Parameters influencing bystander exposure to nicotine in the indoor ambient air during use of an e-cigarette

G. O'Connell[1], S. Colard[1,2], T. Verron[2], X. Cahours[2], and J.D. Pritchard[1]

[1]Imperial Tobacco Limited, Winterstoke Road, Bristol BS3 2LL, UK
[2]SEITA, Imperial Tobacco Group, 48 rue Danton, 45404 Fleury-les-Aubrais, France

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1. Introduction

There is currently a debate on whether the aerosol exhaled following the use of e-cigarettes has implications for the quality of air breathed by bystanders.

We previously developed an air quality model based on a series of equations describing the relationship between the concentration of nicotine in the indoor air from intermittent use of an e-cigarette, the release rate and the factors affecting the dispersion and dilution in the indoor air. Such factors considered include the volume of the indoor environment, the effective air exchange rate and the rate of nicotine loss due to surface deposition. The current work builds upon the air quality model presented previously at the Global Forum on Nicotine conference, Poland 2014 [1].

We used this model to predict bystander exposure to nicotine in the ambient air during use of an e-cigarette in a simulated office environment.

When developing the model a number of parameters were considered including the:

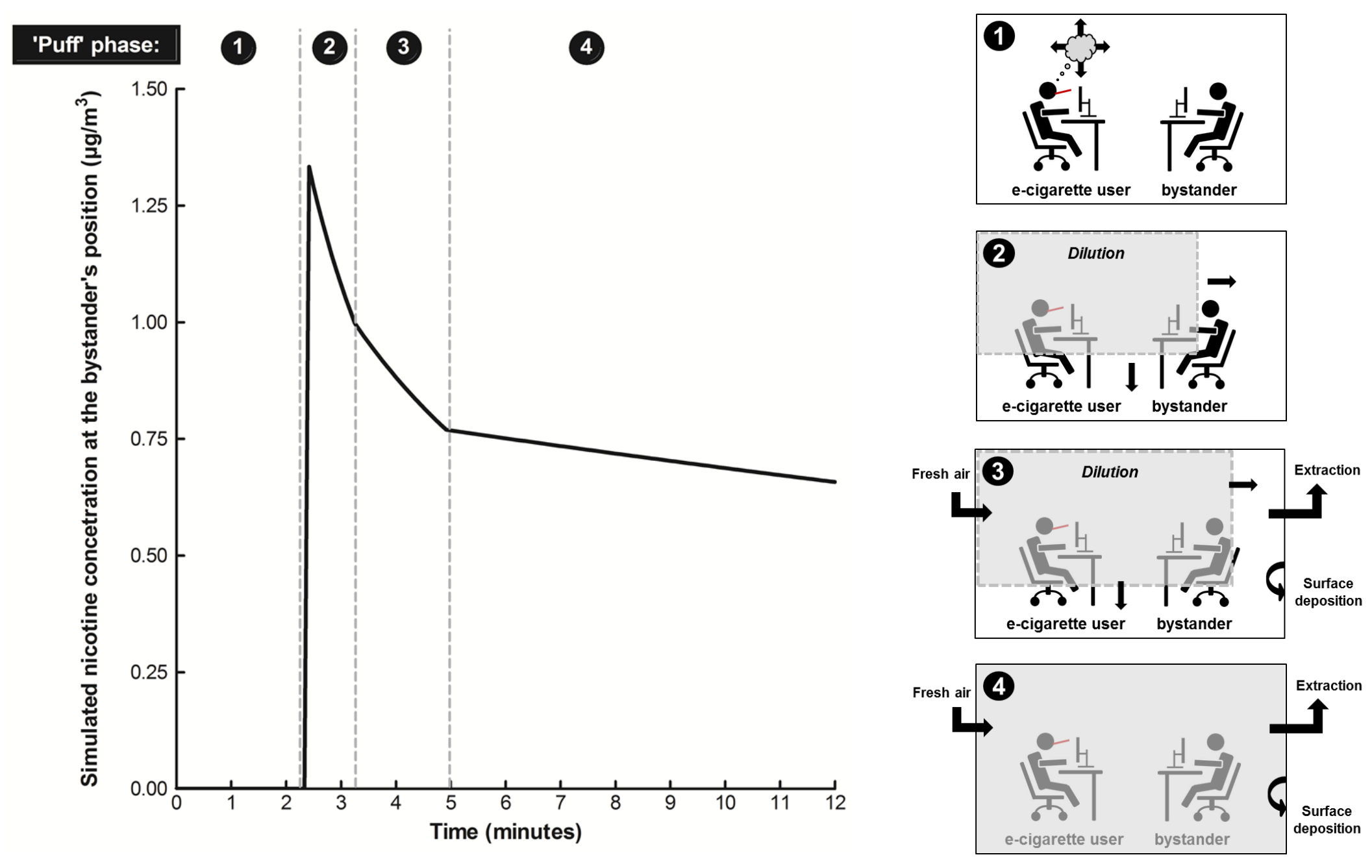
- distance of the e-cigarette user relative to the bystander;
- quantity of nicotine in the exhaled aerosol;
- speed of exhaled aerosol propagation (in the direction of the bystander);
- indoor air exchange rate; and
- speed of exhaled aerosol nicotine deposition.

Here we consider the contribution each of these parameters has on the level of nicotine in the indoor ambient air and therefore bystander exposure.

2. Phases of bystander exposure to exhaled e-cigarette aerosol after a single 'puff': model output

When an e-cigarette user takes a 'puff', the nicotine-containing aerosol is inhaled and a fraction of nicotine is retained by the user. The remaining aerosol is then exhaled, where it is propagated and diluted in the indoor ambient air.

Using the air quality model, four distinct phases of bystander exposure are identified following a single 'puff' and exhalation event (**Figure 1**). The model output is characterised by a peak in nicotine concentration when the exhaled aerosol first reaches the bystander then declines due to aerosol propagation, dilution and any potential surface deposition of nicotine.



Phases of bystander exposure to exhaled aerosol

Phase 1, e-cigarette user takes a single 'puff', inhales the nicotine-containing aerosol and exhales an aerosol into the air which propagates in all directions; bystander is not yet exposed to nicotine in the ambient air.

Phase 2, the peak exposure to nicotine occurs when the exhaled aerosol reaches the bystander; propagation of the exhaled aerosol in the indoor air is not yet complete.

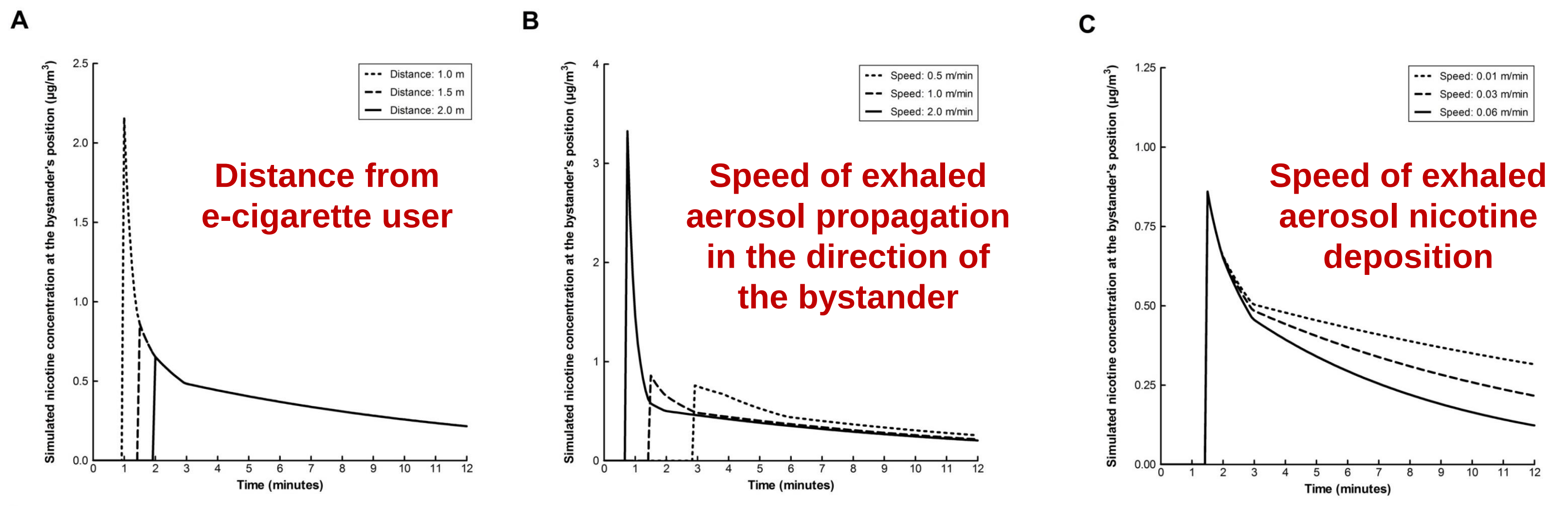
Phase 3, the indoor air exchange begins. There is a reduction in the concentration of nicotine at the bystander's position due to a combination of factors including aerosol propagation, air extraction and any surface deposition of nicotine.

Phase 4, there is a continued reduction in the concentration of nicotine in the ambient air at the bystander's position.

Figure 1 Model output: concentration of nicotine in the indoor ambient air at the bystander's position following exhalation of a single 'puff'.

Model assumptions: the e-cigarette user and bystander are situated 2 m from each other in the same room; the e-cigarette user inhales 60 µg nicotine per puff and retains 50% (the typical nicotine retention rate by e-cigarette users remains unknown); the exhaled aerosol propagates at 0.6 m/min; the room air exchange rate is 1.33 air changes per hour with the air extraction effect beginning once the exhaled aerosol generated by the single 'puff' has been diluted within 80% of the room's volume and that no indoor air is recycled after extraction; and the speed of exhaled aerosol nicotine deposition is 0.06 m/min.

3. Parameters influencing the concentration of nicotine in the indoor air at the bystander's position



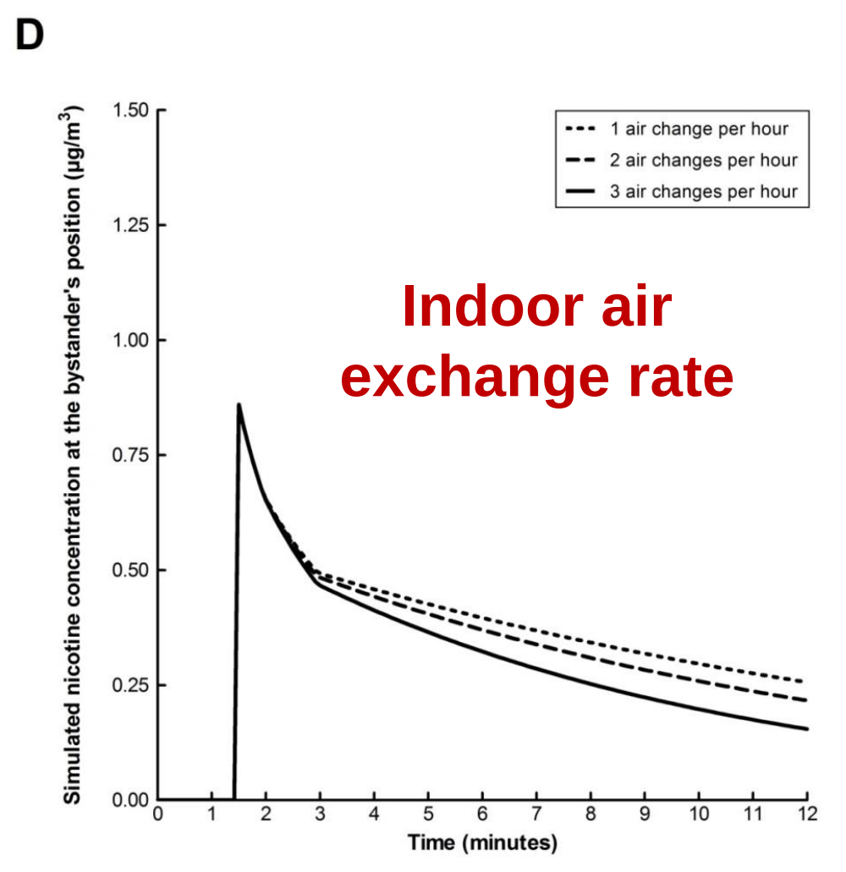


Figure 2 The effect of varying the value of each model parameter in turn, whilst all others remain constant after a single 'puff'.

The effect of changing (**A**) the distance of the bystander from the e-cigarette user from 1, 1.5 and 2 m; (**B**) speed of exhaled aerosol propagation in the direction of the bystander from 0.5, 1.0 and 2.0 m/min; (**C**) speed of exhaled aerosol nicotine deposition from 0.01, 0.03 and 0.06 m/min; and (**D**) air exchange rate from 1, 2 and 3 air changes per hour on the simulated concentration of nicotine in the ambient air at the bystander's position.

When the model parameter value was not varied, it was fixed at the median value i.e. distance from e-cigarette user, 1.5 m; quantity of nicotine exhaled, 20 µg per puff; speed of exhaled aerosol propagation, 1.0 m/min; exhaled aerosol deposition velocity 0.03 m/min; and air exchanges per hour, 2. In all cases the e-cigarette user inhaled 60 µg nicotine with a 50% retention rate (the typical nicotine retention rate by e-cigarette users remains unknown) and exhaled the aerosol into a 37.5 m^3 room.

Our model considers a number of parameters including: (i) the distance of the bystander from the e-cigarette user; (ii) the speed of exhaled aerosol propagation (in the direction of the bystander); (iii) the speed of exhaled aerosol nicotine deposition; (iv) the indoor air exchange rate; and (v) the quantity of nicotine exhaled by the e-cigarette user. Here, the effect of varying the value of each of the model parameters in turn to low, medium or high value (whilst the other parameter values remain constant and fixed at their median value) on the concentration of nicotine in the ambient indoor air during use of an e-cigarette is explored. **Figure 2** shows each individual parameter effects the concentration of nicotine in the ambient air at the bystander's position and how modification of the parameter value influences bystander exposure.

(**A**) ***Distance from e-cigarette user***: the concentration of nicotine in the ambient air at the bystander's position is increased when the distance between the bystander and the e-cigarette user is reduced due to reduced dilution of the exhaled aerosol in a reduced volume of ambient air.

(**B**) ***Speed of exhaled aerosol propagation in the direction of the bystander***: the time taken for the exhaled aerosol to reach the bystander is reduced as the speed of aerosol propagation is increased therefore the maximum concentration of nicotine in the air at the bystander's position is increased. The faster the speed of dilution of the exhaled aerosol, the quicker the decrease in nicotine concentration at the bystander. By calculating the integrals of the curves over a one hour period, the changing speed of exhaled aerosol propagation has little effect on the bystander's exposure: 10.3 µg/m^3/min with a speed of aerosol propagation at 0.5 m/min; 10.8 µg/m^3/min at 1 m/min and 13.3 µg/m^3/min at 2 m/min.

(**C**) ***Speed of exhaled aerosol nicotine deposition***: when the speed of exhaled aerosol deposition is increased from 0.01 to 0.06 m/min, the concentration of nicotine at the bystander's position is decreased and thus the bystander's exposure is reduced from 17.8 to 6.1 µg/m^3/min over a one hour period, respectively.

(**D**) ***Indoor air exchange rate***: the concentration of nicotine in the ambient air at the bystander's position is reduced more rapidly when the number of indoor air changes per hour is increased.

Quantity of nicotine exhaled (data not shown): the concentration of nicotine at the bystander's position is directly proportional to the quantity of nicotine exhaled. When the quantity of nicotine exhaled is increased for 10 to 30 µg, the bystander's exposure is increased from 3.4 to 10.2 µg/m^3/min, respectively.

4. Effect of varying all model parameters on bystander exposure

In Section 3 we evaluated the impact of varying a single parameter in the model on the concentration of nicotine in the ambient air at the bystander's position. Here, we examine the collective effect of varying all five parameters concurrently over an 8 hour working day (including a 1 hour lunch break) in a 37.5 m^3 office where the e-cigarette user takes a single 'puff' once every five minutes.

A dataset was generated by assigning each parameter within the model three values, "low (L)", "medium (M)" and "high (H)", resulting in a total of 243 (3^5) unique modelled scenarios which collectively predicts the range of average nicotine concentrations in ambient air over 8 hours in the workplace. **Figure 3A** demonstrates that across all 243 scenarios, the lowest average 8 hour nicotine concentration (Nic_{LOW}) in the ambient air was 0.2 µg/m^3 (where quantity of nicotine exhaled, L; speed of exhaled aerosol propagation in the bystander's direction, L; speed of exhaled aerosol nicotine deposition, H; distance from e-cigarette user, H; and indoor air exchange rate, H). Conversely, the highest average 8 hour nicotine concentration (Nic_{HIGH}) in the ambient air was 5.8 µg/m^3 (where quantity of nicotine exhaled, H; speed of exhaled aerosol propagation in the bystander's position, H; speed of exhaled aerosol nicotine deposition, L; distance from e-cigarette user, L; and indoor air exchange rate, L). The UK Health & Safety Executive states that the average 8 hour workplace exposure limit (WEL) for nicotine is 500 µg/m^3 [2].

The data from the above figure was subsequently arranged and displayed graphically as a box plots to elucidate the impact that each parameter has on the calculated range of average 8 hour nicotine concentrations (**Figure 3B**). For example, to evaluate the effect of "distance from e-cigarette user" the 243 scenarios were grouped where "distance from e-cigarette user" was constant i.e. low (81 scenarios), medium (81 scenarios) and high (81 scenarios). Changes in the maximum average 8 hour nicotine concentration between the "low" and "high" parameter values were then used to assess the impact that "distance from e-cigarette user" has on the calculated 8 hour average nicotine concentration ranges.

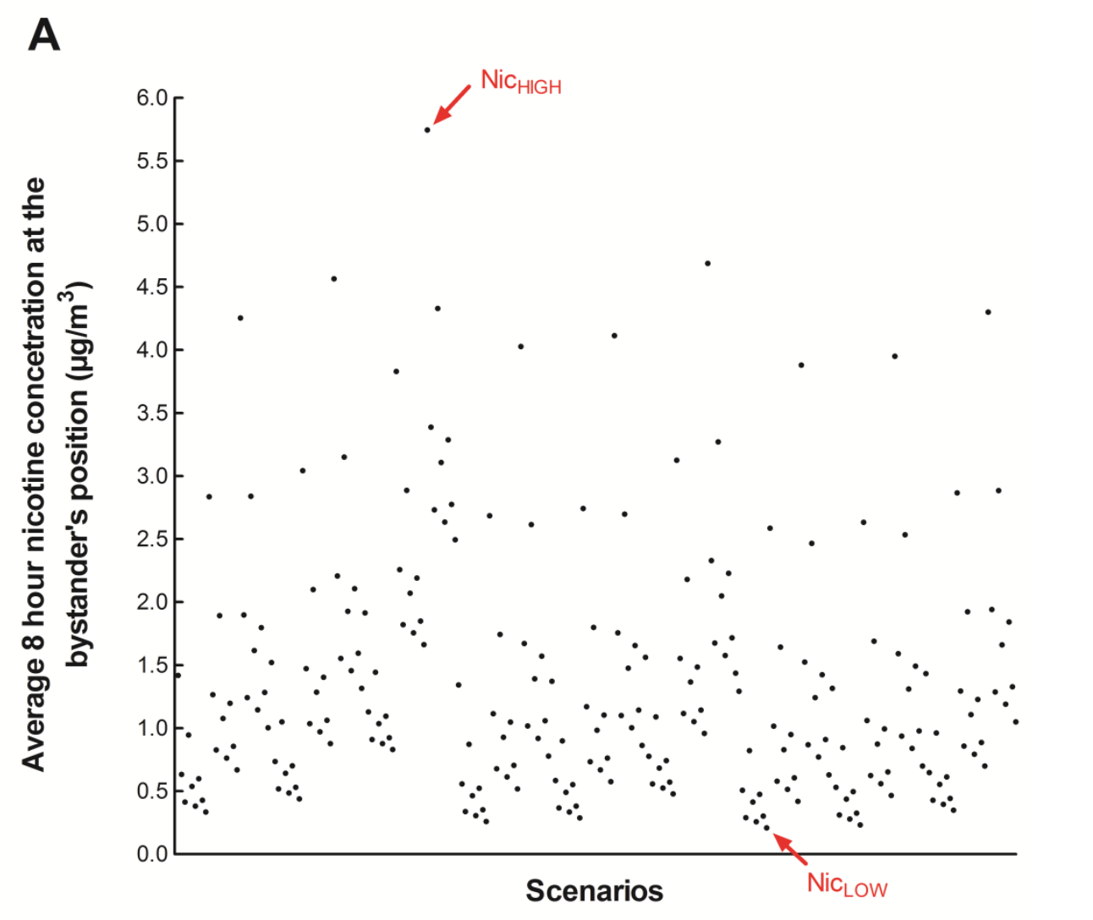


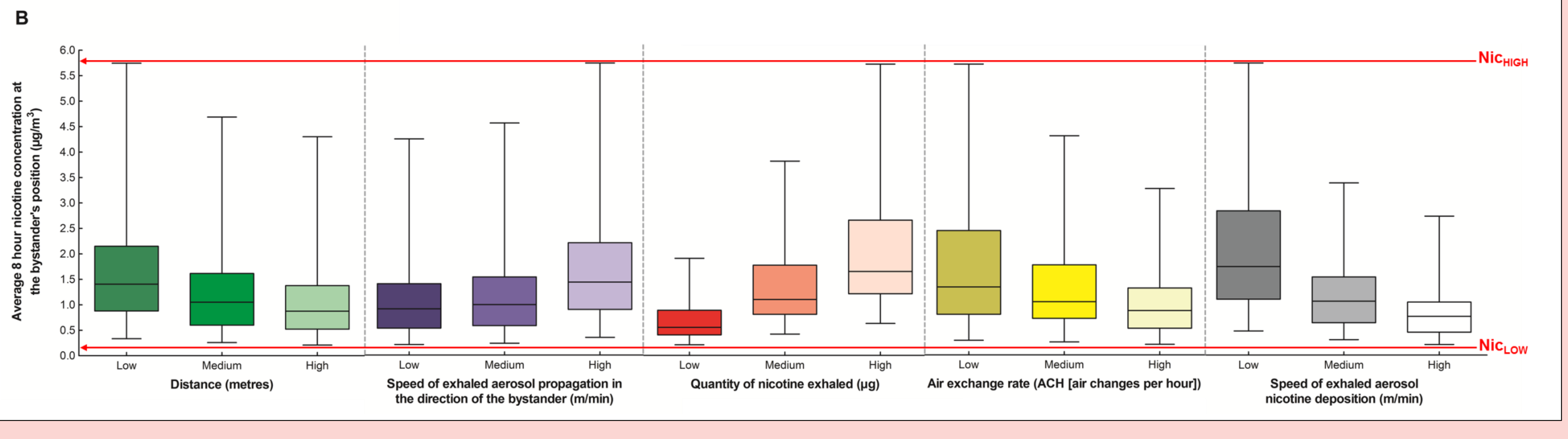
Figure 3A The average 8 hour nicotine concentration at the bystander's position derived from the 243 modelled scenarios. Red arrows represent the highest average nicotine concentration (Nic_{HIGH}) and the lowest average nicotine concentration (Nic_{LOW}).

All model parameters had an impact on the maximum 8 hour average nicotine concentration in the ambient air. An increase in the "quantity of nicotine exhaled" or "speed of exhaled aerosol propagation in the direction of the bystander" resulted in an increase of 67% or 26% in the maximum average 8 hour nicotine concentration in ambient air at the bystander, respectively. An increase in the "speed of exhaled aerosol deposition", "indoor air exchange rate" or "distance from e-cigarette user" resulted in a 52%, 43% or 25% reduction in the maximum average 8 hour nicotine concentration in ambient air at the bystander, respectively. In all cases, the maximum average 8 hour nicotine concentration in ambient air at the bystander was significantly lower than the UK WEL for nicotine.

The most important model parameter identified with regard to bystander exposure was found to be the "quantity of nicotine exhaled". Therefore, it is essential that precise measurements are made regarding the quantity of nicotine retained by the e-cigarette user, i.e. the fraction not exhaled into the ambient air, when determining bystander exposure to nicotine in exhaled e-cigarette aerosol.

Figure 3B The impact that each parameter has on the calculated range of average 8 hour nicotine concentrations in the ambient air at the bystander's position.

Each parameter, was assigned three values: low (L), medium (M) or high (H). Distance of the bystander from the e-cigarette user, 1 (L), 1.5 (M) or 2 m (H); speed of exhaled aerosol propagation in the direction of the bystander, 0.5 (L), 1.0 (M) or 2.0 m/min (L); quantity of nicotine exhaled, 10 (L), 20 (M) or 30 µg (H); air exchange rate from 1 (L), 2 (M) or 3 (H) air changes per hour; and speed of exhaled aerosol nicotine deposition, 0.01 (L), 0.03 (M) and 0.06 m/min (H). Boxes represent the 25th and 75th percentiles, lines inside the boxes are medians and whiskers represent minimum and maximum values. Red lines represent the highest average 8 hour nicotine concentration (Nic_{HIGH}) and the lowest average 8 hour nicotine concentration (Nic_{LOW}) across all scenarios.



5. Conclusions

In our model we demonstrate that the parameters which impact the calculated range of bystander exposure to nicotine the most are the "quantity of nicotine exhaled", "speed of exhaled nicotine deposition" and the "indoor air exchange rate".

The output of the model may be improved by refining the values assigned to the input parameters through experimental studies e.g. quantification of nicotine retention. We are working towards that goal. Studies which attempt to assess bystander exposures to nicotine from exhaled e-cigarette aerosol should be aware that aerosols generated using a smoking machine do not account for nicotine retained by the consumer and may provide misleading conclusions.

Bystander exposures to other exhaled aerosol components may be estimated using this model.

Comparison of model outputs with experimental results will enable refinement and validation of the model. Together, appropriately validated models and robust experimental studies may assist in the development and implementation of evidence based regulation.

Declaration

All authors are employees of Imperial Tobacco Group.

References

[1] Colard *et al*. (2014). Global Forum on Nicotine poster presentation. www.imperialtobaccoscience.com

[2] UK Health & Safety Executive workplace exposure limits. www.hse.gov.uk/pubns/priced/eh40.pdf