Sheringham Shoal and Dudgeon Offshore Wind Farm Extension Projects

Appendix 28.1 - Sheringham and Dudgeon Extension Projects EMF Assessment

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Sheringham Shoal and Dudgeon Offshore Wind Farm Extension Projects EMF assessment

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Executive Summary

The Dudgeon Offshore Wind Farm Extension Project (DEP) and Sheringham Shoal Offshore Wind Farm Extension Project (SEP) will involve installing offshore and onshore export cable circuits using high voltage alternating current (HVAC) technology. Both projects are extensions to the existing Dudgeon and Sheringham Shoal offshore wind farms and will connect onshore at National Grid's existing Norwich Main substation and are electrically independent of both the existing projects. The onshore connections are approximately 60 km and cross the county of Norfolk. SEP and DEP projects are at a concept development stage, with a number of electrical system designs being considered. The current electrical system designs being considered are:

- Option -1: DEP and SEP extension projects developed together, with equally rated export cable circuits
- Option -2: SEP and DEP developed together with unequal export cable circuits
- Option -3: SEP and DEP developed as standalone projects each with its own offshore substation

The impact of each of these options was considered separately. The projects will also cross a number of third-party electrical assets, onshore and offshore.

The purpose of this report is to provide an assessment of the electric and magnetic fields (EMFs) produced by each proposed option and review the compliance of the DEP and SEP against the UK guidelines and policies. The potential impact of the project on compasses, pipeline corrosion and marine life were also considered, as well as the cumulative impact of third-party crossing points.

<u>Offshore</u>

The maximum magnetic fields produced by the worst-case design option was 26.5 µT at the seabed, reducing to 1 µT at 4.4 m vertically above the cables. The magnetic fields reduce quickly with horizontal distance also, where under that same conditions, the magnetic fields on the seabed had reduced to 1 µT, 5.4 m from the cable circuits. The impacts of crossing third-party electrical assets were modest, the maximum combined magnetic field was 34.4 µT at the seabed in worst case conditions.

There are no formal limits for EMF exposure which apply to the marine environment. The SEP and DEP offshore export circuits mitigate the impacts of EMF on marine life by burial techniques which reduce the fields, and the projects use armoured cables for mechanical protection, which additionally act to reduce the EMFs produced. The use of single 3-core cables, compacting the circuit phases also reduces and localises the EMFs significantly.

The mitigation techniques employed by the project should be sufficient to reduce the impacts of EMF on marine life, although more in-depth analysis may be required to quantify specific impacts to certain species.

<u>Onshore</u>

The UK Government, acting on the advice of authoritative scientific bodies, has put in place appropriate measures to protect the public from EMFs. These measures comprise compliance with the relevant exposure limits, and one additional precautionary measure, optimum phasing, applying only to high-voltage overhead power lines. These measures are set out in a Written Ministerial Statement, National Policy statement (NPS) EN-5, and various Codes of Practice.

Calculations demonstrate the maximum magnetic fields from any of the options considered were 9 % of the current exposure limits set to protect members of the public against EMF exposure. The highest magnetic fields would occur where the onshore circuits cross the proposed Hornsea Project Three circuits. The Hornsea Project Three circuits dominate the magnetic fields in the area, but the cumulative impact of the crossing was 18 % of the public exposure limits.

All of the proposed technology options for the SEP and DEP export cables and third-party crossing points would be fully compliant with the Government policy. Specifically, all the fields produced would be below the relevant exposure limits. Therefore, there would be no significant EMF effects resulting from this proposed development.

If it is desirable to reduce the magnetic fields further, consideration of the phase arrangements for each circuit should be made.

Contents

Abbreviations

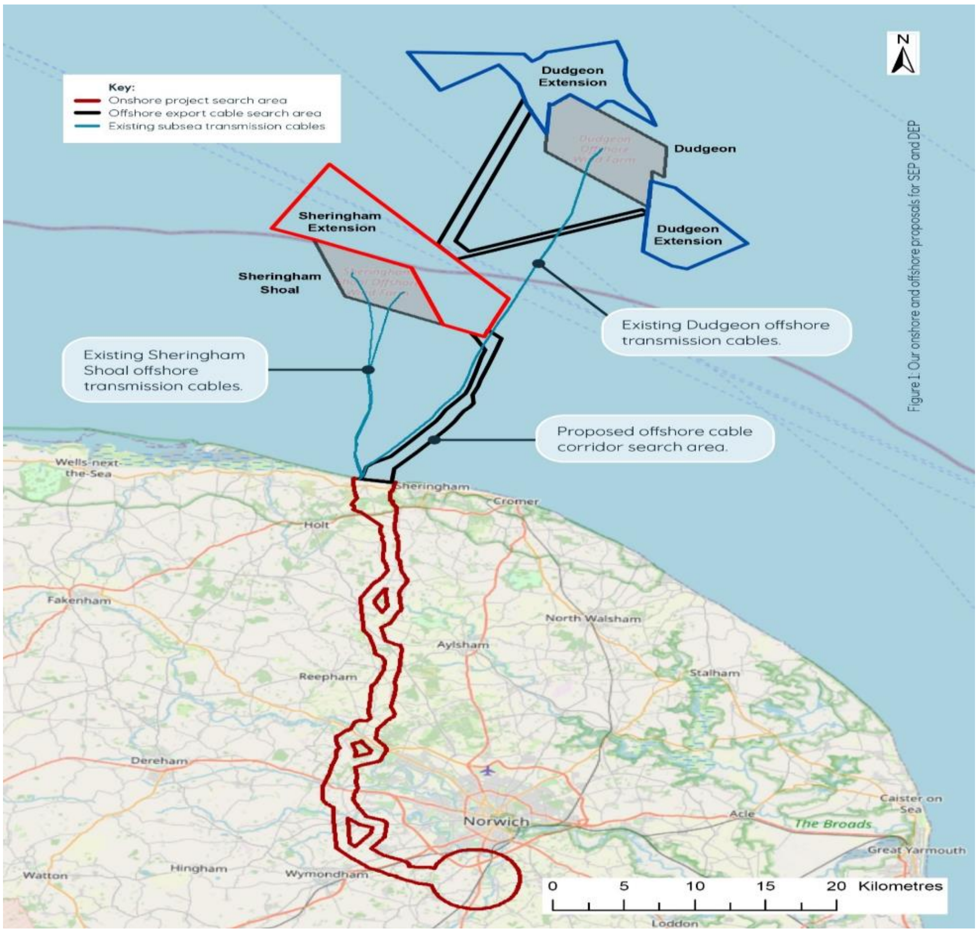
AC	Alternating Current
DC	Direct Current
DEP	Dudgeon Offshore Wind Farm Extension Project
EIA	Environmental Impact Assessment
ELF	Extremely Low Frequency
EMF	Electric and Magnetic Field
Hz	Hertz
HDD	Horizontal Directional Drilling
HPA	Health Protection Agency
HVAC	High Voltage Direct Current
HVDC	High Voltage Alternating Current
IARC	International Agency for Research on Cancer
ICNIRP	International Commission on Non-Ionising Radiation Protection
IPC	Infrastructure Planning Committee
kV/m	KiloVolt per meter
NPS	National Policy Statement
NRPB	National Radiological Protection Board
OSS	Offshore Substation
ONS	Onshore Substation
PHE	Public Health England
SCENIHR	Scientific Committee on Emerging and Newly Identified Health Risks
SEP	Sheringham Shoal Offshore Wind Farm Extension Project
WHO	World Health Organisation
μT	Microtesla

1. Introduction

1.1. Project description

1.1.1. This document provides an assessment of electric and magnetic fields (EMFs) associated with the proposed Dudgeon Offshore Wind Farm Extension Project (DEP) and Sheringham Shoal Offshore Wind Farm Extension Project (SEP). Both projects are extensions to the existing Dudgeon and Sheringham Shoal offshore wind farms, which will connect onshore at National Grid's existing Norwich Main substation. The onshore connections are approximately 60km and cross the county of Norfolk. The potential impact of EMFs from both the offshore and onshore export cables will be assessed. The geographic locations of the projects are shown in Figure 1.1.

Figure 1.1: **Proposed offshore and onshore routes for the Sheringham and Dudgeon offshore wind farm extension projects**



1.1.2. SEP and DEP will form two export circuits, each will be developed as High Voltage Alternating Current (HVAC) cable circuits operating at 50 hertz (Hz). The current electrical system designs being considered are:

- Option -1: SEP and DEP developed together, with equally rated export cable circuits
- Option -2: SEP and DEP developed together with unequal export cable circuits
- Option -3: SEP and DEP developed as standalone projects each with its own offshore substation

The impact of each of these options will be considered separately.

1.1.3. Due to the geographical location of the connections, both the offshore and onshore export cables must cross a number of third-party utilities. This assessment considers the worst-case EMFs from these major crossing points.

1.2. Electric and Magnetic Fields

1.2.1. Electric and magnetic fields and the electromagnetic forces they represent are an essential part of the physical world. Their sources are the charged fundamental particles of matter (principally electrons and protons). EMFs occur naturally within the body in association with nerve and muscle activity, allowing these functions to happen. Humans also experience the natural static magnetic field of the Earth (to which a magnetic compass responds) and natural static electric fields in the atmosphere.

1.2.2. Electric and magnetic fields occur in the natural world, and people have been exposed to them for the whole of human evolution. The advent of modern technology and the wider use of electricity and electrical devices have inevitably introduced changes to the naturally occurring EMF patterns. Energised high-voltage power-transmission equipment, along with all other uses of electricity, is a source of EMFs.

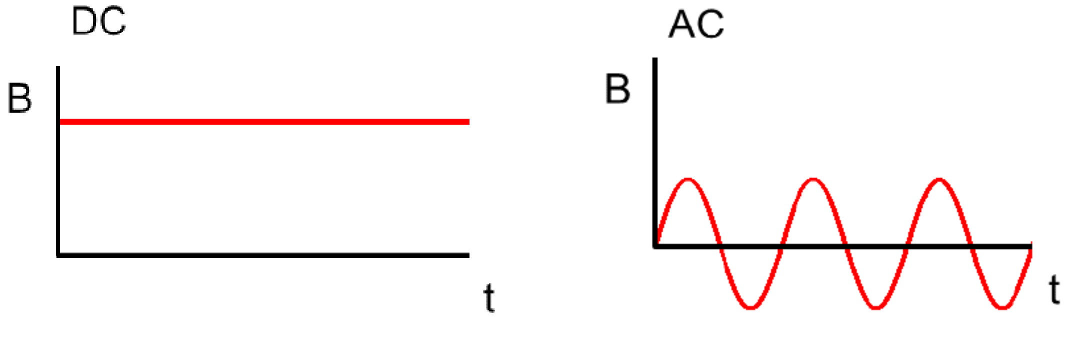
1.2.3. These EMFs have the same frequency as the voltages and currents that produce them. Power cables can be either alternating current or direct current. This project is proposing to install HVAC onshore and offshore connections, with a primary frequency of 50 Hz and these fields are described as power-frequency or extremely-low-frequency (ELF) alternating EMFs. There are areas where the proposed connections cross existing electrical infrastructure, and in some cases, these may be High Voltage Direct Current (HVDC) circuits which operate at a frequency of zero hertz (0 Hz).

1.2.4. A key characteristic of EMFs is their frequency. They always have the same frequency as the electricity that produced them. Most electricity supply in the UK is alternating current (AC) with a frequency of 50 cycles per second or 50 Hz. So, the EMFs it produces also alternate with a frequency of 50 Hz. However, there are an increasing number of electrical connections using direct current (DC) technology, so they will produce steady EMFs that always point in the same direction. (A different set of EMFs again are produced by radiofrequency electricity such as TV, radio and mobile communications – these have frequencies of typically hundreds of millions of Hz.)

1.2.5. The current in HVAC cables will periodically reverse direction with a frequency of 50 Hz (Fig. 1.2). The Earth has no natural AC fields, only those that result from man-made sources, such as those proposed here.

1.2.6. The current from HVDC cables flows in the same constant direction (Fig. 1.2). This will add to the Earth's natural magnetic field, meaning magnetic fields from DC cables have the potential to interfere with magnetic compasses.

Figure 1.2: Direction of AC and DC magnetic fields: Current from DC cables will flow in the same constant direction. Current in AC cables will periodically reverse direction with a frequency of 50 Hz.



Magnetic fields

1.2.7. Magnetic fields are measured in microtesla (μT) and depend on the electrical currents flowing, which vary according to the electrical power requirements at any given time. They are not significantly shielded by most common building materials or trees but do diminish rapidly with distance from the source.

Electric fields

1.2.8. Electric fields depend on the operating voltage of the equipment producing them and are measured in volts per metre (V/m). The operating voltage of most equipment is a relatively constant value. Electric fields are shielded by most common building materials, trees, and fences, and diminish rapidly with distance from the source.

1.2.9. As a consequence of their design, some types of equipment do not produce an external electric field. Neither the offshore nor the onshore cables proposed here will emit electric fields, because the metal sheath surrounding the cable ensures the electric field is confined within the cable.

1.2.10. The Earth's magnetic field can induce an electric field in sea water. The movement of the sea through the magnetic field will result in a small localised electric field being produced. AC magnetic fields will however induce an electric field within a marine organism moving through the field, which is an important consideration for biological impacts[1].

1.2.11. AC and DC electric and magnetic fields have different established biological effects in humans. At high enough levels, DC magnetic fields can cause effects on human beings. The principal effect to be noticed is an effect on blood flow in some of the larger blood vessels as the blood moves through the magnetic field. AC EMFs at 50 Hz can cause induced currents to occur in the body which, if high enough, can interfere with nerves. There are Government adopted exposure limits (discussed in Section 2.2), which are set to protect against these known, direct effects of EMF exposure.

1.2.12. The evidence that leads to some health concerns regarding EMFs from electric power systems is specific to AC fields, at 50 Hz, and does not apply to DC fields. The fact that we have evolved in the Earth's DC magnetic field makes it unlikely that there are any adverse health effects from any sources of fields at these levels. However, DC fields may be an important cue for marine animals, who use DC EMF for navigation and prey detection.

[1] Normandeau, Exponent, T. Tricas, and A. Gill. 2011. Effects of EMFs from Undersea Power Cables on Elasmobranchs and other Marines Species. U.S.Dept. of the Interior, Bureau of Ocean Energy Management, Regulation and Enforcement, Pacific OCS Region, Camarillo, CA. OCS Study BOEMRE 2011-09.

2. Legislation and Policy

2.1. Policy Framework for the Protection of People

2.1.1. At high enough levels, EMFs can cause biological effects, which depending on the frequency of the fields can impact nerve function or blood flow. Whilst there are no statutory regulations in the UK that limit the exposure of people to power-frequency EMFs, responsibility for implementing appropriate measures for the protection of the public lies with the UK Government, which has a clear policy, restated in October 2009 and incorporated in NPS EN-5[2], on the exposure limits and other policies they expect to see applied. Practical details of how the policy is to be implemented are contained in Codes of Practice[3] agreed between industry and the Government.

2.1.2. The Government in turn acts on the scientific advice from Public Health England (PHE), which has responsibility for advising on non-ionising radiation protection, including power-frequency EMFs. The National Radiological Protection Board (NRPB) had this responsibility until it became part of the Health Protection Agency (HPA) on 1 April 2005, which in turn had the responsibility until it was replaced by PHE on 1 April 2013. This report refers to NRPB, HPA or PHE according to the name at the time each statement was issued.

2.1.3. In 2004, following a recommendation by NRPB, the Government adopted exposure guidelines for the public published in 1998 by the International Commission on Non-Ionizing Radiation Protection (ICNIRP)[4], in line with the terms of the 1999 EU Recommendation[5] on public exposure to EMFs. In a Written Ministerial Statement in October 2009[6] (references to the Written Ministerial Statement encompass both the Statement itself and the detailed Response that the Statement introduced) the Government restated this policy of compliance with exposure limits and, acting on the recommendations of a stakeholder process known as SAGE, added a single precautionary measure relating to high-voltage infrastructure, a policy of optimum phasing of some overhead lines. The Government also made clear that no other precautionary measures are appropriate for high-voltage infrastructure.

2.1.4. These two policies - compliance with exposure limits, plus optimum phasing - are the only ones applying to high-voltage infrastructure. NPS EN-5[2] documents these policies and they are explained fully below.

National Policy Statement EN-5

2.1.5. As summarised above, Government has set out clear policies on control of EMF exposures in general. NPS EN-5[2] gives clear guidance on the EMF requirements of all electricity infrastructure projects.

2.1.6. The key provision is in section 2.11.9 and 2.11.10:

> *"…Government has developed with the electricity industry a Code of Practice, "Power Lines: Demonstrating compliance with EMF public exposure guidelines – a voluntary Code of Practice" published in February 2011 that specifies the evidence acceptable to show compliance with ICNIRP (1998) and is also line with the terms of the EU Council Recommendation on EMF exposure.*
>
> *Before granting consent to an overhead line application, the Secretary of State should be satisfied that the proposal is in accordance with the guidelines, considering the evidence provided by the applicant and any other relevant evidence..."*

2.1.7. NPS EN-5[2] has its principal application to Nationally Significant Infrastructure Projects (NSIPs) in England and Wales requiring Development Consent, and this section is cast in terms of an application for an overhead line, but, for EMFs, the principles it sets out are applicable to all developments. NPS

[2] Department of Energy Security and Net Zero. National Policy Statement for Electricity Network Infrastructure (EN-5). London: The Stationary Office, 2024.

[3] Department of Energy and Climate Change. Power Lines: Demonstrating compliance with EMF public exposure guidelines. A voluntary Code of Practice. London, 2012.

[4] International Commission on Non Ionizing Radiation Protection. Guidelines for Limiting Exposure to Time-Varying Electric, Magnetic and Electromagnetic Fields. Health Physics, 1998, 74 (4), p.494.

[5] European Union Council. Recommendation of 12 July 1999 on the limitation of exposure of the general public to electromagnetic fields (0 Hz to 300 GHz) (1999/519/EC). Brussels, 1999.

[6] Department of Health. Government response to the stakeholder advisory group on extremely low frequency electric and magnetic fields (ELF EMFs) (SAGE) recommendations. 2009. (Online) Available from http://webarchive.nationalarchives.gov.uk/20130107105354/http://www.dh.gov.uk/en/Publicationsandstatistics/Publications/PublicationsPolicyAndGuidance/DH_107124

EN-5 states that Government policy is that the NSIPs should comply with the relevant exposure guidelines, and that this should be demonstrated according to the provisions of the Code of Practice. As set out in paragraph 1.2 of NPS EN-1, the National Policy Statement (NPS) may be a material consideration in projects to be consented under the Town and Country Planning Act (1990) and so can be reasonably applied to other major electrical infrastructure projects such as the proposed Dudgeon Extension Project (DEP) and Sheringham Shoal Extension Project (SEP).

2.2. Exposure Limits

2.2.1. In March 2004, the NRPB provided new advice to the Government, replacing previous advice from 1993, and recommending the adoption in the UK of guidelines published in 1998 by the ICNIRP[4]. The Government subsequently adopted this recommendation, saying that limits for public exposures should be applied in the terms of the 1999 EU Recommendation[5]. For DC or static fields, the limits that apply are likewise those given in the 1999 EU Recommendation, in this case derived from 1994 ICNIRP[7] guidelines. Table 2.1 summarises the recommended values.

Table 2.1 Recommended Values for Power Frequencies

Public Exposure Levels	Electric fields	Magnetic fields
	AC	
Basic restriction (induced current density in central nervous system)	**2 mA/m²**	
Reference level (external unperturbed field)	**5,000 V/m**	**100 µT**
Field corresponding to the basic restriction	**9,000 V/m**	**360 µT**
	Static	
Basic restriction	**None**	**40,000 µT**

2.2.2. In recommending these levels, the NRPB considered the evidence for all suggested effects of EMFs. It concluded that the evidence for effects on the nervous system of currents induced by the fields was sufficient to justify setting exposure limits, and this is the basis of their quantitative recommendations[8]. It concluded that the evidence for effects at lower fields, for example the evidence relating to childhood leukaemia (discussed further below), was not sufficient to justify setting exposure limits, but was sufficient to justify recommending that the Government consider possible precautionary actions. Precautionary measures are considered in more detail below.

2.2.3. The EMF limits are documented in NPS EN-5[2] and practical details of their application are explained in the Code of Practice, 'Power Lines: Demonstrating compliance with EMF public exposure guidelines – a voluntary Code of Practice'[3] published by the then Department of Energy and Climate Change (DECC). It is the electricity industry's policy to comply with the Government limits on EMF, and this Code of Practice forms an integral part of this policy.

2.2.4. The ICNIRP guidelines[4] are set so as to prevent external exposure to EMFs that could cause currents to be induced in the body large enough to cause effects on nerves, with a substantial safety margin. These induced currents can be expressed as a current density and it is on current density that the guidelines are based. The ICNIRP guidelines recommend that the general public are not exposed to levels of EMFs able to cause a current density of more than 2 milliAmps per metre squared (mA/m²) within the human central nervous system, as shown in Table 2.1 above. This recommendation is described as the "basic restriction". The external fields that have to be applied to the body to cause this current density have to be calculated by numerical dosimetry, since in-vivo measurements of current density are not practical.

[7] International Commission on Non Ionizing Radiation Protection. Guidelines for Limits of Exposure to Static magnetic fields. Health Physics, 1994.

[8] National Radiological Protection Board. Review of the scientific evidence for limiting exposure to electromagnetic fields (0-300 GHz). Doc NRPB, 2004, 15(3), p.1

2.2.5. The ICNIRP guidelines also contain values of the external fields called “reference levels”. For the public, the reference level for electric fields is 5kV/m, and the reference level for magnetic fields is 100µT. The 1999 EU Recommendation[5] uses the same values as ICNIRP[4].

2.2.6. In the ICNIRP guidelines and the EU Recommendation, the actual limit is the basic restriction. The reference levels are not limits but are guides to when detailed investigation of compliance with the actual limit, the basic restriction, is required. If the reference level is not exceeded, the basic restriction cannot be exceeded, and no further investigation is needed. If the reference level is exceeded, the basic restriction may or may not be exceeded.

2.2.7. The Code of Practice on compliance[3] endorses this approach and gives the values of field corresponding to the basic restriction, stating:

“The 1998 ICNIRP exposure guidelines specify a basic restriction for the public which is that the induced current density in the central nervous system should not exceed 2mA m^{-2}. The Health Protection Agency specify that this induced current density equates to uniform unperturbed fields of 360µT for magnetic fields and 9.0kV m-1 for electric fields. Where the field is not uniform, more detailed investigation is needed. Accordingly, these are the field levels with which overhead power lines (which produce essentially uniform fields near ground level) shall comply where necessary. For other equipment, such as underground cables, which produce non-uniform fields, the equivalent figures will never be lower but may be higher and will need establishing on a case-by-case basis in accordance with the procedures specified by HPA. Further explanation of basic restrictions, reference levels etc is given by the Health Protection Agency.”

2.2.8. The Code of Practice[3] also specifies the land uses where exposure is deemed to be for potentially a significant period of time and therefore where the public guidelines apply. These land uses are, broadly, residential uses and schools.

2.2.9. Therefore, if the EMFs produced by an item of equipment are lower than 9kV/m and 360µT, the fields corresponding to the ICNIRP basic restriction, it is compliant with the ICNIRP guidelines and hence with PHE recommendations and Government policy. If the fields are greater than these values, the equipment is still compliant with Government policy if the land use falls outside the residential and other uses specified in the Code of Practice[3] and it may still be compliant if the fields are non-uniform.

2.3. Precautionary Measures

2.3.1. As well as these established effects, over the past 30 years it has been suggested that exposure to power-frequency magnetic or electric fields of the magnitude encountered in the environment could be linked with various health problems, ranging from headaches to Alzheimer's disease and cancer. The most persistent of these suggestions relates to childhood leukaemia. A number of epidemiological studies have suggested a statistical association between the incidence of childhood leukaemia and the proximity of homes to power transmission and distribution equipment or power-frequency magnetic-field strengths in the homes. However, no causal link has been established between cancer (or any other disease) and magnetic or electric fields and indeed there is no established mechanism by which these fields could cause or promote the disease.

2.3.2. The question of possible health effects of environmental power-frequency fields has been thoroughly reviewed in recent years by a number of national and international bodies. The principal such bodies that have authoritative relevance in the UK are PHE (formerly the HPA), the International Agency for Research on Cancer (IARC), World Health Organisation (WHO), the official scientific advisory committee for the EU, the Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR- disbanded 2016), and the standards-setting body ICNIRP.

2.3.3. When assessing the scientific research on EMFs, it is essential to consider all the evidence and to perform an overall assessment, weighting each strand of evidence and each individual study as appropriate to its strengths and weaknesses. No single study can ever be conclusive (in either direction).

2.3.4. Such reviews have been performed by the authoritative expert bodies, and it is those bodies that provide the most reliable conclusions, and on whose conclusions Government policy is based. The following are summaries of the conclusions of these relevant authoritative review bodies.

The National Radiological Protection Board / The Health Protection Agency / Public Health England

2.3.5. In 2004 the then NRPB published new "Advice on Limiting Exposure to Electromagnetic Fields (0-300GHz)"[9] and accompanied it with a "Review of the Scientific Evidence for Limiting Exposure to Electromagnetic Fields (0-300GHz)"[8]. The former summarises epidemiological evidence as follows (p15):

54 "In the view of NRPB, the epidemiological evidence that time-weighted average exposure to power frequency magnetic fields above 0.4µT is associated with a small absolute raised risk of leukaemia in children is, at present, an observation for which there is no sound scientific explanation. There is no clear evidence of a carcinogenic effect of ELF EMFs in adults and no plausible biological explanation of the association that can be obtained from experiments with animals or from cellular and molecular studies. Alternative explanations for this epidemiological association are possible: for example, potential bias in the selection of control children with whom leukaemia cases were in some studies and chance variations resulting from small numbers of individuals affected. Thus, any judgements developed on the assumption that the association is causal would be subject to a very high level of uncertainty.

55 "Studies of occupational exposure to ELF EMFs do not provide strong evidence of associations with neurodegenerative diseases.

56 "Studies of suicide and depressive illness have given inconsistent results in relation to ELF EMF exposure, and evidence for a link with cardiovascular disease is weak.

57 "The overall evidence from studies of maternal exposure to ELF EMFs in the workplace does not indicate an association with adverse pregnancy outcomes, while studies of maternal exposure in the home are difficult to interpret.

58 "Results from studies of male fertility and of birth outcome and childhood cancer in relation to parental occupational exposure to ELF EMFs have been inconsistent and unconvincing.

59 "All these conclusions are consistent with those of AGNIR[10] .

60 "NRPB concludes that the results of epidemiological studies, taken individually or as collectively reviewed by expert groups, cannot currently be used as a basis for restrictions on exposure to EMFs."

International Agency for Research on Cancer (IARC)

2.3.6. IARC is an agency of the WHO. IARC's Unit of Carcinogen Identification and Evaluation has, since 1972, periodically published Monographs that assess the evidence as to whether various agents are carcinogenic and classify the agents accordingly. In June 2001, a Working Group met to consider static and ELF EMFs[11]. Power-frequency magnetic fields were classified as "possibly carcinogenic", on the basis of "limited" evidence from humans concerning childhood leukaemia, "inadequate" evidence from humans concerning all other cancer types, and "inadequate" evidence from animals. Power-frequency electric fields were judged "not classifiable" on the basis of "inadequate" evidence from both humans and animals. These classifications are consistent with the conclusions reached by the NRPB.

World Health Organization

2.3.7. WHO published an Environmental Health Criteria Monograph in 2007 on ELF EMFs[12], produced by a Task Group that met in 2005. This concluded, in part:

"Chronic effects

Scientific evidence suggesting that everyday, chronic low-intensity (above 0.3-0.4µT) power-frequency magnetic field exposure poses a health risk is based on epidemiological studies demonstrating a consistent pattern of increased risk for childhood leukaemia. Uncertainties in the hazard

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[9] National Radiological Protection Board. Advice on limiting exposure to electromagnetic fields (0-300 GHz). Doc NRPB, 2004, 15(2), p.1

[10] AGNIR.,(2001) NRPB Advisory Group on Non-Ionising Radiation. Power frequency electromagnetic fields and the risk of cancer. Journal of Radiological Protection Vol. 21(2) 190.

[11] Working Group on the Evaluation of Carcinogenic Risks to Humans. Non-ionizing radiation, Part 1: Static and extremely low-frequency (ELF) electric and magnetic fields. (Monographs on the Evaluation of Carcinogenic Risks to Humans, 80). Lyon, IARC, 2002

[12] World Health Organisation, Environmental Health Criteria Monograph No 238 on Extremely Low Frequency Fields, 2007. (Online) Available from http://www.who.int/peh-emf/publications/elf_ehc/en/index.html

assessment include the role that control selection bias and exposure misclassification might have on the observed relationship between magnetic fields and childhood leukaemia. In addition, virtually all of the laboratory evidence and the mechanistic evidence fail to support a relationship between low-level ELF magnetic fields and changes in biological function or disease status. Thus, on balance, the evidence is not strong enough to be considered causal, but sufficiently strong to remain a concern.

A number of other diseases have been investigated for possible association with ELF magnetic field exposure. These include cancers in both children and adults, depression, suicide, reproductive dysfunction, developmental disorders, immunological modifications and neurological disease.

The scientific evidence supporting a linkage between ELF magnetic fields and any of these diseases is much weaker than for childhood leukaemia and in some cases (for example, for cardiovascular disease or breast cancer) the evidence is sufficient to give confidence that magnetic fields do not cause the disease."

Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR)

2.3.8. The Scientific Committee on Emerging and Newly Identified Health Risks is the European Union's authoritative scientific committee covering EMFs (among many other issues). In 2016, it was succeeded by the Scientific Committee on Health, Environmental and Emerging Risks (SCHEER) but all the relevant documents currently existing on EMFs date from the SCENIHR era. In March 2015 SCENIHR published its most recent report on EMFs, "Potential Health Effects of Exposure to EMF"[13]. The section of the abstract concerned with power-frequency fields states:

"Overall, existing studies do not provide convincing evidence for a causal relationship between ELF MF exposure and self-reported symptoms.

The new epidemiological studies are consistent with earlier findings of an increased risk of childhood leukaemia with estimated daily average exposures above 0.3 to 0.4 µT. As stated in the previous Opinions, no mechanisms have been identified and no support is existing from experimental studies that could explain these findings, which, together with shortcomings of the epidemiological studies prevent a causal interpretation.

Studies investigating possible effects of ELF exposure on the power spectra of the waking EEG are too heterogeneous with regard to applied fields, duration of exposure, and number of considered leads, and statistical methods to draw a sound conclusion. The same is true for behavioural outcomes and cortical excitability.

Epidemiological studies do not provide convincing evidence of an increased risk of neurodegenerative diseases, including dementia, related to power frequency MF exposure. Furthermore, they show no evidence for adverse pregnancy outcomes in relation to ELF MF. The studies concerning childhood health outcomes in relation to maternal residential ELF MF exposure during pregnancy involve some methodological issues that need to be addressed. They suggest implausible effects and need to be replicated independently before they can be used for risk assessment.

Recent results do not show an effect of the ELF fields on the reproductive function in humans."

Conclusions from Reviews of Science

2.3.9. There is some scientific evidence suggesting that electric or, particularly, magnetic fields may have health effects at levels below the current UK exposure guidelines. The authoritative classification is that of the WHO, in 2001[11] and reiterated in 2007[12], that power-frequency magnetic fields are "possibly" a cause of cancer, specifically just of childhood leukaemia, with the evidence relating to any other health effect "much weaker". The Government has addressed this uncertainty by adopting precautionary measures relating to various sources of EMFs.

2.3.10. The only specific precautionary measure that relates to high-voltage transmission equipment applies to high-voltage overhead power lines and is a policy of "optimum phasing". "Phasing" is the order in which the conductors of the two circuits are connected relative to each other, and certain phasing arrangements produce lower magnetic fields than others. This policy was introduced in the Written Ministerial Statement of 2009 in response to a recommendation from the Stakeholder Advisory Group

[13] Scientific Committee on Emerging and Newly Identified Health Risks SCENIHR (2015), Potential Health Effects of Exposure to EMF, http://ec.europa.eu/health/scientific_committees/emerging/docs/scenihr_o_041.pdf

on ELF EMFs (SAGE) in its First Interim Assessment[14]. The details are given in a second Code of Practice, 'Optimum Phasing of high voltage double-circuit Power Lines'[15].

2.3.11. All the relevant scientific evidence on EMFs was considered fully in the process of establishing the exposure guidelines that apply in the UK. Those exposure guidelines together with the policy on optimum phasing (and other precautionary policies that relate only to low-voltage equipment) are considered by PHE and the Government to be the appropriate response to that evidence.

2.3.12. The Government has specifically rejected the introduction of "corridors" around overhead power lines (and by extension, other high-voltage equipment such as the underground cables in this proposed development) on EMF grounds, stating of this option[16]:

"The Government therefore considers this additional option to be disproportionate in the light of the evidence base on the potential health risks arising from exposure to ELF/EMF and has no plans to take forward this action."

2.3.13. Having thus established that it is not Government policy to have restrictions on homes and schools near power lines (or, by extension, any other high-voltage equipment), the Statement goes on to say (Paragraph 38):

"It is central Government's responsibility (rather than individual local authorities) to determine what national measures are necessary to protect public health."

2.3.14. This makes it clear that the Government has not introduced any restrictions on constructing new high-voltage equipment close to existing properties on grounds of safety or health risks, and neither is it appropriate for individual local authorities to do so. Therefore, no additional measures or precautions are necessary or appropriate beyond the exposure guidelines and, for overhead lines, the policy on optimum phasing.

2.4. Summary of Policy

2.4.1. The EMF policies applying to high-voltage electricity equipment comprise compliance with the exposure guidelines; for overhead lines, the policy on optimum phasing; the policy on indirect effects expressed in the code of practice; but no other policies. If a development complies with these policies, adequate protection for the public is ensured.

2.5. Effects on magnetic compasses

2.5.1. Magnetic compasses, whether traditional magnetic needle designs or alternatives such as fluxgate magnetometers, operate from the Earth's magnetic field, and are susceptible to any perturbation to the Earth's magnetic field by other sources.

2.5.2. This is a potential issue with direct current (DC) conductors or cables, which produce a static magnetic field that perturbs the geomagnetic field. However, there are no DC cables proposed for use in the project and no DC fields could be produced.

2.5.3. The magnetic fields produced by this project would be 50 Hz fields. These oscillate far too quickly (50 times per second) for a magnetic compass needle to be affected. Fluxgate magnetometers are capable of responding to 50 Hz fields, but, when used as a compass, always have filtering to eliminate unwanted frequencies including 50 Hz. They can cease working correctly if saturated by a high-enough field, but the field required is orders of magnitude higher than would be produced by the Project.

2.5.4. Therefore, this project would have no significant effect on magnetic compasses.

[14] Stakeholder Advisory Group on ELF EMF. SAGE First Interim Assessment. 2007. (Online) Available from http://www.emfs.info/NR/rdonlyres/39CDF32F-4E2E-AD30 -A2B0006B8ED5/0/SAGEfirstinterimassessment.pdf

[15] Department of Energy and Climate Change. Optimum Phasing of high voltage double-circuit Power Lines. A voluntary Code of Practice. London, 2012.

[16] Department of Health. Government response to the stakeholder advisory group on extremely low frequency electric and magnetic fields (ELF EMFs) (SAGE) recommendations. 2009. (Online) Available from http://webarchive.nationalarchives.gov.uk/20130107105354/http://www.dh.gov.uk/en/Publicationsandstatistics/Publications/PublicationsPolicyAndGuidance/DH_107124

2.6. AC Corrosion on pipelines

2.6.1. AC magnetic fields produced by electrical assets can electrically 'couple' with pipelines through capacitive, resistive or inductive coupling. Electrical coupling occurs when pipelines and electrical assets are co-located and can result in corrosion occurring to pipelines, if the conditions are correct.

2.6.2. The way in which the electrical coupling occurs is complex, but one of the main factors effecting the magnitude of induction on a pipeline is the angle at which it crosses HVAC circuits. Where the pipeline crosses at or near to 90° to the HVAC circuit, the effect is minimised because the effective parallel length along which coupling can occur is reduced. Previous industry wide studies have shown that crossings greater than 60° resulted in negligible induction on adjacent pipelines[17].

2.6.3. All third-party assets will be crossed by the proposed cable circuits at or near 90°, therefore AC corrosion is highly unlikely. If crossing angles reduce to below 60°, further investigations will be needed to assess the potential impacts.

2.7. Policy Framework for the Protection of marine life

2.7.1. National Policy Statement EN-3[18] for renewable energy infrastructure provides the primary basis for decisions by the Infrastructure Planning Commission (IPC) on applications it receives for nationally significant renewable energy infrastructure.

2.7.2. A key provision in Paragraph 2.8.245 and 2.8.246 state:

"EMF in the water column during operation, is in the form of electric and magnetic fields, which are reduced by use of armoured cables for interarray and export cables.

Burial of the cable increases the physical distance between the maximum EMF intensity and sensitive species. However, what constitutes sufficient depth to reduce impact may depend on the geology of the seabed" [19]

2.7.3. The mitigation methods suggested in NPS EN-3 include the use of armoured cables for interarray and export cables, and that cables should be buried at sufficient depths. Burial depth can reduce the magnetic fields at distance but to a lesser extent than cable bundling or compact phase arrangements. Therefore, mitigation of EMF from offshore cables can also occur by the arrangements of the bipoles or phases of each circuit. The closer the bipoles or phases in a circuit, the more cancellation of the field occurs and the lower the fields. The use of single 3-core armoured cables, such as proposed for this project, ensures that the phases are in very close proximity, reducing the fields significantly.

Mechanisms of action between EMF and marine species

2.7.4. A general commentary on the effects of EMF on marine species is included. There are no defined limits in terms of EMF to which the cables need to comply in regard to effects on marine life. The research area is relatively new and there is great deal of uncertainty in the science. A review of the impacts of the EMF assessed in this report should be sort from a marine specialist.

2.7.5. There are two fields produced by the cables, a magnetic field which in turn causes an induced electric field. The Earth has its own geomagnetic field meaning that these fields are always naturally present. It has been shown that certain species use these natural fields to aid a number of physiological processes.

2.7.6. Marine species have specialised physiology to detect EMF, but the exact mechanisms of detection are complex, and not fully understood[19]. There are no limits above or below which marine AC EMF are known to have a detrimental impact on marine life and a full impact assessment should be considered.

Magnetic fields

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[17] Finneran, S. & Krebs, B. (2014) 'Advances in HVAC Transmission Industry and its effects on induced AC corrosion, Corrosion No. 2014-4421 (https://www.ingaa.org/File.aspx?id=24732)

[18] Department of Energy Security and Net Zero. National Policy Statement for Renewable Energy Structure (EN-3). London: The Stationary Office, 2024

[19] Bio/Consult, 2005. Infauna monitoring. Horns Rev Offshore Wind Farm. Annual Status Report, 2004, npower Renewables Limited, 2003. Baseline Monitoring Report. North Hoyle Offshore Wind Farm

2.7.7. Marine organisms can detect magnetic fields directly or indirectly through induced electric field detection. Species with the ability to detect magnetic fields directly do so through specialist particles called magnetite. Species with magnetite are sensitive to the geomagnetic field and use it for navigation. Examples of these types of species include salmon, lobsters, crabs, and bivalve molluscs.

2.7.8. Some research papers report that AC fields fluctuate too rapidly for the magnetite to respond mechanically to the imposed force, and that magnetite-based receptor systems may not respond to weak AC magnetic fields[1].

2.7.9. A comprehensive literature review commissioned by Scottish Natural Heritage (SNH) in 2010[20] revealed that EMFs from subsea cables may interact with eels if migration routes take them over cables in shallow water but no evidence of deviation from migration routes was recorded. They concluded that:

"Current knowledge suggests that EMFs from subsea cables and cabling orientation may interact with migrating eels (and possibly salmonids) if their migration or movement routes take them over the cables, particularly in shallow waters (<20m). The effects, if any, could be a relatively trivial temporary change in swimming"

2.7.10. Some species that are able to detect the geomagnetic field not through magnetite, but through induced electric fields, are described as electrosensitive. These species are able to detect the presence of magnetic fields from electric fields induced by movement of an object or water through the magnetic field. The main species that uses this mechanism is Elasmobranchs. It is generally assumed that the induced electric field mode of detection is used for navigation.

2.7.11. The few studies that have looked at the potential effects of the emitted magnetic fields suggest that migratory fish do not deviate from their normal migration path[21, 22]

Electric fields

2.7.12. Some species, mainly Elasmobranchs, have specialist electroreceptive organs which allow them to sense voltage gradient changes. Sensing the induced electric field is mainly used for prey detection and is highly sensitive allowing very weak voltage gradients to be detected, as low as 5 to 20 nV/m. The electroreceptive organs are only used in close proximity to the prey and are highly tuned for the final stages of feeding or detecting others[23]. From the limited research investigating the potential effects of induced electric fields on various species three area of concerns have arisen:

- Repulsion
- Confusion with bioelectric fields
- Physiological effects

2.7.13. Precisely what magnitude of electric field induces an avoidance/ repulsion response in Elasmobranchs is uncertain, however current research suggests that the threshold electric field between attraction and avoidance lies somewhere between approximately 400 and 1000μV/m[23]. It is not clear from the literature which frequencies these apply to or if there are effects outside this range.

2.7.14. A comprehensive review of EMF marine impacts[1] concluded:

"Most marine species may not sense very low intensity electric or magnetic fields at AC power transmission frequencies, AC magnetic fields at intensities below 5 μT may not be sensed by magnetite-based systems (e.g., mammals, turtles, fish, invertebrates), although this AC threshold is theoretical and remains to be confirmed experimentally. Low intensity AC electric fields induced by power cables may not be sensed directly at distances of more than a few meters by the low-frequency-sensitive ampullary systems of electrosensitive fishes."

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[20] Gill, A.B. & Bartlett, M. (2010). Literature review on the potential effects of electromagnetic fields and subsea noise from marine renewable energy developments on Atlantic salmon, sea trout and European eel. Scottish Natural Heritage Commissioned Report No.401

[21] Westerberg, H & Begout-Anras, M.L. (2000) Orientation of silver eel (Anguilla anguilla) in a disturbed geomagnetic field. Advances in Fish Telemetry. Proceedings of the Third Conference on Fish Telemetry in Europe, Norwich, England, June 1999. Eds. Moore, A. & Russel, I. CEFAS Lowestoft.

[22] Westerberg, H. (2000) Effect of HVDC cables on eel orientation. In Merck, T & von Nordheim, H (eds). Technishe Eingriffe in marine Lebensraume. Published by Bundesamt fur Naturschutz.

[23] Centre for Marine and Coastal Studies Ltd. (CMACS). (2011) West Coast HVDC Link environmental Appraisal-Assessment of EMF effects on sub tidal marine ecology. Internal report

3. Baseline Environment

Onshore

3.1.1. Onshore SEP and DEP would be located within a mixture of primarily rural and semirural areas, which accommodate existing electrical assets. All equipment that generates, distributes or uses electricity produces EMFs. The UK power frequency is 50 Hz, which is the principal frequency of the EMFs produced, although HVDC circuits are also present which will be a source of additional DC fields.

3.1.2. Electric and magnetic fields both occur naturally. The Earth's magnetic field, which is caused mainly by currents circulating in the outer layer of the Earth's core, is approximately 50 µT in the UK. This field may be distorted locally by ferrous minerals or by steelwork such as in buildings. At the Earth's surface there is also a natural electric field, created by electric charges high up in the ionosphere, of approximately 100V/m in fine weather.

3.1.3. As detailed earlier in this report, the Earth's natural fields are static, and the power system produces alternating fields. In homes in the UK that are not close to high-voltage overhead lines or underground cables, the average "background" power-frequency magnetic field (the field existing over the whole volume of the house) ranges typically from 0.01 – 0.2 µT with an average of approximately 0.05 µT, normally arising from currents in the low voltage distribution circuits that supply electricity to homes. The highest magnetic fields to which most people are exposed arise close to domestic appliances that incorporate motors and transformers. For example, close to the surface, fields can be 2000 µT for electric razors and hair dryers, 800 µT for vacuum cleaners, and 50 µT for washing machines. The electric field in most homes is in the range 1 – 20 V/m, rising to a few hundred V/m close to appliances[24].

3.1.4. Along the proposed cable circuit route there is existing electrical infrastructure which will produce localised 50 Hz EMF.

Offshore

3.1.5. The current offshore environment where the SEP and DEP export cables run, is home to a number of existing wind farms and associated electrical infrastructure. Each wind farm will have its own infrastructure, which will produce its own localised EMF.

3.1.6. Naturally occurring magnetic fields are present in the marine environment, which again is circa 50 µT.

3.1.7. The Earth's magnetic field can induce an electric field in sea water. The movement of the sea through the magnetic field will result in a small localised electric field being produced. It has been stated that the magnitude of the electric field induced will be dependent upon magnetic field strength, sea water chemistry, viscosity and its flow velocity and direction relative to the lines of magnetic flux. The background geomagnetic field in the area is around 48 µT. Given this, the background induced electric field could range between 4.8 and 60 µV/m in tidal velocities ranging between 0.1 m/s and 1.25 m/s.

3.1.8. AC magnetic fields will however, induce an electric field within a marine organism moving through the field, which is the important consideration for biological impacts[1]. The induced electric field will depend on the size of the organism, its direction of travel in the field and how close it is to the cable. These effects tend to be highly localised as magnetic fields from cables reduce quickly with distance from source. The lower the magnetic field, the lower the induced electric field.

[24] J. Swanson & D.C. Renew, Power-frequency fields and people, Engineering Science and Education Journal, 1994, p 71

4. Description of SEP and DEP

4.1.1. SEP and DEP will be developed as HVAC cable circuits operating at 50 Hz. There are currently three electrical system designs being considered, in all options SEP and DEP are electrically separated, with each extension consisting of a 220 kV export circuit. Descriptions of both the offshore and onshore components for each option are provide below and summarised in Table 4.1.

4.2. Option 1: SEP and DEP extension projects developed in tandem, with equally rated cable circuits

4.2.1. Consists of two 220 kV 3-phase export cable circuits, each with 393 MW capacity. The cable designs for both the offshore and onshore systems are included in Table 4.1, which include one design for the offshore section and two for the onshore section. Onshore circuits will be installed in a trefoil arrangement for the first 50 km from landfall and will then transition into a flat formation for the final 10 km into Norwich Main substation

4.3. Option 2: SEP and DEP developed in tandem with unequal export cable circuits

4.3.1. Consists of two 220 kV 3-phase export cable circuits, the SEP circuit with a 338 MW capacity and the DEP with a 448 MW capacity. The cable designs for both the offshore and onshore systems are included in Table 4.1, which include one design for the offshore section and two for the onshore section. Onshore circuits will be installed in a trefoil arrangement for the first 50 km from landfall and the DEP circuit will transition into a flat formation for the final 10 km into Norwich Main substation.

4.4. Option 3: SEP and DEP developed standalone each with its own offshore substation

4.4.1. This option would consider developing the SEP and DEP connection projects separately, at different points in time. Therefore, each option of the SEP and DEP connection were assessed separately.

Option 3A

4.4.2. The SEP export cables will be one 220 kV 3-phase circuit with a capacity of 338MW. Table 4.1 documents the installation techniques, which in brief are a single 3-core offshore export cable and once onshore, 3 single cables in a trefoil arrangement into Norwich Main substation.

Option 3B

4.4.3. The DEP export circuit will be developed with one 220 kV 3-phase circuit with a capacity of 448MW. Table 4.1 documents the installation techniques, which in brief are a single 3-core offshore export cable and once onshore, 3 single cables in a trefoil arrangement for the first 50 km then a flat formation for the final 10 km into Norwich Main substation.

4.5. Offshore third-party cable circuit crossings

4.5.1. Due to the geographical location of the connections, the offshore circuit cables must cross two existing major third-party electrical connections. This assessment considers the worst-case EMFs from these major crossing points.

Dudgeon offshore wind farm connections

4.5.2. The existing Dudgeon wind farm cables are crossed at 90°. There are two AC circuits operating at 132 kV, each with 198 MW capacity. Each circuit consists of a three core 500 mm^2 cable, buried 1.5 m, with a minimum circuit separation of 40 m.

4.5.3. As both the existing and proposed circuits are AC, the magnetic fields produced can interact with one another. This has been modelled using the worst-case parameters.

Hornsea Project Three offshore wind farm connection

4.5.4. The Hornsea Project Three wind farm application considered using both HVAC and HVDC technology. At the time of writing it is uncertain which technology will be utilised in the final design. If the project uses HVDC technology the crossing point assessment will be the same as the non-crossing points as the DC and AC fields do not interact with one another.

4.5.5. If Hornsea Project Three uses HVAC technology the fields from the SEP and DEP export cables will interact with one another.

4.5.6. The exact design of the proposed Hornsea 3 export cables are unknown. However, the Hornsea Project Three Environmental Statement (ES)25 includes strengths of AC Magnetic fields that presumably corresponded to the levels expected for the project. Therefore, in the absence of more detailed design information, these values were used to assess the cumulative EMFs at the crossing point.

4.6. Onshore third-party circuit crossings

4.6.1. The proposed onshore route of the SEP and DEP circuits crosses two other onshore electrical connections, each of which is considered separately.

Norfolk Vanguard and Norfolk Boreas onshore circuits

4.6.2. These cable circuits will operate using HVDC technology and therefore will not interact with the EMFs from the proposed SEP and DEP cables. However, where the SEP and DEP cable circuits cross these circuits, these will be installed using a horizontal directional drilling (HDD) technique, which alters the installation layout, affecting the magnetic fields produced. The impact of HDD installation has been assessed for this crossing point.

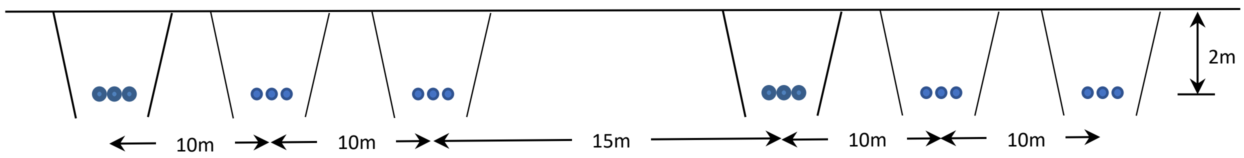
Hornsea Project Three onshore circuits

4.6.3. As previously stated, it is unclear if HVAC or HVDC technology will be deployed for Hornsea Project Three. If HVDC technology is used, only HDD installation needs to be considered and the magnetic fields will be the same as the Norfolk Vanguard and Norfolk Boreas crossing.

4.6.4. Orsted's Hornsea Project Three ES[26] sets out the worst-case scenario for onshore HVAC connections. These design parameters have been used for the assessment.

4.6.5. The Hornsea Project Three connection parameters used in this assessment are six HVAC circuits operating at 220 kV, 1620 A per circuit, buried 1.2 m deep, with 0.5 m phase separation. The layout of six cable circuits is given in Figure 4.1.

Figure 4.1: Hornsea Project Three Onshore HVAC circuit layout (Reproduced from Ref[27])



[25] Orsted. Hornsea 3 offshore wind farm: Environmental Statement, Volume 2, Chapter 3- Fish and Shellfish Ecology. https://infrastructure.planninginspectorate.gov.uk/wp-content/ipc/uploads/projects/EN010080/EN010080-000533-HOW03_6.2.3_Volume%202%20-%20Ch%203%20-%20Fish%20and%20Shellfish%20Ecology.pdf

[26] Orsted Hornsea 3 Offshore Windfarm: Environmental Statement, Annex 3.3- Electro-magnetic (EMF) Compliance Statement. https://orstedcdn.azureedge.net/-/media/www/docs/corp/uk/hornsea-project-three/application-documents/environmental-statement/how036433volume-4--33--emf-compliance-statement.ashx?la=en&hash=1C870590892414A64441977BE64BFB16E42AF04E&hash=1C870590892414A64441977BE64BFB16E42AF04E&rev=f230958feaba44dfad1e3e0796eca9ed

[27] Orsted Hornsea 3 Offshore Windfarm: Environmental Statement, Volume 1, Chapter 3- Project description. https://infrastructure.planninginspectorate.gov.uk/wp-content/ipc/uploads/projects/EN010080/EN010080-000528-HOW03_6.1.3_Volume%201%20-%20Ch%203%20-%20Project%20Description.pdf

Table 4.1: SEP and DEP cable geometries and calculation parameters for all electrical designs

	Option 1					
	Offshore		**Onshore 0-50 km**		**Onshore 50-60 km**	
Extension projects	SEP	DEP	SEP	DEP	SEP	DEP
Cable formation	Trefoil	Trefoil	Trefoil	Trefoil	Flat	Flat
Max current per circuit	1085 A	1085 A	1085 A	1085 A	1085 A	1085 A
Minimum circuit spacing	20m		1m		1m	
Phase spacing			200 mm	200 mm	250 mm	250 mm
Minimum burial depth	0 m	0 m	1.2 m	1.2 m	1.2 m	1.2 m
	Option 2					
	Offshore		**Onshore 0-50 km**		**Onshore 50-60 km**	
Extension projects	SEP	DEP	SEP	DEP	SEP	DEP
Cable formation	Trefoil	Trefoil	Trefoil	Trefoil	Trefoil	Flat
Max current per circuit	929 A	1175 A	929 A	1175 A	929 A	1175 A
Minimum circuit spacing	20 m		1 m		1 m	
Phase spacing			200 mm	200 mm	200 mm	250 mm
Minimum burial depth	0 m	0 m	1.2 m	1.2 m	1.2 m	1.2 m
	Option 3A		**Option 3B**			
	Offshore	**Onshore**	**Offshore**	**Onshore 0-50 km**	**Onshore 50-60 km**	
Extension projects	SEP Only		DEP			
Cable formation	Single cable	Trefoil	Single cable	Trefoil	Flat	
Max current per circuit	929 A	929 A	1175 A	1175 A	1175 A	
Minimum circuit spacing	N/A	N/A	N/A	N/A	N/A	
Phase spacing		200 mm		200 mm	250 mm	
Minimum burial depth	0 m	1.2 m	0 m	1.2 m	1.2 m	
	HDD installation					
Extension projects	Onshore Option 1			Onshore Option 2		
Cable formation	Flat			Flat		
Max current per circuit	1085 A / 1085 A			929 A / 1175 A		
Minimum circuit spacing	20 m			20 m		
Phase spacing	5 m			5 m		
Minimum burial depth	10 m			10 m		

5. Assessment methodology

5.1. Predicted Field Levels

5.1.1. The magnetic field produced by the currents in an electrical circuit falls with distance from the circuit. The magnetic field is highest at the closest point to the conductors and falls rapidly with distance.

5.1.2. For sources of fields with a simple, defined geometry, such as underground cables, calculations are the best way of assessing fields and are acceptably accurate. The calculations of fields presented here follow the provisions specified in the Code of Practice on Compliance[3] and were performed using specialised computer software that has been validated against direct measurement[28] and commercially available software package EFC-400 (Narda).

5.1.3. Calculations from overhead lines and cables usually assume that the line or cables are infinitely long and straight, known as a two-dimensional calculation. The Code of Practice specifies that such calculations are always acceptable. In the present instance, however, due to the complex nature of the crossing points, more sophisticated three-dimensional calculations were performed instead.

5.1.4. Since field strengths are constantly varying, they are usually described by reference to an averaging calculation known as the "root mean square" or RMS. Future mention of power-frequency field strengths in this chapter will mean the RMS amplitude of the power-frequency modulation of the total field, which is the conventional scientific way of expressing these quantities.

5.1.5. To assess compliance with exposure limits, the Code of Practice on Compliance[3] specifies that the maximum fields the installation is capable of producing should be calculated using the following conditions (other conditions in the Code of Practice apply only to overhead lines and are not reproduced here):

- magnetic fields: for the highest rating that can be applied continuously in an intact system (i.e. including ratings which apply only in cold weather, but not including short-term ratings or ratings which apply only for the duration of a fault elsewhere in the electricity system); and
- electric and magnetic fields: for 1 m above ground level, of the unperturbed field, of the 50 Hz component ignoring harmonics, ignoring zero-sequence currents and voltages and currents induced in the ground or earth wire.

5.1.6. These provisions ensure that the calculations for each of the cable design options and crossing points represent worst-case conditions. The circuits will not always operate at this maximum rating, therefore resulting in lower magnetic fields for some of the time, but compliance is assessed for the worst-case conditions.

5.1.7. These calculations assume that there is no attenuation of magnetic fields from any surrounding material (e.g., seabed, earth, grout mattresses, etc.) and that there are no unbalanced currents flowing along the outer sheaths of the cables. Finally, the effect of the cable armouring (ferromagnetic shielding) to reduce the magnetic field outside the cable was not included. Complex modelling of similar cables demonstrated that the armour cable in fact accounted for a 2-fold reduction in the magnetic field[29]. The modelling assumptions were made to ensure that the calculated magnetic-field levels will overestimate the actual field level at any specified loading.

5.2. Combining fields from different sources

5.2.1. When more than one source of EMFs is present, such as two different cable circuits, the EMFs can interact with one another, adding or subtracting to the total field. However, this is only the case if the frequencies that the cables operate at are the same. Alternating Current (50 Hz) and Direct Current (0 Hz) fields do not interact with one another due their differing frequencies (Section 1.2) and should be considered separately.

5.2.2. Both the offshore and onshore cable circuits cross existing electrical infrastructure. Where cables cross existing HVAC cable circuits the fields from each have been modelled and the resulting combined field assessed. Where existing HVDC circuits are crossed, only the magnetic fields from the proposed cables are considered as AC and DC fields do not combine. The AC magnetic fields from the proposed cables

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[28] J. Swanson, Magnetic fields from transmission lines: Comparison of calculations and measurements, IEE Proceedings.-Generator Transmission Distribution, 1995, 142 (5), p481.

[29] M. Silva, E. Zaffanella and J. Daigle. 2006 EMF Study: Long Island Power Authority (LIPA), Offshore Wind Project.

will vary at crossing points due to the fact the installation techniques vary and will influence the magnetic field. The effect of these varying installation techniques has been assessed in Section 6.

5.2.3. Because of the physical properties of EMFs, specifically that they are what is known as "vectors" not "scalars", (i.e. have direction as well as magnitude), the magnitudes of the EMFs from two different sources do not simply add together. The addition of EMFs from different sources is complex, but has the general effect that, when the field from one source is larger than the other, the larger field dominates, with the smaller field making only a small difference to the resulting field.

5.2.4. This assessment uses 3D calculation software to calculate the complex interactions of the magnetic fields where HVAC circuits cross.

5.3. Assessment of Effects

5.3.1. The SEP and DEP export cables would be assessed as having an adverse effect if non-compliance with the EMF exposure limits was demonstrated, using the principles set out in Codes of Practice[3]. Conversely, as specified in NPS EN-5[2], if the proposed projects comply with the exposure limits, EMF effects are assessed as not significant, and no mitigation is necessary.

5.3.2. For the marine environments, total field values are produced and compared to the requirements of NPS EN-3. For interpretation of the potential impacts on marine life physiology, a marine specialist will need to be consulted.

6. Assessment of EMF from SEP and DEP

6.1. Offshore options

6.1.1. The earthed metallic shield that is applied over the insulation of HVAC cables ensures that the electric field will be contained entirely within the insulation, and no external electric field will be emitted.

6.1.2. Magnetic fields are not shielded in the same way as electric fields and will be produced outside the cables, and this has been assessed for each technology option and installation scenario below.

6.1.3. All proposed offshore cable designs consist of a single 3-core conductor cable, which vary in cross-sectional area, depending on the required rating. Within each single cable the 3 conductors vary with distance from one another, which can influence the magnetic field produced. In each scenario the worst-case option was considered.

6.1.4. The magnetic field produced by the cables will in turn induce electric fields in organisms passing through the field. This will be proportional to the magnetic field and the size of the organism.

6.1.5. EMF intensities reduce as a function of distance from the source and are highly localised.

Magnetic fields

6.1.6. Based on the cable design parameters provided by Equinor (Table 4.1) and performed according to the provisions of the Code of Practice, the AC magnetic fields from each of the proposed offshore export options were calculated. All calculations were performed assuming maximum load, minimum circuit separation and minimum burial depth, giving a worst-case scenario.

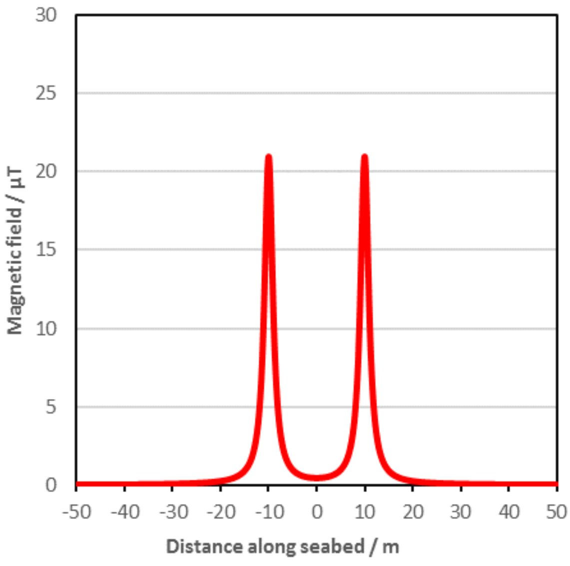
6.1.7. Table 6.1 demonstrates the maximum magnetic field for each option at the seabed and with vertical increasing distance. Figure 6.1 shows the magnetic field along the seabed in a horizontal plane for each of the design options. Figures 6.2a and 6.2b demonstrate the reduction of magnetic fields with both vertical and horizontal distance from the cable circuits when one or two circuits are present. A similar pattern is observed for all installation options.

Table 6.1: Calculated maximum magnetic fields for offshore SEP and DEP export cable circuits options

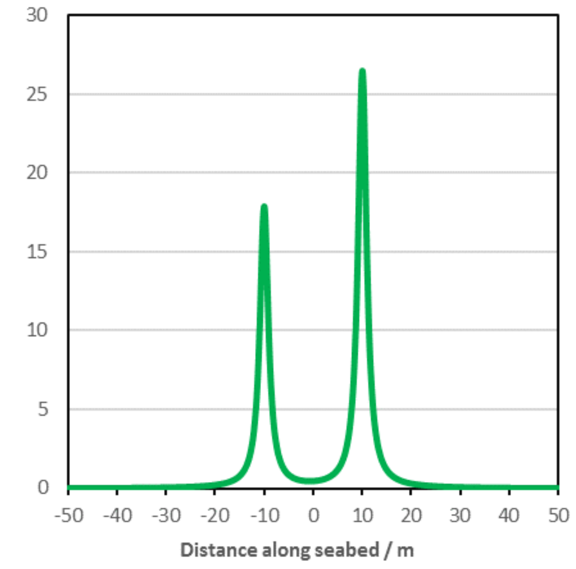
	Magnetic field (μT)						
		Distance above seabed (m)					
	Cable surface	0 m	1 m	2 m	5 m	10 m	20 m
Option 1	1421	20.93	5.45	2.43	0.59	0.17	0.06
Option 2	1653	26.49	6.97	3.13	0.77	0.23	0.07
Option 3A	1217	17.97	4.71	2.13	0.54	0.16	0.05
Option 3B	1653	26.54	7.02	3.18	0.81	0.24	0.07

Figure 6.1: Calculated maximum magnetic fields for offshore SEP and DEP export cable circuits options. Magnetic fields calculated along the seabed perpendicular to the cable circuits.

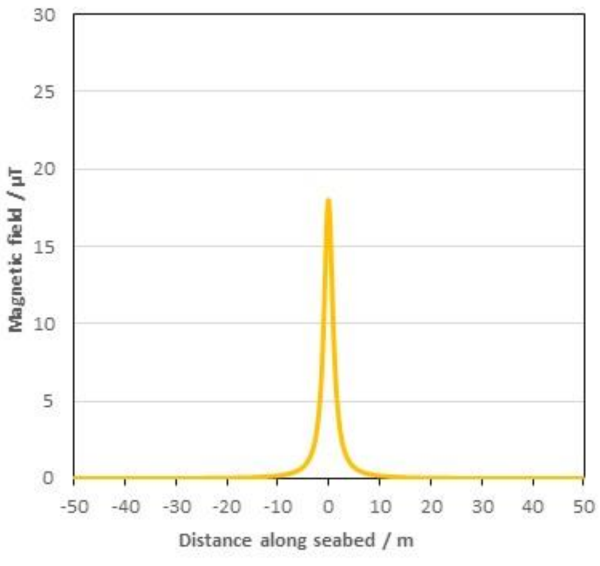
Option 1: SEP and DEP equally rated



Option 2: SEP and DEP unequally rated



Option 3A: SEP circuit only



Option 3B: DEP circuit only

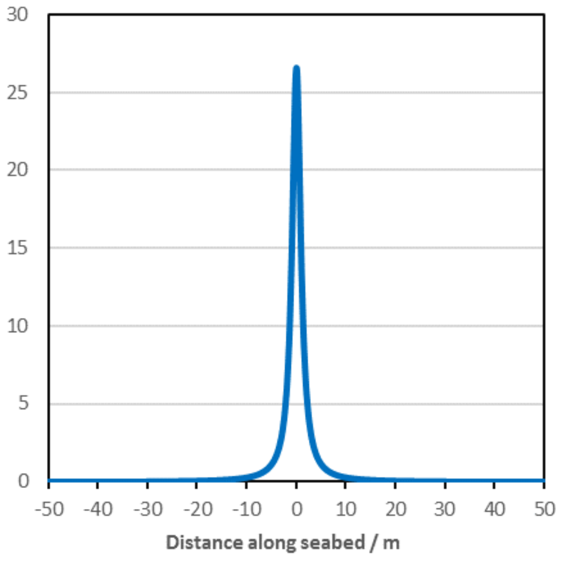


Figure 6.2a: Calculated AC Magnetic Fields from SEP and DEP AC cable circuits with equal circuit ratings: The hashed line running horizontally at 0 on the z-axis represents the seabed location. Colour bands represent magnetic field levels in microtesla with scale given below.

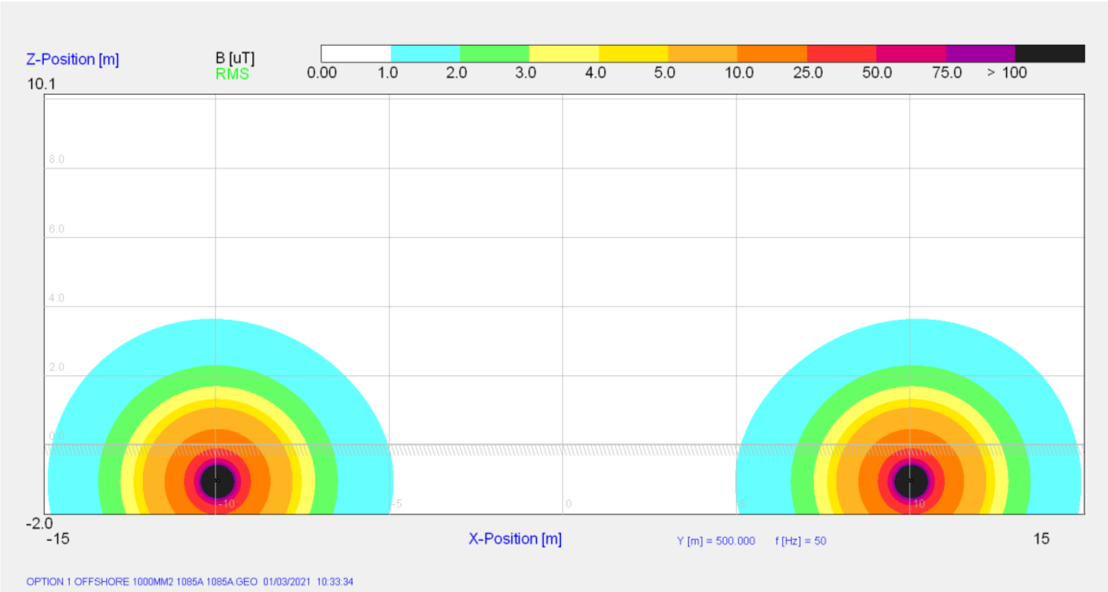
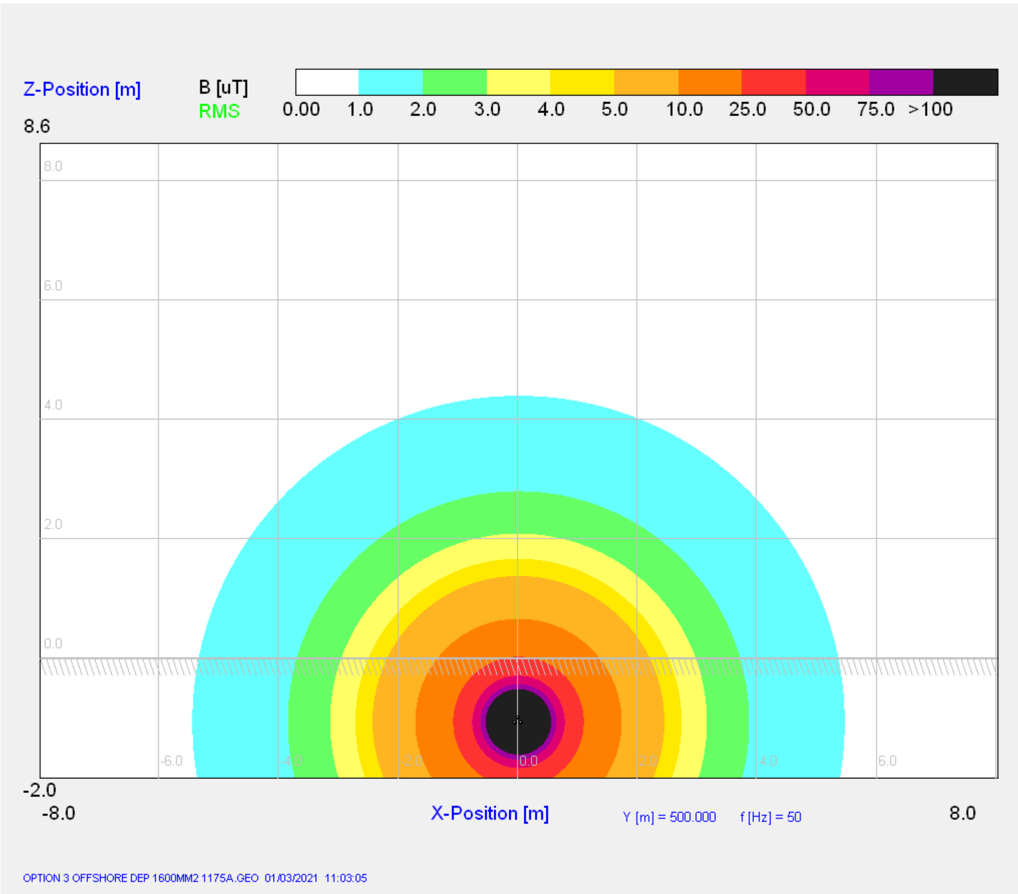


Figure 6.2b: Calculated AC Magnetic Fields from DEP AC cable circuit: The hashed line running horizontally at 0 on the z-axis represents the seabed location. Colour bands represent magnetic field levels in microtesla with scale given below



6.1.8. Unlike DC magnetic fields, those produced by HVAC cables do not interact with the geomagnetic field. The calculations provided are for the total magnetic field without the need to account for the Earth's natural DC field.

6.1.9. The calculated magnetic fields are greatest on the seabed and reduce rapidly with vertical and horizontal distance from the circuits (Figure 6.2a and b). The highest magnetic fields were observed from Options 2 and 3B, due to these options carrying a greater current, but in all cases the maximum magnetic fields were below 27 µT at the sea bed. Where rock burial occurs, there is a possibility that a marine organism could be exposure to higher levels, if small enough to swim through the rocks. The magnetic field at the cable surface is the highest possible exposures and ranged between 1217 and 1653 µT, depending on option. The magnetic fields from all options reduced to very low levels within a few metres from the circuits. It is important to note that these levels do not take account of shielding factors of the cable sheath which would further reduce the fields.

Induced electric fields

6.1.10. The induced electric field within an organism is directly related to the size of the magnetic field and the size of the organism. The method used to calculate the induced electric field is that noted in the BOEMRE report[1] and derived from Reilly[30].

6.1.11. The calculated induced electric field was produced for two sizes of organism. Firstly, a small shark, 150 cm in length and 60 cm wide to represent a worst case. The second calculation represented a fish 30 cm in length and 15 cm wide. The results are presented in Tables 6.2 and 6.3.

6.1.12. As the induced electric fields are directly proportional to the magnetic field, as expected the greatest induced electric fields were observed when considering Option 2. The induced electric field reduced with vertical and horizontal distance from the cable circuits.

6.1.13. The maximum induced electric field in a small shark was 2156 µV/m at the seabed, but this reduced to below 66 µV/m, 5 m from the cable circuits for each option considered. These levels significantly decreased in the smaller fish. The induced electric field was more than 4.5 times lower than that in the shark due to its smaller size.

6.1.14. In all cases the effects were highly localised to a few metres from the cable circuits.

Table 6.2: Modelled maximum induced electric field (µV/m) in a small shark at various distances above SEP and DEP cable circuits.

	Electric field (µV/m)						
	Distance above seabed (m)						
	0 m	**0.3 m**	**1 m**	**2 m**	**5 m**	**10 m**	**20 m**
Option 1	1700	1027	442	198	47.8	13.8	4.9
Option 2	2153	1302	566	255	62.8	18.3	5.9
Option 3A	1460	882	383	173	43.8	13.0	4.1
Option 3B	2156	1312	570	258	65.8	19.7	4.1

[30] P. Reilly. 1991. Magnetic field excitation of peripheral nerves and the heart: a comparison of thresholds. Ned. & Biol. Eng. & Comput., 28: 571-579.

Table 6.3: Modelled maximum induced electric field (µV/m) in a fish 30 cm long, 15 cm wide at various distances above SEP and DEP cable circuits.

	Electric field (µV/m)						
	Distance above seabed (m)						
	0 m	**0.3 m**	**1 m**	**2 m**	**5 m**	**10 m**	**20 m**
Option 1	394	238	103	45.8	11.1	3.2	0.01
Option 2	499	302	131	59.1	14.5	4.2	1.4
Option 3A	339	205	88.8	40.1	10.2	3.0	0.9
Option 3B	500	304	132	59.9	15.3	4.6	1.3

Third party circuit crossing

6.1.15. Due to the complex nature of the cable crossings, the option which gave the highest magnetic fields was modelled. Option 2 was modelled to cross the third-party assets, which will give a very worst case when both SEP and DEP circuits are operational. All other options would result in lower EMFs.

6.1.16. Results will be demonstrated as contour 2D graphs and 1D graphs demonstrating the magnetic field reduction with distance at each crossing point. In all instances, the cables running North-South are the SEP and DEP circuits and those running East-West are the third-party electrical circuits.

Dudgeon offshore wind farm connections

6.1.17. The existing Dudgeon cable circuits are proposed to be crossed at 90° by the SEP and DEP circuits. The crossing point was modelled using EFC-400. Option 2 crossed on the seabed, 1.5 m above the existing circuits. The Dudgeon offshore wind farm consists of two single cable 3-phase circuits which have a maximum capacity of 198MW per circuit. The SEP and DEP circuits would be buried with a minimum of 1 m rock coverage. All calculations have been made at 1 m from the SEP and DEP cable circuits.

6.1.18. Figure 6.3 shows a 2D plot of the magnetic fields from the crossing points of SEP, DEP and existing Dudgeon cable circuits; Figure 6.4 shows the total magnetic fields along the SEP and DEP cable circuits.

6.1.19. There is a slight increase in magnetic fields where the cable circuits cross, which persists for approximately 4 m either side of the crossing point. The maximum magnetic field above the SEP circuit where it crosses the Dudgeon circuit was 19.38 µT, compared to 17.90 µT with no influence of the existing Dudgeon circuits. The maximum magnetic field produced above the DEP circuit where it crosses the Dudgeon circuit was 27.91 µT compared to 24.9 µT, where there was no influence of the existing Dudgeon circuit. This slight increase in magnetic field increases the worst case induced electric field in the same small shark (150 cm length, 60 cm width) to 22.7 mV/m.

Figure 6.3: Calculated AC Magnetic Fields from SEP and DEP AC cable circuits above Dudgeon's existing AC cable circuits with 90 degree crossing angle: Cable circuits running North-South are SEP and DEP circuits which are above Dudgeon's circuits running East-West. Colour bands represent magnetic field levels in microtesla with scale given below**.**

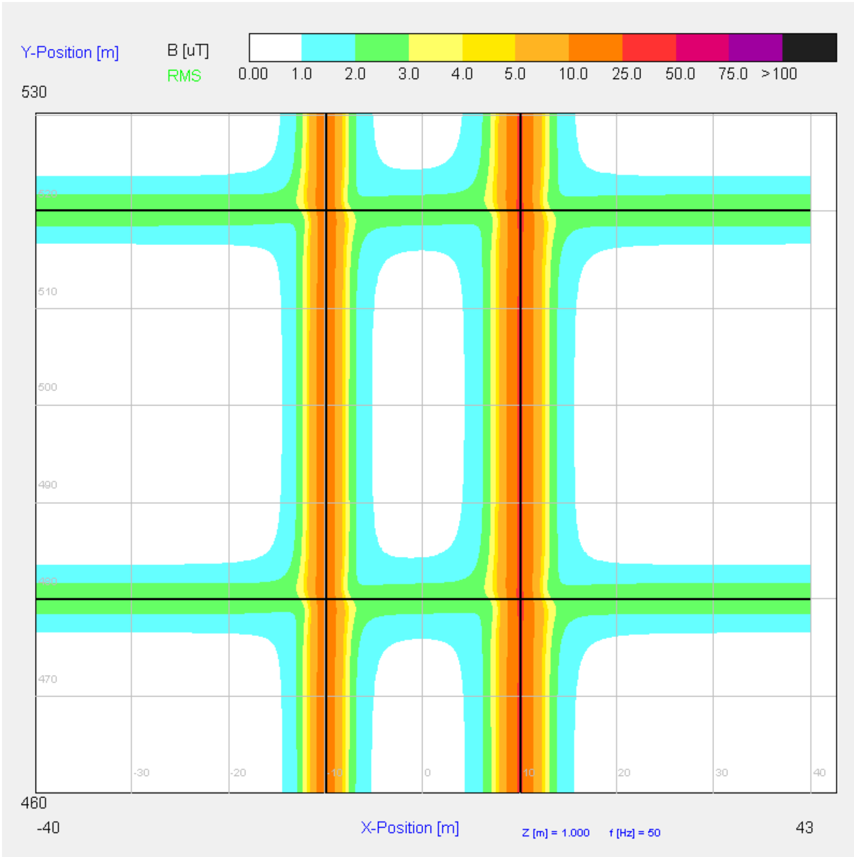
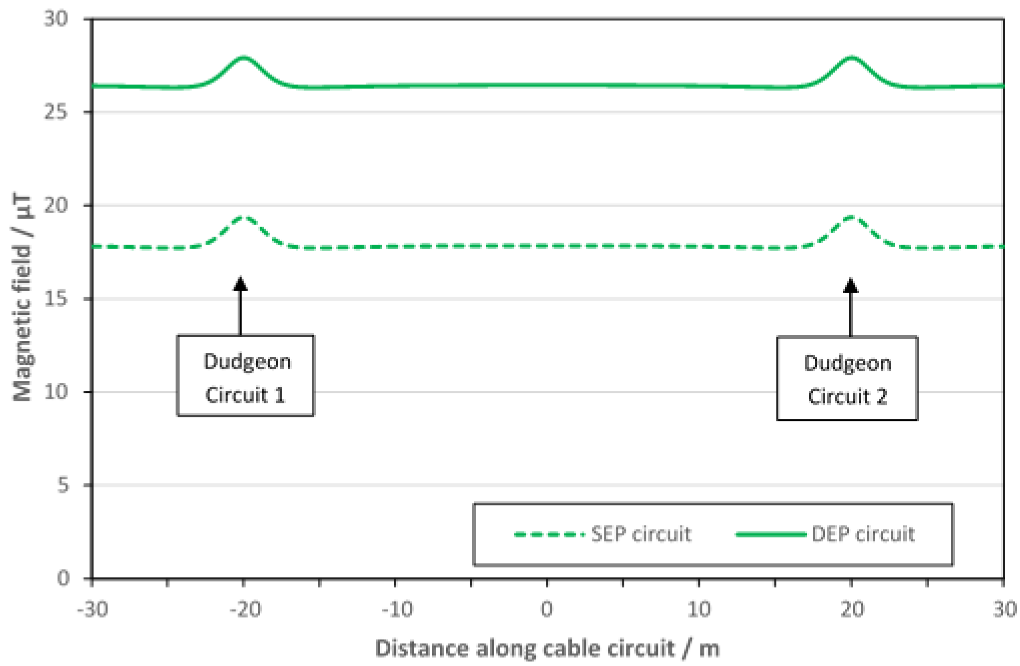


Figure 6.4: Calculated magnetic fields along the SEP and DEP cable circuits crossing the existing Dudgeon cable circuits. Arrows indicate where the existing Dudgeon circuits cross the proposed circuit at a 90° angle



Hornsea Project Three offshore wind farm connection

6.1.20. Lack of design information has prevented 3D modelling of this particular crossing point. Therefore, a very worst-case assumption has been made to add the magnetic fields provided in the Hornsea Project Three ES[25] to the maximum calculated magnetic field from the SEP and DEP circuits provided in Table 6.1. As stated in Section 5.2, magnetic fields are vectors so do not directly add to one another. This method will be a significant overestimation of the predicted magnetic fields and is only used in the absence of other alternatives.

6.1.21. Table 3.21 in the Hornsea Project Three ES[25] states that the AC magnetic fields from the cable circuits are as follows:

Hornsea 3 AC magnetic fields generated by HVAC export cables (Table 3.21[25])

	Distance above seabed		
	0 m	**5 m**	**10 m**
Magnetic field (µT)	7.85	0.35	0.13

6.1.22. Adding the fields above with those in Table 6.1 would result in the following combined magnetic fields for each Option (Table 6.4)

Table 6.4: Combined magnetic fields from Hornsea 3 AC circuit and SEP and DEP circuit crossings.

	Magnetic field (µT)		
	Distance above seabed (m)		
	0 m	**5 m**	**10 m**
Option 1	28.78	0.94	0.30
Option 2	34.34	1.12	0.36
Option 3A	25.82	0.89	0.29
Option 3B	34.39	1.16	0.37

6.1.23. The maximum magnetic fields are given in Table 6.4. The maximum at the seabed for each option ranges between 25.82 and 34.39 µT. These fields reduce rapidly with distance from the circuits and are highly localised to the crossing points. It is important to note that these predicted fields are a significant overestimation.

6.2. Onshore options

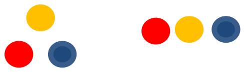
6.2.1. The earthed metallic shield that is applied over the insulation of HVAC cables ensures that the electric field will be contained entirely within the insulation, and no external electric field will be emitted.

6.2.2. Magnetic fields are not shielded in the same way as electric fields and will be produced outside the cables and this has been assessed for each technology option and installation scenario below.

6.2.3. When 3-phase electrical circuits are in close proximity the magnetic fields interact with one another adding and subtracting. The phasing of each circuit is a crucial factor in how the fields interact with one another, affecting the direction of the magnetic field. If magnetic fields are aligned in the same direction, they add to one another producing a greater total field, whereas if they are in opposite directions, they subtract from one another producing a lower field. This not only affects the maximum field, but how quickly the field reduces with distance. The effect of phasing is more prominent when phase conductors increase in distance from one another.

6.2.4. For each onshore installation where each phase is an individual cable, the effects of phasing were considered separately. The phase arrangements for the various installation techniques are as follows:

Table 6.5: Phase arrangement used for each three-phase circuit

Phasing	Trefoil	Flat	Trefoil / Flat
RYB RYB			
RYB BYR			

Electric fields

6.2.5. The earthed metallic shield that is applied over the insulation of the AC cables, which is an inherent part of the cable design, ensures that the electric field is contained within the cable, not leaking out.

6.2.6. The proposed underground cables produce no external electric fields, so are not considered further.

Magnetic fields

6.2.7. Based on the cable design parameters provided by Equinor (Table 4.1) and performed according to the provisions of the Code of Practice, the AC magnetic fields from each of the proposed installation techniques were calculated. All calculations were performed assuming maximum load, minimum circuit separation and minimum burial depth giving a worst-case scenario. For each design, two extreme phase arrangements were modelled to give a worst- and best-case calculation of the magnetic field. A summary of the calculated magnetic fields for each option is provided in Table 6.6.

Option 1

6.2.8. Figure 6.5 shows the magnetic field at 1 m above ground for the trefoil design considered for the first 50 km of the route. The figure indicates the maximum magnetic field and reduction with distance for two phase arrangements indicated in Table 6.5.

6.2.9. Figure 6.6 shows the magnetic field at 1m above ground for the flat formation design considered for the last 10 km of the route, for each phase arrangement.

Figure 6.5: Maximum magnetic fields from Option 1 SEP and DEP circuits, equal capacity, Trefoil arrangements 0 – 50 km. Solid red line represents RYB RYB phase arrangement, dashed red line represents RYB BYR phase arrangement.

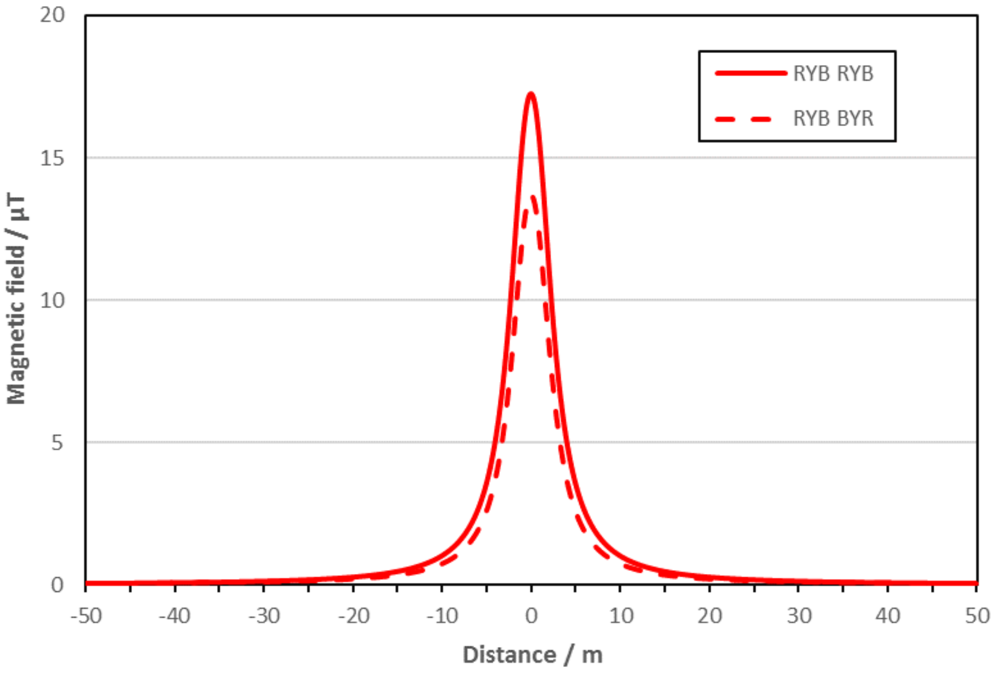
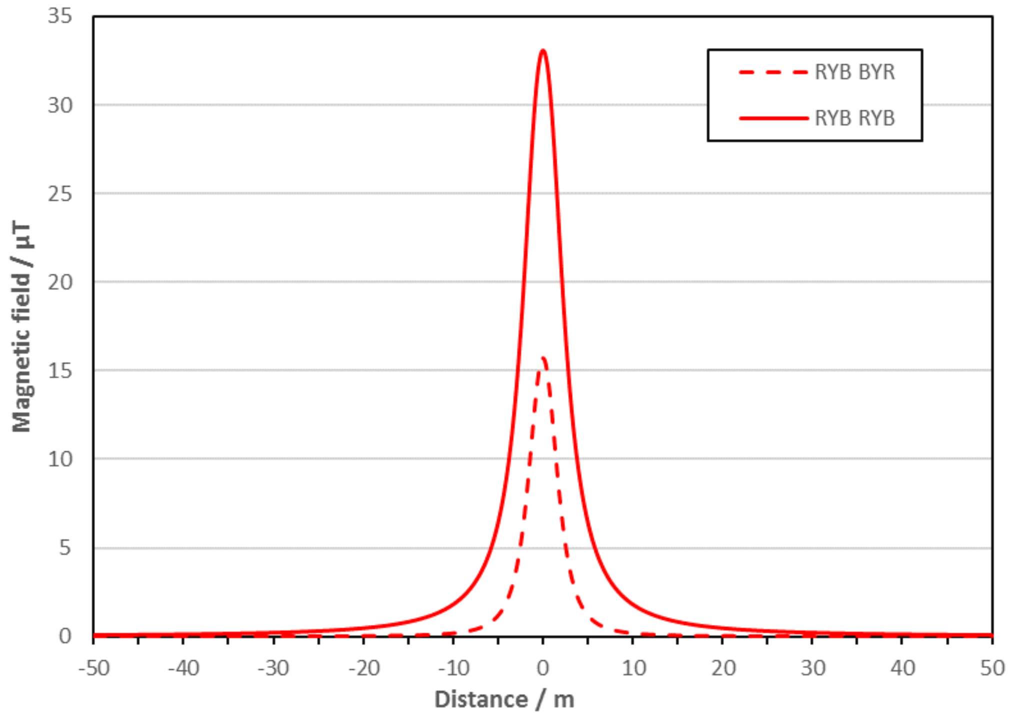


Figure 6.6: Maximum magnetic fields from Option 1 SEP and DEP circuits, equal capacity, Flat circuit installation 50 – 60 km. Solid red line represents RYB RYB phase arrangement, dashed red line represents RYB BYR phase arrangement.



6.2.10. The phase arrangement has an impact on the maximum magnetic field but also how quickly it reduces with distance from the circuits. The maximum calculated magnetic field for the trefoil design is 17.3 µT where the phases were arranged RYB RYB. The maximum field reduces to 13.7 µT, if the phases are transposed. Where circuits are to be installed in flat formation, the maximum magnetic field is 33.1 µT with RYB RYB phasing, and 15.7 µT if the phases are transposed.

Option 2

6.2.11. Figure 6.7 shows the magnetic field at 1 m above ground for the trefoil design considered for the first 50 km of the route. The figure indicates the maximum magnetic field and reduction with distance for two phase arrangements indicated in Table 6.5.

6.2.12. Figure 6.8 shows the magnetic field at 1 m above ground where the SEP circuit is in trefoil arrangement and the DEP circuit is a flat formation considered for the last 10 km of the route. Again, each of the phase arrangements has been considered.

Figure 6.7: Maximum magnetic fields from Option 2 SEP and DEP circuits, unequal capacity, Trefoil arrangements 0-50km of route. Solid green line represents RYB RYB phase arrangement, dashed green line represents RYB BYR phase arrangement.

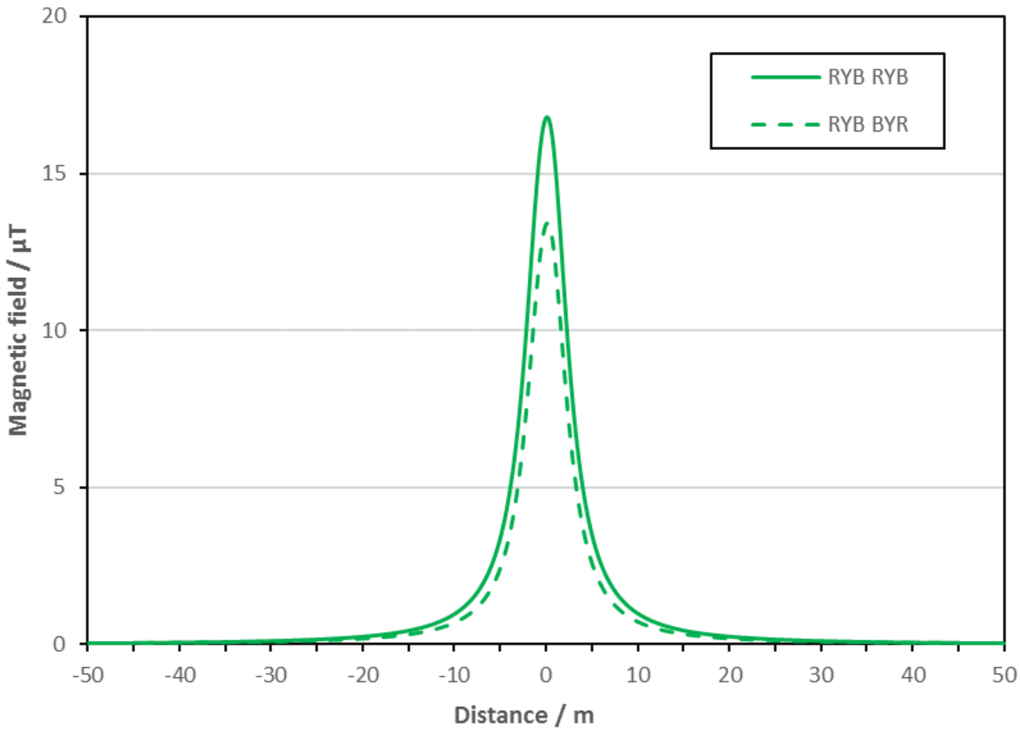
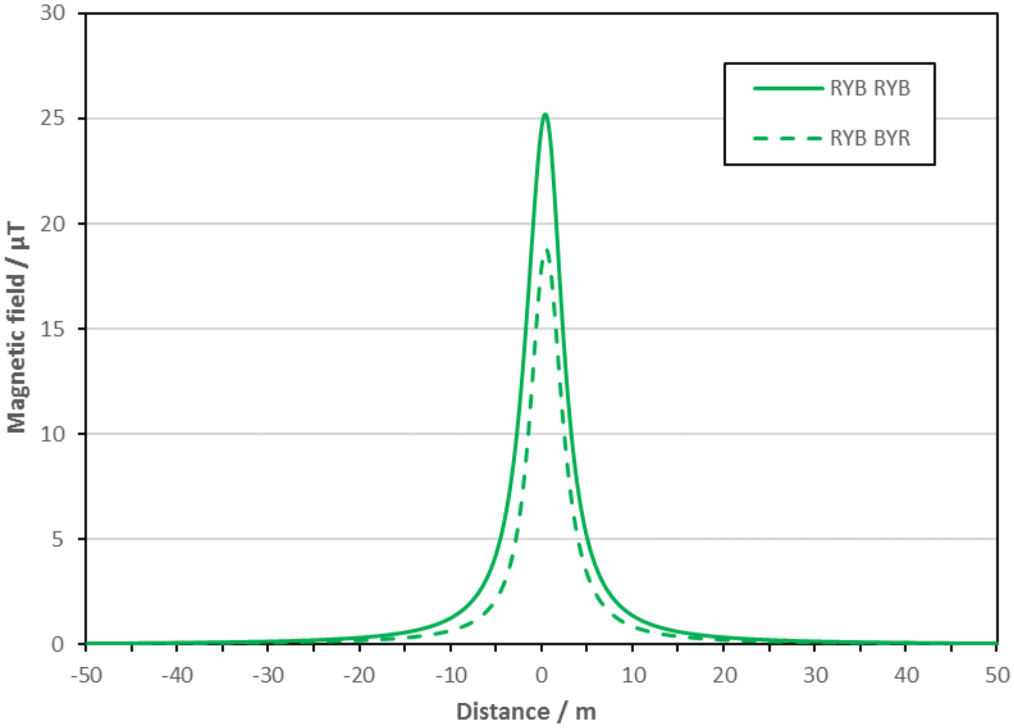


Figure 6.8: Maximum magnetic fields from Option 2: SEP and DEP circuits with unequal capacity. SEP circuit has trefoil design, DEP circuit has a flat arrangement, 50 – 60 km of the route. Solid green line represents RYB RYB phase arrangement, dashed green line represents RYB BYR phase arrangement.



6.2.13. The SEP and DEP circuits are designed with differing capacities in this option, which results in unequal magnetic fields either side of the centre point. This effect is more pronounced where installed as trefoil and flat circuits.

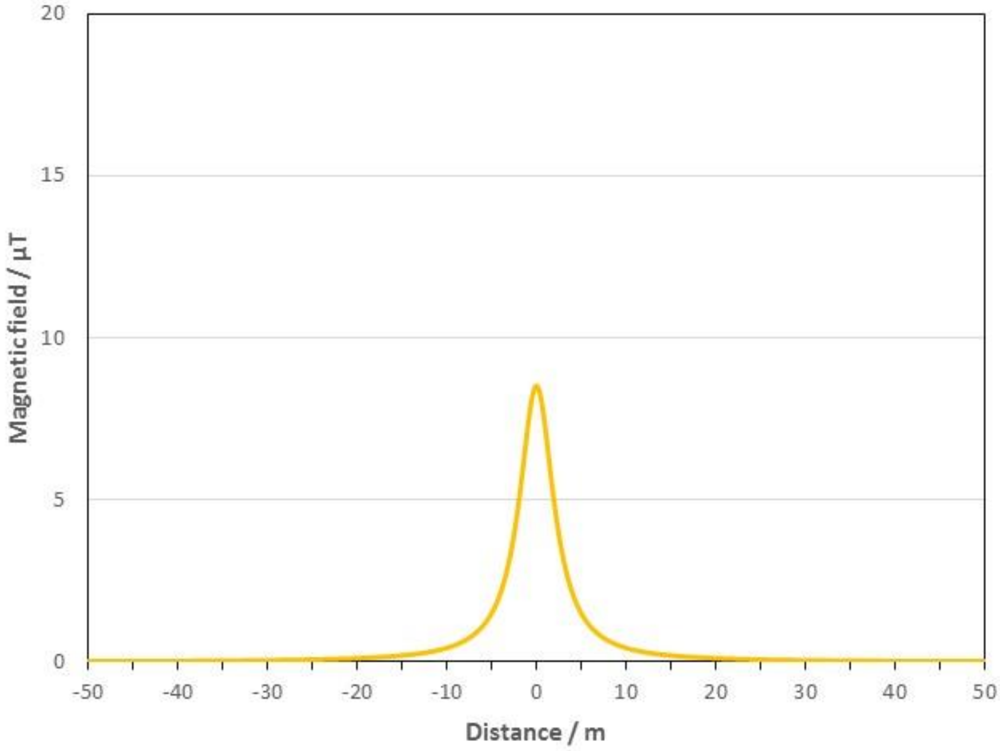
6.2.14. Again, phase arrangements affected the maximum field observed in each option. The highest magnetic fields were observed when RYB RYB phasing was applied to both installation options modelled but had a greater impact where one circuit was flat. The maximum magnetic fields calculated were 16.79 µT where both circuits were trefoil and 25.23 µT with 1 x trefoil and 1 x flat design. Altering the phase arrangements reduces the maximum magnetic field.

Option 3A

6.2.15. This option considers the magnetic field from the SEP export circuit only, which will be installed in trefoil for its entirety.

6.2.16. Figure 6.9 shows the maximum calculated magnetic field at 1 m above ground and how the field reduces with distance. The maximum magnetic field this option can produce is 8.50 µT, reducing to below background levels within 15 m.

Figure 6.9: Maximum magnetic fields from Option 3A: SEP circuit only, installed in trefoil.

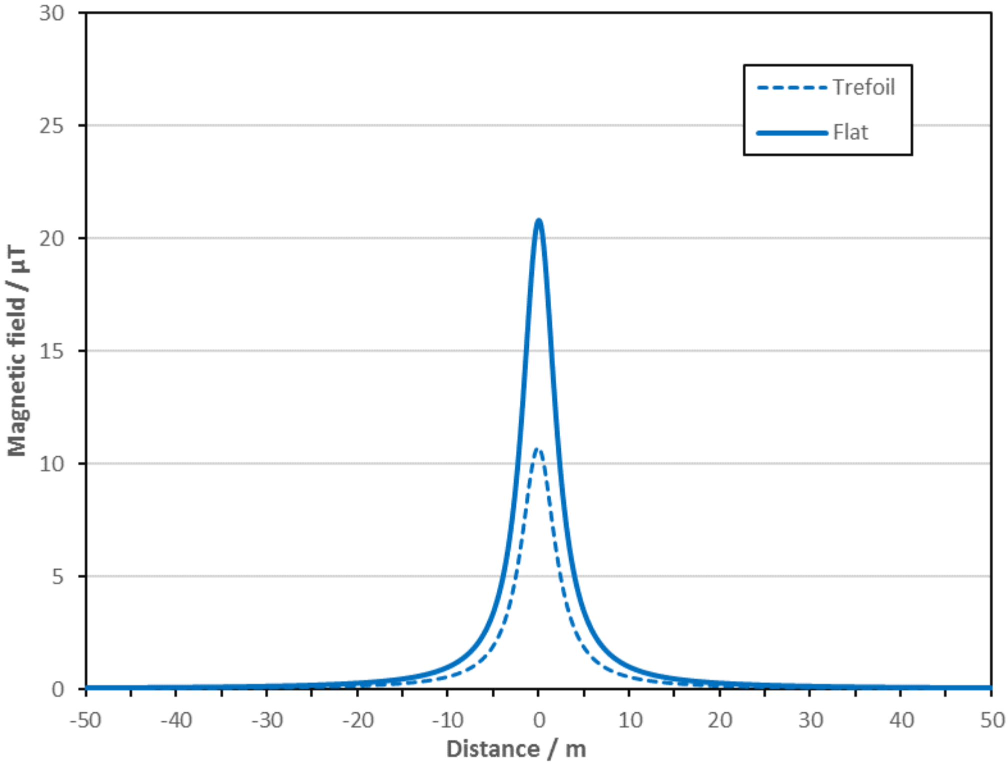


Option 3B

6.2.17. This option considers the magnetic field from the DEP export circuit only, which will be installed in trefoil for the first 50 km of its onshore route, then in a flat formation for the final 10 km.

6.2.18. Figure 6.10 shows the maximum calculated magnetic field at 1 m above ground and how the field reduces with distance for the two installation options. Installing the circuit in flat formation results in slightly higher magnetic fields which reduce less quickly than if the circuit was installed in a trefoil formation. The maximum magnetic field from the trefoil installation was 10.75 µT, or 20.80 µT in a flat formation.

Figure 6.10: Maximum magnetic fields from Option 3B: DEP circuit only, installed in trefoil and flat formation for final 10 km of onshore route.



Third party circuit crossing

6.2.19. Due to the complex nature of the cable crossings, the SEP and DEP option which gave the highest magnetic fields was modelled. Option 1 was modelled to cross the third-party assets, which will give a worst case. All other options would result in lower EMF.

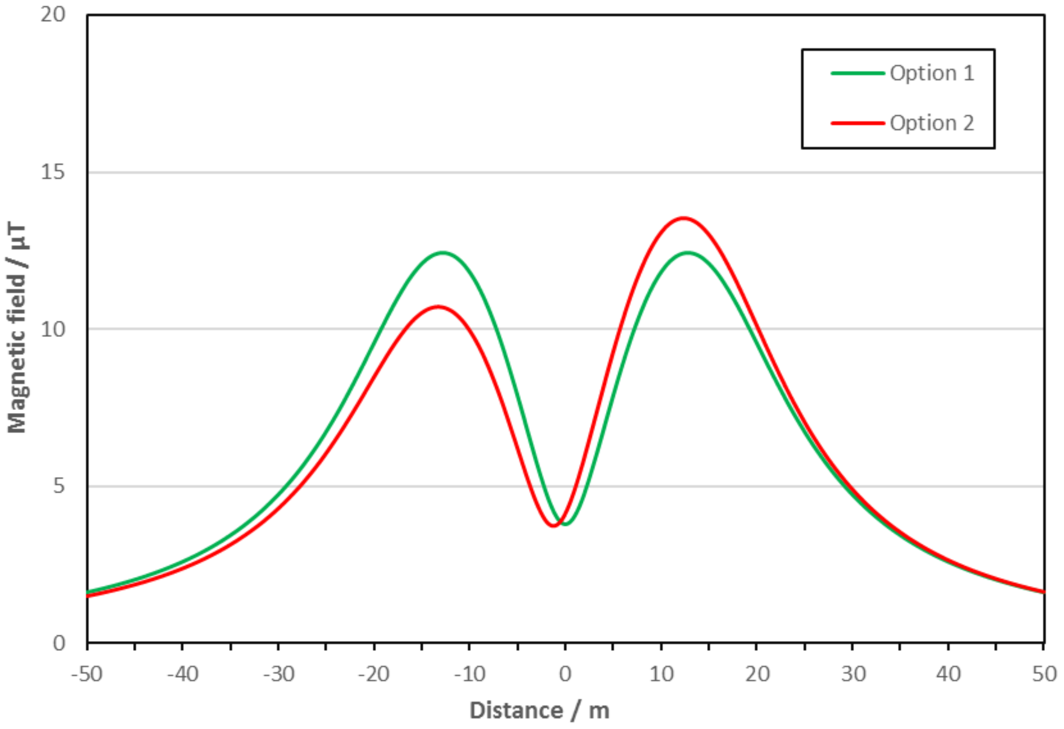
6.2.20. Results will be demonstrated as contour 2D graphs and 1D graphs demonstrating the magnetic field reduction with distance at each crossing point. In all instances, the cables running North-South are the SEP and DEP circuits and those running East-West are the third-party electrical circuits.

Norfolk Vanguard and Norfolk Boreas onshore circuits crossing

6.2.21. The Norfolk Vanguard and Norfolk Boreas circuits are proposed to operate using HVDC technology, therefore the magnetic fields produced by each project will not interact with one another.

6.2.22. To allow the installation of the SEP and DEP circuits under the existing Norfolk Vanguard and Boreas circuits, HDD technology will be used. The cables will be installed at a greater depth, but the phase conductors will increase in distance from one another. The impact of the varied installation technique was modelled. The circuits ratings for both Option 1 and 2 were calculated and are show in Figure 6.11.

Figure 6.11: Maximum calculated magnetic fields from HDD installation. Option 1 circuit ratings indicated by the solid red line; Option 2 circuit ratings indicated by the solid green line.



6.2.23. Installing the cables using HDD, results in slightly lower peak magnetic fields than standard installation but the fields reduce less quickly with distance.

Hornsea Project Three onshore circuits crossing

6.2.24. The Hornsea Project Three onshore cable circuits will be crossed at 90° by the SEP and DEP circuits. It is unclear if HVAC or HVDC technology will be used for the Hornsea Project Three. If HVDC technology is used the calculated fields will be the same as for the Norfolk Vanguard and Norfolk Boreas crossing points.

6.2.25. Assuming HVAC technology is used, the crossing point was modelled using EFC-400. The circuit capacities of Options 1 and 2 were modelled assuming the proposed circuits were 10 m deep, installed using HDD technology and crossing the Hornsea Project Three circuits at 90°. The design parameters of the Hornsea Project Three circuits are provided in Section 4.6 assuming circuit loadings of 1620 A. All calculations have been made at 1m above ground.

6.2.26. Figure 6.12 shows a 2D plot of the magnetic fields from the crossing points of the SEP, DEP and Hornsea Project Three cable circuits where the SEP and DEP circuits have equal capacities (393 MW each); Figure 6.13 shows the total magnetic fields along the SEP and DEP cable circuits for this situation.

6.2.27. Figure 6.14 shows a 2D plot of the magnetic fields from the crossing points of the SEP, DEP and Hornsea Project Three cable circuits where the SEP and DEP circuits have unequal capacities (383 MW and 448 MW); Figure 6.15 shows the total magnetic fields along the SEP and DEP cable circuits for this situation.

6.2.28. There are significant increases in magnetic fields where the circuits cross the Hornsea Project Three circuits, which dominate the total fields. The maximum magnetic field from the Hornsea Project Three cables without the influence of the proposed circuits is 55.2 µT. The SEP and DEP cable circuits are having a modest impact on the magnetic fields already present from the Hornsea Project Three circuits, increasing the maximum to 64.5 µT in the worst-case.

Figure 6.12: Calculated AC Magnetic Fields from Option 1: SEP and DEP AC cable circuits under Hornsea Project Three's AC cable circuits with 90 degree crossing angle: Cable circuits running North-South are SEP and DEP circuits which are below Hornsea Project Three's circuits running East-West. Colour bands represent magnetic field levels in microtesla with scale given below

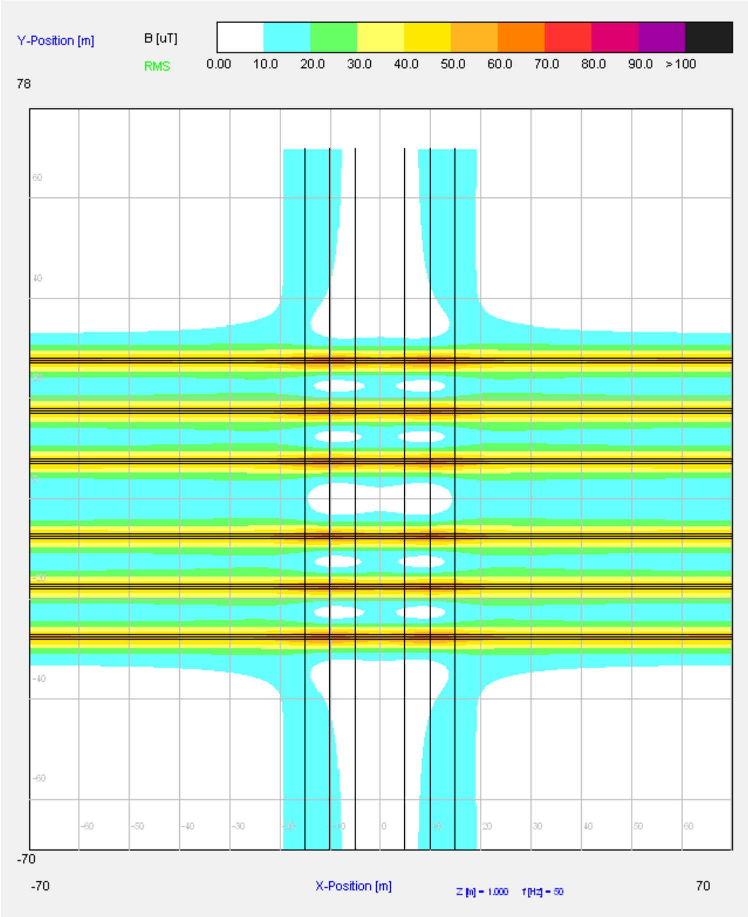


Figure 6.13: **Calculated magnetic fields along the SEP and DEP cable circuits with equal loading (393 MW) crossing the Hornsea Project Three cable circuits.** Arrows indicate where the -proposed DEP and SEP circuits cross the proposed Hornsea Project Three circuits at a 90° angle

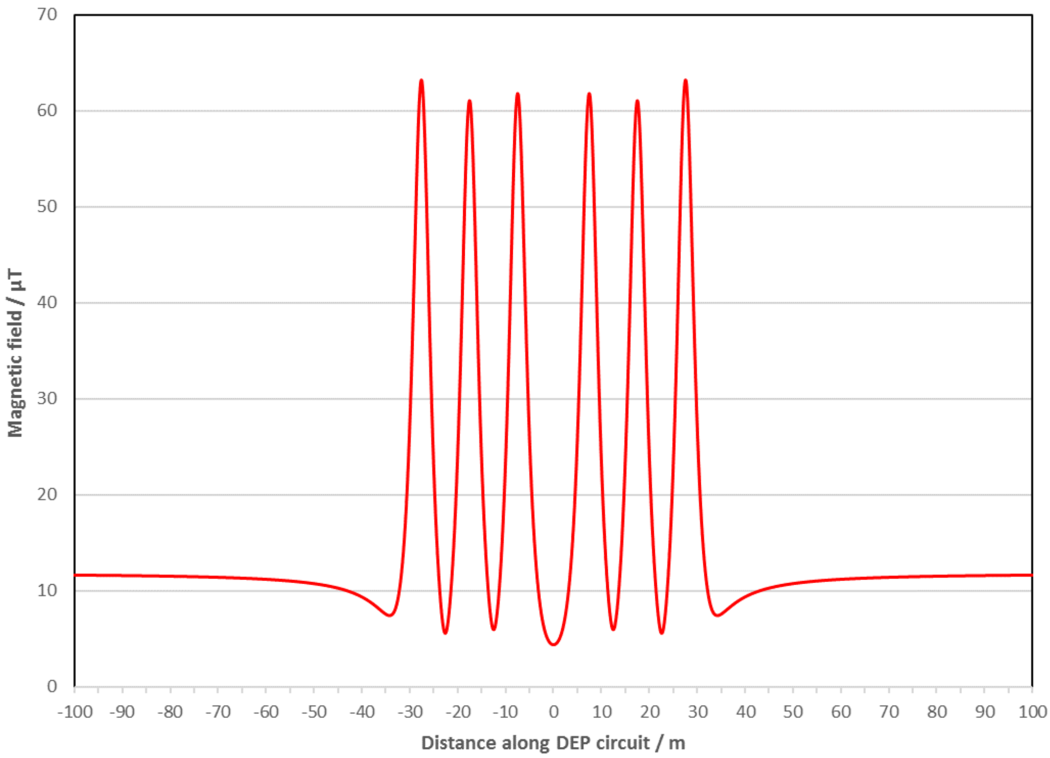


Figure 6.14: Calculated AC Magnetic Fields from Option 3: SEP and DEP AC cable circuits (338 MW & 448 MW) under Hornsea Project Three's AC cable circuits with 90 degree crossing angle: Cable circuits running North-South are SEP and DEP circuits which are below Hornsea Project Three's circuits running East-West. Colour bands represent magnetic field levels in microtesla with scale given below**.**

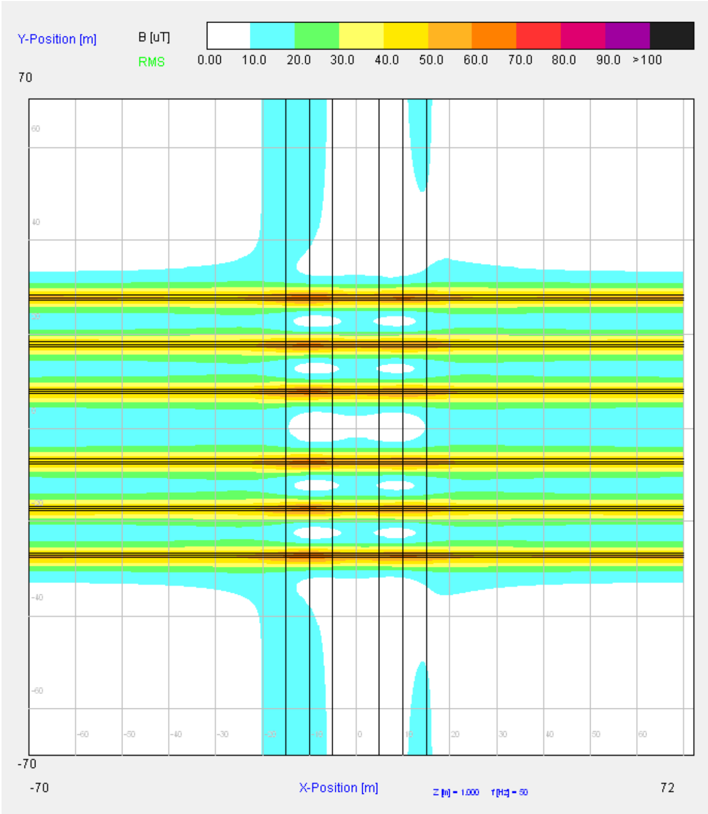
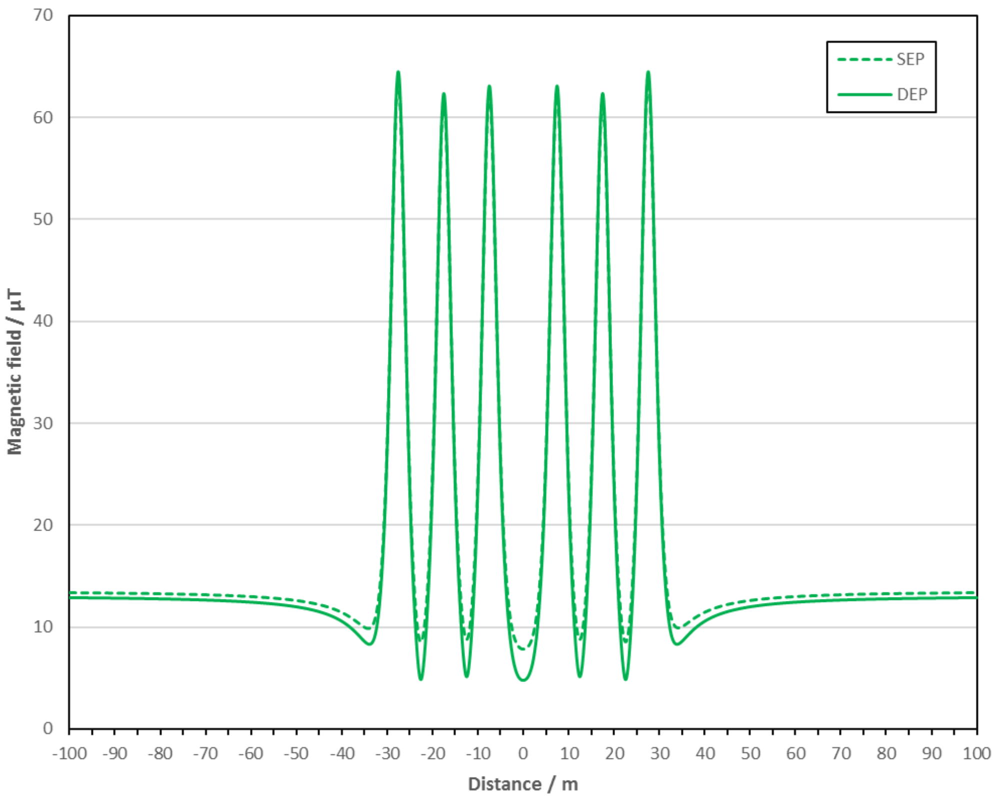


Figure 6.15: Calculated magnetic fields along the SEP and DEP cable circuits with unequal loading (338 MW & 448 MW) crossing the Hornsea Project Three cable circuits. Arrows indicate where the proposed DEP and SEP circuits cross the proposed Hornsea Project Three circuits at a 90° angle



6.3. Summary of Assessment

Offshore summary

6.3.1. The magnetic fields produced by all technology options were highly localised, reducing rapidly from the source due to the singe 3-core cables used. The decrease in magnetic fields occurs both in the vertical water column and horizontally along the seabed. The magnetic fields reduced to below 1 µT at a distance of 5,4 m for all options considered.

6.3.2. Third-party AC circuit crossings resulted in modest increases of AC fields of around 8 µT, which again reduced rapidly with distance, and are localised to the crossing point.

6.3.3. AC magnetic fields induce electric fields within organisms, which vary with the size of the organism and magnetic field strength. The impact of external electric fields, especially those induced by AC fields is unclear, but using worst-case assumptions, the maximum induced electric field in a small shark was 21.7 mV/m.

Onshore summary

6.3.4. For onshore power-frequency (AC) fields, the maximum EMF produced is less than the relevant exposure limit. Therefore, all technology options and the crossing points in all scenarios are compliant with the policies in place in the UK to protect public health and are assessed as having no significant adverse effects.

6.3.5. Due to the number of different scenarios possible and complexity of the crossing points, Table 6.6 gives the maximum AC magnetic field strengths at different distances from the centre of the cable trough(s).

6.3.6. All of the electrical connection options assessed produced magnetic fields significantly below the ICNIRP public exposure limits. Option 1, where both the SEP and DEP circuits had equal exports capacities produced slightly magnetic fields than other options, but the maximum fields were only 9% of the exposure limit.

6.3.7. Where the same technology options cross, i.e. AC with AC, the magnetic field reduces less quickly with distance. This is due to the complex way magnetic fields combine depending on their force and direction. The largest fields were observed where the SEP and DEP circuits cross the proposed Hornsea Project Three cable circuits. The magnetic fields were dominated by those produced by the Hornsea Project Three circuits and the total combined magnetic field was 18% of the ICNIRP guidelines.

Table 6.6: Summary of the calculated maximum magnetic fields and various distances from the outer most conductor for all possible installation scenarios and third-party circuit crossings

		Magnetic field / µT				
Design	Phasing	Maximum	5 m	10 m	25 m	50 m
	Option 1					
Trefoil	RYB RYB	17.27	3.56	1.02	0.17	0.04
	RYB BYR	13.71	2.58	0.72	0.12	0.03
Flat	RYB RYB	33.06	6.42	1.81	0.30	0.08
	RYB BYR	15.72	1.18	0.18	0.01	0.00
	Option 2					
Trefoil	RYB RYB	16.79	3.52	1.00	0.16	0.04
	RYB BYR	13.42	2.60	0.72	0.12	0.03
Trefoil/ Flat	RYB RYB	25.23	5.05	1.38	0.22	0.06
	RYB BYR	18.79	3.32	0.84	0.13	0.03
	Option 3A- SEP circuit only					
Trefoil	n/a	8.50	1.50	0.43	0.07	0.02
	Option 3B- DEP circuit only					
Trefoil	n/a	10.75	1.90	0.55	0.09	0.02
Flat	n/a	20.80	3.42	0.97	0.16	0.04
	HDD Installation					
Option 1	RYB RYB	12.45	11.02	8.07	2.97	1.01
Option 2	RYB RYB	13.52	11.73	8.47	3.04	1.02
	Hornsea 3 crossing point					
Option 1	RYB RYB	63.19				
Option 2	RYB RYB	64.50				

7. Additional Mitigation

Offshore

5.1.1. National Policy Statement EN-3 states that "*Where it is proposed that mitigation measures of the type set out in paragraph 2.6.76 below are applied to offshore export cables to reduce electromagnetic fields (EMF) the residual effects of EMF on sensitive species from cable infrastructure during operation are not likely to be significant. Once installed, operational EMF impacts are unlikely to be of sufficient range or strength to create a barrier to fish movement"*

5.1.2. SEP and DEP proposes to use armoured cables which mitigates both the electric and to an extent the magnetic fields. Cables have also been buried to a depth of 1 m, which again reduces the magnetic fields and is a suggested mitigation technique in NPS EN-3.

5.1.3. NPS EN-3 states a recommended burial depth of 1.5 m to mitigate against EMF impacts, which could be considered. However, the use of single 3-core cables ensures magnetic fields reduce very quickly with distance and ensures that the fields remain highly localised.

Onshore

5.1.4. No mitigation measures for this cable design are necessary as both technology options have been demonstrated to comply with the current public exposure guidelines as detailed in NPS EN-5[2]. If these requirements are met NPS EN-5[2] states that *"no further mitigation should be necessary."*

8. Conclusions

Offshore

5.1.5. There are no formal limits for EMF exposure which apply to the marine environment. The SEP and DEP offshore export circuits are using armoured cables and burial techniques to mitigate the impacts of EMF on marine life. The use of single 3-core cables, compacting the circuit phases, also reduces and localises the EMFs significantly.

5.1.6. The mitigation techniques employed by the project should be sufficient to reduce the impacts of EMF on marine life. The opinions of a marine specialist should be sought.

Onshore

5.1.7. The Government, acting on the advice of authoritative scientific bodies, has put in place appropriate measures to protect the public from EMFs. These measures comprise compliance with the relevant exposure limits, and one additional precautionary measure, optimum phasing, applying only to high-voltage overhead power lines. These measures are set out in a Written Ministerial Statement, National Policy statement EN-5, and various Codes of Practice.

5.1.8. All of the proposed technology options for the SEP and DEP export cables and third-party crossing points would be fully compliant with the Government policy. Specifically, all the fields produced would be below the relevant exposure limits. Therefore, there would be no significant EMF effects resulting from this proposed development.

5.1.9. If it is desirable to reduce the magnetic fields further, consideration of the phase arrangements for each circuit should be made.

ADDENDUM- December 2021

Updated Sheringham Shoal and Dudgeon Windfarm extension projects EMF Assessment

A1. Introduction

This document provides an assessment of electric and magnetic fields (EMFs) associated with the proposed Dudgeon Offshore Wind Farm Extension Project (DEP) and Sheringham Shoal Offshore Wind Farm Extension Project (SEP). The initial assessment considered a range of different design options for the connections and the EMFs produced.

This Addendum provides an updated assessment of EMFs from the SEP and DEP projects, specifically the additional onshore design options considered, and some specific case studies. Additionally, the technology used for the third party Hornsea Project Three connections has been confirmed, allowing confirmation of the EMFs at this crossing location.

A2. Description of additional onshore SEP and DEP designs assessed

SEP and DEP will be developed as HVAC cable circuits operating at 50 Hz. There are currently three electrical system designs being considered, in all options SEP and DEP are electrically separated, with each extension consisting of a 220 kV export circuit.

In addition to the design options considered in the main document, five additional designs were assessed in this Addendum. Where these additional designs could be installed near to existing high voltage electrical circuits, the cumulative impact of both operating simultaneously was assessed. Specifically, the existing Sheringham extension project export circuits are located close to the proposed SEP and DEP routes in some locations. The EMF from both the proposed and existing circuits were assessed, where this was applicable. The existing Sheringham Extension Project cable circuits have been assessed as operating at full 100% capacity in all assessments to give a worst-case scenario.

The additional designs considered are:

- A1: Flat formation Horizontally Directional Drilled design and existing Sheringham Shoal windfarm circuits
- A2: Flat formation direct burial design and existing Sheringham Shoal windfarm circuits
- A3: Trefoil direct burial design and existing Sheringham Shoal windfarm circuits
- A4: Trefoil Horizontally Directional Drilled design and existing Sheringham Shoal windfarm circuits
- A5: Horizontally Directional Drilled 10 m spacing design, 14m burial depth

The design parameters for each onshore design assessed are noted below, including any details of existing assets, if applicable.

The design parameters for the additional proposed SEP and DEP installation techniques used in the calculations are provided in Table A1. For design installations A1 to A4, calculations were performed assuming the existing Sheringham Shoal extension circuits were operating at 100% capacity. The design parameters for the existing Sheringham Shoal Export Project used in all calculations are provided in Table A2. In all cases, the existing Sheringham Export Project circuits were assumed to be 65m from the centre of the DCO boundary of the proposed project, representing a worst case.

A3. Third party crossings

Third party crossings were considered within Section 6 of the main report. There was uncertainty whether HVAC or HVDC technology would be used for the Hornsea Project Three onshore cable circuits. It has been confirmed that the Hornsea Project Three connection will operate using HVDC technology. Therefore, there is no cumulative effect of the two projects crossing, as AC and DC fields do not combine.

The AC magnetic fields from the proposed cables will vary at the crossing points due to the fact the installation techniques vary and will influence the magnetic field. The effect of these varying installation techniques has been assessed in Section 6 and the EMFs will be the same as the Norfolk Vanguard and Norfolk Boreas circuit crossings detailed in Section 6.2.21 to 6.2.23. The maximum calculated fields from this crossing point are shown in Figure 6.11 and summarised in Table 6.6 as HDD installation.

Table A1: SEP and DEP cable geometries and calculation parameters for all electrical designs

	Proposed SEP circuit	Proposed DEP circuit
A1: Flat formation Horizontally Directional Drilled design		
Cable formation	Flat	Flat
Max current per circuit	1085A	1175A
Minimum circuit spacing	10m	
Phase spacing	5m	5m
Minimum burial depth	5m	5m
A2: Flat formation direct burial design		
Cable formation	Flat	Flat
Max current per circuit	1085A	1175A
Minimum circuit spacing	10 m	
Phase spacing	0.25m	0.25m
Minimum burial depth	2m	2m
A3: Trefoil direct burial design		
Cable formation	Trefoil	Trefoil
Max current per circuit	1085A	1175A
Minimum circuit spacing	10m	
Phase spacing	200mm	200mm
Minimum burial depth	1.2m	1.2m
A4: Trefoil Horizontally Directional Drilled design		
Cable formation	Trefoil	Trefoil
Max current per circuit	1085A	1175A
Minimum circuit spacing	20m	
Phase spacing	200mm	200mm
Minimum burial depth	5m	5m
A5: Horizontally Directional Drilled 10 m spacing design		
Cable formation	HDD	HDD
Max current per circuit	1085A	1175A
Minimum circuit spacing	10m	
Phase spacing	10m	10m
Minimum burial depth	14m	14m

Table A2: Existing Sheringham cable geometries and calculation parameters for all electrical designs

Existing Sheringham Export Project design parameters	
No. of circuits	2
Cable formation	Trefoil
Max. current per circuit	840A
Circuit spacing	1m
Minimum burial depth	1.3m

A4. Assessment of EMFs from SEP and DEP extensions projects

The methods used throughout this assessment are described fully in Section 5, and this addendum uses the same methodology.

Electric fields

The earthed metallic shield that is applied over the insulation of the AC cables, which is an inherent part of the cable design, ensures that the electric field is contained within the cable, not leaking out.

The proposed underground cables produce no external electric fields, so are not considered further.

Magnetic fields

Based on the cable design parameters provided in Tables A1 & A2 and performed according to the provisions of the Code of Practice[3], the AC magnetic fields from each of the proposed installation techniques were calculated. Calculations were performed at a typical operation capacity for the cables (50% of maximum load), to represent the typical daily exposures you would expect to measure on most days. However, worst case scenarios were also calculated to demonstrate that even at maximum capacity (100% of maximum load), the cable circuits would not exceed the Government exposure limits set to protect members of the public. All calculations were performed using the phase arrangement RYB BYR.

Design installations A1 to A4 were also calculated assuming the existing Sheringham Shoal circuits were operating at full capacity and were located 65m from the centre of the proposed SEP and DEP circuits.

A4.1. Typical daily loading calculations for A1, A2, A3 and A4 designs

Figures A1 and A2 demonstrate the calculated magnetic field at 1 m above ground for designs A1 to A4, where the SEP and DEP circuits are operating at 50% load. The existing Sheringham Shoal circuit is operating at 100% load, demonstrating the cumulative impact of the circuits operating together. Figure A2 shows the calculated magnetic fields from each design compared to the Government public exposure limit.

Figure A1: Typical (50% loading) calculated magnetic field for four separate installation designs (A1, A2, A3, A4) for the DEP and SEP circuits. The existing Sheringham shoal circuit was calculated with 100% loading located at -65m from the centre of the new SEP and DEP circuits. Each of the four installation methods have been calculated separately. The minimum DCO boundary is marked in blue shading.

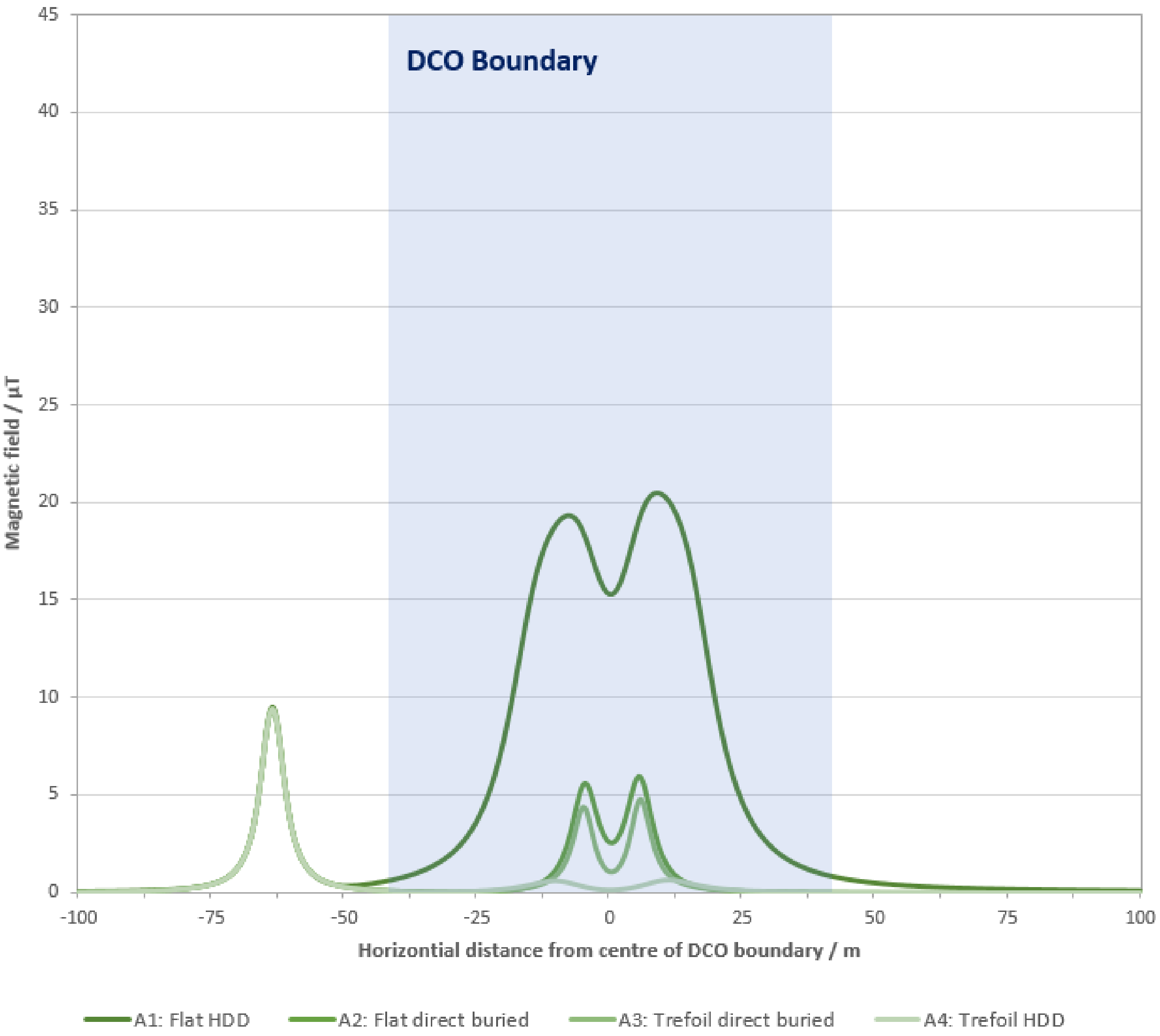
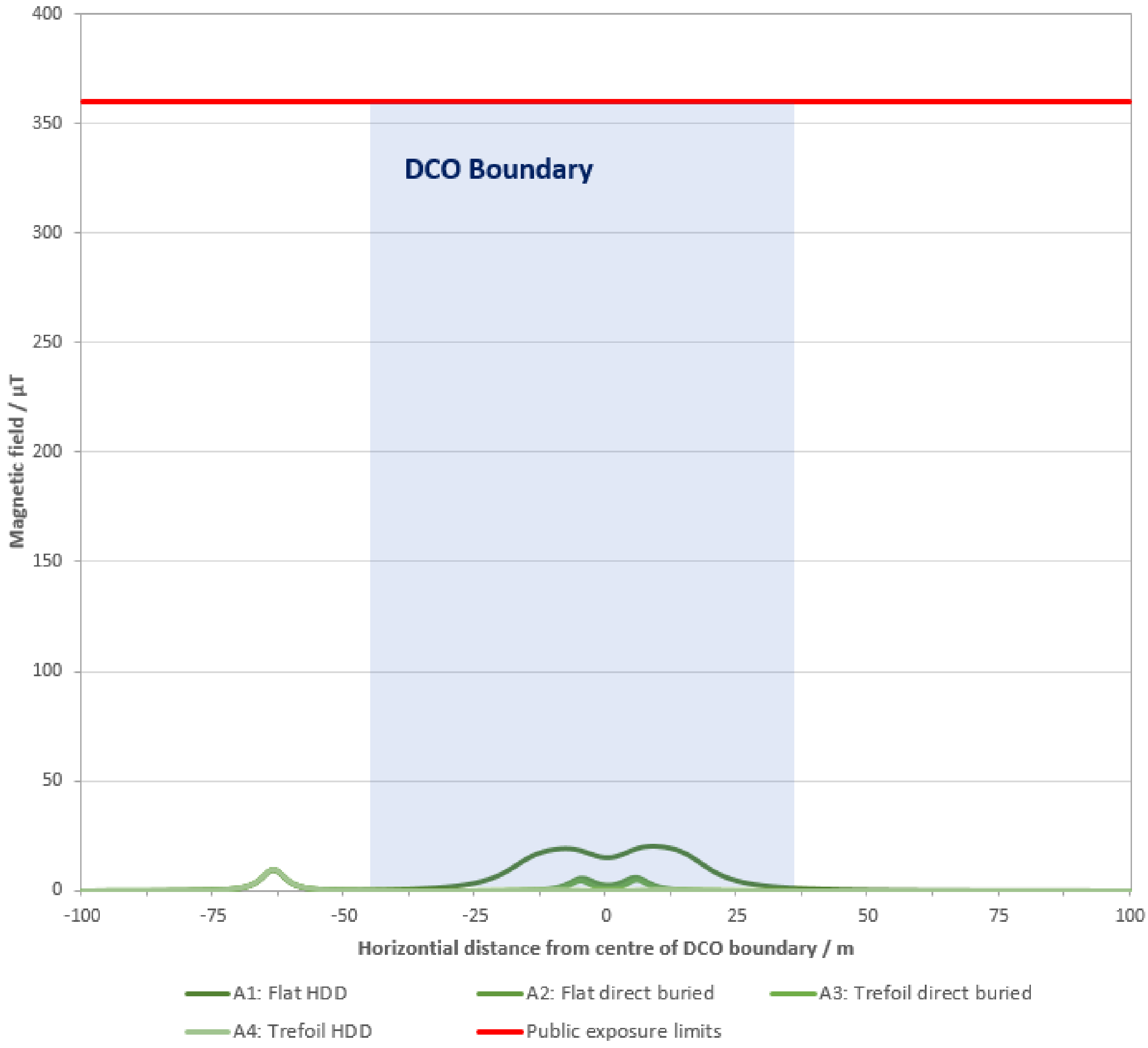


Figure A2: Typical (50% loading) calculated magnetic field for four separate installation designs for the DEP and SEP circuits. The existing Sheringham shoal circuit was calculated with 100% loading located at -65m from the centre of the new SEP and DEP circuits. Each of the four installation methods have been calculated separately. The minimum DCO boundary is marked in blue shading. This includes the Government public exposure limit (Red line).



A4.2. Maximum worst-case loading calculations for A1, A2, A3 and A4 designs

Figures A3 and A4 demonstrate the calculated magnetic field at 1 m above ground for designs A1 to A4, where the SEP and DEP circuits are operating at 100% load. The existing Sheringham Shoal circuit is also operating at 100% load, demonstrating the cumulative impact of both operating at full capacity. The figure indicates the maximum magnetic field and reduction with distance including the existing Sheringham Shoal circuits. Figure A4 shows the calculated magnetic fields from each design compared to the Government public exposure limit.

Figure A3: Maximum (100% loading) calculated magnetic field for four separate installation designs (A1, A2, A3, A4) for the DEP and SEP circuits. The existing Sheringham shoal circuit was calculated with 100% loading located at -65m from the centre of the new SEP and DEP circuits. Each of the four installation methods have been calculated separately.

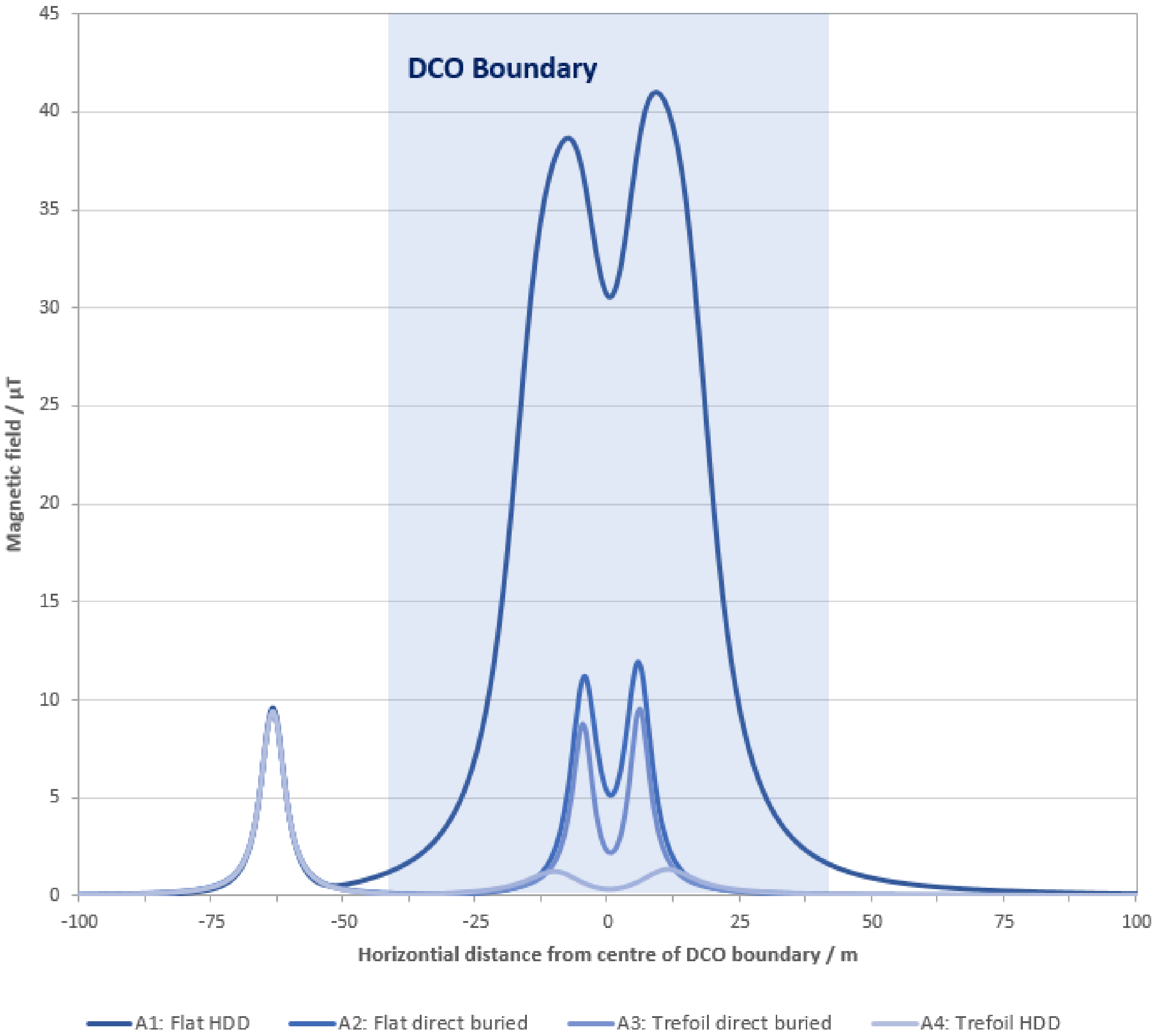
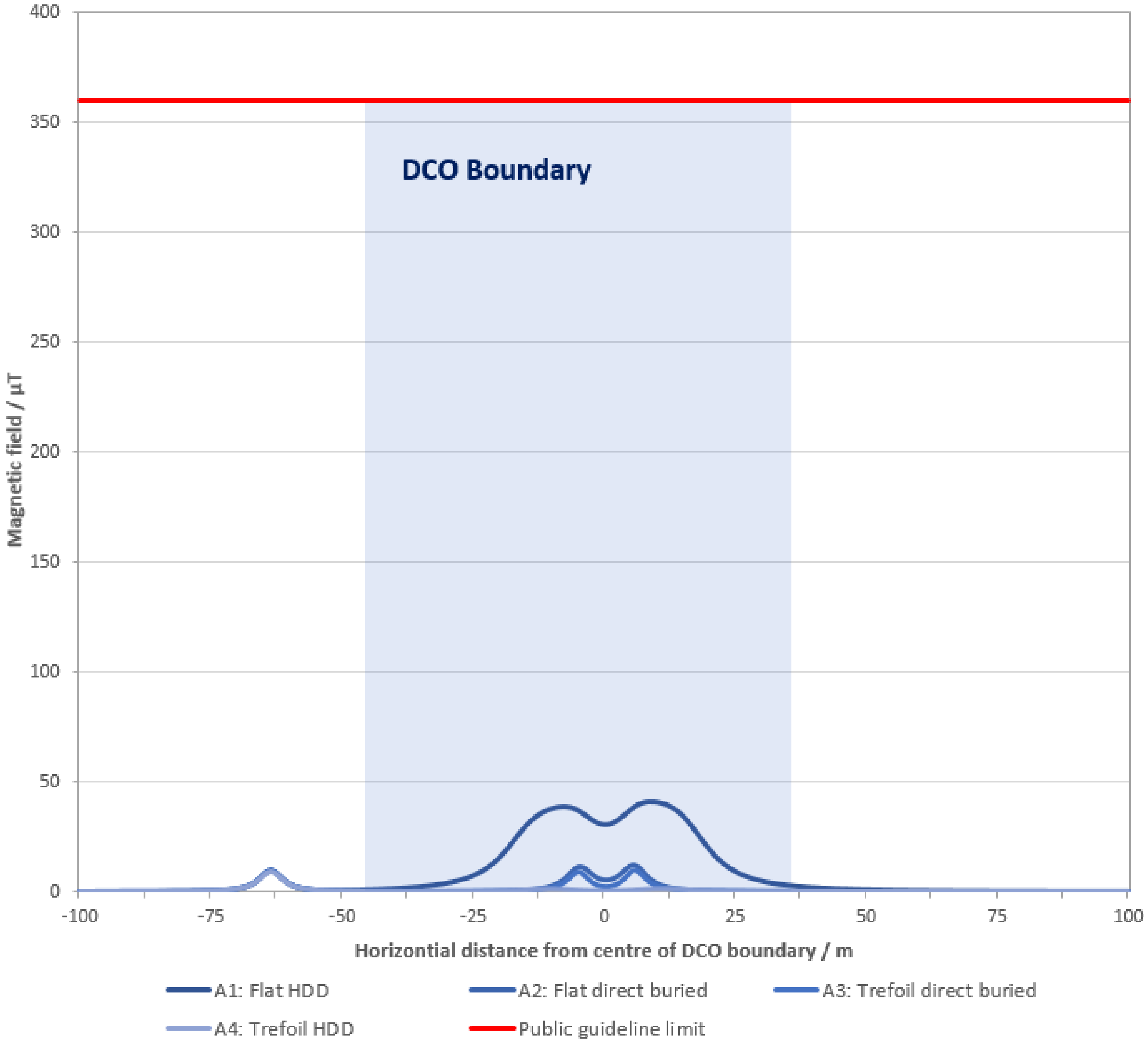


Figure A4: Typical (100% loading) calculated magnetic field for four separate installation designs for the DEP and SEP circuits. The existing Sheringham shoal circuit was calculated with 100% loading located at -65m from the centre of the new SEP and DEP circuits. Each of the four installation methods have been calculated separately. The minimum DCO boundary is marked in blue shading. This includes the Governments public exposure limit (Red line)



A4.3. Typical and maximum worst-case loading calculations for A5 design

Figure A5 demonstrates the calculated magnetic field at 1 m above ground for A5 design, where the SEP and DEP circuits are operation at 100% and 50% load. The figure indicates the maximum magnetic field and reduction with distance for the A5 design where the cables are buried 14m deep. This type of HDD installation, where the individual phases could be installed 10m apart isn't considered close to the existing Sheringham Shoal circuits, so the cumulative impacts were not necessary to consider for this design.

Figure A5: Maximum (100% loading) and typical (50% loading) calculated magnetic field for the A5 installation design of the DEP and SEP circuits. The minimum DCO boundary is marked in blue shading.

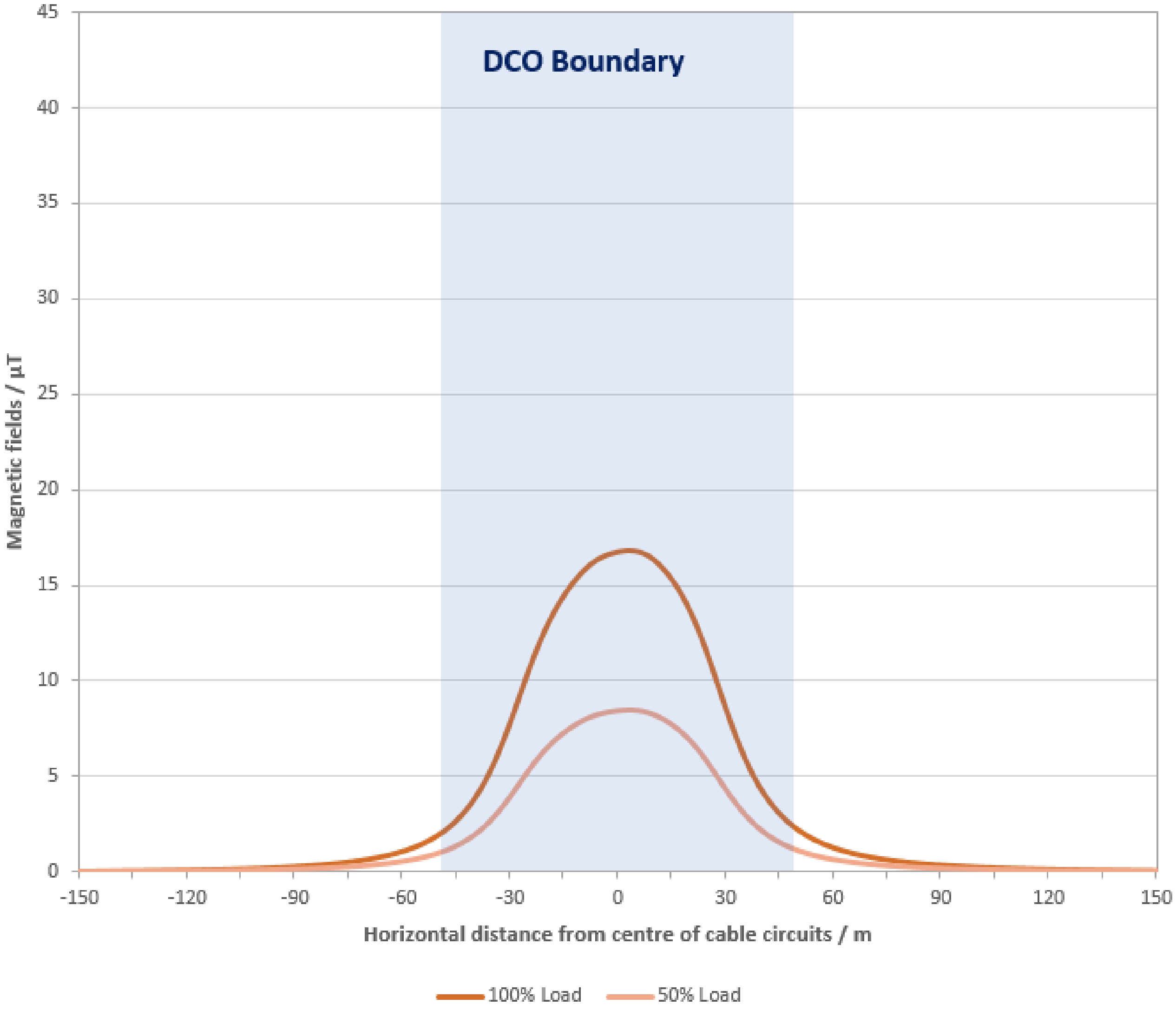
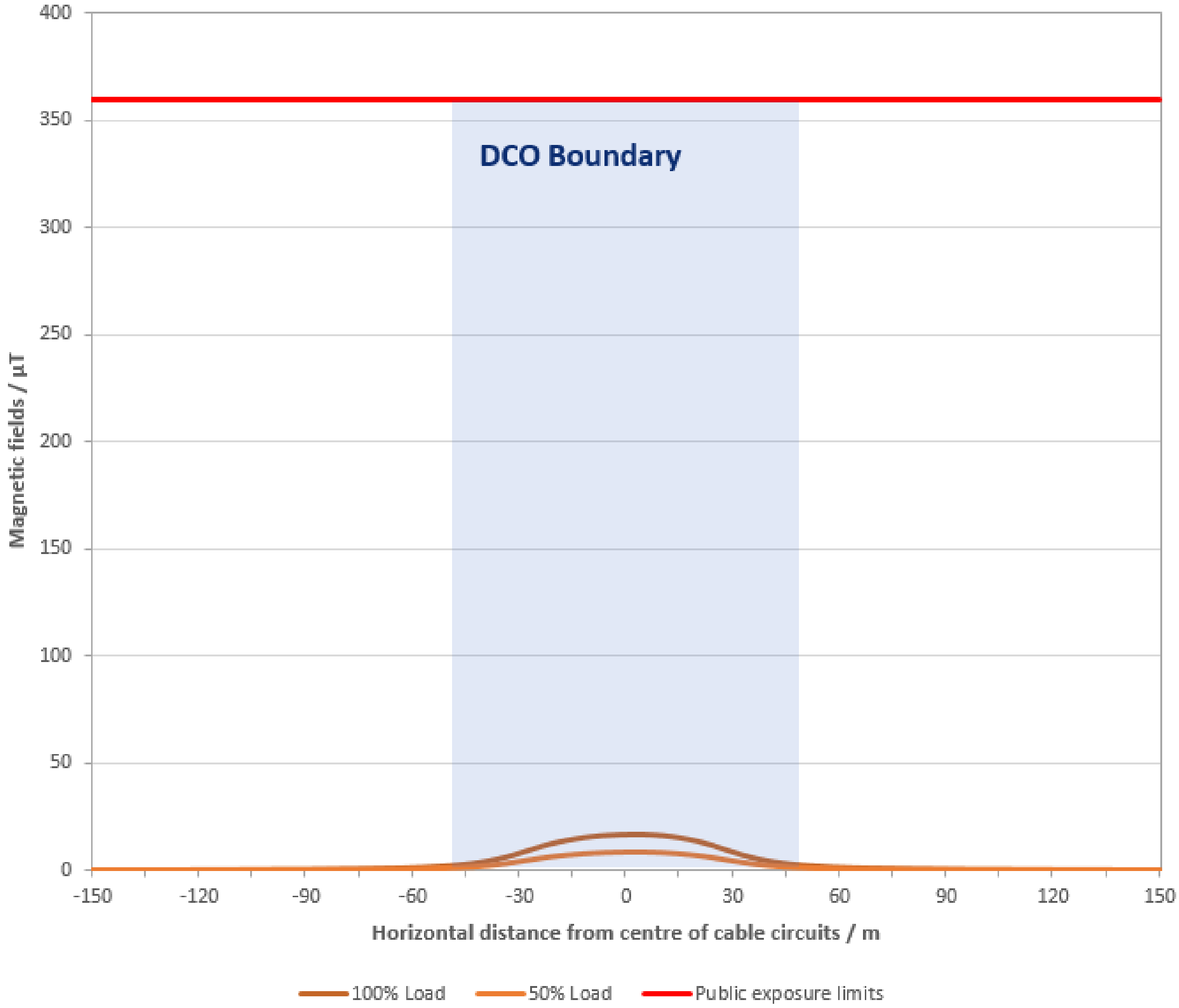


Figure A6: Maximum (100% loading) and typical (50% loading) calculated magnetic field for the A5 installation design of the DEP and SEP circuits. The minimum DCO boundary is marked in blue shading. This includes the Governments public exposure limit (Red line)



A4.5. Assessment summary

All the design options assessed produced magnetic fields significantly below the ICNIRP public exposure limits. This was the case, even in worst case conditions, assuming the circuits were carrying the maximum load producing the highest magnetic fields possible.

Table A3 summarises the maximum and typical calculated magnetic fields from design options A1 to A5. These calculations indicate the maximum magnetic fields within the DCO boundary, and the calculated magnetic fields at the DCO boundary and various distances from that boundary.

Design A1 produced the highest magnetic fields compared to options A2 to A5, but the maximum fields were only 11% of the public exposure limit, directly above the cables. This reduced to 0.5% of the exposure limits at the DCO boundary. All other design produced lower maximum magnetic fields. The magnetic fields from designs A2, A3 and A4 reduce to a background level (see section 3.1.3) at the DCO boundary.

Each design impacts the magnetic fields the cables will produce. Where the individual cables are closer together, the magnetic fields from each cable interacts with one another, partially cancelling each other, leading to lower fields. The HDD cables are installed with a 5 to 10 metre separation, compared to the compact HDD trefoil design which accounts for the difference in magnetic field observed.

The cumulative impacts of design options A1 to A4 were considered, where these designs could be located close to the existing Sheringham Shoal export cables. The proposed and existing cables were assessed assuming both were operating at full capacity, presenting a very worst case, with a minimum separation distance of 65m between the new and proposed projects. As the calculations demonstrate, there is an insignificant effect of the circuits on one another. When both are operating at 100% load each of the circuits fully complies with the ICNIRP Public exposure limits.

In summary, the calculated maximum magnetic fields for all designs assessed throughout the report are less than the public exposure limit. Therefore, all technology options, crossing points and cumulative impacts in all scenarios are compliant with the policies in place in the UK to protect public health and are assessed as having no significant adverse effects.

Table A3: Summary of the calculated maximum and typical magnetic fields for design options A1 to A5. These calculations indicate the maximum magnetic fields with the DCO boundary, and the calculated magnetic fields at the DCO boundary and various distances from that boundary.

	Magnetic field / μT			
Loading	Maximum	Edge of DCO Boundary	10 m from DCO boundary	25 m from DCO boundary
A1: Flat formation Horizontally Directional Drilled design				
Maximum (100%)	40.99	1.73	0.84	0.39
Typical (50%)	20.49	0.86	0.42	0.20
A2: Flat formation direct burial design				
Maximum (100%)	11.72	0.04	0.02	0.01
Typical (50%)	5.96	0.02	0.01	0.01
A3: Trefoil direct burial design				
Maximum (100%)	9.58	0.07	0.04	0.03
Typical (50%)	4.80	0.03	0.02	0.01
A4: Trefoil Horizontally Directional Drilled design				
Maximum (100%)	1.34	0.08	0.05	0.03
Typical (50%)	0.67	0.04	0.02	0.01
A5: Horizontally Directional Drilled 10 m spacing design				
Maximum (100%)	16.83	2.26	1.29	0.66
Typical (50%)	8.42	1.13	0.64	0.33

A5: Conclusions

The Government, acting on the advice of authoritative scientific bodies, has put in place appropriate measures to protect the public from EMFs. These measures comprise compliance with the relevant exposure limits, and one additional precautionary measure, optimum phasing, applying only to high-voltage overhead power lines. These measures are set out in a Written Ministerial Statement, National Policy statement EN-5, and various Codes of Practice.

All of the proposed technology options for the SEP and DEP export cables and third-party crossing points would be fully compliant with the Government policy. Specifically, all the fields produced would be significantly below the relevant exposure limits. Therefore, there would be no significant EMF effects resulting from this proposed development. For most designs evaluated, the magnetic fields reduce to a background level at the DCO boundary.

ADDENDUM B – January 2024

Updated Sheringham Shoal and Dudgeon Windfarm extension projects EMF Assessment

B1. Introduction

This document provides an assessment of electric and magnetic fields (EMFs) associated with the proposed Dudgeon Offshore Wind Farm Extension Project (DEP) and Sheringham Shoal Offshore Wind Farm Extension Project (SEP). The initial assessment considered a range of different design options for the connections and the EMFs produced.

This Addendum provides an updated assessment of EMFs from the SEP and DEP projects, specifically the increased Transmission Entry Capacity from 719 MW to 950 MW. Additionally, the technology used for the third party Hornsea Project Three connections has been confirmed as using HVDC technology, allowing confirmation of the EMFs at this crossing location.

B2. Description of additional onshore SEP and DEP designs assessed

SEP and DEP will be developed as HVAC cable circuits operating at 50 Hz. The SEP and DEP cable circuits are electrically separated, with each extension consisting of a 220 kV export circuit.

In addition to the design options considered in the main document and Addendum A, increased ratings for the five onshore cable designs highlighted in Addendum A are considered. Where these additional designs could be installed near to existing high voltage electrical circuits, the cumulative impact of both operating simultaneously was assessed. Specifically, the existing Sheringham extension project export circuits are located close to the proposed SEP and DEP routes in some locations. The EMF from both the proposed and existing circuits were assessed, where this was applicable. The existing Sheringham Extension Project cable circuits have been assessed as operating at full 100% capacity in all assessments to give a worst-case scenario.

The designs considered at the increased rating are:

- B1: Flat formation Horizontally Directional Drilled design and existing Sheringham Shoal windfarm circuits
- B2: Flat formation direct burial design and existing Sheringham Shoal windfarm circuits
- B3: Trefoil direct burial design and existing Sheringham Shoal windfarm circuits
- B4: Trefoil Horizontally Directional Drilled design and existing Sheringham Shoal windfarm circuits
- B5: Horizontally Directional Drilled 10 m spacing design, 14m burial depth

The design parameters for each onshore design assessed are noted below, including any details of existing assets, if applicable.

The design parameters for the additional proposed SEP and DEP installation techniques used in the calculations are provided in Table B1. For design installations B1 to B4, calculations were performed assuming the existing Sheringham Shoal extension circuits were operating at 100% capacity. The design parameters for the existing Sheringham Shoal Export Project used in all calculations are provided in Table B2. In all cases, the existing Sheringham Export Project circuits were assumed to be 65m from the centre of the DCO boundary of the proposed project, representing a worst case.

B3. Third party crossings

Third party crossings were considered within Section 6 of the main report. There was uncertainty whether HVAC or HVDC technology would be used for the Hornsea Project Three onshore cable circuits. It has been confirmed that the Hornsea Project Three connection will operate using HVDC technology. Therefore, there is no cumulative effect of the two projects crossing, as AC and DC fields do not combine.

The AC magnetic fields from the proposed cables will vary at the crossing points due to the fact the installation techniques vary and will influence the magnetic field. The effect of these varying installation techniques has been assessed in Section 6 and the EMFs will be the same as the Norfolk Vanguard and Norfolk Boreas circuit crossings detailed in Section 6.2.21 to 6.2.23. The maximum calculated fields from this crossing point are shown in Figure 6.11 and summarised in Table 6.6 as HDD installation.

Table B1: SEP and DEP cable geometries and calculation parameters for all electrical designs

	Proposed SEP circuit	Proposed DEP circuit
B1: Flat formation Horizontally Directional Drilled design		
Cable formation	Flat	Flat
Max current per circuit	1300A	1300A
Minimum circuit spacing	10m	
Phase spacing	5m	5m
Minimum burial depth	5m	5m
B2: Flat formation direct burial design		
Cable formation	Flat	Flat
Max current per circuit	1300A	1300A
Minimum circuit spacing	10 m	
Phase spacing	250mm	250mm
Minimum burial depth	1.2m	1.2m
B3: Trefoil direct burial design		
Cable formation	Trefoil	Trefoil
Max current per circuit	1300A	1300A
Minimum circuit spacing	10m	
Phase spacing	200mm	200mm
Minimum burial depth	1.2m	1.2m
B4: Trefoil Horizontally Directional Drilled design		
Cable formation	Trefoil	Trefoil
Max current per circuit	1300A	1300A
Minimum circuit spacing	20m	
Phase spacing	200mm	200mm
Minimum burial depth	5m	5m
B5: Horizontally Directional Drilled 10 m spacing design		
Cable formation	HDD	HDD
Max current per circuit	1300A	1300A
Minimum circuit spacing	10m	
Phase spacing	10m	10m
Minimum burial depth	14m	14m

Table B2: Existing Sheringham cable geometries and calculation parameters for all electrical designs

Existing Sheringham Export Project design parameters	
No. of circuits	2
Cable formation	Trefoil
Max. current per circuit	840A
Circuit spacing	1m
Minimum burial depth	1.3m

B4. Assessment of EMFs from SEP and DEP extensions projects

The methods used throughout this assessment are described fully in Section 5, and this addendum uses the same methodology.

Electric fields

The earthed metallic shield that is applied over the insulation of the AC cables, which is an inherent part of the cable design, ensures that the electric field is contained within the cable, not leaking out.

The proposed underground cables produce no external electric fields, so are not considered further.

Magnetic fields

Based on the cable design parameters provided in Tables B1 & B2 and performed according to the provisions of the Code of Practice[3], the AC magnetic fields from each of the proposed installation techniques were calculated. Calculations were performed at a typical operation capacity for the cables (50% of maximum load), to represent the typical daily exposures you would expect to measure on most days. However, worst case scenarios were also calculated to demonstrate that even at maximum capacity (100% of maximum load), the cable circuits would not exceed the Government exposure limits set to protect members of the public. All calculations were performed using the phase arrangement RYB BYR.

Design installations B1 to B4 were also calculated assuming the existing Sheringham Shoal circuits were operating at full capacity and were located 65m from the centre of the proposed SEP and DEP circuits.

B4.1. Typical daily loading calculations for B1, B2, B3 and B4 designs

Figures B1 and B2 demonstrate the calculated magnetic field at 1 m above ground for designs B1 to B4, where the SEP and DEP circuits are operating at 50% load. The existing Sheringham Shoal circuit is operating at 100% load, demonstrating the cumulative impact of the circuits operating together. Figure B2 shows the calculated magnetic fields from each design compared to the Government public exposure limit.

Figure B1: Typical (50% loading) calculated magnetic field for four separate installation designs (B1, B2, B3, B4) for the DEP and SEP circuits. The existing Sheringham shoal circuit was calculated with 100% loading located at -65m from the centre of the new SEP and DEP circuits. Each of the four installation methods have been calculated separately. The minimum DCO boundary is marked in blue shading.

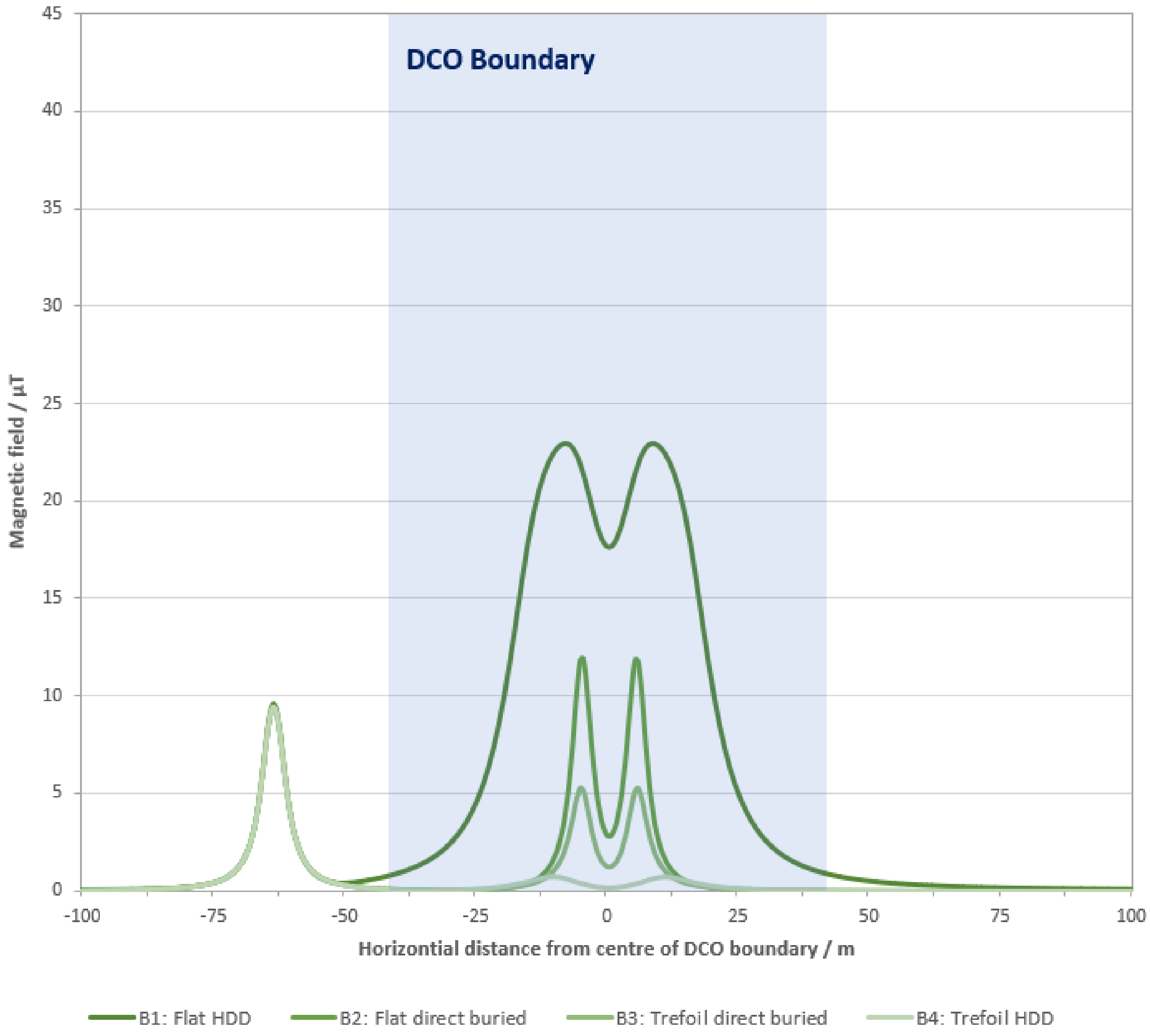
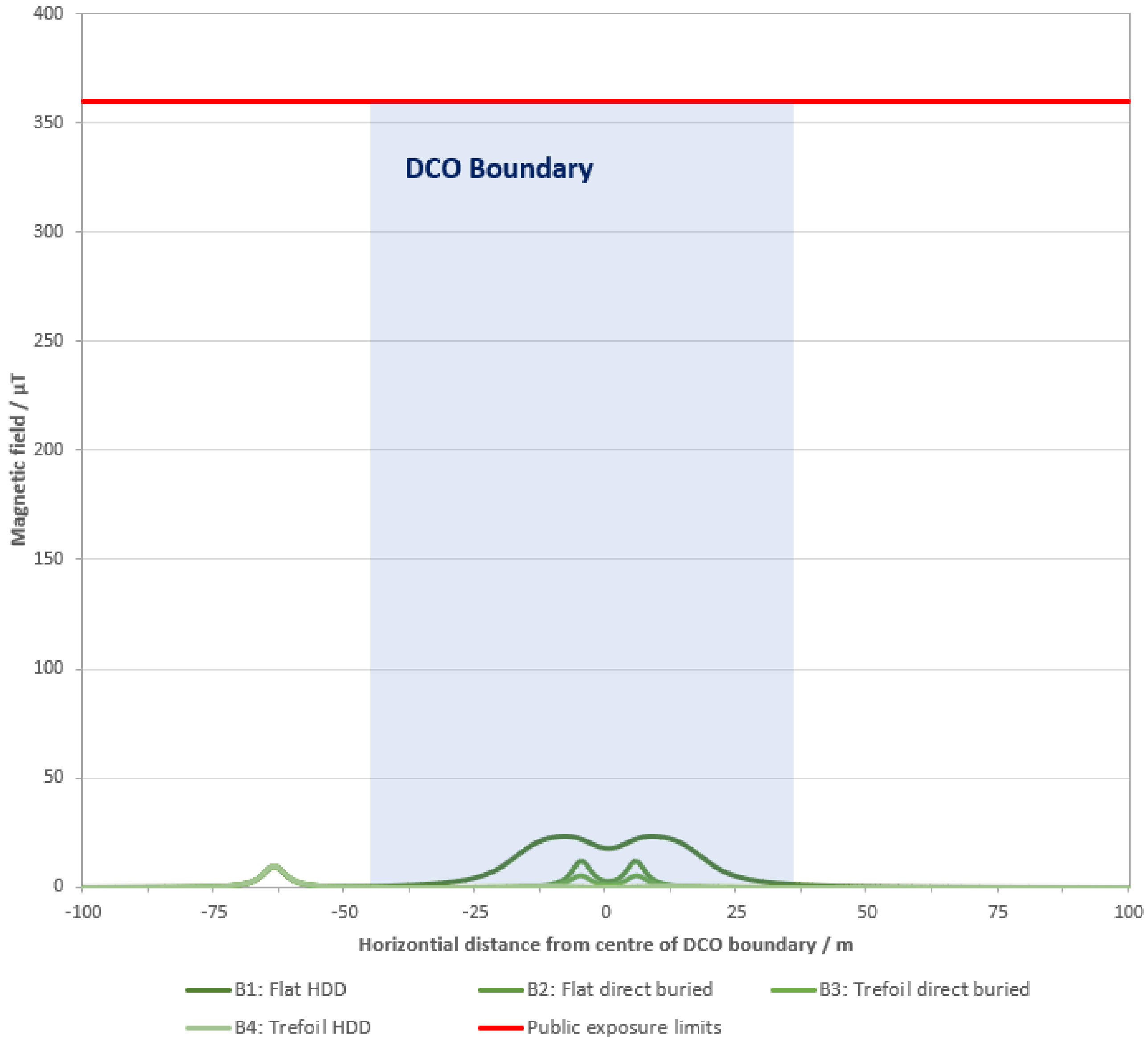


Figure B2: Typical (50% loading) calculated magnetic field for four separate installation designs for the DEP and SEP circuits. The existing Sheringham shoal circuit was calculated with 100% loading located at -65m from the centre of the new SEP and DEP circuits. Each of the four installation methods have been calculated separately. The minimum DCO boundary is marked in blue shading. This includes the Government public exposure limit (Red line).



B4.2. Maximum worst-case loading calculations for B1, B2, B3 and B4 designs

Figures B3 and B4 demonstrate the calculated magnetic field at 1 m above ground for designs B1 to B4, where the SEP and DEP circuits are operating at 100% load. The existing Sheringham Shoal circuit is also operating at 100% load, demonstrating the cumulative impact of both operating at full capacity. The figure indicates the maximum magnetic field and reduction with distance including the existing Sheringham Shoal circuits. Figure B4 shows the calculated magnetic fields from each design compared to the Government public exposure limit.

Figure B3: Maximum (100% loading) calculated magnetic field for four separate installation designs (B1, B2, B3, B4) for the DEP and SEP circuits. The existing Sheringham shoal circuit was calculated with 100% loading located at -65m from the centre of the new SEP and DEP circuits. Each of the four installation methods have been calculated separately.

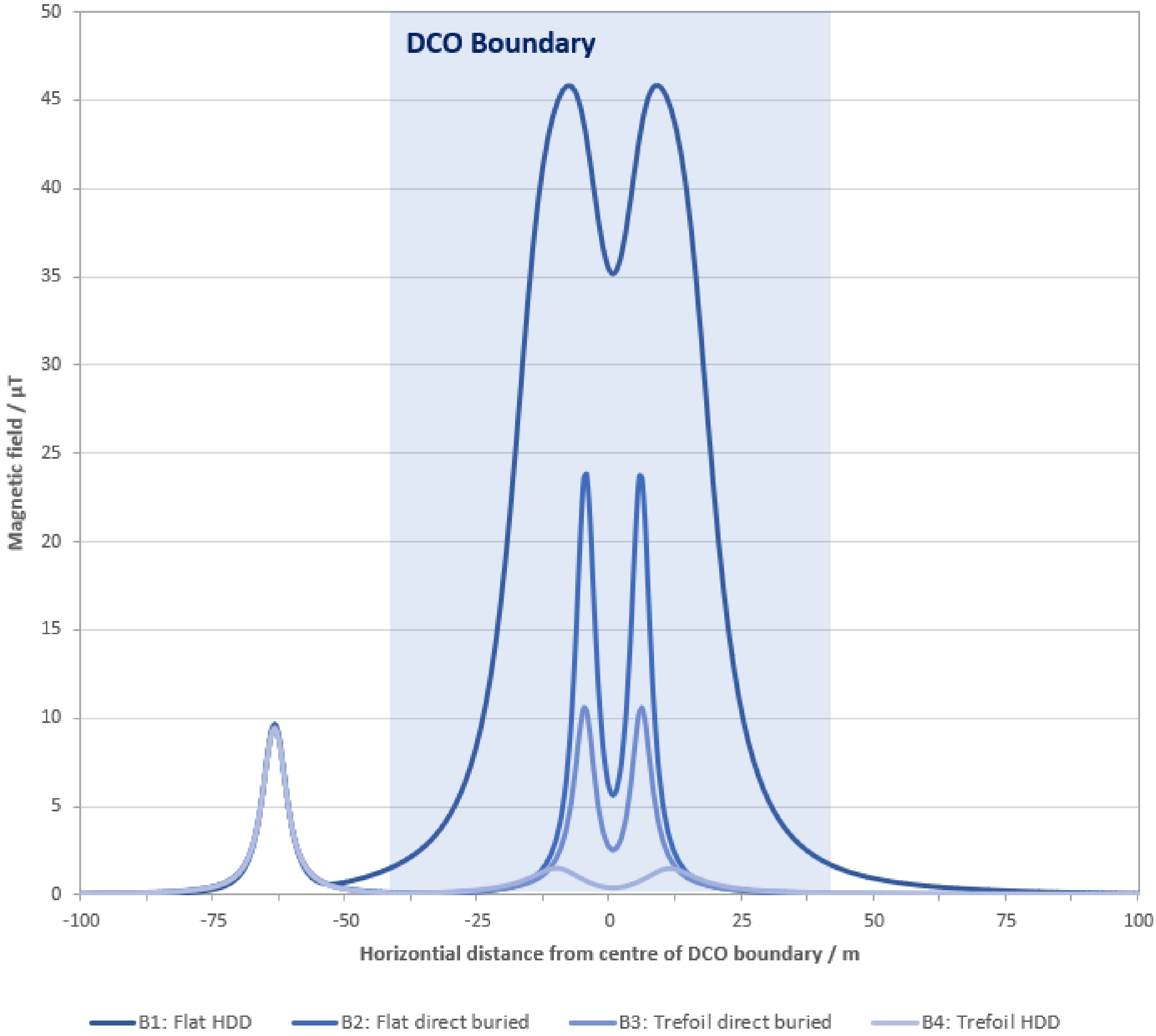
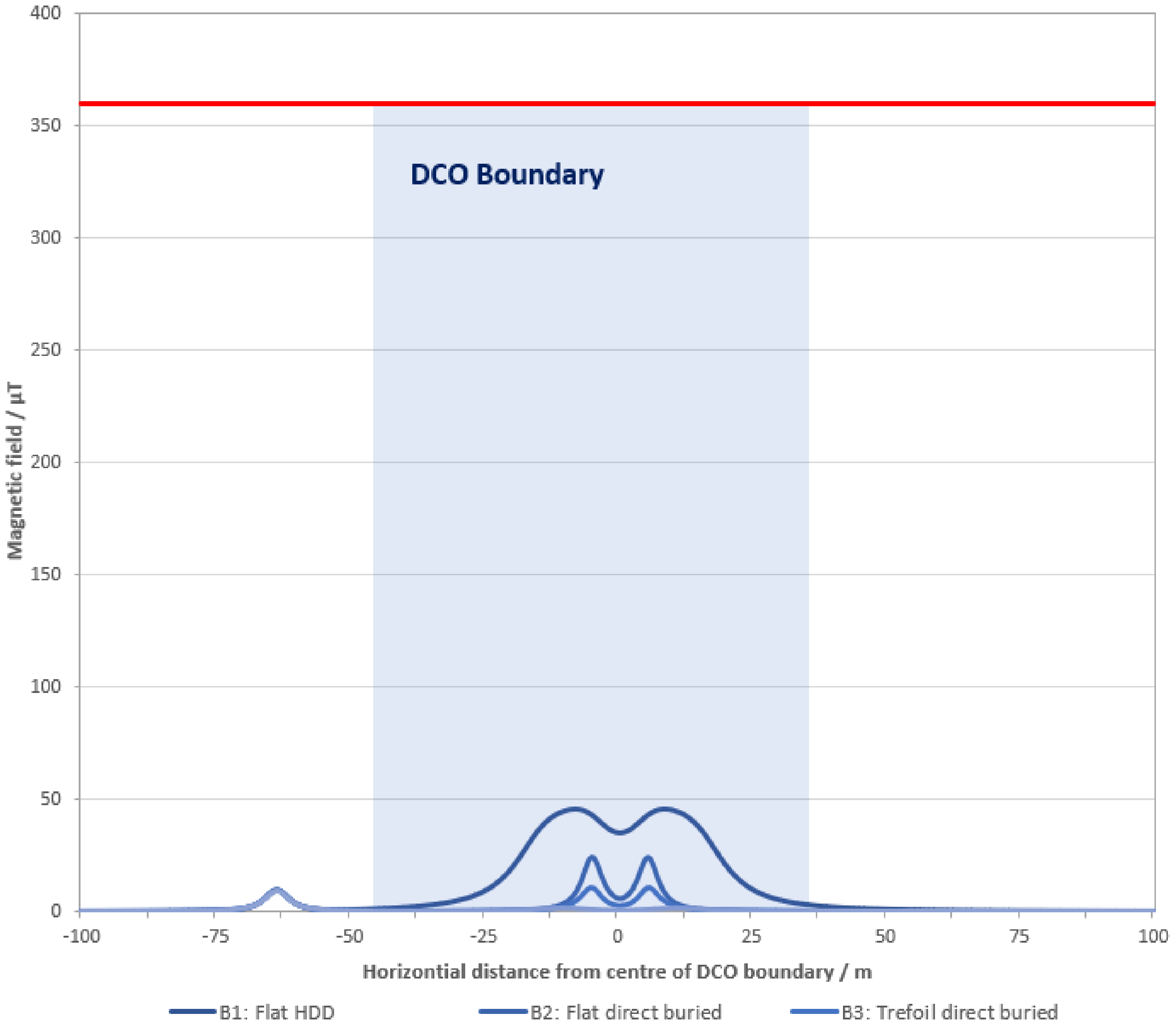


Figure B4: Typical (100% loading) calculated magnetic field for four separate installation designs for the DEP and SEP circuits. The existing Sheringham shoal circuit was calculated with 100% loading located at -65m from the centre of the new SEP and DEP circuits. Each of the four installation methods have been calculated separately. The minimum DCO boundary is marked in blue shading. This includes the Governments public exposure limit (Red line)



B4.3. Typical and maximum worst-case loading calculations for B5 design

Figure B5 demonstrates the calculated magnetic field at 1 m above ground for B5 design, where the SEP and DEP circuits are operation at 100% and 50% load. The figure indicates the maximum magnetic field and reduction with distance for the B5 design where the cables are buried 14m deep. This type of HDD installation, where the individual phases could be installed 10m apart isn't considered close to the existing Sheringham Shoal circuits, so the cumulative impacts were not necessary to consider for this design.

Figure B5: Maximum (100% loading) and typical (50% loading) calculated magnetic field for the B5 installation design of the DEP and SEP circuits. The minimum DCO boundary is marked in blue shading.

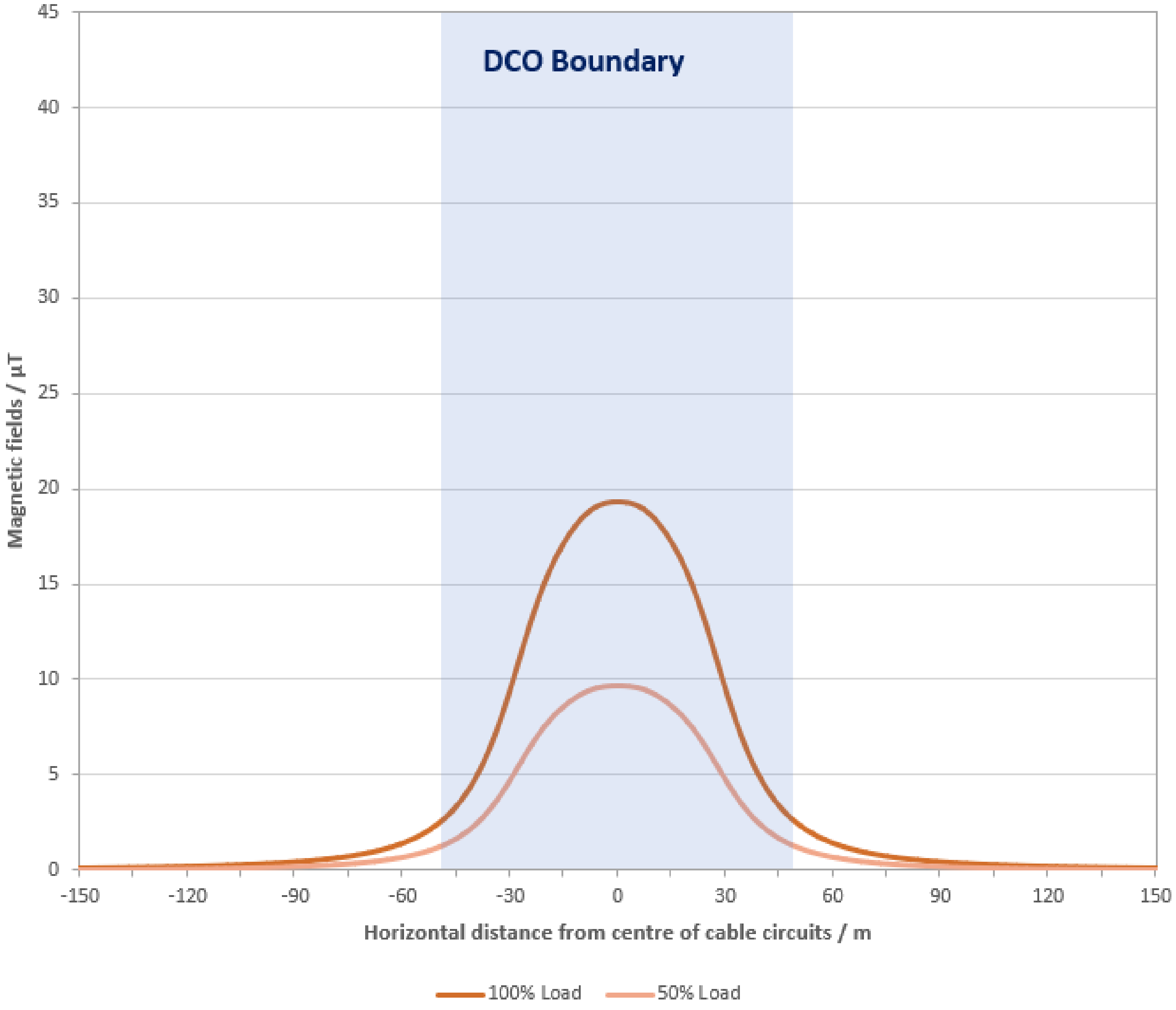
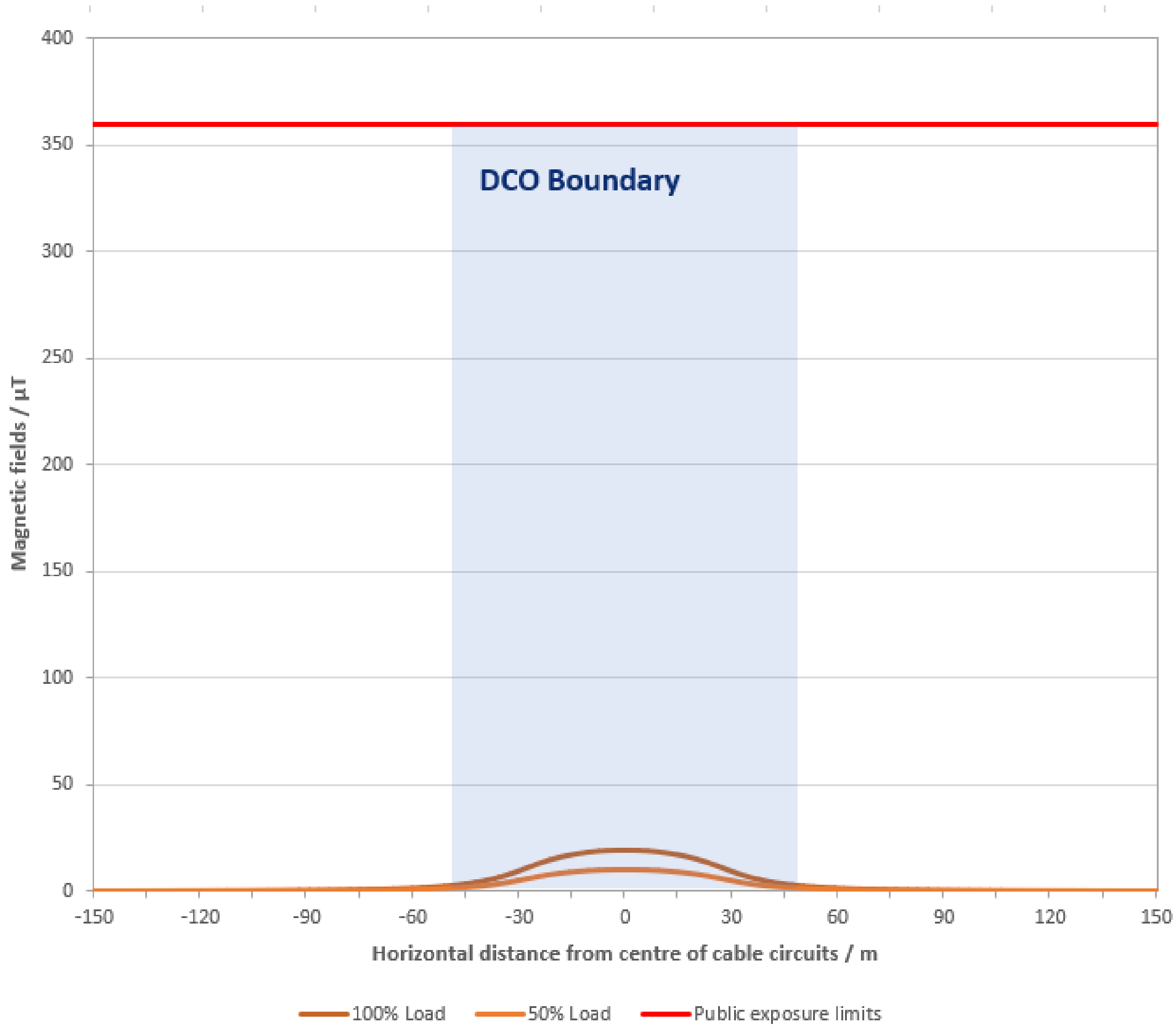


Figure B6: Maximum (100% loading) and typical (50% loading) calculated magnetic field for the B5 installation design of the DEP and SEP circuits. The minimum DCO boundary is marked in blue shading. This includes the Governments public exposure limit (Red line)



B4.5. Assessment summary

All the design options assessed produced magnetic fields significantly below the ICNIRP public exposure limits. This was the case, even in worst case conditions, assuming the circuits were carrying the maximum load producing the highest magnetic fields possible.

Table B3 summarises the maximum and typical calculated magnetic fields from design options B1 to B5. These calculations indicate the maximum magnetic fields within the DCO boundary, and the calculated magnetic fields at the DCO boundary and various distances from that boundary.

Design B1 produced the highest magnetic fields compared to options B2 to B5, but the maximum fields were only 13% of the public exposure limit, directly above the cables. This reduced to 0.5% of the exposure limits at the DCO boundary. All other design produced lower maximum magnetic fields. The magnetic fields from designs B2, B3 and B4 reduce to a background level (see section 3.1.3) at the DCO boundary.

Each design impacts the magnetic fields the cables will produce. Where the individual cables are closer together, the magnetic fields from each cable interacts with one another, partially cancelling each other, leading to lower fields. The HDD cables are installed with a 5 to 10 metre separation, compared to the compact HDD trefoil design which accounts for the difference in magnetic field observed.

The cumulative impacts of design options B1 to B4 were considered, where these designs could be located close to the existing Sheringham Shoal export cables. The proposed and existing cables were assessed assuming both were operating at full capacity, presenting a very worst case, with a minimum separation distance of 65m between the new and proposed projects. As the calculations demonstrate, there is an insignificant effect of the circuits on one another. When both are operating at 100% load each of the circuits fully complies with the ICNIRP Public exposure limits.

In summary, the calculated maximum magnetic fields for all designs assessed throughout the report are less than the public exposure limit. Therefore, all technology options, crossing points and cumulative impacts in all scenarios are compliant with the policies in place in the UK to protect public health and are assessed as having no significant adverse effects.

Table B3: Summary of the calculated maximum and typical magnetic fields for design options B1 to B5. These calculations indicate the maximum magnetic fields with the DCO boundary, and the calculated magnetic fields at the DCO boundary and various distances from that boundary.

	Magnetic field / µT			
Loading	Maximum	Edge of DCO Boundary	10 m from DCO boundary	25 m from DCO boundary
B1: Flat formation Horizontally Directional Drilled design				
Maximum (100%)	45.81	1.84	0.88	0.40
Typical (50%)	22.91	0.92	0.44	0.20
B2: Flat formation direct burial design				
Maximum (100%)	23.8	0.04	0.02	0.01
Typical (50%)	11.91	0.02	0.01	0.01
B3: Trefoil direct burial design				
Maximum (100%)	10.37	0.08	0.05	0.03
Typical (50%)	5.19	0.04	0.02	0.01
B4: Trefoil Horizontally Directional Drilled design				
Maximum (100%)	1.48	0.09	0.05	0.03
Typical (50%)	0.75	0.04	0.03	0.01
B5: Horizontally Directional Drilled 10 m spacing design				
Maximum (100%)	19.29	3.90	2.05	0.94
Typical (50%)	9.64	1.95	1.02	0.47

B5: Conclusions

The Government, acting on the advice of authoritative scientific bodies, has put in place appropriate measures to protect the public from EMFs. These measures comprise compliance with the relevant exposure limits, and one additional precautionary measure, optimum phasing, applying only to high-voltage overhead power lines. These measures are set out in a Written Ministerial Statement, National Policy statement EN-5, and various Codes of Practice.

All of the proposed technology options for the SEP and DEP export cables and third-party crossing points would be fully compliant with the Government policy. Specifically, all the fields produced would be significantly below the relevant exposure limits. Therefore, there would be no significant EMF effects resulting from this proposed development. For most designs evaluated, the magnetic fields reduce to a background level at the DCO boundary.

B6: Cambridge to Norwich Railway Crossing

The proposed Dudgeon Offshore Wind Farm Extension Project (DEP) and Sheringham Shoal Offshore Wind Farm Extension Project (SEP) cable circuits cross the Network Rail Breckland line which runs between Cambridge and Norwich. This section provides an assessment of the calculated field levels for maximum circuit ratings and the cable designs proposed for this area.

B6.1 Cable design and assessment methodology

The cables will be installed using trenchless technology crossing the railway perpendicularly. An assessment of the magnetic fields produced at the crossing point is provided for the proposed installation geometries detailed in Table B4 using maximum circuit ratings.

Underground cables produce no external electric field because of the metallic sheath which surrounds the cable and are therefore not considered further.

Figures B9 details the typical profile of the cables for the B7 Rail Crossing Type 2 design and the aerial photograph with cable locations marked from Drawing no. C282-MU-Z-XS-00159-01.

Table B4: SEP and DEP cable geometries and calculation parameters for Breckland line crossing

	Proposed SEP circuit	**Proposed DEP circuit**
	B6: Rail Crossing Type 1	
Cable formation	Trefoil	Trefoil
Max current per circuit	1300A	1300A
Minimum circuit spacing	10m	
Phase spacing	200mm	200mm
Minimum burial depth	10m	10m
	B7: Rail Crossing Type 2	
Cable formation	Flat	Flat
Max current per circuit	1300A	1300A
Minimum circuit spacing	10 m	
Phase spacing	5m	5m
Minimum burial depth	10m	10m

The magnetic field produced by the currents in an electrical circuit falls with distance from the circuit. The magnetic field is highest at the closest point to the conductors and falls rapidly with distance.

For sources of fields with a simple, defined geometry, such as underground cables, calculations are the best way of assessing fields and are acceptably accurate. The calculations of fields presented here follow the provisions specified in the Code of Practice on Compliance[3] and were performed using specialised computer software that has been validated against direct measurement[31] and commercially available software package EFC-400 (Narda).

These calculations assume that there is no attenuation of magnetic fields from any surrounding material (e.g., seabed, earth, grout mattresses, etc.) and that there are no unbalanced currents flowing along the outer sheaths of the cables. Calculations were performed at 100% load conditions for minimum burial distance.

B6.2 Railway crossing magnetic field assessment

Figures B7 and B8 demonstrates the calculated magnetic field at ground level (0m) for Rail crossing designs B6 and B7, where the SEP and DEP circuits are operation at 100% load. Details of the maximum magnetic fields at various distances from the installation are detailed in Table B5 for each of the proposed designs.

[31] J. Swanson, Magnetic fields from transmission lines: Comparison of calculations and measurements, IEE Proceedings.-Generator Transmission Distribution, 1995, 142 (5), p481.

Figure B7: Maximum (100% loading) calculated magnetic field for the B6 Rail Crossing Type 1 installation design of the DEP and SEP circuits. The blue shading indicates the location of the railway which crosses perpendicular to the cables.

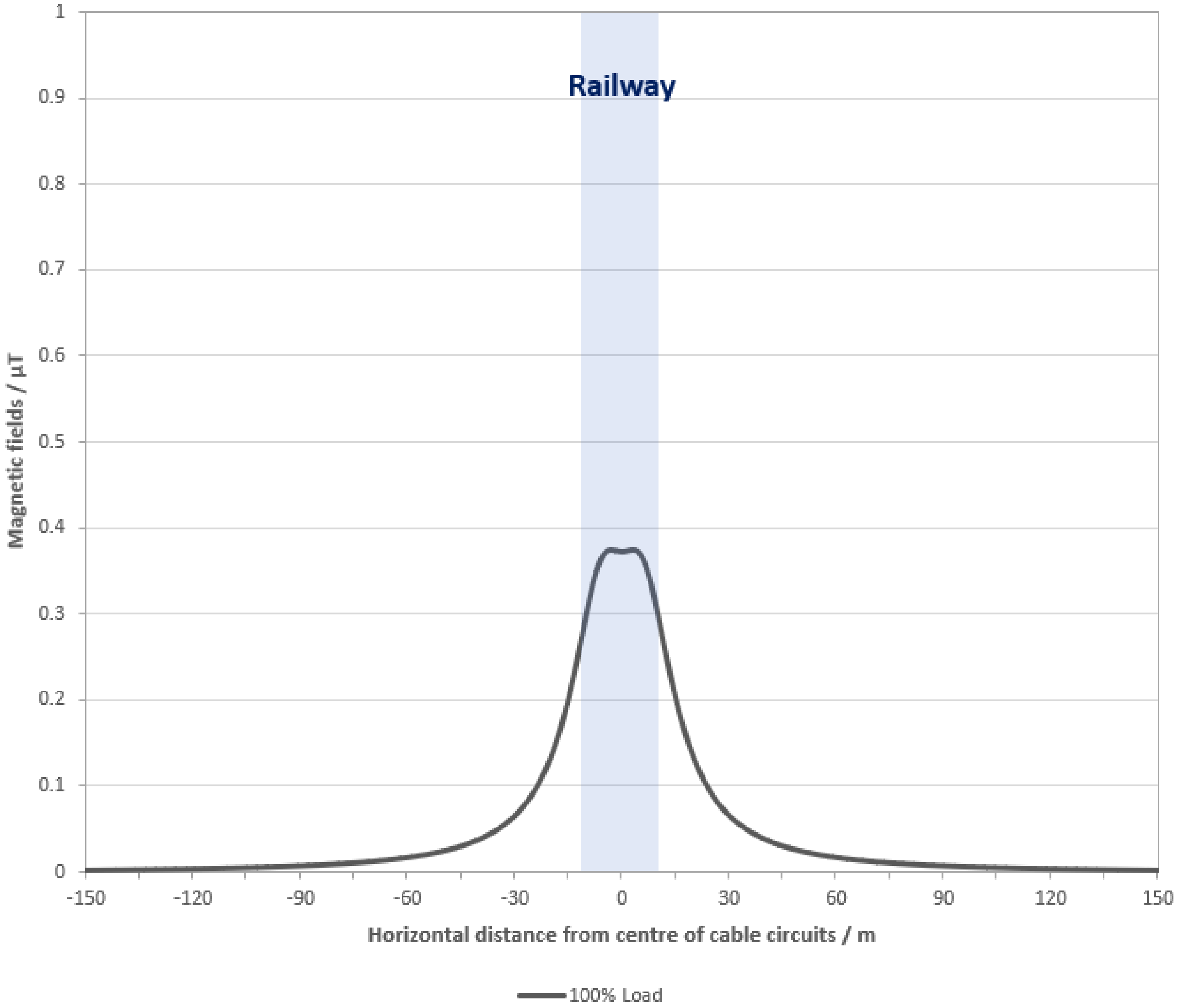


Figure B8: Maximum (100% loading) calculated magnetic field for the B7 Rail Crossing Type 2 installation design of the DEP and SEP circuits. The blue shading indicates the location of the railway which crosses perpendicular to the cables.

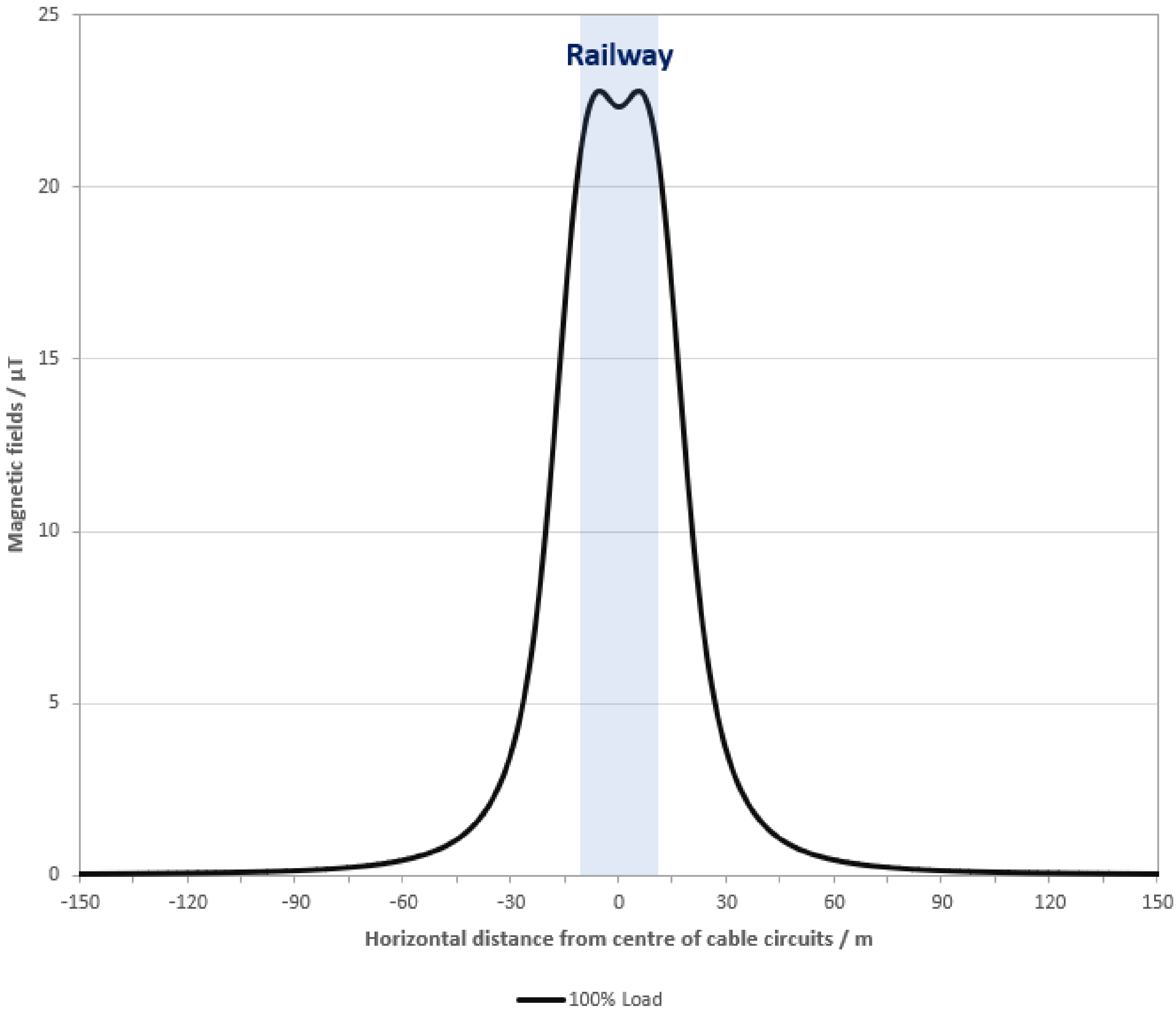


Table B5: SEP and DEP cable geometries and calculation parameters for Breckland line crossing

	Magnetic field / µT		
Loading	Maximum	Edge of railway track	20 m from cable centre
B6: Rail Crossing Type 1			
Maximum (100%)	0.37	0.37	0.13
Typical (50%)	0.19	0.18	0.08
B7: Rail Crossing Type 1			
Maximum (100%)	22.8	22.8	10.7
Typical (50%)	11.4	11.4	5.4

B6.3 Railway crossing assessment conclusions

Rail crossing design type 2 (B7) produced the highest magnetic fields at the railway location of 19.8 µT at 100% load. Rail crossing type 1 design (B6) result in significantly lower magnetic fields producing 0.28 µT at the railway location. The reduction in magnetic fields is due to the cables being in close proximity in the trefoil arrangement, enabling the magnetic fields to cancel each other to a degree from each phase.

The cables cross perpendicular to the railway track and there is no parallelism between the cable circuits and railway.

Figure B9: Typical profile of the cable crossing under the railway crossing and the aerial photograph with cable locations marked. Two circuits are detailed, each consisting of three cables, indicated by the pink and blue lines.