Powerfrequency EMFs and Health Risks

This article is separated into 12 sections, each of which can be individually downloaded. It is a 'work in progress' incorporating new information whenever time permits.

Section 3

Cancer

1. Introduction; electricity consumption; measuring meaningful exposure; static electric field from high voltage direct current transmission; precautionary recommendations; EMFs interacting with the environment or other substances; geomagnetic field (GMF) changes; a French study in 2009; residential exposure; mitigating biological effects; campaigning organisations

2. Occupational exposure; occupational research

3. Cancer; Sources of magnetic field exposure and cancer risk; leukaemia; brain cancer; breast cancer; neuroblastoma; other cancer; immune system effects; tamoxifen, doxorubicin and other drug effects; similarities to other chemical effects

4. Cellular changes and potential mechanisms; DNA breaks and changes; EEG changes; other cellular changes; potential mechanisms for interaction between exogenous EMFs and biological processes; free radical effects; effects on other cellular processes; airborne pollutant effects; other potential synergistic effects

5. MRI; contrast enhancement; individual experiences of reactions; MRI vs CT; cardiac scan; the European Physical Agents Directive; research

6. Electronic surveillance systems in shops, airports, libraries, etc.

7. Light at Night and Melatonin; circadian rhythm disruption; clock genes; plant, animal and insect effects

8. General reproductive effects; miscarriage and other effects of female exposure; powerfrequency exposure and male sperm; protective treatments

9. Other effects; ageing; amyotrophic lateral sclerosis (ALS); animal effects; anxiety; asthma; autism; bacteria; behaviour changes; birth defects; effects on blood; bone changes; brain damage; cardiovascular effects; dementia; developmental effects; depression and suicide; EEG changes; energy metabolism; eye effects; gastric effects; genetic defects; hearing effects; heart; insulin and electric fields; interference problems; kidney effects; learning and memory effects; lung, spleen and liver; medical implants; mental health problems; nervous system; neurobehavioural effects; neurodegenerative effects

10. Other effects; obesity; olfactory effects; other neurological and psychological effects; pain perception; Parkinson's disease; protective effects of EMFs; skin; sleep; synergistic effects; teeth; thyroid; weight change; some experimental problems; government advisory bodies

11. Positive health effects; apoptosis; cancer treatment; cell survival and differentiation; wound healing

12. References – 937 references

The concern about the potential effect of EMFs on cancer was triggered by a study by Wertheimer & Leeper in 1979 that showed a 2 to 3 fold increase in childhood leukaemia associated with living near to high power electricity wires. Since that time childhood leukaemia has been the subject of most of the EMF research, in order to try to replicate or disprove the Wertheimer & Leeper findings. Other types of cancer have also been investigated and associated with power-frequency EMFs.

Sources of magnetic field exposure and cancer risk

1998 Simkó - Different human cell types respond differently to EMF. Dose-dependent induction of apoptosis and genotoxic effects, resulting in increased micronucleus formation, could be demonstrated in the transformed cell line, whereas the non-transformed cell line did not show statistically significant effects. These findings suggest that EMF could be a promotor but not an initiator of carcinogenic effects.

1999 Floderus – In a study of 1,596,959 men and 806,278 women, between 1971 and 1984, occupations with a magnetic field exposure were analysed. The most notable finding for men was an increased risk of testicular cancer in young workers, and for women a clear association emerged for uterine cancer. The outcome suggests an interaction with the endocrine/immune system.

2000 Greenland – A pooled analysis of 12 studies, showing that magnetic field levels over 0.3 μT nearly doubled the risk of childhood leukaemia.

2000, 2001 Ahlbom and Schuz & Ahlbom 2008 - Analyses of international studies on electric and magnetic fields (EMFs) and childhood leukaemia, including the results of a study in the UK, showed that children exposed to magnetic fields above a level of 0.4 microtesla (μT) were at twice the risk of contracting the disease.

2001 Erren - A meta-analysis of 43 papers concluded that there was an association between exposure to EMFs at work or at home and a risk of breast cancer in women and men, despite the fact that results from individual studies were very variable and in part contradictory. The author felt that the variation may have been to do with the misclassification of exposure and the possible misclassification of the disease itself.

2005 The biggest UK study, led by Gerald Draper, found a doubling in risk of childhood leukaemia up to 600 metres from the 2 largest (400kV and 275kV) powerlines. About 5% of the UK population live at this distance. Professor Denis Henshaw of Bristol University said "*These findings not only strengthen further the evidence that children living in proximity to high voltage powerlines are at increased risk of childhood leukaemia, but in finding effects up to 600 metres away they invoke electric field corona ion effects as a possible causal mechanism. The fact that this study has looked at the birth address is particularly important because the initial damage that may lead to leukaemia is thought to occur in utero.*" O'Carroll & Henshaw (2008) investigated the data from 2 reviews looking at health effects arising from exposure to power-frequency EMFs. They reported that 33 independent adult leukaemia studies tabled by IARC yielded 23.5 positives and 9 significant-positives. From 43 representative results from CDHS, there were 32 positive and 14 significant-positives. There were no significant-negative results in either list. Results for adult brain cancer gave a similar, but less clear, message.

2006 Kabuto - children in magnetic field levels of 0.4 microtesla or more were 3 times more likely to develop leukaemia and 5 times more likely to develop ALL.

2007 Lowenthal - prolonged residence close to high-voltage power lines, especially early in life, (before 15 years over 3 times more likely, before 5 years nearly 5 times more likely) may increase the risk of developing illnesses such as leukaemia and lymphoma.

2009 P Li – The risk of children developing brain tumours, especially astroglial tumours was increased if their mothers were occupationally exposed to EMFs during the pregnancy. The risk was doubled for sewing machine operators exposed both before conception and during the pregnancy.

2010 Malagoli – Children living near powerlines in northern Italy were found to be 3 times more at risk of getting leukaemia when they were exposed to levels of at, or above 0.1 μT. They were over 5 times more at risk of getting ALL.

2010 Sohrabi – Children living less than 600 metres from a powerline were nearly 3 times more likely to develop ALL, with an odds ratio of 9.93 for 123kV lines; 10.78 for 230kV lines and 2.98 for 400kV lines.

2011 Marcilio – A small increase in leukaemia mortality was observed among adults living in houses exposed to magnetic fields above 0.3 μT. The risk was limited to lower voltage lines.

2011 Wang – Adult acute myeloid leukaemia linked to very low levels of powerfrequency EMF exposure, both occupational and residential, (0.2 μT) in a meta-analysis of 9 papers.

2011 Schuz – Accepts the assessment that ELF-MFs of 0.4 μT are a possible carcinogen and may cause childhood leukaemia remains valid.

2013 Sun – 7 case-control studies and 11 cohort studies were identified in a meta-analysis. The authors found a statistically significant increase in male breast cancer with EMF exposure.

2013 Sermage-Faure – In the Geocap study, the authors included all the 2,779 cases of childhood acute leukaemia diagnosed in France between 2002-2007 and 30,000 contemporaneous population controls. They found an increased risk of childhood acute leukaemia in those living within 50 metres of high-voltage overhead power lines.

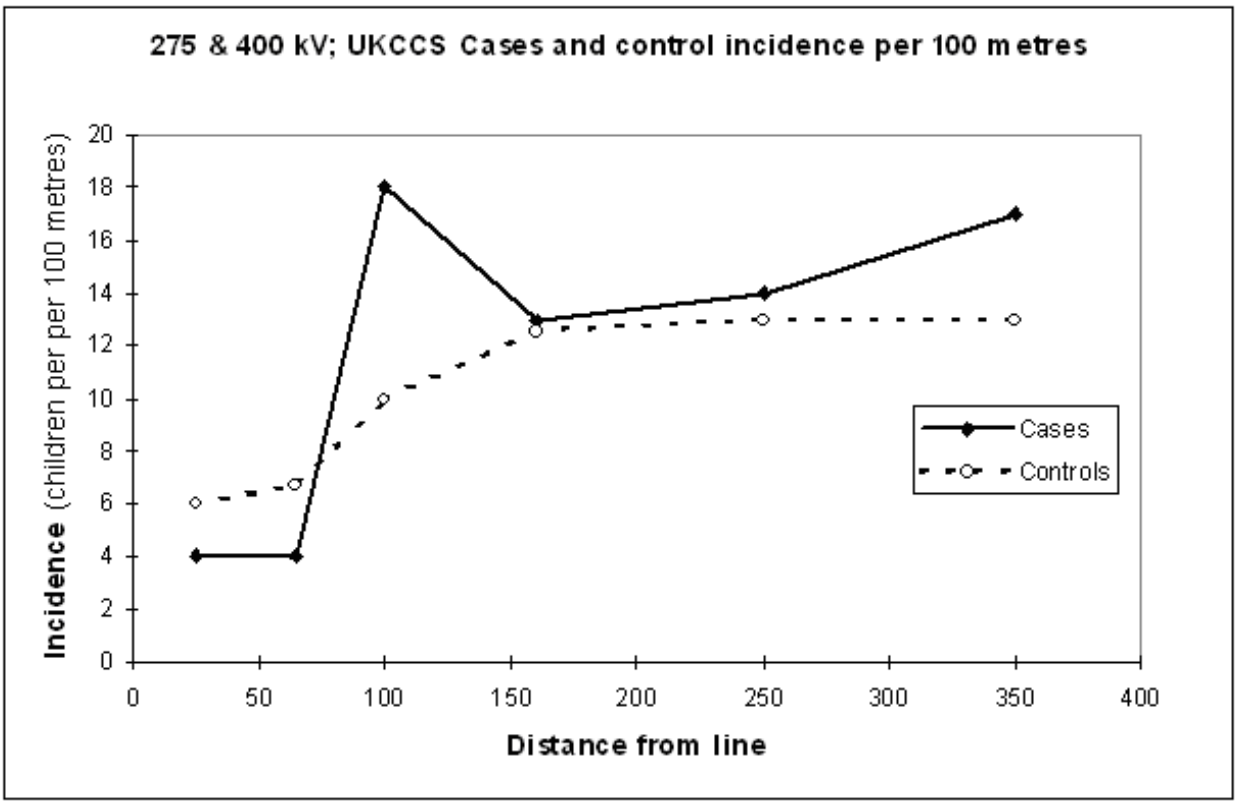
2014 Zhao – Concludes in a meta-analysis of 9 studies, 11,699 cases and 13,194 controls that magnetic field exposure level equal to, or greater than 0.2 microtesla may be associated with childhood leukaemia.

2015 Zhang – In a meta-analysis of 42 studies, an increased cancer risk was identified with exposure to ELF-MFs. Residential exposure was found to be associated with a higher risk in comparison to occupational exposure, exposure to electric blankets and other household appliances. A slight increased risk was found in premenopausal breast cancer.

2016 Bunch - The elevated risks for childhood leukaemia that the authors had previously found for overhead power lines they say may be higher for older age at diagnosis and for myeloid rather than lymphoid leukaemia.

The field levels of 0.2 to 0.4 μT are well below levels found near high voltage powerlines where values can reach several microtesla or even tens of microtesla, though they are significantly above the average level found in the home, which is about 0.05 μT, though it *can* vary from 0 to 0.68 μT (Lacy-Hulbert 1998, Preece 2000, Kheifets 2005).

The Ahlbom studies have since led the International Agency for Research on Cancer (IARC) in 2002 to classify magnetic fields as a possible carcinogen.



From the UK Childhood Cancer Study (UKCCS) published in 2000.

Leukaemia

There was a gradual increase in the incidence of childhood leukaemia in the 20th century (Shah & Coleman 2007). A peak in childhood acute lymphoblastic leukaemia (ALL) began to appear in the UK in the 20s and slightly later in the USA, along with the electrification of these countries (Milham & Ossiander 2001).

In a review of studies by (Busljeta 2000) the authors concluded that there is a link between powerfrequency fields and childhood leukaemia and brain tumours in children and adults. Kheifets (2006) suggests that the fraction of childhood leukaemia cases possibly attributable to ELF exposure across the globe appears to be small. However, she says, there remain a number of uncertainties in the attributable fractions estimates, particularly in the exposure distributions.

Eddie O'Gorman, Chairman of leading UK charity CHILDREN with CANCER UK, who has himself lost a child to leukaemia, said "*We have to do everything we can to protect young lives: there is now a clear case for immediate government action. Planning controls must be introduced to stop houses and schools being built close to high voltage overhead power lines.*"

In 2004, the Public Health Minister set up a Stakeholder Advisory Group on EMFs (SAGE) to examine the issue of precaution against EMF exposures in the UK. The first interim assessment of SAGE, (a group made up of government bodies, electricity distribution networks and lobby groups) was released in April 2007, and found that the link between proximity to powerlines and Childhood Leukaemia was sufficient to involve a precautionary recommendation, including an option to underground new build powerlines where possible and to prevent the building of new residential buildings within 60m of existing powerlines." The cost benefit ratio for childhood leukaemia alone is about 20:1, but when all the other documented health risks (headaches, adult leukaemias and brain tumours, miscarriage, Motor Neurone Disease, etc.) are taken into account the ratio is about 1:50, a very worthwhile reason for implementing the 60 metre distance

moratorium on new buildings and new powerlines. However, the government has not implemented precautionary legislation as a result of the findings of this group.

It is not only children, with the rapidly changing cells in their bodies as they grow who are vulnerable, there is a greater risk of adults developing leukaemia in residential magnetic fields above 0.2 microtesla. The risk does not seem to apply to either brain tumours or female breast cancer.

Lagroye (2011)suggested that cryptochromes (CRY), which are part of the molecular circadian clock machinery, is a ubiquitous protein likely to be involved in cancer cell growth and DNA repair. The radical pair mechanism and related CRY molecules have recently been identified in birds and other non-mammalian species as a sensor of the geomagnetic field, involved in navigation, which can be disturbed by EMFs. This may be a mechanism by which EMFs are associated with cancer, but the same research has not been done with people or mammals as yet.

Not all of the studies looking at potential mechanisms that attempt to explain the relationship come up with answers (Kirschenlohr 2012).

Kavet & Hooper (2009) and Kavet (2011) suggest that bathing children when there is a voltage between bathtub plumbing fixtures and the drain could result in their being exposed to contact currents. They felt that contact current has the characteristics of a factor which could explain the association of magnetic fields with childhood leukaemia. As non-conductive materials are being used more, it may explain some of the reduction in leukaemia incidence.

A study by Vallejo (2001) concluded that chronic exposure of mice to a 50 Hz magnetic field could be related to the development of leukaemia.

In female mice, the incidence of chronic myeloid leukaemia in a group exposed to 50 Hz fields for 12 hours a day was significantly greater than in the control group. The size of seminiferous tubules in the EMF exposed groups of male mice was significantly less than the control group, affecting fertility (Qi 2015).

Brain cancer

In a meta-analysis of 13 studies, Mezei (2008) found a possibility of a modest increase in risk of childhood brain cancer with residential magnetic field exposure of 0.3/0.4 microtesla. They found the results were more or less consistent, with the exception of studies using wire-codes.

An increased risk of brain cancer was observed among men who had ever held a job with an average magnetic field exposure greater than 0.6 microtesla. The risk was more than five-fold for men diagnosed with glioblastoma multiforme (Villeneuve 2002).

Breast cancer

Caplan (2000) reviewed studies of both occupational and residential exposure to EMFs to look at possible links to breast cancer, as a potential explanation of the increased incidence of breast cancer in industrialised countries. They concluded that there was sufficient data to warrant further investigation, which has, in fact, happened. Both van Wijngaarden (2001) and Kliukiene (2004) found that breast cancer in women was associated with calculated magnetic field levels as a result of residential and occupational exposure, (especially non-menopausal women Zhao 2014), but neither Davis (2002,2007) nor C Chen in a meta-analysis (2010) found that the incidence of breast cancer was increased. Q Chen (2013), in a review of 23 studies found an increased risk for female breast cancer, especially for premenopausal and oestrogen receptor positive (ER+)

groups. The fact that not all groups were sensitive to EMF exposure could explain some of the mixed results that have been found and further, selected, studies may cast light on any potential link and mechanism. Fedrowitz & Löscher (2012) observed rat strain differences in the magnetic field (MF) response of breast tissue, so that the genetic background plays a role in MF effects.

Milham (2004) found an increase in male breast cancer with occupational exposure. Pollán (2001) looked at male breast cancer and occupational exposure to EMFs, and found the results inconclusive, but suggested that large variations in exposure (transients) may be associated with an increased risk. A meta-analysis by Sun (2013) of 18 studies concluded that EMF exposure may be associated with the increase risk of male breast cancer.

Thun-Battersby (1999) and Fedrowitz (2002) found that magnetic fields made particular breast cancer cells in rats grow much more rapidly, but not in all the rat strains tested (Fedrowitz 2004, 2005), implying that there may be a difference in sensitivity between the different strains. Long-term exposure of female rats treated with a chemical carcinogen (DMBA), in an alternating MF of low flux density, promoted the development and growth of mammary tumours, indicating that MF exposure exerts tumour-promoting and/or co-promoting effects (Mevissen 1998).

Boorman (2000) in a review on EMF exposure on laboratory rats and mammary cancer development concluded "*The totality of rodent data does not support the hypothesis that power-frequency magnetic-field exposure enhances mammary cancer in rodents, nor does it provide experimental support for possible epidemiological associations between magnetic-field exposure and increased breast cancer risk.*"A further study by Fedrowitz & Löscher in 2008 suggested that the Fischer 344 rats were an ideal inbred strain of rats to investigate the mechanisms for EMF effects as they seemed so responsive. Fedrowitz's research colleague, Wolfgang Löscher, had already identified (2001) that the co-carcinogenic effect of magnetic fields was not straightforward.

There may be a difference in the type of breast cancer that could develop as a result of exposure, and an age window of vulnerability. In a study by Feychting (1998), women younger than 50 years old at diagnosis, were seven times more likely to develop oestrogen receptor-positive breast cancer when exposed to magnetic field levels over 0.1 microtesla (μT), a very low field that can be found in many houses and work environments. Occupational exposure over 0.25 μT had three times the risk (Forssén 2000). Fields of 1.2 μT significantly disrupted the anti-oestrogenic effect of melatonin in breast cancer cells (Girgert 2010). (Li 2005) found that 0.4 mT magnetic fields altered MCF7 cells and possibly many physiological functions of normal cells. Beniashvili (2005) demonstrated a highly significant increase in breast cancer in elderly women more exposed to magnetic fields from household electrical appliances (including personal computers (more than 3 hours a day), mobile telephones, television sets, air conditioners, etc.) than a group less exposed.

Shi (2013) found that long-term night shiftwork exposure may lead to the methylation-dependent downregulation of miR-219, which may in turn lead to the downregulation of immunomediated antitumor activity and increased breast cancer risk.

Working at night has been associated with an increased risk of breast cancer by Hansen (2001). It is possible that this may be due to the women being exposed to light (part of the electromagnetic spectrum) which has an inhibitory effect on melatonin, a potent anti-cancer hormone as a contributory factor if not a main cause. There is more information in the Light at Night section in "Melatonin suppressors".

A positive correlation between night shift work and breast cancer risk was described in 8 out of 12 studies in a review of 12 studies by Leonardi (2012). Rabstein (2013) found that people working long-term night-shift work were nearly 5 times more likely to develop ER-negative breast cancers.

Both the circadian system alteration and the melatonin output reduction, related to the exposure to light-at-night during night shift work, remain the most valid hypotheses on the causal relation of shift work and breast cancer. Overall, the results suggest that there is an association between night shift work and breast cancer development in western countries.

Neuroblastoma

A high magnetic field exposure could enhance the cell proliferation in a neuroblastoma cell line (Pozzi 2007, Trillo 2013). A synergistic effect with high magnetic fields and chemical agents affected apoptosis and differentiation in neuroblastoma cells (Pirozzoli 2003). Falone (2016) showed that exposure to a 50 Hz magnetic field led to significantly increased neuroblastoma cell proliferation after 5-15 days indicating a more aggressive tumour growth. Martínez (2012, 2016) suggested the response to EMFs by neuroblastoma cells was mediated by the MAPK-ERK ½ signalling pathway. Kesari (2015) concluded that exposure of human neuroblastoma cells to a 50 Hz magnetic field could induce DNA damage.

Sulpizio (2011) found that extremely low frequency magnetic field exposure could trigger significant changes in the protein profile of SH-SY5Y cells. In particular, those involved in cellular defence mechanisms and organization increased as a consequence of the MF exposure. The authors concluded that ELF MFs could trigger a shift towards a more invasive neuroblastoma.

The results of a study by Luukkonen (2017) indicate that MF exposure can alter DNA responses in neuroblastoma cells.

Other cancer

Nie & Henderson (2003) found that exposure to a 60 Hz field activated some cancer cells, including leukaemia and breast cancer cells.

A report by Tynes (2003) found that the risk of developing malignant melanoma, a form of skin cancer, doubled for men and nearly tripled for women in residential fields above 0.2 microtesla. The fields were only calculated and were averaged over time, which are not the most useful measures of exposure. Calculated fields were also used in the study by Savitz (2000) which found that the risk of brain cancer mortality increased with exposure to EMFs at work. Klaeboe (2005) found an elevated risk for brain tumours with residential exposure to magnetic fields.

Extremely low frequency magnetic fields increased cell proliferation and decreased differentiation in liver cancer cells (Cid 2012). Magnetic fields induced a proliferative response in two human cancer cell lines. However, significant differences were observed between the responses of the two cell types, indicating that the underlying mechanisms is cell type-specific (Trillo 2012).

Living near powerlines was associated with a significantly increased risk of all cancers, and primary and secondary cancers in an Italian study (Fazzo 2009). A review by Comba & Fazzo (2009) reported not only increases in primary and secondary malignant neoplasms, but also ischaemic disease and haematological diseases, as a result of living near powerlines.

Baldi (2011) found an increased risk for meningioma with ELF EMF exposure occupationally. They also found the risk higher in those living within 100 metres of powerlines.

The level of cancers in a school in California was higher than expected, when Milham & Morgan (2008), instead of looking at average electromagnetic field levels, investigated high frequency voltage transients. They found that the risk of cancer associated with this exposure was 64%,

especially for thyroid and uterine cancer and malignant melanoma. A single year of employment at this school increased a teacher's cancer risk by 21%.

Boorman points out (2000) the difficulties of replication of study results. He concludes *"experimental techniques provided some clues for the differences in experimental results between the regional facility and the original investigator. Studies of subtle effects require extraordinary efforts to confirm that the effect can be attributed to the applied exposure."*

Electric light exposure at night can disrupt the circadian rhythm and many other physiological processes that are under circadian control. Because of this, Stevens (2012) suggests that ill-timed electric light exposure to pregnant women, to neonates, infants, and small children may increase cancer risk in those children.

Ornithine decarboxylase (OCD), an enzyme which is upregulated in a wide variety of cancers, was stimulated by 70% when EMFs were turned on and off every 10 seconds or more. Continuous exposure of at least 600 cycles at a time are needed to stimulate the enzyme's activity but interruptions for just 6 cycles reverse the effect.

Kapri-Pardes (2017) indicated that cells are responsive to ELF-MF at field strengths much lower than previously suspected and that the effect may be mediated by NADP oxidase.

Immune system effects

Part of the immune system, the NK (or natural killer) cells can be suppressed by a 50 Hz magnetic field (Canseven 2006). Extremely low frequency electromagnetic fields significantly suppress the immune response to tumour cells, by decreasing the white cell blood count (Knesevic 2005) or affecting the levels of T(H)1 cytokines (Salehi 2013).

Tamoxifen, doxirubicin and other drug effects

Various studies (Harland 1999, Blackman 2001, Girgert 2005, 2008, supported by Ishido 2001) have demonstrated that magnetic fields higher than 1.2 microtesla prevent the anti-cancer drug Tamoxifen from working. In fact a magnetic field of 1.2 microtesla actually caused the cancer to grow by 15%.

The breast cancer drug, doxorubicin has been shown to be less effective when the patient is exposed to light at night (LAN). LAN reduces the production of melatonin which acts as both a tumour metabolic inhibitor and also establishes the sensitivity of breast tumours to Doxorubicin. The authors of the paper indicate that light at night-induced circadian disruption of nocturnal melatonin production contributes to a complete loss of tumour sensitivity to Dox chemotherapy (Xiang 2015).

In a study by Brisdelli (2014) ELF magnetic fields were able to render K562 human leukaemia cells resistant to quercetin-induced cell death, having a negative effect on treatment.

Extremely low-frequency EMFs resulted (Cho 2007) in an enhancement of the cytotoxicity of bleomycin (BLM) in human fibroblast cells.

The link between EMF exposure and cancer certainly seem to point to a need for taking simple precautionary measures to reduce exposures to EMFs wherever possible, though the effects seem to be variable depending on other circumstances (Bułdak 2012).

Cancer is not the only health problem associated with EMFs, see the other articles in the series.

Similarities to other chemical effects

G Chen (2000) found that ELF-EMF had a similar effect on cell differentiation as did exposure to chemical-tumour promoters.