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Estimating Toxic Risk Exposure to Populations Inside Buildings

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Baker Engineering and Risk Consultants, Inc. (BakerRisk) has performed quantitative risk analyses (QRAs) for many facilities including companies handling anhydrous ammonia and other toxic materials. This paper compares several methods of estimating toxic risk exposure to personnel located within buildings.

Historically, toxic risk impacts have been assessed simplistically by developing geographic contours for threshold values and applying corresponding vulnerability values for personnel within those areas (e.g., a dose function is applied by assuming an exposure time). Building occupants were treated in a similar manner as outdoor personnel, although mitigation factors were often applied to credit toxic gas detection, ventilation isolation, and protective equipment such as escape packs.

Using a detailed method of evaluating toxic risks to personnel in buildings accounts for the calculated concentration at the building for each scenario, ventilation intake rate, ventilation isolation reliability, leak tightness of the building, lethality of the toxin, duration of the release, protective equipment, and clean purge air supplies, as applicable. In addition, rather than plotting the impact area and assessing it in a series of directions, the detailed method calculates the probability of directionalities of interest. This eliminates issues with long, narrow toxic plume "petals" that can result in toxic risks being underestimated.

This presentation provides an overview of simple vs. detailed toxic risk analysis methods. An example case will show how calculations are performed and how results are presented. A series of sensitivities will be discussed to explain how effective various potential mitigation strategies would be in improving safety.

1. Typical toxic impact calculations

Figure 1 shows a typical toxic dispersion prediction along with several buildings within the toxic plume. In this example, the toxic material is ammonia. A typical method of predicting consequences for this type of toxic exposure is to assume indoor concentration is the same as outdoors and apply a probit equation to the assumed exposure duration for the category of concentration. In the example shown in Figure 1, Building 1 is in the "low" consequence (probability of death) plume while Buildings 2 and 3 are in the "medium" consequence plume. No buildings are in the "high" consequence plume.

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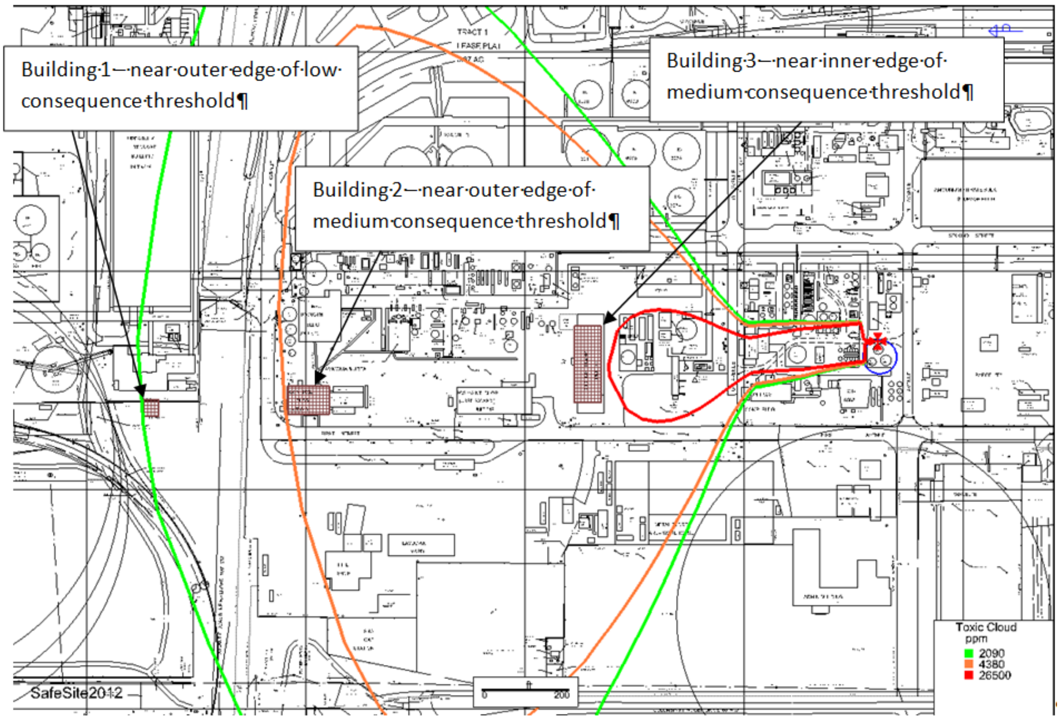

Figure 1: Typical toxic plume prediction

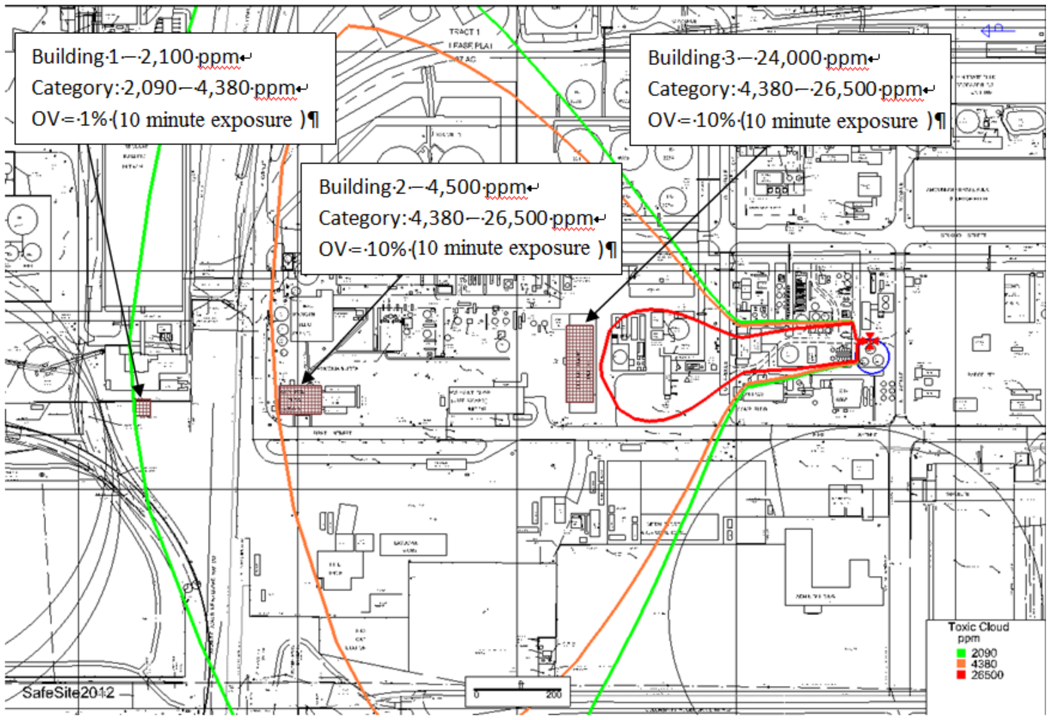

Figure 2: Toxic concentrations vs. concentration categories

Consequences may be reported for occupants by assuming they evacuate the building, even if they would actually shelter-in-place. This is not a very good representation of what really occurs. People who shelter-in-place should be assumed to remain in the building and continue being exposed by the hazard for as long as the hazard is present (function of isolation time and blowdown duration).
Figure 2 shows the difference between toxic concentrations calculated for buildings and concentration categories for those buildings.
Categorizing toxic concentration can lead to dramatic discrepancies between predicted severity and actual severity of a given hazard. In Figure 2, Buildings 2 and 3 are both categorized as medium consequence (assigned 10 % vulnerability), but the concentration at Building 3 is significantly higher than at Building 2. The vulnerability values also do not account for HVAC isolation reliability or building leak tightness.

2. Enhanced toxic impact calculations

Using a detailed method of evaluating toxic risks to personnel in buildings means accounting for the specific concentration predicted at the building for each scenario rather than the concentration category. It also requires building specific information such as ventilation intake rate, ventilation isolation reliability, and building leak tightness to be factored into calculations. Wind speed should also be addressed to account for its impact on infiltration rate. The release duration should be used to determine the exposure time. The resulting indoor concentration versus time profile, along with material toxicity forms the basis for a defensible and realistic occupant vulnerability (OV) calculation. As applicable, mitigation factors can be applied to account for protective equipment.

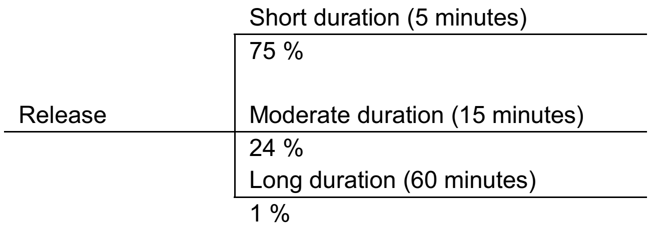

Figure 3: Simple event tree of example conditional probabilities for release duration

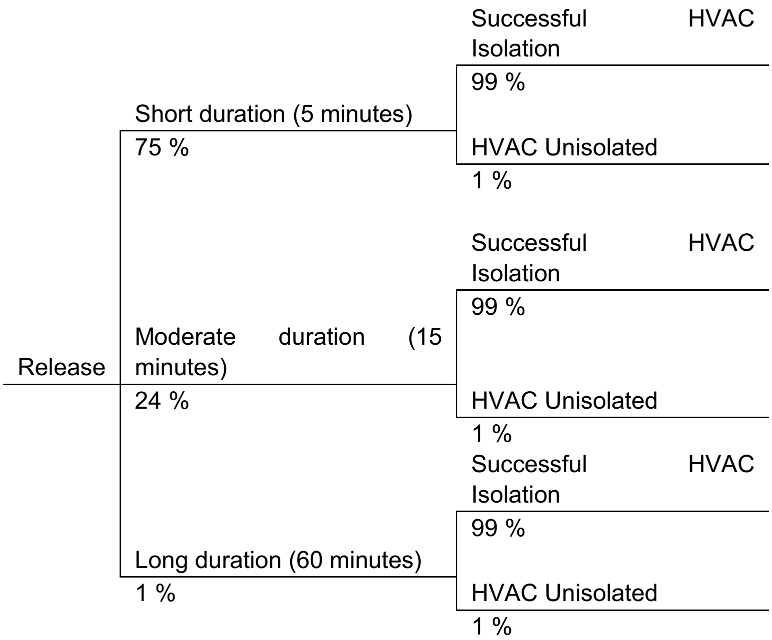

Figure 4: Event tree of example conditional probabilities

To provide an accurate risk result for a given toxic release scenario, a range of likely release durations and associated conditional probabilities should be assessed. For example, a release may be modeled as a 5 minute duration (rapid isolation and limited inventory blowdown) with a 75 % conditional probability, 15 minute release (delayed isolation) with a 24 % conditional probability, and 60 minute release (long duration) for the remaining 1 %. See the example event tree in Figure 3.

A building's ventilation and infiltration characteristics should be explicitly modeled in an enhanced toxic risk calculation. For example, a building may have 6 air changes per hour (ACH) of forced ventilation with 10 % of that flow coming from fresh air (ingression = 0.6 ACH), which is typical for an office building, and tests may show that its air exchange rate due to infiltration is 0.3 ACH with 5 mph winds outside. Detection of toxics may be detected at HVAC inlets and alarms alert occupants to trip the HVAC system, which have been determined to occur with 99 % reliability (Figure 4).

The indoor concentrations as a function of time for the 60 minute release case with and without HVAC isolation are shown in Figure 5.

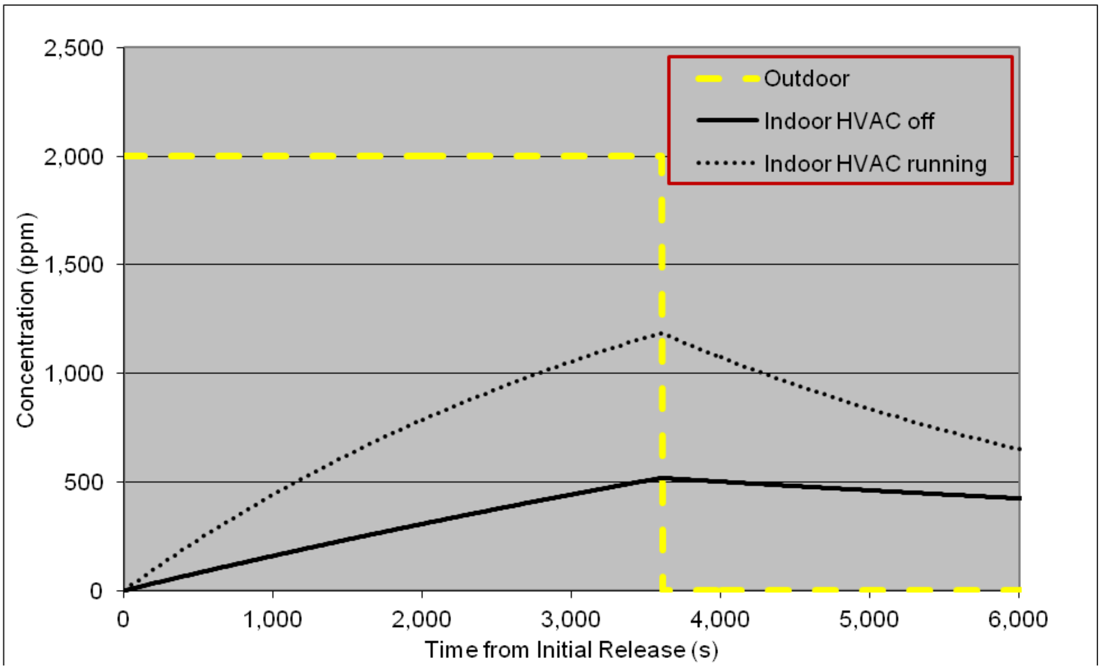

Figure 5: Building 3 indoor concentration vs. time

Consequences of being exposed to these concentration profiles as well as 5 and 30 minute release profiles (same shapes but end earlier on the graph) are calculated by applying the integral (area under the curve) of the corresponding probit equation for the chemical. The scenario is split into multiple possible cases for the enhanced calculation (multiple durations, HVAC on or off), and each case is assessed for likelihood and consequence. Results are added to give a better picture of toxic risk to building occupants.

3. Comparison of results

Results of an enhanced toxic risk exposure calculation can be dramatically higher or lower than results from a simplified analysis. However, results from the enhanced method are more defensible and should be more accurate. Table 1 provides a comparison of results of the example case described above, based on a standard simplified toxic risk calculation method and the enhanced method described above. (Blank cells indicate negligible vulnerability.)

Table 1: Comparison of results from simplified and enhanced methods

Bldg	Duration	OV - Traditional	OV - Enhanced
1	5 min	1 %	
	15 min		
	60 min		
2	5 min	10 %	
	15 min		
	60 min		0.2 %
3	5 min	10 %	
	15 min		0.3 %
	60 min		21 %

Notice that the traditional (simple) method is generally very conservative, although it can also be nonconservative. The case where the building is at the high end of the concentration category and the release lasts longer than the assumed generic exposure duration (last row of the table) shows that traditional toxic impact calculations may predict only 10 % vulnerability while a more detailed impact calculation predicts 21 % vulnerability.

By implementing the enhanced calculation method, indoor toxic risks are more accurately predicted. This means attention is better focused on areas of true concern. In addition, the method provides a robust way of quantifying the potential safety benefit of implementing risk mitigation strategies such as more reliable toxic gas detection and timely HVAC isolation capabilities, better leak tightness of the building, more rapid detection and isolation of the toxic source, etc. This results in better input to decisions regarding safety improvements and project priorities.

Following is a summary of significant advantages gained by performing enhanced indoor toxic risk calculations instead of following traditional calculation methods:

- Enhanced calculations account for release duration and wind speed, which are typically not explicitly addressed in traditional indoor toxic impact calculations. These key parameters have a significant impact on indoor concentration and are required to accurately predict consequences and risk.
- Enhanced calculations explicitly factor HVAC ingression rate, HVAC isolation reliability, and building leak tightness into risk calculations. Traditional calculations typically use unsubstantiated factors to account for these parameters or may not address them at all. By explicitly calculating the effect of these parameters on risk results, sensitivity studies can be performed.
- Enhanced calculations use the predicted concentration at the building rather than the concentration category as input to consequence calculations. This refinement produces more accurate results and generally reduces conservatism.

4. Conclusion

Indoor toxic impact calculations have traditionally been performed using simplified methods that fail to provide a means to quantify the safety benefit of implementing typical risk mitigation strategies. Results of traditional toxic risk calculations tend to give conservative results that can cause facilities to designate disproportionate resources to mitigating toxic hazards than hazards that are modelled more accurately. Enhanced toxic risk calculations provide a means of accurately quantifying toxic risk to building occupants. They also enable sensitivity studies to be performed to quantify safety benefits available through implementation of potential mitigation strategies.

By accurately assessing toxic risks to building occupants and evaluating safety benefits available through implementation of potential mitigation strategies, management can properly select and prioritize projects to optimize safety.

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