Public Health England

Protecting and improving the nation's health

A review of the effectiveness of sheltering in reducing doses from atmospheric releases of radioactivity

ADMLC, 7 September 2017

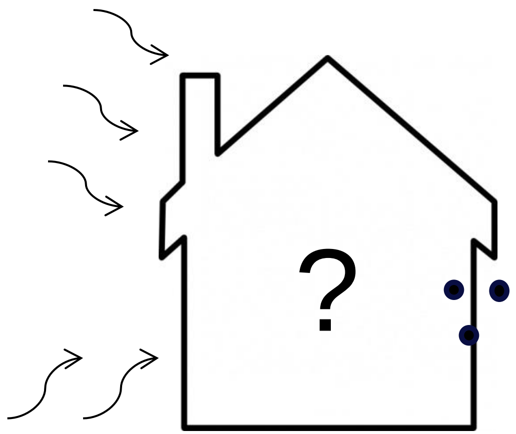
Peter Bedwell, Jon Sherwood, Simon Field, Stephanie Haywood, Jo Brown, Hugh McNamara
Radiation Assessments Department
PHE, Centre for Radiation, Chemical and Environmental Hazards

Sheltering

To remain indoors (or move indoors) to protect against a hazard which is outdoors.

In the event of a release of radioactive material to the environment, while outdoor airborne activity remains at high levels, the dose a person receives will be less if they are indoors than if they remain outside.

The building structure shields against gamma radiation (photons) emitted by material in the plume or deposited on the ground outside (and inhalation).



Derivation of DRF (deterministic assessment and simplistic approach)

- The level of protection can be represented by the Dose Reduction Factor (DRF), where the DRF is the ratio of the dose actually received (with the countermeasure in place) to the dose that would have been received without any countermeasures.
- Initially considering a deterministic assessment and simplistic approach…

$$DRF = \frac{f\lambda_e}{\lambda_e + \lambda_d + \lambda_r}$$

where

f is the fraction filtered by the building fabric

λ_e is the rate at which air enters the building (ach)

λ_d is the rate of deposit on internal surfaces (h^{-1})

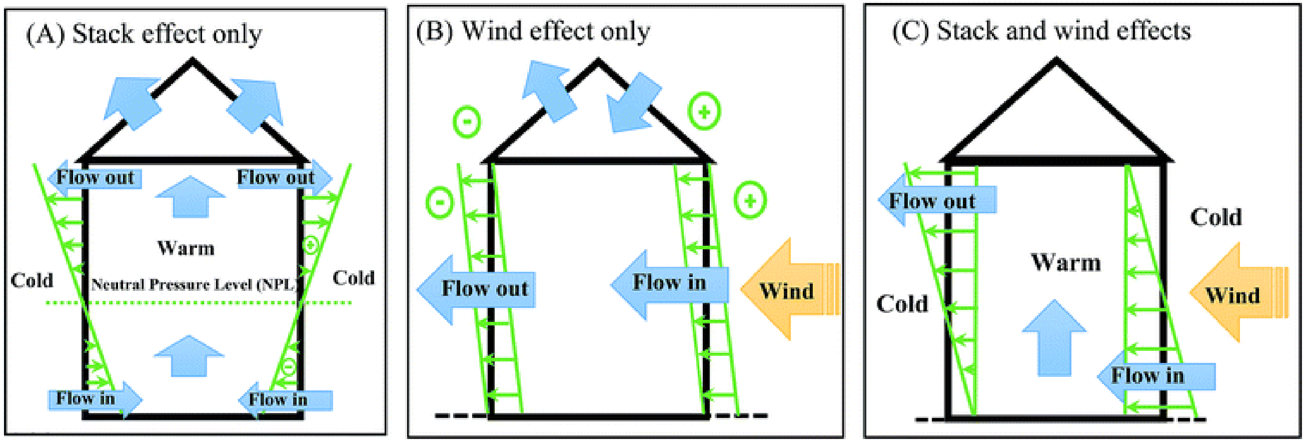
λ_r is the rate of radioactive decay (h^{-1})

- A set of Python scripts "InAirCalc" were developed to perform the above

Estimating air exchange rates

Wind induced pressure (wind speed at building height) + stack induced pressure (temperature of outdoor & indoor environments) = external pressure on the building envelope.

Ext pressure used to estimate ventilation rate ($m^3\ s^{-1}$) & air exchange rate (h^{-1}) (on the basis of knowledge of the volume of the building)*.



Single site meteorological data:

x4 coastal sites & x3 years => mean air exchange rate of ~0.6 h^{-1} (& DRF of 0.6)

*Reference = BRE

Picture courtesy of: http://pubs.rsc.org/-/content/articlehtml/2017/em/c6em00504g

Wind direction also affects ingress

- But difficult to widely consider for emergency planning & response.
- Assumed that the wind direction was perpendicular to the face of the building, resulting in a maximum ventilation rate.
- BRE considered how different wind directions (0, 15, 30 and 45 degrees) relative to the orientation of the building impact upon the wind driven pressures on the building shell.
- It is evident that building pressures vary significantly more as a function of building density than as a function of wind direction.
- It can be inferred that the ventilation rate varies by a factor of two (for rural environments), or less, as a function of wind direction.
- For regions described as “suburban” the building pressures vary little as a function of wind direction.

Mean air changes per hour (h^{-1}) as a function of coastal site location (around England) and year of meteorological data

		Site			
		A	B	C	D
Year	2004	0.58	0.55	0.57	0.58
	2006	0.59	0.55	0.57	0.57
	2008	0.62	0.59	0.61	0.60

Air changes per hour (h^{-1}) as a function of meteorology for a range of statistical endpoints

Min	2.5th %ile	5th %ile	50th %ile	95th %ile	97.5th %ile	Max	Mean
0.05	0.21	0.25	0.57	0.93	0.99	1.44	0.58

Derivation of DRF (probabilistic assessment & more comprehensive approach)

λ_r does not vary with time.

λ_d will vary with time but is assumed to be constant as a function of time in this study.

λ_e is assumed to vary with time (by way of the wind speed & the difference in temperature between indoors and outdoors).

$$C_i^{(n)} = e^{-g^{(n,n-1)}}\left(C_i^{(n-1)} + \frac{1}{2}\Delta t\left(f^{(n-1)}\lambda_e^{(n-1)}C_o^{(n-1)} + f^{(n)}\lambda_e^{(n)}C_o^{(n)}e^{g^{(n,n-1)}}\right)\right)$$

where

$$g^{(n,n-1)} = \frac{1}{2}\Delta t\left(\lambda_{tot}^{(n-1)} + \lambda_{tot}^{(n)}\right)$$

and

$$\Delta t = t^{(n)} - t^{(n-1)}$$

and

$$\lambda_{tot} = \lambda_e + \lambda_d + \lambda_r$$

Probabilistic assessment using NAME (in PACE)

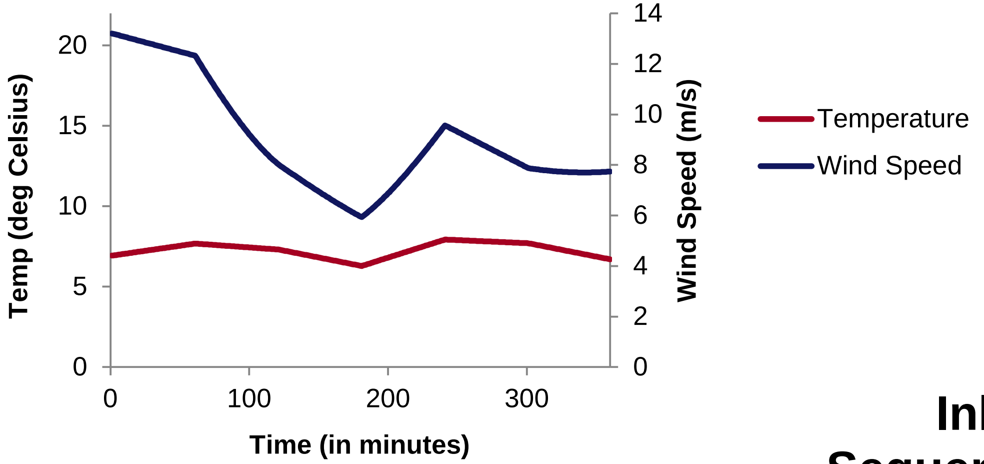
- used the Met Office's 1.5 km NWP meteorological data and performed 144 cyclic samples (sampling the diurnal and annual variability observed in the meteorological dataset)
- estimated time averaged air concentrations
- on an output spatial grid of 12 receptor points, all equidistant from each other and all at a single radial distance from a centre point and release location
- on a temporal resolution of one minute
- and extracted a time series of single site meteorological data, notably wind speed and outdoor temperature (for use in the estimation of the air exchange rates).

Dose reduction factors estimated over 144 meteorological sequences, 12 receptors and eight scenarios

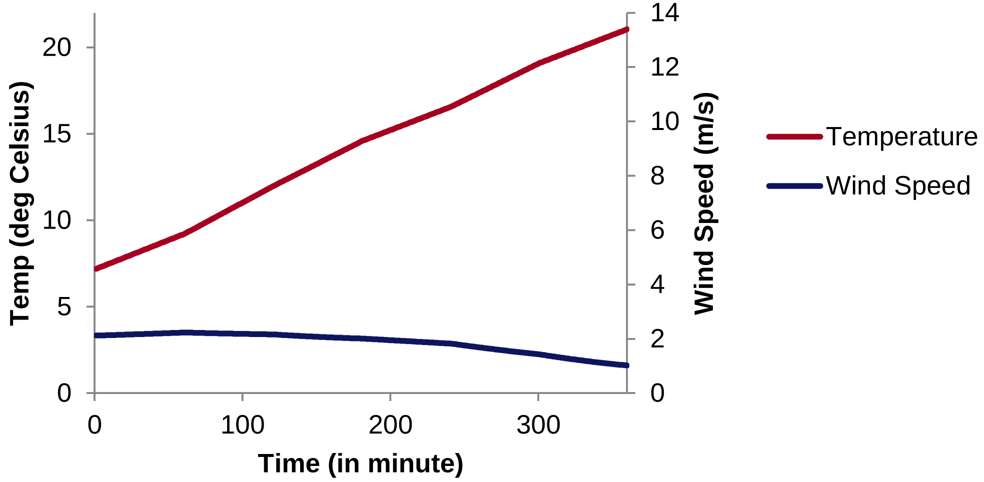
	Default	10 km - receptor to release location distance	2012 – year of NWP met data	Alternate coastal site	Inland site	Instant release duration	30 min release duration	8 hr release duration
Mean	0.58	0.58	0.60	0.58	0.59	0.58	0.58	0.58
Min	0.32	0.30	0.10	0.17	0.16	0.38	0.38	0.30
Max	0.85	0.85	0.81	0.75	0.74	0.83	0.84	0.85
5th %ile	0.43	0.45	0.42	0.37	0.37	0.43	0.43	0.41
50th %ile	0.59	0.60	0.63	0.61	0.61	0.59	0.59	0.59
95th %ile	0.70	0.70	0.71	0.70	0.70	0.71	0.71	0.70

Default = 2 km - release location to receptor distance; 2011 – year of NWP met data; coastal site; 2 hr release duration

Default Scenario - Met Sequence resulting in the Max DRF



Inland Site Scenario - Met Sequence resulting in the Max DRF



Estimates of DRF for a range of sheltering strategies

	instant	30min	2hr	8hr
Strategy	Average	Average	Average	Average
end0	6.0E-01	6.0E-01	6.0E-01	5.9E-01
cross0	1.7E-01	2.2E-01	3.2E-01	4.0E-01
zero0	2.0E-01	2.5E-01	3.5E-01	4.4E-01
zero10	2.5E-01	3.0E-01	3.8E-01	4.6E-01
zero-10	5.4E-01	3.7E-01	4.2E-01	4.9E-01
zero30	3.4E-01	3.7E-01	4.3E-01	4.9E-01
zero-30	8.2E-01	6.9E-01	4.9E-01	5.4E-01
zero60	4.3E-01	4.4E-01	4.9E-01	5.2E-01
zero-60	8.7E-01	8.6E-01	5.9E-01	5.9E-01
zero120	5.2E-01	5.3E-01	5.5E-01	5.6E-01
zero-120	9.1E-01	9.1E-01	8.6E-01	6.8E-01

	instant	30min	2hr	8hr
Strategy	95th %ILE	95th %ILE	95th %ILE	95th %ILE
end0	7.08E-01	7.08E-01	7.08E-01	6.98E-01
cross0	2.97E-01	3.26E-01	4.48E-01	5.89E-01
zero0	4.04E-01	4.30E-01	5.10E-01	6.23E-01
zero10	4.37E-01	4.62E-01	5.29E-01	6.32E-01
zero-10	9.51E-01	7.39E-01	7.13E-01	7.29E-01
zero30	4.92E-01	5.13E-01	5.74E-01	6.44E-01
zero-30	9.51E-01	9.25E-01	7.85E-01	8.11E-01
zero60	5.71E-01	5.77E-01	6.19E-01	6.60E-01
zero-60	9.52E-01	9.51E-01	8.53E-01	8.43E-01
zero120	6.58E-01	6.62E-01	6.72E-01	6.79E-01
zero-120	9.53E-01	9.53E-01	9.46E-01	8.79E-01

End0 = the time at which the indoor concentration tends to zero
Cross0 = the time at which the outdoor concentration and indoor concentration “cross”
Zero0 = the time of the first zero outdoor concentration

Picture courtesy of: https://www.flickr.com/photos/axelhartmann/501187415

Conclusions

- Presented findings:
  - DRF varies little as a function of the annual average meteorological conditions (by year or by site)
  - DRF varies significantly as a function of hourly varying meteorological conditions
- Next step = publish recommendations (x1 paper) and findings (x1 paper)
- Practical application of findings (eg in emergency response)?
- Future work: where in a building is best to shelter (using multi-room models?)?

Questions