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Communication 1

EXECUTIVE SUMMARY

Human Exposure to Unconventional Oil and Gas Development: A Literature Survey for Research Planning

HEI-Energy Research Committee

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Trusted Science, Clean Environment, Better Health

Human Exposure to Unconventional Oil and Gas Development: A Literature Survey for Research Planning

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Health Effects Institute — Energy
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EXECUTIVE SUMMARY

Unconventional oil and natural gas development (UOGD) has expanded rapidly in the United States in recent years. Accompanying this expansion has been a growing body of scientific literature about human exposures to environmental agents arising from UOGD (hereafter "UOGD exposures"). This report surveys the literature relevant to these environmental exposures. The Energy Research Committee (the Committee) of the Health Effects Institute–Energy (HEI-Energy) conducted the survey as part of a larger effort to understand the current state of the science on UOGD exposures and their potential health effects. The Committee will use results from this survey and a companion review of epidemiology literature on potential health effects of UOGD exposures (HEI-Energy Research Committee 2019) to inform HEI-Energy's planning for future research to better understand exposures associated with UOGD.

UOGD Defined

UOGD refers to the development and production of oil and natural gas as practiced starting around the beginning of the 21st century through multistage hydraulic fracturing in horizontal wells. UOGD processes occur on and off the well pad and include:

- *field development*: exploration, site preparation, vertical and horizontal drilling, well completion (casing and cementing, perforating, acidizing, hydraulic fracturing, flowback, and well testing) in preparation for production, and management[1] of wastes;
- *production operations*: extraction, gathering, processing, and field compression of gas; extraction and processing of oil and natural gas condensates; management of produced water[2] and wastes; and construction and operation of field production facilities; and
- *post-production*: well closure and land reclamation.

Approach to the Survey

The Committee consists of multi-disciplinary scientists from across the United States with expertise in air quality, epidemiology, exposure assessment, hydrology, medicine, petroleum engineering, risk assessment, and toxicology. Along with HEI-Energy staff, the Committee conducted a survey of peer-reviewed and gray scientific literature that provides information about potential UOGD exposures. The goals for the survey are to summarize research efforts to date and the approaches investigators have used to characterize releases from UOGD that might lead to exposures, identify knowledge gaps about potential exposures, and begin planning for research that addresses the gaps. The Committee also toured UOGD operations and convened two public workshops at the outset of the survey to hear from knowledgeable representatives from federal and state government, the oil and gas industry, environmental and public health nongovernmental organizations, academia, and community organizations about their priorities for research.

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[1] Management of wastes and produced water refers to their handling from creation to disposal, including collection, storage, transport, treatment, reuse, recycling, and disposal.

[2] Produced water is naturally-occurring water that comes out of the ground along with oil and gas. (Adapted from: American Geosciences Institute 2019). The characteristics of produced water vary and use of the term often implies an inexact or unknown composition. (Adapted from: Schlumberger 2019)

Conceptual Framework

Understanding human exposures to UOGD-related chemical agents (e.g., criteria and hazardous air pollutants, radioactive material, and odorous compounds) and non-chemical agents (e.g., noise, light, and vibration) represents a complex undertaking. UOGD processes involve a multitude of agents released to air, water, and other environmental media, with levels varying by region, extent of operations, operator practices, and other factors. Furthermore, variation in time–activity patterns (e.g., time spent at residential versus work locations and indoor versus outdoor locations) among potentially exposed populations complicates efforts to quantify human exposures to agents originating from UOGD.

The Committee framed its literature survey within a conceptual model of exposure (Figure ES-1) to facilitate understanding of research related to potential exposures and where knowledge gaps exist. An ideal exposure study would provide information about each element of the conceptual model, including identification of specific UOGD chemical or non-chemical agents, documentation of the release to the environment (e.g., emissions rate or noise measurement) and transport to a specific medium, route of exposure (e.g., inhalation of air in a residential area or ingestion of drinking water), and the magnitude, freqency, and duration of exposure for a specific population. In so doing, the study would allow one to determine whether a complete exposure pathway connects a specific UOGD agent with a specific population and, if so, to have the exposure information necessary to judge its importance for health.

Figure ES-1. Conceptual model of potential exposure pathways associated with UOGD.

Survey of the Literature

The survey of the literature was guided by the following question:

What is known about potential UOGD-related human exposures?

The Committee surveyed peer-reviewed and gray literature published between January 1, 2000 and July 10, 2019 that contribute to understanding how people might be exposed to chemical agents or non-chemical agents released directly from UOGD to the environment. Such releases may be operational (e.g., permitted air emissions), accidental (e.g., spills and leaks), or unauthorized (e.g., illegal discharges).

All potentially useful studies were considered whether or not the investigators set out to study human exposures. This included studies that characterized one or more elements of an exposure pathway, such as the chemical and non-chemical agents associated with UOGD operations, the ways that these agents are released to and behave within the environment, the concentrations of agents in air, water, and other environmental media, and the potentially exposed populations and their time–activity patterns, which influence whether and how exposures occur. The Committee developed a set of questions to facilitate its survey for understanding exposures to UOGD and identifying knowledge gaps (Box ES-1).

Overview of the Exposure Literature

In response to the rapid increase of UOGD in the United States, scientific inquiries about human exposure to chemical and non-chemical agents from UOGD operations also increased (Figure ES-2). The literature search revealed hundreds of citations for studies that have been conducted to understand environmental impacts associated with UOGD, including many reporting measured or predicted levels of UOGD-related agents in air, water, and other environmental media. These studies focused on major oil and gas

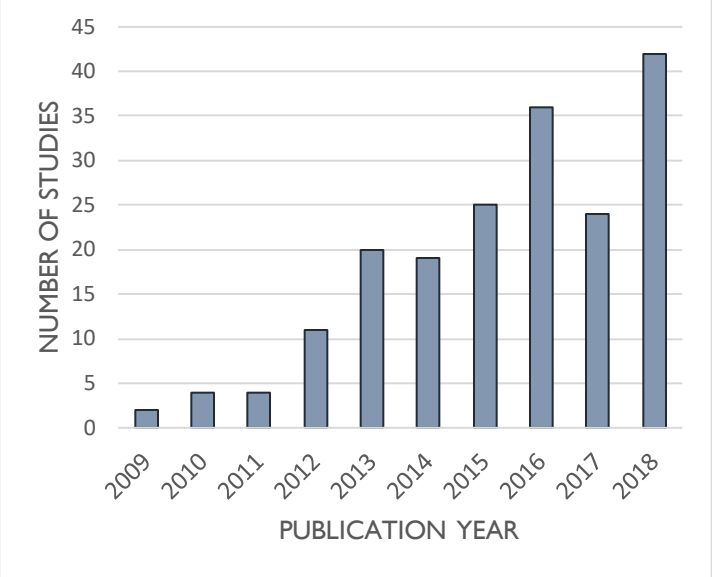
producing regions in the United States; that is, in shale plays located within sedimentary basins where UOGD is active (Figure ES-3).

Box ES-1. Questions to facilitate the review of literature for understanding exposures to UOGD

1. Did the investigators demonstrate a link between their monitoring or modeling results and UOGD?
2. Did the investigators identify which human populations, if any, could be exposed to the chemical or non-chemical agent(s) investigated in the study?
3. Are the monitoring or modeling results potentially useful for understanding exposure to UOGD-related agents (e.g., likelihood, frequency, duration, or magnitude) for:
   a. The location and population under study?
   b. Other locations and populations?
4. Monitoring studies: Did the investigators select appropriate sampling and analytical methods and use them properly (e.g., proper calibration)?
5. Modeling studies: Was model selection, parameterization, and evaluation appropriate?
6. Is there information missing from the paper that limits inferences about realized or potential exposures to UOGD-related agents? If so, explain.
7. Are study results subject to important uncertainties with respect to addressing the study objectives? If yes, what are they, and are they quantified or discussed qualitatively?
8. How does the paper inform the potential design of a future exposure study (consider both positive and negative aspects of the study)?

The majority of studies focused on levels of agents in the air (n=114), with most measuring or modeling concentrations of non-methane volatile organic compounds (VOCs) and particulate matter in or near areas with UOGD, and with some assessing air quality from secondary pollutant formation (e.g., ozone). Other studies focused on levels of agents in water (n=82), primarily as a result of accidental releases, with most measuring or modeling concentrations of VOCs, metals, and other chemicals associated with flowback and produced water.

Figure ES-2. Number of studies reporting measured or predicted levels of UOGD-related chemical and non-chemical agents by year of publication (Publication year based on year of electronic publication; Appendix A includes the list of publications).

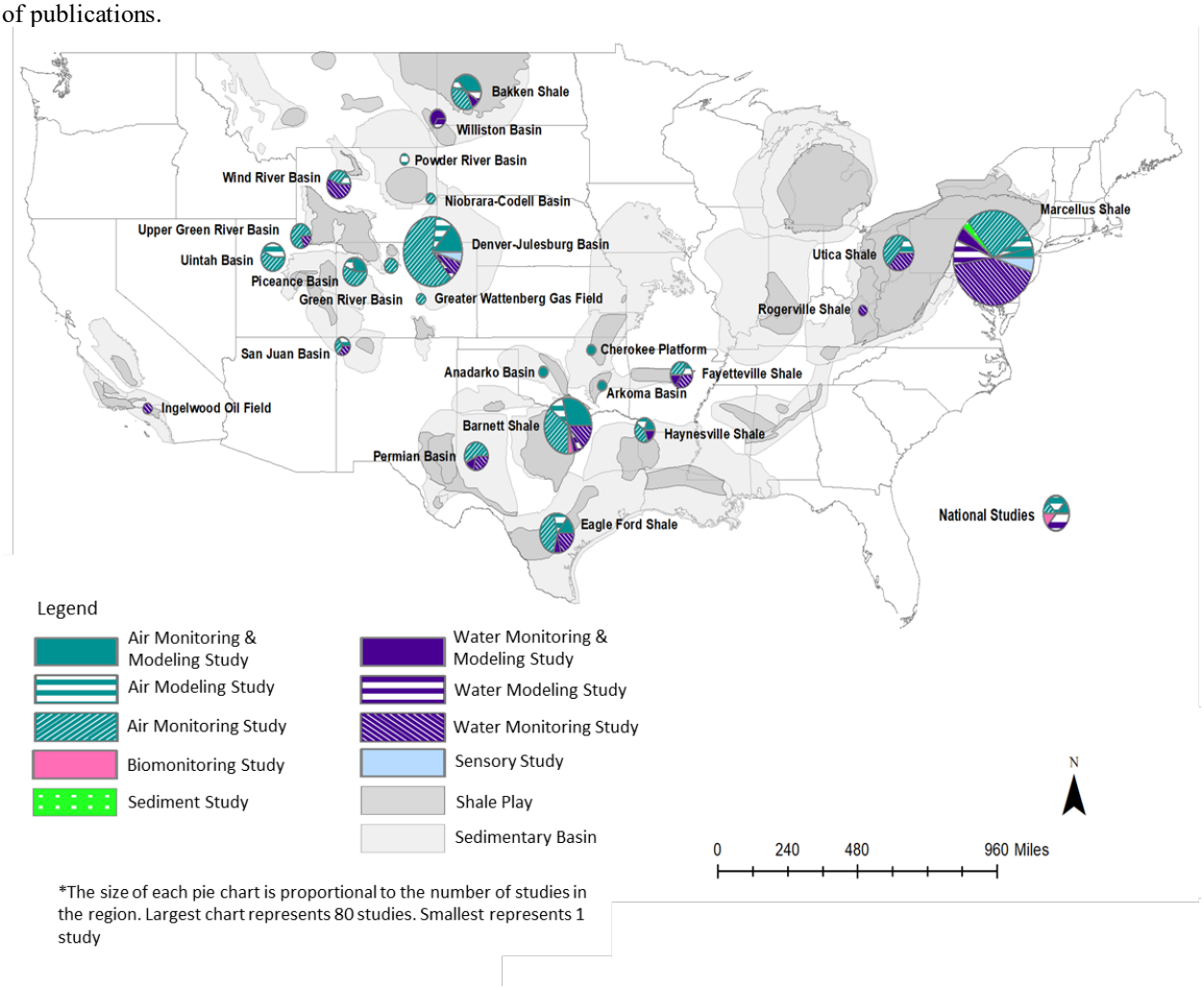


Many of the water-related studies were conducted in the Marcellus region. Fewer studies characterized noise, odor, and light exposures (n=7) or UOGD-related agents in soil (n=28). Five studies used biomonitoring techniques to measure concentrations of chemicals or related metabolites in people's blood, urine, or hair.

Most studies focused on a single environmental medium. Methods used in these studies varied from direct sampling and analysis of the media of interest to modeling levels of agents in a given medium over time and space. For example,

several regional air studies used modeling techniques to predict secondary pollutant formation under different atmospheric conditions.

Figure ES-3. Study locations relative to shale basins and plays, by media investigated. Appendix A includes the list of publications.



THE COMMITTEE'S FINDINGS

Strengths of the Literature in Assessing Human Exposure to UOGD

Overall, the studies contained useful information for understanding human exposures, including those conducted without this specific goal. The studies helped to characterize UOGD-related human exposures by contributing to our understanding of atmospheric and hydrological conditions that affect fate and transport of agents through the environment, the relationship between operations and types or levels of emissions, and pathways of potential exposures. In addition, some investigators were resourceful in their use of previously published data, such as air quality data collected as part of state monitoring programs.

Some investigators used methods that were useful for isolating UOGD sources. Some measured emissions on well pads and used the data, along with meteorological and topographical data, to analyze air quality changes over space and time. Studies sometimes involved the use of various tracers or markers to estimate the levels of agents in air or water that were attributable to UOGD. Other investigators

assessed the chemical concentrations before, during, and after UOGD activities, enabling an evaluation of potential impacts specific to those activities.

Studies of greatest utility for addressing the Committee's guiding question were those that shed light on spatial variability of agent concentrations (e.g., by sampling at various distances from a well pad) and temporal variability (e.g., by sampling over multiple sampling periods during a variety of UOGD activities, meteorological conditions, seasons, and times of day).

A subset of studies was conducted with the aim of characterizing human exposure to chemicals, noise, and light. To do so, investigators collected samples in areas where people spend much of their time, including air sampling in residential communities and water sampling of drinking-water wells. Some studies involved affected communities through discourse and participation, thereby providing results to the affected communities and benefiting from local knowledge. In addition, some state agencies conducted air sampling in response to community concerns.

Knowledge Gaps about Human Exposure to UOGD

The quantity of data on levels of UOGD-related agents in the environment continues to increase along with efforts to use the data to quantify human exposure. Nevertheless, important knowledge gaps remain in our understanding of who might be exposed, how exposures might arise, how exposures vary over time and across regions, and the likelihood of exposure.

Few studies provided the information necessary for linking environmental concentrations of agents to specific UOGD-related sources (e.g., diesel-powered equipment) or to distinguish between contributions from UOGD and other sources, such as conventional oil and gas development. In addition, the generalizability of study results to UOGD operations, geographic areas, and populations beyond those investigated in the studies is not clear.

PLANNING FOR EXPOSURE RESEARCH

Given the current state of knowledge on UOGD and potential exposures, the Committee recommends further investigation to improve understanding of human exposures to UOGD to support decision-making by community members, public health officials, regulators, oil and gas operators, and others. Informed by its review and input received from workshop participants, the Committee identified priority knowledge gaps and developed a set of characteristics critical to high-quality and policy-relevant research.

Research Questions

The Committee framed knowledge gaps as research questions within the conceptual model of exposure (Figure ES-1; Table ES-1). In general, understanding the agents and mechanisms by which human exposures arise is central to being able to generalize study results to different sets of regional conditions, operational practices, and population characteristics. For each knowledge gap, the Committee provided examples of research activities.

Anticipated Attributes of Research

Based on findings from this review, a parallel review of UOGD-related epidemiology literature (HEI-Energy Research Committee 2019), and consultations with stakeholders, the Committee will prepare a Research Solicitation requesting proposals to fill knowledge gaps about human exposures to UOGD. The Committee is charged with overseeing selection and implementation of all research and ensuring its quality and utility for understanding human exposure to UOGD.

Although the knowledge gaps in Table ES-1 represent separate elements of the conceptual model of exposure, future research projects funded by HEI-Energy will ideally include multiple, if not all, elements of an exposure pathway. In defining the scope of research, the Committee recognizes the value of a better understanding of air- and water-related exposures, achieved with comprehensive, high-quality research that characterizes the range of exposure conditions across regions of the United States.

Table ES-1. Knowledge gaps framed as example research questions.

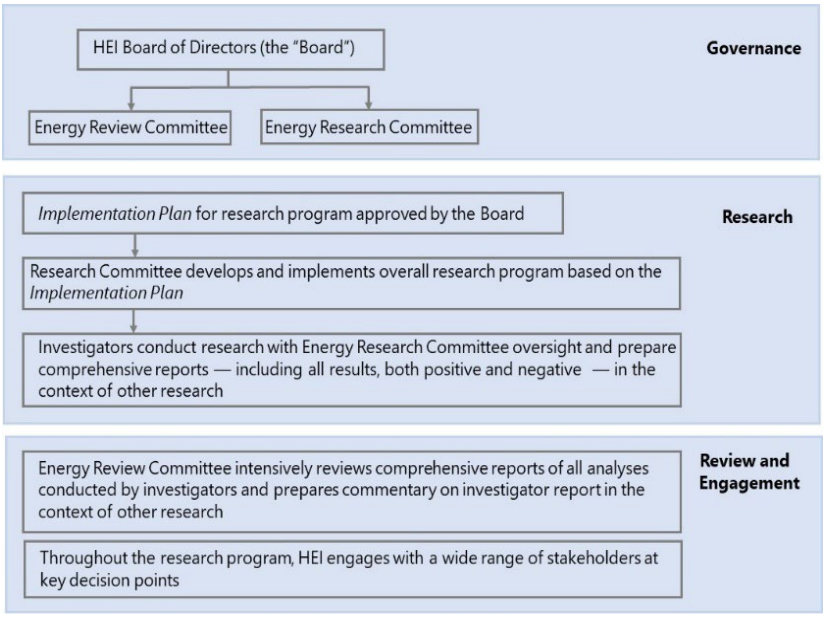
UOGD SOURCES
1. How do the characteristics (i.e., the likelihood, composition, magnitude, frequency, and duration) of potential environmental releases from UOGD vary over space and time as a function of differences in the geological formations, meteorology, and variable practices among operators, across phases of development, or in response to technological innovation, changing regulations and guidance, and community concerns?
2. **a.** What is the relative contribution of operational, accidental, and unauthorized releases to environmental concentrations of UOGD agents[1] in air? How might they contribute disproportionately to total emissions? How can emissions from individual UOGD processes be best quantified? Can measurements of the release of methane or other chemicals be used to help inform estimating non-methane emissions associated with UOGD operations? How can we use longer term observations (e.g., routine ground-based and satellite, including flares) observations to estimate historical trends in emissions? **b.** What is the relative contribution of operational, accidental, and unauthorized releases to environmental concentrations of UOGD agents in surface water and groundwater?
RELEASE MECHANISMS AND TRANSPORT PATHWAYS
3. **a.** How does variation in regional conditions (e.g., meteorology and topography) affect the levels of UOGD agents in air over various temporal scales (e.g., hourly, diurnally, and seasonally) as a result of chemical transformation and transport? What methods are available to characterize the fate and transport of UOGD releases to the air? **b.** How does variation in regional conditions (e.g., topography, geochemistry, geophysics, and hydrology) affect the levels of UOGD agents in water over various temporal scales (e.g., seasonally) as a result of chemical transformation and transport? What methods are available to characterize the fate and transport of UOGD releases to water? **c.** To what extent does UOGD contribute to increased levels of non-chemical exposures (e.g., noise, light, and vibration) within and across regions and operations?
4. **a.** How can levels of UOGD agents in air be distinguished from levels contributed by other natural (e.g., naturally occurring methane) and anthropogenic (e.g., conventional oil and gas development) sources? What is the relative contribution of air emissions from UOGD to local and regional concentrations? **b.** How can levels of UOGD agents in water be distinguished from levels contributed by other natural and anthropogenic sources? What is the relative contribution of water releases from UOGD to local and regional concentrations?
POPULATIONS
5. What are the characteristics[2] of populations potentially exposed to UOGD agents at local and regional scales?
6. Which population behaviors (e.g., time–activity patterns) influence the potential for exposure to UOGD agents? To what extent do exposures to UOGD agents differ among individuals within and among exposed populations?
7. How can exposure monitoring methods (e.g., study design, instrumentation, and other technologies) accurately characterize total personal and population-wide exposures to UOGD over time and space?

[1]UOGD agents might be released to the environment as:

- Operational releases: In accordance with applicable regulations (e.g., permitted discharges to surface water, equipment emissions to ambient air, and vehicle exhaust),
- Accidental releases: As a result of poor practices (e.g., improper waste disposal, malfunctioning equipment, and explosions), or
- Unauthorized releases: As a result of illegal activities (e.g., unapproved disposal of waste materials).

[2]Population characteristics include numerous factors, such as age, sex, race, ethnicity, socioeconomic status, health status, size of the population, activity patterns, and other factors.

Figure ES-4. Overview of HEI-Energy model for providing impartial scientific research.



In preparing its Research Solicitation and reviewing proposals submitted in response, the Committee seeks research that possesses the characteristics in Table ES-2. In its Research Solicitation, the Committee will specify that several key components are required for a research program to be selected, including study of agents of potential concern for health, relevant geographic areas, necessary technical and community engagement expertise on the investigator team, a detailed quality assurance project plan, and an a priori study interpretation and communication plan, among other general components of a high-quality study.

Looking Ahead to HEI-Energy's Research Solicitation

HEI-Energy will fund research that informs policy decisions about how best to protect public health in the oversight of UOGD. The new research program is modeled after HEI's existing successful model for providing high quality, impartial scientific information about air quality and health (Figure ES-4). Key components include:

- *Independent governance* of the research program with leadership by a board of directors unaffiliated with sponsors;
- *Balanced funding* from governmental agencies, the oil and gas industry, and occasionally private foundations;
- *High-quality science* with research competitively selected for funding and overseen by the Energy Research Committee, which consists of knowledgeable scientists that have been vetted for bias and conflict of interest;
- *Extensive peer review* of science by an Energy Review Committee, which consists of knowledgeable scientists that have been vetted for bias and conflict of interest, that works independently of the Energy Research Committee to provide peer review and commentary on research;
- *Open and extensive engagement with stakeholders*, including local community members and officials in study locations;
- *Communication* of all results, including both positive and negative findings, in the context of other relevant research; and
- *Provision of impartial science* for better informed decisions without advocating policy positions.

HEI-Energy expects to distribute the Research Solicitation to the broad scientific community, seeking multi-disciplinary teams with the skill and capacity to mobilize exposure studies in one or more major oil and gas-producing regions of the United States. The Research Committee will prioritize proposals that

align with the characteristics listed in Table ES-2. Throughout the selection, implementation, and review of research projects, HEI-Energy and the Committee will provide oversight to ensure quality and effective communication with stakeholders about research progress.

Table ES-2. Characteristics of appropriate research identified by HEI-Energy Research Committee (in alphabetical order).

Criterion	Description
Brings value to and informs decision-making	Is useful to communities in study areas, government officials, industry, and other stakeholders. Ideal study designs will be informed by successful engagement with the communities in study areas and other stakeholders.
Broadly generalizable	Designed to be broadly generalizable across geographic regions, UOGD operating conditions, or communities over time, including periods of low and high UOGD activity, without sacrificing validity.
Determines whether an exposure pathway links a UOGD process with a community	Links one or more chemical or non-chemical agents directly released to the environment from a UOGD process to a potentially exposed community. The research allows for the detection of possible causal links between one or more UOGD processes (e.g., specific equipment, activity, or phase of development) and resulting human exposures. The study is designed to distinguish between agents released from UOGD and non-UOGD sources.
Expands understanding of temporal and spatial variability of exposure	Selected study locations and designs will substantially fill important gaps in understanding of variability in exposure conditions over temporal and spatial scales relevant for decision-making by communities, regulators, industry, and other stakeholders.
Optimizes use of the research budget by maximizing efficiency	Ensures that the research budget is spent on gathering data and information that is not already available (e.g., by incorporating or complementing existing data and information) and that prioritization and sequencing of data collection maintains a focus on exposures of possible concern.
Useful for assessing health risk	Collects data or analyzes existing data (or establishes practical exposure assessment methodologies) that is useful for assessing the potential for human health effects at resolutions relevant for application in an epidemiology study or risk assessment.

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