Hornsea Project Four: Preliminary Environmental Information Report (PEIR):

Volume 4, Annex 4.3: Electro-Magnetic Fields (EMF) Compliance Statement

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Glossary

Development Consent Order (DCO)	An order made under the Planning Act 2008 granting development consent for one or more Nationally Significant Infrastructure Projects (NSIP).
Effect	Term used to express the consequence of an impact. The significance of an effect is determined by correlating the magnitude of the impact with the importance, or sensitivity, of the receptor or resource in accordance with defined significance criteria.
High Voltage Alternating Current (HVAC)	High voltage alternating current is the bulk transmission of electricity by alternating current (AC), whereby the flow of electric charge periodically reverses direction.
High Voltage Direct Current (HVDC)	High voltage direct current is the bulk transmission of electricity by direct current (DC), whereby the flow of electric charge is in one direction.
Hornsea Four	The fourth offshore wind farm project within the former Hornsea Zone. Referred to as Hornsea Four throughout the Preliminary Environmental Information Report (PEIR).

Acronyms

Acronym	Definition
ARIMMORA	Advanced Research on Interaction Mechanisms of electro-Magnetic exposures with Organisms for Risk Assessment
CoP	Code of Practice
DCO	Development Consent Order
DECC	*(former) Department of Energy and Climate Change*
EIA	Environmental Impact Assessment
EU	European Union

Acronym	Definition
ELF	Extremely low frequency
EMF	Electric and magnetic fields or electromagnetic field
HPA	(former) Health Protection Agency
HSE	Health and Safety Executive
IARC	International Agency for Research on Cancer
ICNIRP	International Commission on Non-Ionizing Radiation Protection
IEC	International Electrotechnical Commission
NGET	National Grid Electricity Transmission
NPS	National Policy Statement
NRPB	(former) National Radiological Protection Board
NSIP	Nationally Significant Infrastructure Project
PEIR	Preliminary Environmental Information Report
PHE	Public Health England
PINS	Planning Inspectorate
SAGE	Stakeholder Advisory Group on ELF EMFs
SCENIHR	Scientific Committee on Emerging and Newly Identified Health Risks
SoCC	Statement of Community Consultation
SoS	Secretary of State
TCE	The Crown Estate
WHO	World Health Organisation

Units

Unit	Definition
GW or MW or kW	Gigawatt or megawatt or kilowatt (power)
μT or mT or T	Microtesla, millitesla or Tesla (magnetic flux density – 'magnetic field')
A or kA	Ampere or kiloampere (current)
Hz	Hertz (frequency: oscillations per second)
m	Metre (distance)
V or kV	Volt or kilovolt (electrical potential)
$V.m^{-1}$ or $kV.m^{-1}$	Volts or kilovolts per metre (electric field)

1. Introduction

1.1.1.1 Ørsted Hornsea Project Four Ltd (hereafter Hornsea Four) is proposing to develop Hornsea Project Four Offshore Wind Farm (hereafter Hornsea Four). Hornsea Four will be located approximately 65 km offshore of the East Riding of Yorkshire in the Southern North Sea and will be the fourth project to be developed in the former Hornsea Zone. Hornsea Four will include both offshore and onshore infrastructure including an offshore generating station (wind farm), export cables to landfall, and connection to the electricity transmission network.

1.1.1.2 This onshore electricity transmission infrastructure will comprise either, or a combination of, high voltage alternating current (HVAC) or high voltage direct current (HVDC) underground cables (both referred to as 'onshore cables') within the export cable corridor (ECC), an onshore substation (OnSS) and, in the case of HVAC, an offshore HVAC booster station. Finally, there will be a short section of HVAC onshore cables connecting the OnSS to the existing National Grid Electricity Transmission (NGET) substation at Creyke Beck.

1.1.1.3 Full details of the onshore transmission infrastructure and its design envelope are provided in **Volume 1, Chapter 4: Project Description**.

1.2 Aims and Objectives

1.2.1.1 The onshore transmission infrastructure will generate electric and magnetic fields (EMFs) when in operation. HVAC infrastructure will generate EMFs principally at 50 Hz and HVDC infrastructure will generate static fields (0 Hz). The 50 Hz EMFs generated by this type of electricity transmission are often referred to as power frequency or extremely low frequency (ELF) EMFs. ELF EMFs are produced wherever electricity is generated, transmitted or used. Static EMFs are also common, generated by some electrified rail systems for example. Public exposure to ELF EMFs therefore comes from a wide range of sources in the human environment, alongside static electric and magnetic fields from the natural environment.

1.2.1.2 This annex provides an assessment of the static and ELF EMFs that would be generated by the Hornsea Four onshore transmission infrastructure, giving maximum predicted field strengths to assess compliance with health protection guidelines for public exposure to EMFs.

1.2.1.3 This annex does not cover EMFs generated by offshore transmission infrastructure or any assessment of potential impacts to offshore ecology, which is considered in **Volume 2, Chapter 3: Fish and Shellfish Ecology** and **Volume 2, Chapter 4: Marine Mammals**. Occupational exposure to EMFs (e.g. for maintenance workers once the onshore transmission infrastructure is operational) is also not covered. The operator will be subject to the Control of Electromagnetic Fields at Work Regulations 2016 (SI 2016 No. 588 Health and Safety) and to the general duty of care to employees under the Health and Safety at Work Act (1974) and relevant health and safety regulations. It is also expected that the operator will have regard to the guidance from the Health and Safety Executive (HSE) and to the occupational exposure guidelines published by the International Commission on Non-Ionizing Radiation Protection (ICNIRP).

1.3 Consultation

1.3.1.1 An Environmental Impact Assessment (EIA) Scoping Report was submitted to the Planning Inspectorate (PINS) in October 2018, and the Secretary of State has provided a Scoping Opinion dated November 2018 that appends the responses of statutory consultees including local authorities and was subsequently followed by a later consultation response from Public Health England (PHE).

1.3.1.2 PHE's consultation response refers to its standing advice on the health effects of ELF EMFs, to public health protection exposure guidelines and the UK government's policy in that regard, and to the former Department of Energy and Climate Change's (DECC) voluntary Code of Practice that is followed by the electricity industry. These sources of health protection advice and guidelines are discussed in detail in **Section 3** of this annex.

1.4 Approach and structure

1.4.1.1 The approach to this assessment seeks to provide information regarding EMFs, the scientific evidence base and the guideline exposure limits in place to protect health, to address potential public perception of risk in addition to showing compliance with those guidelines. The annex structure is as follows:

- Remainder of this section – an introduction to EMFs;
- **Section 2** – a summary of the health evidence base and view of health protection bodies;
- **Section 3** – the guideline exposure standards set to protect health, with discussion of how these have been adopted in the UK and how they are applied;
- **Section 4** – a conservative assessment of the maximum static and ELF EMFs that could be produced by the proposed development, showing compliance with the guideline public exposure standards; and
- **Section 5** – a conclusion, bringing together the assessment's findings.

1.5 Electric and magnetic fields

1.5.1.1 Electromagnetic fields and the electromagnetic forces they represent are a fundamental part of the physical world. Electromagnetic forces are partly responsible for the cohesion of material substances and they mediate processes of chemistry, including those in human cells. EMFs occur naturally within the human body (through nerve and muscle activity) and also exist in the form of the magnetic field created by the earth and electric fields in the atmosphere.

1.5.1.2 ELF EMFs are part of the electromagnetic spectrum, which also encompasses radio waves, microwaves, infrared, visible light, ultraviolet, x-rays and gamma rays. At higher frequencies, electric and magnetic fields are coupled together and referred to as electromagnetic fields;

as the frequency decreases, the coupling decreases, and at the 50 Hz frequency used for HVAC electricity transmission or for static fields, it is appropriate to think in terms of separate electric and magnetic fields.

1.5.1.3 Unlike ionizing radiation found in the upper part of the electromagnetic spectrum (such as gamma rays emitted by radioactive materials, or x-rays), static and ELF EMFs cannot break the bonds that hold molecules in cells together and therefore cannot directly produce ionisation that could be damaging to cellular material. Therefore, static and ELF EMFs are categorised as 'non-ionising radiation'.

1.5.1.4 EMFs are strongest close to the point at which they are generated (e.g. a current-carrying conductor) and decrease rapidly in strength with distance from the source. As a rule, the strength of radiated energy measured from a given line source is inversely proportional to the square of distance from its source. ELF EMFs strengths and electrical currents throughout this document are given as root mean square figures (RMS, an averaging calculation), due to the sinusoidal nature of current, voltage and EMFs in the context of HVAC transmission, which is the conventional scientific way of expressing these quantities.

1.5.2 Electric fields

1.5.2.1 Electric fields are created in spaces between points at different voltages. Voltage (potential difference) can be described as the pressure behind the flow of electricity, analogous to the pressure of water in a hose. Electric field strengths are typically expressed in kilovolts per metre ($kV.m^{-1}$).

1.5.2.2 The static atmospheric electric field at ground level is normally about 100 volts per metre ($V.m^{-1}$) in fine weather and may rise to many thousands of volts per metre during thunderstorms. Electricity in homes is at a voltage of 230 V but outside homes it is distributed and transmitted at higher voltages, from 400 V up to 400 kV in the UK.

1.5.2.3 Generally, the higher the voltage, the greater the electric field. However, electric fields are readily screened by metals, most building materials and a degree of screening is offered by trees, hedges, and other earthed objects. This means that underground cables do not produce an electric field above ground level due to the grounding of the cable sheath.

1.5.3 Magnetic fields

1.5.3.1 Magnetic fields are produced by current, which is the flow of electricity. Current can be likened to the volume of water flowing in a hose when the nozzle is open. Anything that uses or carries mains electricity is potentially a source of power frequency magnetic fields. Magnetic field strengths are expressed in microteslas (μT).

1.5.3.2 The strength of both static and time-varying magnetic fields from electrical equipment depends on the current carried by it, where generally, the greater the current, the greater the magnetic field. As such, magnetic fields come from a wide range of sources and vary significantly within households, workplaces and the built and natural environment.

1.5.3.3 Typical residential exposure to ELF magnetic fields is in the range of 0.01 μT (microteslas) to 0.2 μT (Energy Networks Association, 2013). Low-voltage distribution circuits, household wiring and electrical appliances are typically the main sources of residential exposure, although in some cases nearby high-voltage transmission can contribute to higher-than-average residential exposure (Maslanyj, et al., 2005). Electrical appliances can sometimes generate significant ELF magnetic fields (shown in **Table 1**), albeit near and with exposure therefore typically of a short duration.

1.5.3.4 The time-varying magnetic field from Alternating Current (AC) mains electricity is separate to the Earth's natural (static) magnetic field, which varies between about 30 μT at the equator and 60 μT in high latitudes, being approximately 50 μT in the UK (British Geological Survey, n.d.).

1.5.3.5 Magnetic field strength *B* (strictly speaking magnetic flux density) can be calculated using the Biot-Savart law, from which the following equation can be derived:

1.5.3.6 $B = \frac{\mu_0 I}{2 \pi r}$Where:
B = Magnetic flux density (T)
μ_0 = Permeability of free space = $4 \times \pi \times 10^{-7}$(H m^{-1})
I = Current through conductor (A)
r = Distance from centre of conductor (m)

Table 1: Example magnetic fields from household appliances.

Appliance	Magnetic field (μT)	Distance (cm)
Hair dryer	6 – 2,000	3
Vacuum cleaner	2 – 20	30
Microwave	4 – 8	30
Dishwasher	0.6 – 3	30
Television	0.01 – 0.15	100

Sources: (World Health Organisation, n.d.) (citing German Federal Office for Radiation Safety).

2. Health Evidence Base

2.1.1.1 Electricity transmission and use is ubiquitous in the developed world, meaning that the entire population of a developed country such as the UK experiences ELF EMFs exposure in daily life. Strong static and ELF EMFs are known to interact with the human body, with detectible physiological effects. For these reasons, extensive scientific research has been undertaken, particularly over the last 40 years, into the potential for static or ELF EMFs exposure to cause adverse health effects. This research has formed the basis for health protection guidelines discussed in **Section 3**.

2.2 HVAC ELF EMFs

2.2.1.1 Scientific knowledge in this field is substantial, being based on many epidemiological, animal and in-vitro studies. Reviews of this evidence base have been undertaken by several national and international health protection bodies over the course of the last two decades, to summarise the findings of published research, form conclusions and give health protection advice (where applicable) based on the weight of evidence.

2.2.1.2 These health protection bodies include: the World Health Organisation (WHO); the International Agency for Research on Cancer (IARC); the International Commission on Non-Ionizing Radiation (ICNIRP); the European Commission's Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR); and in the UK the former National Radiological Protection Board (NRPB), later the Radiation Protection Division of the former Health Protection Agency (HPA), which in 2013 became part of the Centre for Radiation, Chemical and Environmental Hazards in Public Health England (PHE).

2.2.1.3 Possible health outcomes ranging from reproductive defects to cardiovascular and neurodegenerative diseases have been examined but have not been substantiated (McKinlay, et al., 2004a) (McKinlay, et al., 2004b) (ICNIRP, 1998) (ICNIRP, 2010) (SCENIHR, 2009) (SCENIHR, 2013) (SCENIHR, 2015).

2.2.2 Reproductive, Cardiovascular, Neurodegenerative Disease and Genotoxic Effects

2.2.2.1 Initial research examining reproductive defects and exposure to ELF EMFs during pregnancy has focused mainly on the use of electric blankets and electrically heated beds. IARC (2002) concluded in 2002 that there is little evidence to support an association of exposure to ELF EMFs with adverse reproductive outcomes. Reviewing further research since then (mainly cohort studies based on residential proximity to power lines), SCENIHR noted one study that indicated an association between foetal EMFs exposure and later development of asthma, but concluded that recent evidence does not show an effect on reproductive health (SCENIHR, 2015).

2.2.2.2 WHO (2007), ICNIRP (2010) and SCENIHR (2009) have reported some evidence suggesting a possible link between ELF EMFs and certain neurodegenerative diseases but consider the evidence at present inadequate to demonstrate this association and note that no biological mechanism for ELF EMFs exposure (at levels below guideline limits for public exposure) to cause neurodegenerative disease has been established.

2.2.2.3 A literature review article (Consales, et al., 2012) published in 2012 regarding ELF EMFs and neurodegenerative disorders provided a good summary of the emerging evidence, particularly in relation to Alzheimer's disease, Parkinson's disease, Amyotrophic Lateral Sclerosis (ALS) and Huntingdon's disease. The review notes that this is a relatively novel area of research, and that fewer studies have been undertaken (mainly of occupational exposure), compared to studies of EMFs and cancer.

2.2.2.4 The evidence regarding whether ELF EMFs exposure is linked to, and a cause of, neurodegenerative disease is mixed. Epidemiological evidence correlates ELF EMFs exposure with Alzheimer's and ALS disease incidence. However, the evidence did not show a link with Parkinson's disease and Huntingdon's disease. The review notes that the epidemiological evidence in this area is limited by the fact that neurodegenerative diseases are not recorded in registries in the same way as cancers (making disease records less reliable) and that studies have generally not measured exposure but estimated it by occupation (e.g. power sector workers) or from interviews about daily activity.

2.2.2.5 Although possible causal mechanisms for neurodegenerative disease have been put forward, only limited experimentation in animals has been undertaken and the results have not supported these hypotheses. Research for Huntingdon's Disease involving studies on the brains of animals has shown evidence of a neuroprotective effect from EMF exposure.

2.2.2.6 A 2009 study in Switzerland (Huss, et al., 2009) found an association between close residential proximity (<50 m) to high-voltage transmission infrastructure and risk of Alzheimer's disease based on death certificate data; however, a more recent study in Denmark using more robust data (based on Alzheimer's case diagnosis rather than death records) did not find an association (Frei, et al., 2013). A recent occupational exposure study of ALS found an association with ELF magnetic field exposure, identified by proxy using job categories (Koeman, et al., 2017) and a similar cohort study of Danish utility workers, again using job categories to estimate exposure found mixed evidence: higher risks of dementia, motor neurone disease, multiple sclerosis and epilepsy in the highest exposure category but a lower risk (than the general population average) for Parkinson's disease (Pedersen et al, 2017). A 2014 UK study of motor neurone disease, Alzheimer's disease and Parkinson's disease using the CEGB cohort (with relatively detailed estimates of magnetic field exposure) did not find any statistically significant associations (Sorahan & Mohammed, 2014). SCENIHR's most recent opinion is that the evidence since 2009 does not support a conclusion that ELF EMFs exposure increases Alzheimer's disease risk (SCENIHR, 2015).

2.2.2.7 Both IARC and WHO consider the potential for an association between cardiovascular disease and ELF EMFs exposure to be speculative and weak, given the evidence (IARC, 2002) (WHO, 2007). ICNIRP notes that heart muscle cells are less sensitive to direct stimulation than nerve tissue, and its public health protection guidelines are set based on established effects that occur below the threshold at which direct nerve tissue or muscle tissue stimulation is possible. SCENIHR concluded in 2007 that "*An effect of heart rate variability seen in laboratory studies was the basis for a hypothesis that ELF* [EMFs] *exposure might affect the risk of cardiovascular disease and some initial epidemiologic results supported this. However, later well controlled studies have dismissed this hypothesis.*" (SCENIHR, 2007) (page 36) and in its 2009 opinion did not find any sufficient evidence to change that conclusion, stating that an association between cardiovascular disease and ELF EMFs is "*considered unlikely*" (SCENIHR, 2009) (page 43). This conclusion is supported by further heart disease studies from McNamee *et al.* (McNamee, et al., 2010) (McNamee, et al., 2011).

2.2.2.8 ELF EMFs are part of the non-ionising spectrum and as such do not have enough energy to cause direct damage to cell macromolecules leading to genotoxic effects through ionisation. Although there is little evidence of mutation directly caused by ELF magnetic fields, additional research has been recommended by WHO (WHO, 2007).

2.2.3 Cancer

2.2.3.1 Potential for ELF EMFs to cause cancer has been extensively studied. No causal link with cancers, such as adult leukaemia, brain tumours and breast cancer, has been established. Analysis has included studies of electricity workers with occupational exposure to ELF EMFs and adults and children with residential exposure. Pooled analyses (combining the results of multiple studies) and weight-of-evidence reviews have not found consistent epidemiological evidence of an association between ELF EMFs and adult leukaemia, or child or adult brain tumours, or a plausible biological mechanism for causation (IARC, 2002) (WHO, 2007) (Kheifets, et al., 2010) (Sorahan, 2012).

2.2.3.2 A further common concern is the potential for ELF EMFs exposure to indirectly increase breast cancer incidence through affecting melatonin production in the body. Melatonin may offer some protection against breast cancer development. A 2006 review of scientific studies by the former HPA (Health Protection Agency, 2006) concluded that the evidence does not show that exposure to ELF EMFs affects melatonin levels or the risk of breast cancer. WHO goes further in concluding that the evidence is sufficient to give confidence that ELF magnetic fields do not cause breast cancer (WHO, 2007).

2.2.3.3 In 2002 IARC classified ELF magnetic fields as 'possibly carcinogenic to humans' based on a possible link to childhood leukemia at field strengths below the ICNIRP guideline public exposure limits. 'Possibly carcinogenic' is the lowest of three carcinogenicity classifications used by IARC ('carcinogenic', 'probably carcinogenic', and 'possibly carcinogenic'). To put this in context, this category presently has 299 other agents, including Aloe vera.

2.2.3.4 This classification is based on evidence that a correlation has been found between chronic exposure to weak ELF magnetic fields (at around 0.3–0.4 microtesla or greater) and an increased risk of childhood leukaemia. WHO and ICNIRP conclude that the results of pooled analyses (Ahlbom, et al., 2000) (Greenland, et al., 2000) for a number of international studies reduce the possibility that this correlation is due to chance, but do not rule out potential bias or confounding variables. The evidence base for a causal link between ELF EMFs and childhood leukaemia remains inconclusive, as despite extensive research, no plausible mechanism for a weak magnetic field to cause the disease has been established.

2.2.3.5 Additional research in the period since the 2007 WHO review has been carried out to further investigate the possibility of a causal link between ELF EMFs and childhood leukaemia. However, the evidence examined remains inconclusive: some evidence of a possible increase in childhood leukaemia risk at long-term magnetic field exposure, in the order of 0.3–0.4 μT, continues to support the IARC classification of ELF EMFs as a possible carcinogen (e.g. (Kheifets, 2010) (Schüz, 2011) (Sermage-Faure, et al., 2013) (Zhao, et al., 2014)), but again evidence of a causal relationship or a mechanism to explain causation has not been shown. It is probable that this uncertainty will not be fully resolved in the near future, as even large epidemiological studies (of the type already conducted) lack the statistical power to identify weak effects on a small affected population with a high degree of confidence, in particular given study limitations in the area of estimating long-term exposure and linking this to particular ELF EMFs sources.

2.2.3.6 The Advanced Research on Interaction Mechanisms of electromagnetic exposures with Organisms for Risk Assessment' (ARIMMORA) project has further assessed "*the underlying biophysical mechanisms and to clarify a possible causal relationship between ELF MF exposure and cancer, especially childhood leukaemia*" (ARIMMORA Partners, n.d.) (page 2) and has undertaken a risk assessment following the IARC methodology. A mouse model of the most common form of childhood leukaemia developed for the project allowed further investigation of possible causal mechanisms, but further research was called for before definitive conclusions could be drawn (Schüz et al, 2016). The risk assessment concluded that the evidence reviewed was still consistent with the IARC group 2B classification and was *insufficient to impact decisions on safety policy at present*" (ARIMMORA Partners, n.d.) (page 19). The final report called for research to be accelerated and a precautionary approach for ELF magnetic field exposure to continue to be applied (*ibid*).

2.2.3.7 The largest series of studies of childhood cancer and ELF EMFs exposure has been undertaken by the Childhood Cancer Research Group at the University of Oxford, published in 2005, 2010 and 2014. The original study is sometimes referred to as the Draper study after the 2005 publication's lead author. The study in 2005 (Draper, et al., 2005) initially found an association between childhood leukaemia and ELF EMFs exposure, based on residential distance from high-voltage power lines. However, a re-analysis in 2010 (Kroll, et al., 2010) to improve the study to use calculated magnetic field strength (rather than distance as a proxy for exposure) indicated that the initial distance-based finding of risk was implausible as it extended to a distance at which magnetic field strength would be negligible and below typical household background.

2.2.3.8 The study was extended again in 2014 (Bunch, et al., 2014) to add evidence from Scotland and for 132 kV overhead lines and to present trend in risk over time. This showed that the apparent elevated risk is greatest in earlier decades of the time period considered in the study (1962-2008), which suggests that a factor that changes over time (such as population characteristics) is more likely to be the explanation than a physical effect from power lines. A study in Denmark (Pedersen, et al., 2014) designed using a comparable approach, to provide independent verification of these findings, did not find an excess leukaemia risk for children living within 200 m or 600 m of high-voltage power lines. A third comparable study (Kheifets, et al., 2015) to further extend this evidence has been undertaken in California, and found a slight excess of childhood leukaemia cases within 50 m of a transmission line over 200 kV (albeit with a wide confidence interval), but no evidence of increased risk at distances beyond 50 m, for lower-voltage lines, or for cancers of the central nervous system (Crespi, C, et al., 2016).

2.2.3.9 Overall this illustrates the difficulties of reliance on epidemiological evidence for a very small disease risk, and the need to consider the overall weight of evidence including animal and human cell studies.

2.2.3.10 Key questions when considering mixed evidence regarding a possible health risk are whether there is a statistically significant and strong relationship between exposure and health effect; whether there is a dose-response relationship (greater effect with greater exposure); whether different types of evidence are consistent (epidemiological studies, studies in animals, studies in human cells); and whether it is biologically plausible that exposure could create the health effect (Repacholi, 2012) (Bradford Hill, 1965).

2.2.3.11 In the case of EMFs and childhood leukaemia, the statistical evidence of epidemiological studies is mixed; and although taken together does suggest a risk, it does not show a clear dose-response relationship across studies; very extensive studies in animals and human cells have not established a mechanism for low-strength magnetic fields to cause cancer; and the existence of such a mechanism is considered biologically implausible by the health protection bodies cited above.

2.2.3.12 As some evidence suggests that there is a possible increase in risk of childhood leukaemia at long-term exposure to magnetic field strengths in the order of >0.3–0.4 µT, it could be argued that it may be appropriate to apply the precautionary principle and consider further intervention to reduce potential risk. A full discussion of this issue, which is a matter of national policy, is outside the scope of this document. A paper published by Maslanyj *et al.* (Maslanyj, et al., 2010) gives a useful treatment of the position. The authors conclude that although there is "*no clear indication of harm at field levels implicated … the aetiology of childhood leukaemia is poorly understood. Taking a precautionary approach suggests that low-cost intervention to reduce exposure is appropriate. This assumes that if the risk is real, its impact is likely to be small. It also recognises the consequential cost of any major intervention. The recommendation is controversial in that other interpretations of the data are possible, and low-cost intervention may not fully alleviate the risk.*" (page 8). The paper notes that due to uncertainties in the evidence and the fact that they may not be resolved in the near future, "*despite the need for evidence-based policy making, many of the decisions remain value driven and therefore subjective*" (*ibid*).

2.2.3.13 The recommendation of a precautionary stance echoes WHO's 2007 view, which suggested that the use of "*suitable precautionary measures to reduce exposure is reasonable and warranted*" (WHO, 2007) (page 13) in view of uncertainties about the effects of chronic magnetic field exposure, but that due to the weakness of the evidence for a link between exposure to ELF magnetic fields and childhood leukaemia, the benefits of exposure reduction on health are unclear. WHO emphasised that any precautionary measures should not compromise the benefits of electric power and that the costs of any precautionary measures to further reduce exposure would only be justified where they are very low or have no cost. It is also consistent with the ARIMMORA risk assessment recommendations for "*prudent avoidance*" between power lines and schools or nurseries (Bounds, 2015) (section 6).

2.2.3.14 The view of ICNIRP, expressed in the most recent guidelines for public exposure to low frequency time-varying fields, is that "*the currently existing evidence that prolonged exposure to low frequency magnetic fields is causally related with an increased risk of childhood leukaemia is too weak to form the basis of exposure guidelines*" (ICNIRP, 2010) (page 2).

2.2.3.15 The process that has been followed at a national level, to review the health evidence base and international guidance, consider with public and expert stakeholders whether additional precautionary measures are warranted, and set public health protection guidelines into policy, is summarised in **Section 3**.

2.3 HVDC Static EMFs

2.3.1.1 The potential health impacts of Direct Current (DC) EMF have received less research attention than AC, due to the lower perceived potential for health risk given the more limited physical interaction of static fields with the body. Research has focused primarily upon acute exposure to relatively high-strength static magnetic fields in the order of several tesla (T), especially since the advent of magnetic resonance imaging (MRI) as a medical technique, in which magnetic field strengths of up to 9.4 T are used (WHO, 2006). Other exposures studied include workers experiencing strong static magnetic fields from welding, and exposure from DC rail transport systems.

2.3.1.2 WHO (*ibid*) notes that local exposure to strong static electric fields can occur from activities such as walking on carpet (up to 500 kV m^{-1}) and from cathode ray tube (CRT) screens (up to 20 kV m^{-1}), and states that although no long-term studies have been conducted from which chronic or delayed effects of exposure can be determined, the few studies of acute effects suggest that the only adverse acute health effects are associated with direct perception of fields and discomfort from micro-shocks. Accordingly, and as the HVDC cables will not generate an external electric field, health effects of static electric field exposure are not discussed further.

2.3.1.3 WHO and ICNIRP (ICNIRP, 2009) summarise research conducted into the biological effect of static magnetic fields. Biological interaction with a static magnetic field is primarily through movement within it, for instance of the whole body (leading to induced electric fields or currents, similar to the effect of an AC magnetic field) or of blood within the body. Mechanical effects (in which a static magnetic field can exert a torque force upon paramagnetic materials) and effects upon certain metabolic reactions through electron spin interactions may also occur.

2.3.1.4 Exposure to static magnetic fields of greater than 0.1 T has been shown to induce minor changes in blood flow around the heart and in other major blood vessels; however, no significant health impacts resulting from this have been found for exposures up to 8 T (*ibid*). WHO notes that it is possible that there is increased risk to people who are susceptible to specific heart conditions (e.g. re-entrant arrhythmia).

2.3.1.5 Laboratory studies of humans have shown that movement within static magnetic fields of greater than approximately 2-3 T can cause a range of transient sensory effects, including a metallic taste, nausea/vertigo, and phosphenes (sensation of seeing non-existent small flashes of light). Sensitivity varies by individual, and no significant health impacts due to exposure in fields up to 8 T have been shown (*ibid*).

2.3.1.6 Little or no epidemiological research has been conducted into long-term health impacts of exposure to static magnetic fields in the order of tens of μT (typical of HVDC underground cables or overhead powerlines) due to the low perceived potential for health impacts, based upon the known interaction mechanisms and evidence of low impact from acute exposure to field strengths two orders of magnitude greater.

2.3.1.7 Epidemiological studies have been conducted into the long-term health of certain worker groups, notably MRI operators, welders and those working at aluminium smelters, where exposure can be in the tens of mT range. The methodological quality of studies and data available is limited, but no strong influence upon the health outcomes studied (including cancer incidence and reproductive health) has been found (*ibid*). WHO states that the evidence from clinical and laboratory studies is insufficient to draw firm conclusions with regard to potential long-term effects. The carcinogenicity of static magnetic fields is regarded as not classifiable by IARC due to inadequate evidence (IARC, 2002).

3. Public Exposure Guidelines

3.1 Development of guidelines

3.1.1.1 Health protection guidelines for public and occupational exposure to static and ELF EMFs have been published by ICNIRP in 1994, 1998, 2009 and 2010. These guidelines have been reviewed and used in a number of sources of recommendations and advice on exposure to EMFs, including European Commission (EC) Recommendation 1999/519/EC (European Council, 1999) for the adoption of ICNIRP's 1994 and 1998 guidelines by member states of the European Union (EU). A further EU Directive (2013/35/EU) (European Parliament and Council, 2013) relates specifically to the health and safety of workers in environments affected by EMFs and has been transposed into UK legislation as the Control of Electromagnetic Fields at Work Regulations 2016 (SI 2016 No. 588 Health and Safety).

3.1.1.2 In the UK, the former Health Protection Agency's (HPA's) Radiation Protection Division[1] recommended that the UK adopts the 1998 ICNIRP guidelines, and the government responded by adopting the guidelines under the terms of the EC Recommendation. This recommendation is based on advice on limiting exposure to EMFs published by NRPB in 2004, following a review of the relevant scientific data (McKinlay, et al., 2004a) (McKinlay, et al., 2004b).

1 The Radiation Protection Division was formed in 2005 from the former NRPB, which was the independent statutory body established to give advice on EMFs, including advice on safe levels of occupational and public EMFs exposure. In 2013 it became part of the Centre for Radiation, Chemical and Environmental Hazards in PHE.

3.1.1.3 In 2004, following the NRPB's review of the scientific evidence, a Stakeholder Advisory Group on ELF EMFs (SAGE) was set up to consider whether any further precautionary measures, in addition to use of the ICNIRP guidelines, were warranted. SAGE was funded by the UK Government, electricity industry and a leukemia charity and explicitly sought views from a wide range of stakeholders in an inclusive process. In 2007, SAGE's first interim assessment (SAGE, 2007) made a series of recommendations for precautionary measures to further reduce public ELF EMFs exposure from high-voltage electricity transmission. These included optimal phasing for overhead power lines and implementing 'no-build corridors' around power lines.

3.1.1.4 The UK Government's response, published in 2009 (Department of Health; Department for Communities and Local Government; Department of Energy and Climate Change, 2009), adopted the recommendation for optimal phasing for overhead lines but did not consider that no-build corridors were a proportionate precautionary measure, given the evidence base. This was based on the views of its scientific advisors and is in line with the WHO's 2007 recommendation that precautionary measures are only warranted where they are very low-cost or have no cost. SAGE has subsequently made further recommendations regarding household wiring and appliances.

3.1.1.5 Building on the outcomes of the SAGE process, in 2011 DECC published a voluntary code of practice (CoP) detailing the recommended approach for demonstrating compliance with adopted ELF EMFs exposure guidelines, subsequently updated in March 2012 (DECC, 2012a). The CoP "*has been developed following publication of the Government response to the Stakeholder Advisory Group on extremely low frequency electric and magnetic fields (ELF EMFs) (SAGE) First Interim Assessment…* [and] *agreed by the Department of Energy and Climate Change with the Department of Health, the Energy Networks Association, the Welsh Assembly, the Scottish Executive, the Northern Ireland Executive and the Health and Safety Executive*" (page 2). It implements the 1998 ICNIRP guidance for AC fields under the terms of the 1999 EC Recommendation, in the UK context.

3.1.1.6 The CoP is used to show compliance with guideline public exposure limits for Nationally Significant Infrastructure Projects (NSIPs) in England and Wales.

3.2 National Policy Statement EN-5

3.2.1.1 Guidance on the issues to be assessed for offshore renewable energy developments has been obtained through reference to the Overarching National Policy Statement (NPS) for Energy (EN-1) (DECC, 2011a), the NPS for Renewable Energy Infrastructure (EN-3) (DECC, 2011b) and the NPS for Electricity Networks Infrastructure (EN-5) (DECC, 2011c). NPS EN-1 and NPS EN-3 refer to NPS EN-5 as the primary guidance document in relation to onshore grid connection infrastructure.

3.2.1.2 NPS EN-5 Section 2.10 reviews the sources of advice, guidelines and recommendations on EMF. At paragraph 2.10.5 it states that "*Government policy is that exposure of the public should comply with the ICNIRP (1998) guidelines in terms of the EU Recommendation. The* *electricity industry has agreed to follow this policy. Applications should show evidence of this compliance as specified in 2.10.9 below*".

3.3 Code of Practice

3.3.1.1 The CoP states that the public exposure limit guideline values are for uniform, unperturbed fields near ground level, such as would be experienced from an overhead line. Although higher (less stringent) levels could be established on a case-by-case basis, the CoP states that the guideline levels would never be lower. As such, the guideline levels specified in the CoP are used as a conservative basis for the assessment in this annex. The CoP specifies on page five that compliance of overhead lines and underground cables at voltages of >132 kV should be shown by "*a calculation or measurement of the maximum fields (i.e. directly under the line, or directly above the cable)*". However, for all substations and for overhead lines or underground cables at ≤132 kV, the CoP states that compliance with the public exposure guidelines is assumed, based on evidence published by the Energy Networks Association for types of infrastructure that by design are not capable of causing exceedance of the public exposure guideline limits.

3.3.1.2 The CoP specifies that, given the terms of the 1999 EC Recommendation, assessment of EMF exposure against the general public exposure guidelines is only required in general for residential exposure or certain other cases of long-term exposure of potentially vulnerable groups (e.g. schools). The CoP states that "*In other environments, where exposure can be deemed not to be for a significant period of time, the ICNIRP occupational guidelines, rather that the ICNIRP general public guidelines, shall be deemed to apply*" (page 4).

3.3.2 Guidelines used in this assessment

3.3.2.1 Public exposure to EMFs from the Hornsea Four onshore transmission infrastructure will be both transient (e.g. on public footpaths) and residential. To be conservative, EMFs exposure from the Hornsea Four onshore transmission infrastructure has therefore been assessed against the general public (as opposed to occupational) exposure guideline, in **Section 4**.

3.3.2.2 **Table 2** summarises the relevant AC (time-varying) and DC (static) field exposure guidelines. For AC fields, the 'basic restriction' level to protect health is for induced current in the central nervous system. The reference level for external fields indicates a threshold beyond which the potential for induced current to exceed the 'basic restriction' should be investigated. Reference levels have been published by ICNIRP and by the former HPA. They relate to the same 'basic restriction' published by ICNIRP in 1998. The reference levels given in the CoP are those specified by the former HPA, on the basis of modelling undertaken by Dimbylow (Dimbylow, 2005). For DC fields, although the ICNIRP guideline level for magnetic field exposure is 40 mT (1994) or 400 mT (2009), ICNIRP discusses the need for "*practical policies… to prevent inadvertent harmful exposure of people with implanted electronic medical devices and implants containing ferromagnetic materials, and injuries due to flying ferromagnetic objects*" (ICNIRP, 2009) (page 511) and in that context makes reference to a lower restriction level of 0.5 mT suggested by the International Electrotechnical Commission (IEC) in 2002 (IEC, 2002).

Table 2: Static and ELF EMFs exposure guidelines adopted in the UK.

Description		Occupational	Public
AC fields – 1998 ICNIRP guidelines, as adopted in the UK under the 1999 EC Recommendation and in the CoP			
'Basic restriction' (the quantity that must not be exceeded)	Induced current density in the central nervous system	10 mA m^{-2}	2 mA m^{-2}
ICNIRP reference level (not a limit in itself but a guideline for when 'basic restriction' investigation may be required)	Magnetic field	500 μT	100 μT
	Electric field	10 kV m^{-1}	5 kV m^{-1}
CoP reference level (not a limit in itself but a guideline for when 'basic restriction' investigation may be required)	Magnetic field	1,800 μT	360 μT
	Electric field	46 kV m^{-1}	9 kV m^{-1}
DC magnetic fields – 1994 ICNIRP guidelines, as adopted in the UK under the 1999 EC Recommendation			
'Basic restriction' (the quantity that must not be exceeded).	Magnetic field. 'Ceiling value' (occupational) and continuous exposure (public).	2 T	40 mT
ICNIRP / IEC indirect effects protective value.	Magnetic field. Indirect effects (movement of ferromagnetic objects and implants, including pacemakers).	n/a	0.5 mT

Sources: (ICNIRP, 1998) (DECC, 2012a) (ICNIRP, 1994) (IEC, 2002) (European Council, 1999)

3.3.2.3 Although ICNIRP published updated guidance for 50 Hz magnetic fields in 2010 (ICNIRP, 2010) that gives a less stringent 200 μT reference level for general public magnetic field exposure, due to changes in the basis of the basic restriction, and updated guidance giving a less stringent 400 mT level for static magnetic fields (ICNIRP, 2009), the 1999 EC recommendation for use of the more stringent 1998 and 1994 ICNIRP guidance, respectively, remains the basis of UK guidance and the CoP.

3.3.2.4 A second Code of Practice (DECC, 2012b), likewise arising from the SAGE recommendations, concerns implementing 'optimum phasing' of dual-circuit overhead lines where feasible. Transposing the order of phases can reduce the maximum field strength due to greater cancellation in the fields between the phases of each circuit. However, this Code of Practice is applicable specifically for dual-circuit overhead power lines and is not applicable to the proposed development, where underground cables are closely grouped together in a trench and may be bundled in a trefoil formation.

4. EMFs from Hornsea Four

4.1.1.1 As summarised in the introduction, the proposed transmission infrastructure development will comprise either HVAC or HVDC underground cables (both referred to as 'onshore cables), an OnSS and, in the case of the HVAC option, an offshore HVAC booster station. Finally, there will be a short section of ECC connecting the OnSS to the existing NGET substation at Creyke Beck.

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4.1.1.2 Full details of the onshore transmission infrastructure and its design envelope are provided in **Volume 1, Chapter 4: Project Description**.

4.1.1.3 As discussed in **Section 3**, the CoP states that compliance with the public exposure guidelines set to protect health is assumed for all substations at their publicly accessible perimeter and for underground cables operated at 132 kV or less, without the need for more detailed assessment, on the basis of evidence published by the Energy Networks Association (ENA) showing that by design such infrastructure is not capable of causing exceedance of the public exposure guideline limits. For other infrastructure, a calculation or measurement of the maximum field strength is required, under the calculation or measurement conditions specified in the CoP.

4.1.1.4 The Hornsea Four onshore transmission infrastructure is expected to operate above the 132 kV CoP threshold for assessment, so a calculation of field strengths has been undertaken. Although the CoP is for HVAC infrastructure, in this case the same requirement has been taken as applying to HVDC infrastructure, to ensure both elements of the onshore transmission infrastructure have been assessed.

4.1.1.5 Each HVAC circuit would comprise three conductors and each HVDC circuit would typically comprise two conductors (with the potential for an additional neutral return conductor). The number of circuits required depends on the total power that must be transmitted and the transmission voltage that is used. **Volume 1, Chapter 4: Project Description** defines a design envelope of Hornsea Four, indicating that up to six onshore HVAC or three HVDC circuits may be required.

4.1.1.6 For the purpose of assessing magnetic field exposure, the worst-case scenario is where the onshore underground cables carry the highest current, which would occur at the lowest voltage for a given amount of power transmitted by each circuit. From the project design envelope, scenarios of six HVAC circuits at 220 kV with current of 1.62 kA or three HVDC circuits at 300 kV with current of 2.59 kA have been selected as worst-case for the assessment.

4.1.1.7 Underground cables do not produce an external electric field at ground level due to the shielding of the cable sheath and burial material.

4.1.1.8 **Volume 1, Chapter 4: Project Description** shows that the HVAC conductors may be laid in the cable trenches in either a flat or bundled trefoil formation, and both options have been assessed. The HVDC conductors would be laid flat. Although the maximum burial depth is 2 m below ground level to the top of the conductors, the target burial depth will generally be 1.2 m and in some sections may be 0.7 m (in particular circumstances where 1.2 is not feasible). The minimum burial depth would be worst-case for maximum magnetic field exposure (due to the source being closer to receptors above ground) and 0.7 m depth has therefore been used in the assessment.

4.1.1.9 Where relevant, the physical arrangement of phases in each circuit has been assessed in the configuration that would generate the maximum field strength. The calculation results given below have therefore been made on a conservative basis.

4.1.1.10 The onshore electricity transmission infrastructure would not be energised during construction or decommissioning (no electricity transmitted) and therefore there would be no electric or magnetic field generated at those times.

4.1.2 Onshore HVDC converter/HVAC substation

4.1.2.1 Due to the distance between substation components and the closest publicly-accessible point (the outer wall or perimeter fence), the greatest EMFs exposure in the vicinity of substations is typically from the overhead lines or underground cables entering and exiting them (National Grid, n.d.) (Danby, 2011).

4.1.2.2 The magnetic field strength from the HVAC or HVDC onshore cables connecting to the OnSS and Creyke Beck NGET substation have been assessed in the sections below. The OnSS and Creyke Beck NGET substation perimeter fences and/or building walls (where relevant) will provide screening of the electric field and this would not be expected to exceed the general public exposure guideline.

4.1.3 HVAC underground cables

4.1.3.1 The maximum calculated magnetic field strength for each HVAC ECC design option is shown in **Table 3**, with the greatest value being 55 μT, well below (15% of) the CoP 360 μT public exposure guideline limit set to protect health.

4.1.3.2 All calculations are shown at 1 m above ground as specified in the CoP, and distances are given perpendicular to the centreline of the cable trenches. As illustrated in **Figure 1**, the magnetic field strength drops rapidly with distance from the source and the maximum strength is typically above the mid-point of the circuits or above one circuit, depending on the phasing and cancellation effects between them (for which the results of the worst-case arrangement in each case are shown).

Table 3: Magnetic field strength from HVAC underground cables.

CoP reference level: 360 μT				
Design		**Trefoil**	**Flat**	
Maximum (μT) †		23.30	55.20	
Distance (m)		17.50	27.50	
Percentage of reference level		6.5%	15.3%	
Distance (m) ‡	**μT**	**% of reference level**	**μT**	**% of reference level**
0	1.74	0.5%	5.62	1.6%
5	8.27	2.3%	18.96	5.3%
10	7.49	2.1%	18.92	5.3%
20	7.54	2.1%	19.77	5.5%
30	8.25	2.3%	18.05	5.0%
40	0.41	0.1%	0.68	0.2%
50	0.10	<0.1%	0.17	<0.1%

† Maximum above the cables. This may be above a conductor rather than 0 m lateral distance from the centreline.
‡ With the exceptions noted above, distances are given perpendicular to the centre point between the six circuits.
Calculated field strengths are unperturbed and at 1 m above ground level.

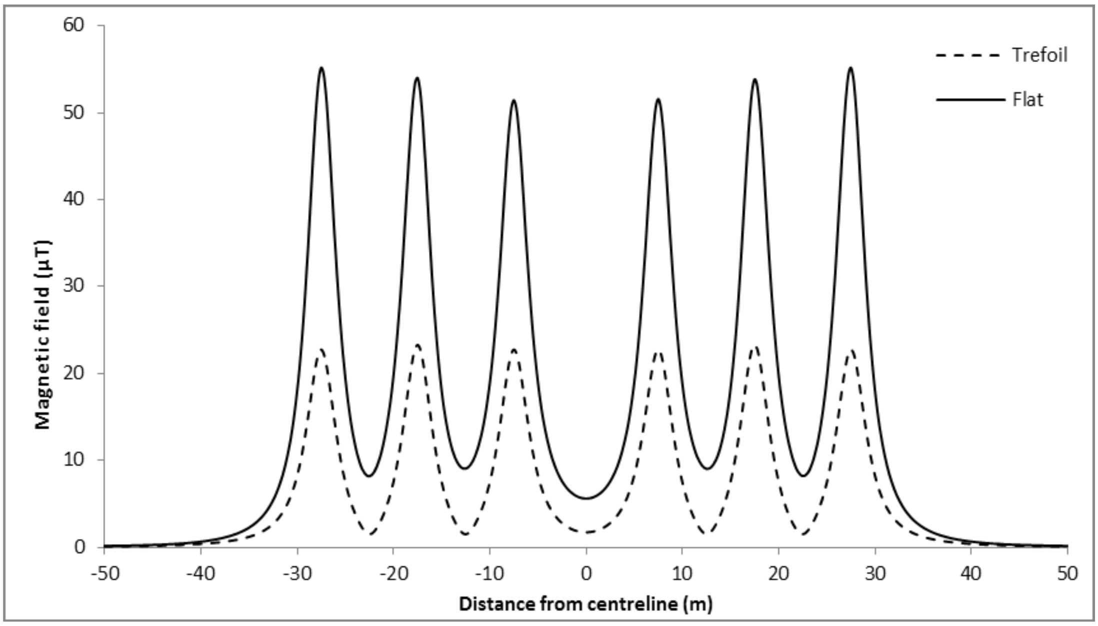

Figure 1: Magnetic field strength from HVAC underground cables.

4.1.4 HVDC underground cables

4.1.4.1 The maximum calculated magnetic field strength for each HVDC ECC design option is shown in **Table 4**, with the greatest value being 27 μT, well below (5% of) the 500 μT guideline recommended by ICNIRP and IEC, and greatly below the 40,000 μT ICNIRP public exposure guideline limit set to protect health.

4.1.4.2 All calculations are shown at 1 m above ground as specified in the CoP, and distances are given perpendicular to the centreline of the cable trenches. As illustrated in **Figure 2**, the magnetic field strength drops rapidly with distance from the source and the maximum strength is typically above the mid-point of the circuits or above one circuit, depending on the relative positions of the positive and negative conductors in each circuit (for which results of the worst-case arrangement in each case are shown).

Table 4: Magnetic field strength from HVDC underground cables

ICNIRP / IEC guideline level: 500 μT		
Maximum (μT) †	27.13	
Distance (m)	6.25	
Percentage of reference level	5.4%	
Distance (m) ‡	**μT**	**% of reference level**
0	7.28	1.5%
5	17.43	4.1%
10	20.33	3.6%
20	18.24	0.2%
30	1.09	0.1%
40	0.11	<0.1%
50	<0.1	<0.1%

† Maximum above the cables. This may be above a conductor rather than 0 m lateral distance from the centreline.

‡ With the exceptions noted above, distances are given perpendicular to the centre point between the two circuits. Calculated field strengths are unperturbed and at 1 m above ground level.

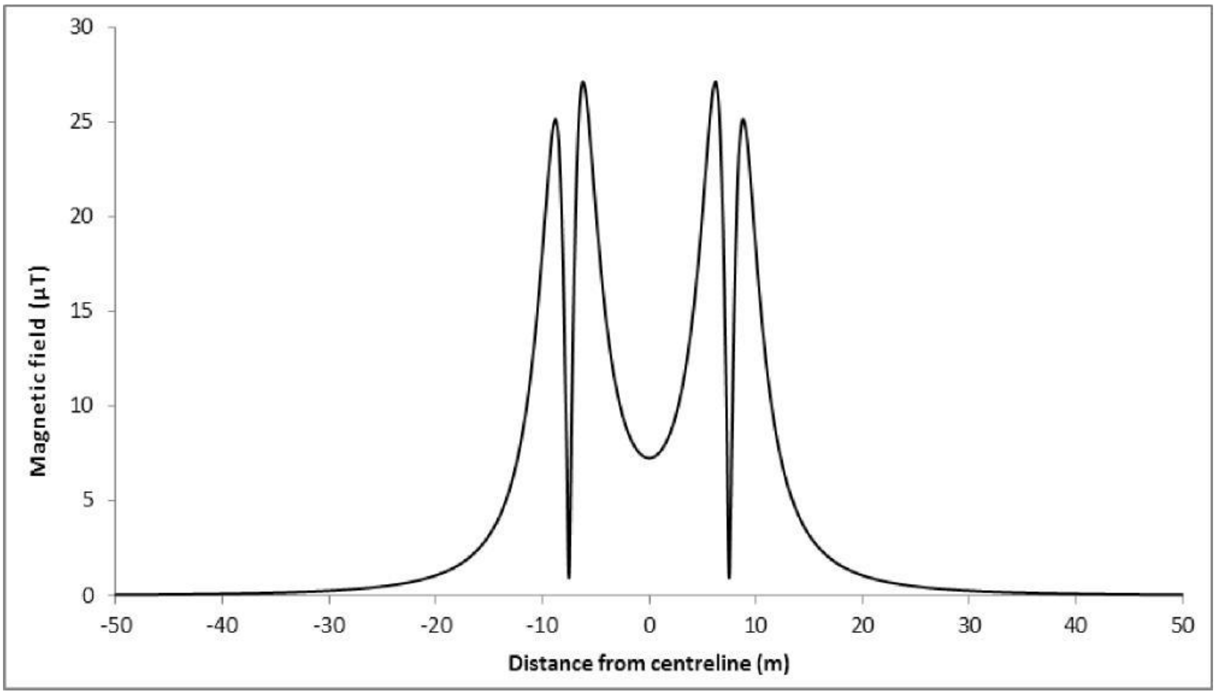

Figure 2: Magnetic field strength from HVDC underground cables.

5. Cumulative EMFs from Hornsea Four and Other Developments

5.1.1.1 Magnetic field strength decreases rapidly with distance from the source, as has been illustrated in **Figure 1** and **Figure 2**. In addition, the vector nature of electric and magnetic fields means that the combined field strength from multiple sources would not typically be as great as the scalar sum of their maximum strength. In practice, this means that magnetic field strength at a given location tends to be dominated by one source (the largest and/or nearest) where several sources in the area are present. As such and considering the large margin of compliance with the public exposure guidelines, no significant cumulative impacts from other existing or proposed sources are anticipated.

6. Summary and Conclusions

6.1.1.1 Hornsea Four will require construction and operation of onshore electricity transmission infrastructure to provide a connection for exporting electricity generated by the wind farm to the national electricity grid. The onshore transmission infrastructure will comprise either high voltage alternating current (HVAC) or high voltage direct current (HVDC) underground cables, and an OnSS. Finally, there will be a short section of HVAC ECC connecting the onshore substation to the existing Creyke Beck NGET substation. These electricity transmission infrastructure components will generate static and power-frequency electric and magnetic fields (EMFs).

6.1.1.2 EMFs are part of the natural world, and are also produced wherever electricity is generated, transmitted or used. Public exposure to power-frequency EMFs comes from a range of sources including household wiring and appliances, low-voltage distribution power lines or underground cables, and high-voltage transmission power lines or underground cables. Exposure to static EMFs comes from the earth's natural magnetic field, atmospheric electrical field, and human sources such as appliances and electric rail lines.

6.1.1.3 Magnetic field strengths are usually measures in microteslas (μT) or milliteslas (mT) and electric field strengths in volts per meter ($V.m^{-1}$) or kilovolts per meter ($kV.m^{-1}$).

6.1.1.4 Typical residential exposure to power-frequency magnetic fields is in the range of 0.01 μT to 0.2 μT. Low-voltage distribution circuits, household wiring and electrical appliances are typically the main sources of residential exposure. Household appliances can sometimes generate higher magnetic fields, albeit typically for a short duration while in use. Examples of magnetic field strengths from household appliances in operation are 6 to 2,000 μT at 3 cm distance from a hairdryer in use, or 2 to 20 μT at 30 cm from a vacuum cleaner or microwave.

6.1.1.5 The Earth's natural (static) magnetic field varies between about 30 μT at the equator and 60 μT in high latitudes, and is approximately 50 μT in the UK. The earth's static atmospheric electric field at ground level is normally about 100 $V.m^{-1}$ in fine weather and may rise to many thousands of volts per metre during thunderstorms.

6.1.1.6 It is possible for strong static and power-frequency EMFs to have a detectible physiological effect on the body. Very extensive scientific research has been undertaken to investigate whether there is potential for adverse health effects from EMFs exposure. International and national health protection bodies have reviewed this data using a weight of evidence approach and have recommended conservative guidelines for public EMFs exposure, set to protect health.

6.1.1.7 Guidelines have been published by the International Commission on Non-Ionizing Radiation Protection (ICNIRP). They form the basis of an EC Recommendation and have been adopted in the UK, on the basis of advice from the government's scientific health advisors, in the form of a Code of Practice agreed with the electricity industry. This specifies reference levels that should not be exceeded in order to ensure public health protection. The Code of Practice is referenced in the National Policy Statement for Electricity Networks Infrastructure, which states that the Planning Inspectorate "*should satisfy itself that the proposal is in accordance with the guidelines, considering the evidence provided by the applicant and any other relevant evidence.*"

6.1.1.8 The public health protection guideline reference level specified in the Code of Practice for power-frequency magnetic field exposure is 360 μT and for electric field exposure it is 9 $kV.m^{-1}$. For static magnetic fields, the guideline recommended by ICNIRP is 40 mT for general public exposure and 0.5 mT (500 μT) to protect those with implanted medical devices. There is no specific guideline exposure limit for static electric fields. These guidelines are for long-term or continuous public exposure.

6.1.1.9 Maximum magnetic field strengths have been calculated for the proposed underground cable designs, using worst-case assumptions where required, in accordance with the approach specified in the Code of Practice.

6.1.1.10 The maximum calculated power-frequency magnetic field from the HVAC underground cables is 55 μT, well below (15% of) the Code of Practice 360 μT public exposure guideline limit set to protect health. The maximum calculated static magnetic field from the HVDC underground cables is 27 μT, well below (5% of) the 500 μT ICNIRP guideline exposure level.

6.1.1.11 Field strengths drop rapidly with distance from the source, and the field strength to the sides of the cable route away from the conductors would be lower than these maxima for both HVAC and HVDC. This is illustrated in plots of field strength by distance shown in **Figure 1** and **Figure 2**.

6.1.1.12 Underground cables do not produce an external electric field at ground level due to the shielding of the cable sheath and burial material.

6.1.1.13 The onshore electricity transmission infrastructure would not be energised during construction or decommissioning (no electricity transmitted) and therefore there would be no electric or magnetic field generated at those times.

6.1.1.14 Due to the distance between substation components and the closest publicly-accessible point (the outer wall or perimeter fence), the greatest EMFs exposure in the vicinity of substations is typically from the overhead lines or underground cables entering and exiting them. Magnetic fields associated with underground cables have been discussed above. The OnSS and Creyke Beck NGET substation perimeter fences and/or building walls (where relevant) will provide screening of the electric field and this would not be expected to exceed the general public exposure guideline.

6.1.1.15 In conclusion, on the basis of the guidance for EMFs from electricity infrastructure adopted in the UK and the published evidence to support that, it is considered that the levels of EMFs from the proposed development would be well below the guideline public exposure reference levels set to protect health.

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