
Abstract
Researchers conduct biomonitoring studies to characterize the prevalence of environmental chemicals in participants’ bodies by testing their blood, urine, or other media. These test results are returned to participants in a process called “report-back.” Designing effective report-back is complicated by several uncertainties related to interpreting personal chemical results. Chemical levels do not inform participants about the sources of their exposure, the health implications of exposure, or if and how they can reduce exposure. In this position paper we investigate how an interactive expert system can help participants identify potential sources of exposure and exposure reduction strategies.

Author Keywords
Biomonitoring; visualization; personal data; expert systems

ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous

Introduction
In biomonitoring studies, researchers test participants’ blood, urine, or other biological samples for...
environmental chemicals. The results are used by researchers to characterize the public's exposure to these chemicals, and to investigate their relationship to human health. Researchers are increasingly returning personal exposure results to study participants in a process called "report-back."

Participants interpret their results through a process of sense-making, in which participants assign meaning to their results and decide how to react. In our research [3], we have found participants ask several questions in this process:

- What chemicals were found?
- How much?
- Where did they come from?
- What does this mean for my health?
- How can I reduce my exposure?

The first two questions can be answered definitively: analytical testing tells us exactly how much of each chemical was found in a sample. The source of uncertainty in biomonitoring results is not the data itself, but its implications, represented in the latter three questions. In this respect, biomonitoring data is similar to genetic testing results, where different gene variants have uncertain health effects [11]. The latter questions, addressing the implications of exposure, can be answered with varying levels of certainty:

- Source: Sometimes exposure can be pinpointed to a particular source, like an industrial source near where the participant lives. Other chemicals may have multiple exposure pathways, for example, if they are used in many different products or bioaccumulate in food sources. Furthermore, exposure to persistent chemicals may have happened many years earlier, making it hard to identify a specific source.
- Health implications: There are varying degrees of evidence for health outcomes depending on the amount and type of research that has been conducted. Many chemicals lack guidelines for safe-unsafe levels.
- Exposure reduction: Uncertainty in exposure reduction is closely tied to source uncertainty. If a specific source can be identified (e.g., a participant's couch contains added flame retardants), then suggesting an alternative is sometimes possible (e.g., consider replacing the couch with a flame retardant-free model).

In this position paper, we focus on the uncertainty of source. Participants experience modal uncertainty when they are unaware of possible exposure pathways [2]. If this uncertainty can be reduced, then empirical uncertainty follows [2]: of all possible exposure pathways, which one was the actual source of exposure? We are interested in interfaces and design techniques that help participants explore the space of exposure possibilities and identify which ones are relevant to them.

Specifically, we propose incorporating an expert system into interactive, web-based results reports. By guiding participants through the space of possible exposure pathways and building evidence for each pathway, the expert system will reduce participants’ uncertainty related to exposure sources.
DERBI
Silent Spring Institute developed the Digital Exposure Report-Back Interface (DERBI), a framework for providing online exposure reports to participants of biomonitoring studies [1]. The framework incorporates:

- Exposure graphs that visually display individual chemical levels relative to the study distribution and national averages;
- Syntheses of scientific knowledge about the health effects of chemicals and chemical groups;
- Descriptions of known exposure pathways for chemicals and chemical groups; and
- Exposure reduction suggestions.

Currently, exposure pathways and exposure reduction strategies are presented as a list. Participants can hover over a tip to see how it connects to their individual results. An interactive expert system augments the current interface by taking an evidence-based approach to identifying possible exposure pathways and directing participants to personally-relevant exposure reduction strategies.

Expert System for Source Identification
Expert systems are a model-based approach to inference in which a knowledge base and set of production rules are used to generate new facts. Expert systems have been developed for a range of applications, including medical diagnosis [8, 12], providing smoking cessation recommendations [9], and interpreting results from aquatic biomonitoring [4, 10]. For biomonitoring report-back, an expert system will connect exposure data and personal behaviors to exposure pathways. Participants interact with the system by answering series of yes-no questions.

There are several advantages to using an expert system for interpreting biomonitoring results. Scientific understanding of emerging contaminants is evolving, so any digital representation of this knowledge should be easily updateable. This is straightforward in an expert system through modifying existing rules or adding new ones.

Expert systems can be augmented to incorporate uncertainty in a number of ways, including by associating uncertainty factors with each production.

Figure 1: Exposure reduction tips for flame retardant chemicals as found in a web-based DERBI report
rule [12]. This correlates well with our application because sources of exposure are never certain, especially when exposure is possible through multiple pathways or may have occurred years in the past.

Some rules will require input from the participant, while others will be decidable based on known information, like the participant’s exposure results. For example, a ratio of PCB congeners is predictive of whether the exposure was predominantly from diet, through eating contaminated fish, or other sources [5]. Further questions could build on this, such as by asking participants about how often they eat fish that are suspected of having higher levels of PCBs.

### Table 1: Example expert rules that associate exposure data and personal behaviors to exposure pathways

<table>
<thead>
<tr>
<th>Condition</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>IF participant’s PCB exposure profile is consistent with exposure from diet</td>
<td>THEN PCB exposure may be coming from dietary sources, especially fish [5].</td>
</tr>
<tr>
<td>IF participant has a high level of PCB 11</td>
<td>THEN PCB exposure may be coming from commercial pigments in paints [7].</td>
</tr>
<tr>
<td>IF participant regularly consumes farmed salmon AND has a high level of PCB exposure relative to national averages</td>
<td>THEN PCB exposure may be coming from farmed salmon consumption [6].</td>
</tr>
</tbody>
</table>

### Interface

The system will use a familiar “wizard”-style user interface to guide participants through the expert system process. Questions can have additional information associated with them—for example, describing how to check whether your furniture follows a particular flammability standard, an indicator for flame retardant use. When the expert system identifies a possible exposure source, the participant will be able to view relevant exposure reduction tips, and can choose to continue using the system to identify other possible exposure pathways. It is possible that multiple possible pathways are identified; the system could display a summary of the model findings ordered by relative likelihood. Care is necessary to so that participants don’t overestimate the certainty of the model results. If the system fails to identify a source, the participant will be referred for an interview with a researcher with expertise in exposure science. If new exposure pathways are identified through interviews, they can be added to the expert system’s knowledge base.

### Conclusion

Reporting back biomonitoring results to participants involves the communication of uncertainty not because the data are uncertain, but because the implications of the data are uncertain. This paper addresses the uncertainty related to sources of exposure. Expert systems can help participants by guiding them through the space of possible exposure pathways to ones that are most likely to have caused the exposure.

### References

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