Power lines and health: cancer in adults

To: the State Secretary of Infrastructure and Water Management,
the Minister of Economic Affairs and Climate Policy and
the Minister of Social Affairs and Employment

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Health Council of the Netherlands

contents

summary

In the Netherlands, a precautionary policy is in place with regard to power lines. The purpose of this policy is to avoid, as much as possible, creating new situations in which children are subjected to long-term exposure to magnetic fields with an annual average field strength above 0.4 microtesla that are generated by overhead power lines. This precautionary policy is partly based on an earlier advisory report issued by the Health Council of the Netherlands. In 2000, the Council concluded that there are indications that children who live near such power lines are at a greater risk of developing leukaemia than other children. The cause is unknown, although the magnetic fields generated by the power lines may play a role.

Three advisory reports

The State Secretary for Infrastructure and the Environment (now Infrastructure and Water Management) asked the Health Council of the Netherlands to update the advisory report issued in 2000 and to focus not only on childhood leukaemia, but also on Alzheimer's disease and cancer in adults. The report on childhood leukaemia was published in 2018. In that report, the Health Council suggested considering an expansion of the precautionary policy to other sources of long-term exposure to magnetic fields generated by the electrical grid, such as underground power cables, transformer stations and transformer substations.
The current report relates to cancer in adults. Neurodegenerative diseases are addressed in a separate report.

Working method

The Committee on Electromagnetic Fields of the Health Council has analysed the scientific data on a possible relationship between exposure to magnetic fields generated by power lines and other sources, such as transformers, and the occurrence of various types of cancer in adults. It has mainly focused on epidemiological studies, taking into account studies on exposure in both residential areas and the workplace.
In some occupational groups, the average level of exposure to magnetic fields is substantially higher than in residential areas. If magnetic fields can affect health, this will be more evident among such occupational groups. However, it should be noted that workers are a more homogeneous group than the general population, as the latter includes potentially more vulnerable groups such as children, the elderly and chronically ill people.

In most epidemiological studies, the level of exposure to magnetic fields is approximated. In residential studies, the assessment of the magnetic field strength in the home is usually based on calculations or measurements. Sometimes, the distance between the home and

an overhead power line is used as a proxy for the level of exposure. In occupational studies, the level of exposure is usually reconstructed based on the employees' job history.

Epidemiological studies can show that, at certain levels of exposure, a certain illness occurs more frequently than would otherwise be expected. Such an association does not necessarily mean that exposure causes the illness, although it can be an indication for possible causation.

Conclusions

Residential studies revealed an association between the proximity of overhead power lines and an increased risk of leukaemia in adults. In occupational studies, exposure to magnetic fields above the background level was also found to be associated with an increased risk of leukaemia. The Committee considers this to be suggestive of a causal relationship. These findings are in line with the conclusion from the previous Health Council report that there are indications of an increased risk of leukaemia among children who live in the vicinity of overhead power lines for a prolonged period.

With regard to the other investigated types of cancer, residential studies did not show associations between the proximity of overhead power lines and disease risk. However, the scale and quality of this research are limited. The Committee therefore considers the result from the residential studies to be insufficient to infer a causal relationship between the proximity of power lines and the risk of developing these types of cancer.

Among occupational groups with substantially higher levels of exposure to magnetic fields than found in residential areas, associations have also been found for several other types of cancers than leukaemia. Associations were found between occupational exposure and the risk of developing male breast cancer, brain cancer and pancreatic cancer. The Committee considers the associations found in the workplace to be suggestive of a causal relationship between occupational exposure and these types of cancer.

In order to establish a causal relationship, additional information from experimental research (including animal studies) and mechanistic studies is necessary. The most recent reviews of such studies do not provide additional support for a causal relationship.

Recommendations

Residential studies suggest that leukaemia is more prevalent among adults who live near overhead power lines. The Committee considers this to be an additional argument in support of the current policy concerning overhead power lines, which is already based on precaution due to earlier indications of a possible causal relationship between proximity to power lines and the risk of childhood leukaemia.
The Committee also considers this to be an additional argument in support of the previous recommendation to consider expanding this

policy to underground power cables and other sources of long-term exposure to magnetic fields from the electrical grid, such as transformer stations and transformer substations.

The Committee has found indications that occupational exposure to magnetic fields that is substantially higher than can be found in residential areas could be related to a higher risk of various types of cancer. As a precaution, it therefore recommends restricting occupational exposure to magnetic fields to as low a level as is reasonably possible.

The Committee does not expect that more epidemiological research will provide greater certainty in the short term regarding the effect of exposure to magnetic fields on the risk of cancer. The Committee believes that more research into possible underlying biological mechanisms would be more effective.

Due to the energy transition, there has been a substantial increase in use of wind turbines and solar panels as a primary source of energy. The use of electric cars and heat pumps is also on the rise. As a result of these changes in production and consumption, more electricity will need to be transported. Consequently, levels of exposure to magnetic fields in the vicinity of components of the electrical grid and in some workplaces may increase. For this reason, the Committee recommends monitoring of the level of exposure to magnetic fields in residential areas and in the workplace.

01 introduction

The State Secretary for Infrastructure and the Environment (now Infrastructure and Water Management) asked the Health Council to update its 2000 advisory report on the health effects of living near overhead power lines.[1] In that report, the Council noted that there is a reasonably consistent association between living in the vicinity of overhead power lines and an increased incidence of leukaemia in children. This would mean that one case of childhood leukaemia every two years may be linked to the presence of overhead power lines.

The State Secretary asked the Health Council the following questions:

1. Is there a link between living within a certain distance from overhead power lines and the occurrence of health risks such as childhood leukaemia, other types of cancer in children and adults, and Alzheimer's disease, and does the voltage on the lines play a role?
2. Is there a link between exposure to extremely low frequency magnetic fields and the occurrence of health risks?
3. If there is an increased risk associated with spending long periods in the vicinity of overhead power lines, are there indications of factors other than the magnetic field that are associated with the presence of overhead power lines that could explain this risk?

The standing Committee on Electromagnetic Fields has divided its response to the request for advice into three parts:

- an advisory report on leukaemia and other types of cancer in children, published on 18 April 2018[2]
- an advisory report on cancer in adults, this report, submitted to the Minister of Infrastructure and Water Management (IenW), the Minister of Economic Affairs and Climate Policy (EKZ) and the Minister of Social Affairs and Employment (SZW) on 29 June 2022
- an advisory report on neurodegenerative diseases, submitted to the same ministers at the same time as this report.

A list of the Committee's members can be found at the end of this advisory report. The request for advice and the accompanying letter can be found at www.gezondheidsraad.nl.

1.1 Background

In 1979, US researchers discovered that the incidence of childhood leukaemia was higher in the vicinity of overhead power lines (the distribution lines that often run in between houses in the United States) than further away.[3] Power lines generate extremely low frequency (ELF) electric and magnetic fields (see Chapter 2; for the sake of brevity, the term 'magnetic fields' is used in the rest of this report to refer to ELF magnetic fields). The question arose as to whether exposure to these fields could potentially cause childhood leukaemia. This led to further research focusing not only on childhood leukaemia, but also on other types of cancer in children and adults and on other diseases.

Some studies found associations between exposure to the magnetic fields generated by power lines or electrical equipment and the occurrence of

certain diseases. For more information on what this means, see the box below.

Association or causal relationship

When talking about relationships between exposure to a specific factor, such as magnetic fields, and the risk of a specific disease, a distinction is made between an *association* and a *causal relationship*. An association between exposure and the risk of disease means that these two things occur together more often than might be expected by chance. A causal relationship means that the disease is a direct result of the exposure. An association between exposure and disease, resulting from a statistical analysis, is not in itself conclusive evidence of the cause. The cause cannot be determined based on statistics alone. Additional information is needed, for example from experimental research or based on a plausible biological mechanism of action.

Methodology

In this section, the Committee summarises its approach to the literature analysis for this advisory report. The Committee has primarily focused on epidemiological research and additional, supporting information from animal studies and mechanistic research in the most recent reviews. The analysis included articles up to January 2022.
A more detailed description of the Committee's methodology can be found in the background document to this report. The background document contains an overview of the selected studies, the protocol for the systematic analysis of the epidemiological data, the detailed results of the meta-analyses and explanatory notes on the classifications of evidential value for a causal relationship between exposure and disease.

Different types of cancer

The Committee investigated the relationship between exposure to magnetic fields and the risk of specific types of cancer in adults, for which sufficient information was available from targeted research: leukaemia, breast cancer (in women and in men), brain cancer, testicular cancer, pancreatic cancer, lung cancer, prostate cancer and skin melanomas.

Residential and occupational exposure

With regard to residential exposure to magnetic fields, the primary focus of the request for advice, the Committee looked at whether the risk of the listed diseases is related to the distance from home to high-voltage power lines (as a measure of exposure) or to the measured or calculated residential exposure to magnetic fields.

For some types of cancer, research was also carried out into a link between the use of electric bed warmers (such as electric blankets and heating elements for waterbeds) and the occurrence of the disease. The Committee assessed these studies separately.

The Committee considered not only residential exposure, but also occupational exposure. In some occupations, exposure to magnetic fields

can be considerably higher than in the residential environment. If the magnetic field can cause health problems, this is more likely to be evident in people who are exposed to relatively high magnetic field strengths in their profession, such as electric welders or people who work at a power plant. A substantially larger amount of research has therefore been carried out into possible effects of occupational exposure. The Committee notes, however, that the general population varies more widely in composition than the working population, and includes groups that are potentially more vulnerable, such as children, the elderly and people with chronic diseases.

For occupational exposure, the Committee compared the risk of the diseases considered in workers who had spent a long time (one or more years) working in a profession where exposure is higher than the background level to the risk in workers exposed at the background level. In the analysis, the Committee makes a distinction between epidemiological studies of occupational exposure in the general population and research in specific industrial populations, such as electricity company employees. Generally speaking, exposure can be better characterised in the latter populations, which is why the Committee attaches the greatest value to the results of these studies when it comes to occupational exposure.

Both residential and occupational studies use different measures of exposure: average exposure over a specific period, expressed in microtesla (μT), or cumulative exposure, expressed in μT-years. Both are typically divided into different categories. For these studies, the Committee has calculated an average risk estimate for all exposure categories and regarded this as a measure for ‘ever exposed above the background level’. The meta-analyses were then carried out using these average risk estimates.

Meta-analyses

Where three or more suitable epidemiological studies are available on a specific question, the Committee has carried out meta-analyses.
A meta-analysis involves combining the results of various studies to produce a single risk estimate. The Committee has used the meta-analyses to calculate the relative risk for the exposure category ‘ever exposed above the background level’ compared to the exposure category ‘never exposed above the background level’. Alongside each risk estimate, the Committee also gives the 95% confidence interval in brackets. The 95% confidence interval is a measure of the uncertainty of the estimate (see box). The Committee also states whether there was a high level of heterogeneity in the risk estimates for the studies included in the meta-analysis. The meta-analyses provide two measures of heterogeneity: I^2 and tau^2. The Committee has only used I^2. A high level of heterogeneity (defined in this report as $I^2 > 60\%$) means that the results of the individual studies are ambiguous. This means that less value can be assigned to the risk estimate from the meta-analysis.

For the meta-analyses of studies on occupational exposure, in addition to the main analysis of exposure above the background level versus exposure at the background level, the Committee has also carried out a number of subanalyses to obtain a better understanding of how completeness of the occupational history and reliability of the disease diagnosis affect the risk estimates and heterogeneity. Where possible, the Committee has also carried out subanalyses of the data on highest level of exposure and longest duration of exposure. The results of both the main analyses and the subanalyses can be found in the background document. The Committee discusses the conclusions in this advisory report.

Where possible, the Committee bases its conclusions on the subanalysis of the studies that took into account the complete occupational history of the workers, in other words studies where the exposure has been determined for all occupations an individual has had, making it possible to calculate an average or cumulative exposure over their entire working life. The Committee feels that this data provides the most reliable reflection of occupational exposure. If not enough data is available for this subanalysis, the Committee bases its conclusions on the main analysis, in other words on all studies regardless of completeness of the occupational history. The data used in the advisory report is marked in the background document. Not enough data is available on residential exposure to carry out comparative subanalyses.

The Committee also considered the possibility of selective publication, in other words that studies that did not find a link are less likely to be published. This publication bias could distort the results of the meta-analyses. Results of cohort studies in the general population and in industrial populations are usually published regardless of outcome, due to their scale and the amount of funding involved. The Committee therefore expects a negligible level of bias in its findings due to selective publication.

Risk estimate and confidence interval

The risk estimate shows the estimated risk of a specific effect in a specific situation compared to the control situation, in other words the relative risk. For example, a risk estimate of 1.3 means that the estimated risk of a disease occurring is 1.3 times as great, or 30% higher, in people who have been exposed than the risk in people with no or less exposure. A risk estimate of 0.9 means that the risk is 0.9 times as great, or 10% lower. A risk estimate of 1 means that the risk of the disease is similar in both situations.

Most studies report relative risks, rate ratios (RR) or odds ratios (OR) as a risk estimate. Some studies also use other measures of risk: the SMR (standardised mortality ratio), SIR (standardised incidence ratio) and SRR (standardised rate ratio). A ratio of 1 or 100% means that there is no difference in risk between the exposed group and the population as a whole.

The 95% confidence interval shows the uncertainty of the risk estimate and the limits within which we expect the actual risk to lie. It means that if we were to repeat the study 100 times in the same population with different random samples, the actual risk would lie within the confidence interval in 95 cases. If the 95% confidence interval contains the value 1, we refer to the relationship found as not statistically significantly increased or decreased. If the lower limit of the 95% confidence interval is greater than 1, we refer to a statistically significantly increased risk. If the upper limit of the 95% confidence interval is less than 1, we refer to a statistically significantly decreased risk.

Strength of evidence for a causal relationship

Finally, the Committee checks whether, based on the available research data and its meta-analyses of this data, it can draw a conclusion as to a possible causal relationship between exposure and the disease investigated. To this end, it uses the internationally applied US Environmental Protection Agency (EPA) methodology, which it has used in previous advisory reports[2,4] and which distinguishes between five different classifications based on the quality, nature and scale of the research data (see table 1).[5]

Table 1 EPA classification of the strength of evidence for a causal relationship between exposure and disease

Classification
Causal relationship proven
Causal relationship likely
Indications of a causal relationship
No statements can be made regarding a causal relationship
Causal relationship unlikely

A detailed description of these classifications of the strength of evidence for a causal relationship can be found in the background document.

The Committee applies this methodology as follows. It regards a statistically significant association in a meta-analysis of epidemiological studies as an indication of a causal relationship. If the association is not statistically significant, but the risk estimate is relatively high (1.25 or higher), the Committee also regards this as an indication of a causal relationship. This is because if few studies are available, the statistical

power of the meta-analysis is low. The Committee only assigns higher classifications (causal relationship likely or proven) where there is additional evidence from experimental or mechanistic research. If little or too little high-quality research has been carried out or various studies contradict each other, the Committee feels that no statements can be made regarding a causal relationship. Where sufficient epidemiological research of high quality has been carried out and there is absolutely no indication of a causal relationship, the Committee opts for the classification ‘causal relationship unlikely’. Where the Committee reaches the conclusion that a causal relationship is unlikely in the case of occupational exposure, then it deems the same conclusion to apply in principle to residential exposure, as this type of exposure is lower. Where the Committee believes that there are indications of a causal relationship in the case of occupational exposure, it will in principle not reach the conclusion of ‘causal relationship unlikely’ for residential exposure.

1.2 Reading guide

The advisory report starts with an explanation in Chapter 2 of a number of technical terms and exposure characteristics. In Chapters 3 to 10, the Committee discusses the results of the meta-analyses of the studies on the relationship to residential and occupational exposure to magnetic fields. The diseases leukaemia, breast cancer, brain cancer, testicular cancer, pancreatic cancer, lung cancer, prostate cancer and skin melanomas are addressed in that order. In Chapter 11, the Committee discusses the correlation between the findings and issues recommendations.

02
power lines and magnetic fields

This chapter gives a brief explanation of magnetic fields, plus a description of a number of technical terms and exposure characteristics.

2.1 Voltage, current and fields

The voltage on a power line causes an electric field. When current is passing through the line, a magnetic field is also generated. Electric fields and magnetic fields spread in different ways. Figure 1 demonstrates this in a simple diagram.

The current on the power grid switches from positive to negative and back again 50 times per second (alternating current), or at a frequency of 50 hertz (Hz). This is an extremely low frequency (ELF). By way of comparison, mobile phones operate at much higher frequencies of around 900 and 2000 megahertz (one megahertz is a million hertz).

Electric fields and magnetic fields propagate in different ways

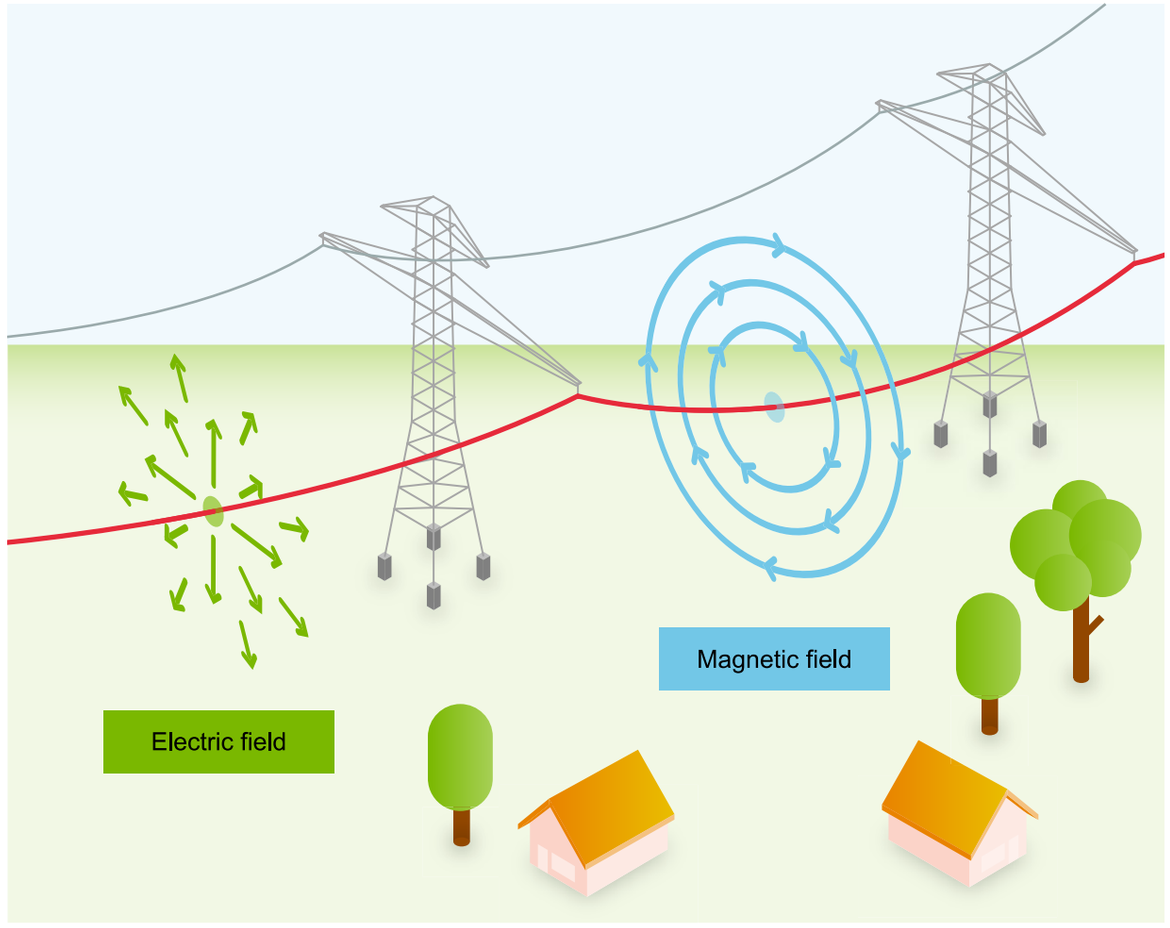

Figure 1 Diagram showing the electric and magnetic field around a high-voltage power line

The power grid

The power grid between power stations and homes is made up of transport and distribution lines and cables. Lines are overhead connections, while cables lie underground.

Transport connections in the Netherlands are high-voltage power lines or cables with a voltage of 380 or 220 kilovolts (kV: 1 kV is 1000 V). They transport the current from the station to a substation. They are the motorways of power transmission. High-voltage power lines and cables also run between substations and transformer stations, but with a lower voltage of 150, 110 or 50 kV. Transport from the transformer stations to the transformer boxes in residential and business premises takes place by means of distribution cables with a medium voltage of 25, 20, 12.5, 10, 6, 5 or 3 kV. In the transformer boxes, the voltage is reduced further to 400 and 230 V and carried to the final destination through low-voltage distribution cables.

In the Netherlands, overhead power lines are almost exclusively high-voltage power lines. In other countries, distribution lines sometimes also run above ground.

2.2 Field strength

At extremely low frequencies, a distinction is made between electric and magnetic fields, which have different properties. The electric field is considerably weakened by trees, plants and buildings (see figure 2). Its ability to penetrate materials is negligible, resulting in a surface charge that is discharged to the ground. Inside a home, the electric field generated by a nearby power line is easily 10 to 100 times weaker than outside the home. By contrast, the magnetic field is only weakened by obstacles to a very small extent. It easily penetrates homes and the human body (see figure 2). Studies on the relationship between overhead power lines and possible health effects therefore focus on exposure to magnetic fields rather than exposure to electric fields.

A magnetic field is invasive, an electric field is not

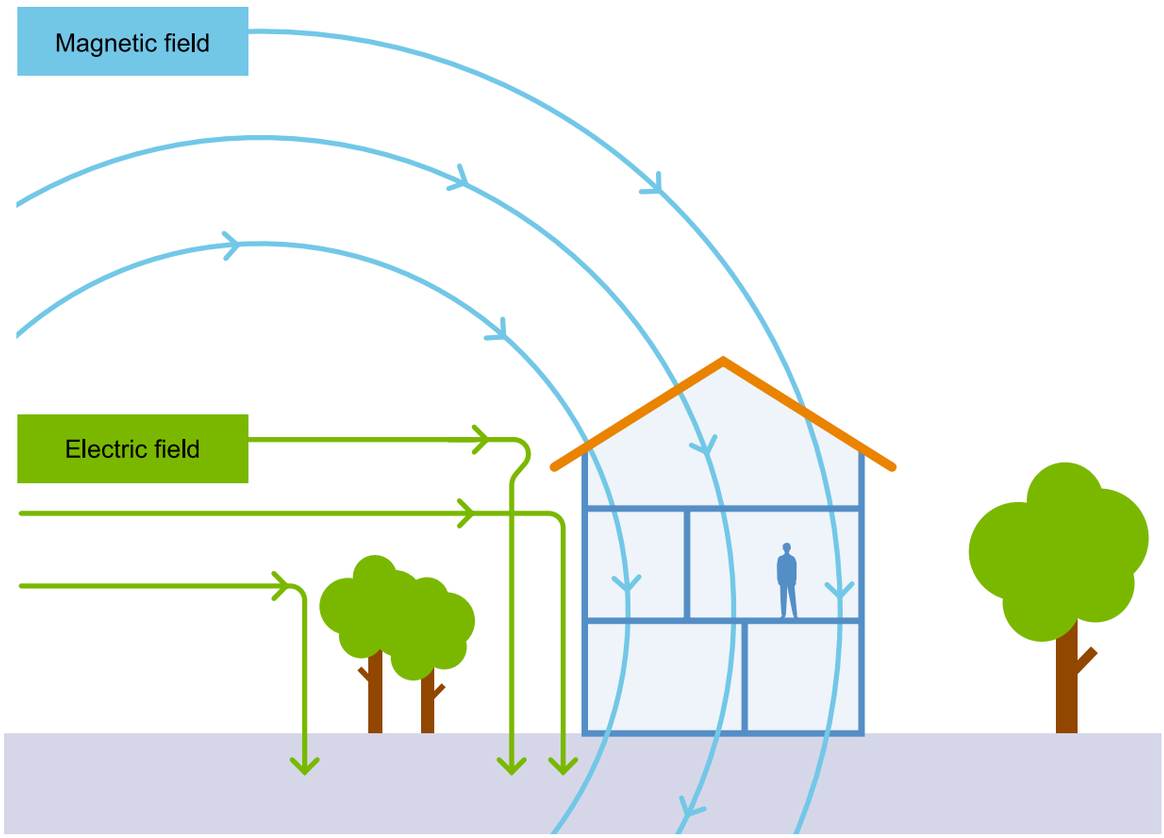

Figure 2 Diagram showing the extent to which electric and magnetic fields penetrate materials

The strength of a magnetic field is expressed in tesla (T). In practice, the strength of magnetic fields generated by the power system is always expressed in microtesla (μT = 1 millionth T). The more current passes through a line, the stronger the magnetic field. The strength of the magnetic field falls rapidly as the distance to the line increases (see figure 3). Broadly speaking, field strength is four times lower when the distance is doubled. The distance to an overhead high-voltage power line also depends on the extent to which the line droops between two masts (the 'sag'). The hotter conductors (the actual lines) become, the more they sag. The heat depends on a number of factors, such as the strength of the current through the conductor and the ambient temperature. In practice, the situation is more complex as there are several conductors and a number of electric circuits in a high-voltage power line, which can cause partial local 'cancellation' or weakening of magnetic fields. Where new connections are installed, efforts are made to ensure that the magnetic fields of the different conductors cancel each other out as much as possible to minimise the total strength of the magnetic field generated at ground level by a high-voltage power line.

The larger the distance to the electricity lines, the weaker the magnetic field

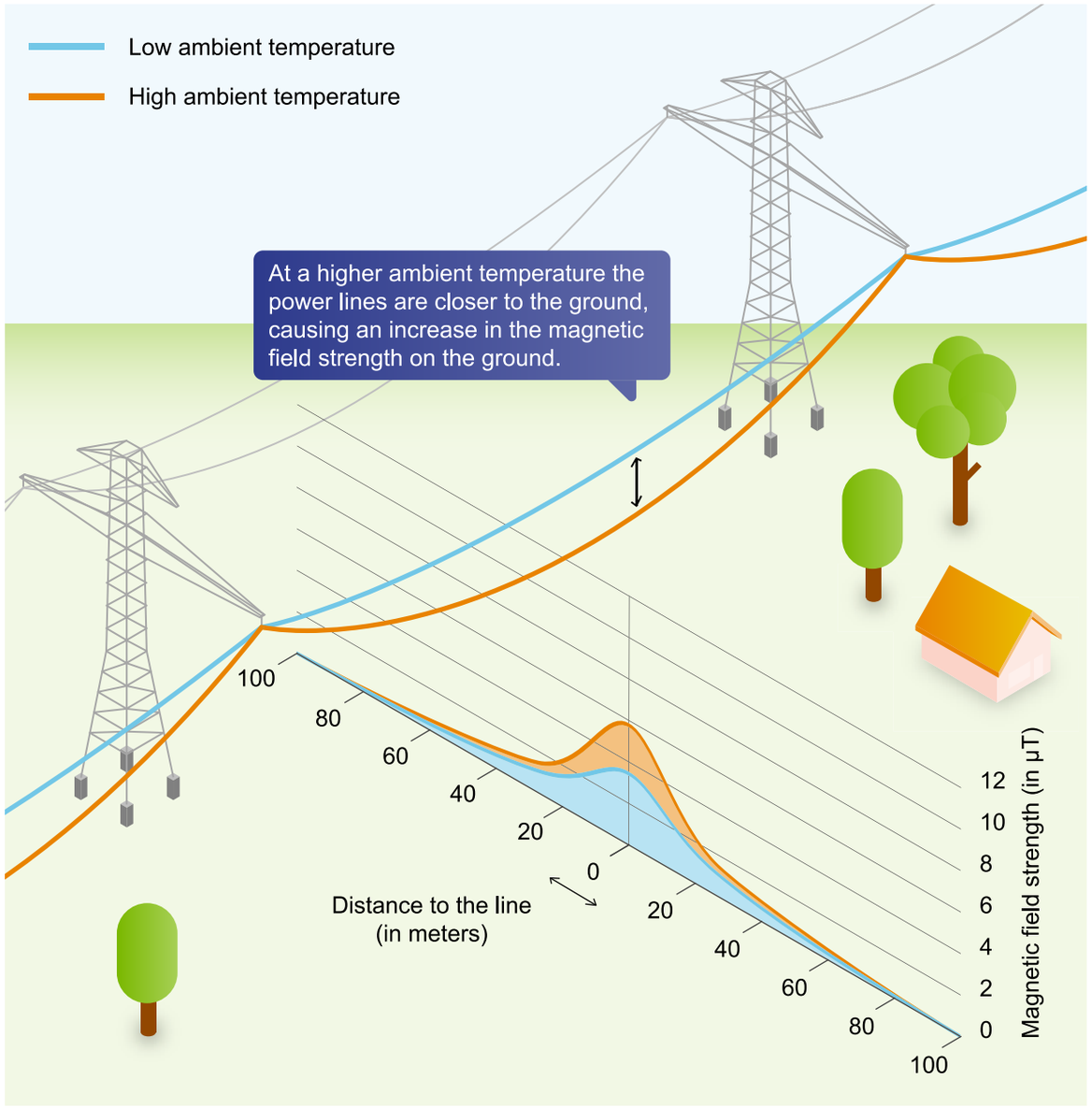

Figure 3 Relationship between distance to the line and magnetic field strength on the ground

On average, field strengths in the residential environment do not exceed 0.1-0.2 μT in a 24-hour period.[6-10] This exposure comes from the power system in the home and from the use of electrical equipment.
The presence of a high-voltage power line can increase average exposure to over 1 μT (see figure 3). This also applies to residing in the vicinity of other power grid components, such as underground high-voltage cables, high-voltage stations and indoor or outdoor transformers. Short-lasting peak exposures during the use of household appliances can rise to several dozen μT if the distance between the device and the user is only a few centimetres.[10] In the case of electric bed warmers, such as electric blankets and heating elements in waterbeds, which are often used close to the body for long periods of time, exposure can rise to more than 2 μT for electric blankets and up to 0.04 μT for waterbeds.[10]

Occupational exposure can be considerably higher than residential exposure, for instance in the case of electricians (peak exposure of up to more than 50 μT) and people employed in the electricity industry (peak exposure of up to 500 μT), welders (up to 5 μT) and train drivers (peak exposure of up to more than 50 μT).[11-13] Such peak exposures can occur more frequently than peak exposures in the home, depending on the nature of the work. For the previously mentioned occupations, the average exposure over a working day in the workplace can rise to 26 μT.[13,14]

2.3 Determining exposure

The exposure of individual people to magnetic fields can only be determined accurately by means of long-term measurements on the body. Such measurements are rarely carried out in epidemiological studies, and where they are carried out, it is mainly in industrial populations.
Most studies use methods that yield a rough estimate of actual exposure.

Determining residential exposure

A rough estimate of residential exposure can be made based on the distance of the home to a high-voltage power line (usually measured as the distance to the centre of the line at ground level). The voltage on the line may or may not be taken into account. Exposure can also be estimated by measuring or calculating the magnetic field strength in or next to the home over a shorter or longer period. In order to calculate cumulative exposure, or average exposure over a longer period, information on residential history is also needed: at what addresses have the people in question resided?

The advantage of distance as a measure of exposure is that it is easy to determine to a reasonable level of accuracy. The disadvantage is that it is a very rough measure of actual exposure to the magnetic fields generated by power lines, because actual exposure also depends on other factors such as height of the line above the ground (see figure 3), configuration of the lines and, most importantly, the amount of current being transported

through the line. Current can fluctuate significantly over time. However, this information is generally not available.

The measured or modelled exposure to the magnetic field is a more relevant measure of exposure than distance, but its calculation also has limitations. Measurements are not necessarily more accurate than modelled exposure. For residential measurements, researchers are dependent on the cooperation of residents. Refusal to cooperate can lead to selective participation and therefore potential bias of the results. This problem does not exist in the case of modelled exposure. In addition, measurements of magnetic field strength in the home are carried out over a maximum period of a few days, whereas modelled exposure is determined over a longer period that in some cases covers many years. For a longer period, this means that measurements can give a less accurate picture of the exposure than modelled exposure. On the other hand, modelled exposure as a result of the presence of a high-voltage power line does not generally take into account exposure from other sources near to or inside the home, such as indoor transformers in apartment buildings, the electricity system in the house and the use of electrical appliances. The latter usually only results in short-lasting peak exposures on top of the more long-term exposure from the electricity system in the home and nearby high-voltage power lines. One exception to this rule is bed warmers (electric blankets and heating elements for waterbeds), which usually do result in long-term exposure.

Another factor that plays a role in studies of residential exposure is the fact that people often spend a not inconsiderable part of the day outside of the home, for example at work or school. The exposure to magnetic fields at these other locations can be lower or higher than at home.

Determining occupational exposure

Occupational exposure is determined in a variety of ways.[15] Some estimates that use extensive measurements of exposure in specific occupations are reasonably accurate. Others are less accurate, such as those simply based on the fact that exposure is higher for a specific job. In some cases, a job-exposure matrix (JEM) is also used. The matrix links an occupation to an intensity of exposure, which can be measured or estimated by experts such as an occupational hygienist.

Some studies verify an individual's complete occupational history, which can provide an insight into the total or average exposure throughout a person's working life. Other studies only take into account a person's main occupation or most recent occupation when determining exposure. Examples include studies that retrieve information about a person's occupation from registers of deaths, or that are based on information from one or more population censuses. This gives a less accurate picture of total exposure.

Studies of occupational exposure assume a 40-hour working week. In certain jobs, occupational exposure is so high that exposure from other sources in the environment is more or less insignificant.[16] The exposure pattern in the residential and occupational environment can substantially differ.

03 leukaemia

Research in th residential environment has identified an association between the proximity of high-voltage power lines and an increased risk of leukaemia in adults. An association has also been found between occupational exposure to magnetic fields above the background level and an increased risk of leukaemia. The Committee sees this as indications of a causal relationship.

This chapter summarises the results of the meta-analyses carried out by the Committee. Details of all studies and the analyses can be found in the background document.

3.1 Residential exposure

The Committee found 20 studies that investigated the relationship between residential exposure and the occurrence of leukaemia (regardless of type) in adults. Of these, 12 studies were not included in the analyses for various reasons (see the background document). The Committee used the data from the eight remaining studies to carry out meta-analyses.[17-24]

Some studies investigated specific types of leukaemia separately in addition to, or instead of, leukaemia in general. For acute myeloid leukaemia (AML), six studies in the residential environment provided sufficient data for separate analyses, two of which relate to the use of electric bed warmers.[19-21,24-26]

3.1.1 Leukaemia in general

Four studies were found that used distance to high-voltage power lines as a measure of exposure. The meta-analysis of data on living at a distance of 0 to 50 metres from a power line gives a risk estimate of 1.40 (1.10-1.78).[17,20,22,23]

The meta-analysis of the eight studies that looked at exposure to magnetic fields gives a risk estimate for the occurrence of leukaemia of 1.11 (0.98-1.26) for the category of ever exposed above the background level as a result of living in the vicinity of a power line.

3.1.2 AML

The Committee found four studies that investigated the relationship between residential exposure to magnetic fields and risk of AML separately. For the category of ever exposed above the background level, the meta-analysis gives a risk estimate of 1.41 (1.10-1.80).

The Committee found two studies that investigated the relationship between the use of electric bed warmers and the occurrence of AML. In the first study, a risk estimate of 0.9 (0.5-1.6) was found.[25] In the second study, the risk estimate was 0.9 (0.7-1.2).[26]

3.2 Occupational exposure to magnetic fields

The Committee found 62 studies that investigated the relationship between occupational exposure to magnetic fields and the occurrence of leukaemia. Of these, 32 studies were not included in the analyses for various reasons (see the background document). The Committee used the data from the 30 remaining studies of occupational exposure to carry out meta-analyses.[19,21,27-54] In these meta-analyses, the Committee made a distinction between studies of occupational exposure in the general population and studies focusing on specific industrial populations, such as electricity company employees.

Some of these studies investigated specific types of leukaemia in addition to, or instead of, leukaemia in general. For AML, 17 studies provided sufficient data for separate analyses.[21,26,28-33,37,40,47-49,52,53,55]

3.2.1 Leukaemia in general

The meta-analyses of the studies with a complete occupational history give a risk estimate of 1.08 (0.89-1.31) for the risk of leukaemia in workers from the general population. The risk estimate for the exposure of workers from industrial populations is 1.13 (0.96-1.34).

3.2.2 AML

For studies with a complete occupational history, the risk estimate for the risk of AML in workers from the general population is 0.94 (0.79-1.11). The risk estimate for workers from industrial populations is 2.11 (0.84-5.31). In this case, the heterogeneity between the studies is high.

3.3 Conclusions

The epidemiological studies analysed show that the risk of leukaemia is an estimated 1.4 times higher in people living between 0 and 50 metres from a high-voltage power line. The risk of AML was also found to be an estimated 1.4 times higher for residential exposure. As a result, the Committee is of the opinion that for leukaemia, and also specifically for AML, the classification ‘indications of a causal relationship’ applies to residential exposure.

The meta-analyses of the studies of occupational exposure of workers from the general population show no significantly increased risks of leukaemia and AML. For workers from industrial populations, however, the risk of AML was found to be more than double. This increase is not statistically significant, but this could be related to the low number of studies. The Committee attaches the most importance to these studies, as the diagnosis (AML) and exposure assessment are most accurate in industrial cohorts. It is not possible to determine an exposure-effect relationship due to the nature of the studies. Due in part to the fact that an association with the risk of AML was also found in the residential environment, where levels of exposure are lower, the Committee considers the EPA classification ‘indications of a causal relationship’ to

apply to the relationship between the risk of leukaemia, and specifically AML, and occupational exposure to magnetic fields.

04
breast cancer

Overall, studies in the residential environment do not reveal any associations between exposure to magnetic fields and the risk of breast cancer. However, some individual studies suggest otherwise and the Committee therefore feels that no statements can be made regarding a causal relationship in the residential environment. An association was indeed found between exposure and disease in the case of occupational exposure to magnetic fields above the background level. This applies to both men and women. The Committee sees this as an indication of a causal relationship.

This chapter summarises the results of the meta-analyses carried out by the Committee. Details of all studies and the analyses can be found in the background document.

4.1 Residential exposure

The Committee found 20 studies that investigated the relationship between residential exposure and the occurrence of breast cancer. A total of 19 studies looked at breast cancer in women, while one study looked at breast cancer in men. The studies relate to the proximity of high-voltage power lines or the use of electric bed warmers.

4.1.1 Breast cancer in women

The Committee found 19 studies that investigated the relationship between residential exposure and the occurrence of breast cancer in women. Of these, one study was not included in the analyses (see the background document). The Committee used the data from the 18 remaining studies to carry out meta-analyses. These studies look at the relationship between living in the vicinity of overhead power lines or between the use of electric bed warmers and the occurrence of breast cancer in women.[18,20,23,56-70]

The meta-analysis gives a risk estimate of 1.04 (0.92-1.17) for living at a distance of less than 100 metres from a high-voltage power line and the occurrence of breast cancer in women.

For exposure to magnetic fields above the background level as a result of living in the vicinity of a high-voltage power line, the meta-analysis gives a risk estimate of 1.02 (0.88-1.18) for the occurrence of breast cancer in women. The heterogeneity between these studies is high.

The Committee also carried out a meta-analysis of the studies that investigated the occurrence of breast cancer in women in relation to the use of electric bed warmers. The risk estimate for the category ‘ever used an electric bed warmer’ is 1.02 (0.96-1.09).

4.1.2 Breast cancer in men

The Committee found a single study that investigated the relationship between residential exposure and the occurrence of breast cancer in men.

For exposure to magnetic fields with a field strength of 0.2 μT or higher, the risk estimate was 2.1 (0.3-14.1).[57]

4.2 Occupational exposure to magnetic fields

The Committee found 48 studies that investigated the relationship between occupational exposure to magnetic fields and the occurrence of breast cancer. Of these, 29 related to breast cancer in women and 19 to breast cancer in men.

4.2.1 Breast cancer in women

The Committee found 29 studies that investigated the relationship between occupational exposure to magnetic fields above the background level and the occurrence of breast cancer in women. Of these, 10 studies were not included in the analyses for various reasons (see the background document). The Committee used the data from the 19 remaining studies of occupational exposure to carry out meta-analyses.[35,43,48,51,53,58,62,71-82]

In these meta-analyses, the Committee made a distinction between studies of occupational exposure in the general population and studies focusing on specific industrial populations, such as electricity company employees.

For studies with a complete occupational history, the meta-analysis for workers from the general population results in a risk estimate of 1.05 (0.99-1.11). The risk estimate for workers from industrial populations is 1.05 (1.00-1.11). Because there are too few studies that involve a complete occupational history, this risk estimate is based on all studies.

4.2.2 Breast cancer in men

The Committee found 19 studies that investigated the relationship between occupational exposure to magnetic fields and the occurrence of breast cancer in men. Of these, six studies were not included in the analyses for various reasons (see the background document).
The Committee used the data from the 13 remaining studies of occupational exposure to carry out a meta-analysis.[32,39,48,74,81,83-90]

This meta-analysis shows an increased risk of breast cancer in workers from the general population who are exposed to magnetic fields in the workplace. The Committee has calculated a risk estimate of 1.31 (1.07-1.61). Because there are too few studies that involve a complete occupational history, this risk estimate is based on all studies. For studies with a complete occupational history, the risk estimate for workers from industrial populations is 0.74 (0.35-1.53).

4.3 Conclusions

The meta-analyses of epidemiological studies on living in the vicinity of high-voltage power lines or residential exposure to magnetic fields or use of electric bed warmers show no associations with the risk of breast cancer in women. As some individual studies produced results that deviate from the overall picture, the Committee considers the EPA classification ‘no statements can be made regarding a causal relationship’ to apply.

The meta-analysis of studies on occupational exposure of workers shows no increased risk of breast cancer in women and an estimated 1.3 times higher risk of breast cancer in men. It is not possible to determine an exposure-effect relationship due to the nature of the studies. Based on the associations found, the Committee considers the EPA classification ‘indications of a causal relationship’ to apply to the relationship between risk of breast cancer in men and occupational exposure to magnetic fields. The classification for breast cancer in women is ‘no statements can be made regarding a causal relationship’.

05
brain cancer

Research in the residential environment shows no associations between living within 50 metres of a high-voltage power line and the risk of brain cancer. The research is limited in scale, however, and the Committee therefore feels that no statements can be made regarding a causal relationship. An association was indeed found in the case of occupational exposure to magnetic fields above the background level. The Committee sees this as an indication of a causal relationship between the risk of brain cancer and occupational exposure.

5.1 Residential exposure

The Committee found 14 studies that investigated the relationship between residential exposure to magnetic fields and the occurrence of brain cancer. Of these, six studies were not included in the analyses for various reasons (see the background document). The Committee used the data from the eight remaining studies to carry out meta-analyses.[18-20,22-24,91,92]

Two studies were found that investigated not only exposure to magnetic fields, but also the relationship between distance to high-voltage power lines and the occurrence of brain cancer. In the first study, the risk estimate for living at a distance of between 0 and 50 metres from a high-voltage power line is 1.22 (0.88-1.69)[23]; in the second study, the risk estimate is 1.3 (0.8-2.1).[20]

For exposure to magnetic fields above the background level as a result of living in the vicinity of a high-voltage power line, the meta-analysis gives a risk estimate of 0.99 (0.89-1.09) for the occurrence of brain cancer.

5.1.1 Occupational exposure to magnetic fields

The Committee found 56 studies that investigated the relationship between occupational exposure to magnetic fields and the occurrence of brain cancer. Of these, 24 studies were not included in the analyses for various reasons (see the background document). The Committee used the data from the 32 remaining studies of occupational exposure to carry out meta-analyses.[19,27-29,31,32,34,35,37-40,42,44,48,51-53,81,92-104]

In these meta-analyses, the Committee made a distinction between studies of occupational exposure in the general population and studies focusing on specific industrial populations, such as electricity company employees.

The meta-analysis of the studies with a complete occupational history gives a risk estimate of 1.03 (0.93-1.13) for the risk of brain cancer in workers from the general population.

For the studies with a complete occupational history, the risk estimate for exposure of workers from industrial populations is 1.30 (1.08-1.57).

5.2 Conclusions

The analysed epidemiological studies of residential exposure to magnetic fields show no association with the risk of brain cancer. The Committee considers the EPA classification ‘no statements can be made regarding a causal relationship’ to apply.

The meta-analysis of the studies of occupational exposure of workers from the general population shows no association with the risk of brain cancer. An association was indeed found for workers from industrial populations: the risk is estimated to be 1.3 times higher. It is not possible to determine an exposure-effect relationship due to the nature of the studies. Based on the association found, the Committee considers the EPA classification ‘indications of a causal relationship’ to apply to the relationship between risk of brain cancer and occupational exposure to magnetic fields.

06
testicular cancer

Research in the residential environment shows no association between living in the vicinity of high-voltage power lines and the risk of testicular cancer. No associations were also found in the case of occupational exposure to magnetic fields above the background level. As research in the residential environment is limited and the results of the studies on occupational exposure vary, the Committee concludes that no statements can be made regarding a causal relationship.

6.1 Residential exposure

There is no data on testicular cancer in relation to distance from home to high-voltage power lines.

One study was found that investigated the relationship between cumulative exposure to magnetic fields from high-voltage power lines in the residential environment, expressed in μT-year, and the occurrence of testicular cancer.[18] The incidence of testicular cancer is no higher in men who have ever been exposed to magnetic fields above the background level than in the general population. The Committee has calculated an incidence ratio (SIR) of 0.91 (0.78-1.29).

One study was also found that investigated the relationship between the use of electric bed warmers and the occurrence of testicular cancer.[105] A risk estimate of 1.00 (0.70-1.40) was found for men who had ever used an electric bed warmer.

The Committee did not carry out any meta-analyses due to the low number of studies.

6.2 Occupational exposure to magnetic fields

The Committee found 18 studies that investigated the relationship between occupational exposure to magnetic fields and the occurrence of testicular cancer. Of these, eight studies were not included in the analyses for various reasons (see the background document). The Committee used the data from the 10 remaining studies of occupational exposure to carry out meta-analyses.[27,32,43,48,74,81,87,106-108]

In these meta-analyses, the Committee made a distinction between studies of occupational exposure in the general population and studies focusing on specific industrial populations, such as electricity company employees.

The Committee's meta-analyses did not show an increased risk of testicular cancer with occupational exposure to magnetic fields for either type of study. For the studies in workers from the general population, the Committee has calculated a risk estimate of 1.03 (0.86-1.23). For the studies in workers from specific industrial populations, the risk estimate is 0.93 (0.81-1.06). Because there are too few studies in both the general population and specific industrial populations that involve a complete occupational history, these risk estimates are based on all studies.

6.3 Conclusions

The analysed epidemiological studies of residential exposure to magnetic fields show no association with the risk of testicular cancer. Due to the low number of studies, however, the Committee considers the EPA classification ‘no statements can be made regarding a causal relationship’ to apply.

The meta-analysis of the studies of occupational exposure of workers both from the general population and in industrial populations show no increased risk of testicular cancer. Because the results of the studies vary, the Committee considers the EPA classification ‘no statements can be made regarding a causal relationship’ to also apply to the relationship between risk of testicular cancer and occupational exposure to magnetic fields.

07
pancreatic cancer

Research in the residential environment shows no associations between living in the vicinity of high-voltage power lines and the risk of pancreatic cancer. The research is limited in scale, however, and the Committee therefore feels that no statements can be made regarding a causal relationship. An association was indeed found in the case of occupational exposure to magnetic fields above the background level. The Committee sees this as an indication of a causal relationship.

7.1 Residential exposure

One study was found that investigated the relationship between distance to high-voltage power lines and mortality from pancreatic cancer.[56]
A comparison of mortality from pancreatic cancer in people who resided at a distance of less than 100 metres from a high-voltage power line in the five years prior to diagnosis and mortality from pancreatic cancer in the total population shows a mortality ratio (SMR) of 124 (25-361).

One study was found that investigated the relationship between cumulative exposure to magnetic fields from high-voltage power lines in the residential environment, expressed in μT-year, and the occurrence of pancreatic cancer.[18] The incidence of pancreatic cancer is no higher in people who have ever been exposed to magnetic fields above the background level than in the general population. The Committee has calculated an incidence ratio (SIR) of 1.04 (0.94-1.16).

The Committee did not carry out any meta-analyses due to the low number of studies.

7.2 Occupational exposure to magnetic fields

The Committee found 15 studies that investigated the relationship between occupational exposure to magnetic fields and the occurrence of pancreatic cancer. Of these, four studies were not included in the analyses for various reasons (see the background document).
The Committee used the data from the 11 remaining studies of occupational exposure to carry out meta-analyses.[27,32,39,43,48,74,81,85,106,109,110]

In these meta-analyses, the Committee made a distinction between studies of occupational exposure in the general population and studies focusing on specific industrial populations, such as electricity company employees.

The meta-analyses show an increased risk of pancreatic cancer in workers from the general population who have been exposed to magnetic fields above the background level in the workplace. The Committee has calculated a risk estimate of 1.11 (1.05-1.16). Because there are too few studies that involve a complete occupational history, this risk estimate is based on all studies.

The meta-analyses of the studies with a complete occupational history in workers from industrial populations show no increased risk of pancreatic cancer in the case of occupational exposure to magnetic fields. The risk estimate is 1.00 (0.78-1.28). The heterogeneity between the studies is high.

7.3 Conclusions

The analysed epidemiological studies of residential exposure to magnetic fields show no increase in the risk of pancreatic cancer. Due to the low number of studies, however, the Committee considers the EPA classification ‘no statements can be made regarding a causal relationship’ to apply.

The meta-analysis of the studies in workers from the general population shows an estimated 1.1 times higher risk of pancreatic cancer, but no higher risk for workers from industrial populations. It is not possible to determine an exposure-effect relationship due to the nature of the studies. Based on the association found, the Committee considers the EPA classification ‘indications of a causal relationship’ to apply to the relationship between risk of pancreatic cancer and occupational exposure to magnetic fields.

08
lung cancer

Research in the residential environment shows no associations between the proximity of high-voltage power lines and the risk of lung cancer. The research is limited in scale, however, and the conclusion is therefore that no statements can be made regarding a causal relationship.
No association was also found in the case of occupational exposure to magnetic fields. The conclusion for occupational exposure is therefore also that no statements can be made regarding a causal relationship.

8.1 Residential exposure

One study was found that investigated the relationship between distance to high-voltage power lines and mortality from lung cancer.[56] Mortality from lung cancer was similar among people who had resided at a distance of less than 100 metres from a high-voltage power line in the five years prior to diagnosis to that among the population as a whole. A mortality ratio (SMR) of 114 (65-185) was found.

One study was found that investigated the relationship between cumulative exposure to magnetic fields from high-voltage power lines in the residential environment, expressed in μT-year, and the occurrence of lung cancer.[18] The incidence of lung cancer was not higher in people who have ever been exposed to magnetic fields above the background level than in the population as a whole. The Committee has calculated an incidence ratio (SIR) of 0.92 (0.85-1.00).

The Committee did not carry out any meta-analyses due to the low number of studies.

8.2 Occupational exposure to magnetic fields

The Committee found 20 studies that investigated the relationship between occupational exposure to magnetic fields and the occurrence of lung cancer. Of these, seven studies were not included in the analyses for various reasons (see the background document). The Committee used the data from the 13 remaining studies of occupational exposure to carry out meta-analyses.[27,32,39,40,42,43,48,52,53,74,81,106,111]

In these meta-analyses, the Committee made a distinction between studies in workers from the general population and studies focusing on specific industrial populations, such as electricity company employees.

The meta-analyses show no increased risk of lung cancer with exposure to magnetic fields in workers from the general population. The Committee has calculated a risk estimate of 0.95 (0.79-1.14). Because there are too few studies that involve a complete occupational history, this risk estimate is based on all studies. The heterogeneity between the studies is high.

The meta-analyses of the studies with a complete occupational history in workers from industrial populations also show no increased risk of lung

cancer with exposure to magnetic fields. The risk estimate is 1.02 (0.92-1.14). The heterogeneity between the studies is high.

8.3 Conclusions

The analysed epidemiological studies of residential exposure to magnetic fields show no association with the risk of lung cancer. Due to the low number of studies, however, the Committee considers the EPA classification ‘no statements can be made regarding a causal relationship’ to apply.

The meta-analysis of the studies of occupational exposure in workers from the general population also shows no increased risk of lung cancer. The same applies to studies of occupational exposure in workers from industrial populations. It is not possible to determine an exposure-effect relationship due to the nature of the studies. As a result of the heterogeneity between the studies, the Committee considers the EPA classification ‘no statements can be made regarding a causal relationship’ to apply to the relationship between risk of lung cancer and occupational exposure to magnetic fields.

09
prostate cancer

Research in the residential environment shows no associations between living in the vicinity of high-voltage power lines and the risk of prostate cancer. The research is limited in scale, however, and the conclusion is therefore that no statements can be made regarding a causal relationship. An association was indeed found in the case of occupational exposure to magnetic fields above the background level. The Committee sees this as an indication of a causal relationship.

9.1 Residential exposure

There is no data on prostate cancer in relation to distance from home to high-voltage power lines.

One study was found that investigated the relationship between cumulative exposure to magnetic fields from high-voltage power lines in the residential environment, expressed in μT-year, and the occurrence of prostate cancer.[18] The incidence of prostate cancer is no higher in men who have ever been exposed to magnetic fields above the background level than in the population as a whole. The Committee has calculated an incidence ratio (SIR) of 0.99 (0.91-1.07).

One study was also found that investigated the relationship between the use of electric bed warmers and the occurrence of prostate cancer.[112] A risk estimate of 1.4 (0.9-2.2) was found for men who had ever used an electric bed warmer.

The Committee did not carry out any meta-analyses due to the low number of studies.

9.2 Occupational exposure to magnetic fields

The Committee found 14 studies that investigated the relationship between occupational exposure to magnetic fields and the occurrence of prostate cancer. Of these, five studies were not included in the analyses for various reasons (see the background document). The Committee used the data from the nine remaining studies of occupational exposure to carry out meta-analyses.[27,32,39,40,43,74,81,106,113]

In these meta-analyses, the Committee made a distinction between studies of occupational exposure in the general population and studies focusing on specific industrial populations, such as electricity company employees.

The meta-analyses give a risk estimate of 1.06 (1.00-1.12) for the occurrence of prostate cancer in workers from the general population. Because there are too few studies that involve a complete occupational history, this risk estimate is based on all studies. The meta-analyses of the studies with a complete occupational history in workers from industrial populations give a risk estimate of 1.02 (0.88-1.17) for the occurrence of prostate cancer with occupational exposure to magnetic fields.

9.3 Conclusions

The analysed epidemiological studies of residential exposure to magnetic fields show no associations with the risk of prostate cancer. Due to the low number of studies, however, the Committee considers the EPA classification ‘no statements can be made regarding a causal relationship’ to apply.

The meta-analyses of the studies of occupational exposure do not show an increased risk. As a result of the heterogeneity between the studies, the Committee considers the EPA classification ‘no statements can be made regarding a causal relationship’ to apply to the relationship between risk of prostate cancer and occupational exposure to magnetic fields.

10 skin melanomas

Research in the residential environment shows no association between living in the vicinity of high-voltage power lines and the risk of skin melanomas. The research is limited in scale, however, and the conclusion is therefore that no statements can be made regarding a causal relationship. No association was also found in the case of occupational exposure to magnetic fields above the background level. For the occupational environment too, where the results of the studies are ambiguous, the Committee cannot make any statements regarding a possible causal relationship between exposure to magnetic fields and skin melanomas.

10.1 Residential exposure

The Committee found four studies that investigated the relationship between residential exposure to magnetic fields and the occurrence of skin melanomas. The Committee used this data to carry out meta-analyses.[18,23,114,115]

One of these studies also investigated the relationship between distance to high-voltage power lines and the occurrence of melanomas. The risk estimate for living at a distance of between 0 and 50 metres from a high-voltage power line is 0.82 (0.61-1.11).[23]

For exposure to magnetic fields above the background level as a result of living in the vicinity of a high-voltage power line, the meta-analysis gives a risk estimate of 1.10 (0.78-1.55) for the occurrence of skin melanomas.

10.2 Occupational exposure to magnetic fields

The Committee found eight studies that investigated the relationship between occupational exposure to magnetic fields and the occurrence of skin melanoma. Of these, two studies were not included in the analyses for various reasons (see the background document). The Committee used the data from the six remaining studies of occupational exposure to carry out meta-analyses.

In these meta-analyses, the Committee made a distinction between studies of occupational exposure in the general population and studies focusing on specific industrial populations, such as electricity company employees.

Two studies were found in participants from the general population. In the first study, the risk estimate for exposure above the background level is 1.39 (1.32-1.47).[43] In the second study, the risk estimate is 1.11 (0.87-1.41).[114]

The meta-analysis of the data from the four studies in industrial populations shows no increased risk of skin melanomas with exposure to

magnetic fields above the background level.[39,48,74,81] The Committee has calculated a risk estimate of 1.01 (0.89-1.16). Because there are too few studies that involve a complete occupational history, this risk estimate is based on all studies.

10.3 Conclusions

The analysed epidemiological studies of residential exposure to magnetic fields show no associations with the risk of skin melanomas. Due to the low number of studies, the Committee considers the EPA classification ‘no statements can be made regarding a causal relationship’ to apply.

One of the two studies showed an increased risk of skin melanomas in workers from the general population, while the other did not. The meta-analyses of the studies in workers from industrial populations show no increased risk of skin melanomas for occupational exposure. It is not possible to determine an exposure-effect relationship due to the nature of the studies. On the basis of these findings, the Committee considers the EPA classification ‘no statements can be made regarding a causal relationship’ to apply to the relationship between the risk of skin melanomas and occupational exposure to magnetic fields.

11 recommendations

For most of the types of cancer investigated, few studies are available on residential exposure and some of them use proximity to high-voltage power lines as a measure of exposure to the magnetic field, which is less accurate than determining exposure to magnetic fields by means of measuring or modelling. For most types of cancer, no associations were found between residential exposure to magnetic fields and risk of disease in adults.

The Committee only found an association in the case of leukaemia. As for children, the incidence of leukaemia is higher in adults who live close to high-voltage power lines. The Committee sees this as an indication of a causal relationship.

For occupational exposure to magnetic fields above the background level, the Committee has found associations with the risk of leukaemia, breast cancer in men, brain cancer and pancreatic cancer. The risks of these types of cancer are estimated to be between 1.1 and 2.1 times higher. The Committee sees this as an indication of a causal relationship. For the other types of cancer, not enough data is available or the variation in the study results is too great to make a statement regarding a possible causal relationship.

In table 2, the Committee states what it considers the study results to mean in terms of evidence, based on the EPA classification, of a causal relationship between exposure to magnetic fields and the different types of cancer. It does this separately for residential exposure and occupational exposure.

Table 2 Evidential value for a causal relationship between exposure and disease

Disease	Residential	Occupational
Leukaemia, including AML	Indications of a causal relationship	Indications of a causal relationship
Breast cancer in women	No statements can be made regarding a causal relationship	No statements can be made regarding a causal relationship
Breast cancer in men	No statements can be made regarding a causal relationship	Indications of a causal relationship
Brain cancer	No statements can be made regarding a causal relationship	Indications of a causal relationship
Testicular cancer	No statements can be made regarding a causal relationship	No statements can be made regarding a causal relationship
Pancreatic cancer	No statements can be made regarding a causal relationship	Indications of a causal relationship
Lung cancer	No statements can be made regarding a causal relationship	No statements can be made regarding a causal relationship
Prostate cancer	No statements can be made regarding a causal relationship	No statements can be made regarding a causal relationship
Melanoma	No statements can be made regarding a causal relationship	No statements can be made regarding a causal relationship

The occupational exposures investigated are considerably higher than residential exposures. If the magnetic field can cause health problems, this is more likely to be evident in people who are exposed to relatively high magnetic field strengths in their profession, such as electric welders or people who work at a power plant. The indications of a causal relationship with occupational exposure cannot simply be extrapolated to

the residential environment, although they do indicate that magnetic fields may have the potential to cause health problems. Further research will have to show whether this is actually the case, what the underlying mechanism of action is, what the dose-effect relationships are and whether there are exposure levels at which no adverse effects occur. It should also be noted that the population exposed in the residential environment also includes groups that are potentially more vulnerable, such as children, the elderly and people with chronic diseases, and that exposure is more prolonged than in the occupational environment.

In 2002, the International Agency for Research on Cancer (IARC) classified extremely low frequency magnetic fields as 'possibly carcinogenic to humans' (category 2B) primarily on the basis of associations with childhood leukaemia identified at that time.[116] These associations were confirmed by the Committee in its first partial advisory report in 2018, based in part on more recent literature.[2] In this advisory report, the Committee has also identified an association between both residential and occupational exposure to EMV and leukaemia in adults. Associations identified in epidemiological research are indications, but not evidence, of a causal relationship. Additional data from experimental research is needed to provide such evidence, which is largely lacking in the case of leukaemia. Further experimental research on other types of cancer is indeed available. In 2007, the WHO published an extensive review that concluded that there is no experimental evidence that extremely low frequency magnetic fields can cause cancer.[117] A 2016 review by the Swedish Radiation Safety Authority (SSM) reached the conclusion that nothing has changed since that time.[118] No more recent high-quality reviews of experimental studies are available.

The request for advice asks whether the voltage on the line may be relevant. However, there are no studies that analyse line voltage as a possible factor.

11.1 Recommendations

Further research

The Committee does not expect that further (retrospective) epidemiological research will provide greater certainty in the short term. The Committee does, however, recommend monitoring residential and occupational exposure to magnetic fields. The use of wind turbines and solar panels as a primary energy source has increased considerably in recent years. At the same time, we are witnessing a surge in the popularity of electric cars and heat pumps. Changes in the production and consumption of electricity are leading to an increase in the transport of electricity and thus, probably, to higher exposures to magnetic fields in the vicinity of power lines and in some workplaces. Research into biological mechanisms of action may provide additional information on causal relationships.

Precaution

The current policy concerning overhead power lines is based on the principle of precaution due to indications of a causal relationship between exposure to magnetic fields and the risk of childhood leukaemia. In its previous advisory report, the Committee recommended considering broadening the precautionary policy to underground power cables and other sources of long-term exposure to magnetic fields generated by the electrical grid, such as transformer stations and transformer substations. For most of the types of cancer in adults investigated, the current analyses provide no indication that the general population is at an increased risk due to residential exposure to magnetic fields. The only exception is leukaemia. The Committee sees this finding as a further argument in favour of precautionary policy.

Given the indications of an increased risk of various types of cancer from occupational exposure to magnetic fields above the background level, the Committee recommends the precautionary measure of keeping occupational exposure as low as reasonably achievable (ALARA).

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Power lines and health: cancer in adults

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