A SCREENING-LEVEL RANKING OF TOXIC CHEMICALS AT LEVELS TYPICALLY FOUND IN INDOOR AIR

PK Johnston[1*], G Hadwen[2], J McCarthy[2] and JR Girman[1]

[1]Indoor Environments Division, U.S. Environmental Protection Agency, Washington, DC, USA
[2]Environmental Health & Engineering, Inc., Newton, MA, USA

ABSTRACT
The U.S. Environmental Protection Agency (EPA) has several programs aimed at addressing radon, environmental tobacco smoke, and several other well-recognized indoor air pollutants. To prioritize activities for other chemicals typically found in indoor air, based on current data, EPA is developing a screening-level, risked-based ranking analysis, which is currently being revised. This paper presents the methodology used, and results found, for the analysis provided in the draft report. While the basic methodology will not change, the final results might be significantly different. In the draft analysis, monitoring data on "typical" levels of pollutants found indoors were combined with publicly available health indices to develop ranking scores for both acute and chronic exposures. Because monitoring data were available for only 112 chemicals and only 59 of the chemicals could be ranked, many chemicals found indoors might rank higher, given more complete information.

INDEX TERMS
Ranking, VOCs and SVOCs, Metals, Monitoring data, Health indices.

INTRODUCTION
The U.S. Environmental Protection Agency (EPA) Office of Air and Radiation (OAR) is currently developing a strategy to assess and mitigate the risks from certain types of chemical pollutants (i.e., the 188 chemicals or classes of chemicals listed as Hazardous Air Pollutants (HAPs) under the Clean Air Act (CAA) and other similar pollutants and mixtures). On July 19, 1999, EPA published a Federal Register notice on the Integrated Urban Strategy of the National Air Toxics Program (64 FR 38706) that listed 33 HAPs or HAP groups believed to pose the greatest threat to public health, in the largest number of urban areas, from outdoor sources. The basis of this list was a Technical Support Document (Smith *et al.*, 1999) that provided a screening-level ranking and selection of HAPs from outdoor sources. A similar analysis had not been done to rank and select chemical pollutants from indoor sources. The focus of this paper is EPA's approach to achieving this objective. This ranking analysis will be a first step in determining the key chemical pollutants typically found in indoor air, based on the data currently available; it will allow EPA to focus its efforts on obtaining more complete information on these chemicals.

It should be noted that this ranking analysis is limited to individual chemicals rather than mixtures (e.g., environmental tobacco smoke, or ETS) and does not include radon, inorganic chemicals, or biological contaminants. EPA already has mature programs to address radon and ETS. If they had been included in this ranking, they would each have ranked about two

* Contact author e-mail: johnston.pauline@epa.gov

orders of magnitude higher than the top-ranked chemicals. Although ETS is not ranked as such, a number of components of this mixture (e.g., formaldehyde, acetaldehyde, and benzene) have been ranked as individual chemicals. Certain inorganic chemicals (e.g., carbon monoxide, ozone, and nitrogen oxides) were excluded from the ranking for programmatic reasons; these are pollutants for which EPA sets National Ambient Air Quality Standards in outdoor air and they do not occur in the CAA list of HAPs. Similarly, biological contaminants are not included on the HAPs list and were not included in the ranking analysis. However, even if EPA were to decide to include biological pollutants in our analysis, we could not rank them using this methodology because there are no currently recognized health indices.

The analysis only addresses inhalation exposures. No attempt has been made in this screening-level assessment to address exposures such as those of a child eating leaded paint or crawling on floors that have been sprayed with pesticides. In addition, it should be made clear that, due to its inherent uncertainties, the ranking is useful only as a relative ranking (i.e., to determine the chemicals in the top tier) versus an absolute ranking (i.e., to perform a 1,2,3… ranking of individual chemicals).

Finally, because monitoring data and health indices are only available for a small number of the thousands of chemicals typically found in indoor air, this analysis is not a final definitive analysis of the key pollutants typically found in indoor air. There may be many chemicals that would rank higher than the chemicals found at the top of the ranking analysis, given full data. As such, the results will be refined as more data are developed; they are a starting point in identifying data gaps that will need to be filled for a more complete understanding.

The EPA Science Advisory Board reviewed a draft version of the ranking analysis (EH&E, 2000). Comments from the review were received in December 2001 (U.S. EPA, 2001), and EPA will be revising the draft analysis based on their comments. This paper will present the methodology used, and results found, for the draft analysis. Although the basic methodology will not change, the final results might be significantly different.

METHODS

The development of the draft ranking analysis was based in large part on the methodology in the Technical Support Document for the Integrated Urban Air Toxics Strategy. Monitoring data for air pollutants (both chemicals listed as HAPs and other chemicals) from ten U.S. studies were used. The studies were performed during the last 10 to 15 years, and focused on non-industrial buildings (i.e., homes, schools, and office buildings). Data were chosen to represent "typical" values that may be expected in the building types studied. Some of the data are from recent analyses performed by EPA in 100 office buildings, using the EPA Building Assessment Survey and Evaluation (BASE) protocol (U.S. EPA, 1994), and in several schools, using a similar protocol. The other data are from additional EPA studies as well as studies by organizations outside of EPA (i.e., the California Air Resources Board and Bell Communications Research). The data span a broad range of chemicals, and include data for metals, aldehydes, volatile organic compounds, and semi-volatile organic compounds (e.g., pesticides, phthalates, and polyaromatic hydrocarbons).

Four subsets of monitoring data from each study were used, when available: "indoor" average (or, alternatively, median) concentrations, "indoor minus outdoor" average (or median) concentrations, "indoor" 95th percentile (or, alternatively, 90th percentile or maximum) concentrations, and "indoor minus outdoor" 95th percentile (or 90th percentile or maximum) concentrations. The use of "indoor minus outdoor" concentrations allowed us to see the

contribution, at a minimum, of indoor sources to the total concentrations indoors (i.e., it assumes that 100% of the concentration outdoors makes its way indoors). Although some studies included personal monitoring data, only area samples were used because the personal monitoring data were not restricted to indoor activities. The monitoring data were used as exposure surrogates and true exposures were not calculated (i.e., exposures were not apportioned by building, population, time-activity pattern, etc.).

Two methods were used to calculate "indoor minus outdoor" concentrations. Where EPA had raw data (i.e., for the EPA BASE and schools studies), the difference between the indoor and outdoor level was calculated for each building. Then, the mean and 95th percentile across all buildings was calculated. For the other studies, the "indoor minus outdoor" values were simply the indoor mean minus the outdoor mean or the indoor 95th percentile minus the outdoor 95th percentile. The latter method may not represent the concentration associated with pollutants from indoor sources as accurately, particularly for the 95th percentile value, because the data are not matched by building.

Pollutants detected indoors at a frequency of less than 10% were excluded from the analyses because of uncertainties involved in determining the mean concentration for these data. Although values must be assigned to samples below the limit of quantitation (LOQ) in determining the mean, the values used by the authors of the ten studies varied (i.e., two studies used 1/8 the LOQ, four studies used ½ the LOQ, and the method used for the remaining 4 studies was not reported). For analytes that are detected infrequently, the values assigned to results less than the LOQ can significantly affect estimates of the mean; however, it cannot be determined which method would provide a more accurate estimate.

To calculate the ranking values, each of the four monitored concentrations, as determined above, was divided by an appropriate "risk-based concentration (RBC)." Details on the general process for the selection of the RBCs can be found in the Technical Support Document, and involved the compilation of acute and/or chronic dose response values from six agencies (i.e., EPA, the Agency for Toxic Substances and Disease Registry, the National Advisory Committee for Acute Exposure Guideline Levels, the American Industrial Hygiene Association, the National Institutes for Occupational Safety and Health, and the California Environmental Protection Agency). The sources of dose-response values were prioritized and the final values were determined based on availability of the dose-response data for each chemical within these prioritized sources. The values for acute and non-cancer dose responses were taken directly from the literature, and represent exposure concentrations (e.g., mg/m^3) considered not to result in significant risk of adverse non-cancer effects. For cancer effects, the upper-bound dose response value was inverted to represent exposure concentrations associated with fixed levels of upper-bound predicted lifetime cancer risk (i.e., 10^{-6} or 10^{-4} lifetime cancer risk). The values calculated for non-cancer and cancer effects were further grouped into "Case 1" and "Case 2" RBCs. When values for both cancer and non-cancer effects were available for a chemical, Case 1 RBCs were the lesser of the cancer value for 10^{-6} lifetime cancer risk and the non-cancer value; Case 2 RBCs were the lesser of the cancer value for 10^{-4} lifetime cancer risk and the non-cancer value. When data were available for only cancer or non-cancer effects, the Case 1 and Case 2 RBCs were based on the respective value.

Following selection of the appropriate RBCs, four ranking values based on chronic toxicity were calculated, where possible, for each chemical in each study by dividing each of the two average, or median, values (for the "indoor" concentration and the "indoor minus outdoor"

concentration) by the two chronic (Case 1 and Case 2) RBCs. Two ranking values based on acute toxicity were calculated by dividing each of the two 95th percentile, or 90th percentile to maximum, values by the acute RBC. In cases where there were monitoring data for a chemical in more than one study, the ranking values calculated for each study were averaged to provide one result.

RESULTS

As stated previously, the uncertainties in this analysis allow for a relative ranking only. Therefore, rather than presenting the numerical results found in the draft report, the chemicals which fell within two orders of magnitude below the top score for the chronic analyses are presented. Eighteen chemicals occurred at the top of both the "indoor" Case 1 and Case 2 analyses. These included two aldehydes (acetaldehyde and formaldehyde), seven pesticides [aldrin, alpha- and gamma-BHC, chlordane, dichlorvos, dieldrin, and heptachlor], four chlorinated solvents [carbon tetrachloride, methylene chloride (or dichloromethane), tetrachloroethylene (or perchloroethylene), and trichloroethylene], arsenic, benzene, chloroform, chloromethane (or methyl chloride), and 1,4-dichlorobenzene. All of these chemicals scored high in the Case 1 analysis for cancer effects; acetaldehyde, gamma-BHC, chlordane, and dichlorvos scored high in the Case 2 analysis for non-cancer effects. Nine additional chemicals at the top of the "indoor" chronic Case 2 analysis included two chlorofluorocarbons (dichlorodifluoromethane and trichlorofluoromethane), n-hexane, manganese, 4-methyl-2-pentanone (or methyl isobutyl ketone), naphthalene, toluene, 1,1,1-trichloroethane (or methyl chloroform), and mixed xylenes. These chemicals ranked high in the Case 2 analysis for effects other than cancer. Based on the "indoor minus outdoor" analyses, four of these chemicals (arsenic, carbon tetrachloride, chloromethane, and manganese) appear to originate predominately outdoors. How well these chemicals represent the "top" tier of the chronic analyses depends on both the uncertainties in the monitoring data (and their use as an exposure surrogate) and in the RBCs. As far as the latter are concerned, there is variability among science policy decisions that are made to address uncertainties in the dose-response assessments from which the RBCs are drawn. The impacts of uncertainties in both the monitoring data and the RBCs on the ranking analysis will be assessed more fully as part of the final ranking. It is believed, however, that the uncertainties will be less for the chronic analyses than for the acute analyses.

The results of the acute analyses from the draft report are not presented here; acute RBCs for the same chemical may vary between agencies more than the chronic RBCs. In addition, there is more uncertainty in the determination of the concentration at the 95th percentile (or 90th percentile or maximum), the exposure surrogate used in the acute ranking, than in the determination of the mean (or median) concentration, the exposure surrogate used in the chronic ranking. A further analysis of these uncertainties and their impact on the acute ranking is warranted.

DISCUSSION

Limitations and uncertainties

Although care has been taken in the selection of the studies to be included in the ranking analysis and in its design, this "screening-level" analysis has a number of limitations and uncertainties. For example, as discussed above, the ranking analysis does not include all chemicals found in indoor air. Therefore, there may be some chemicals that present important risks indoors that will not be found by this analysis. In addition, it is important to understand that this analysis is meant only to provide a "relative" rather than an "absolute" ranking. Assessments of some of the limitations and uncertainties in the ranking analysis will be

performed as we respond to comments provided on the draft report; however, some will remain. It should be noted that most of the limitations and uncertainties in this relative ranking are important only to the extent that they may result in substantial mis-ranking. The key question is: how often might one focus on a pollutant that poses a relatively low risk at the expense of one with a relatively high risk?

There are a number of limitations and uncertainties related to the monitoring data and its use as an exposure surrogate. Although EPA has attempted to select monitoring studies that provide typical levels of, and potential exposures to, toxic chemicals in indoor air, the data provided may not, indeed, be "typical." Some of the data come from studies in specific geographic regions rather than across the whole United States, and all of the data are from studies in residences, office buildings, and schools. All indoor environments (e.g., shopping malls, restaurants, and day care centers) are not represented, and data for each chemical may be from only one or two of the three main environments or from only one or two of the ten studies. The assumption has been made that, in general, the typical levels in each of these buildings are comparable. No attempt has been made in this screening-level analysis to apportion the data based on time spent in any individual environment. Neither has there been an attempt to apportion solely the time spent indoors versus outdoors, in part because the time spent indoors is generally much greater than that spent outdoors (approximately 90%). Area data were used instead of personal data. Some of the data are older and may not represent current levels in indoor air (e.g., banned pesticides, toxic chemicals that have been removed from products). Some uncertainties have also resulted from data manipulations (e.g., differences between studies in the methods to calculate the mean or to calculate the “indoor minus outdoor” values, or use of a maximum value when a 95^{th} percentile value was not available). In addition, short-term samples were used to estimate chronic exposures and may not have captured temporal variability in pollutant concentrations (e.g., seasonal application of pesticides or variations in formaldehyde concentrations as pressed wood products age). Finally, data for metals did not include speciation data; because the hazard indices for metals are generally for the most toxic species, rankings for metals tend to be “worst case.”

The RBCs also have uncertainties associated with them. The determination of the RBCs was dependent upon a prioritization scheme. Inconsistencies in the policies of the agencies that determine the RBCs may effect the prioritization, as discussed above. In addition, many of the chemicals in the ranking analysis have not yet been subjected to sufficient toxicological testing, and existing results for others have not yet been developed into dose-response assessments.

It should also be noted that this ranking analysis focuses on “typical” levels of exposure and effects on the general population. As such, even with refinements, this analysis tends not to select pollutants that may occur at very high levels indoors under certain exposure scenarios (e.g., chemical exposures from businesses co-located with residences, or the infrequent use of high-emitting products indoors). Additional studies must continue to evaluate high-level scenarios of concern and to determine the potential risks from them.

Use of the final ranking and selection

Data gaps in the ranking analysis will focus research efforts in many areas (source characterization, exposure assessment, hazard identification, dose-response assessment, and risk assessment). The analysis will also allow EPA to focus its voluntary risk reduction efforts. Factors to be considered in assessing potential risks and risk management options include the sources of the chemicals, disproportionate risks to certain populations (e.g.,

children and minorities), the ease of implementation, and whether others are addressing the risks.

CONCLUSIONS AND IMPLICATIONS

EPA has several programs aimed at addressing radon, ETS, and several other well-recognized indoor air pollutants of concern. To assist in prioritizing other activities, EPA is developing a screening-level, risk-based ranking analysis to rank other toxic chemicals typically found in indoor air, based on currently available information.

ACKNOWLEDGEMENTS

The authors would like to acknowledge Deirdre Murphy and Roy Smith in the EPA Office of Air Quality Planning and Standards for their input in developing the prioritization scheme for the health indices used for the RBCs.

This study was supported by the U.S. Environmental Protection Agency (EPA) but was not subjected to EPA's formal peer review. The conclusions of this paper are those of the authors and are not necessarily those of the EPA.

REFERENCES

EH&E. 2000. *Ranking Air Toxics Indoors.* Draft Report. Prepared for the Indoor Environments Division, U.S. Environmental Protection Agency, by Environmental Health & Engineering, Inc., Newton, MA. EH&E Report #11863.

Smith RL, French CL, Murphy DL, and Thompson R. 1999. *Ranking and Selection of Hazardous Air Pollutants For Listing Under Section 112(k) of the Clean Air Act Amendments of 1990*. Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, July 28, 1999. http://www.epa.gov/ttn/atw/urban/urbanpg.html (as accessed in January 2002).

U.S. EPA. 2001. *Review of the Office of Radiation and Indoor Air's Draft Methodology for Ranking Indoor Air Toxics: An SAB Report. A Review by the Environmental Health and Integrated Human Exposure Committees of the EPA Science Advisory Board (SAB).* Washington, DC: EPA Science Advisory Board, U.S. Environmental Protection Agency. EPA-SAB-EHC/IHEC-02-004. http://www.epa.gov/sab/fiscal02.htm (as accessed in January 2002).

U.S. EPA. 1994. *A Standardized EPA Protocol for Characterizing Indoor Air in Large Office Buildings*. Washington, DC: Office of Research and Development and Office of Air and Radiation, U.S. Environmental Protection Agency.