Inhalation Exposure to Contaminants From a Water Distribution System

INTRODUCTION

When contaminants are present, various studies have shown that a number of activities involving the use of drinking water potentially can release harmful amounts of volatile contaminants or generate aerosols that contain contaminants. Showering and the use of ultrasonic humidifiers have been shown to produce substantial quantities of aerosols. Ultrasonic humidifiers, which create a cool mist by means of ultrasonic vibration, can release larger amounts of both microorganisms and dissolved minerals than steam vaporizors. Volatile contaminants can also be inhaled during showering. During a contamination incident in a water distribution system, individuals engaged in showering or humidifier use could potentially inhale large quantities of contaminated aerosol particles or volatile chemicals. To address this concern a software capability was developed to allow the system-wide quantification of potential adverse health effects associated with inhalation exposure during showering and during the use of ultrasonic humidifiers. This capability has been incorporated into the consequence estimation module (CEM) of the U.S. Environmental Protection Agency's (EPA's) Threat Ensemble Vulnerability Assessment, Sensor Placement Optimization Tool (TEVA-SPOT) (See Figure 1). This advancement represents a major step forward in the capability to quantitatively assess the consequences from inhalation exposures associated with the use of contaminated drinking water.

APPROACH

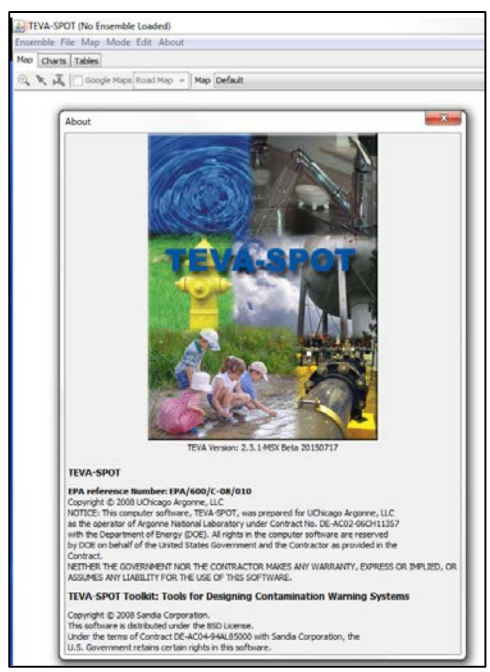

Figure 1. TEVA-SPOT's "About Box."

Drinking water distribution systems (WDS) can be contaminated either intentionally or unintentionally. WDS contamination has the potential to cause adverse health effects in the population and numerous studies have considered such ingestion consequences. The potential also exists for short-term inhalation exposures to elevated air concentrations of contaminants during a contamination incident. Various domestic uses of water can release volatile contaminants or generate contaminated aerosols. The largest inhalation exposures to volatile contaminants in water result from showering (Hines, SA, et al., 2013). The EPA's Homeland Security Research Program (HSRP) conducted a screening-level assessment of the relative potential for inhalation exposure to aerosol-borne contaminants associated with common water uses and found that ultrasonic and cool mist (impeller) humidifiers and showering produce the highest exposure doses (Hines, SA, et al., 2013). (Cool mist (impeller) humidifiers were found to be slightly less important than ultrasonic humidifiers.) Unlike

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ingestion exposures, potential inhalation exposures during a water distribution system contamination incident have received little attention.

A flexible, extensible analytical framework was developed to quantify the consequences of contamination incidents (Davis et al., 2014). It relies on the use of the TEVA-SPOT software for situations in which substantial system-specific information is available. This technical brief outlines modifications to TEVA-SPOT that were made to enable modeling of the system-wide adverse human health effects associated with inhalation exposure to microbial and chemical contaminants. Both volatile and non-volatile chemical contaminants are considered in the model. Various studies have examined the inhalation of volatile chemicals and aerosols produced by showering and the use of humidifiers. However, the results of these studies have not been used to assess system-wide health effects during a contamination incident.

The TEVA-SPOT analysis framework was expanded to determine these inhalation-related consequences. To determine the inhalation-related adverse effects requires estimating the quantity of contaminant that is inhaled by individuals who use water from the WDS. Obtaining such an estimate requires estimating the water and air concentrations of the contaminant at the locations where exposures occur and accounting for the behavior of the individuals at those locations.

Exposures during a contamination incident may occur over a short period of time and the timing of the actual exposures is important because of the changing contaminant concentration in the water. Consequently, the incorporation of an inhalation showering pathway into the analytical framework of TEVA-SPOT required the development of a timing model for showering and the use of statistical models for frequency and duration of showering incidents. Data on humidifier use is much less developed than for showering. Therefore, a more simplified behavior model was developed for humidifiers to allow sensitivity analyses to be carried out to determine how the parameters describing humidifier use influence potential system-wide consequences. Additionally, TEVA-SPOT's CEM was expanded to allow the user to easily perform Monte Carlo analyses (e.g., for uncertainty and sensitivity analyses).

FEATURES OF APPROACH

The capability to estimate exposure, dose, and consequences associated with inhalation during showering and ultrasonic humidifier use was incorporated into the CEM of TEVA-SPOT. A five step process is used for assessing inhalation exposures and determining consequences. First, TEVA-SPOT estimates contaminant concentrations in water at points of water use throughout the WDS during the contamination incident (see Figure 2 which shows water concentrations of a contaminant versus time at two different receptor locations in a WDS during a contamination incident). Next, TEVA-SPOT accounts for the behavior of individuals using water from the system. In step 3, TEVA-SPOT estimates the air concentrations of contaminants at points of exposure at the time when individuals are using water. In step 4, TEVA-SPOT estimates potential inhalation doses for individuals. Finally, in step 5, TEVA-SPOT determines the statistics for water system-wide consequences.

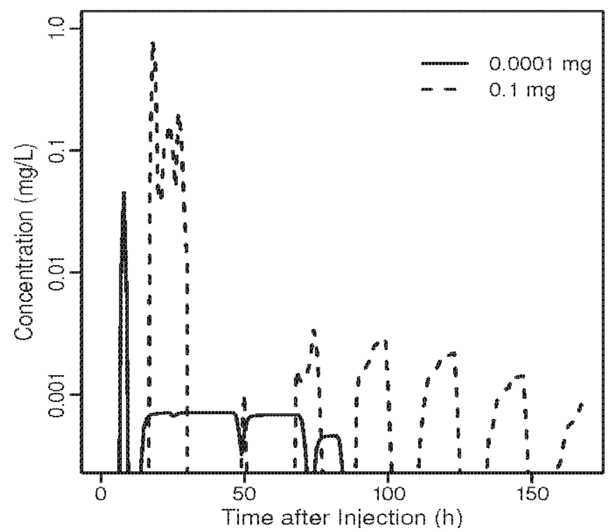

Figure 2. Illustration of temporal nature of contaminant concentrations at two different receptor locations in a WDS during a contamination incident.

A capability was added to TEVA-SPOT to account for the behavior of individuals associated with showering and ultrasonic humidifier use. Figure 3 shows a probability density function for daily starting times for showering incidents developed using data collected by time-use surveys (ATUS, 2013).

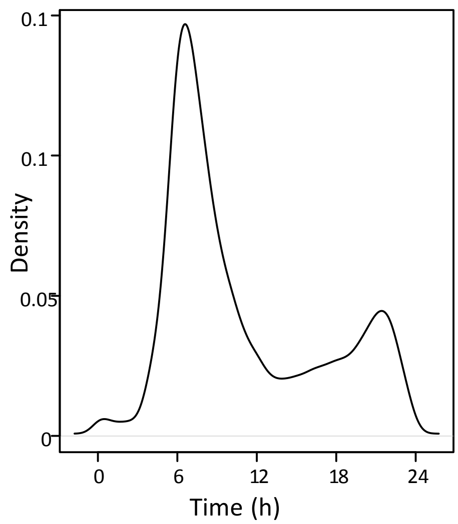

Figure 3. Probability density function for the starting times of single, daily showering incidents developed with time-use data collected by the U.S. Census Bureau.

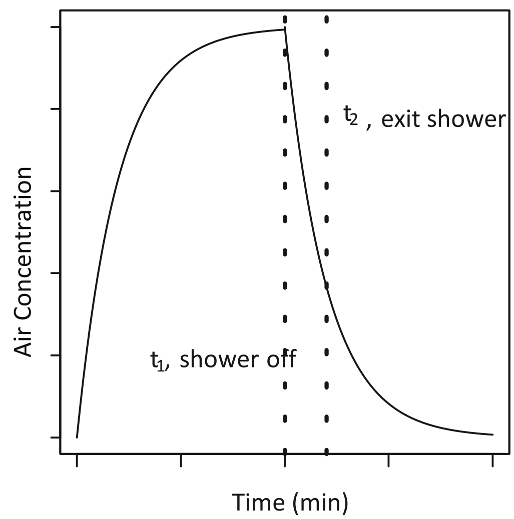

Figure 4. Showering inhalation model accounts for the time variability of air concentration of a contaminant during showering.

The plot in Figure 3 shows starting times for single showering incidents (i.e., a person takes only one shower each day). Models were also developed and incorporated into TEVA-SPOT that estimate air concentrations of contaminants at points of exposure when contaminated water is being used. Figure 4 illustrates how the air concentration of a contaminant varies with time during showering and after the shower is turned off.

These various models were incorporated into TEVA-SPOT to allow inhalation doses to be estimated for individuals. Statistics for water system-wide consequence can then be determined. Figure 5 is a screen capture of TEVA-SPOT's new exposure pathway module - inhalation from showering. On the left side of the panel the user enters parameter values and inputs (i.e., dose levels) for determining consequences based on dose level; the right side of the panel (if selected) has parameter inputs that are used to obtain dose response (i.e., some defined health effect end point) based consequences. The screen capture shows example parameter inputs for a volatile chemical.

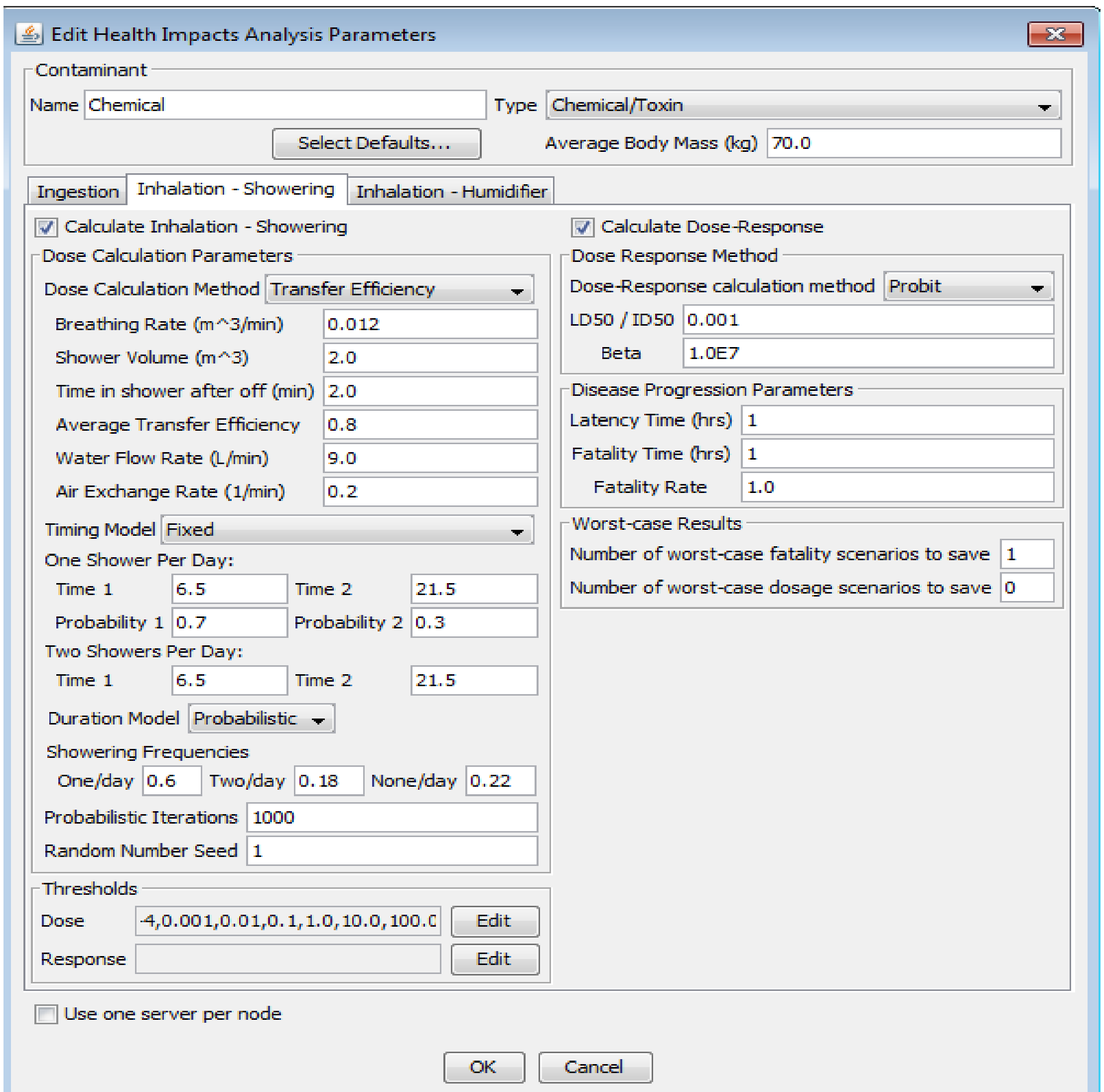

Figure 5. Screen capture from TEVA-SPOT's CEM showing example parameter inputs for a volatile chemical.

FURTHER DEVELOPMENT

The TEVA-SPOT analysis framework is flexible and readily extended, so, if desired, it can accommodate future enhancements related to improved network models, improved models for the behavior of individuals, and the consideration of additional sources of microbial and volatile and non-volatile chemical contaminants.

FOR MORE INFORMATION

TEVA-SPOT is an open source software program composed of software modules. TEVA-SPOT uses EPANET (Rossman, 2000) to simulate contaminant transport in a water distribution system.

TEVA-SPOT can be obtained from EPA website (http://www.epa.gov/nhsrc/index.htm). The intended audience for this tool is water utilities and those supporting water utilities interested in assessing population-based consequences from inhalation of microbial and volatile and non-volatile chemical contaminants from drinking water.

To learn more contact Robert Janke (janke.robert@epa.gov) or visit our website (http://openwateranalytics.github.io/epanet-rtx/index.html) for underlying TEVA-SPOT and EPANET modules' source code.

If you have difficulty accessing this PDF document, please contact Kathy Nickel (Nickel.Kathy@epa.gov) or Amelia McCall (McCall.Amelia@epa.gov) for assistance.

REFERENCES

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Disclaimer

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