Assessing Cumulative Risks
to Guide Public Exposure Levels Following Disasters

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Abstract
The public is increasingly aware of the potential for multiple chemicals to cause adverse health effects that may not be
accounted for when assessing single chemicals alone. This is especially true in disaster situations, where high levels of
many contaminants can be released. Pressures for affected cities to return to normal can be strong, and urban exposures
can be difficult to control. To assure health protection in these situations, it is important to consider the possible effects
of combined exposures across multiple media and over various population groups. These integrated analyses consider
fate, availability of toxicity data and health-based guidelines, and application of cumulative risk approaches. Under-
standing environmental fate is key to accounting for the appropriate chemical form over various exposure periods of
interest, ranging from acute (emergency response) to chronic (final cleanup). Rigorous toxicity data are typically un-
available for humans, and are sometimes limited to anecdotal information or medical case reports. While more data are
typically available for animal toxicity, information is often limited across durations of interest, and extrapolation to
estimate human effects introduces considerable uncertainty. Although a number of health-based guides exist, gaps are
considerable and relevance to the exposure period of interest is again crucial. Cumulative risk approaches are begin-
ning to be applied to assess joint exposures and toxicities of multiple contaminants that could be released, and these
more systematic analyses are expected to further inform preparedness planning and response for disaster events.

1. Need for Exposure Levels to Support Disaster Response
A wide variety of disasters can release contaminants to the environment, from floods and fires to acci-
dents or intentional acts of malice. Several recent tragedies such as hurricane Katrina in New Orleans and
the World Trade Center tragedy in New York City have demonstrated how widespread the resulting con-
tamination problems and associated health concerns can be (Fox et al., 2006; Landrigan et al., 2004).
When disaster strikes, protecting human health is a top priority. Given that these disasters can involve
hundreds of different contaminants, cumulative risks can be a key issue for health officials. That is, re-
sponse measures need to consider more than single exposures and health effects of individual chemicals.
Potential joint effects of multiple contaminants via multiple exposure routes, including ingestion, inhala-
tion, and dermal absorption, can be important to health protection decisions especially when concentra-
tions are high following a catastrophic release.

As part of preparedness planning, health-based levels are being considered for a number of contami-
ants that could threaten urban air or drinking water supplies. Public officials need to know if various
water uses (from drinking and cooking to bathing, cleaning, and watering) should be curtailed when water
supplies are contaminated, and similarly if access restrictions or evacuation versus shelter-in-place should
be imposed when urban air is contaminated. Health-based exposure guides can help answer these ques-
tions, by indicating at what concentrations exposures could be considered safe, or safe enough, or tole-
rable for different activities following a release. By developing these levels proactively before other disa-
sters occur, they can be available to guide effective responses if/when they are needed in the future.

The basic set of public exposure levels simply represent concentrations designed to serve as triggers
for various response measures – from no action to limited or complete restrictions (e.g., of water use or
building/urban area occupancy). These levels are derived from a measured scientific evaluation of exi-
sting toxicological data. Several grades of effect severity are assessed to support a set of exposure levels,

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corresponding to different activity needs for various individuals following a release – from emergency responders and rescue/recovery workers to individuals restoring critical functions (such as power), and eventually to the general public restoring their normal lives. These graded severities are designed to indicate levels at which: no adverse effects are expected, some mild effects may occur, more serious effects could occur, and exposures could be lethal. Knowing these levels is crucial for practical and protective responses.

Further complicating the effort to develop a graded suite of health-based exposure guides is the need for these levels to span several durations, for the released contaminants and their degradation products. These durations track with the phases of a disaster response, as indicated below. Toxicity data relevant to each are essential to determining useful exposure levels. The emergency response period typically extends to 24 hours, so acute toxicity data are important for this phase. Rescue and recovery efforts can extend several days to weeks, during the initial phase of consequence management. This can also be a crucial period for conducting or restoring critical functions, and also for forensics. In addition, it can be a make-or-break stretch for at least localized economic survival of small businesses. During this same time, a large number of people in the affected population will seek to regain at least some access to their homes and workplaces, and some use of water supplies. Thus, toxicity data for repeat exposures of limited duration are relevant to the information needs for this period.

The final decontamination and cleanup that completes consequence management and return to normalcy can be protracted, for example lasting several months to a couple years. Thus, toxicity data are also needed for subchronic exposures. For comparison, chronic exposures can be taken as a lifetime, or at least 10% of a lifetime (EPA, 2007), which some assume to be 70 years.

2. Technical Issues and Approaches

A number of technical issues affect the development of public exposure levels for disasters:

1. Contaminant fate is not sufficiently understood across both media (air and water) and over time. This information represents the first step of the cumulative assessment, as it identifies the multiple chemicals that could be associated with a single chemical release. This context is essential for appropriate chemicals and forms to be addressed for each duration. The approach taken to address this issue is to review current scientific literature to characterize the physical-chemical properties, persistence, and transformation of each threat contaminant in both water and air. By developing a matrix to indicate what chemicals are expected to be present in each medium over different time periods, the subsequent toxicity evaluation and ultimate exposure guides can focus in the species appropriate for a given interval. To illustrate, a trimethylated compound that completely hydrolyzes within minutes would only be considered for acute exposure levels, while its transformation products (including the hydrolysis product methanol, in water as well as in humid air) would form the basis of the longer durations.

2. Human data are very limited for most contaminants across all durations of interest. Some exist from subchronic to chronic occupational studies, but those conditions are rarely well controlled, and the exposure term is not well characterized. In a few cases, epidemiological data exist for public populations, such as for arsenic exposure. Limited data exist for acute exposures, from both accidental poisonings (e.g., drinking bleach) and intentional exposures (e.g., suicide attempts) – but again, the precise exposure level is generally poorly characterized. Of key interest for general public exposure levels is information on human variability and differential susceptibility, and those data are even more limited. The approach taken to address this issue is to compile and evaluate the current scientific literature and also review relevant toxicity values that have been developed to support human health assessments (especially those that reflect more recent analyses, to capture both updated toxicity knowledge and derivation methodologies). From this evaluation, key gaps are identified to focus the subsequent assessment of animal data and modeling efforts.
3. Animal data are limited for all contaminants and durations of interest. These dose-response data have historically been used as surrogates to frame the evaluation of potential health effects for humans. Although animal toxicity studies have been conducted for a large number of chemicals, coverage does not approach that needed for the candidate threat contaminants and set of durations. Most acute studies focus on the lethality endpoint, and most chronic studies are designed to indicate effects from lifetime exposures. Neither addresses the primary needs for practical exposure guides for disasters. The approach taken to address this issue parallels that described for human data. In this case, emphasis is placed on those species considered most relevant for a given contaminant/health effect endpoint of concern. For example, the juvenile swine is considered a better predictor of human health effects from lead exposures than rodents. Thus, those data would be prioritized to support the tiered exposure guides for that contaminant.

4. Existing standards/limits do not provide sufficient coverage across contaminants in both air and water. Several agencies and organizations have developed exposure limits and guidelines applicable to the emergency period, including acute guidelines for public exposures to air, and chronic guidelines for lifetime “safe daily” levels in water and air. However, coverage is very incomplete across all contaminants and durations of interest. The approach taken to address this issue is to compile relevant limits and guidelines that have been developed by various organizations. These range from emergency guides for the public (acute) to occupational limits for workers (repeat, chronic, primarily air exposures) and health advisories for drinking water (acute to chronic). The limits and their bases were compared and reviewed to determine what insights might be gained to support an integrated set of graded exposure levels for air and drinking water for disaster situations.

5. Traditional derivation methods do not account for cumulative effects, that is, the combined effects of multiple contaminants by multiple exposure routes. For most disasters, exposures will involve many contaminants and several routes. Moreover, these exposures will be incremental to baseline levels and body burdens. Thus, to adequately assess the protectiveness of exposure guides being developed, it is important to consider their “real-world” context, i.e., as mixtures and mixed exposures rather than as individual contaminants. The approach taken to address this issue is to review the scientific literature to identify relevant assessment methodologies as well as chemicals for which interactions have been identified. Several scientific studies have indicated the potential for higher-than-additive (e.g., synergistic) effects for certain chemical pairs, and initial guidance has been developed for assessing chemical mixtures. Contaminants can be grouped per potential for interactions, considering co-occurrence as well as toxicity characteristics, notably similarity of toxicokinetics (absorption, distribution, metabolism, and elimination) and toxicodynamics (mode/mode of toxic action).

3. Findings

The following findings have been identified from initial cumulative risk evaluations of exposure guides for health protection in the event of a disastrous release:

1. Fate: The review of scientific data across a large number of contaminants indicates that persistence and transformation products in air and water are not well characterized across both media. Relatively few data were found for specific degradation products in air. Instead, information typically exists about the fate process (e.g., hydroxyl radical reaction, including rates), while the reaction products themselves are often not identified. In contrast, more data exist to address aquatic fate, and for some compounds information can be found that is directly relevant to common drinking water conditions, such as persistence under typical pH and temperature ranges. Of all technical issues affecting the development of exposure levels, this one is most amenable to resolution, as further data collection is relatively reasonable in terms of cost, time, and existing capabilities.
2. Human data: The dearth of human toxicity data represents the most significant limitation for developing public exposure levels to support disaster responses. Nevertheless, if a release occurs, actions will have to be taken — so it is crucial to provide health-based information developed from a measured scientific review to the extent possible, i.e., making the most of data and modeling/predictive tools that do exist. It cannot be overemphasized that reflex-“protective” decisions such as evacuating an area or shutting off a water supply could in fact cause much more harm (including deaths that could have been avoided) than no action or limited restrictions. Thus, whatever information is available is needed to provide the best context possible for effective health protection measures.

3. Animal data: Although these data are not as limited as human data, coverage is inadequate across the durations and severities needed to support practical exposure guides for disaster response. Note that although further studies can be conducted, they are typically very expensive and time-consuming (consider standard two-year rodent studies). Thus, a review of existing studies for an initial set of contaminants was combined with results of the parallel effort for human data (above), and also a review of existing guidelines (below), to help focus priorities for future research on critical data gaps.

4. Existing standards/limits: From the review of existing guidelines and standards, no single basis was found to be best for air or drinking water. This simply reflects the differences underlying available limits, and it is important to clearly present those bases so officials and the public will understand their basic assumptions and intended application. This review also emphasizes the importance of chemical-specific assessments rather than applying a generic hierarchy to determine health-based exposure levels for the public in disaster situations.

5. Cumulative effects: The initial evaluation identified a limited amount of interaction data, such as for certain organic chemical pairs (e.g., carbon tetrachloride and ethanol) and certain metal pairs (e.g., arsenic and chromium). Groupings were found to be a useful way of highlighting common target organs and effects of concern. This initial screen/grouping helps focus the considerable effort involved in more quantitative cumulative risk assessments on those combinations considered to have greater opportunity for interaction, as overlain with chemical data for facilities considered more vulnerable to disastrous releases.

In summary, methods and data exist to more systematically address potential cumulative risks associated with catastrophic contaminant releases than in the past. This information can better inform disaster response measures to assure overall health protection throughout the emergency response and consequence management periods.

Bibliography


