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POWER FREQUENCY EMFs AND HEALTH RISK:
Is there a link and how can we investigate it?

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Richard Box's 'Field', February 2004
(Photo: Stuart Bunce, www.richardbox.com)

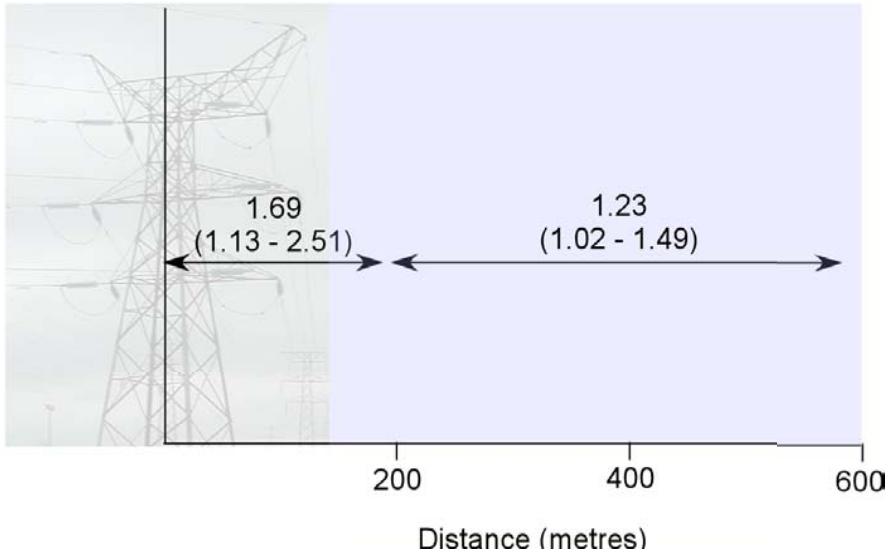
University of BRISTOL

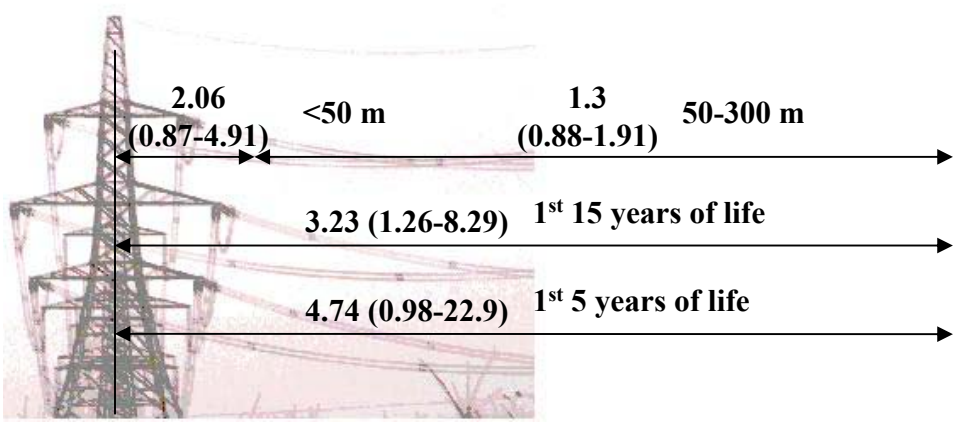
Fighting Britain's biggest childhood cancer
CHILDREN with LEUKAEMIA

Outline

- Epidemiological and laboratory studies
- Aetiology of childhood leukaemia
- Radical pair mechanism
- Melatonin disruption
  - Relevant magnetic field metrics
- Corona ion hypothesis
  - Ion and aerosol measurements
- Summary and conclusions

Epidemiological studies





- **Draper (2005) -** 29,081 children with cancer, 9,700 with leukaemia 1962-1995 (322 cases < 600 m)
- Relative Risk increased for < 200 m and 200-600 m distance from powerline at birth address

- **Lowenthal (2007) -** 854 patients aged 0-94 diagnosed with leukaemia 1972-1980 in Tasmania
- Odds Ratio increased up to 300 m from powerline
- Higher ORs for early exposure

Epidemiological studies

- **Ahlbom (2000) and Greenland (2000) – pooled analyses of MF and childhood leukaemia**
- **Elevated risk (OR/RR ~ 2) for MF > 0.4 and > 0.3 μT respectively**
- **ALS (motor neurone disease), miscarriage, depression, suicide, brain tumours, adult leukaemia also linked with MF**
- **California Department of Health Sciences (2002) 158 positive, 50 significant positive associations out of 212 examined**
- **Classification 2B "possible human carcinogen" (IARC, 2002)**
- **Current public exposure limits in UK equivalent to 100 μT (ICNIRP, 1998)**

Laboratory studies

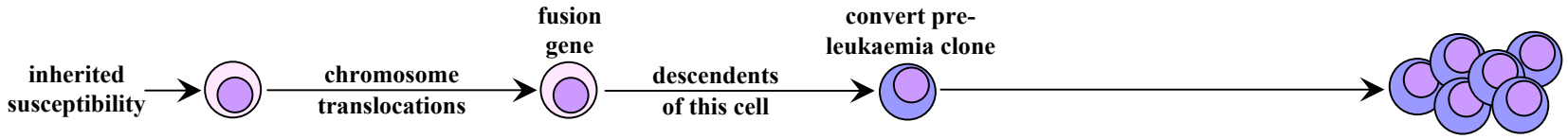
- **Juutilainen (2006)** review of 65 toxicological studies examining effect of magnetic fields on enhancement of known carcinogens

- **Enhanced effects** shown for majority of studies examined – unlikely due to publication bias

- However, most looked at fields **> 100 μT** – cannot give information about low fields tested by Ahlbom/Greenland

Aetiology of childhood leukaemia

- **500 cases/yr in UK, increased 5-fold since 1900**
- **'2-hit' process – initiation *in-utero*, later progression to disease**
- **Paternal pre-conceptual exposure, maternal and foetal exposure *in-utero* and exposure in childhood all areas of interest**
- **Linked with traffic pollution (exposure to carcinogenic PAHs), natural radiation and MFs. (In addition, maternal obstetric X-rays generally not used today)**

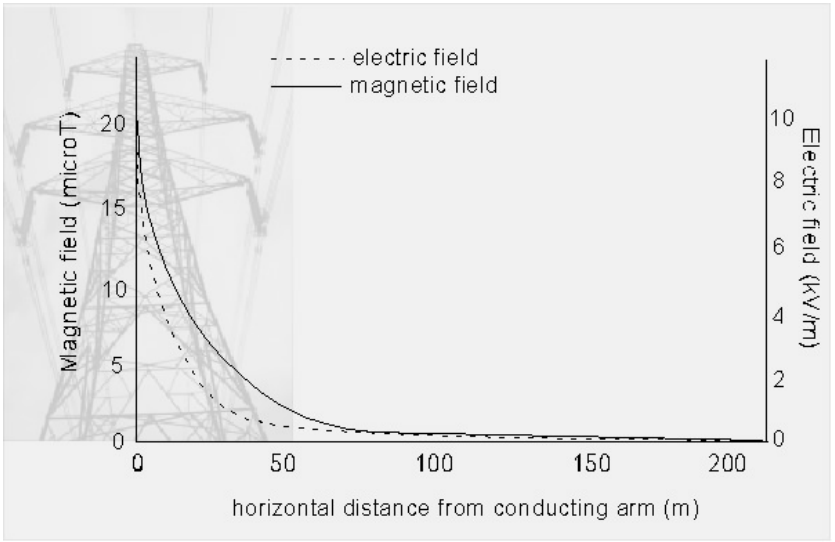


Initiation thought to occur predominantly *in utero* (Greaves, 2002. BMJ, 324, 283-287)

~1 in 100 initiation events thought to progress to leukaemia

Power line magnetic and electric fields

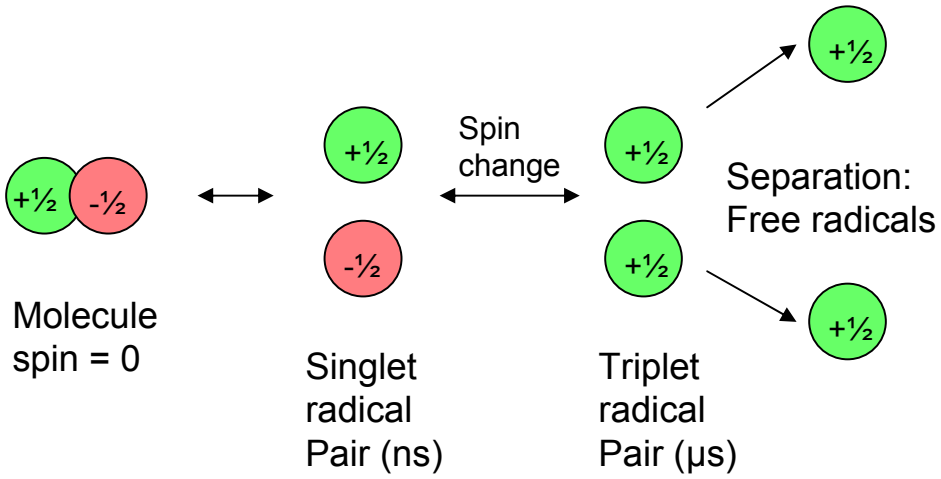
- **AC field strengths under 275 kV line:**
  - *50 Hz electric field: 10 kV m^{-1}*
  - *50 Hz magnetic field: 20 μT**
- **Compare this to typical (DC) values:**
  - *Atmospheric electric field: 0.1-0.2 kV m^{-1}*
  - *Geomagnetic field: 30-60 μT*
- **How can effects be observed far enough away from line that E and B fields are at 'background' levels?**
- **How can effects due to tiny modifications to B field (0.4 μT) be seen at all?**

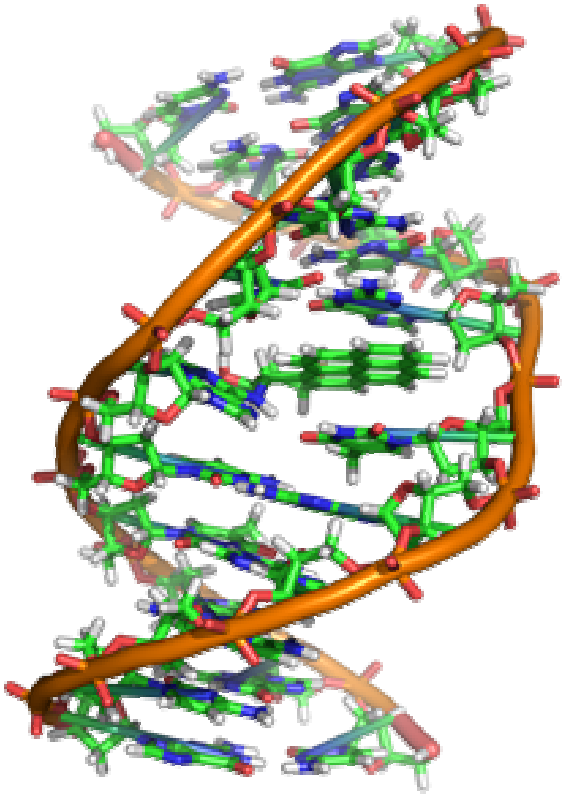


*** Dependent on line load**

Biophysical mechanisms – Radical Pair Mechanism

- **Free radicals react with DNA, causing damage**
- **When two radicals created from one precursor, spin states are coupled (+½, -½) – singlet state**
- **If the spin of one of the species changes, radical pair will have parallel spins – triplet state**





Biophysical mechanisms – Radical Pair Mechanism

- Pairs assumed only to recombine in singlet state
- Triplets more likely to separate, becoming free radicals and be available for reaction for longer time
- Low field effects – previously degenerate energy states resolve **(Timmel, 1998)**
- Increases probability of transitions from **singlet to triplet state** of radicals
- Singlet-to-triplet ratio lower, more radicals in triplet form – longer-lived

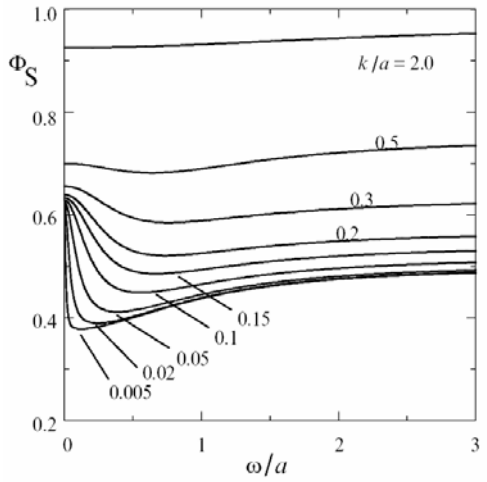


Figure 1. Magnetic field dependence of the singlet recombination yield Φ_S of a one-proton radical pair for various rate constants k, calculated using equation (12). k and the magnetic field strength ω are given in multiples of the hyperfine coupling constant a. When the recombination is slow, a magnetic field much smaller than the hyperfine coupling can produce a 40% drop in Φ_S from 5/8 to 3/8.

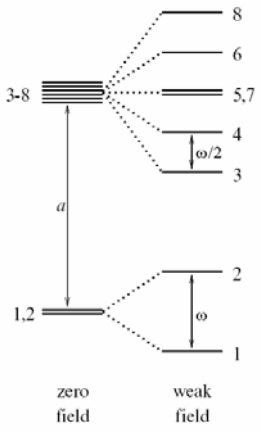
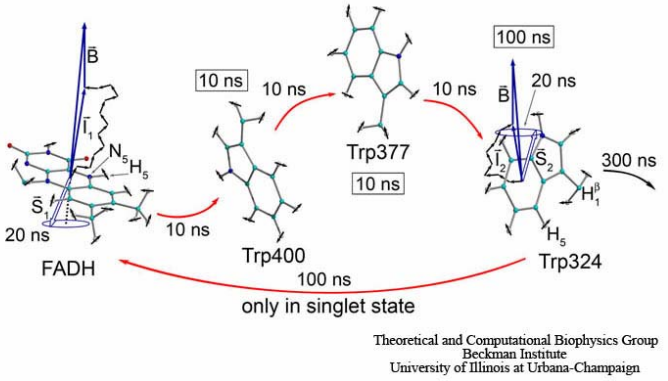


Figure 3. Energy levels of a one-proton radical pair in zero field (left) and in the presence of a weak ($\omega \ll a$) magnetic field (right). a and ω are, respectively, the hyperfine coupling and the electron Larmor frequency, $\omega = \gamma B_0$.

Biophysical mechanisms – Animal navigation

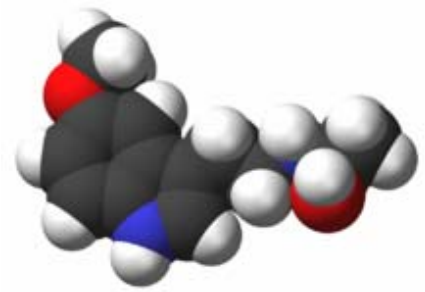
- Many animals can detect and use tiny changes in the Earth's 'static' magnetic field – both its strength and orientation – for navigation
- Robins detect changes of 80 nT (Ritz, 2004) and homing pigeons sensitive to 10-20 nT (Wiltschko, 2005)
- Magnetite particles in beak
- Radical Pair Mechanism in eye (cryptochromes)
- Some amphibians have receptors in pineal gland…

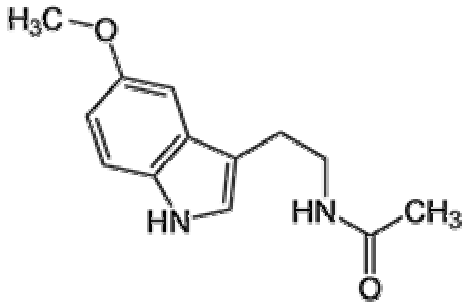


(www.ks.uiuc.eu/Research/cryptochrome)

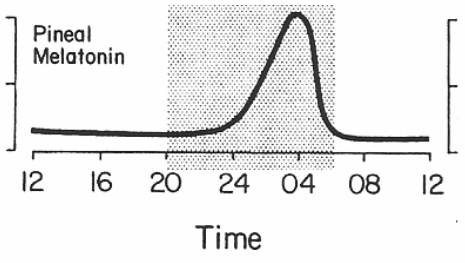
Biophysical mechanisms – Melatonin disruption

- Melatonin produced in pineal gland
- Ganglion cells in eye (not visual system) signal when there is **no light** – pineal melatonin produced at night
- Also highly effective anti-oxidant (radical scavenger) – anti-cancer agent **(Reiter, 1994)**
- Both preventative and potentially during treatment – *in vivo* evidence using nocturnal blood **(Blask, 2005)**
- Melatonin could link apparently disparate health outcomes discussed earlier





Melatonin
(N-acetyl-5-methoxytryptamine)

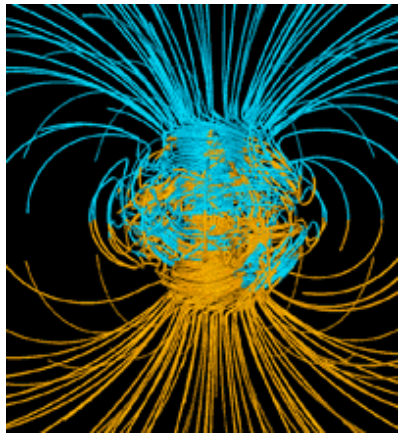


Biophysical mechanisms – Melatonin disruption

- 'Light at night' decreases melatonin – could contribute to increased cancer risk (night-shift workers)
- Melatonin suppression first proposed for both EMF and light-at-night (Stevens, 1987)
- Henshaw & Reiter (2005) - magnetic fields ≥ 0.2 μT can cause melatonin suppression
- Characteristics of field may also have an influence – e.g. square-wave MFs have greater effect than sinusoidal MFs
- Some evidence for non-linear dose-response curve

Biophysical mechanisms – Geomagnetic effects

- Seasonal variations in health effects due to natural magnetic fluctuations **(Palmer, 2006)**
- Solar- and Geomagnetic activity linked with rates of suicide, depression, 'vestibular experiences' and even stock market returns!
- K-index describes **temporal variability** in 'static' magnetic field at Earth's surface
- Studies have investigated 'disturbances' as low as **tens nT** (K=3)
- Evidence that a subsection (10-15%) of people may be **predisposed to health effects** related to magnetic fluctuations

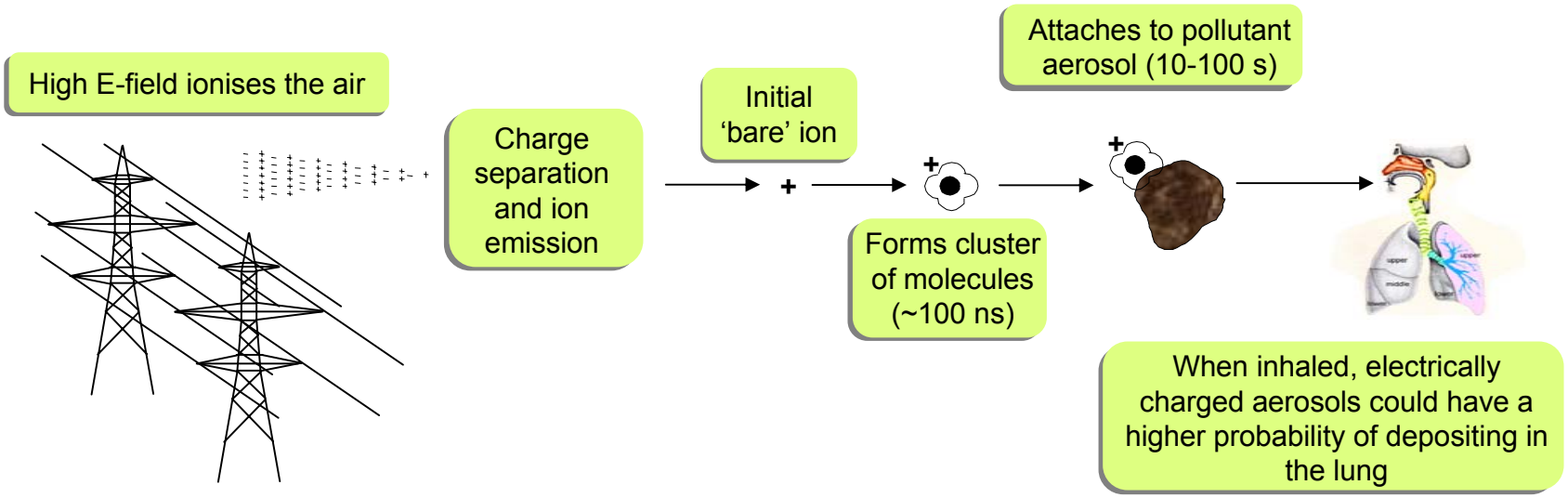


Biophysical mechanisms – Relevant metrics

- Key word in many of descriptions is ***fluctuation***
- Appears that (rapid) changes in field cause effects
- Many epidemiological and laboratory studies use **time-weighted average (TWA)** field magnitude
- Much **information is lost** in this way – signalling spikes, peak values, orientation and polarisation
- **'False negatives'** may result
- Determination of correct biological response (if any) needs **physical measurements** of the correct field properties

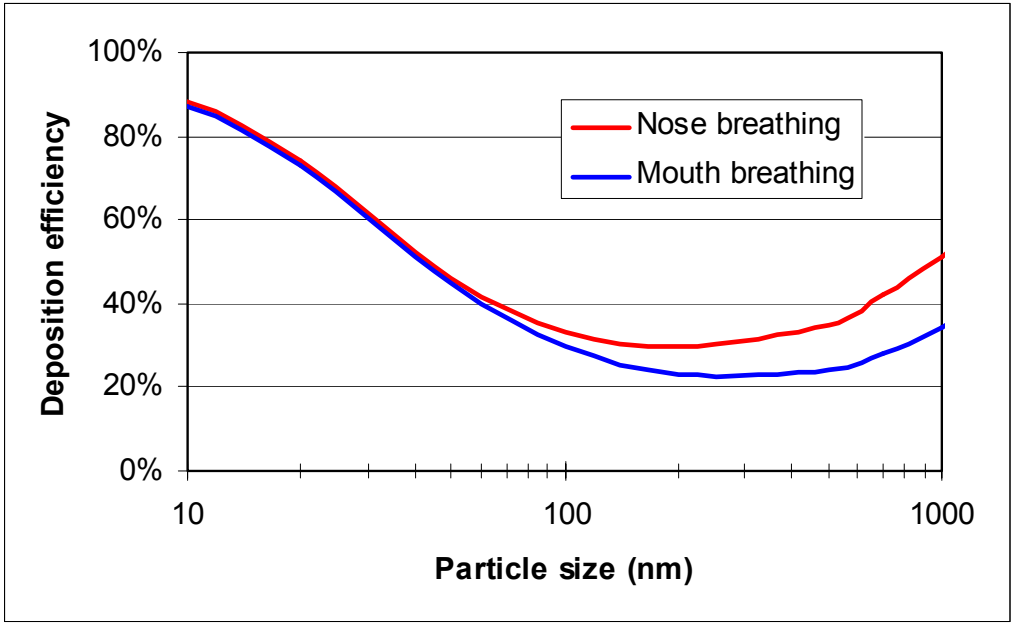
Corona ion hypothesis

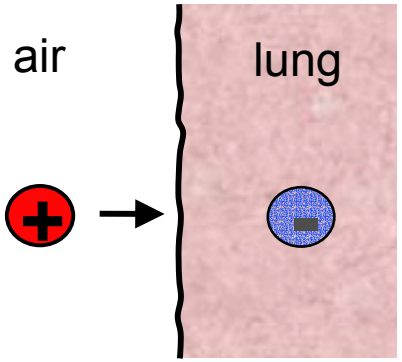
- Direct fields cannot explain findings of Draper and Lowenthal distant from the power lines
- Indirect mechanism could be due to corona ions (Fews, 1999)
- High voltage line ionises the air and forms atmospheric small-ions
- Small-ions attach to pollutant aerosols, changing their charge state
- Increased charge on aerosols can lead to increased lung retention



Lung deposition and electric charge

- ICRP (1994) particle deposition efficiency
- In sub-micron range, not all particles deposited
- Charged particles near conducting surface induce a charge on the conductor
- Equivalent to charge of equal magnitude, opposite sign, equidistant from surface
- Image force increases chance of lung deposition





Lung deposition and electric charge

- **Cohen (1998)** – metal cast of upper lung airways – up to 6-fold increased deposition
- **Melandri (1983)** – increased retention above threshold charge for given particle size in human volunteers
- Several **other deposition mechanisms** in the lung occur (diffusion, inertia, gravity)
- Is charging state of aerosols near power line sufficient to have a significant effect?

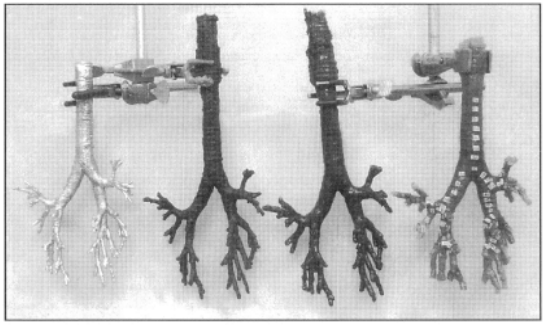


Fig. 1. Casts are shown at various stages in production: a) metal master cast, b) after application of a thin layer of conducting plastic, c) after application of additional supporting layers of clear silicone, and d) hollow cast after removal of metal core. The markings on (d) indicate where the cast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

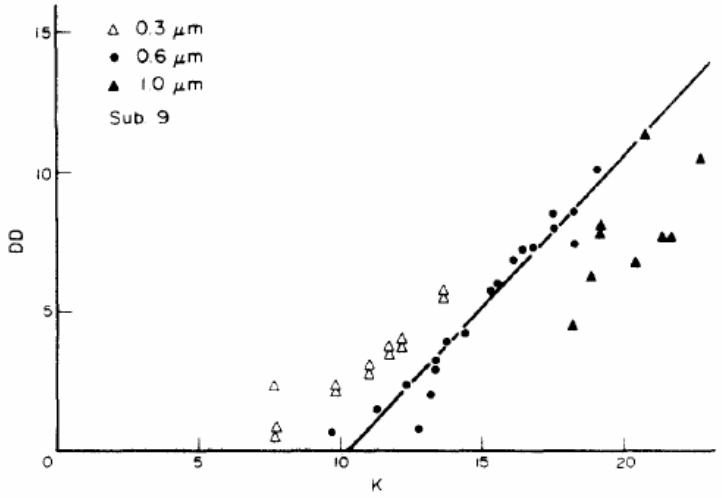
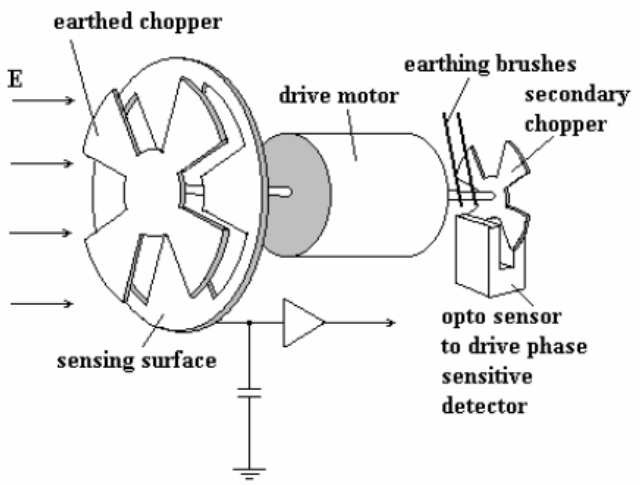
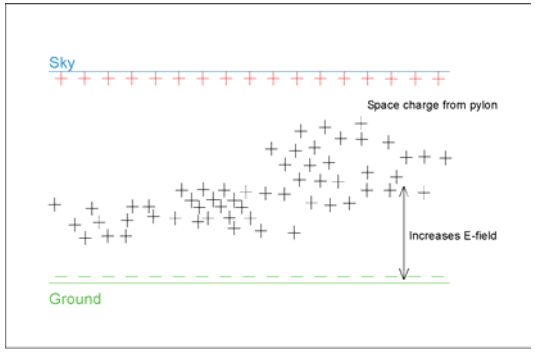


Fig. 7. Electrostatic excess deposition (%) for subject 9, at 0.3, 0.6 and 1.0 μm, positive charges.

Corona ion DC electric field measurements

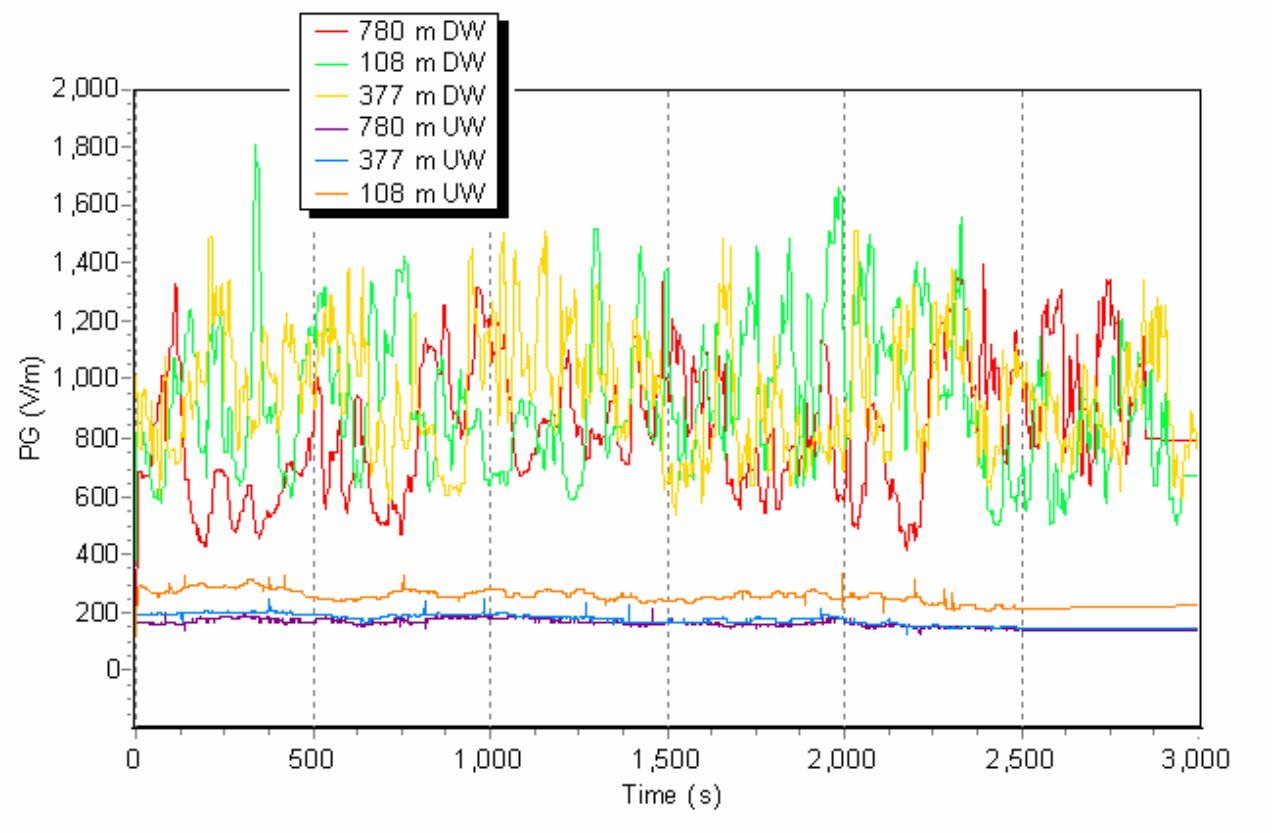
- DC field mill meters used to measure **electric field** near power lines
- Work by alternately covering and uncovering a sensing electrode
- AC signal received proportional to DC field strength





(John Chubb Instrumentation, www.jci.co.uk)

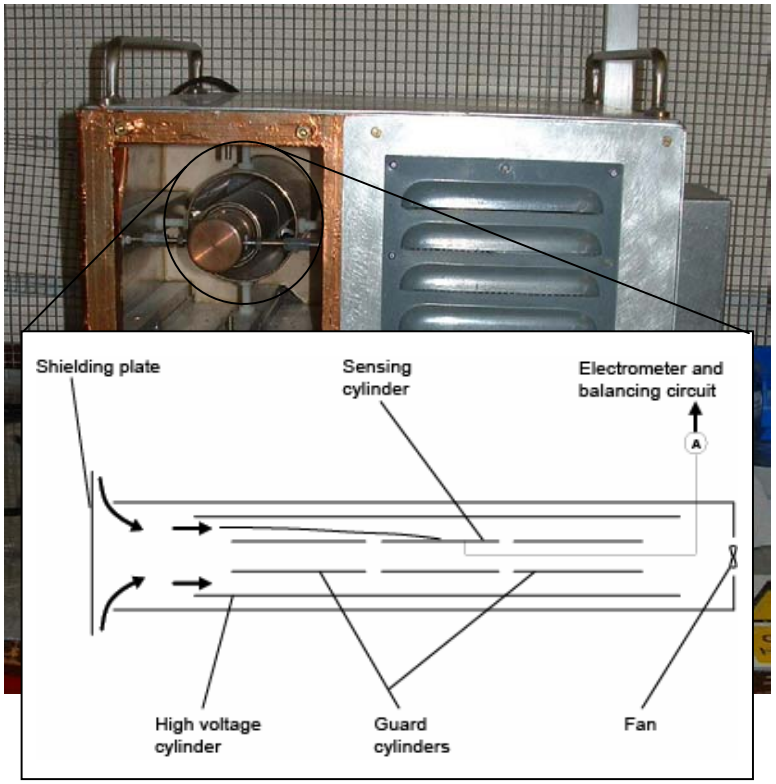
Corona ion DC electric field measurements



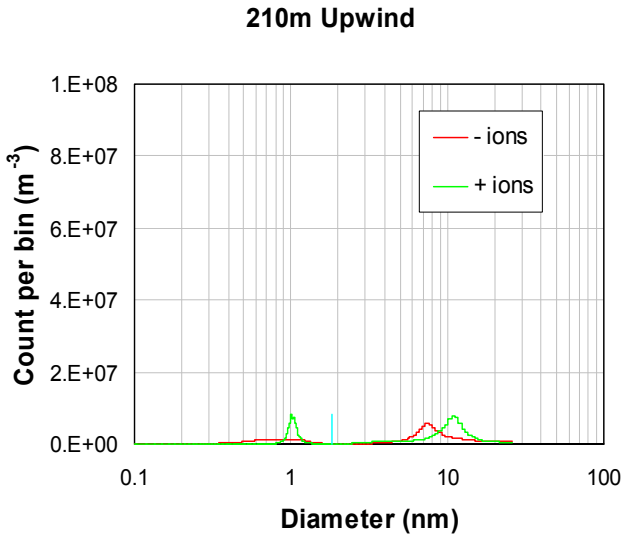
- 6 contemporaneous DC field meters near a 400 kV line in Somerset
- Upwind – DC field relatively stable
- Downwind – DC field is much higher (+ve corona)
- Also displays more variability

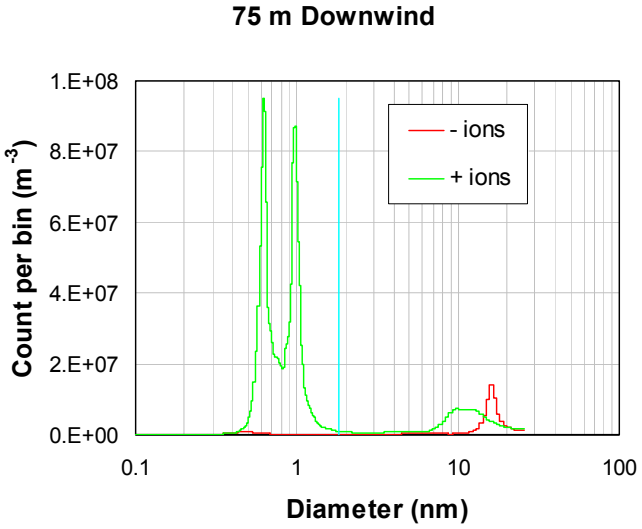
Corona ion mobility spectrometry measurements

- Concentration and mobility of small ions (< 1.6 nm) and nano-aerosols (1.6 – 30 nm) also measured
- Aspiration Condenser Ion Mobility Spectrometer (ACIMS)
- Air drawn through cylindrical capacitor
- Voltage on outer cylinder varied stepwise from 0 to ± 5 kV
- Charged particles deflect in electric field onto central electrode
- Ion current at electrode is converted to a mobility spectrum after 'scan'



Corona ion mobility spectrometry measurements



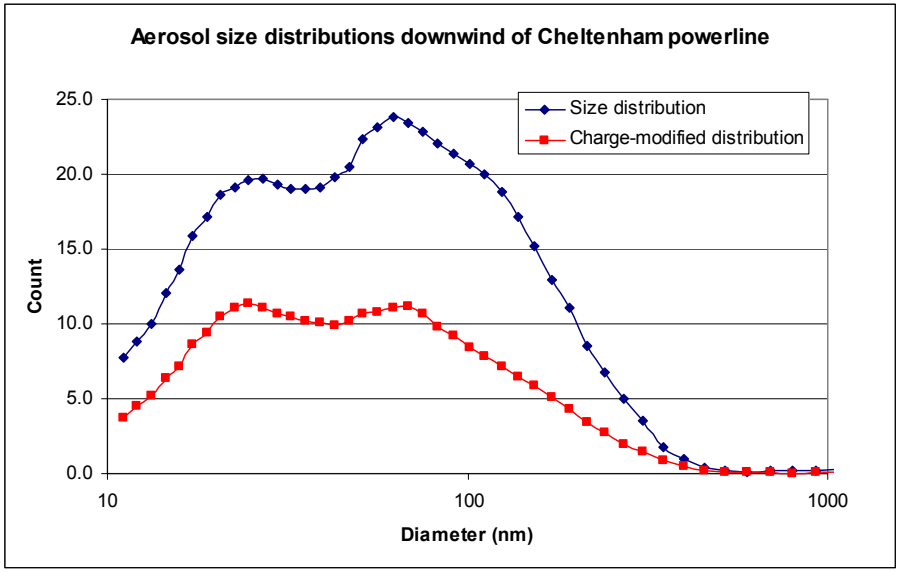


- Example – measurements made at 275 kV line near Cheltenham, Glos.
- Typical outdoor background ion concentrations 200 – 250 cm^{-3}
- Elevated to up to 6000 cm^{-3} downwind
- Ion attachment to aerosols evidenced by increasing +ve/-ve ratio

Location	Ratio +ve/-ve	
	aerosol	ions
210m Up	0.9	1.1
75m Down	1.8	99.1
220m Down	3.2	8.3

Aerosol size distribution and charge state measurements

- Submicron (10 – 1000 nm) aerosols measured using Sequential Mobility Particle Sizer (SMPS)
- Gives aerosol size distribution
- Using two at the same site allows investigation of charge state
- Average mobility increased if there is more charge on aerosols
- Causes a shift in distribution
- By fitting a theoretical charge distribution to measurement, calculate expected 'modified' distribution due to charge



Summary and conclusions

- There is a body of epidemiological and laboratory evidence suggesting a causal link between power-frequency EMF exposure and adverse health effects
- Plausible biophysical mechanisms exist which could explain these findings
- However associations are strong only for a few diseases
- Epidemiological studies would be strengthened by the use of appropriate metrics
- Laboratory studies could shed some light on which of these metrics may prove most important
- There is a continuing need for physical measurements of EMF characteristics, in order to move forward in both areas

Acknowledgements

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