information on activities during the sampling period to explain variation in the sample (or differences between sub-groups) for the monitoring results. The time/activity diary characterizes the frequency and duration of specific activities and use of micro-environmental compartments during the period in which environmental and personal sampling takes place. The dietary intake diary captures a simple listing of the foods eaten during environmental and biological contaminant measurements.

A few meteorology measurements, generally at local airports, have been found to be useful in the past. These include wind direction and speed, mixing height, and dew point, with the 3-hour averages generally sufficient. Socioeconomic data is normally obtained from the census and other sources as part of the sample design.

## **4.4 Archival**

Some proportions of both environmental and biospecimen samples are proposed to be archived after collections to minimize the immediate cost impacts from the associated analyses and provide a wide time window to secure funding if necessary. This pre-supposes that samples and/or their extracts can reasonably be archived with minimal loss of data quality. Preliminary assessments of the archival options have been made to support the suggested plan in Tables 1-1 and 1-2, but a detailed assessment in the subsequent workplan must be made to fully cross-walk the archival planning with the impacts on the data quality and the QAPP. Extended archival is not desirable in any case, considering the long-term costs.

## **5. Quality Assurance**

The level of data quality required to support the objectives and hypotheses for DESIGN II is high to support a fully defensible effort. The strong statistical basis for the effort demands that the quality of all metrics be known and incorporated into all data summaries and data

analyses. Achieving the necessary level of defensibility for the databases and findings requires that DQOs for each metric be established and subsequent quality monitoring conducted to assure that these DQOs are adequately attained. The DESIGN II plan provides only benchmark DQOs (e.g., see suggested method performance data for analytes in the appendices) to assist in defining the expected comprehensiveness of the plan and to assist in providing cost estimates.

The full quality assurance/quality control (QA/QC) plan would be defined in the Quality Assurance Project Plan (QAPP), which would be prepared as part of the subsequent detailed workplan that defines how DESIGN II would be implemented.

The total percentage of the budget affected by QA/QC considerations in defining a fully defensible database is roughly expected to be as much as 15–20%.

## **5.1 Data Quality Objectives**

Because of the extraordinary difficulty in making environmental measurements and because most of these methods are state-of-the-art rather than standard off-the-shelf, it is necessary to pay much more attention to QA/QC considerations than in more established monitoring programs. These include use of deuterated controls to determine recoveries unambiguously, laboratory and field blanks to determine where contamination (if any) occurs, laboratory and field controls, internal and external standards, flow controls, traceable to National Institute of Standards and Technology, chain-of-custody procedures, a written set of SOPs, computerized checks on data entry, 100% rechecking of some data entry forms, careful analysis of outliers before validating data, and many other daily procedures and checks. Fortunately, much of this work has been performed in preparation for the NHEXAS program. However, it's important to recognize that QA/QC sample and analyses will be a substantial portion of the program's cost.

## **6. Database Development and Analyses**

Year 0 (the year before starting DESIGN II) will entail the design of a database and the development of data management procedures. The system will be used to direct the field work, including QA/QC activities, by developing an information shell that identifies all data items to be obtained and the schedule for their collection, shipping, weighing, chemical analyses, etc. Thus, the system would be used to monitor the status of each item (by tracking field and laboratory activities), as well as to receive, assemble, and process the data. Where practical, separate files will be maintained for the various types of data (e.g., for metals' concentrations in water, VOCs' concentrations in air, questionnaire items) because such data will come into the database at different times and from different sources (e.g., different laboratories). The final files will be maintained as PC SAS files that can be linked by the appropriate identifiers (e.g., environmental media, times, locations, sample IDs, participant IDs, household IDs), as needed for a particular type of data analysis. Data processing will include procedures for identifying data problems, such as incomplete items, internal and external inconsistencies, potential outliers, and duplicate records. Resolution of such problems, along with appropriate documentation, will also be a necessary component of the system.

After the field work begins and data become available, various types of routine data analyses will be performed at least annually. In addition, special-purpose analyses will

undoubtedly be necessary to address specific issues as they arise. The routine analyses can be classed as follows:

- (1) Preliminary and exploratory analyses
- (2) Development of sampling weights
- (3) Formal statistical analyses.

It should be noted that subsequent model-based analyses, aimed at extending inferences beyond the time frame and scope of the actual field effort (e.g., risk assessment type activities), are not considered a part of the Plan C activities.

## **6.1 Preliminary and Exploratory Analyses**

These analyses are performed first. They involve producing univariate and bivariate tabulations and/or plots of all data items (both questionnaire and direct physical measurements). One purpose is to ensure, to the extent possible, that the data are accurate and are as complete as possible. Peculiar patterns, unexplained missing values, potential outliers, and inconsistencies in the data are identified and reviewed for possible rectification. For the physical measurements, the percentage detected (i.e., percentage exceeding limits of detection) are determined, with the intent of eliminating those combinations of chemicals and media having low percentage detected from further analysis. The preliminary tabulations (e.g., histograms) of the physical measurements also serve to show general shapes of distributions that may suggest the desirability of making data transformations (e.g., taking logarithms) before performing other types of statistical analysis or modeling. The raw tabulations of questionnaire items serve to show those items that are of marginal (or no) use in subsequent statistical analyses and modeling efforts (e.g., if all or almost all participants or homes fall into a single response category) or items that need transformation to be of use (e.g., collapsing a multi-category item into one with only two or three levels).

Other preliminary analyses, which should be conducted periodically during the time of data collection, involve summarizing the QA/QC data. For instance, the summaries should allow an assessment of laboratory precision and of relative bias over the course of the data collection effort. To the extent possible, the design of the QA/QC program and of the data analyses should seek to identify the magnitude of various sources of error.

## **6.2 Adjustments to Sampling Weights**

DESIGN II involves using annual probability-based sampling of households and persons. In general, the selection probabilities will not be the same for all participants in the study or all households in the study. Consequently, the formal data analyses need to account for these unequal selection probabilities by assigning a person-level and/or household-level sampling weight to each observation. One step in the design of such sampling plans is the development of initial sampling weights. However, missing data will occur for various reasons and adjustments to the sampling weights (e.g., using weighting class non-response adjustments) must be made before conducting the formal analyses. These weights may also need to be adjusted to compensate for any overrepresentation of any particular season of the year (i.e., seasons are used to form weighting classes, forcing each to be equally represented).

### **6.3 Statistical Analyses**

These analyses include the estimation of the general target population's short-term exposure distributions and associated environmental (and biological) media concentration distributions; they also include estimation of similar distributions for relevant subpopulations. In particular, they involve generating pertinent descriptive statistics associated with the measured quantities, such as means, standard deviations, and selected percentiles. Such estimates are used to address the primary study hypotheses (e.g., to assess exposure and concentration differences among subpopulations, such as counties and urban/rural areas), as well as other hypotheses (e.g., to assess exposure differences for persons with different activities and/or with different potential indoor contaminant sources). Sampling weights are used in these data analyses so that the resultant estimates will apply to the survey population of person-3-days (or person-days) (if person-level sampling weights are used) or of household-3-days (or household-days) (if household-level sampling weights are used). In addition to producing the weighted estimates, it is important that the analysis yield valid estimates of the precision of the estimated quantities. Even though standard statistical software packages (e.g., SAS) can be used to generate the weighted estimates, the precision measures generated by such software do not properly account for the sampling design; to do so, other special-purpose software is needed. For example, the RTI-developed SURvey DATA Analysis (SUDAAN) software product designed for analysis of data from complex sample survey designs can be used to produce such estimates, along with their SEs (Shah et al., 1995).

Other analyses are used to examine associations of analyte levels (e.g., associations between exposure and biological markers, between exposure and environmental media measurements, or between two (or more) exposure pathways). These analyses may be useful for understanding the relative contributions of the various pathways, understanding the degree to which the pathways are dependent upon one another and understanding how alternate ways of measuring exposure-related quantities relate to one another (e.g., indoor air versus personal air). The first step in these analyses is to estimate correlations; both Spearman and Pearson correlations will be used, the latter being applied where necessary on a transformed (e.g., logarithmic) scale. Regression models may also be used as a part of this analysis. Both weighted and unweighted correlations and regressions are performed, as needed. These simple associations and regressions (and the previously described subpopulation comparisons) cannot be expected to provide a complete understanding of complex dose/exposure/concentration relationships; rather, these results are used to help guide any subsequent modeling efforts.

## **7. Exposure Modeling**

Exposure modeling from the collected DESIGN II data, specifically for Delaware scenarios, allows extrapolations to be made in many ways for many years.

### **7.1 Total Exposure Modeling**

The collection of multimedia, multiroute exposure data allows for the assessment of the contributions of each media/route to the total exposures. This will be robust for all routes except dermal, which can only be estimated for the dermal exposure route. Because only adults (those 18 years of age and older) are proposed for study, the dermal route in most cases is not expected to be a significant contributor for most contaminants. Narrowing the contributions by routes and Delaware CCDs allows for better comparisons across state geographic areas, as well as for

making exposure inferences that can be potentially more closely linked to adverse health hotspot outcomes. Of course, this is not necessarily the case for long latency period outcomes, such as cancer, unless historical longitudinal exposure data are available and information on the participant's residency during the past periods can be established.

## **7.2 Modeling Personal Exposures from Fixed-Location Measures**

Centralized location measures to allow the Delaware DNREC to estimate exposure levels for both air (and possibly water) provide cost-effective data, but only if the selected location can be modeled to truly represent the population's exposure distributions. Although distributional means and medians have proven to be predictable for some air PM components, the extremes of the distribution (most exposed and least exposed) cannot be assessed with data such as would be collected by the DESIGN II plan for Delaware. Spatial and temporal modeling to define the value of existing or proposed monitoring locations will allow DNREC to readily characterize site representativeness for various cohorts, both spatially and temporally (e.g., across seasons).

## **7.3 Database Development for Source Attribution Modeling**

Enabling targeted source signature chemistry at air (only) receptor (personal, indoor, residence outdoor, and ambient site locations) will provide the DESIGN II results to be robustly associated with key Delaware source categories (e.g., coal-fired power plants, gasoline and diesel-powered vehicles, refinery complexes, regional background). RTI will work with DNREC to apply the DESIGN II data to facilitate receptor modeling, but only limited modeling is proposed here. The collected data will be placed into database files that are very amenable to both CMB and PMF receptor modeling. RTI could certainly assist DNREC/DHSS in conducting comprehensive CMB or PMF modeling if requested to do so.

## **8. Reporting**

The wide range of reporting requirements to support this design will be made clear in the full study workplan. These requirements would be based on the needs of DNREC and DHHS. A critical component of the reporting would be the preparation of at least one peer-reviewed journal article submittal jointly with DNREC and/or DHHS key staff for publication. This would provide the peer review necessary for the plan and would document the exposure levels that can be then be cited back to the affected Delaware public

## **9. Proposed Research Project Structure**

### **9.1 Detailed Work Plan Preparation**

Before any study of this nature can be undertaken, it is necessary to carefully plan all of the details and to document these details so that high-quality data will be collected to meet the objectives of Delaware's program. This is accomplished by preparing a detailed workplan, which consists of three volumes: Volume 1 is the study design, Volume 2 contains all the field and laboratory protocols and SOPs, and Volume 3 is the QA/QC document.

### **9.2 DNREC and DHHS Potential Roles**

The potential roles for both DNREC and DHSS to support DESIGN II will be proposed in the initial workplan and agreed upon before the study. A key role would be "selling" the value

of the program to the public and assisting in the recruitment and retention efforts to maximize the strength of the probability-based selection. Another would be the documentation of the study (e.g., photography of participants, residences) for both scientific purposes and to describe the values of the effort as it proceeds—all pending participant consent to allow the documentation. During the post-collect/analysis data summary phase each year, personal data specific for each participant—especially levels that exceed important thresholds—should be summarized in a manner by DNREC/DHSS suitable to provide in a follow-up mailing or meeting. This aspect would be a valuable “selling point” to facilitate participant during the enrollment process.

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## **Attachments**

1. Delaware map showing counties, CCDs, cancer cluster data by CCD, and key features.
2. Delaware map of Sussex County, showing CCDs, cancer cluster data by CCD, and key features.
3. Detailed DESIGN II Environmental Analyte Listings and Associated Data Quality Targets for Indoor and Outdoor Air.

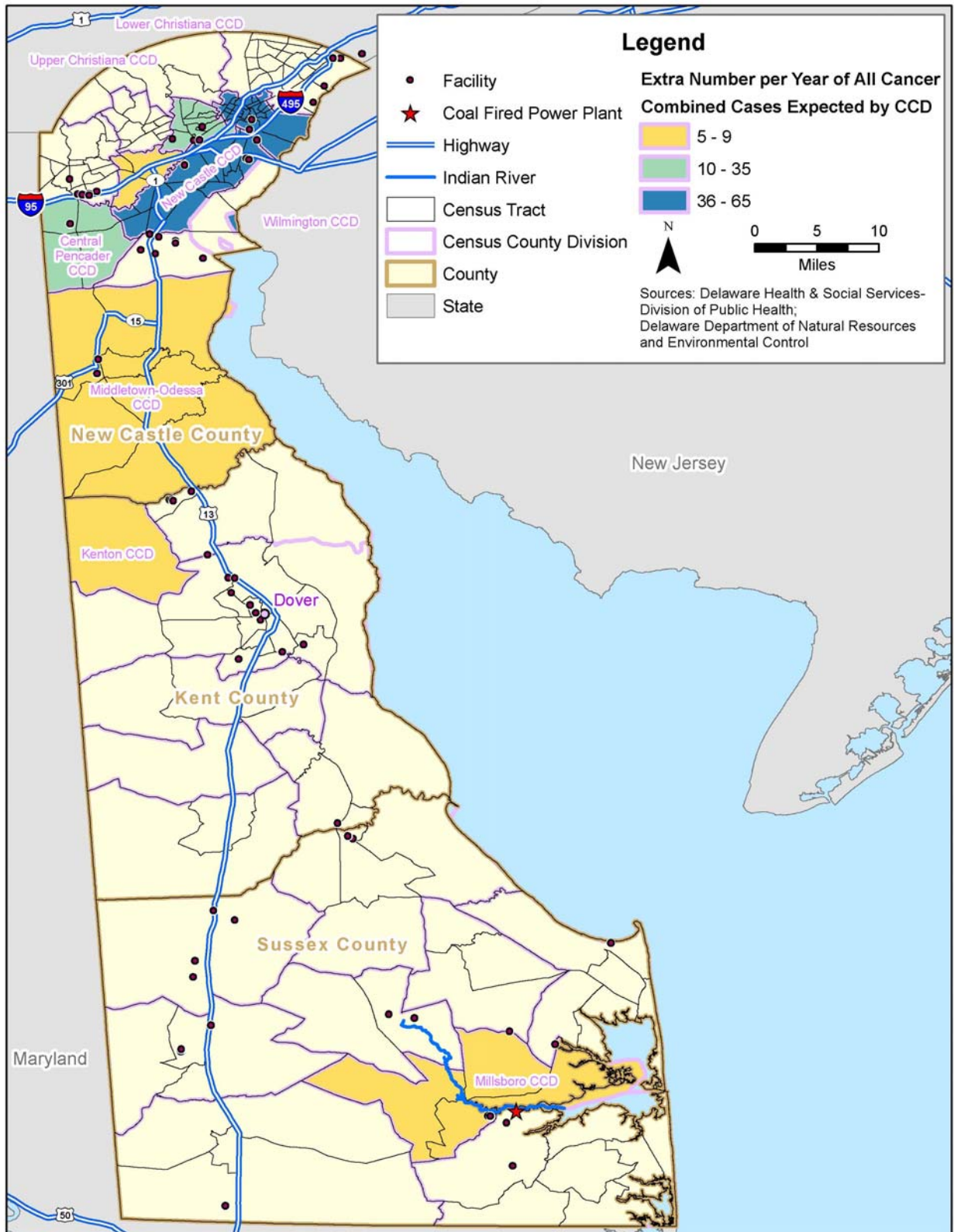


Figure A-1. Delaware map showing CCDs, cancer cluster data, and major contaminant sources.

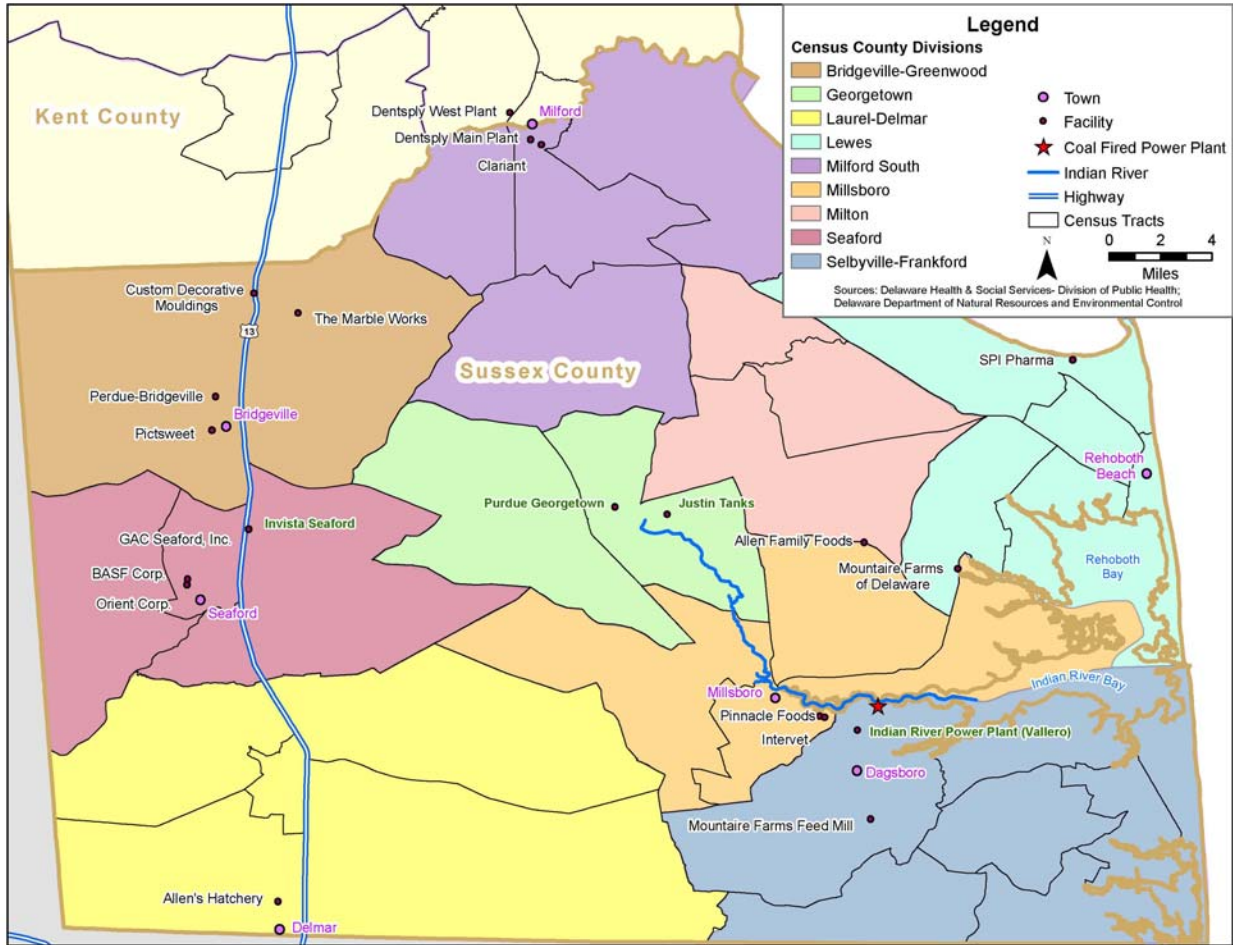


Figure A-2. Delaware map focusing on Sussex County, showing CCDs, cancer cluster data, and major contaminant sources.

Table A-1. Proposed Method DQO targets for DESIGN II

Analyte Class	Analyte	Analytical Method	MDL/MQL	Occurrence—Mean	Occurrence—Median	Occurrence—Maximum	Reference (Study)
Soot; diesel exhaust	PM <sub>2.5</sub>	Gravimetric	1.0/3.0 µg/m <sup>3</sup>				U.S. EPA, 2008a (DEARS)
	PM <sub>10</sub>	Gravimetric		31–42 µg/m <sup>3</sup>	38–31 µg/m <sup>3</sup>	260 µg/m <sup>3</sup>	U.S. EPA, 2008 (NHEXAS Arizona)
			1.0/3.0 µg/m <sup>3</sup>				U.S. EPA, 2008a (DEARS)
	PM <sub>coarse</sub>	Gravimetric					
	Elemental carbon	TOC/TOR	0.2/0.6 µg/m <sup>3</sup>				U.S. EPA, 2008a (DEARS)
	Organic carbon	TOC/TOR	0.2/0.6 µg/m <sup>3</sup>				U.S. EPA, 2008a (DEARS)
Minerals*	Silica	XRD	5 µg/sample				
	Asbestos	PCM	7 fibers/mm <sup>3</sup>				
Metals*	Arsenic, inorganic (+3 and +5), organic, selected organic As acid and oxides; arsenobetaine and arsenocholine (biospecimens only),	IC-ICP-MS	0.2 ng/m <sup>3</sup> (total)	0.67–0.83 ng/m <sup>3</sup>	0.50–0.69 ng/m <sup>3</sup>	7.2 ng/m <sup>3</sup>	U.S. EPA, 2008b (NHEXAS Region 5)
			0.036 ng/m <sup>3</sup> (total)	0.88–1.1 ng/m <sup>3</sup>			DNREC, 2005
	Beryllium	ICP-MS	0.002 ng/m <sup>3</sup>	0.008–0.017 ng/m <sup>3</sup>			DNREC, 2005
	Cadmium	ICP-MS	0.9 ng/m <sup>3</sup>	1.2 ng/m <sup>3</sup>	0.53 ng/m <sup>3</sup>	31 ng/m <sup>3</sup>	U.S. EPA, 2008b (NHEXAS)
			0.024 ng/m <sup>3</sup>	0.20–0.28 ng/m <sup>3</sup>			DNREC, 2005
	Lead	ICP-MS	7.6–9.4 ng/m <sup>3</sup>	13–15 ng/m <sup>3</sup>	5.8–8.1 ng/m <sup>3</sup>	290 ng/m <sup>3</sup>	U.S. EPA, 2008b (NHEXAS Region 5)
			0.073 ng/m <sup>3</sup>	3.4–8 ng/m <sup>3</sup>			DNREC, 2005
	Manganese	ICP-MS	46 ng/m <sup>3</sup>	66–83 ng/m <sup>3</sup>	64–65 ng/m <sup>3</sup>	219 ng/m <sup>3</sup>	U.S. EPA, 2008 (NHEXAS Arizona)
			0.049 ng/m <sup>3</sup>	4.6–18 ng/m <sup>3</sup>			DNREC, 2005
	Mercury	CVAA					
Nickel, total	ICP-MS	540 ng/m <sup>3</sup>				U.S. EPA, 2008 (NHEXAS Arizona)	
		0.073 ng/m <sup>3</sup>	2.1–6.9 ng/m <sup>3</sup>			DNREC, 2005	

Analyte Class	Analyte	Analytical Method	MDL/MQL	Occurrence— Mean	Occurrence— Median	Occurrence— Maximum	Reference (Study)
Metals* (continued)	Selenium	ICP-MS	309 ng/m <sup>3</sup>	520–690 ng/m <sup>3</sup>	490–550 ng/m <sup>3</sup>	1,500 ng/m <sup>3</sup>	U.S. EPA, 2008 (NHEXAS Arizona)
	Chromium (VI)	IC	25–27 ng/m <sup>3</sup> (total)	9.1–18 ng/m <sup>3</sup>	3.3–4.0 ng/m <sup>3</sup>	1,700 ng/m <sup>3</sup>	U.S. EPA, 2008b (NHEXAS Region 5)
			0.049 ng/m <sup>3</sup> (total)	1.7–3.8 ng/m <sup>3</sup>			DNREC, 2005
PAHs*	EPA priority PAHs	GC-MS	0.02/0.06 ng/m <sup>3</sup>				U.S. EPA, 2008a (DEARS)
			0.3 ng/m <sup>3</sup>	ND–30 ng/m <sup>3</sup>			DNREC, 2005
			0.01–0.04 ng/m <sup>3</sup>	.03–400 ng/m <sup>3</sup>		1,200 ng/m <sup>3</sup>	Wilson et al., 2003
Carbonyls	Formaldehyde	HPLC	6.0/18.0 µg/m <sup>3</sup>				U.S. EPA, 2008a (DEARS)
			0.0002 µg/m <sup>3</sup>	0.0043 - 0.0051 µg/m <sup>3</sup>			DNREC, 2005
	Acetaldehyde	HPLC	5.0/15.0 µg/m <sup>3</sup>				U.S. EPA, 2008a (DEARS)
			0.0001 µg/m <sup>3</sup>	0.0013 - 0.0013 µg/m <sup>3</sup>			DNREC, 2005
Acrolein	HPLC	0.5/1.5 µg/m <sup>3</sup>				U.S. EPA, 2008a (DEARS)	
Volatile organic compounds	Benzene	GC-MS	0.04 µg/m <sup>3</sup>	5.1 µg/m <sup>3</sup>	2.8 µg/m <sup>3</sup>	119 µg/m <sup>3</sup>	NCHS, 2007 (NHANES)
			0.73–0.91 ng/m <sup>3</sup>	3.7–7.7 ng/m <sup>3</sup>	2.9–4.7 ng/m <sup>3</sup>	156 µg/m <sup>3</sup>	U.S. EPA, 2008b (NHEXAS Region 5)
			99 pptv				U.S. EPA, 2008a (DEARS)
	1,3-butadiene	GC-MS	0.035 µg/m <sup>3</sup>	0.46–1.37 µg/m <sup>3</sup>			DNREC, 2005
			0.4 µg/m <sup>3</sup>				U.S. EPA, 2008 (NHEXAS Arizona)
			234 pptv				U.S. EPA, 2008a (DEARS)
			0.12 µg/m <sup>3</sup>	0.04–0.30 µg/m <sup>3</sup>			DNREC, 2005
	Isoprene	GC-MS					
	Vinyl chloride	GC-MS					
			0.067 µg/m <sup>3</sup>	0.02–0.22 µg/m <sup>3</sup>			DNREC, 2005
Bromodichloromethane	GC-MS						
Chloroform	GC-MS	0.011 µg/m <sup>3</sup>	2.7 µg/m <sup>3</sup>	1.1 µg/m <sup>3</sup>	54 µg/m <sup>3</sup>	NCHS, 2007 (NHANES)	

Analyte Class	Analyte	Analytical Method	MDL/MQL	Occurrence— Mean	Occurrence— Median	Occurrence— Maximum	Reference (Study)
Volatile organic compounds (continued)			1.1 $\mu\text{g}/\text{m}^3$	1.5–2.6 $\mu\text{g}/\text{m}^3$	0.86–1.6 $\mu\text{g}/\text{m}^3$	31 $\mu\text{g}/\text{m}^3$	U.S. EPA, 2008b (NHEXAS Region 5)
			0.13 $\mu\text{g}/\text{m}^3$	0.08–0.13 $\mu\text{g}/\text{m}^3$			DNREC, 2005
	Carbon tetrachloride	GC-MS	0.74 $\mu\text{g}/\text{m}^3$	1.0–1.1 $\mu\text{g}/\text{m}^3$	0.78–1.2 $\mu\text{g}/\text{m}^3$	1.75 $\mu\text{g}/\text{m}^3$	U.S. EPA, 2008 (NHEXAS Arizona)
			252 pptv				U.S. EPA, 2008a (DEARS)
			0.30 $\mu\text{g}/\text{m}^3$	0.54–0.56 $\mu\text{g}/\text{m}^3$			DNREC, 2005
	1,2-dibromoethane	GC-MS					
			0.17 $\mu\text{g}/\text{m}^3$	ND–0.01 $\mu\text{g}/\text{m}^3$			DNREC, 2005
	1,4-dichlorobenzene	GC-MS	0.02 $\mu\text{g}/\text{m}^3$	46 $\mu\text{g}/\text{m}^3$	2.2 $\mu\text{g}/\text{m}^3$	2200 $\mu\text{g}/\text{m}^3$	NCHS, 2007 (NHANES)
			0.77 $\mu\text{g}/\text{m}^3$	0.54–4.0 $\mu\text{g}/\text{m}^3$	0.39–0.57 $\mu\text{g}/\text{m}^3$	120 $\mu\text{g}/\text{m}^3$	U.S. EPA, 2008b (NHEXAS Region 5)
			70 pptv				U.S. EPA, 2008a (DEARS)
			0.066 $\mu\text{g}/\text{m}^3$	0.08–0.22 $\mu\text{g}/\text{m}^3$			DNREC, 2005
	Trichloroethylene	GC-MS	0.0099 $\mu\text{g}/\text{m}^3$	4.16 $\mu\text{g}/\text{m}^3$	0.006 $\mu\text{g}/\text{m}^3$	330 $\mu\text{g}/\text{m}^3$	NCHS, 2007 (NHANES)
			1.0 $\mu\text{g}/\text{m}^3$	1.6–2.0 $\mu\text{g}/\text{m}^3$	0.54–0.64 $\mu\text{g}/\text{m}^3$	77 $\mu\text{g}/\text{m}^3$	U.S. EPA, 2008b (NHEXAS Region 5)
			1,540 pptv				U.S. EPA, 2008a (DEARS)
			0.12 $\mu\text{g}/\text{m}^3$	0.06–0.11 $\mu\text{g}/\text{m}^3$			DNREC, 2005
	Tetrachloroethylene	GC-MS	0.0095 $\mu\text{g}/\text{m}^3$	5.2 $\mu\text{g}/\text{m}^3$	0.78 $\mu\text{g}/\text{m}^3$	659 $\mu\text{g}/\text{m}^3$	NCHS, 2007 (NHANES)
			1.6 $\mu\text{g}/\text{m}^3$	2.8–7.4 $\mu\text{g}/\text{m}^3$	1.9–2.4 $\mu\text{g}/\text{m}^3$	660 $\mu\text{g}/\text{m}^3$	
			57 pptv				U.S. EPA, 2008a (DEARS)
			0.21 $\mu\text{g}/\text{m}^3$	0.11–0.53 $\mu\text{g}/\text{m}^3$			DNREC, 2005
	Toluene	GC-MS	0.11 $\mu\text{g}/\text{m}^3$	49 $\mu\text{g}/\text{m}^3$	16 $\mu\text{g}/\text{m}^3$	6,300 $\mu\text{g}/\text{m}^3$	NCNH, 2007 (NHANES)
		3.5 $\mu\text{g}/\text{m}^3$	11–41 $\mu\text{g}/\text{m}^3$	10–25 $\mu\text{g}/\text{m}^3$	750 $\mu\text{g}/\text{m}^3$	U.S. EPA, 2008b (NHEXAS Region 5)	
		81 pptv				U.S. EPA, 2008a (DEARS)	
		0.083 $\mu\text{g}/\text{m}^3$	1.38–1.49 $\mu\text{g}/\text{m}^3$			DNREC, 2005	

Analyte Class	Analyte	Analytical Method	MDL/MQL	Occurrence— Mean	Occurrence— Median	Occurrence— Maximum	Reference (Study)
Volatile organic compounds (continued)	o-xylene	GC-MS	0.017 $\mu\text{g}/\text{m}^3$	9.6 $\mu\text{g}/\text{m}^3$	2.2 $\mu\text{g}/\text{m}^3$	2,300 $\mu\text{g}/\text{m}^3$	NCHS, 2007 (NHANES)
			0.86–1.2 $\mu\text{g}/\text{m}^3$	3.3–9.2 $\mu\text{g}/\text{m}^3$	2.7–3.9 $\mu\text{g}/\text{m}^3$	940 $\mu\text{g}/\text{m}^3$	U.S. EPA, 2008b (NHEXAS Region 5)
			74 pptv				U.S. EPA, 2008a (DEARS)
			0.067 $\mu\text{g}/\text{m}^3$				
	m,p-xylene	GC-MS	0.024 $\mu\text{g}/\text{m}^3$	30 $\mu\text{g}/\text{m}^3$	6.0 $\mu\text{g}/\text{m}^3$	8,400 $\mu\text{g}/\text{m}^3$	NCHS, 2007 (NHANES)
			0.92 $\mu\text{g}/\text{m}^3$	4.1–21 $\mu\text{g}/\text{m}^3$	3.7–6.6 $\mu\text{g}/\text{m}^3$	2,800 $\mu\text{g}/\text{m}^3$	U.S. EPA, 2008b (NHEXAS Region 5)
			157 pptv				U.S. EPA, 2008a (DEARS)
			0.14 $\mu\text{g}/\text{m}^3$	0.21–2.25 $\mu\text{g}/\text{m}^3$			DNREC, 2005
	Ethylbenzene	GC-MS	0.016 $\mu\text{g}/\text{m}^3$	11 $\mu\text{g}/\text{m}^3$	2.3 $\mu\text{g}/\text{m}^3$	2,200 $\mu\text{g}/\text{m}^3$	NCHS, 2007 (NHANES)
			0.22 $\mu\text{g}/\text{m}^3$	1.3–5.1 $\mu\text{g}/\text{m}^3$	0.91–2.3 $\mu\text{g}/\text{m}^3$	27 $\mu\text{g}/\text{m}^3$	U.S. EPA, 2008 (NHEXAS Arizona)
			99 pptv				U.S. EPA, 2008a (DEARS)
			0.048 $\mu\text{g}/\text{m}^3$	0.098–0.66 $\mu\text{g}/\text{m}^3$			DNREC, 2005
	1,2,4-trimethylbenzene	GC-MS					
			0.076 $\mu\text{g}/\text{m}^3$	0.12–0.78 $\mu\text{g}/\text{m}^3$			DNREC, 2005
	1,3,5-trimethylbenzene	GC-MS	0.32 $\mu\text{g}/\text{m}^3$	1.1–2.5 $\mu\text{g}/\text{m}^3$	1.0–2.0 $\mu\text{g}/\text{m}^3$	7 $\mu\text{g}/\text{m}^3$	U.S. EPA, 2008 (NHEXAS Arizona)
			374 pptv				U.S. EPA, 2008a (DEARS)
	Methyl <i>t</i> -butyl ether	GC-MS	0.039 $\mu\text{g}/\text{m}^3$	5.1 $\mu\text{g}/\text{m}^3$	0.01 $\mu\text{g}/\text{m}^3$	180 $\mu\text{g}/\text{m}^3$	NCHS, 2007 (NHANES)
	Styrene	GC-MS	0.83 $\mu\text{g}/\text{m}^3$	1.6–2.1 $\mu\text{g}/\text{m}^3$	1.4–1.9 $\mu\text{g}/\text{m}^3$	15 $\mu\text{g}/\text{m}^3$	U.S. EPA, 2008b (NHEXAS Region 5)
			201 pptv				U.S. EPA, 2008a (DEARS)
		0.14 $\mu\text{g}/\text{m}^3$	0.09–0.17 $\mu\text{g}/\text{m}^3$			DNREC, 2005	

Analyte Class	Analyte	Analytical Method	MDL/MQL	Occurrence— Mean	Occurrence— Median	Occurrence— Maximum	Reference (Study)
Volatile organic compounds (continued)	<i>o</i> -dichlorobenzene	GC-MS	0.51 $\mu\text{g}/\text{m}^3$				U.S. EPA, 2008 (NHEXAS Arizona)
			76 pptv				U.S. EPA, 2008a (DEARS)
			0.13 $\mu\text{g}/\text{m}^3$	0.06–0.07 $\mu\text{g}/\text{m}^3$			DNREC, 2005
	<i>m</i> -dichlorobenzene	GC-MS	0.58 $\mu\text{g}/\text{m}^3$				U.S. EPA, 2008 (NHEXAS Arizona)
			70 pptv				U.S. EPA, 2008a (DEARS)
			0.066 $\mu\text{g}/\text{m}^3$	0.06–0.07 $\mu\text{g}/\text{m}^3$			DNREC, 2005
	1,1-dichloroethene	GC-MS	0.49 $\mu\text{g}/\text{m}^3$				U.S. EPA, 2008 (NHEXAS Arizona)
			67 pptv				U.S. EPA, 2008a (DEARS)
			0.19 $\mu\text{g}/\text{m}^3$	0.00–0.01 $\mu\text{g}/\text{m}^3$			DNREC, 2005
	<i>cis</i> -dichloroethene	GC-MS	1.1 $\mu\text{g}/\text{m}^3$				U.S. EPA, 2008 (NHEXAS Arizona)
			385 pptv				U.S. EPA, 2008a (DEARS)
			0.14 $\mu\text{g}/\text{m}^3$	ND–0.01 $\mu\text{g}/\text{m}^3$			DNREC, 2005
	1,1-dichloroethane	GC-MS	0.49 $\mu\text{g}/\text{m}^3$				U.S. EPA, 2008 (NHEXAS Arizona)
			177 pptv				U.S. EPA, 2008a (DEARS)
			0.089 $\mu\text{g}/\text{m}^3$	ND–0.02 $\mu\text{g}/\text{m}^3$			DNREC, 2005
	1,2-dichloroethane	GC-MS	0.54 $\mu\text{g}/\text{m}^3$				U.S. EPA, 2008 (NHEXAS Arizona)
			275 pptv				U.S. EPA, 2008a (DEARS)
			0.063 $\mu\text{g}/\text{m}^3$	0.04–0.05 $\mu\text{g}/\text{m}^3$			DNREC, 2005
	1,1,1-trichloroethane	GC-MS	1.4 $\mu\text{g}/\text{m}^3$	2.5–6.6 $\mu\text{g}/\text{m}^3$	1.5–3.0 $\mu\text{g}/\text{m}^3$	186 $\mu\text{g}/\text{m}^3$	U.S. EPA, 2008b (NHEXAS Region 5)
			0.6 $\mu\text{g}/\text{m}^3$	2.6–5.4 $\mu\text{g}/\text{m}^3$	1.8–3.2 $\mu\text{g}/\text{m}^3$	23 $\mu\text{g}/\text{m}^3$	U.S. EPA, 2008 (NHEXAS Arizona)
		153 pptv				U.S. EPA, 2008a (DEARS)	
		0.17 $\mu\text{g}/\text{m}^3$	0.15–0.17 $\mu\text{g}/\text{m}^3$			DNREC, 2005	

Analyte Class	Analyte	Analytical Method	MDL/MQL	Occurrence— Mean	Occurrence— Median	Occurrence— Maximum	Reference (Study)
Volatile organic compounds (continued)	1,1,2-trichloroethane	GC-MS	0.9 $\mu\text{g}/\text{m}^3$				U.S. EPA, 2008 (NHEXAS Arizona)
			153 pptv				U.S. EPA, 2008a (DEARS)
			0.20 $\mu\text{g}/\text{m}^3$	ND			DNREC, 2005
	1,1,,2,2-tetrachloroethane	GC-MS	0.50 $\mu\text{g}/\text{m}^3$				U.S. EPA, 2008 (NHEXAS Arizona)
			0.15 $\mu\text{g}/\text{m}^3$	0.10 $\mu\text{g}/\text{m}^3$			DNREC, 2005
	Chlorobenzene	GC-MS	0.39 $\mu\text{g}/\text{m}^3$				U.S. EPA, 2008 (NHEXAS Arizona)
			62 pptv				U.S. EPA, 2008a (DEARS)
			0.13 $\mu\text{g}/\text{m}^3$	0.05–0.10 $\mu\text{g}/\text{m}^3$			DNREC, 2005
Semivolatile organic compounds*	Levogluconan	GC-MS	0.2/0.6 $\text{ng}/\text{m}^3$				U.S. EPA, 2008a (DEARS)
	Hopanes (4 compounds)	GC-MS	0.02/0.06 $\text{ng}/\text{m}^3$				U.S. EPA, 2008a (DEARS)
	Fatty acids (4 compounds)	GC-MS	0.2/0.6 $\text{ng}/\text{m}^3$				U.S. EPA, 2008a (DEARS)
Gases	Ozone	IC Passive	3/9 ppb				U.S. EPA, 2008a (DEARS)
	SOx	IC Passive	8/24 ppb				U.S. EPA, 2008a (DEARS)
	NOx	IC Passive	3/9 ppb				U.S. EPA, 2008a (DEARS)
Radiation	Radon	Scintillation					
PCBs and dioxin*	PCBs, 12 dioxin-like congeners	GC-MS	.04 $\text{ng}/\text{m}^3$	ND–6.7 $\text{ng}/\text{m}^3$		51 $\text{ng}/\text{m}^3$	Wilson et al., 2003
	2,3,7,8-dibenzodioxins	GC-HRMS	2–19 $\text{fg}/\text{m}^3$	1–830 $\text{fg}/\text{m}^3$			DNREC, 2005
	2,3,7,8-dibenzofurans	GC-HRMS	2–19 $\text{fg}/\text{m}^3$	1–90 $\text{fg}/\text{m}^3$			DNREC, 2005
Organochlorine pesticides*	DDT (6 compounds)	GC-MS	0.1 $\text{ng}/\text{m}^3$	0.06–0.12 $\text{ng}/\text{m}^3$		0.31 $\text{ng}/\text{m}^3$	Wilson et al., 2003
	Hexachlorobenzene	GC-MS					
	Lindane (BHC) (multiple compounds)	GC-MS	0.1 $\text{ng}/\text{m}^3$	0.25–7.4 $\text{ng}/\text{m}^3$		10.8 $\text{ng}/\text{m}^3$	Wilson et al., 2003
	Mirex	GC-MS					
	Kepone (chlordecone)	GC-MS					
	Chlordane	GC-MS	0.1 $\text{ng}/\text{m}^3$	0.57–7.7 $\text{ng}/\text{m}^3$		28 $\text{ng}/\text{m}^3$	Wilson et al., 2003

Analyte Class	Analyte	Analytical Method	MDL/MQL	Occurrence— Mean	Occurrence— Median	Occurrence— Maximum	Reference (Study)
Organochlorine pesticides* (continued)	Oxychlorane	GC-MS					
	Heptachlor	GC-MS	0.1 ng/m <sup>3</sup>	0.9–34 ng/m <sup>3</sup>		133 ng/m <sup>3</sup>	Wilson et al., 2003
	Heptachlor epoxide	GC-MS					
	Endosulfan	GC-MS					
	Toxaphene	GC-MS					
	Dieldrin	GC-MS	0.1 ng/m <sup>3</sup>	0.06–0.18 ng/m <sup>3</sup>		0.78 ng/m <sup>3</sup>	Wilson et al., 2003
	Endrin	GC-MS	0.1 ng/m <sup>3</sup>	0.09–0.25 ng/m <sup>3</sup>		0.69 ng/m <sup>3</sup>	Wilson et al., 2003
	Aldrin	GC-MS	0.1 ng/m <sup>3</sup>	0.08–2.74 ng/m <sup>3</sup>		4.7 ng/m <sup>3</sup>	Wilson et al., 2003
Non-persistent pesticides*	Organophosphate scan	GC-MS	0.1 ng/m <sup>3</sup>	0.6–160 ng/m <sup>3</sup>		1,100 ng/m <sup>3</sup>	Wilson et al., 2003
	Pyrethroid scan	GC-MS					
Microbiologicals*	Endotoxin and $\beta$ 1,3 glucan	Limulus amoebocyte lysate					
PBDEs*	BDE 47	GC-MS or GC-ECD		53–107 pg/m <sup>3</sup>			Lorber, 2008
	BDE 99	GC-MS or GC-ECD		51–79 pg/m <sup>3</sup>			Lorber, 2008
	BDE 153	GC-MS or GC-ECD		3.9–5 pg/m <sup>3</sup>			Lorber, 2008
	DecabromoDE	GC-MS or GC-ECD		25–121 pg/m <sup>3</sup>			Lorber, 2008
Perfluorinated acids*	PFOA	HPLC-MS/MS					
	PFOS	HPLC-MS/MS					
	PFNA	HPLC-MS/MS					
Other chemicals*	Dialkylphthalate scan, including DEHP	GC-MS	0.04 ng/m <sup>3</sup>	31–288 ng/m <sup>3</sup>		474 ng/m <sup>3</sup>	Wilson et al., 2003
	Bisphenol A/Alkylphenol scan	GC-MS	0.1 ng/m <sup>3</sup>	1.3–169 ng/m <sup>3</sup>		402 ng/m <sup>3</sup>	Wilson et al., 2003

\*This matrix-analyte class may be archived for later analysis.