Power lines and health part I: childhood cancer

To: the State Secretary of Infrastructure and Water Management
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Health Council of the Netherlands

contents

executive summary

In the Netherlands, on average approximately 135 new cases of childhood leukaemia are diagnosed each year. There are indications that the risk of getting this disease is twice as high in children living near overhead power lines than in other children. This means that one case of childhood leukaemia every two years may be associated with the presence of overhead power lines. Exposure to the magnetic fields generated by the power lines could be responsible for this, although other (unknown) factors and chance cannot be excluded. Motivated by a Health Council report published in 2000, the Netherlands Government recommends local and provincial authorities and electric power transport companies to apply a precautionary policy. The aim is to prevent as much as possible that new situations will arise with long-term exposure of children to magnetic fields from overhead high-voltage power lines that exceed an annual average level of 0.4 microtesla.

Request for advice

The then State Secretary for Infrastructure and the Environment (currently Infrastructure and Water Management) asked the Health Council to update its 2000 report and to consider not only leukaemia but also other health effects. This report, the first in a series of three, deals with childhood cancer. The other two reports, to be published later, will discuss cancer and neurodegenerative diseases in adults.

Two type of studies: using distance and magnetic field strength

The Electromagnetic Fields Committee of the Health Council re-analyzed the data on a possible relationship between exposure to magnetic fields generated by overhead and underground power lines and the incidence of childhood cancer. It did so in greater detail and including the most recent studies. Most studies do not measure the exact exposure of children, because that is too complex and time-consuming. Instead, some studies consider the distance between a child's residence and the power line. Because the strength of the magnetic field generated by the line decreases with increasing distance, the distance provides an indication for the magnetic field strength in the residence. In other studies, the residential magnetic field strength has been assessed by measurements or calculations, or combinations of the two.

Childhood leukaemia

Overall, the results indicate an increasing risk of childhood leukaemia with decreasing distance and increasing magnetic field strength. The risk estimate is higher when the magnetic field strength is assessed more accurately. The most representative exposure estimate is the assessment of the magnetic field strength in all residences of a child between birth and diagnosis. Based on these data, the estimated leukaemia risk seems to be more than two and a half times higher in children that have been long-term exposed to an average magnetic field strength of

0.3 to 0.4 microtesla or higher compared to children that are exposed at background level. There is considerable uncertainty in this risk estimate, but the Committee considers it highly unlikely that in reality there is no increased risk. These new analyses confirm the earlier conclusions of the Health Council.

Other types of cancer

For other types of cancer in children only data are available on brain tumours and lymphomas. Only for brain tumours sufficient data are available to carry out analyses. In studies using distance as a measure of exposure, no indications for an association with brain cancer in children have been found. In studies using the magnetic field strength as an exposure metric, the risk of brain cancer seems almost 1.5 times higher in children that have been long-term exposed in their homes to magnetic field strengths averaging 0.4 microtesla or more. There is considerable uncertainty in this risk estimate and the Committee considers it more likely that the increase is a chance finding than in the case of leukaemia.

Conclusions

The analyses of the Committee provide indications of an association between exposure to magnetic fields around overhead power lines and the incidence of childhood leukaemia and possibly brain tumours. When the results are summarized in terms of the framework for assessing causality of the US Environmental Protection Agency, the Committee concludes that they are ‘suggestive of a causal relationship’ between magnetic field exposure and both leukaemia and brain tumours. However, the indications are weaker for brain tumours than for leukaemia. For both cancer types there is insufficient evidence for the qualification of a ‘likely’ or ‘proven causal relationship’, also because there is no supporting evidence from animal studies.
Regarding the risk of childhood lymphomas, there is insufficient data to infer on causality.
An influence of other factors that are associated with the presence of overhead power lines cannot be excluded. However, this has not been shown in research to date. It can also not be excluded that the observations, in particular those concerning brain tumours, are chance findings.

Recommendations

The current scientific knowledge does not give the Committee reason to recommend the State Secretary for Infrastructure and Water Management to reconsider the current policy regarding overhead power lines. Since there are indications for a causal relationship between exposure to magnetic fields and increased risks of childhood leukaemia and brain tumours, and magnetic fields are not blocked by soil or construction materials, the Committee suggests the State Secretary from a public health perspective to consider extending the precautionary policy to underground power cables and other sources of long-term exposure to magnetic fields from the electricity grid, such as transformer stations and transformer houses.

01 introduction

There are indications that children living near overhead power lines are at increased risk of getting leukaemia compared to other children. The reason is unclear: magnetic fields generated by these power lines may play a role in this. Motivated by a Health Council advisory report published in 2000, the Netherlands Government recommends local and provincial authorities and electric power transport companies to apply a precautionary policy. The aim is to prevent as much as reasonably possible that the construction of new overhead power lines or new houses, schools and day-care centres leads to new situations of long-term exposure of children to magnetic fields exceeding an annual average level of 0.4 microtesla. In 2014, the State Secretary for Infrastructure and the Environment (currently: Infrastructure and Water Management) asked the Health Council to update its 2000 report and to consider not only childhood leukaemia but also other health effects that may be associated with the presence of overhead power lines.

1.1 Background

In 1979, American researchers found a higher incidence of childhood leukaemia near overhead power lines (i.e. the distribution lines that often run between houses in the USA) than farther away.[1] Power lines generate so-called extremely low frequency (ELF) electric and magnetic fields (see Chapter 2). The question arose whether exposure to these fields might be the reason for this. This resulted in further research, which not only focussed on childhood leukaemia but also on other types of cancer in children and adults, and other diseases.

In 2002, the International Agency for Research on Cancer (IARC), an agency of the World Health Organization (WHO), classified ELF magnetic fields as ‘possibly carcinogenic to humans’, mainly because epidemiological studies showed a fairly consistent association between exposure to such fields and an increased risk of childhood leukaemia.[2]

The Health Council has published several reports on this subject.[3-7] In 2000[4], the council drew a conclusion similar to that of IARC: ‘The data obtained in epidemiological research [indicate] a fairly consistent association between living near overhead power lines and a slightly increased risk of childhood leukaemia.’

An association is a *statistical* relationship which does not necessarily imply causation (see box). The council then concluded that a causal relation with exposure to ELF magnetic fields cannot be assessed only from the results of epidemiological research. In a 2012 report on potential causes of childhood leukaemia published by the Health Council together with the Superior Health Council of Belgium, similar conclusions to those in the 2000 report were drawn.[8]

Association or causal relationship

When considering relationships between exposure to a certain factor, such as ELF magnetic fields, and a disease, such as childhood leukaemia, a distinction is made between associations and causal relationships. An association refers to a situation in which a certain exposure and a specific disease occur together more frequently than expected based on chance. A causal relationship refers to a situation in which a specific disease is the result of a certain exposure. An association between a certain exposure and a specific disease shown in a statistical analysis does not necessarily mean that they are causally related. A causal relation cannot be assessed based on statistics alone. Additional information is needed, for instance, based on experimental research or referring to a biological mechanism.

1.2 Childhood leukaemia in the Netherlands

Childhood leukaemia is a rare condition. In the Netherlands, on average approximately 135 new cases of childhood leukaemia are diagnosed each year[9] in a population of approximately 2.8 million children aged 0-15 years.[10] This number includes all types of childhood leukaemia. Most cases, over 80%, involve acute lymphatic leukaemia. Other types of leukaemia are acute myeloid leukaemia and chronic types of leukaemia.

About fifteen years ago, the Health Council and the National Institute for Public Health and the Environment (RIVM) estimated the number of children in the Netherlands living in close proximity to an overhead power line to be approximately 15,000.[4,11] It was calculated that approximately one case of childhood leukaemia in the Netherlands every two years might be the result of living near an overhead power line, assuming that the risk in this population is approximately twice as high and the relationship is causal.

Since 2005, based on these potential health risks and the associated social concern, the Netherlands Government has been recommending local and provincial authorities and electric power transport companies to apply a precautionary policy. They are advised ‘when determining spatial plans and the trajectory of overhead high-voltage power lines, or in the event of changes to existing plans or existing overhead high-voltage power lines, the creation of new situations whereby children undergo long-term stays in the areas around overhead high-voltage power lines within which the annually averaged magnetic field is greater than 0.4 microtesla (the magnetic field zone), is to be avoided as much as reasonably possible’.[12] A further explanation of this advice was published in 2008.[13]

1.3 Request for advice

The then State Secretary for Infrastructure and the Environment (currently: Infrastructure and Water Management) wanted to know whether new research data give cause to reconsider the precautionary policy. Therefore, she asked the Health Council to update the previous reports based on the following questions:

1. Is there a relationship between residential distance to overhead power lines and health risks including childhood leukaemia, other types of cancer in children and adults, and Alzheimer’s disease, and does the voltage of the power lines play a role in this?

2. Is there a relationship between exposure to ELF magnetic fields and health risks?
3. If there is an increased risk associated with being in close proximity to overhead power lines for a sustained period of time, are there indications for factors other than the magnetic field associated with the presence of overhead power lines that could explain this risk?

The Electromagnetic Fields Committee of the Health Council will answer the request for advice. Due to the various health risks included in the request, the answer has been divided into three parts:

- in part I, the Committee discusses childhood leukaemia and other types of childhood cancer;
- in part II, the Committee discusses leukaemia and other types of cancer in adults;
- in part III, the Committee discusses Alzheimer's disease and other neurodegenerative diseases.

On 18 April 2018, part I was presented to the State Secretary for Infrastructure and Water Management.
The request for advice, the composition of the Committee and the cover letter can be found on www.healthcouncil.nl.

1.4 Methodology

The Committee re-analysed the data on a possible relationship between exposure to magnetic fields generated by overhead and underground power lines and the incidence of childhood cancer. It did so in greater detail and including the most recent studies. The scientific literature search included two types of epidemiological studies:

- studies examining the association between residential distance to overhead power lines and the incidence of childhood cancer, and
- studies examining the association between residential magnetic field strength and the incidence of childhood cancer.

The studies included in this report generally do not differentiate between various types of childhood leukaemia. As a result, the analyses and conclusions pertain to childhood leukaemia in general.

Three committee members with epidemiological and statistical expertise independently assessed the quality of the available studies. This procedure resulted in a joint quality judgement. A distinction was made between studies of *sufficient* and studies of *insufficient* quality. Only studies of sufficient quality were included in the report. A study was considered insufficient if the three experts concluded that the results were likely to be biased.

The Committee then performed a meta-analysis based on the results from the studies of sufficient quality for each type of cancer (see box), both for distance and magnetic field strength, in order to carry out a systematic evaluation of all data available. The Committee compared the results from its own meta-analyses with those from recently published pooled analyses or meta-analyses. Descriptive reviews of scientific literature have not been included in this report.

Meta-analyses and pooled analyses

In meta-analyses and pooled analyses, results from different studies with similar scopes and approaches are combined to derive one risk estimate from all data available.
In a pooled analysis, original raw data from several studies are collected, analysed as one data set and adjusted for potential confounders.
In a meta-analysis, published risk estimates from a number of studies are collected and used to calculate one average risk estimate. In a meta-analysis, one depends on how risks have been estimated and potentially corrected in the individual studies. In a pooled analysis, the researchers can make their own decisions about this.

The Committee has limited itself to epidemiological studies, because these are the main source of information on this topic. For an overview of animal and cell culture experiments, two important reviews are referred to.[14,15]

When assessing studies examining the association between exposure to ELF magnetic fields and the incidence of childhood cancer, the Committee checked the strength of evidence for inferring causation in case an increased risk was found. The Committee uses the framework for assessing causality of the US Environmental Protection Agency (EPA), that differentiates between the following classifications:[16]

- causal relationship proven;
- causal relationship likely;
- suggestive of a causal relationship;
- inadequate to infer a causal relationship;
- causal relationship unlikely.

The search strategies, the quality criteria, an overview of the studies and quality assessments, and an explanation of the classifications of strength of evidence can be found in the background document.

1.5 Reading guide

The report begins with a short explanation of some technical terms in Chapter 2.
In Chapter 3, the Committee discusses the data on the relationship between the incidence of childhood leukaemia and residential distance to overhead power lines, and the relationship between the incidence of childhood leukaemia and exposure to magnetic fields generated by overhead and underground power lines.
In Chapter 4, similar data pertaining to other types of childhood cancer are discussed.

In Chapter 5, the Committee discusses factors other than magnetic field strength that might explain the associations found.
In Chapter 6, the Committee gives its final conclusions and advice.

02
power lines and magnetic fields

2.1 Voltage, current and fields

The voltage of a power line creates an electric field. A power line carrying a current also creates a magnetic field. An electric field and a magnetic field propagate in different ways. Figure 1 is a simplified representation of this.

Electric field and magnetic field propagate in different ways

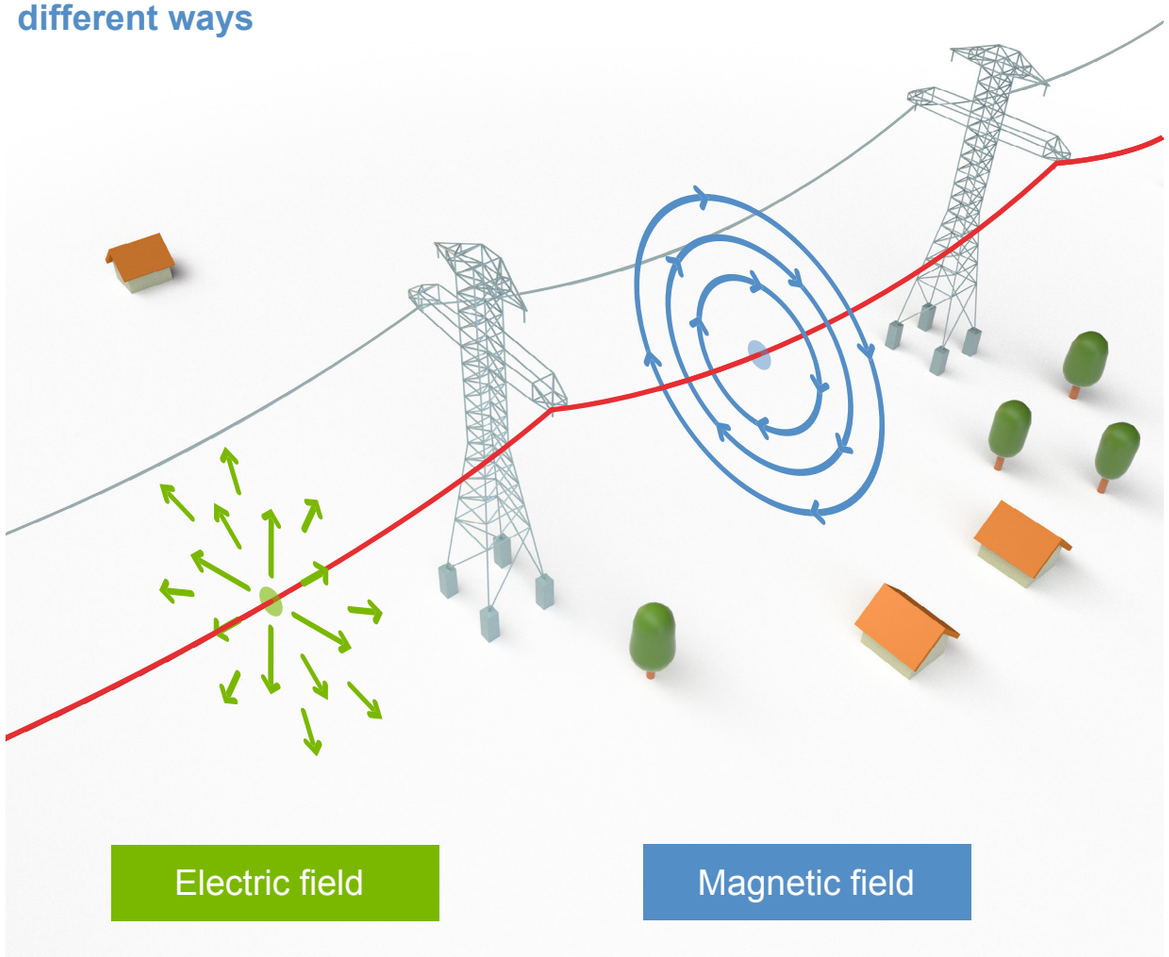

Figure 1. Schematic representation of an electric and a magnetic field generated by a power line

The voltage in the electricity grid changes polarity 100 times a second (50 cycles of 2 polarity changes, alternating current), in other words at a frequency of 50 hertz (Hz). This is an extremely low frequency (ELF). In comparison, mobile phones operate at much higher frequencies, approximately 900 to 2,000 megahertz (one megahertz is one million hertz).

The electricity grid

The electricity grid between power plant and residence consists of transmission and distribution lines and cables. Lines are overhead connections, whereas cables are located underground.
In the Netherlands, transmission connections are high-voltage power lines or cables with a voltage of 220 or 380 kilovolt (kV; 1 kV is 1,000 V). They carry electricity from the power plant to a substation. They are the highways of electricity transport. There are also high-voltage power lines and cables between substations and transformer stations, though with a lower voltage of 50, 110 or 150 kV. Electricity is carried from transformer stations to transformer houses in residential areas and near companies by distribution cables with a medium voltage of 3, 5, 6, 10, 12.5, 20 or 25 kV. In the transformer houses, the voltage is further reduced to 400 and 230 V. The electricity is then carried by low-voltage distribution cables to the final destination.
In the Netherlands, overhead power lines are (almost) always high-voltage lines. In other countries, distribution lines may also run overhead.

2.2 Field strength

Electric field strength is expressed in volts per meter (V/m). The higher the voltage, the stronger the electric field. Magnetic field strength is expressed in tesla (T). In practice, the magnetic field strength produced by the electricity system is always expressed in microtesla (μT = one millionth T). The more electricity a line carries (i.e. the higher the current), the stronger

the magnetic field. Magnetic field strength drops rapidly as the distance to the line increases. Roughly, the field strength drops by a factor of four if the distance is doubled. The distance to a conductor, and therefore the magnetic field strength, also depends on the extent of sagging between two pylons (see Figure 2). The extent of sagging increases as the conductors get warmer. This depends on the strength of the current carried by the conductor and the ambient temperature, among other things. In practice, the situation is more complex because a high-voltage line contains several conductors and electric circuits, causing local partial ‘extinction’ or weakening of the magnetic fields. In order to implement the precautionary policy, the aim is to keep the corridor around high-voltage lines where the magnetic field strength exceeds an annual average level of 0.4 μT, the ‘magnetic field zone’, as narrow as possible when new connections are being constructed.

An electric field is considerably weakened by trees, plants and buildings. It hardly permeates materials and creates a surface charge that is transported to the ground. Inside a residence, the electric field from a power line is usually 10 to 100 times weaker than outside. By contrast, the magnetic field is hardly weakened by plants, building materials, soil or other obstacles. It easily permeates houses and the human body, see Figure 3. Therefore, studies examining the relationship between overhead power lines and possible health effects tend to focus on magnetic fields instead of electric fields.

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

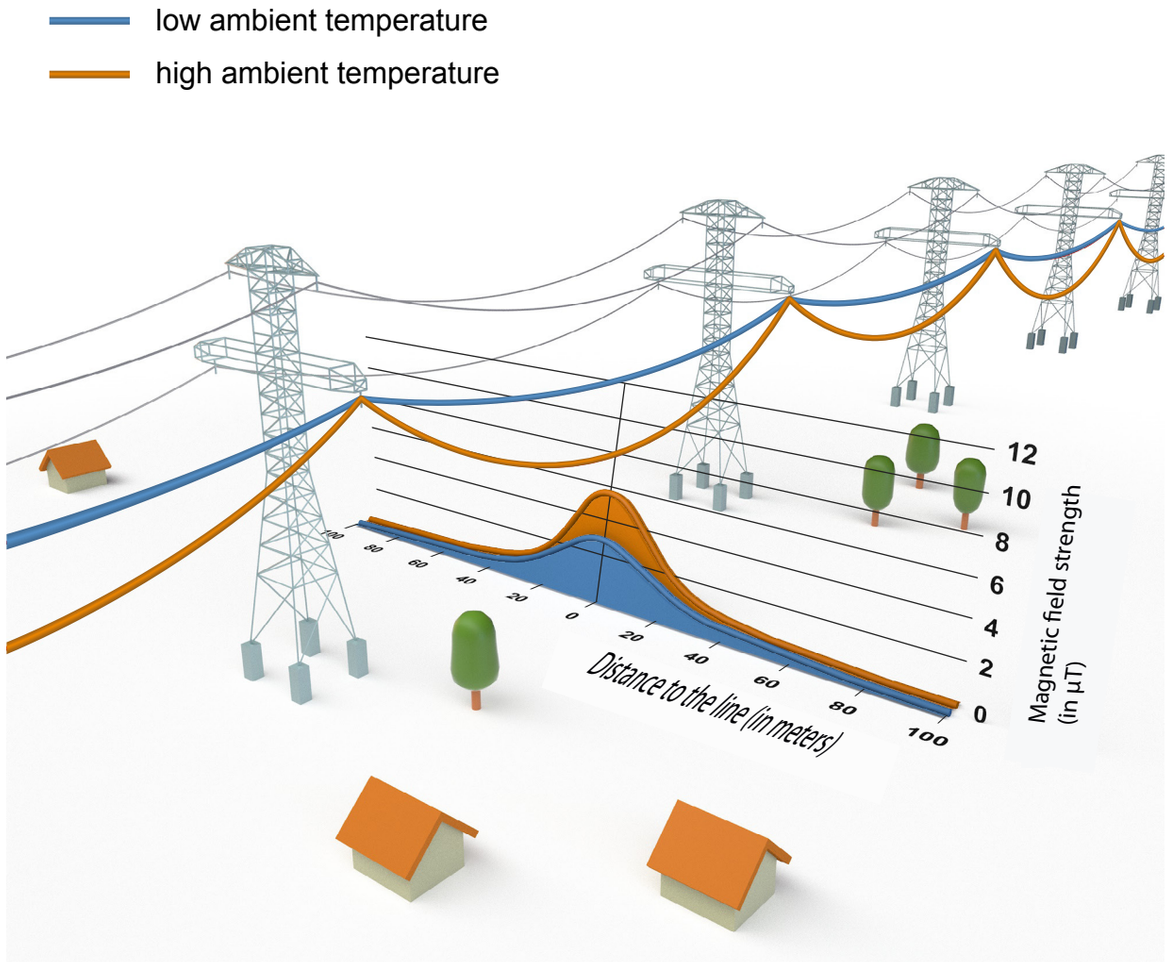

Figure 2. Relationship between distance to a power line and magnetic field strength on the ground.

An electric field is not invasive, but a magnetic field is

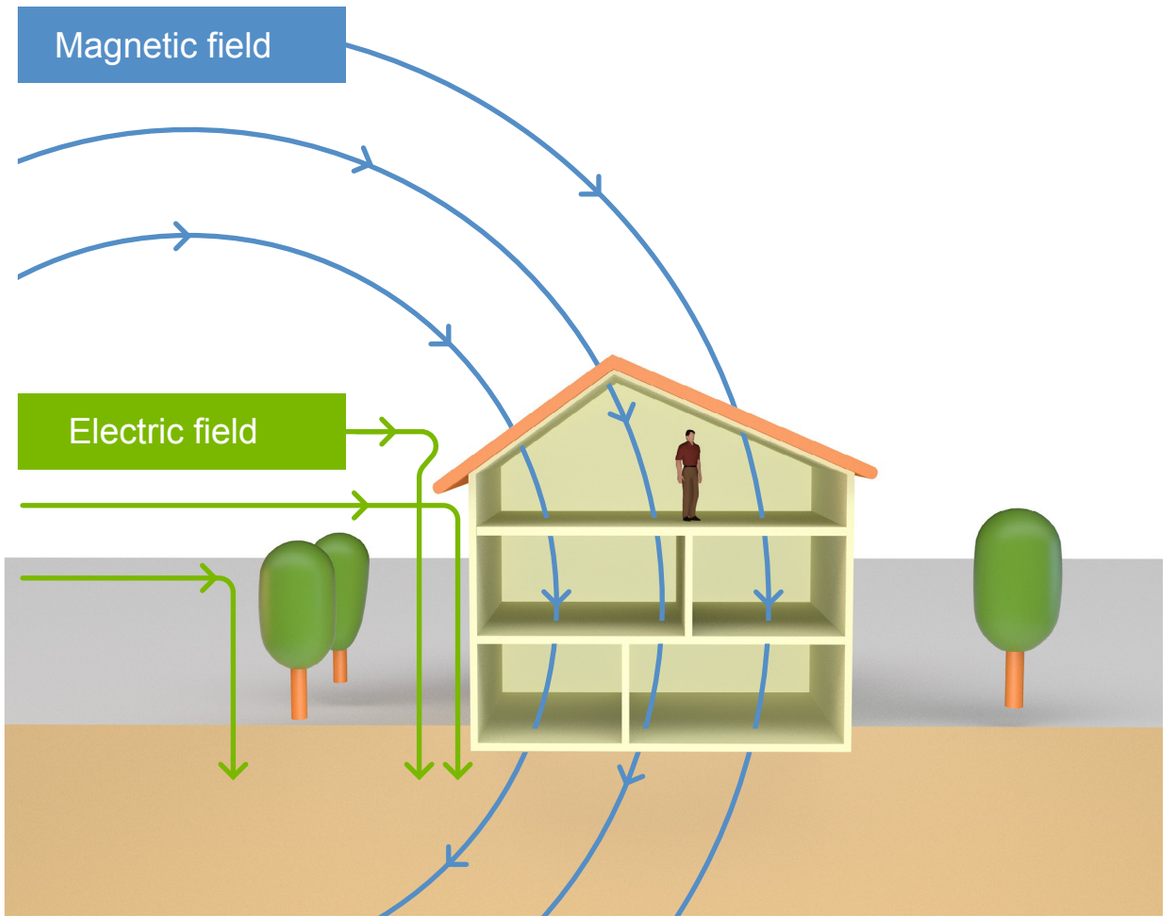

Figure 3. Schematic representation of the level of pervasiveness of electric and magnetic fields

2.3 Exposure assessment

It is not easy to accurately assess the exposure of an individual to magnetic fields. The only way to do this is to perform long-term measurements on the body. However, this method is expensive and time-consuming and is therefore seldom used in epidemiological studies. The majority of studies do not measure the exact exposure. Instead, they consider the *residential distance* to a high-voltage power line (usually expressed in terms of distance to the centre of the line at ground level) or the *magnetic field strength* measured or calculated in or near the residence. Both exposure measures have their limitations.

Distance as exposure measure has the advantage of being easily and reasonably accurately assessable. It has the disadvantage that it is only a rough measure of exposure to the magnetic fields produced by power lines. This exposure also depends on other factors, such as power line height above ground (see Figure 2) and the amount of electricity carried by the line in particular. This can fluctuate considerably over time.

In this respect, magnetic field strength is a more accurate exposure measure. However, the assessment of magnetic field strength also has its limitations. Magnetic field strength can either be measured or calculated. Measurements are not necessarily more accurate than calculations. When performing measurements in a house, the researchers depend on whether or not residents are willing to cooperate. Refusal by residents to cooperate

may lead to non-representative results (participation bias). This is not an issue when performing calculations. In addition, exposure is usually calculated over a longer period of time, sometimes over many years, whereas residential magnetic field strength measurements only are performed over a few days at most. As a result, measurements are less representative of long-term exposure.

Both studies considering distance as exposure measure as well as studies considering magnetic field strength as exposure measure also encounter other complicating factors. Firstly, (for a large) part of the day people are often elsewhere, for instance, at school or at work. There, exposure to magnetic fields may be lower, but also higher than in their own house. Secondly, high-voltage power lines are not the only sources of exposure to magnetic fields. Home appliances, too, generate magnetic fields during use. This usually results in short peak exposures in addition to the chronic exposure to magnetic fields generated by power lines.

Various studies examining health effects deal with these complicating factors in different ways, and not always at the same level of accuracy. That also determines the quality of the study.

03
childhood leukaemia

Based on all research data available, the Committee found an association between long-term exposure to ELF magnetic fields and an increased risk of childhood leukaemia. The more accurate the exposure assessment, the clearer the association. Studies considering distance to an overhead power line as exposure measure did not find a clear association, whereas studies considering magnetic field strength as exposure measure did. The association found was clearest when field strength was measured or calculated in all residences of a child between birth and diagnosis. This is the most representative measure of long-term exposure. Exposure to a magnetic field strength exceeding 0.3 to 0.4 μT is associated with an estimated risk of leukaemia 2.7 times higher (95% confidence interval 1.6-4.8) compared to exposure to background levels.

3.1 Distance to overhead power lines

3.1.1 Quality of available studies

The Committee identified 23 studies examining the relationship between distance to overhead power lines and the incidence of childhood leukaemia. According to the Committee, the quality of 9 of these studies was insufficient (see Table 1). The Committee performed a meta-analysis based on the data from the other 14 studies.

The Committee also checked whether pooled analyses or meta-analyses have been published based on studies considering distance as exposure measure. They found one: the pooled analysis from Kheifets et al. (2010).[17]

The Committee also found one study examining the relationship between the distance to underground high-voltage power cables and the incidence of childhood leukaemia.[18] This study was beyond the scope of this report and therefore not included in the analyses. However, it was included in the analysis of magnetic field strength (§ 3.2), because it is irrelevant whether magnetic field strength is generated by an overhead or underground connection.

According to the Committee, it is possible that the results are biased, as some studies not finding any associations between distance and the incidence of childhood leukaemia may not have been published (publication bias).

Details of all studies and risk estimates can be found in the background document.

Table 1. Quality analysis of studies examining the relationship between distance and the risk of childhood leukaemia

Sufficient quality		Insufficient quality
Feychting & Ahlbom (1993)[19]	Kabuto et al. (2006)[27] [a]	Coleman et al. (1989)[33]
Petridou et al. (1997)[20]	Wünsch-Filho et al. (2011)[28] [b]	Myers et al. (1990)[34]
Tynes & Haldorsen (1997)[21]	Sermage-Faure et al. (2013)[29]	Fajardo-Gutierrez et al. (1993)[35]
Li et al. (1998)[22]	Bunch et al. (2014)[30] [c]	Olsen et al. (1993)[36]
McBride et al. (1999)[23]	Pedersen et al. (2014)[31]	Mizoue et al. (2004)[37]
Bianchi et al. (2000)[24] [a]	Crespi et al. (2016)[32]	Feizi et al. (2007)[38]
Kleinerman et al. (2000)[25]		Abdul Rahman et al. (2008)[39]
UK Childhood Cancer Study (2000)[26]		Sohrabi et al. (2010)[40]
		Tabrizi & Bidgoli (2015)[41]

[a] Included in the pooled analysis of Kheifets et al. (2010).[17]
[b] Unpublished data from this study have been included in the pooled analysis of Kheifets et al. (2010).[17]
[c] Update of data from Kroll et al. (2010)[42] included in the pooled analysis of Kheifets et al. (2010).[17]

3.1.2 Pooled analysis 2010

In 2010, Kheifets et al.[17] published a pooled analysis based on data from studies considering distance as exposure measure. They included five studies published since 2000[24,27,42-44] and one study that had not yet been published.[28] None of the nine studies the Committee considered to be of insufficient quality were included in this pooled analysis.

Kheifets et al. differentiated between three categories of distances to high-voltage power lines: 0 to 50 metres, 50 to 100 metres and 100 to 200 metres. They concluded that the smaller the distance to high-voltage power lines, the higher the risk of childhood leukaemia. The pooled analysis of Kheifets et al. showed that a distance of 0 to 50 metres to a high-voltage power line was associated with a 1.6 times higher estimated risk (please note: all risk estimates in the text have been rounded off to the nearest decimal). Only the increase in estimated risk associated with this specific distance category is statistically significant, see Table 2. See the box for an explanation of risk estimates and significance.

Risk estimate and confidence interval

The risk estimate reflects the estimated probability of a certain effect occurring in a specific situation compared to the control situation. For instance, in this case, a risk estimate of 1.3 refers to a situation in which children living near high-voltage power lines have a 1.3 times, i.e. 30%, higher estimated chance of getting leukaemia compared to children living further away. A risk estimate of 0.9 refers to a situation in which the chance found is 0.9 times higher, i.e. 10% lower.

The 95% confidence interval (CI) indicates the level of uncertainty of the risk estimate found. It means that if we repeat the study 100 times in the same population by taking different samples, we will find that the actual association (in this case: the actual relative risk) occurs 95 times within the confidence interval. A relative risk of 1 refers to a situation in which the chance of getting leukaemia is the same as in the control situation. If the 95% CI includes the value 1, the identified association is not statistically significant. If the lowest value of the 95% CI is greater than 1, we consider the increase in risk statistically significant.

It is also possible to make statistical statements about an identified association based on a statistical test. This produces a p-value, which indicates the probability to observe the identified or an even stronger association if there is in fact no association. An association is referred to as being statistically significant if the p-value is less than 5%.
It is important to note that statistical significance does not prove the presence of an association (just like a statistically insignificant result does not prove the absence of an association). In addition, statistical significance neither demonstrates nor excludes causation.

3.1.3 Analyses made by the Committee

The Committee performed a meta-analysis based on the data from the 14 studies of sufficient quality, including the original data from two studies[24,27] which have also been included in the pooled analysis of Kheifets et al. (2010),[17] see Table 1. Considering the other three studies from the pooled analysis of Kheifets, the original publications of two studies (Lowenthal et al., 2007[43] and Malagoli et al., 2010[44]) did not contain any data on distance (Kheifets obtained these data directly from the researchers). A published update of the third study (Kroll et al., 2010[42]) has been included in the meta-analysis made by the Committee (Bunch et al., 2014[30]).

In order to be able to compare the results from the meta-analysis with the results from the pooled analysis of Kheifets, the Committee differentiated between the same three categories of distance to high-voltage power lines: 0 to 50 metres, 50 to 100 metres and 100 to 200 metres. In the request for advice, it is asked whether the voltage of the power lines may be relevant. Therefore, the Committee has also made an analysis for the same categories only based on the data of high-voltage power lines with a voltage higher than 200 kV.

The meta-analysis performed by the Committee showed that a distance of 0 to 50 metres was associated with a 1.2 times higher risk estimate. It also showed that a distance of 50 to 100 metres was associated with a 1.3 times higher risk estimate, and that a distance of 100 to 200 metres was associated with a 0.9 times higher (i.e. a decreased) risk estimate. Only the increase in estimated risk associated with a distance of 50 to 100 metres is statistically significant. The Committee also used these data to analyse whether the risk increases as the distance decreases. This relationship between distance and response was not statistically significant (p=0.20).

The data from the analysed studies pertaining to all three distance categories were heterogeneous, i.e. the results from the individual studies included in the meta-analysis were not uniform. This reduces the power of the meta-analysis.

The analysis of the data on high-voltage power lines with a voltage of 200 kV or higher produced a risk estimate of 1.5 for distances of 0 to 50 metres, a risk estimate of 1.1 for distances of 50 to 100 metres and a risk estimate of 1.0 for distances of 100 to 200 metres. These risk estimates were not statistically significant. The risk is not markedly higher compared to the risk associated with the power lines irrespective of their voltages. Therefore, there are no indications that the voltage of the power line plays an important role in the risk estimation. However, this analysis is based on only two to four studies for each distance category.

Table 2 summarises the results from the pooled analysis of Kheifets et al. and the results from the meta-analysis performed by the Committee. More

information on the analyses and the included data can be found in the background document.

Table 2. Analysis of data on the relationship between distance and the risk of getting childhood leukaemia

Distance to overhead power line	Risk estimate[a]	95% CI[a]	Number of studies
Pooled analysis Kheifets et al.[17]			
0-50	**1.59**	**1.02-2.50**	6
50-100	1.30	0.89-1.91	6
100-200	1.20	0.90-1.59	6
>200 (reference)	1.00		
Meta-analysis Committee			
0-50	1.22	0.93-1.61	11
50-100	**1.27**	**1.02-1.58**	9
100-200	0.90	0.72-1.12	3
Reference[b]	1.00		
Meta-analysis Committee voltage ≥200 kV			
0-50	1.45	0.78-2.70	4
50-100	1.06	0.74-1.50	4
100-200	1.01	0.73-1.40	2
Reference[b]	1.00		

[a] See the box in § 3.1.2 for an explanation of risk estimation and confidence interval. Statistically significant values are indicated in bold text.

[b] The reference distances considered in the various studies are not similar.

According to the Committee, five of these studies were of insufficient quality (see Table 3). The Committee performed meta-analyses based on the data from the other 24 studies.

Table 3. Quality of studies examining the relationship between magnetic field strength and the risk of getting childhood leukaemia

Sufficient quality		Insufficient quality
Savitz et al. (1988)[47 b]	Bianchi et al. (2000)[24 c]	Tomenius (1986)[62 b]
London et al. (1991)[48]	Schüz et al. (2001)[55]	Coghill (1996)[63 b]
Feychting & Ahlbom (1993)[19 a b]	Kabuto et al. (2006)[27 c]	Feizi et al. (2007)[38]
Olsen et al. (1993)[36 a b f]	Meji-Arangure et al. (2007)[56]	Jirik et al. (2012)[64]
Verkasalo et al. (1993)[49 a b]	Malagoli et al. (2010)[43]	Tabrizi & Bidgoli (2015)[41]
Linet et al. (1997)[50 a b]	Does et al. (2011)[57]	
Tynes & Haldorsen (1997)[21 a b]	Wünsch-Filho et al. (2011)[28 d]	
Dockerty et al. (1998)[51 a b]	Bunch et al. (2015)[18]	
Michaelis et al. (1998)[52 a b]	Pedersen et al. (2015)[58]	
Green et al. (1999)[53 b]	Salvan et al. (2015)[59]	
McBride et al. (1999)[23 a b]	Bunch et al. (2016)[60 e]	
UK Childhood Cancer Study (1999)[54 a g]	Kheifets et al. (2017)[61]	

[a] Included in the pooled analysis of Ahlbom et al. (2000).[45]

[b] Included in the pooled analysis of Greenland et al. (2000).[46]

[c] Included in the pooled analysis of Kheifets et al. (2010).[17]

[d] Unpublished data from this study have been included in the pooled analysis of Kheifets et al. (2010).[17]

[e] Update of data from Kroll et al. (2010)42 included in the pooled analysis of Kheifets et al. (2010).[17]

[f] Not included in the current analysis; update in Pedersen et al. (2015).[58]

[g] Not included in the current analysis, because the scope and period probably overlap with those of the more recent study of Bunch et al. (2015).[18]

3.2 Magnetic field strength

3.2.1 Quality of available studies

The Committee identified 29 studies examining the relationship between magnetic field strength and the incidence of childhood leukaemia.

The Committee also checked for published meta-analyses or pooled analyses. In 2000, two pooled analyses were published: Ahlbom et al.[45] and Greenland et al.[46] In 2010, the above-mentioned pooled analysis of Kheifets et al. was published.[17]

According to the Committee, these studies were not likely to be subject to publication bias. Studies pertaining to this subject are generally large-scaled and consequently expensive, and are therefore almost always published.

Details of all studies and their results can be found in the background document.

3.2.2 Pooled analyses from 2000 and 2010

Ahlbom et al. (2000)[45] performed a pooled analysis based on data from nine studies considering magnetic field strength as expose measure. They concluded that exposure to a magnetic field strength of 0.4 μT or higher is associated with a 2.0 times higher risk of childhood leukaemia.

Greenland et al. (2000)[46] performed an analysis based on data from 12 studies considering magnetic field strength as expose measure. They concluded that exposure to a magnetic field strength of 0.3 μT or higher is associated with a 1.7 times higher risk of childhood leukaemia.

The most recent pooled analysis is that of Kheifets et al. (2010).[17] In this analysis, the data from seven studies published later than the analyses of Ahlbom and Greenland are combined. Kheifets et al. calculated that exposure to a magnetic field strength of 0.4 μT or higher is associated with a 1.5 times higher risk of childhood leukaemia. In accordance with Ahlbom's analysis, the analysis of Kheifets et al. shows a relationship between exposure and response: the stronger the estimated magnetic field children are being exposed to, the higher the risk of getting leukaemia.

Table 4 summarises the results from the three pooled analyses.

3.2.3 Analyses made by the Committee

The Committee performed meta-analyses based on the data from the 24 studies of sufficient quality (including the data from the original studies included in the pooled analyses of Ahlbom, Greenland and Kheifets). These include studies in which field strength has been measured as well as studies in which field strength has been calculated. In order to perform the analysis, a distinction was made between three levels of magnetic field strength exposure:

- 0.1 to 0.2 μT (or 0.1 to 0.3 μT, depending on how the exposure categories were defined in the individual studies);
- 0.2 to 0.3 μT (or 0.3 to 0.4 μT, depending on how the exposure categories were defined in the individual studies);
- 0.3 μT or higher (or 0.4 μT or higher, depending on how the exposure categories were defined in the individual studies).
- The reference groups could vary, depending on how the exposure categories were defined in the individual studies.

The meta-analysis performed by the Committee, in which all studies have been included, shows that exposure to a magnetic field strength of more than 0.3 or 0.4 μT is associated with a statistically significant increase in risk of childhood leukaemia. The estimated risk is 1.6 times higher (95% CI 1.1-2.3). This corresponds with the results from previously published pooled analyses (see Table 4). Based on these data, the Committee also performed a meta-regression analysis in order to examine whether increasing exposure levels are associated with an increasing risk. The Committee could not find a statistically significant exposure-response relationship (p=0.15).

In further analyses, the Committee made a distinction between studies measuring or calculating magnetic field strength in different residences (the address where the child was born, the address where the child lived at the time of diagnosis, and any other addresses during the birth-diagnosis interval), and studies only making assessments in one residence (the address where the child was born or the address where the child lived at the time of diagnosis). The first method generates a better representation of long-term exposure than the second method.

The meta-analysis of studies assessing all residences shows that exposure to a field strength higher than 0.3 or 0.4 μT is associated with a 2.7 times higher estimated risk (95% CI 1.6-4.8), compared to studies only assessing one residence, which showed a 1.2 times higher estimated risk

Table 4. Analysis of data on the relationship between magnetic field strength and the risk of getting childhood leukaemia

Exposure (magnetic field strength in μT)	Risk estimate[a]	95% CI[a]	Number of studies
Pooled analysis Ahlbom et al. (2000)[45]			
≥0,4	**2.00**	**1.27-3.13**	9
0.2-<0.4	1.11	0.84-1.47	9
0.1-<0.2	1.08	0.89-1.31	9
<0.1 (reference)	1.00		
Pooled analysis Greenland et al. (2000)[46]			
>0.3	**1.68**	**1.23-2.31**	9
>0.2-≤0.3	1.06	0.78-1.44	8
>0.1-≤0.2	1.01	0.84-1.21	12
≤0.1 (reference)	1.00		
Pooled analysis Kheifets et al. (2010)[17]			
≥0.4	1.46	0.80-2.68	7
0.2-<0.4	1.22	0.78-1.89	7
0.1-<0.2	1.07	0.81-1.41	7
<0.1 (reference)	1.00		
Meta-analysis Committee, all studies			
>0.3 of >0.4	**1.62**	**1.13-2.34**	12
0.2-0.4	1.18	0.93-1.50	13
0.1-0.2 of 0.1-0.3	**1.18**	**1.00-1.39**	18
Reference[b]	1.00		
Meta-analysis Committee, magnetic field strength assessed at all residential addresses			
>0.3 of >0.4	**2.71**	**1.55-4.75**	5
0.2-0.4	1.35	0.99-1.84	6
0.1-0.2 of 0.1-0.3	1.19	0.96-1.46	9
Reference[b]	1.00		
Meta-analysis Committee, magnetic field strength only assessed at address at birth or diagnosis			
>0.3 of >0.4	1.21	0.79-1.85	7
0.2-0.4	0.99	0.69-1.42	7
0.1-0.2 of 0.1-0.3	1.19	0.86-1.65	9
Reference[b]	1.00		

[a] An explanation of risk estimates and confidence interval can be found in the text box in § 3.1.2. Statistically significant values are indicated in bold text.

[b] The reference groups considered in the various studies are not similar.

(95% CI 0.8-1.9) (see Table 4). A meta-regression analysis showed no statistically significant exposure-response relationship (p=0.07) in the group with ‘various addresses’.

The heterogeneity of the results from the various studies is relatively low.

Table 4 summarises the results from the published pooled analyses and the results from the meta-analyses performed by the Committee. More information on the analyses and the included data can be found in the background document.

3.3 Conclusions

The meta-analyses of the Committee based on the data on distance to overhead power lines and the incidence of childhood leukaemia show no clear associations between these two parameters. Within a distance of 0 to 100 metres, there is no clear association between decreasing residential distance to a power line and increasing risk estimates. A distance of 0 to 50 metres is associated with a 1.2 times higher estimated risk. A distance of 50 to 100 metres is associated with a 1.3 times higher estimated risk. A distance of 100 to 200 metres is not associated with an increased risk. However, it should be noted that this estimate has been derived from only three studies.

Although the analyses show no clear indication that the voltage of the power line affects the level of risk, there is only a limited number of studies available on high-voltage power lines with a voltage of 200 kV or higher.

The results of the studies included in the meta-analyses are heterogeneous, which reduces the power of the outcomes of the meta-analyses performed by the Committee.

However, the meta-analyses of the Committee based on measured and/or calculated magnetic field strength data do show a clear association with an increased risk of childhood leukaemia. The Committee most values the analysis which only includes studies assessing exposure in all residences between birth and diagnosis, because this generates the relatively best representation of long-term exposure. This analysis shows that a field strength higher than 0.3 to 0.4 μT is associated with a 2.7 times higher estimated risk (95% CI 1.6-4.8). This is higher than the estimates described in previous studies, although the confidence intervals of previous risk estimates overlap with the confidence levels of current risk estimates. A statistically significant exposure-response relationship has not been found, though.

These findings confirm the results from previously published pooled analyses and previous conclusions drawn by the Health Council.

Overall, based on the available data on associations between magnetic field strength and an increased risk of childhood leukaemia, the Committee sees ‘suggestions’ of a causal relationship. According to the Committee, the EPA classifications ‘causal relationships likely’ and ‘causal relationship proven’ are not applicable, because there is hardly any additional evidence from animal experiments or in vitro studies, and a clear insight into a possible underlying mechanism has not yet been provided.[14,15]

04
other types of childhood cancer

When considering other types of cancer, there are only data available on brain tumours and lymphomas. Based on the very limited amount of data, it can only be concluded that there are no indications for an association between residential distance to overhead power lines and the risk of childhood brain tumours. However, the Committee did find indications for an association between long-term exposure to a magnetic field strength higher than 0.3 to 0.4 μT and the risk of childhood brain tumours. Although the estimated risk is 1.4 times higher, the level of uncertainty is high. When considering lymphomas, there are too few data available to draw any conclusions.

4.1 Brain tumours: distance

Only two studies examined the relationship between distance to overhead high-voltage power lines and other types of childhood cancer. Both studies focused on brain tumours. Although they were of sufficient quality to include in this report, it is not useful to perform a meta-analysis based on only two studies.

According to Feychting and Ahlbom (1993)[19], a distance of 50 metres or less was associated with a reduced risk of childhood brain tumours (risk estimate 0.5; 95% CI 0.0-2.8). In Bunch et al. (2014)[30] a distance of 0 to 200 metres was associated with a risk estimate of 1.1 (95% CI 0.8-1.4).

4.2 Brain tumours: magnetic field strength

4.2.1 Quality of available studies

In 2010, a pooled analysis of Kheifets et al. was published[65], which combined the data from 10 studies examining the relationship between ELF magnetic field strength and the incidence of childhood brain tumours. Since then, three new studies have been published, one of which (Bunch et al. 2016)[60] is an extension of a previous study (Kroll et al. 2010).[42] The study of Bunch et al. (2015)[18] focuses on magnetic fields generated by underground cables. The analysis of the quality of the studies is shown in Table 5.

Table 5. Quality of studies examining the relationship between magnetic field strength and the risk of childhood brain tumours

Sufficient quality	Insufficient quality
Savitz et al. (1988)[47] [a]	UK Childhood Cancer
Feychting & Ahlbom (1993)[19] [a]	Study (1999)[54] [a d]
Olsen et al. (1993)[36] [a c]	Schüz et al. (2001)[67] [a]
Verkasalo et al. (1993)[49] [a]	Saito et al. (2010)[68] [a]
Preston-Martin et al. (1996)[66] [a]	Bunch et al. (2015)[18]
Tynes & Haldorsen (1997)[21] [a]	Pedersen et al. (2015)[58]
	Bunch et al. (2016)[60] [b]

[a] Included in the pooled analysis of Kheifets et al. (2010).[65]
[b] Update of data from Kroll et al. (2010)[42] included in the pooled analysis of Kheifets et al. (2010).[17]
[c] Not included in the current analysis; update in Pedersen et al. (2015).[58]
[d] Not included in the current analysis, because the scope and period probably overlap with those of the more recent study of Bunch et al. (2016).[60]

According to the Committee, it is possible that the results pertaining to brain tumours are biased, as some studies not finding any associations may not have been published (publication bias). Brain tumours are often secondary outcomes of studies examining the relationship between high-voltage power lines and childhood leukaemia. It is possible that only significant secondary outcome results are described.

4.2.2 Pooled analysis 2010

Based on an analysis of 10 studies, Kheifets et al. concluded that a magnetic field strength higher than 0.4 μT is associated with a 1.2 times higher estimated risk of a brain tumour. According to the researchers, this analysis offers 'little evidence' of an association between exposure to ELF magnetic fields and childhood brain tumours.

4.2.3 Analyses made by the Committee

The Committee performed a meta-analysis based on the data from ten studies included in the pooled analysis of Kheifets (with an update of data from one of these studies, see above) and two new studies (Pedersen et al. (2016)[58] and Bunch et al. (2015)[18]). In the analysis, a distinction was made between four levels of magnetic field strength exposure:

- 0 to 0.1 μT (the reference category);
- 0.1 to 0.2 μT (or 0.1 to 0.3 μT, depending on how the exposure categories were defined in the analysed studies);
- 0.2 to 0.4 μT;
- 0.3 μT or higher (or 0.4 μT or higher, depending on how the exposure categories were defined in the analysed studies).

In the meta-analysis performed by the Committee, the highest exposure level, i.e. exposure higher than 0.3 or 0.4 μT, is associated with a 1.4 times higher estimated risk of a brain tumour (95% CI 0.8-2.7). Based on these data, the Committee also performed a meta-regression analysis to examine whether increasing exposure levels are associated with an increasing risk. However, no statistically significant exposure-response relationship was found (p=0.08).

Table 6 summarises the results from the pooled analysis of Keifets and the results from the meta-analysis performed by the Committee. More information on the analyses and the included data can be found in the background document.

The meta-analysis shows a higher risk estimate than the pooled analysis of Kheifets et al. (2010).[65] This may be explained by the fact that the meta-analysis performed by the Committee included two recent studies[18,58] which both show an association between exposure levels higher than 0.3 or 0.4 μT and an increase in risk. One of these studies pertains to exposure to magnetic fields generated by underground cables.

Table 6. Analysis of data on the relationship between magnetic field strength and the risk of childhood brain tumours

Exposure (magnetic field strength in µT)	Risk estimate[a]	95% CI[a]	Number of studies
Pooled analysis Kheifets et al. (2010)[65]			
≥0.4	1.15	0.60-2.21	10
0.2-<0.4	0.77	0.43-1.37	10
0.1-<0.2	0.90	0.60-1.37	10
<0.1 (reference)	1.00		
Meta-analysis Committee			
>0.3 of 0.4	1.44	0.77-2.69	6
0.2-0.4	1.29	0.74-2.27	7
0.1-0.2 of 0.1-0.3	0.96	0.74-1.24	8
Reference [b]	1.00		

[a] An explanation of risk estimates and confidence interval can be found in the box in § 3.1.

[b] The reference groups considered in the various studies are not similar.

4.3 Lymphomas: magnetic field strength

4.3.1 Quality of available studies

No meta-analyses or pooled analyses on lymphomas have been published. However, six studies focussing on leukaemia also included data on lymphomas. Table 7 describes the quality analysis of these studies. The details of these studies can be found in the background document.

Similar to brain tumours, the Committee deems it possible that the study results regarding lymphomas are biased, because studies not finding any associations may not have been published ('publication bias').

Lymphomas are often secondary outcomes of studies examining associations between high-voltage power lines and childhood leukaemia. It is possible that only significant secondary outcome results are described.

Table 7. Quality of studies examining the relationship between magnetic field strength and the risk of childhood lymphomas

Sufficient quality	Insufficient quality
Savitz et al. (1988)[47]	Verkasalo et al. (1993)[49]
Feychting & Ahlbom (1993)[19]	Tynes & Haldorsen (1997)[21]
Olsen et al. (1993)[36] [a]	Pedersen et al. (2015)[58]

[a.] Not included in the current analysis; update in Pedersen et al. (2015).[58]

4.3.2 Analyses made by the Committee

The results of the meta-analysis suggest an association between long-term exposure to magnetic fields and the incidence of childhood lymphomas. Exposure to a field strength higher than 0.2 µT is associated with a 1.9 times higher estimated risk. However, it should be noted that the level of uncertainty of this risk estimate is high (95% CI 0.8-4.9). The number of studies is limited. In addition, each study included only limited numbers of children with lymphoma (varying from 0 to three cases in the highest exposure category). Based on these data, the Committee also performed a meta-regression analysis to examine whether increasing levels of exposure are associated with an increasing risk. However, no statistically significant exposure-response relationship was found (p=0.18). Therefore, the Committee considers it not justified to draw conclusions.

Table 8 summarises the results of the meta-analysis performed by the Committee. More information on the analysis and the data used can be found in the background document.

Table 8. Meta-analysis of the Committee on data on the relationship between magnetic field strength and the risk of childhood lymphomas

Exposure (magnetic field strength in µT)	Risk estimate[a]	95% CI[a]	Number of studies
>0,2	1,91	0,75-4,86	3
0,01-0,2 of 0,1-0,4	1,02	0,63-1,63	4
Reference[b]	1,00		

[a] See the box in § 3.1 for an explanation of risk estimates and confidence intervals.

[b] The reference groups considered in the various studies are not similar.

4.4 Conclusion

Only a limited amount of data is available on the distance to overhead power lines and the incidence of childhood brain tumours. These limited data do not indicate an association.

However, the data on magnetic field strength and the incidence of childhood brain tumours do suggest an association. The meta-analysis performed by the Committee shows that a field strength higher than 0.3 to 0.4 µT is associated with a 1.4 times higher estimated risk (95% CI 0.8-2.7). This means that the indications for an association between exposure to ELF magnetic fields and an increased risk of childhood brain tumours shown in the analysis of Kheifets et al. (2010) have become somewhat stronger. The Committee did not find a statistically significant exposure-response relationship.

The studies focusing on childhood lymphomas included only very limited numbers of patients. Therefore, the Committee considers it not justified to draw conclusions based on these data.

According to the Committee, the strength of evidence for a causal relation between exposure to electromagnetic fields and an increased risk of childhood brain tumours can be best classified as ‘suggestive of a causal relationship’. However, the Committee considers the indications less strong compared to those for childhood leukaemia. According to the Committee, the relationship between exposure to magnetic fields and childhood lymphomas can be classified as ‘inadequate to infer a causal relationship’ due to the limited number of studies performed and the limited number of patients included in these studies.

05
factors other than magnetic fields

Not only ELF magnetic fields but also other factors may be associated with the presence of overhead power lines. It cannot be excluded that one or more of these other factors play a role in the associations found in studies considering distance or magnetic field strength as exposure measure. Neither can it be excluded that some of the associations found are chance findings.

Epidemiological studies have always looked for confounders as a possible explanation for the associations found. There are also various hypotheses about other possible causes. According to the Committee, none of these confounders or hypothetical causes provide a valid scientific explanation for the association observed between living near overhead power lines and the incidence of childhood cancer, though.

5.1 Confounders

There are factors that may be associated with the presence of overhead power lines and leukaemia. These factors may bias the results of studies. For instance, families living near high-voltage power lines may have a lower socioeconomic status compared to families living further away. After all, houses near high-voltage power lines may be cheaper. The 2012 Health Council advisory report on possible causes of childhood leukaemia[8] concluded that there was insufficient epidemiological evidence for a direct association between socioeconomic status and childhood leukaemia.

Traffic density may be a confounder as well. High-power voltage lines are sometimes located alongside busy arterial roads. In these areas, exposure to exhaust fumes can take place. Studies examining the relationship between traffic density and childhood leukaemia do show an association.[69] However, in studies examining overhead power lines, adjustments made for traffic density did not affect the final results.[45,56,58]

5.2 The corona hypothesis

Within a short distance (a few metres) of the wires of a high-voltage power line, the presence of a strong electric field may cause electrical discharges in the air, which are referred to as the corona. These discharges can charge particulate matter. A hypothesis put forward several years ago is that this process enables particulate matter to enter the body more easily and cause health effects.[70] In 2007 and 2011, RIVM concluded that overhead high-voltage power lines do not affect the adverse effects of particulate matter. Charging levels of particulate matter generated by overhead high-voltage power lines are too low to cause these particles to ‘stick’ to the respiratory tract, lungs and skin more than usual.[71,72]

5.3 The contact current hypothesis

Another hypothesis is that the occurrence of contact current may explain the association found between exposure to a magnetic field and childhood leukaemia.[73] This question is particularly relevant in the United States, where grounding of the electricity grid often takes place through the

(metal) water pipes. If a child is sitting in a metal bath, contact with a tap may cause an electric current (a so-called contact current) which may play a role in the development of leukaemia. Several studies have examined this hypothesis.[74] It is shown that contact currents can occur (although these are too weak to be felt). However, a relationship between contact currents and the incidence of leukaemia has not been found.

06 conclusions and advice

Previous Health Council reports concluded that epidemiological research indicates a fairly consistent association between living near overhead power lines and an increased risk of childhood leukaemia.[4-6] Motivated by these reports, the Government recommended applying a precautionary policy regarding overhead high-voltage power lines.

The Committee has now re-analysed all available relevant epidemiological data on childhood leukaemia and other types of childhood cancer. It did so in greater detail and including the most recent studies. The Committee concludes that the recent analyses confirm and consolidate the previous conclusions.

Data on distance have only limited information value

The data on distance to overhead power lines and the incidence of different types of childhood cancer do not show clear associations. However, it should be noted that the amount of data of sufficient quality is limited. The risk of childhood leukaemia seems 1.2 times higher in children living within approximately 50 metres from an overhead power line. However, the results of the studies show considerable heterogeneity. According to the Committee, publication bias cannot be excluded either. Therefore, the Committee does not consider these findings alone to be a strong indication that a shorter residential distance is associated with an increased risk of childhood leukaemia.

Although the analyses do not show a clear indication that the magnitude of the voltage on the line affects the risk estimate, this may be explained by the limited numbers of studies focusing on lines with voltages of 200 kV or higher.

There are hardly any data available on the incidence of other types of cancer. There are only two studies available on brain tumours and distance to high-voltage power lines. These show no indications for an association.

In these analyses, distance to a high-voltage power line is considered a (gross) measure of exposure to magnetic fields. Exposure to the magnetic field increases as the distance to an overhead power line is shorter and the voltage of the line, and the associated current, is higher.

Data on magnetic field strength do show a clear association

The data on the magnetic field strength and the incidence of different types of childhood cancer do show clear associations.

The analyses indicate that long-term exposure to a field strength higher than 0.3 to 0.4 μT is associated with a 1.6 times higher estimated risk of childhood leukaemia. However, the exposure-response relationship was not statistically significant. When considering only the studies assessing the exposure in all residences of a child between birth and diagnosis,

which generate a better representation of long-term exposure, the estimated risk is 2.7 times higher. In these studies, too, the exposure-response relationship was not statistically significant. The heterogeneity of the studies, which could make it more difficult to interpret the findings, is low. According to the Committee, these studies were not likely to be subject to publication bias. Studies pertaining to this subject are generally large-scaled and consequently expensive, and are therefore almost always published.

With regard to the relationship between other types of cancer and magnetic field strength, only data on brain tumours and lymphomas are available. The Committee found an association between long-term exposure to a magnetic field strength higher than 0.3 to 0.4 μT and a 1.4 times higher estimated risk of childhood brain tumours (95% CI 0.8-2.7). However, no statistically significant exposure-response relationship was found.

The studies focusing on childhood lymphomas could only include very limited numbers of patients. Therefore, the Committee considers it not justified to draw conclusions based on these data. Although there are also data on cancer in general available, the Committee does not consider these data specific enough to include in the analysis.

According to the Committee, the results regarding brain tumours and lymphomas may be biased, because studies not finding any associations may not have been published (publication bias). Brain tumours and lymphomas are often secondary outcomes in studies examining the associations between high-voltage power lines and childhood leukaemia. It is possible that only significant secondary outcome results are described.

Suggestions of a causal relationship

According to the Committee, a causal relationship between exposure to ELF magnetic fields and an increased risk of childhood leukaemia and brain tumours has not been proven, although there are indications for such relationship. These indications are stronger for leukaemia compared to those for brain tumours. According to the Committee, the risk of childhood lymphomas should be classified as ‘inadequate to infer a causal relationship’ in accordance with the EPA framework due to the limited number of studies performed and the limited number of patients included in these studies.

According to the Committee, the risk of childhood leukaemia and brain tumours should be classified as ‘suggestive of a causal relationship’ in accordance with the EPA framework, because:

- the meta-analyses performed by the Committee based on the updated research data show an association between exposure to magnetic fields and childhood leukaemia and brain tumours. The association found between exposure to magnetic fields and childhood leukaemia is clearer as the assessment of exposure is more accurate;

- the meta-analyses are based on several observational studies in humans which are of sufficient quality and performed by different research groups;
- the outcomes are consistent with previous findings described in the 2000 Health Council advisory report [4] and several pooled analyses;[17,45,46]
- there are no indications that factors other than the magnetic field can explain the association observed.

According to the Committee, the available evidence is not sufficient to justify the EPA classification 'causal relationship likely', because:

- the evidence only consists of observational research in humans;
- factors other than the magnetic field or chance cannot be excluded;
- there is hardly any additional evidence based on animal experiments or in vitro research;
- there is no insight into a possible underlying mechanism.[14,15]

According to the Committee, the indications for brain tumours are weaker than those for childhood leukaemia. In addition, the Committee considers it possible that the results for brain tumours and lymphomas are biased due to publication bias.

No indications for other factors

Factors which may bias the outcomes of studies examining the relationship between living near high-voltage power lines and the incidence of childhood cancer are low socioeconomic status and traffic density. However, in studies in which adjustments were made for these factors, the outcome was not shown to be affected by these adjustments.

There are also various hypotheses about other possible causes. According to the Committee, none of these hypothetical causes provide a valid scientific explanation for the association observed between living near overhead power lines and the incidence of childhood cancer.

Other as yet unknown factors or chance cannot be excluded.

Extension of precautionary policy

Overall, the current scientific knowledge does not give the Committee reason to recommend the State Secretary for Infrastructure and Water Management to reconsider the current policy regarding overhead power lines. Since there are indications for a causal relationship between exposure to magnetic fields and increased risks of childhood leukaemia and brain tumours, and magnetic fields are not blocked by soil or construction materials, the Committee suggests the State Secretary from a public health perspective to consider extending the precautionary policy to underground power cables and other sources of long-term exposure to magnetic fields from the electricity grid, such as transformer stations and transformer houses.

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