RRX87: Powerline corona ions – their impact on human exposure to air pollution.

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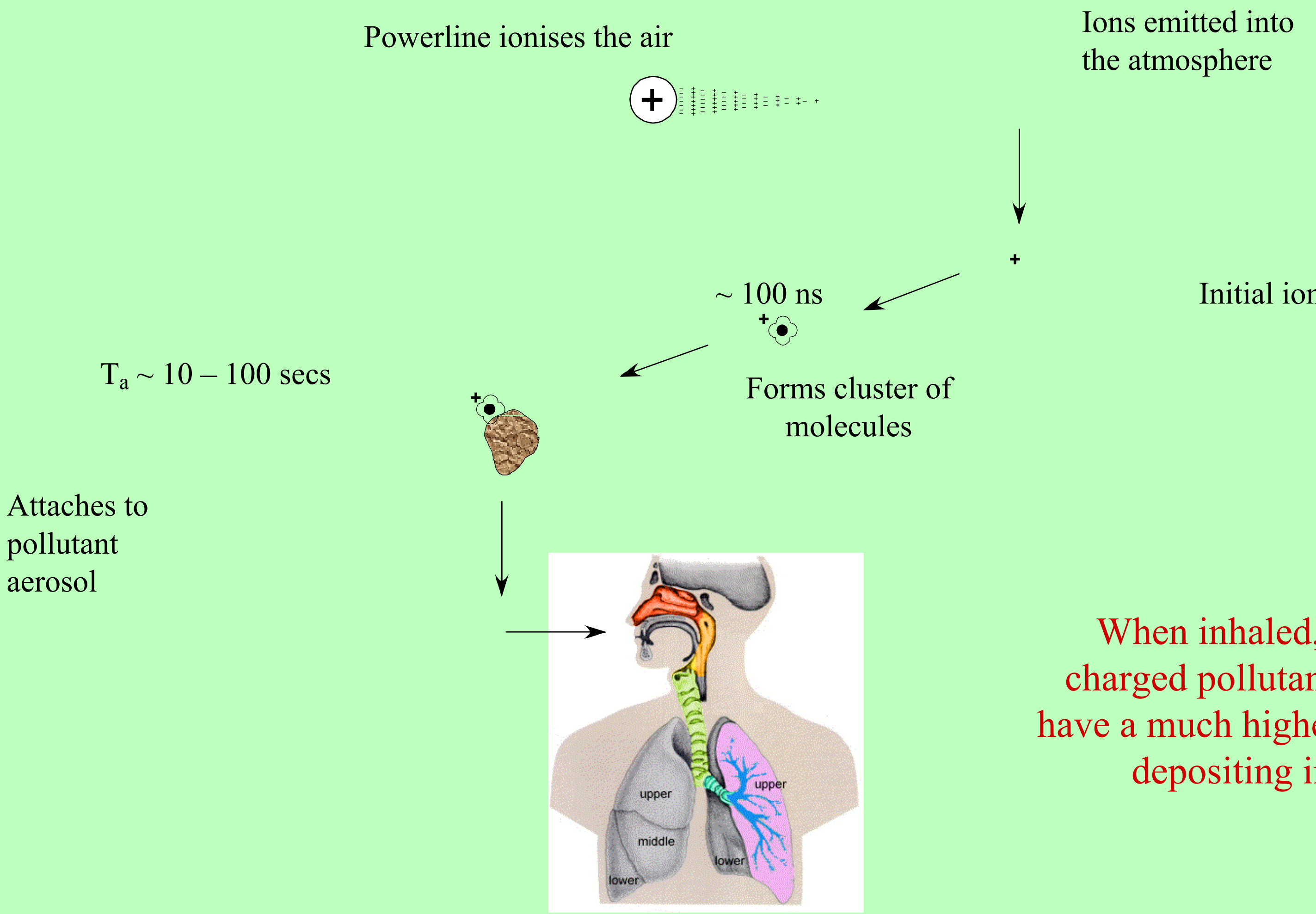
Fate of corona ions in the atmosphere



When inhaled, electrically charged pollutant aerosols can have a much higher probability of depositing in the lung

Fews *et al*. 1999, 2002, 2005

Notes on Previous Slide

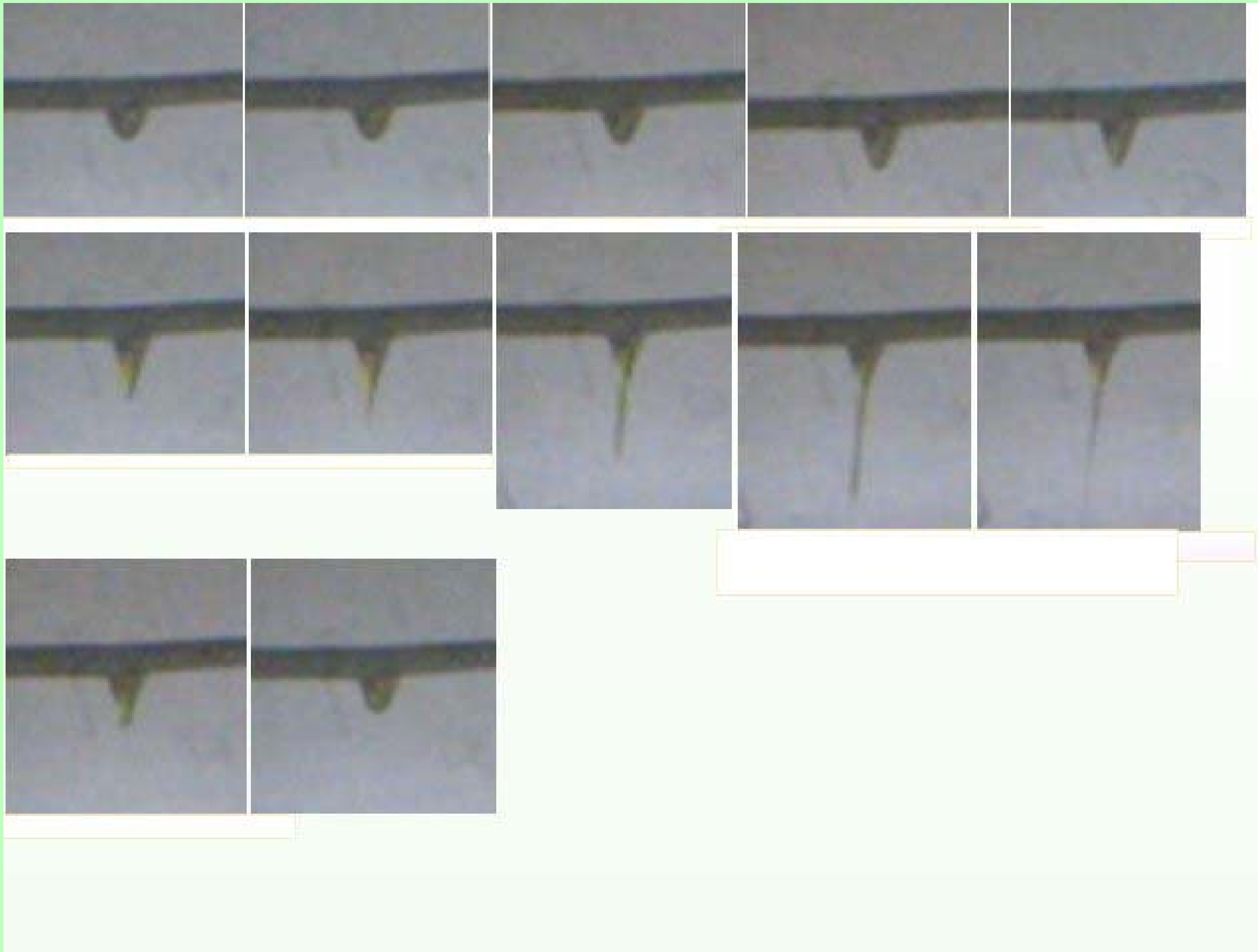
- High voltage powerlines can and frequently do ionise the air splitting it up into electrons and molecular ions of nitrogen and oxygen. These are emitted into the atmosphere. For reasons that are not fully understood efficient charge separation occurs, leading to separate clouds of predominantly positive or negative ions. The slide considers an example of an initial positive ion. Within a very short period of time (around 100 nano-seconds) this ion attracts a cluster of molecules, mainly water molecules producing what is known as a small ion around 1 nano-metre (nm) in size. On a timescale of 10 – 100 seconds this ion will then attach itself to a particle of air pollution thereby increasing the charge-state on the latter (for example, from uncharged to singly charged). This ion-aerosol rate of attachment is governed by known physics. It depends on the ion-aerosol attachment coefficient and also the ion and aerosol densities in air. When the now electrically charged aerosol particle is inhaled it then has a higher probability of depositing in the lung as opposed to simply being exhaled again. The enhanced deposition occurs by mirror-charge effects. When a charged particle approaches the surface it sees its opposite charge by reflection in that surface, leading to electrostatic attraction to that surface.
- The following four slides provide more information of the various steps outlined in the above scenario.

- Corona losses can be up to 0.1 mA per metre of powerline or up to 6.25×10^{14} charges per metre per second - even if most of these are absorbed by the line, there is potentially a high flux emitted into the atmosphere

- Corona ion effects have been seen up to 7 km from powerlines

Notes on Previous Slide

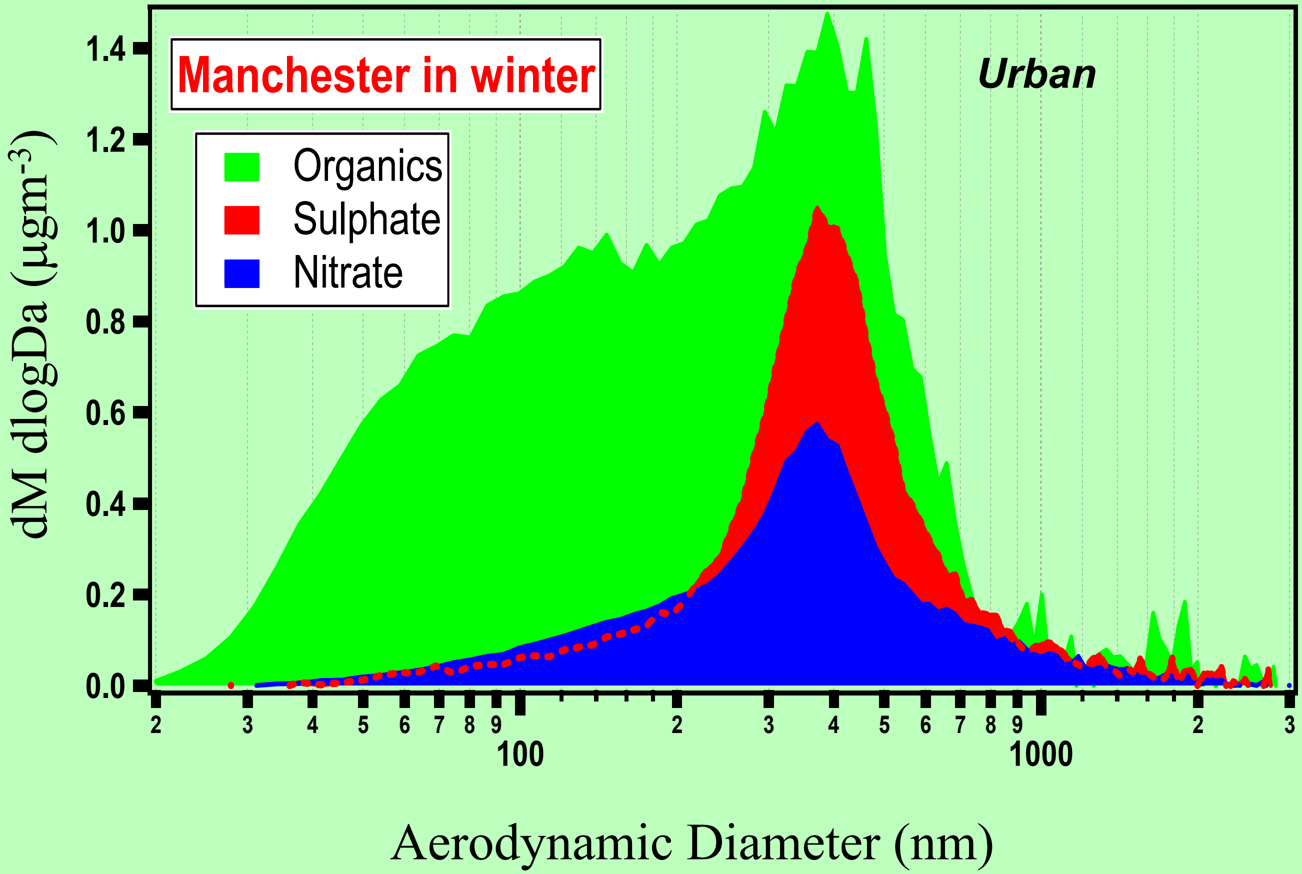
- As stated in the slide, corona ion losses are such that potentially a very high flux of corona ions can be emitted into the atmosphere in high corona conditions. Measurements in the 1950s, confirmed in our own work today, show that corona ion effects can be detected from up to 7 km from powerlines.



Evolution of corona ion emission from “Taylor cones”

Notes on Previous Slide

- Corona losses from powerlines occur due to sharp edges on the powerline cables, for example, due to corrosion of the line with age or due to a presence of dirt, flakes of straw and so on. In addition, water drops on powerlines create streams of ions known as “Taylor cones”. Here, the high electric field gradient around the water droplet stretches the droplet leading to the emission of a stream of highly charged mist droplets.

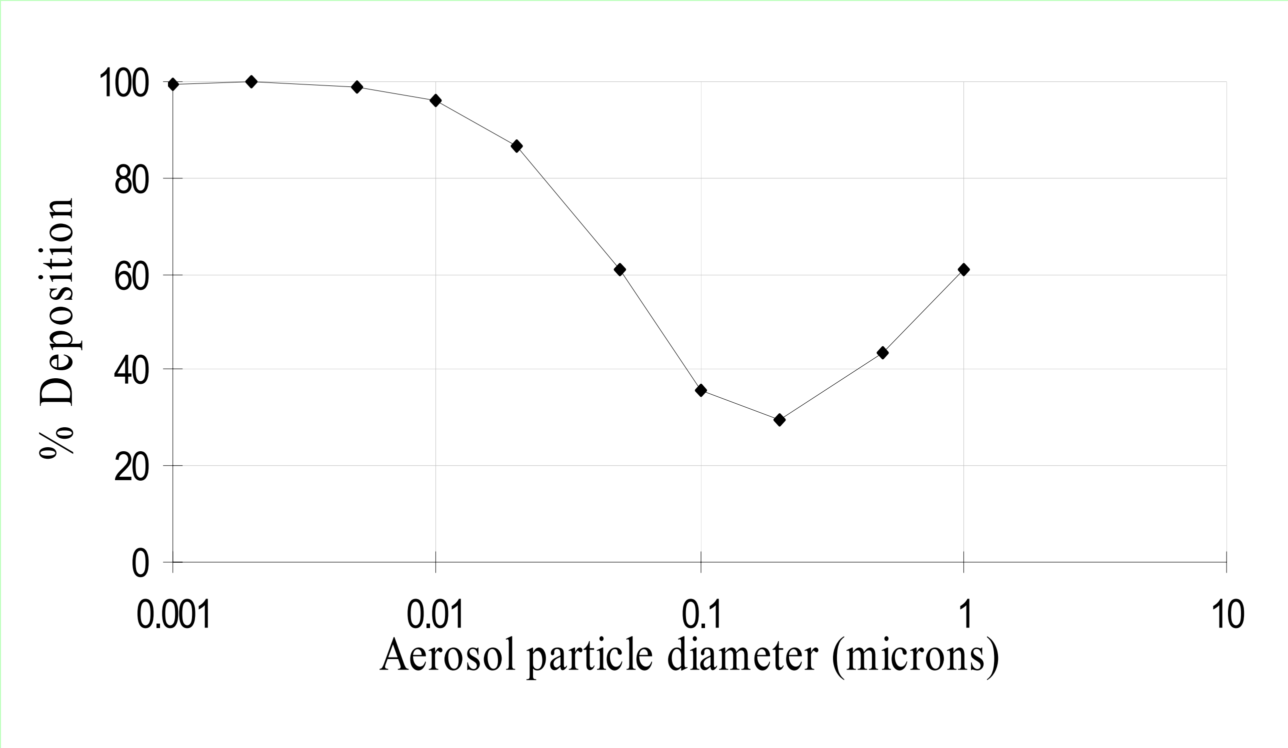


With permission of Drs M Rami Alfarra and Hugh Coe.

Notes on Previous Slide

- In considering the aerosol particles to which corona ions attach, we are particularly interested in aerosols arising from air pollution and in the chemicals they contain. This slide kindly supplied by Drs Rami Alfarra and Hugh Coe at the University of Manchester (formerly UMIST) shows some of their earlier work in measuring the content of pollutant aerosols in the atmosphere. Of particular interest is the organic content because this includes the potentially carcinogenic polycyclic aromatic hydrocarbons (PAHs). These organics, shown in green, predominantly occupy the smaller size range of pollutant aerosols. On this log plot, half of the organics are contained up to a size range of about 230 nm. For this reason we have special interest in the single charging of aerosols up to this approximate size.

Not all of what is inhaled is deposited in the lung



Total lung deposition according to the ICRP 66 lung model

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- This slide shows the ICRP lung deposition model, itself derived from human data. It shows the percentage of aerosol particles that are deposited in the lung on inhalation. The highly diffusive small aerosols, 1 – 10 nm, tend to be fully deposited on inhalation. At the other end of the size range, above 1000 nm or 1 μm, particles are again likely to deposit in the lung, this time predominantly by a process of impaction. At 200 nm we are at the minimum in lung deposition probability on inhalation. In other words, at this size only around 30% of inhaled particles are deposited in the lung, the remaining 70% are simply exhaled again.

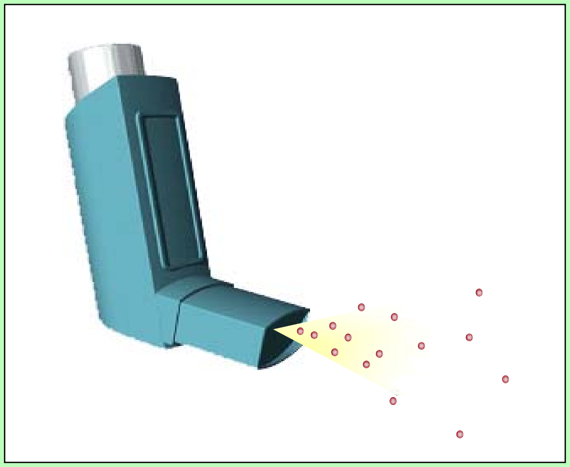
Kim & Jacques (2000) have validated the ICRP 66 lung deposition model on 22 human volunteers. For 100 nm non-hygroscopic metallic aerosols, total lung deposition on inhalation was around 25% only

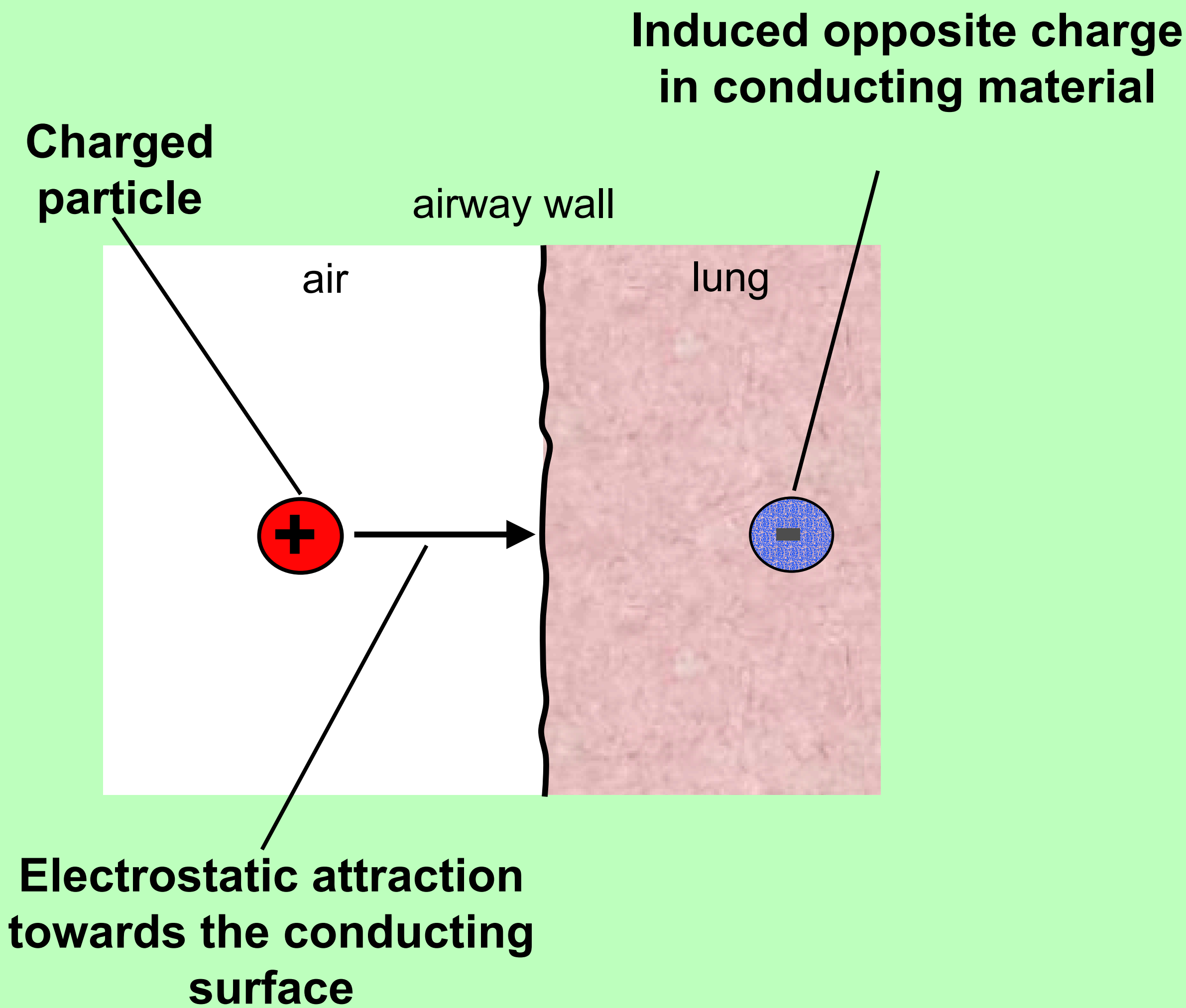
Lung Region	**Fractional deposition at 100 nm (%)**	
	Men (11)	Women (11)
Head	0.2 ± 0.5	0.6 ± 0.7
Tracheobronchial	5.7 ± 3.2	7.8 ± 1.8
Alveolar	18.2 ± 6.2	19.0 ± 2.9
Total	**24.1 ± 8.9**	**27.4 ± 4.1**

Notes on Previous Slide

- Kim & Jacques (2000) have validated the ICRP lung deposition model using human volunteers. The authors used 100 nm non-hygroscopic metallic aerosols so that the aerosols would not change their size on inhalation, for example, by gathering water. In the table, on average only 24.1% of the aerosols were deposited in the lungs of males and 27.4% in the lungs of females.

Schematic of mirror charge





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- Inhalers, when sprayed, utilise charging by friction to more deposit efficiently inhaled particles in the lungs. Charged particles are attracted towards a conductive surface (like the lung wall) because of the "mirror charge" effect. This is an electrostatic attraction between a mobile charged particle in a non-conducting medium (such as air) towards a conducting surface. It can be visualised as if an equal and opposite charge has been induced in the conducting material, the same distance from the surface and because the particle and its "image" are of opposite polarity the mirror charge force is attractive. As the charged particle moves closer to the surface the force increases, accelerating the particle towards the wall.

Charging of inhaled aerosol particles increases their probability of lung deposition

Cohen *et al*. (1998) studied the deposition of singly charged vs. natural charge state 20 and 125 nm particles

For singly charged 20 nm particles, deposition in the airways was 3.4 ± 0.3 times higher than for their natural charge state. For singly charged 125 nm the corresponding increased deposition was 2.4 ± 0.3.

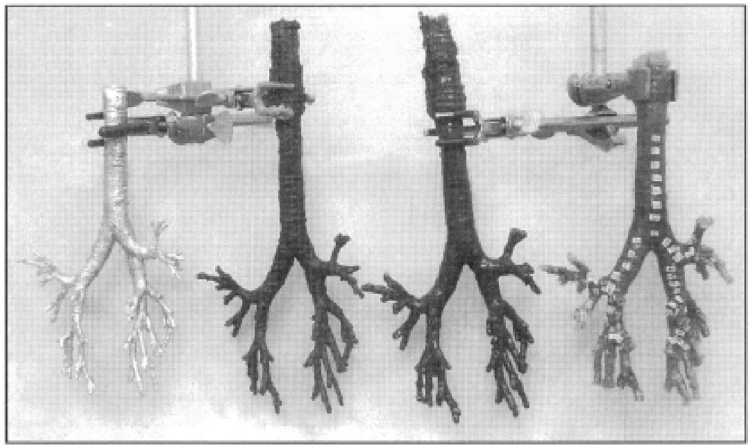


Fig. 1. Casts are shown at various stages in production: a) metal master cast, b) after application of a thin layer of conducting plastic, c) after application of additional supporting layers of clear silicone, and d) hollow cast after removal of metal core. The markings on (d) indicate where the cast will be cut for analysis of individual segments.

(*Health Physics* **74**(5), 554-560)

Notes on Previous Slide

- Beverly Cohen and colleagues in New York measured the effects of electrical charging of aerosol particles on their deposition in metal alloy casts of the human airways. They used 20 and 125 nm particles. As indicated, for singly-charged 20 nm particles, deposition in the airways was 3.4 ± 0.3 times higher than for their natural charge state. For singly-charged 125 nm the corresponding increased deposition was 2.4 ± 0.3. These findings are important because the dimensions of lung alveoli, around 150 – 200 μm when fully inflated, is such that increased deposition of singly-charged 20 and 125 nm particles would also be expected in the alveoli.

Risk assessment of possible annual excess cases of ill health in people living near high voltage powerlines in the UK, as a result of corona ion and other electric field interactions with air pollution

(Henshaw, *Medical Hypotheses*, Vol. **59** (1), 39-51, 2002)

Condition	**Possible excess cases annually in the UK near high voltage powerlines***
(i) Lung cancer mortality	200 – 400
(ii) Other illnesses associated with air pollution	2,000 – 3,000
(iii) Childhood leukaemia**	2 – 6

*Assumes 30% increased lung deposition

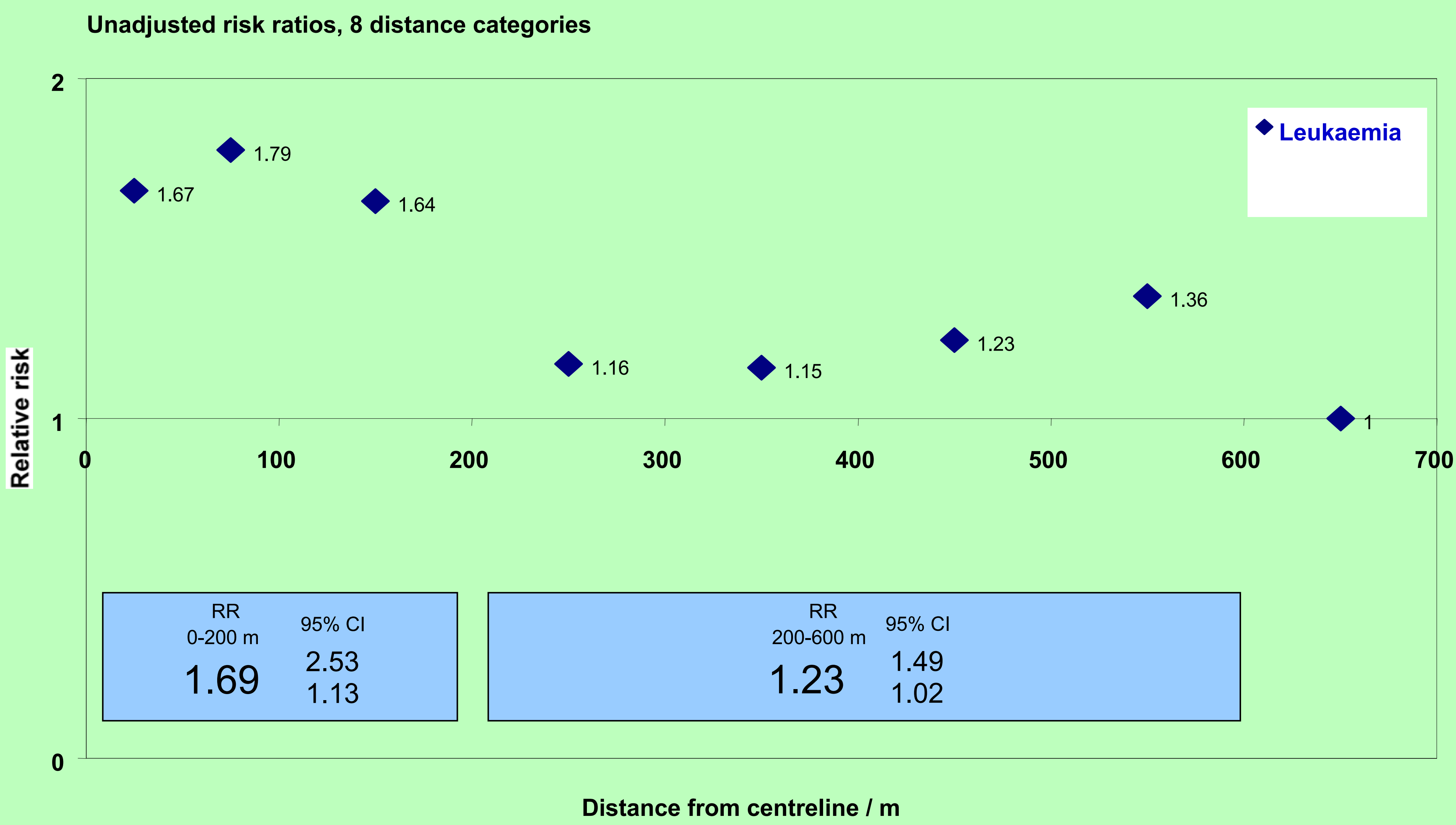
**Knox *et al.* 2005a,b, 2006 – childhood cancer & air pollution

Notes on Previous Slide

- Henshaw (2002) published a risk assessment of the number of excess cases annually of air pollution related illnesses that might occur in populations living within 400 m of high voltage powerlines in the UK. The assessment considered a modest 16% single charging of aerosols, resulting in a 30% increase lung deposition. As indicated, 200 – 400 excess cases of lung cancer, 2000 – 3000 excess cases of cardiovascular illnesses, aggravated asthmas and allergies and 2 – 6 excess cases of childhood leukaemia are calculated to occur annually in those living within 400 m of powerlines in the UK.

- The estimates for childhood leukaemia require that air pollution is a causal factor for the disease. There is interesting recent evidence to this effect in the three studies published by Knox (2005a, b, 2006).

Draper *et al.* BMJ, 330: 1290-1295 (2005).



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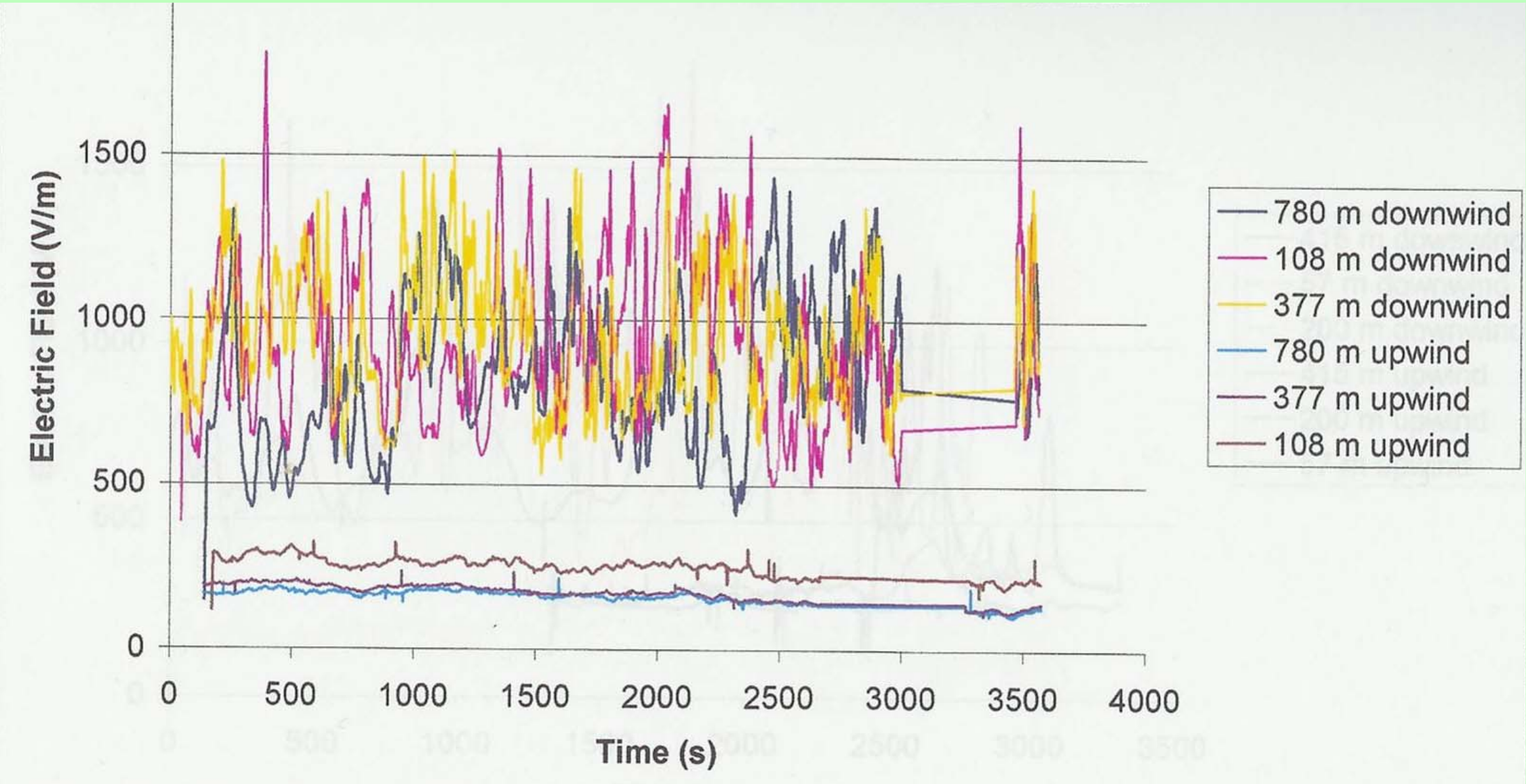
- In 2005 Draper *et al*. published the results of the world's largest study of childhood leukaemia near high voltage powerlines. The study considered children living near National Grid 275 and 400 kV powerlines in England and Wales in the period 1962 – 1995. In addition to finding increased incidence of childhood leukaemia within 200 m of these lines (RR = 1.69, 95% CI: 1.13 – 2.53), within range of the direct electric and magnetic fields, the authors found increased incidence in the range 200 – 600 m, compared with greater than 600 m (RR = 1.23, 95% CI: 1.02 – 1.49). This latter finding is beyond the range of the direct electric and magnetic fields, but within the range of potential corona ion effects. In this sense these findings of Draper *et al*. support a corona ion model. More will be said about this later in this talk.

Six contemporaneous measurements upwind and downwind of a 400 kV powerlines at Lower Godney, 18th July 2000



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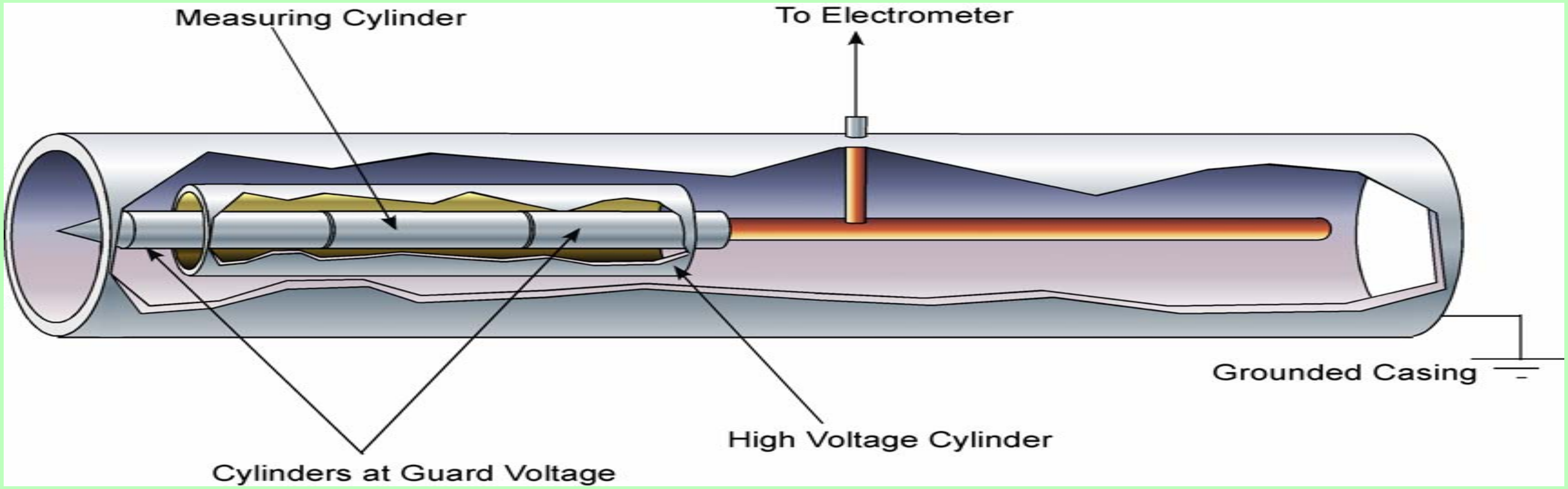
- One relatively simple method of measuring corona ion emission from high voltage powerlines, is to study distortions in the natural DC electric field in the atmosphere as measured at ground level. In this example, six DC field mill meters were placed 108, 377 and 780 m either side of the 400 kV powerline at Lower Godney. On the day of the measurements there was a cross wind, so that three of the instruments were upwind and three downwind of the powerline. The output from these instruments was logged simultaneously in a laptop computer over a period of 1 hour. Upwind, the traces are similar and remarkably stable over the whole measurement period. The average DC field, up to 200 V m-1, is typical of fair weather conditions. Downwind, however, the average atmospheric DC field is just below 1000 V m-1, indicating the presence of positive corona ions and the subsequent pool of charged aerosols being carried downwind. What is remarkable is that the three downwind traces, at 108, 377 and 780 m are remarkably similar, indicating that corona ion effects are as strong 780 m downwind from the powerline as they are close to the powerline. More detailed examination of the traces, which will not be considered in this talk, reveals that structure differences reflect that close to the line the space-charge in the atmosphere consists predominantly of unipolar corona ions *per se* and at 780 m mainly charged aerosols. It should be emphasised that it is the unipolar nature of corona ions that leads to excess charging of aerosols. Such unipolar clouds can persist in the atmosphere for 1 hour or more before becoming sufficiently dispersed to neutralise themselves against the background distribution of positive and negative ions in the atmosphere. Therefore, depending on wind velocity, corona ion space-charge can sometimes be carried very large distances from powerlines.

Small Ion Mobility Spectrometer

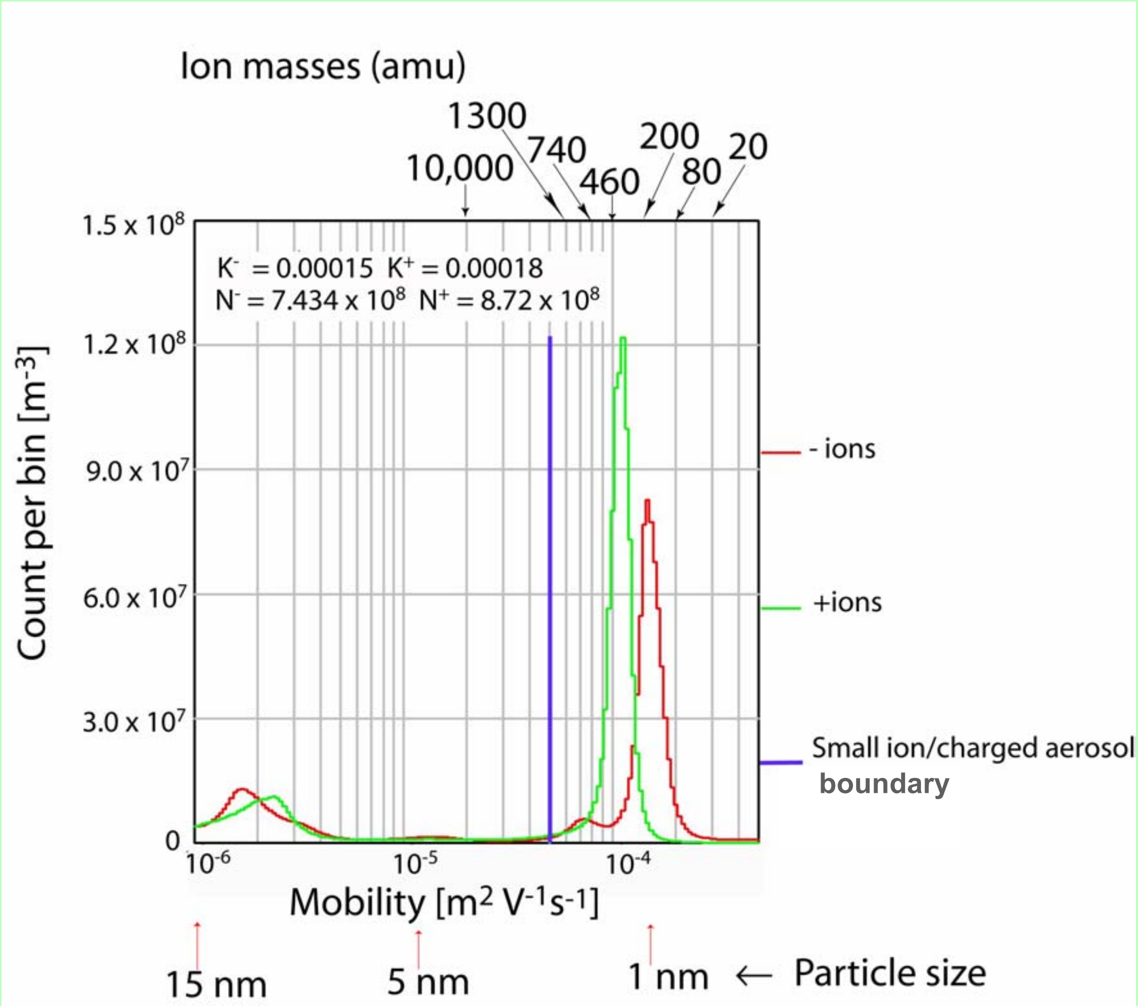


- Size range: 0.5 – 50 nm
- Air Passage Width: 20 mm
- Sensing length: 120 mm
- Scanning voltage 2 – 5000 V (typically 1000 V outdoor air)
- Data acquired in ~ 15 minutes
- Time at each voltage 4 seconds < 250 V, 8 seconds > 250 V

Notes on Previous Slide

- Notwithstanding our measurements using DC field mill meters, we have now constructed two ion and charged aerosol mobility spectrometers to measure directly these quantities near powerlines. The slide shows a schematic diagram of one of our spectrometers developed by Dr Peter Fews (Fews *et a*l. 2005). Air is drawn into the spectrometer from the right. A high voltage is applied across the two concentric cylinders resulting in deflection of either small ions or charged aerosols according to their electrical mobility. The voltage is applied in steps controlled from a PC from which the ion current is subsequently measured. The instrument can acquire a spectrum outdoors in just 15 minutes. At present, this instrument covers the typical size range 0.5 – 50 nm and is governed by the maximum voltage that can be applied across the sensing cylinders prior to breakdown in outdoor conditions.

Typical background small ion and charged aerosol spectrum in rural locations away from powerlines and traffic exhausts



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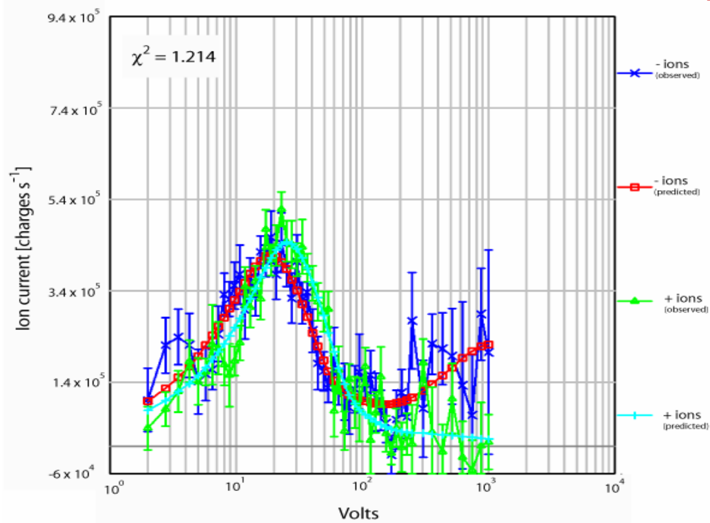
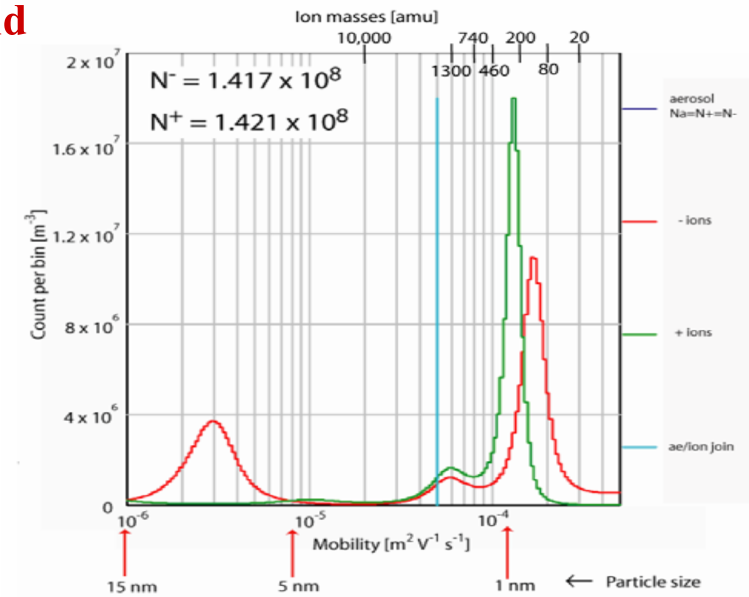
- The graph shows a typical background small ion and charged aerosol spectrum in a rural location away from powerlines and traffic exhaust pollution. The data also serves to demonstrate the resolution of the spectrometer. Increasing mobility, corresponding to decreasing aerosol size, is plotted in a histogram. The spectrum consists mainly of the background small ions typically existing in the atmosphere. In this example there is an excess of positive small ions. Note that these are around 1 nm in size, comprising each clusters of molecules of around 500 amu. Thereafter, there is a dearth of aerosols up to 15 nm in size. One would expect that the majority of the background charged aerosol spectrum to extend from a few tens of nm upwards and so is not seen in this plot.

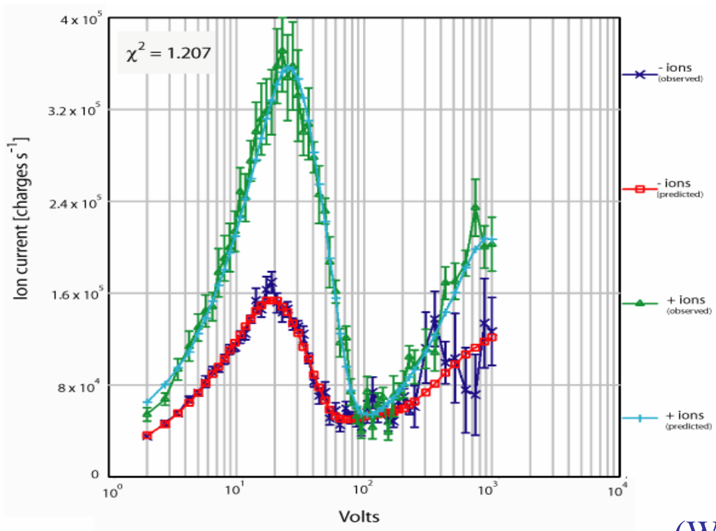
Contemporaneous ion mobilities near a 400 kV line at Lower Godney, 18th Dec. 2003

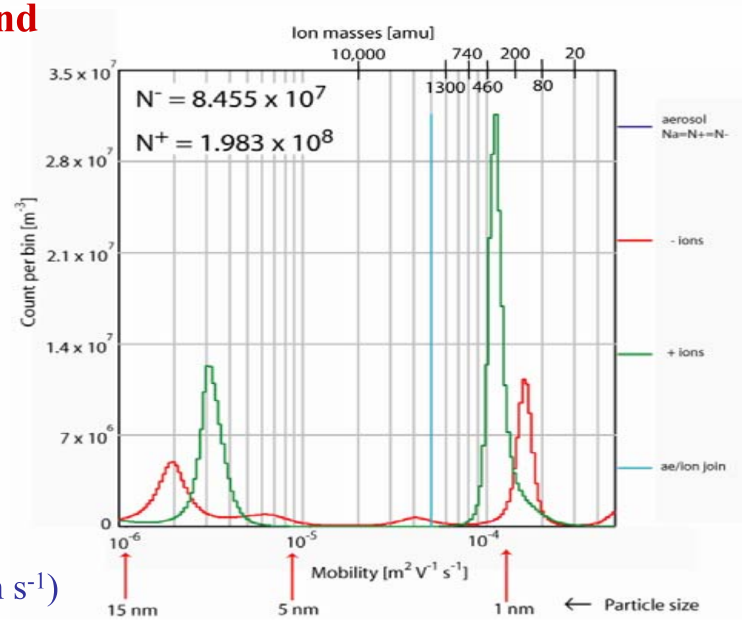
180 m Upwind





165 m Downwind



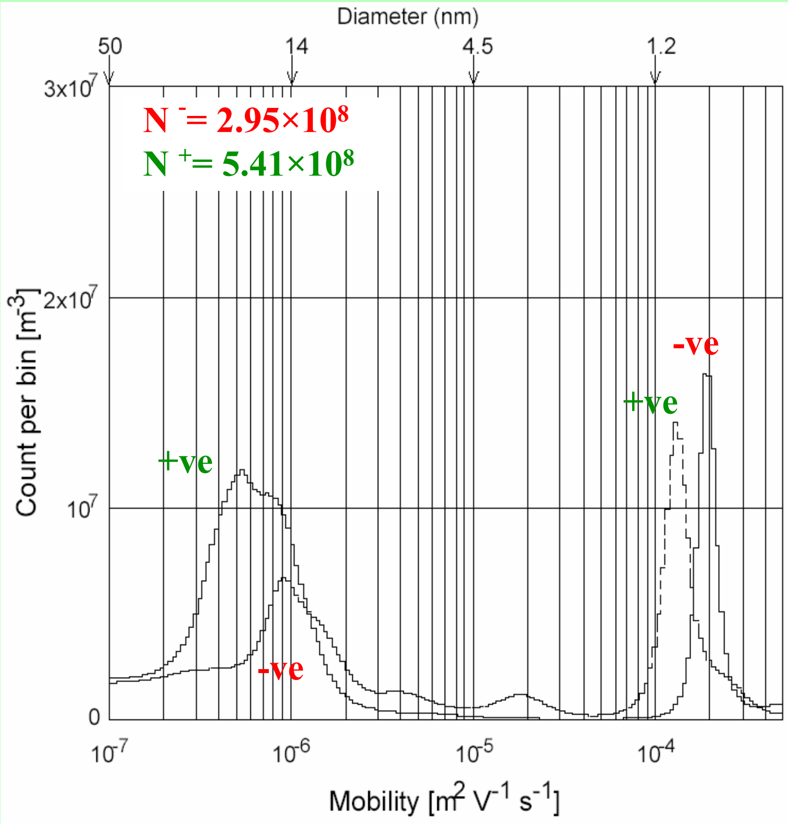


(Wind speed 0.38 m s^{-1})

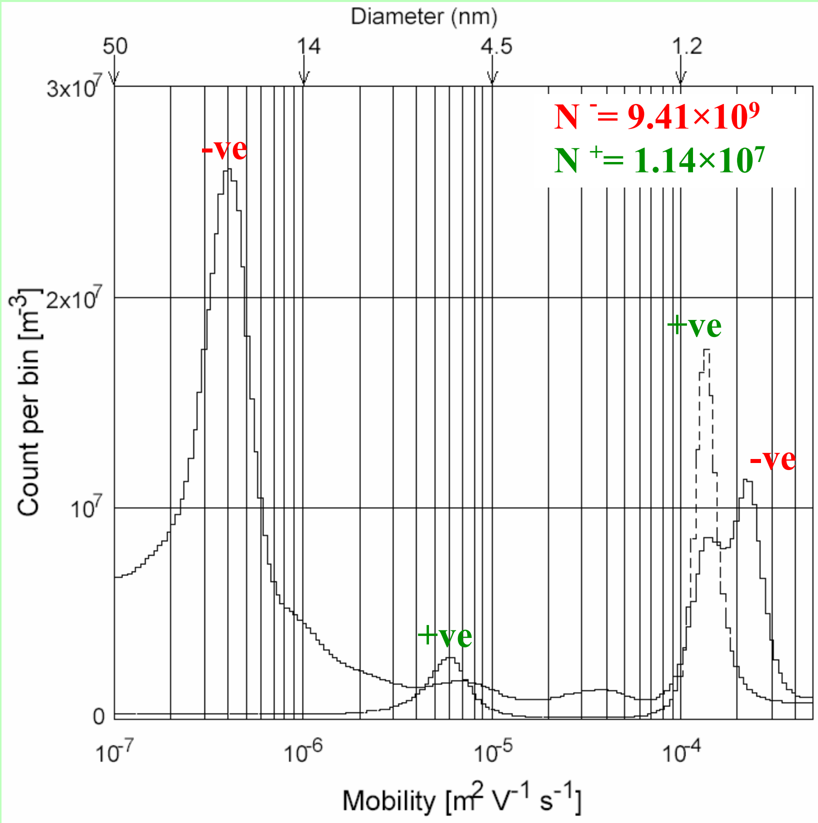
Notes on Previous Slide

- The plots show the results of contemporaneous measurements of small ions and charged aerosols (up to 15 nm) 180 m upwind and 165 m downwind of the 400 kV powerline at Lower Godney. The wind speed was 0.38 m s-1 indicating that at 165 m downwind considerable attachment of small ions to aerosols would have occurred. The numbers N+ and N- shown on the graph refer to total small-ion concentration. It is clear that downwind there is an imbalance in ion concentration i.e. there are 2.5 times the number of positive small ions than negative ones downwind, whereas upwind the concentrations are very similar. In addition, there is a peak in positive charged aerosols that is not seen upwind of the powerline.

(a) 330 m upwind



(b) 532 m downwind



(Wind speed 1.4 m s^{-1})

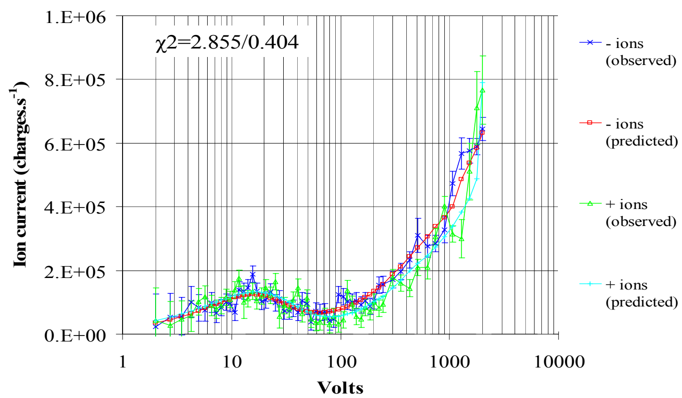
Contemporaneous spectra from the 275 kV line at Puxton, 30th April 2004

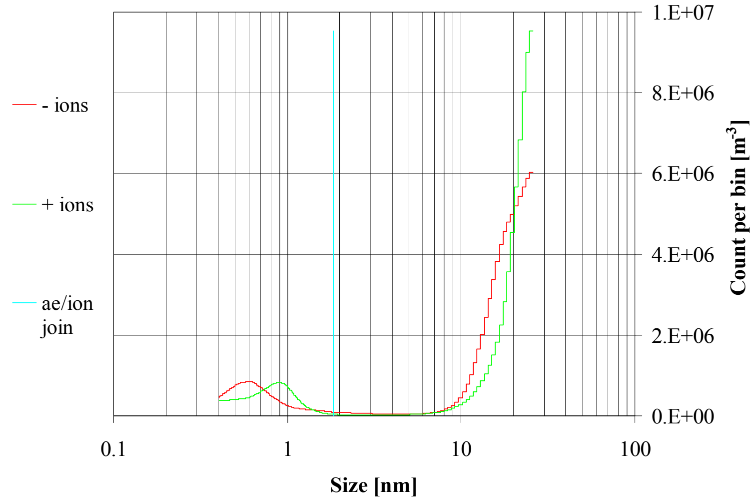
Notes on Previous Slide

- The graph shows the results of contemporaneous measurements of small ions from charged aerosols (up to 50 nm) 330 m upwind and 532 m downwind of the 275 kV powerline at Puxton. The wind speed was 1.4 m s-1, suggesting that at 532 m downwind considerable ion aerosol attachment would have occurred. On this graph, the numbers N+ and N- refer to the aerosol concentration of each polarity. There is a 30-fold increase in the number of charged negative aerosols downwind compared with upwind, while the positively charged aerosols are efficiently discharged by the high numbers of negative ions attaching to them

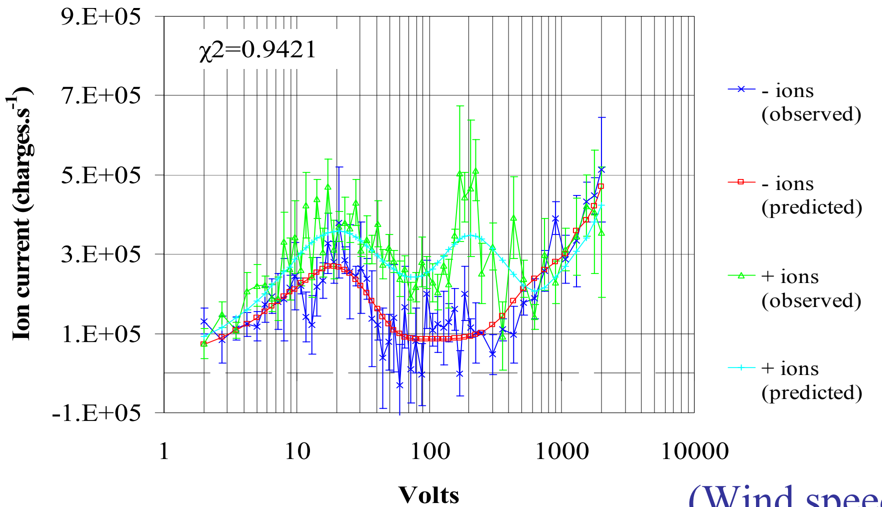
Spectra from a 275 kV line near Pilning, 16th June 2006

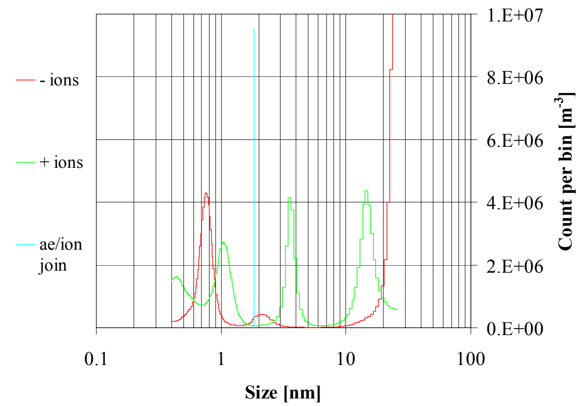
180 m Upwind





45 m Downwind

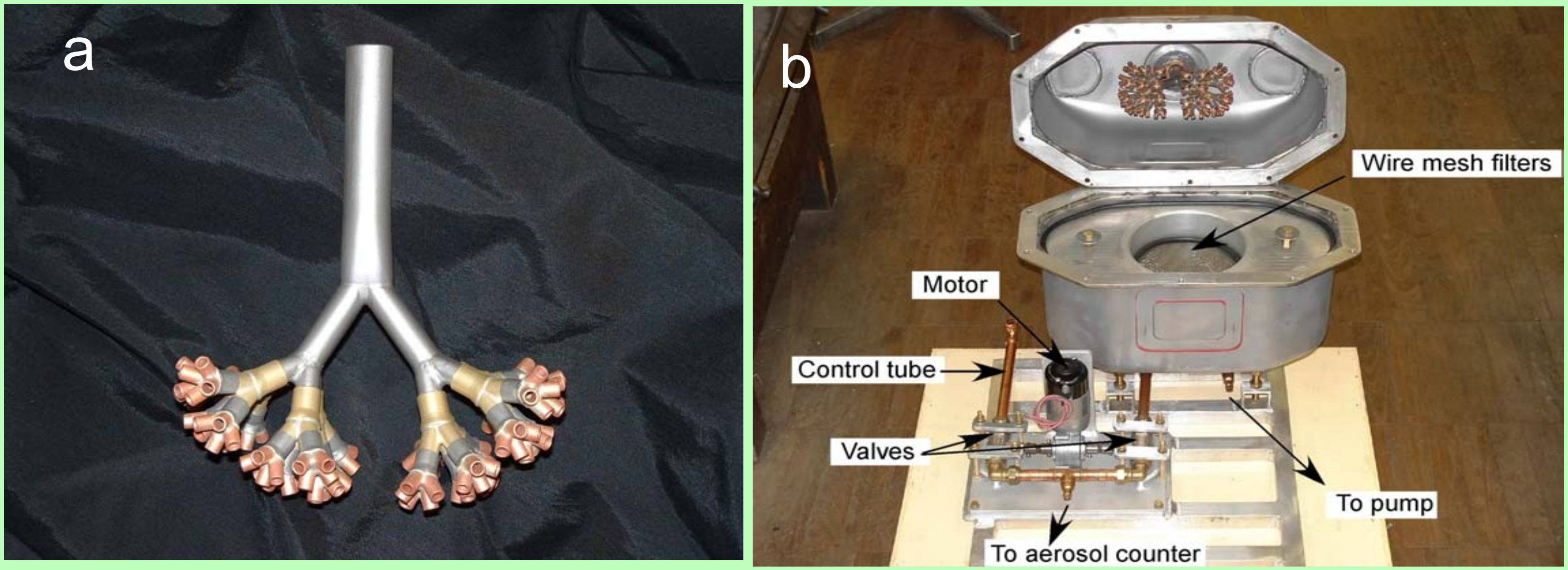




(Wind speed 1.6 m s^{-1})

Notes on Previous Slide

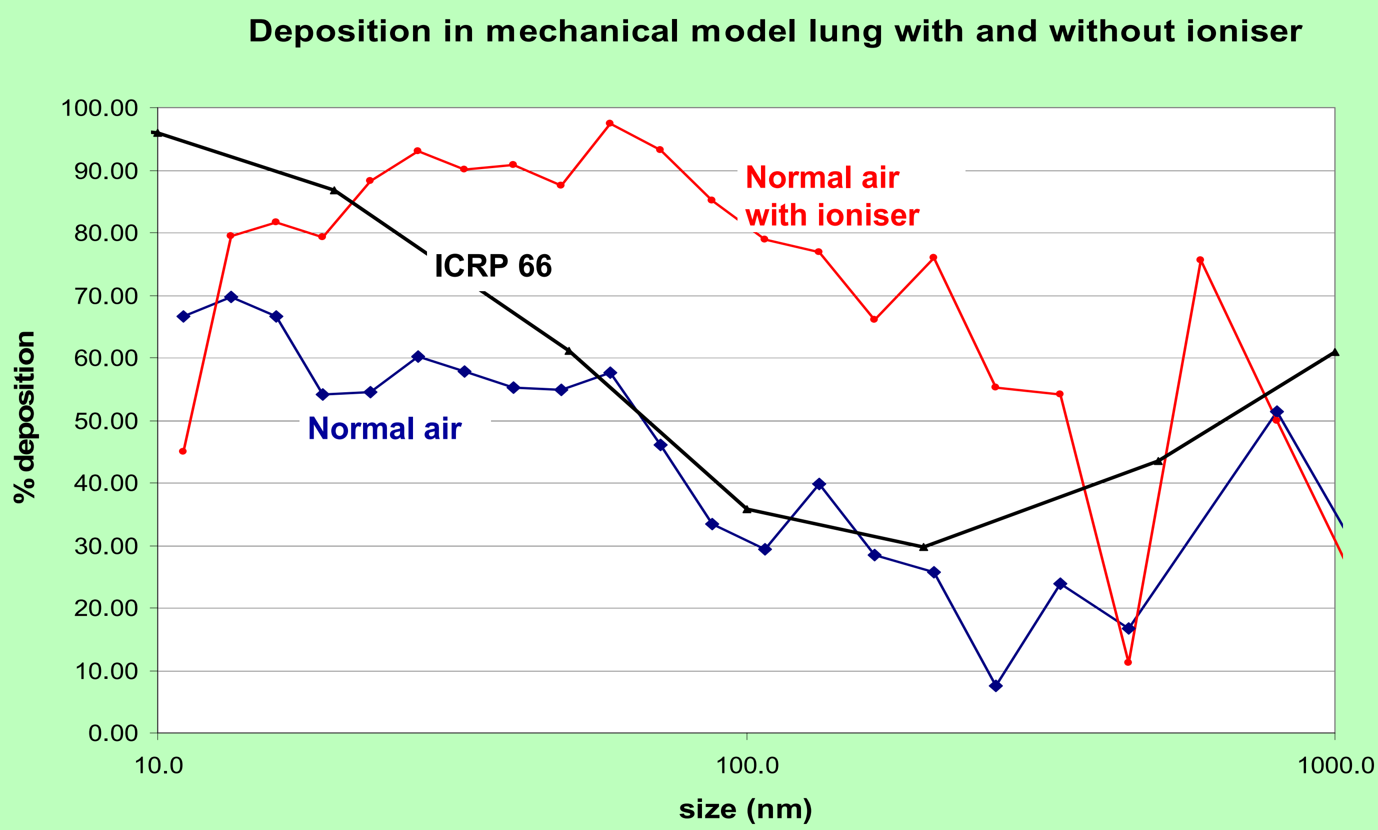
- Non-contemporaneous measurements of small ions and charged aerosols (up to 25 nm) 180 m upwind and 145 m downwind of the 275 kV powerline at Pilning. The wind speed was 1.6 m s-1, in this case suggesting that at 45 m downwind a relatively small proportion of corona ions would have attached to aerosols. Clear differences are seen in the raw data (the voltage versus ion current plots) downwind compared with upwind. There is an excess of positively charged ions and aerosols together with a peak at a scanning voltage of 200 V. In the charged aerosol plot a peak at around 3.5 nm is seen downwind. This comprises evidence of charged nano-aerosols which represent an intermediate stage between corona ion production and total attachment of these ions to aerosols. This peak has not been observed further downwind, probably due to a combination of aerosol growth and coagulation.



Keitch model lung: (a) branching of the bronchial tree, (b) the complete set-up

Notes on Previous Slide

- Paul Keitch in our team has built a mechanical model of the human lung. The airways down to the fourth generation are represented by a series of metal tubes. These are placed in a housing which also contains a wire mesh filter which mimics the alveoli. Air is drawn through the mechanical lung and the number of aerosols passing through is counted using a GRIMM SMPS-C differential mobility analyser (DMA). Attached to the lung is an open tube which acts as a control, so that the size distribution of particles in the air can be obtained. Under computer control, air can either be sampled through the control (where we expect no deposition) or through the lung itself (where deposition will occur). Air intake is alternated between control and lung with each cycle of the DMA (which normally takes around 3 minutes) so the measured number of particles at each size can be compared and a deposition fraction calculated.



Deposition in mechanical model lung with and without ioniser
100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
% deposition
10.0
100.0
1000.0
size (nm)
Normal air with ioniser
ICRP 66
Normal air

Notes on Previous Slide

- This slide shows the model lung in comparison with the ICRP 66 lung model under standard conditions and also when a domestic room ioniser was used. There is reasonably good agreement with the ICRP model but due to low counting statistics, deposition for sizes above 400 nm deviates from the expected deposition. It can be seen that with the ioniser there is significant increase in deposition. The number of ions produced in the room from this type of ioniser is around 50000 cm-3, which is considerably more than would be found close to a powerline.

Some preliminary results from model lung near to high voltage powerlines

Date	Location	Corona polarity	Precipitation	% deposition downwind	% deposition upwind	Difference
Increased deposition downwind						
18_11_2004	Latteridge	Negative	Moderate rain	39.0	34.0	5.0
02_12_2004	Lower Godney	Positive	Dry	31.0	25.2	5.8
13_01_2005	Lttle Sodbury End	Positive	Dry	28.8	23.2	5.6
13_01_2005	Lttle Sodbury End	Positive	Dry	26.0	21.6	4.4
27_01_2005	Lower Godney	Positive	Dry	29.1	26.2	2.9
27_01_2005	Lower Godney	Positive	Dry	50.7	49.7	1.0
Increased deposition upwind						
02_11_2004	Little Sodbury	Both, mostly negative	Constant, fine drizzle	12.3	15.6	-3.3

Table 4.1 *Summary of results found for the effect of corona ions found downwind of powerlines on aerosol deposition in Keitch's model lung.*

Holly Welch and Phillipa Evesham (2005)

Notes on Previous Slide

- Measurements upwind and downwind of various powerlines around the Bristol using the mechanical lung have shown a small excess of deposition in the model lung downwind. The exception at Little Sodbury is probably due to a main road at the upwind site. These increases are modest but this may be due to insufficient distance from the power line to the measurement sites for full ion-aerosol attachment to occur.

Can we square the circle with Draper *et al.* ?

- Knox (2005a, b, 2006) has published three papers reporting a series of statistically significant associations and dose response information between the incidence of childhood cancer and sources of petro-chemical air pollution in Great Britain
- We can certainly point to powerlines, 400, 275 and 132 kV which emit sufficient corona to explain the finding of Draper *et al.* (2005) in terms of the corona ion model
- What we cannot do is claim that all powerlines in England & Wales, from 1962 – 1995 are/were in sufficient corona to account for Draper *et al*'s findings

Notes on Previous Slide

- The text on this slide is largely self explanatory, the issue is not the validity of the corona ion model, rather than the degree. For our measurements, we are naturally targeting powerlines rich in corona to provide sufficient flux for measurement purposes. Observations here would square with Draper *et al*. However we cannot say that this is the case for all powerlines both throughout England and Wales and throughout the period 1962-1995. For the moment we have to leave the matter there and await the outcome of further research.

Acknowledgements

We thank the **Department of Health**

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Registered Charity No. 298405. Inaurgurated in 1988 by Diana, Princess of Wales in memory of Jean and Paul O'Gorman

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