Propagation of Uncertainty through the Hazard Chain

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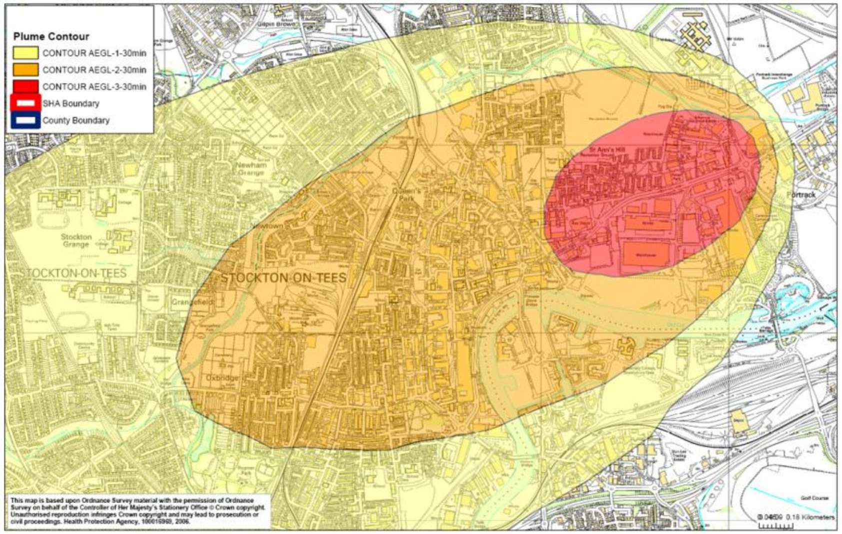
Background

- In the case of a civil emergency involving the accidental or deliberate release of a chemical or biological agent there is an urgent need to produce a **hazard assessment**

- This assessment generally consists of a **hazard area**, describing areas of contamination at known levels of risk
  - For example:
    - Lethal levels of agent
    - Incapacitating levels of agent
    - Probability of infection (biological)



The Hazard Chain

- The process of calculating a **hazard area** has the following steps:

1. Specify inputs
    - Meteorology, e.g. wind direction
    - Source term: mass of agent, release mechanism etc.
2. Run a **dispersion model** → *extent of contamination*
3. Perform a **dose calculation** → *dose inhaled by people*
4. Calculate **realisation of effects** → *casualty impact*

- Each step is complex with numerous inputs and model choices
- This process is known as the ***Hazard Chain***

The Problem of Uncertainty

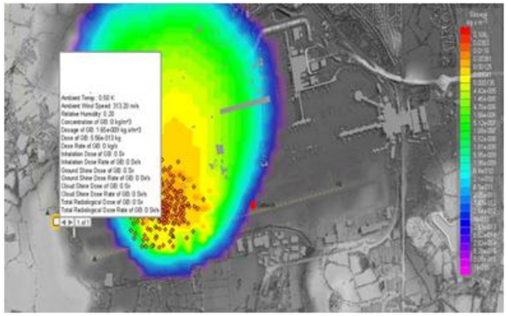
- A limitation of this modelling approach is the ***lack of uncertainty estimation***
- Uncertainty arises in each step of the hazard chain, however is currently not represented
- *Uncertainty must be propagated through the chain and represented in a clear and concise manner to inform better decision-making*

- Consider each step in the chain…

Dispersion Modelling

- Dispersion is represented by a Gaussian puff model with the following outputs:
  - **Mean concentration** over time at specified locations
  - **Variance of concentration** over time at specified locations

- For the purpose of this workshop assume meteorology and source term parameters are known



- There are two major sources of uncertainty:
  - Natural variation due to turbulence
  - Model uncertainty due to the approximation of the physical process

- ***How do we best account for theses sources of uncertainty?***

Validation Data

- Validation has been undertaken on the **Urban Dispersion Model**
  - A summary and full report can be provided

- The validation gives an overview of the types of error expected from the dispersion model

- ***What are the most appropriate means of representing these uncertainties throughout the hazard chain?***

Calculating Inhaled Dose (D_{inhal})

- Inhaled dose is calculated via the following equation:

$$D_{inhal} = R_c \cdot R_{BR} \int_0^t \left(\frac{c - c_{thr}}{R_c} \right)^n \cdot \left(\frac{BR}{R_{BR}} \right)^n \mathrm{d}t'$$

  - BR Breathing rate; $m^3 \cdot s^{-1}$
  - R_c Reference concentration level; $kg \cdot m^{-3}$ (1×10^{-6})
  - R_{BR} Reference breathing rate; $m^3 \cdot s^{-1}$ (2.5×10^{-3})
  - n Toxic load exponent; dmnl (1)
  - t Current time; s
  - c Air concentration
  - c_{thr} Threshold concentration; $kg \cdot m^{-3}$

Some Terminology

- **Dosage**, Ct (kg·m^{-3}·s) – concentration integrated over time
- **Dose**, D (kg) – mass of agent received

- Toxicology data are often given in the form of a D_{50} or Ct_{50},
  - Median dose or dosage causing a specified **effect** in 50% of the population
  - Prefixed by a letter relating to the effect:
    - Chemical miosis (*eye* effects) (ED_{50})
    - Chemical incapacitation (ID_{50})
    - Chemical lethality (LD_{50})
    - Biological infection (ID_{50})

Uncertainty from Breathing Rate

- The inhaled dose will vary greatly depending on **breathing rate**
  - It is not constant through time
  - It will vary from person to person
  - It will change in response to a threat

- A summation can be performed to allow breathing rate to change
  - Derived in accompanying notes

- ***What is the best means of incorporating this uncertainty?***

Dose-response Calculation

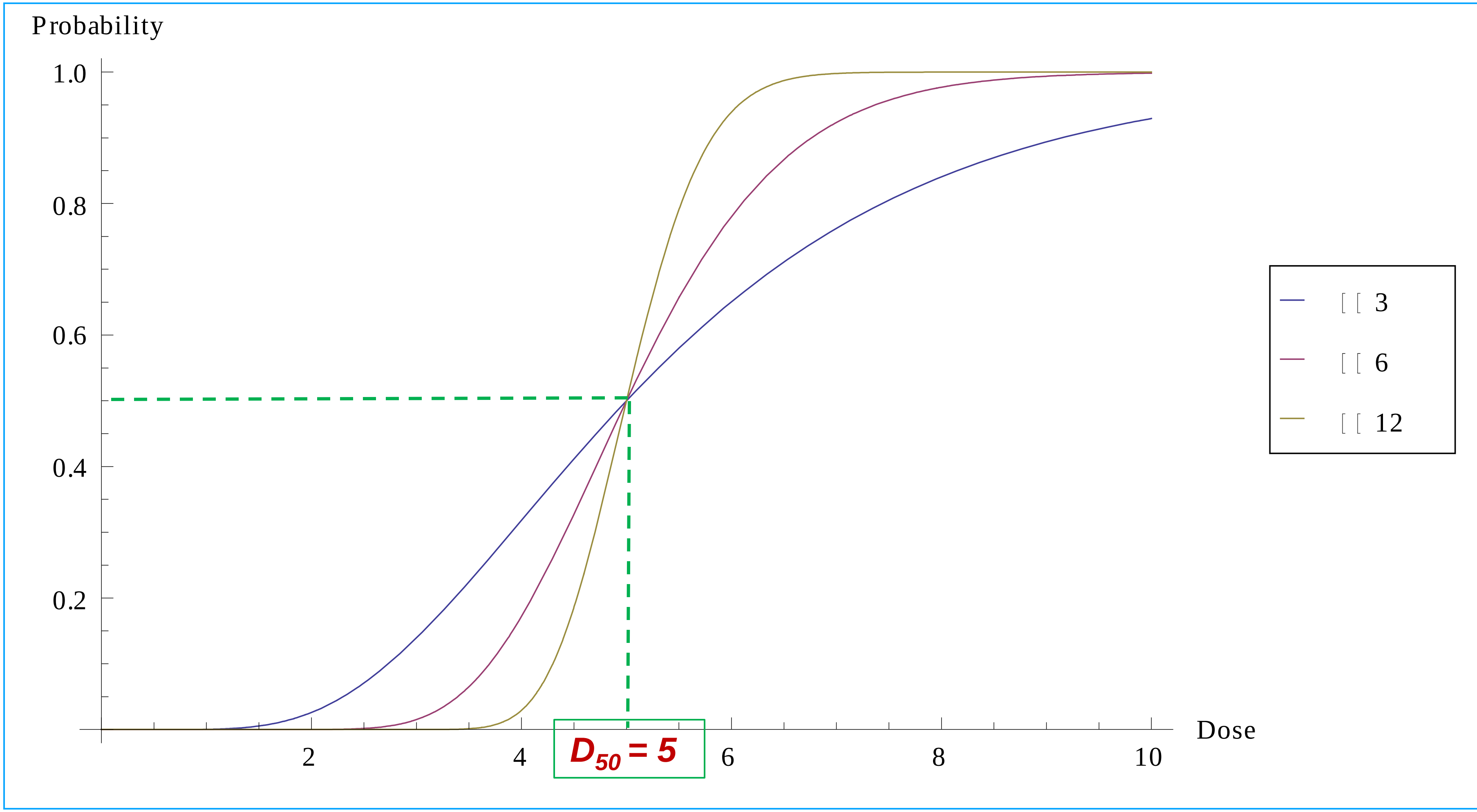
- **Dose-response** relationships are used to determine the probability of a specified **effect** occurring, given changes in dose received
  - E.g. incapacitation, lethality, infection…
- Commonly a **probit model**:

$$\mathrm{B}(\beta_i, D_{50,i}, D) = P(i) = \frac{1}{2}\left\{1 + \mathrm{erf}\left[\frac{\beta_i}{\sqrt{2}}\log_{10}\left(\frac{D}{D_{50,i}}\right)\right]\right\}$$

  - $P(i)$ Probability of an effect, i, occurring; dmnl
  - β_i Probit slope for effect i; dmnl
  - D Received dose of agent; kg
  - $D_{50,i}$ Dose causing effect i in 50% of the population; kg

INHALED DOSE

Example Probit Curves



Probit Uncertainty

- Probit slopes for hazardous agents are generally constructed using limited data
- There are large, sometimes unknown, levels of uncertainty associated with them
- ***How do we best represent uncertainty within this model?***
- ***How does this propagate through the rest of the hazard chain?***

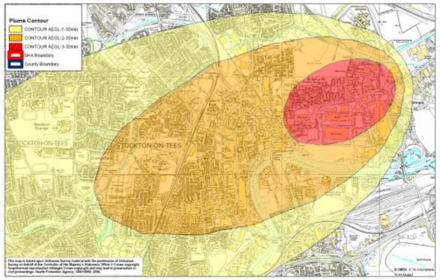
Realisation of Effects

- The attribution of a '***Lucky Number***' provides a simple method of deciding if an effect has occurred or not, for each person:
  - Probability of an effect, e.g. incapacitation, provided by dose-response model
  - A *Lucky Number* is assigned to each individual for each agent in order to take into account the variation in individuals' response to different agents
  - If this probability exceeds the *Lucky Number,* then the effect is deemed to have occurred
- Random number sampled uniformly from (0,1]
  - When compared to the log-normally distributed probability of effect, will also give a log-normal distribution, centred around the D_{50}
- ***How could this process be improved?***

Other considerations

- In addition to the basic elements of the hazard chain, there are numerous other inputs that could be accounted for, e.g.
  - Whether an individual receives treatment
  - How soon treatment can be provided
  - Where people are located within the plume
  - How their movement/behaviour effects their inhaled dosage
- **Each of these could also be incorporated into the hazard chain**

Summary of Issues to Explore (1)



- What is the most appropriate means of representing dispersion model error, in order to propagate through the hazard chain?
- Is there a better way of calculating the received dosage? How do we incorporate uncertainty into this calculation?
- How should we model uncertainty in the probability of an effect occurring to a given person, given
  - The lack of data to fit the probit slope,
  - Mitigating factors such as treatment?

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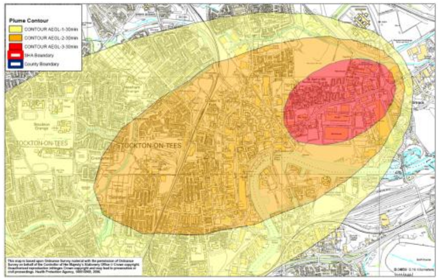
Summary of Issues to Explore (2)



- How do we capture the uncertainty in the realisation of the effects, given additional uncertainties such as
  - Location of individuals within the plume,
  - Population movement within the plume,
  - Relation of breathing rate to location and movement?

- More generally:
  - How do we propagate uncertainty through the hazard chain in a time efficient manner?
  - How do we present this uncertainty to non-expert decision-makers in an understandable and timely manner?

Conclusion

- Dstl provides advice to support civilian and military decision-makers in the face of potentially high-impact threats

- ***Improvements to modelling the hazard chain will provide direct benefit to decision-makers in times of crisis***