6 Alpha Associates Limited
Quatro House, Frimley Road
Camberley, Surrey
GU16 7ER
Tel: +44 (0) 203 371 3900
Web: www.6alpha.com

# Unexploded Ordnance Threat and Risk Assessment with Risk Mitigation Strategy

**Project:** ***A05 Brittany***

Meeting the requirements of the UK's Construction Industry Research and Information Association's

UXO Risk Management Framework:

"Assessment and Management of the Unexploded Ordnance Risk in the Marine Environment (C754)"

**6 Alpha Project Number:** 8811

**Report Version:** Client Draft V1.0

**Author(s):** L. Hayes

**Quality Reviewer:** S. Cooke

**Released By:** L. Gregory

**Date of Release:** 14th April 2021

## Disclaimer



The material presented within this document is for information purposes only and comprises a declaration of the author's professional judgement. It does not constitute a warranty or guarantee, expressed or implied, nor does it relieve any other party of its responsibility to abide by contract documents, applicable codes, standards, regulations, or ordinances. 6 Alpha Associates nor any of its employees assumes any legal responsibility for the accuracy or completeness of the source reference material used in the compilation of this document. 6 Alpha Associates nor any of its employees will not be held liable in any way for any loss or damage incurred by third parties directly or indirectly deriving from the interpretation relating to geophysical, geological, or geotechnical information held within this document.

This UXO threat and risk assessment is considered a living document. Should the proposed geotechnical investigation, cable installation and/or wind turbine installation methodologies change, further evidence of UXO sources be found, or if UXO is found during these or other operations, then this assessment for the Study Site is to be reassessed and updated by 6 Alpha Associates Ltd.

## Document Control

**Report Version:** 8811_UXOTARA_with_RMS_A05 Brittany_DNVGL_Client Draft_V1.0

| Version | Date | Author(s) | GIS Technician | Reviewed by | Released by |
|---|---|---|---|---|---|
| Client Draft V1.0 | 14/04/2021 | LH | LH | SC | LG |

# Executive Summary

## Study Site

*DNVGL* has commissioned *6 Alpha Associates* to deliver a desk-based Unexploded Ordnance (UXO) threat and risk assessment, for Geotechnical Investigation (GI), cable installation and Wind Turbine Generator (WTG) foundation installation, at the *A05 Brittany Offshore Wind Farm (OWF)*. A risk mitigation strategy for the proposed GI operations has also been commissioned.

The proposed location of the *A05 Brittany OWF* has been provided by the Client and has been presented at Figure 1.

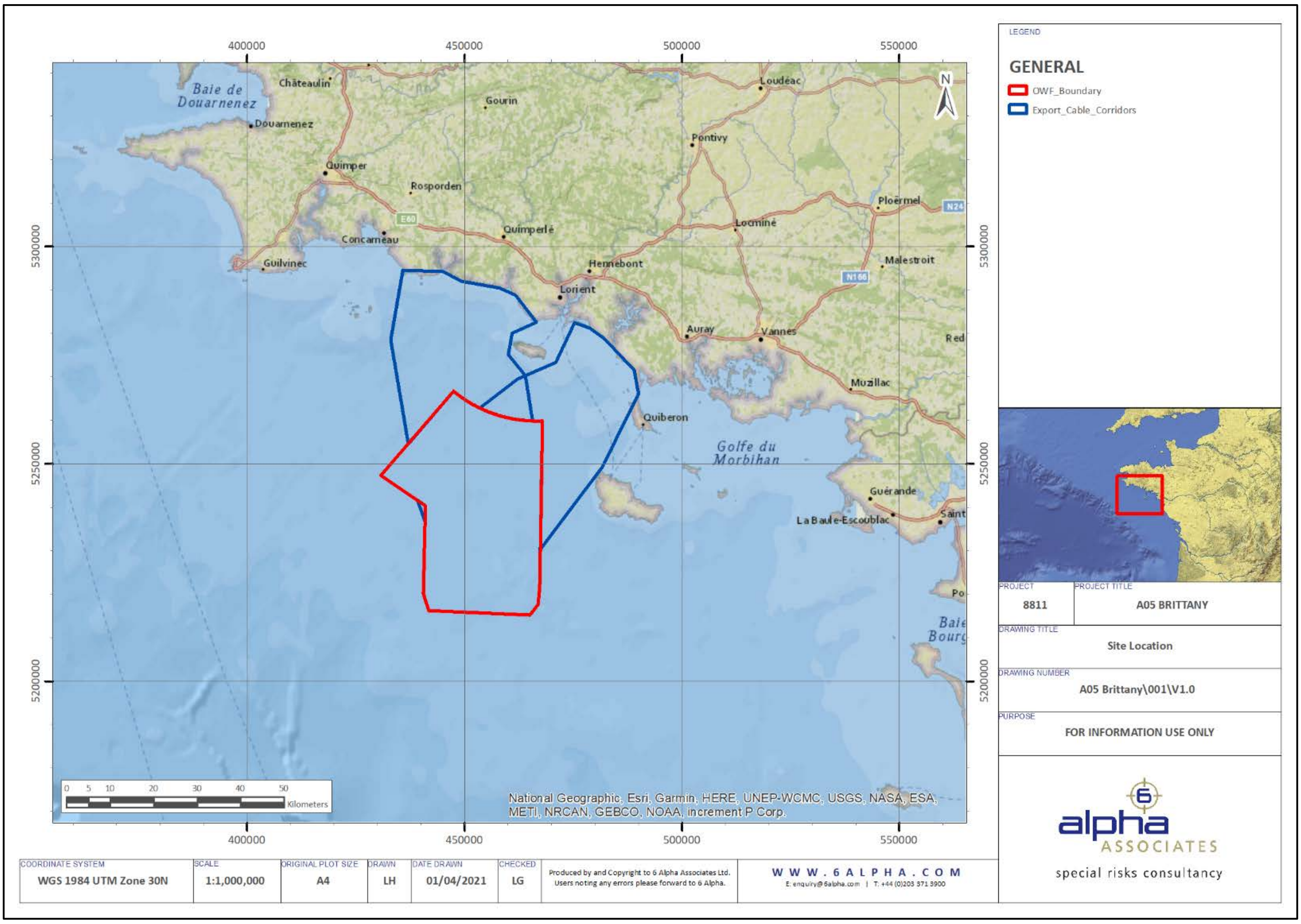



Figure 1 – Site Location

## UXO Threat and Risk Assessment Summary

A tabulated summary of the findings of the threat and risk assessment is presented in Figure 2:

| Intrusive Operation | UXO | UXO Risk (10m WD) | UXO Risk (26m WD) | UXO Risk (40m WD) | UXO Risk (60m WD) |
|---|---|---|---|---|---|
| Geotechnical Investigation | Aerial Bombs | HIGH | HIGH | MEDIUM | MEDIUM |
| | Naval Mines | HIGH | HIGH | HIGH | MEDIUM |
| | Projectiles | MEDIUM | LOW | LOW | LOW |
| Pre-Lay Operations | Aerial Bombs | VERY HIGH | VERY HIGH | HIGH | HIGH |
| | Naval Mines | VERY HIGH | VERY HIGH | HIGH | HIGH |
| | Projectiles | HIGH | MEDIUM | MEDIUM | LOW |
| Cable Installation and Burial | Aerial Bombs | VERY HIGH | VERY HIGH | HIGH | HIGH |
| | Naval Mines | VERY HIGH | VERY HIGH | HIGH | HIGH |
| | Projectiles | HIGH | MEDIUM | MEDIUM | LOW |
| Wind Turbine Installation | Aerial Bombs | HIGH | HIGH | HIGH | MEDIUM |
| | Naval Mines | HIGH | HIGH | HIGH | HIGH |
| | Projectiles | HIGH | MEDIUM | MEDIUM | LOW |
| Protection Operations | Aerial Bombs | HIGH | HIGH | HIGH | MEDIUM |
| | Naval Mines | HIGH | HIGH | HIGH | HIGH |
| | Projectiles | HIGH | MEDIUM | MEDIUM | LOW |
| Enabling Operations | Aerial Bombs | HIGH | HIGH | HIGH | MEDIUM |
| | Naval Mines | HIGH | HIGH | HIGH | HIGH |
| | Projectiles | HIGH | MEDIUM | MEDIUM | LOW |

**Figure 2 – Representative UXO Risk Assessment Summary**


www.6alpha.com
+44 (0) 2033 713 900
enquiry@6alpha.com

The data presented at Figure 2 is intended as an indicative summary of UXO threats and risks. Torpedoes were not included for presentation purposes because they were assessed to pose MEDIUM UXO risks and they do not require bespoke mitigation (i.e. associated risks can be mitigated when mitigating more significant hazards e.g. HE bombs and naval mines).

## UXO Risk Zones

The zoning of UXO risk is based on several factors, including the nature, scope and geospatial distances between UXO threat sources and taking in to account the expected water depths. Nonetheless, the categorisation of UXO risk is not universal throughout the Study Site, and there are areas of VERY HIGH, HIGH and MEDIUM categories of risk.

The highest "worst-case scenario" level UXO risk zones for all GI and installation operations are depicted at Figure 3.

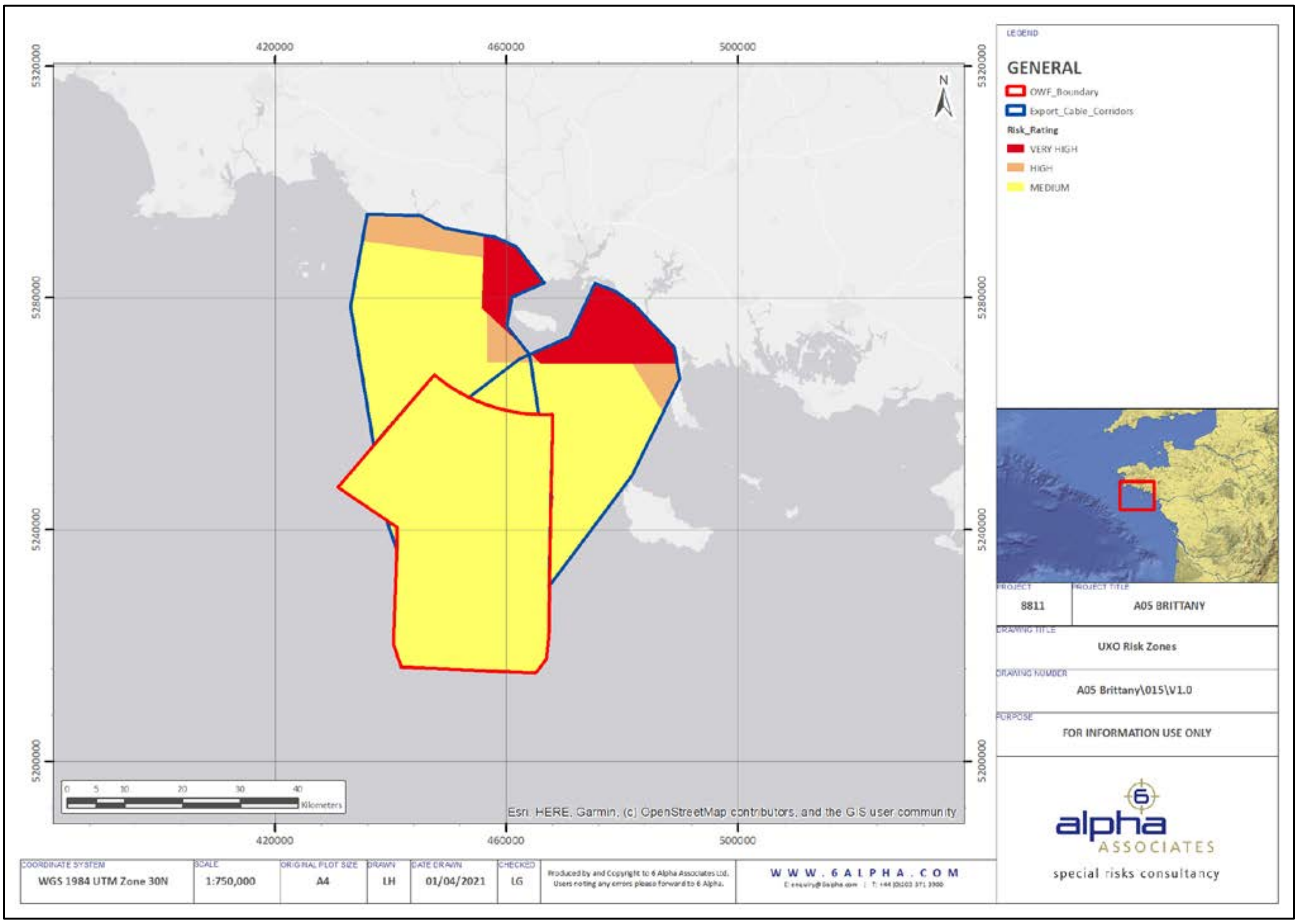



**Figure 3 – UXO Risk Zones**

*6 Alpha* have also zoned the UXO risk associated with GI works only and those risk zones are presented at Figure 4.

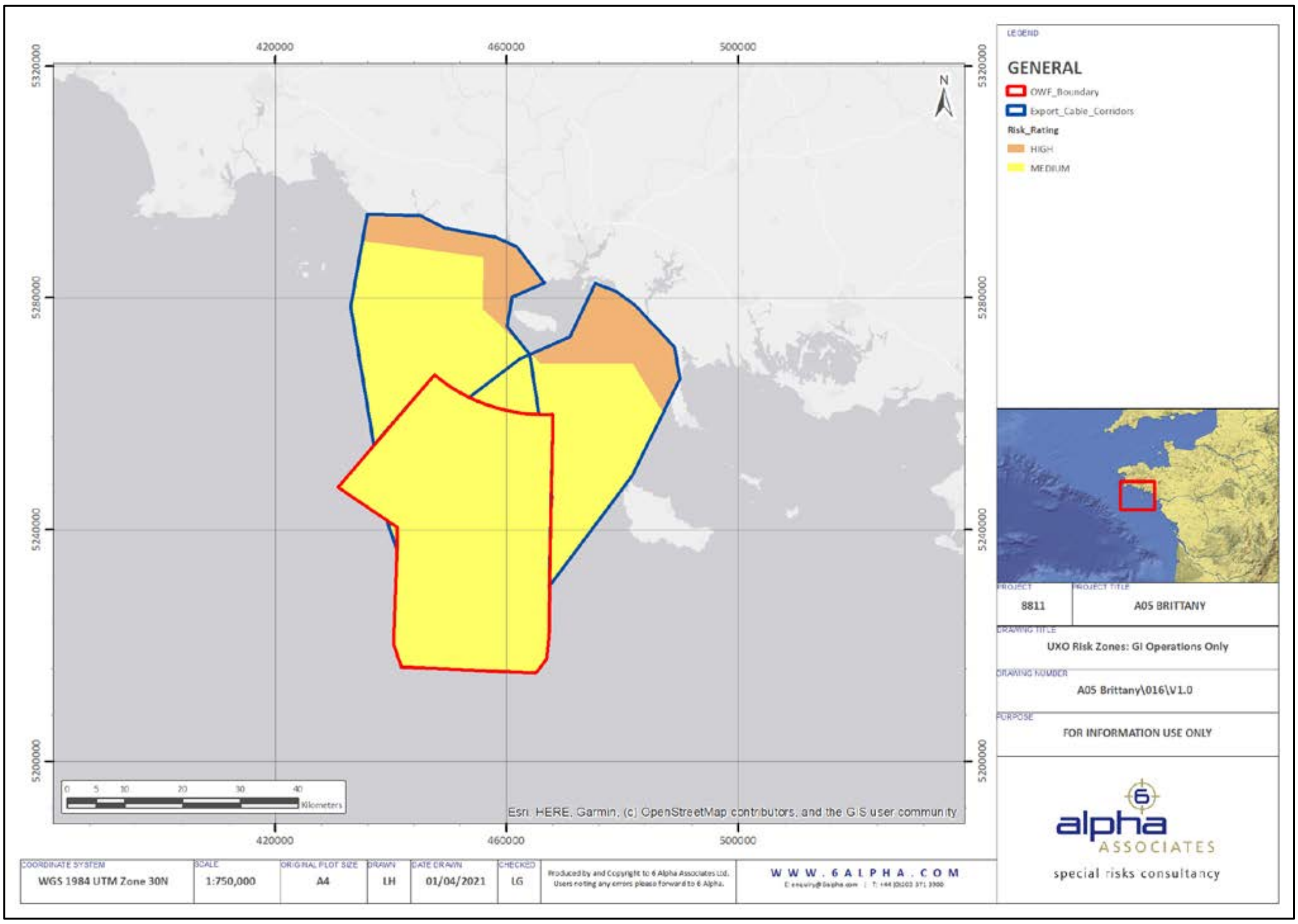



**Figure 4 – UXO Risk Zones: GI Only**

It is possible that the UXO risk zones could be refined further through delivery of a tactical level UXO risk mitigation document and through further detailed risk analysis. However, the precise types and locations of any intrusive GI operations would need to be considered, together with the water depths and likely shallow sub-seabed conditions, in order to further refine the UXO risk zoning, in either the OWF array and/or its inter-array and export cable corridors.

## Conclusions

### Generally

The nature and scope of the UXO risks vary across the OWF area and for each export cable corridor, based upon a source-pathway-receptor review in general, as well as an analysis of the probability of encountering and of initiating UXO and the prospective consequences of doing so, in particular. The nature and extent of the risks posed are partly predicated by *6 Alpha's* assessment of the type, extent and aggressiveness of the proposed intrusive operations.

In the offshore environment, the effects of the depth of water upon potential UXO initiation consequences (and *inter alia* the resultant through seabed and through-water shock wave), will be partly or wholly risk mitigative with the exception of large Net Explosive Quantity (NEQ) UXO threats and in such circumstances, where the risk is partly and sufficiently mitigated, the residual risks might well be tolerated.

Nonetheless, some UXO risks posed by the proposed operations have been categorised as either VERY HIGH or HIGH because they are generally associated with the unplanned initiation of large NEQ UXO in the nearshore sectors – such as naval mines and aerial bombs, with the generation of prospective risks by sub-seabed operations such as GI, cable installation and WTG foundation installation, as well as similar enabling or supporting operations. Such risks are considered intolerable. MEDIUM category UXO risks are also posed by certain other types of UXO and/or intrusive sub-seabed operations in deeper water.

As a result, *6 Alpha* have zoned such offshore UXO risks into different categories and have defined the requirements for their mitigation, based upon underwater explosive effects modelling and the variable likelihood that UXO may be encountered within different areas of the OWF.

**UXO Risks to Surface Vessels and their Crew**

UXO risks that are posed to vessels and their crew are most severe in shallow water (defined for the purposes of UXO risk analysis as 26m Lowest Astronomical Tide (LAT), or shallower). Although the UXO risk is generally greater during prospective installation operations than it is during point-focal GI operations.

In addition, the prospective consequences for surface vessels generally reduces as the depth of water between the vessel and the point of a UXO initiation increases, the water depths throughout the OWF area and the export cable corridors are expected to be sufficient to wholly mitigate threat spectrum NEQ UXO risks posed by medium sized naval mines, and therefore, the level of UXO risk is generally categorised as MEDIUM in the OWF and offshore sectors of the export cable corridors.

Furthermore, the UXO risk to point-focal GI operations is reduced, particularly in deeper water. For example, the UXO risk during GI operations in water depths of 60m LAT is categorised as MEDIUM, whereas installation operations at the same depth may still generate a HIGH level of UXO risk depending on the types of UXO likely to be present and their NEQ.

If divers are deployed to facilitate subsea operations, then they may also be exposed to significant UXO risks, because divers are especially vulnerable to UXO if it is initiated underwater and fatalities can be generated hundreds of meters from the seat of such explosions (subject to the NEQ in the UXO).

### UXO Risks to Underwater Equipment

Underwater equipment and, subject to water depths, their support vessels, are unlikely to be sufficiently robust to withstand the consequences of an initiation of most threat spectrum UXO. The prospective UXO risks posed to underwater equipment are therefore classified as at least HIGH in all depths of water.

## Recommendations

*6 Alpha* recommends that the UXO risk is mitigated within the bounds of the As Low As Reasonably Practicable (ALARP) risk reduction principal. For example, if project stakeholders are willing and able to tolerate some low NEQ UXO risks associated with subsea equipment, then a better value for money solution may be afforded in terms of UXO risk mitigation, by the avoidance of those costly and time-consuming risk mitigation measures that reduce the risks associated with low NEQ UXO threats (in deep water especially). Therefore, *6 Alpha* has recommended that only those risks that are specific, unreasonable and likely to be considered intolerable by most project stakeholders (i.e. those categorised as HIGH and VERY HIGH), are mitigated in order to reduce them to ALARP, in accordance with *EU* and national laws.

The following UXO risk mitigation recommendations have therefore been made, in order to reduce UXO risks to ALARP:

### UXO Risk Mitigation Strategy for GI - Overview

The UXO risk mitigation strategy has been designed for GI operations only, and there are three main options to consider in order to reduce such UXO risks ALARP, based upon a source-pathway-receptor model.

*6 Alpha*'s approach is that UXO risk can effectively be reduced to ALARP, by removing one (or more) element(s) of the model or otherwise mitigating the risks associated with a single element of the model. The three main strategic risk mitigation options based upon source-pathway-receptor modelling are, in priority order:

### Avoidance

A strategy of pUXO detection and avoidance is proposed as the most cost effective and efficient method of reducing UXO risks to ALARP. By surveying for and avoiding direct or indirect contact with





www.6alpha.com
+44 (0) 2033 713 900
enquiry@6alpha.com

any pUXO, by moving the locations of GI operations where necessary, such risks are appropriately and effectively reduced.

**Removal of Risk Receptors**

A second option is to remove the receptor element (of the source-pathway-receptor model), by moving certain sensitive and vulnerable receptors (typically crews of offshore vessels), to a safe distance from the point of the intrusive activity and thus the potential UXO (pUXO) hazard, so that it will diminish sufficiently the prospective blast, fragmentation and/or shock wave consequences to reduce UXO risks to ALARP. Clearly, this is not always achievable and such a course of action is commonly impractical.

**Removal of Threat Sources**

Where GI operations cannot be moved in order to avoid pUXO, an alternative (but commonly, time consuming and costlier) option, is to verify pUXO by investigation and where it is confirmed UXO (cUXO), to remove it (effectively removing the source element of the source-pathway-receptor model) - either by moving it to a position where it can do no harm (but only when it is safe to do so and wherever permit licencing and consent condition allow such actions), and/or destroying it or otherwise rendering it safe.

**Residual Risk Tolerance**

Following the implementation of the risk mitigation strategy, UXO risks will not be reduced to “zero”. Residual UXO risks will likely remain in the offshore environment due to *inter alia*, the limits of geophysical UXO survey technology, data interpretation limitations and the fact that small scale low NEQ UXO threats might be tolerated, which is acceptable under the auspices of the ALARP risk reduction principle. Such residual risks have been tolerated on many other projects, in very similar circumstances. Such an approach therefore, is likely to be deemed acceptable by a wide variety of project stakeholders and regulators and it is thus consistent with all reasonable UXO risk management standards, practices and frameworks.

**UXO Risk Mitigation Measures**

The GI risk mitigation strategy should be enacted through the design and implementation of risk mitigation measures, as follows:

- Proactive Measures:

- **Geophysical UXO Survey**; a geophysical UXO survey is to be designed (and subsequently undertaken) to detect threat spectrum UXO as follows:
    - **SSS**; high-resolution Side Scan Sonar should be employed (>600kHz frequency);
    - **MBES**; Multi-Beam Echo-Sounder survey is often corroborative and helpful in delivering UXO target discrimination; its outputs should therefore be employed to compliment SSS data;
    - **MAG**; subject to the locations and type of GI being undertaken, the juxtaposition of GI work vessel(s) and the water depths, geophysical UXO survey by magnetometer (or in combination gradiometer) may or may not be required. *6 Alpha* can better advise when the details of the GI operations are known;
- **Anomaly Selection**; geophysical UXO survey data (is to be employed in order to select those anomalies that model as pUXO. *6 Alpha* can discriminate pUXO from benign seabed (or sub-seabed) detritus. Our recommendation is that pUXO should be avoided (see below); or, where it cannot be avoided, it may have to be verified by investigation (also see below);
- **pUXO Avoidance**; pUXO is to be avoided either by 15m (the latter is a baseline and *6 Alpha* standard safety distance but may be reduced through the medium of a Technical Advisory Note), measured from the edge of any sub seabed GI tool;
- **pUXO Investigation**; where pUXO avoidance criteria cannot be met (which is not expected to be an issue for the GI campaign), then target investigation must be undertaken to verify and classify pUXO as either cUXO, or as seabed debris. Any Target Investigation ought to be undertaken, remotely where possible;
- **UXO Disposal**; following the inspection of pUXO, those items verified as cUXO will require either: movement (e.g. to the edge of the consent corridor – where it is permitted and safe to do so) and/or render safe either by low-order/deflagration or by sympathetic detonation.

- Reactive Measures:
    - **Emergency Management Plans;** are to be written and distributed to all vessels involved with GI operations;

- **Tool-Box Briefs**; are to be delivered to all personnel intimately involved with GI activities;
- **On-Call UXO Response**; an office based, on-call UXO response option can provide rapid assistance and advice, if UXO is unexpectedly discovered - even after proactive risk mitigation measures have been executed - during any and all subsequent activities associated with GI operations.

**Minimum UXO Threat Item**

The recommendation for the minimum threat items to be detected by geophysical UXO survey is variable throughout the Study Site depending on a number of factors including but not limited to; water depth, likely GI methodology, the nature of the UXO threat, prospective vessel slant range and vessel robustness. It should also be noted that the minimum threat item is based on a UXO threat item's ferrous metal content rather than its physical dimensions or any other factor.

In water depths of up to 10m LAT, the minimum UXO threat item to be detected by geophysical UXO survey is:

- 10.5 cm leFH 18 Artillery Projectile with a ferrous metal mass of 13kg.

In water depths of between 10m and 26m LAT, the minimum UXO threat item for survey is:

- *US* AN-M30 100lb HE Bomb with a ferrous metal mass of 26kg.

In water depths of between 26m and 40m LAT, the minimum UXO threat item for survey is:

- *British* 500lb MC Bomb with a ferrous metal mass of 111kg.

Where water depths exceed 40m LAT, the minimum UXO threat item for geophysical UXO survey should instead be the following:

- *British* Mark XVII Naval Mine with a ferrous metal mass of 68kg.

**ALARP Safety Sign-Off Certification**

In order to evidence that the UXO risk during forthcoming GI operations has been appropriately reduced by the implementation of a recommended and agreed UXO risk mitigation strategy, ALARP safety sign-off certificates can be delivered warranting that the GI campaign can be undertaken safely and in accordance with all national and regional safety and legal standards.

*6 Alpha* recommend that the UXO risk mitigation strategy is subsequently updated and expanded to encompass risk mitigation measures for OWF foundation and all cable installation works, which are expected to be scheduled later in the project cycle.



www.6alpha.com
+44 (0) 2033 713 900
enquiry@6alpha.com

# Contents

# List of Appendices

# List of Annexes






www.6alpha.com
+44 (0) 2033 713 900
enquiry@6alpha.com

# Acronyms and Abbreviations

| | |
|---|---|
| **AAA** | Anti-Aircraft Artillery |
| **AHT** | Anchor Handling Tugboat |
| **ALARP** | As Low As Reasonably Practicable |
| **CIRIA** | Construction Industry Research and Information Association |
| **CPT** | Cone Penetration Testing |
| **cUXO** | Confirmed UXO |
| **DP** | Dynamically Positioned |
| **EU** | European Union |
| **GI** | Geotechnical Investigation |
| **GP** | General Purpose |
| **HE** | High Explosive |
| **km** | Kilometre |
| **kg** | Kilogram |
| **KHz** | Kilohertz |
| **LAT** | Lowest Astronomical Tide |
| **LSA** | Land Service Ammunition |
| **MAG** | Magnetometer |
| **MBES** | Multi Beam Echo Sounder |
| **MC** | Medium Capacity |
| **MPa** | Mega Pascal(s) |
| **NEQ** | Net Explosive Quantity |
| **OSPAR** | Oslo-Paris Convention for the Protection of the North-East Atlantic |
| **OWF** | Offshore Wind Farm |
| **PEXA** | Practice and Exercise Area |
| **PLGR** | Pre-Lay Grapnel Run |
| **pUXO** | Potential UXO |
| **RAF** | Royal Air Force |
| **RC** | Route Clearance |
| **RMS** | Risk Mitigation Strategy |
| **SAA** | Small Arms Ammunition |
| **SQRA** | Semi-Quantitative Risk Assessment |
| **SSS** | Side Scan Sonar |
| **TARA** | Threat and Risk Assessment |
| **TNT** | Trinitrotoluene |
| **UK** | United Kingdom |
| **US** | United States |
| **UXO** | Unexploded Ordnance |
| **WD** | Water Depth |
| **WTG** | Wind Turbine Generator |
| **WWI** | World War One |
| **WWII** | World War Two |

# Key Definitions

There are several terms that are used within this UXO threat and risk assessment report, namely:

**Key Industry Definitions**

- **As Low As Reasonably Practicable (ALARP)** – a term used in the management of safety-critical and safety-involved systems. The ALARP principle is that risks shall be reduced as low as reasonably practicable, which is effectively a (UK) legal minimum requirement;
- **Best Practice –** those standards for controlling risk which have been judged and recognised by a regulatory body as satisfying the law, when those standards are applied in an appropriate manner;
- **Competency –** a person or organisation with sufficient training, experience, and knowledge;
- ***De Minimis*** – an abbreviated form of the Latin maxim *de minimis non curat lex*, "the law cares not for small things". In terms of risk management, risks that are defined as too small to be of concern and exempt from further consideration; the purpose being, to avoid a disproportionate use of finite resources by mitigating a virtually inexhaustible supply of insignificant or low-level risks;
- **Hazard –** anything that has the potential to cause harm or damage;
- **Precautionary Principle –** an action with the potential risk to cause harm or damage without certainty or scientific consensus that the action is not harmful or damaging. The burden of proof that the action is not harmful or damaging falls upon those undertaking risk assessment and taking risk mitigation action;
- **Risk –** the intentional interaction of something of value with the potential for danger, harm, or loss;
- **Risk Assessment** – a systematic process of identifying and evaluating the potential risks of an action or undertaking;
- **Threat –** anything that has the potential to cause harm or damage, but especially UXO;
- **Uncertainty –** an unknown element that is not fully understood to properly inform the decision-making process;
- **Unexploded Ordnance (UXO)** – any unexploded munition with an explosive or chemical fill that failed to initiate and poses a risk of causing harm or damage.

## Key Historical Definitions

- **Allies (WWI)** – the alliance between the *British Empire*, *France*, *Russia* and the *USA*, though many other “associated powers” are sometimes labelled collectively as the “Allies”;
- **Allies (WWII)** – the alliance between the *British Empire*, *France*, the *Soviet Union* and the *USA*, though many other “associated powers” are also sometimes labelled collectively as the “Allies”;
- **Axis** – the alliance between *Germany*, *Italy*, and *Japan* during WWII;
- **Central Powers** – the alliance between the *German Empire*, *Austria-Hungary*, the *Ottoman Empire* and *Bulgaria* during WWI;
- **Grand Fleet** – the main *British Royal Navy* fleet of ships during WWI;
- **High Seas Fleet –** The name of the battle fleet of the *German Imperial Navy* that was created in 1907 and saw action in WWI;
- **Luftwaffe** – the official name of the *German* air force between 1933 and 1946;
- **Kriegsmarine** – the name given to the *German* navy between 1935 and 1945.

# 1 Introduction

## 1.1 Project Overview

DNVGL (the *Client*) has commissioned 6 Alpha Associates (*6 Alpha*) to deliver a desk based Unexploded Ordnance (UXO) threat and risk assessment study, for Geotechnical Investigation (GI), cable installation and wind turbine installation of the *A05 Brittany Offshore Wind Farm (OWF)*. A Risk Mitigation Strategy has also been commissioned and designed, but as requested as this stage, only for the mitigation of UXO risks associated with GI operations.

The proposed development will be located in the *Bay of Biscay*, off the coast of *Brittany* in the *North Atlantic Ocean*.

The location of the OWF and its associated export cable corridors is presented at Appendix 1.

## 1.2 UXO in the Marine Environment

The military activities and conflicts of the 20th Century have left a legacy of munitions contamination in the marine environment and it is now a relatively common occurrence to encounter UXO during subsea investigation and installation activities.

### 1.2.1 Generic UXO Threats

All military technology has an inherent base failure rate, meaning that not all ordnance functions as the designer intended, during either its training or operational use. It is generally accepted that during WWII approximately 10% of *German* aerially delivered bombs failed to explode – *Allied* bomb failure rates are estimated to be slightly higher. Offshore and onshore bombing targets were also simply missed, and bombs were also jettisoned from aircraft when evading an adversaries’ attacks and/or when seeking to reduce aircraft weight during a return journey and to deliver a higher safety margin when landing.

Wartime training and operations also employed live munitions filled with high explosives (as well as other substances and materials including toxic chemicals or ignition/burning agents in incendiary bombs), which may have remained after the training exercises and operations had been completed. From the outset of WWI, and throughout WWII, sea mines were deployed in significant quantities in both offensive and defensive naval operations and their residue poses a further UXO contamination threat to intrusive sub-seabed activities in the marine environment. Conventional and chemical munitions dumping was also prevalent in these periods with little consideration given to future safety implications. There was also widespread unrecorded dumping of Small Arms Ammunition (SAA) and

Land Service Ammunition (LSA) that was not only perceived to be inconsequential, but also undertaken without regard to munitions dump positional accuracy - resulting in so-called "short dumping". Some dumped munitions may also have migrated from their original locations because of natural seabed sediment transportation and other forces. Modern military training areas, such as offshore firing ranges, may have also contributed to the background UXO contamination in the offshore environment.

Besides the clearance of naval minefields in order to open sea lanes, minimal effort was made in the immediate post-war periods to clear the unexploded bombs and projectiles that contaminated the seabed. As such, unexploded munitions relating to previous conflicts, but particularly WWII-era munitions, often pose a considerable contamination threat source in the marine environment.

### 1.2.2 Generic UXO Risks

The explosive or chemical fill within UXO rarely becomes inert or loses its effectiveness with age, but the explosive fill may change or crystallise over time - increasing the high explosive's sensitivity to a physical shock or an impact. Trigger mechanisms and fuses, which may have failed, may corrode and deteriorate in the saltwater environment becoming more sensitive to detonation when subjected to an impact or a physical shock. It is therefore possible, that a significant impact on the UXO case, and the resultant effect upon the fuse, may cause its inadvertent detonation.

Prospective UXO incidents that may result in harm are generally considered low probability-high consequence events, which present a challenge when designing project, public and commercial safety policies. Nonetheless, there are clear safety risks associated with UXO encounters for any subsea operation that interacts with the seabed. UXO risks must be considered and managed in order to protect offshore personnel from injury or, in the very worst-case scenario prospective fatalities; as well as to fulfil the Clients' statutory obligations under the auspices of national and/or *European Union (EU)* law.

Further information regarding national and international legislation, and the management and reduction of UXO risk to As Low As Reasonably Practicable (ALARP), is presented at Annex A and is indicative of the safety benchmark to which *6 Alpha* adhere.

## 1.3 UXO Industry Best Practice

The *United Kingdom's (UK) Construction Industry Research and Information Association* (CIRIA) has published a best practice guide for the assessment and management of UXO risk in the marine environment (document reference C754, first published February 2016), that not only has significant and wide-reaching offshore industry recognition, but also has been formally endorsed by the *UK*'s

*Health and Safety Executive* and subsequently, by other regulatory bodies internationally. *6 Alpha* were *CIRIA's* lead technical author for this publication and as such, it guides *6 Alpha's* UXO risk management practices. Whilst this project is being undertaken in *French* waters, CIRIA C754 guidance has been successfully employed on similar projects throughout the *EU*.

Therefore, in undertaking this threat and risk assessment, *6 Alpha* have not only brought to bear our offshore UXO risk management expertise and technical experience, but we have also benchmarked our delivery of offshore service provision with the CIRIA C754 guide, in order to ensure compliance with industry best practice and to manage UXO risks in accordance with ALARP risk reduction criteria.

Nonetheless, whilst the *CIRIA* guide outlines "what" steps are to be taken to manage the UXO risk, it lacks detail concerning "how" these steps are to be executed, in order to reduce such risks to ALARP. Where such finer detail is lacking in the *CIRIA* guidance, *6 Alpha* has filled those gaps through the careful and appropriate application of our UXO risk management strategic framework.

## 1.4 UXO Risk Management Strategic Framework

To manage and to ameliorate prospective UXO risks, *6 Alpha* has developed a detailed UXO risk management strategic framework that is not only in line with CIRIA guidance but also, is in accordance with ALARP risk reduction principles. At Section 5 of CIRIA's C754 guide, the risk management framework is divided into five key phases that correspond with those employed by *6 Alpha*, as presented at Table 1.4. A full overview of *6 Alpha's* UXO Risk Management Framework is presented for completeness, at Appendix 2.

| 6 Alpha Risk Management Framework | UXO Risk Management Phase | CIRIA C754 Risk Management Framework | Delivered within Report? (✔/✘) |
|---|---|---|---|
| UXO Threat Assessment | **PHASE ONE** | UXO Threat Assessment | ✔ |
| UXO Risk Assessment | **PHASE TWO** | UXO Risk Assessment | ✔ |
| Strategic Risk Mitigation Options | **PHASE THREE** | UXO Risk Management Strategy | ✔ |
| Risk Mitigation Design and Specification | **PHASE FOUR** | UXO Risk Mitigation (Planning) | ✘ |
| Implementation | **PHASE FIVE** | UXO Risk Mitigation (Delivery) | ✘ |

**Table 1.4:** *6 Alpha* and *CIRIA* UXO Risk Management Frameworks.

Notwithstanding *CIRIA's* guidance, the purpose of this report is to address Stages One, Two, and Three of the UXO risk management framework, for GI only in the latter case. The potential nature and scope of the UXO threat at the Site is addressed initially (at Stage One), before the potential UXO risk pathways are identified and analysed in order to assess the UXO risks associated with the proposed GI, cable installation and wind turbine installation works (at Stage Two).

Once the associated UXO risks have been assessed, recommendations for site-specific UXO risk mitigation measures (at Stage Three) are outlined for GI operations, which (if implemented fully), will ensure and evidence that a suitable and appropriate UXO risk management strategy has been planned and delivered, in order to reduce UXO risks to ALARP.

## 1.5 Source – Pathway – Receptor Model

The source-pathway-receptor model is a conceptual risk model employed by *6 Alpha* across all marine projects (as per *CIRIA* guidance and industry best practice), that informs the way in which UXO risks are assessed for each seabed intrusive activity associated with the project. The model also helps to explain the link between the separate sections of this report and the UXO risk assessment at Section 6. The components of the model are as follows:

### 1.5.1 UXO Sources

The nature and scope of the UXO threat is summarised in the UXO threat assessment (at Section 3) and it forms the source element of the source-pathway-receptor model.

### 1.5.2 UXO Pathways

The UXO pathways are the routes by which the sources can reach the receptors. Marine UXO pathways are likely to be either by contact and/or through soil or water energy transfer, through which the resulting shock wave (generated by a UXO source, or sources) may reach potential receptors. Nonetheless, surface events (e.g., if UXO is inadvertently brought back to the vessel and is initiated), may also generate a through-air risk pathway in which blast and fragmentation from the UXO sources may also reach the receptors.

UXO risk pathways may be generated by a variety of GI, cable installation and wind turbine installation operations that interact with the seabed. Therefore, the Client's intended operations have been assessed and summarised (at Section 4), to demonstrate the potential risk pathway elements of the model.

### 1.5.3 UXO Receptors

Receptors are defined as anything which might be adversely affected by the consequences of an inadvertent detonation of any UXO source through an identified pathway. The proximity, robustness and sensitivity of such receptors is important, not only in determining their capacity to withstand such high explosive effects, but also in defining what degree of UXO risk might be tolerated (if any). For example, risks to underwater equipment might be tolerated by some (or all) stakeholders but risks to personnel that might generate injuries (in general) and fatalities (in particular), are highly unlikely to be considered tolerable.

Typically, offshore receptors include, but are not limited to, the GI and installation equipment; the cable, wind turbines and their protective systems; as well as underwater (e.g. Work-Class Remotely Operated Vehicle) and surface vessels, and where appropriate, their crews. Divers are also especially vulnerable to underwater high explosive effects, as are marine mammals.

# 2 Scope and Structure of the UXO Risk Assessment

## 2.1 Report Structure

This report comprises a desk-based collation and review of readily available documentation and records (which have been summarised separately in Section 2.2), relating to the types of UXO that might be encountered at the Site, in order to assess the potential UXO risks and in light of them, to design a suitable and appropriate risk mitigation strategy to reduce such risks to ALARP.

Therefore, the report has been structured to summarise the relevant data and to present the UXO threats. Considering the proposed GI, cable installation and wind turbine installation activities, a risk assessment will be undertaken, and a risk mitigation strategy will be presented for the GI operations. The following aspects will be covered:

- The sources of prospective UXO contamination that might be encountered within the bounds of the Study Site will be summarised;
- Where they are known, the Client's intended GI, cable installation and wind turbine installation activities will be outlined. Where such methodologies have not yet been outlined, a variety of prospective options will be presented;
- An assessment of the water depths (in terms of Lowest Astronomical Tide (LAT)) across the extent of the Site will be considered, in order to assess the prospective UXO detonation consequences;
- The likely UXO risk receptors will be identified;
- A Semi-Quantitative Risk Assessment (SQRA) will be undertaken;
- Conclusions will be drawn, and recommendations made, in order to present a viable and cost-efficient risk mitigation strategy, benchmarked with reducing UXO risks to ALARP.

## 2.2 Information Sources

*6 Alpha* has employed the following generic sources of information to inform and to compile this report:

- *European Marine Observation and Data Network*;
- *James Martin Centre for Nonproliferation Studies*;
- *National Geospatial-Intelligence Agency*;

- *Naval Historical Centre* at *Portsmouth*;
- *Oslo-Paris Convention for the Protection of the North-East Atlantic (OSPAR) databases*;
- *Royal Navy* (Diving Units);
- *Service Hydrographique et Océanographique de la Marine;*
- *Theatre History of Operations;*
- *UK National Archives* at *Kew*;
- *UK Hydrographic Office* at *Taunton*.

*6 Alpha's* "*Azimuth*" database also contains digitised historic charts, aerial photographs and other extensive analogue records from an exhaustive range of additional national, regional and global archives and/or data sets that have also been digitised. That database has been heavily drawn upon to deliver the UXO threat assessment element of this report.

## 2.3 Constraints and Limitations

This UXO threat and risk assessment is constrained and limited by the information available to *6 Alpha* at the time of writing, as well as that UXO information that is reasonably accessible in a variety of archives, which *6 Alpha* have digitised and georeferenced or have otherwise summarised in written form.

This document may require updates and changes, especially wherever and whenever the circumstances and factors associated with assessing UXO risk change. For example, if UXO threats are subsequently discovered and they are different from those that have been anticipated, and/or if expected GI, cable or wind turbine installation methods are significantly changed.

In such circumstances, risks may require re-evaluation and risk mitigation recommendations may need to be subtly altered. Such changes are to be made by *6 Alpha*, in order to ensure the continued technical veracity and risk management efficacy, of this document.

# 3 Sources of Unexploded Ordnance Contamination

## 3.1 UXO Hazard Assessment

Significant archive research associated with the Study Site has been undertaken in order to corroborate and to highlight, any and all potential sources of UXO contamination as well as to assess their likelihood of encounter. This assessment is therefore, based upon UXO defined geospatial threat source positions and the anticipated level of contamination from background UXO threats situated upon and within, 5km of the OWF boundary and its associated export cable corridors. Where it is deemed appropriate, potential UXO threats that are located further than 5km from the Site, have also be considered for analysis. Such potential sources of UXO are summarised in Table 3.1.

| Potential Sources of UXO (within 5km) | Likelihood of UXO Contamination | Associated UXO Threat Items |
|---|---|---|
| Aerial Bombing | **Highly Likely:** There is evidence of significant aerial bombing occurring at *Lorient*. | HE bombs |
| Naval Engagements | **Unlikely:** There is evidence of WWI-era naval engagements and limited WWII-era engagements within the Study Site. | Naval Projectiles and Torpedoes |
| Naval Minefields | **Highly Likely:** There is evidence of significant WWII-era *Allied* mining operations occurring the Study Site. | Naval Mines |
| Military Practice and Exercise Areas | **Unlikely:** There is evidence of modern PEXA intersecting some areas of the Study Site. | N/A |
| Coastal Armaments | **Likely:** The Study Site was located within the firing template of numerous coastal armaments. | AAA Projectiles |
| Munitions Related Shipwrecks and Aircraft | **Highly Likely:** There is evidence of numerous munitions related shipwrecks within the Study Site. | Shipwreck Related Munitions |
| Munitions Dumping (within 10km) | **Highly Likely:** Three conventional munitions dumps were documented within 2km of the export cable corridors. | Conventional Dumped Munitions |

**Table 3.1:** Summary of Potential UXO Sources within 5km of the Site Boundary


www.6alpha.com
+44 (0) 2033 713 900
enquiry@6alpha.com

The core types of UXO threats that have been summarised in Table 3.1 are discussed in detail subsequently and they will be subjected to a risk assessment, based upon the proposed operations that are outlined at Section 4 of this report. Background information detailing generic military ordnance and UXO classification, is presented separately at Annex B.

## 3.2 Aerial Bombing

Air dropped bombs may be encountered in areas where conflict and/or an air campaign has occurred, although the precise locations of bombing raids and aerial attacks have not always been accurately documented - especially in the offshore environment. Nonetheless, there is evidence to suggest that aerially delivered High Explosive (HE) iron bombs may pose a potential UXO contamination threat at the Study Site.

For example, the landfall points associated with the export cable corridors are situated in close proximity of *Lorient*, a major naval base during WWII. Following the occupation of *France*, the *German Organisation Todt* began construction of reinforced submarine pens on the *Keroman Peninula*, near *Lorient* (situated 4.2km to the north-west of the export cable corridors) - these pens were documented as a primary bombing target by *Allied* forces. The first *Allied* air raid against these submarine pens was launched by the (British) Royal Air Force (*RAF)* in 1940, although the most intense aerial bombing missions were undertaken in 1943-44 when, unable to penetrate and destroy the submarine pens themselves, targets throughout the city were instead bombed leading to widespread destruction with approximately 5,000 buildings rendered uninhabitable or else totally destroyed. Although this bombing campaign was largely limited to targets in the city of *Lorient* (targeting typically, the harbour and power plant), it is highly likely that other targets of opportunity in the harbour or on the coast (such as Anti-Aircraft Artillery (AAA) batteries), in closer proximity of the export cable corridors, would also have been targeted.

Furthermore, four vessels were recorded as having been sunk by aerial bombing and/or gunfire during WWII, within 5km of the export cable corridors. All four vessels were sunk by *RAF* Aircraft, with the *German* patrol boat *V-1421* sunk directly within the western export cable corridor on the 15$^{th}$ July 1944. In addition to these vessels, a *German Junkers 52 Mausi* aircraft was shot down during an aerial battle near *Lorient* and crash-landed into the water 2.3km to the north-west of the eastern export cable corridor. These aircraft and shipwrecks resulting from aerial bombing (and skirmishes), highlight the threat posed by aerially delivered ordnance within the export cable corridors, although there is less evidence of their deployment in the OWF area itself.

Further details regarding this and other munitions related shipwrecks within the area, are presented at Section 3.7.

Furthermore, there is a residual, but largely unquantifiable UXO contamination threat, posed by prospective bomb-jettisoning activities associated with the nearby *Kerlin Bastard Airfield* (located 4.8km to the north-east). *Kerlin Bastard Airfield* was opened in 1942 by the *Luftwaffe* and supported long-range aircraft for reconnaissance and anti-shipping operations over the *North Atlantic*. Although an order to dismantle the airfield was issued in 1944, ahead of the *Allied* invasion of *France*, the site remained in military use following WWII having been renamed the *Lann Bihoue Naval Air Base*.

As was common at the time, it is plausible that HE bombs were jettisoned at sea by military aircraft that were returning to land at this airfield, to ensure that for safety purposes, aircraft did not attempt to land with live bomb loads onboard that would also potentially take the aircraft beyond their weight limits designed to ensure a safe landing. HE bombs may also have been jettisoned at sea by *Allied air*craft before or after air raids in the vicinity, in order to lighten their aircraft for the purposes of either evading their adversaries' attacks or, to reduce their aircrafts' weight for their return journeys. Such a threat is, however, almost impossible to quantify without such instances being recorded (and often, such events were either inaccurately recoded or more commonly were not recorded at all).

A geo-referenced summary of the aerial bombing threat at the Site is presented at Appendix 3.

## 3.3 Naval Engagements

The combatant navies of WWI and WWII commanded fleets that consisted of armed surface craft such as destroyers and battleships, as well as more covert craft such as submarines and motor torpedo boats – all of which were armed with a variety of weapons systems. Thus, the nature and the scope of naval engagements that were fought throughout WWI and WWII varied significantly from encounter-to-encounter and were dependant on the types of vessels involved. As with the aerial bombardment case in the offshore environment, the specific locations of the majority of naval engagements were not commonly nor accurately recorded. Nevertheless, there is evidence to suggest that naval engagements occurred within the bounds of the Study Site, particularly during WWI.

Such evidence is readily presented by an analysis of *6 Alpha's* in-house *Azimuth* database which indicates that there are 14 shipwrecks located within the proposed OWF and its associated export cable corridors that are indicative of historic naval engagements occurring in the area of the proposed *A05 Brittany* project. A further 3 wrecks originating from historic naval combat are located within 5km of the proposed OWF area and export cable corridors.

All 17 of these vessels were sunk by *German* submarine activity during WWI, having been either scuttled by gunfire and/or explosive charges, or else sunk by torpedoes. Based on the dates of these engagements and the class of submarines involved, the torpedoes used are likely to be of the 50cm G7 variant. In addition, a further UXO contamination threat is presented by the diverse types of naval guns that may have been employed during such engagements, in addition to the armaments and munitions carried by vessels that were sunk within the area. Nevertheless, the prospective magnitude of these threats is reduced somewhat by the limited operational capacity of most submarines and the relative rarity of WWI ordnance encounters in the marine environment.

In contrast, there is very little evidence of WWII-era naval engagements within the bounds of the proposed OWF and its associated export cable corridors, despite the presence of the major *German* submarine base at *Lorient* (situated 4.2km to the north-west). Only one shipwreck was identified within the southern sector of the OWF dating to this period, being the *Dutch* cargo ship *SS Berenice*, which was torpedoed and sunk by the submarine *U-65* on the 22$^{nd}$ June 1940.

The geospatial extent of the contamination threat relating to naval engagements is presented at Appendix 4. Further corroborating evidence of the nature and scope of the naval engagements and the shipwrecks that were generated as a result, are presented at Section 3.7.

## 3.4 Naval Minefields

A naval sea mine is a self-contained high-explosive weapon that is placed in the water in order to destroy ships and/or submarines. All mines were fused so that they detonated, either upon impact or otherwise upon a close encounter with a ship. During WWI and WWII, naval mines were generally employed either offensively, in order to hamper enemy shipping and to blockade harbours; or defensively, in order to protect shipping and by creating safe movement zones through them.

During WWI and WWII, defensive minefields were often laid by surface craft whereas offensive minefields were often laid by aircraft or submarines - the latter therefore delivering an element of secrecy to the positions of the mine laying operations. Minefields that were deployed by aircraft or submarines, were also less likely to be accurately recorded than those laid by surface vessels and as such, the exact positions of these types of mine lays are difficult to corroborate with any degree of certainty.

Nonetheless, there are clear records to suggest that naval mining poses a direct UXO contamination threat at the Study Site.

### 3.4.1 WWI Minefields

*Allied* or *Central Powers* minefields were not recorded within the vicinity of the proposed OWF. Nevertheless, an analysis of shipwreck data in the area indicated that four vessels were sunk by *German* submarine-deployed mines in 1917-18, within the bounds of the export cable corridors. Consequently, it is likely that covert mine-deployment was undertaken along the *French* coastline near *Lorient* by *German* submarines - although the type of mine(s) deployed could not be established. Nonetheless, based upon the submarine activity recorded in the area, it is considered likely that the mines may have been the *German UC*-variety (*British* designation Type II), as they were commonly employed during WWI.

The georeferenced location of the recorded shipwrecks resulting from WWI mines in relation to the Study Site is presented at Appendix 5.

### 3.4.2 WWII Minefields

Detailed desk-based research of historical records and plans has indicated at least three mapped WWII minefields that intersected the Study Site at various points - and together they comprised more than 2,500 mines. These minelaying operations were of various natures and significance but, when considered collectively, they are likely to provide a significant UXO contamination threat across portions of the OWF and its export cable corridors. The *Allied* minelaying operations consisted of *British* surface craft deploying 470 *British* Mark XVII mines in two minefields (designated *HG* and *HJ 4*) located in the north-western sector of the OWF and intersecting its western export cable corridor. In addition, *Mine Garden Artichoke* comprised a total of 2,068 A Mark I-IV mines deployed over several years and it was situated in the nearshore sectors of both export cable corridors. A second aerially deployed *Mine Garden* (nick-named *Gorse*) was located to the east of *Quiberon* (located approximately 1.7km to the south-east) although it was abandoned in 1942, having then comprised 55 A Mark I-IV mines.

In addition, a detailed analysis of related shipwreck data has also identified one mine-related shipwreck within the bounds of the western export cable corridor that originates from WWII, with another four shipwrecks within 5km of the export cable corridors – all of which are within the bounds of *Mine Garden Artichoke*. This data corroborates the evidence associated with *Allied* mines having been deployed in large quantities near *Lorient* and it further suggests that WWII mines may pose a direct and significant UXO contamination threat at the Study Site.

An assessment of the positions of the minefields and mine-related shipwrecks suggests that WWII mines of different varieties are collectively, likely to pose a significant contamination threat across much of the Study Site. It is considered much more likely that WWII naval mines will be encountered (by comparison with WWI mines), as they are estimated to be encountered in the marine environment at a rate of approximately, once a month. Given this comparative encounter ratio, and the nature and scope of the evidenced minelaying operations that intersected the proposed OWF and export cable corridors in multiple areas, the probability that WWII-era naval mines have contaminated the area is assessed as “Highly Likely”.

The georeferenced location of the recorded WWII minefields and shipwrecks resulting from WWII mines in relation to the Study Site is presented at Appendix 6.

## 3.5 Military Practice and Exercise Areas (PEXA)

The *Bay of Biscay* has been used for much of the 20th and 21st Century by the *French* military, as well as international alliances such as *NATO*, to conduct training and weapons systems testing. These activities may have employed live or practice munitions (the latter being difficult to distinguish from the former once abandoned on the surface of the seabed for many years), which in most cases are likely to have remined in the marine environment once the training activities have ceased.

### 3.5.1 Historic Training Areas

Historic military training areas have not been recorded either within the bounds of or intersecting the Study Site, nor within 5km of its boundaries. Nonetheless, it is quite possible that naval vessels - across the entire area - and/or coastal artillery batteries at either landfall area, may have fired their weapons systems for validation and/or range finding purposes, and that such events are unlikely to have been recorded. Nonetheless, the likelihood of contamination from this source is considered to be remote and it constitutes a background threat.

### 3.5.2 Modern PEXA

A total of nine *French* military PEXA intersect the Study Area, primarily situated across the eastern export cable corridor. The two PEXA situated in the west of the proposed OWF are designated *Armorique D18D* and *Belle Ile 18*, and they are used for air-to-air firing and naval firing exercises, respectively. The remaining seven PEXA are all located within the eastern export cable corridor and are recorded as either naval and/or artillery firing areas.

Nonetheless, it is unspecified as to whether live ordnance has been used during such naval training and so, modern naval and artillery projectiles might be considered as part of the background UXO contamination threat in these select locations. In addition, the former *German* submarine base at

*Keroman* (situated 4.2km to the north-west) was retained by the *French Navy* following WWII and remained in military use until its eventual closure in 1997.

The georeferenced location of these modern military PEXA in relation to the Study Site is presented at Appendix 7.

## 3.6 Coastal Armaments

Along the *North Sea* and *North Atlantic* coastline of occupied *Europe*, the *German Organisation Todt*, undertook the construction of thousands of permanent defensive positions facing the sea, that collectively formed the *"Atlantikwall"* – which consisted of concrete bunkers, machine gun positions, military fortifications, and AAA positions (amongst other things). Though the *Atlantikwall* was unfinished by the time of the *Allied* invasion of *Europe,* many of these defensive positions were armed and were fully operational. A total of 599 defensive installations related to the *Atlantikwall* were located within 5km of the export cable corridor landfall areas*,* although it is likely that some of the features identified were constructed by the *French* military and simply repurposed by the occupying *German* forces. There is, therefore, very likely to be a residual threat posed by LSA and SAA from the probable stationing of troops at some, if not all of these locations.

Nevertheless, the major source of prospective contamination is likely to be posed by AAA projectiles associated with the AAA batteries deployed in this area, with a total of 273 emplacements having firing ranges overlapping, at least part of the Study Site. Supplementary research also suggests that the majority of the AAA guns in this area were of either 5cm, 7.5cm or 10.5cm calibre, whilst some larger calibre guns may also have been deployed alongside smaller calibre AAA and machine guns – notably and in ponticular the 34cm gun calibre coastal artillery battery that was located at *Plouharnel*.

The likelihood of AAA contamination from these guns is also considered and classified as "Likely", up to approximately 37km from the landfall areas (based on the maximum firing ranges of the coastal armaments then in the area).

A geo-referenced summary of all recorded coastal armaments at the *Atlantikwall* that had a firing range encompassing the Site, is presented at Appendix 8.

## 3.7 Munitions Related Shipwrecks and Aircraft

Merchant and naval vessels that were sunk in WWI and WWII may have contained munitions - either as armament and/or cargo. The extent of UXO contamination may vary, depending upon the nature and integrity of the wrecks. Wreck investigations have found that munitions can spill from ships as they sink and break up, otherwise their ordnance may be sealed within their holds and remain immobile.

Similarly, military aircraft that were shot down or otherwise had to ditch into the sea, may have also carried munitions. It is unlikely that any ship would have been sunk in the first exchange of fire due to the relative inaccuracy of WWI- and WWII-era weapons and it is likely that many bombs, projectiles, and torpedoes missed their targets. Regardless of the type of weapons systems employed to attack ships or aircraft, it is entirely feasible that several exchanges of fire would have preceded a successful attack. There may, therefore, also be UXO (in the form of iron bombs and/or gun projectiles) situated in the regions of those wrecks that may have been sunk by such exchanges of fire.

Table 3.7. summarises the quantity of potential munitions related shipwrecks located within 5km of the Study Site.

| Distance from Site | Cause of Sinking | | | | Total |
|---|---|---|---|---|---|
| | Air Raid | Mined | Naval Skirmish | Other | |
| On-Site | 1 | 5 | 15 | 0 | 21 |
| <500m | 1 | 0 | 0 | 0 | 1 |
| 500m - 1km | 0 | 0 | 0 | 0 | 0 |
| 1km – 2km | 0 | 0 | 1 | 0 | 1 |
| 2km – 5km | 3 | 4 | 2 | 3 | 12 |

**Table 3.7:** Munitions related shipwrecks within 5km of the Site, together with their cause of sinking.

An analysis of the data presented in Table 3.7, together with corroborative evidence gathered from *6 Alpha's Azimuth* UXO database, highlights the scale of historical warfighting activities within the OWF and its export cable corridors, which may have led to a UXO contamination threat, evidenced by not less than 21 munitions related shipwrecks having been documented within its boundaries. A further 14 munitions related shipwrecks were also recorded within 5km of its boundaries. Generally, the closer the munitions related shipwreck to the Study Site, the more likely a UXO contamination threat, is to have been generated within it.

The majority of the munitions related shipwrecks within the Study Site can be traced to naval engagements occurring within WWI, particularly the actions of *German* submarines in torpedoing and scuttling *Allied* merchant vessels off the coast of *Brittany*. Nonetheless, a reasonable number of shipwrecks in the wider area date from WWII, including those sunk by aerial bombing, as well as having been due to naval engagements and significantly, to the effects of naval mines.

Two vessels sunk within the Study Site are documented as having carried military munitions of their own which, following their sinking, are likely to have remained either within the body of the shipwreck or else on the seabed in close proximity to it – notably the *German* submarine *U*-171, which struck a naval mine on the 9th October 1942 and was sunk within the western export cable corridor. Nevertheless, any shipwrecks or aircraft identified within the Study Site or else in its close proximity, regardless of their munitions related history, are to be treated with caution and may anyway be the subject of routine avoidance.

A georeferenced summary of the proximity of all munitions-related shipwrecks located in proximity of the Site is presented at Appendix 9.

## 3.8 Munitions Dumping

Stockpiles of *Allied, Central Powers*, and *Axis* munitions of the conventional variety (i.e., HE filled), and chemical munitions that had been earmarked for wartime use, were disposed of at the end of both World Wars. As a cost effective and military expedient, conventional and chemical munitions were often dumped offshore or into suitable bodies of water inland, such as lakes.

Whilst the centre of mass of such dumpsites were recorded, the logistical accuracy of dumping such munitions was then, less than perfect. Such munitions were commonly short-dumped and although some chemical and conventional munitions were dumped in small munitions' containers the effects of their break-up and subsequent munitions migration may well have further spread the theoretical extent of such contamination.

An analysis of pertinent naval and admiralty charts and relevant marine environment protection agency databases has identified one conventional munitions dump within the western export cable corridor north-west of *Île de Groix*, with a further three dumps located between *Lorient* and *Groix* (370m to the north-west), south-west of *Île de Groix* (820m to the north-east), and near *Concarneau* (1.7km to the west).

The exact types of conventional munitions dumped at these locations is not known however and therefore, it is not possible to assess the specific type of UXO that may be encountered. Nonetheless, research indicated that in April 2012, an unexploded shell was dredged in *Lorient Harbour* and that it was transported to and emplaced at the munitions dumpsite (370m to the north-west of the eastern export cable corridor).

The georeferenced locations of munitions dumps recorded near to the Site are presented at Appendix 10.

## 3.9 Previous UXO Encounters

An analysis of the OSPAR database indicated that at least 61 conventional munitions have been encountered within the export cable corridors previously, in addition to a further 56 conventional munitions encounters within 5km of their boundaries. There are no documented munitions encounters within the proposed OWF array itself, however. The vast majority of encounters have been recorded on the foreshore, suggesting that munitions are highly likely to be encountered in the nearshore sectors.

In addition, *6 Alpha's* research has revealed the following:

- In May 2009, an artillery projectile was found on *Kerouriec Beach, Morbihan* (situated at the eastern export cable corridor landfall);
- In August 2009, an artillery projectile was found on *Kerhillio Beach, Morbihan* (situated at the eastern export cable corridor landfall);
- In July 2010, an artillery projectile was found on *Magouëro Beach, Morbihan* (situated at the eastern export cable corridor landfall);
- In August 2010, an artillery projectile was found by a fisherman at *Magouëro Beach, Morbihan* (situated at the eastern export cable corridor landfall);
- In August 2012, an artillery projectile was found on *Kerouriec Beach, Morbihan* (situated at the eastern export cable corridor landfall);
- In September 2012, eight modern *French* naval rockets containing spotting charges were destroyed after being found on *Île de Groix* (situated approximately 1.9km to the north-west);
- In July 2013, a 15cm artillery projectile was encountered on *Sainte-Barbe beach* (situated at the eastern export cable corridor landfall).

Such encounters serve to highlight the longevity of the threat that might be posed by UXO in the marine environment in general. The georeferenced locations of nearby recorded munitions encounters are presented at Appendix 11 and further information concerning *inter alia*, the longevity of the UXO threat in the marine environment is included at Annex C.

## 3.10 UXO Threats – Summary

Based upon the threat assessment the following types of UXO, complete with their measurements, estimated ferrous mass, and expected Net Explosive Quantity (NEQ) (based upon equivalent Trinitrotoluene (TNT) masses), may pose a UXO threat at the project Site:

### 3.10.1 Aerially Delivered Iron Bombs

| Designation | Length x Diameter | Ferrous Mass | NEQ |
|---|---|---|---|
| *American* AN-M66 HE Bomb | 1,778mm x 592mm | 448kg | 507kg |
| *British* 1,000lb MC Bomb | 1,334mm x 451mm | 202-225kg | 309kg |
| *American* AN-M65 HE Bomb | 1,349mm x 478mm | 196kg | 253kg |
| *British* 1,000lb GP Bomb | 1,334mm x 411mm | 325kg | 161.9kg |
| *British* 500lb MC Bomb | 1,041mm x 328mm | 111-121kg | 136.5kg |
| *American* AN-M64 HE Bomb | 1,143mm x 361mm | 127kg | 121kg |
| *British* 250lb MC Bomb | 699mm x 254mm | 51kg | 67.8kg |
| *British* 500lb GP Bomb | 925/945mm x 328mm | 148kg | 65.5kg |
| *American* AN-M57 HE Bomb | 914mm x 277mm | 59kg | 59kg |
| *British* 250lb GP Bomb | 650/701mm x 259mm | 82kg | 30kg |

| Designation | Length x Diameter | Ferrous Mass | NEQ |
|---|---|---|---|
| *American* AN-M30 HE Bomb | 737mm x 208mm | 26kg | 26kg |

### 3.10.2 Torpedoes

| Designation | Length x Diameter | Ferrous Mass | NEQ |
|---|---|---|---|
| *German* 53.3cm G7a Torpedo | 7,200mm x 533mm | 1,248kg | 366kg |
| *German* 50cm G7 Torpedo | 7,000mm x 500mm | 1,170kg | 253.5kg |

### 3.10.3 Naval Projectiles

| Designation | Body Length x Diameter | Ferrous Mass | NEQ |
|---|---|---|---|
| *German* 8.8cm Naval Projectile | 394mm x 88mm | 12.38kg | 1.42kg |

### 3.10.4 Naval Mines

| Designation | Length x Diameter | Ferrous Mass | NEQ |
|---|---|---|---|
| *British* A Mark I-IV Mine | 2,280mm x 470mm | 340kg | 340kg |
| *British* Mark XVII Mine | 1,219mm x 1,020mm | 68kg | 227kg |
| *German* UC 200 Mine | 800mm x 800mm | 191kg | 141.1kg |

### 3.10.5 Artillery Projectiles

| Designation | Body Length x Diameter | Ferrous Mass | NEQ |
|---|---|---|---|
| *German* 34cm Artillery Projectile | 1,500mm x 340mm | 553.3kg | 21.7kg |

| Designation | Body Length x Diameter | Ferrous Mass | NEQ |
|---|---|---|---|
| *German* 20cm Artillery Projectile | 953mm x 203mm | 111kg | 8.93kg |
| *German* 17cm Artillery Projectile | 806mm x 170mm | 54.4kg | 6.4kg |
| *German* 15cm Artillery Projectile | 680mm x 150mm | 40.79kg | 3.91kg |
| *German* 12.8cm Artillery Projectile | 958mm x 128mm | 22.61kg | 3.08kg |
| *German* 10.5cm Artillery Projectile | 391/489mm x 105mm | 13kg | 1.85kg |
| *German* 8.8cm Artillery Projectile | 386mm x 88mm | 8.2kg | 0.71kg |
| *German* 7.5cm Artillery Projectile | 358mm x 75mm | 5.99kg | 0.51kg |
| *German* 4.7cm Artillery Projectile | 187mm x 47mm | 1.31kg | 0.18kg |
| *German* 5cm Artillery Projectile | 165/208mm x 50mm | 2.1kg | 0.17kg |
| *German* 4cm Artillery Projectile | 184mm x 40mm | 0.83kg | 0.068kg |
| *German* 3.7cm Artillery Projectile | 162mm x 20mm | 0.72kg | 0.03kg |
| *German* 2cm Artillery Projectile | 78mm x 20mm | 0.12kg | 0.006kg |

A geo-referenced chart depicting the range of UXO contamination sources across the Study Site is presented at Appendix 12.


www.6alpha.com
+44 (0) 2033 713 900
enquiry@6alpha.com

# 4 UXO Risk Pathways - Planned Operations

The Client has informed *6 Alpha* that a variety of GI works (undermentioned), are to be undertaken at the Site. These planned works are summarised to evidence the potential UXO risk pathways that may be generated, should such work encounter threat spectrum UXO - as identified in Section 3. The proposed scope of work associated with cable installation and WTG foundation installation has yet to be confirmed and therefore, *6 Alpha* have presented a range of typical methodologies that might be employed.

## 4.1 Geotechnical Investigation

The Client has stated that the following GI work is planned in advance of cable installation and wind turbine installation operations are expected to be carried out across the Study Area; and significantly, some of them in shallow waters (<5m). In general, a risk pathway may be generated if there is direct contact between the leading edge of the GI equipment and an item of UXO. The following methodologies are expected to be employed as part of the GI campaign:

### 4.1.1 Boreholing

Borehole operations employ kinetic energy to invasively penetrate the seabed. Such techniques are capable of initiating UXO, especially if the leading edge of the borehole equipment comes into contact with UXO.

### 4.1.2 Cone Penetration Testing (CPT)

CPT measures the resistance to penetration of the seabed, using a steel rod with a conical tip. Given that this methodology employs kinetic energy to invasively penetrate the seabed, it is, therefore, possible that if the CPT tool comes into direct contact with UXO, the kinetic energy generated may be sufficient to cause its initiation.

### 4.1.3 Vibrocoring

Vibrocoring employs the force of gravity, combined with kinetic energy (supplied by a vibrating head), to drive a sampling-core into the seabed, in order to collect sub-seabed samples. Therefore, given the kinetic energy involved in the process, vibrocoring is considered to be capable of initiating UXO, especially if the leading edge of the sampling equipment comes into direct contact with it.

## 4.2 Pre-Lay Operations

Pre-Lay Grapnel Run (PLGR) and Route Clearance (RC) will likely be employed to ensure that the cable route is clear of *inter alia*, disused communication cables and other seabed debris, which may prove detrimental to the cable lay and post-lay burial equipment.

PLGR operations generally involve towing an array of spear-point grapnels along the surface of the seabed along the designated cable Route Position List (RPL). Such operations may encounter and initiate UXO that is either very shallow buried or, that is located on the surface of the seabed. PLGR is not a UXO risk mitigative method and nor should it be considered as such in other than the most extreme circumstances (and only where no other technique is likely to work – in such conditions it needs careful supervision and risk mitigation). RC operations also typically involve the identification and removal of specific and significant impediments to cable lay and/or burial, such as boulders, anchors, chain, steel-wire rope, disused cables, and obstructions generated by wrecks and the like.

It is possible that pre-lay operations could cause a UXO detonation event, if pre-lay equipment comes into direct contact with it.

## 4.3 Cable Installation

An overview of potential cable installation methodologies is described briefly below, in order to inform subsequently the risks that UXO might pose to such techniques. The methodologies described below are not exhaustive, nor are they specific to this project however, they serve to illustrate the risks associated with a variety of commonly employed cable installation and burial methodologies.

### 4.3.1 Surface Laid Cable

The cable may be laid on the surface of the seabed and then subsequently buried. Cables are also surface laid where they cross-existing infrastructure (such as existing pipelines and other cables), as they cannot be buried at these locations.

The kinetic energy associated with surface laying the cable, subject to amongst other factors the mass of the cable per liner meter, the water depth and rate of lay, might be sufficient to initiate UXO - especially if the cable makes direct contact with it. Even if the cable lay energy is considered insufficient to initiate UXO (because e.g., the cable is relatively low mass and it is laid slowly), it is not considered best practice to deliberately overlay UXO with cables and in such circumstances, Post-Lay Inspection and Burial (PLIB) is likely to be both compromised and/or jeopardised.

### 4.3.2 Jetting

Where soft seabed conditions are encountered, jetting seabed sediments can be employed to bury cables either concurrently or in a sperate operation once it has been laid on the surface of the seabed. Jetting fluidises the seabed to enable burial of the cable to its target depth of burial.

Jetting procedures are considered a more benign and less aggressive installation methodology (as compared with e.g., mechanical cutting) and it is therefore, less likely to inadvertently initiate UXO when benchmarked with other methods. Despite this, a risk pathway may still be generated if direct contact is initiated between UXO and the jetting tool itself or the direct or indirect effects of its high-pressure water jetting system.

### 4.3.3 Ploughing

Displacement ploughs create an open V-shaped trench into which the cable can be concurrently laid. This process causes significant disturbance to the seabed as the trench can be up to 3m wide, whilst the plough can have a skid footprint of up to 10m wide, between its support skids. The open trench can be then backfilled using blades mounted to the rear of the plough, thus burying concurrently the cable behind it. The large footprint, significant mass of the machine and the kinetic energy it generates could collectively, encounter and initiate UXO.

Alternatively, a non-displacement plough could be used to cut through the seabed using a thin blade-like shear, through which the cable runs. This method generates a reduced level of disturbance to the seabed, by comparison with a displacement plough and it creates a narrow trench (usually between 0.3m and 1.0m wide). In such circumstances the trench, is normally backfilled as the cable is laid.

The risk considerations associated with plough methodologies are generated by the mass of the shear (and any supports skids) and their velocity, which in combination may be sufficient to initiate UXO either directly or indirectly.

### 4.3.4 Open Cut Trenching

Open cut trenching is typically utilised to bury and thus protect the cable, at the cable landing point onshore. Trenching can be undertaken by a terrestrial-based excavator during low tide and during these operations, a transition or joint-pit(s) may also be excavated.

There are several risk factors to consider for trenching and excavation operations; firstly, the mass of the excavator bucket and its operating velocity may be sufficient to initiate any UXO that might be encountered directly and/or indirectly, if it is in very close proximity. Second, the excavated material is expected to be used to back-fill the trench once the cable has been emplaced within it. If the excavated material is contaminated with UXO, the back-filling operation may also present an inadvertent risk pathway in that UXO might then be initiated.

Nonetheless, the risks that might be presented on "land" (defined for the purposes of this report, as above the high-water mark), are beyond the scope of this document. *6 Alpha* can consider separately the risks associated with trenching and excavation operations, together with those that might otherwise be presented at the cable landing point, in line with CIRIA guidance for managing UXO risks in the onshore environment – which differs from the UXO risk management guidance for offshore cable installation projects.

## 4.4 Cable Protection and Crossing Operations

Where offshore cable burial is not possible and also where existing cables or pipelines are crossed, some form of surface cable protection is likely to be required. Options that might be considered include but are not limited to the following:

### 4.4.1 Concrete Mattress and/or Rock Placement

To protect any existing (live and in-use) cable(s), concrete mattresses and/or rock placement may be employed to facilitate cable crossing(s), or split-piping may be applied to protect the cable. A UXO risk pathway may be generated by the emplacement of mattresses, rock (or rock-bags) or split-pipe, alongside and over the cable, although the probability of an inadvertent UXO detonation is dependent upon the resultant kinetic energy generated by the emplacement of the protection method and the juxtaposition, sensitivity and NEQ, of such UXO.

The potential risks may well be reduced if direct contact with UXO is avoided. And where there is potential UXO (pUXO) in their close proximity, then the cable protection system(s) are not only to be deployed in a controlled fashion but also and as slowly as is reasonably practicable (because the resultant kinetic energy generated is reduced) and that minimum pUXO safety avoidance distances are adhered to.

### 4.4.2 Third Party and Out-of-Service Cables

In consideration of third-party cable crossing and/or the removal of out-of-service cables, it is assumed that such cables would not have been (deliberately) installed on top of, or in very close proximity to UXO. Nonetheless, this does not mean that UXO will not be encountered anywhere within the export cable corridors (nor the associated OWF area), and therefore, a risk pathway may still be generated depending on the precise methodology employed to install the cable in areas where third-party or out-of-service cables are located.

## 4.5 Wind Turbine Installation Operations

The following techniques have been considered for WTG foundation and offshore platform installation:

### 4.5.1 Monopile Support Structures

A monopile support structure is employed where the tower of the wind turbine is supported by a single structure rooted in the seabed and is the most commonly employed foundation type when installing WTG foundations in shallow water (typically, not exceeding 60m deep). A typical method of WTG foundation installation involves driving the piles into the seabed using high energy impact-hammers powered by either steam or hydraulics, often from by a jack-up barge platform. As this method delivers significant kinetic energy as the piles are driven into the seabed, any UXO encountered directly is almost certain to be initiated, with any UXO in the immediate vicinity of such operations being placed at risk of being initiated indirectly by the through seabed shock, generated by such activities.

Drilling may be considered as an alternative methodology, which is most suitable in areas where the seabed is composed of hard sub seabed strata, that has sufficient strength to make the installed structure self-supporting. The probability of UXO encounter remains largely the same as with the employment a high-energy impact hammer due to the intense, invasive force exerted upon and through the seabed.

### 4.5.2 Jacket Support Structures

Alternatively, the use of jacket support structures is commonly considered for offshore converter platform installation. The potential for UXO encounter and initiation is similar to that associated with WTG monopile installation although the piles used are of a much smaller diameter and are generally expected to be emplaced with less energy. Nonetheless, given that the same holistic installation methodologies are usually used for jacket support structures as with monopiles, the likelihood of UXO initiation remains similar.

### 4.5.3 Scour Protection Systems

It is expected that the WTG foundations may require some form of anti-scour protection, which is usually provided in the form of either static or dynamic rock armour which is emplaced after the installation operations are complete. The type and extent of anti-scour protection depends upon the soil and seabed conditions as well as the type of foundations employed.

If rock or scour protection systems are employed, the UXO risk is dependent upon the resultant kinetic energy generated during their installation, which may be considered sufficient to initiate a variety of different types of UXO.

## 4.6 Enabling Operations

The following methodologies may be employed to facilitate the planned GI works and/or cable installation and WTG foundation installation operations:

### 4.6.1 Dynamically Positioned (DP) Vessels

DP vessels employ computer-controlled systems to automatically maintain their position and heading by using propellers and thrusters. Position reference sensors and satellite navigation, combined with wind sensors, motion sensors, and gyrocompasses provide information to a computer that maintains vessels' positions, constantly accounting for the magnitude and direction of environmental forces affecting them. DP vessels are commonly used to support a wide variety of sub-seabed operations, such as foundation and cable installation.

If a DP vessel does not make contact with the seabed (because it is not anchored and will not ground) then a prospective encounter with UXO from such a work platform does not presents a UXO pathway and thus a risk is not generated. A risk however might be presented in shallow water, if thrusters disturb UXO in close proximity of the influence of the thruster and that is located either on the surface of the seabed or otherwise, shallow buried beneath it.

### 4.6.2 Anchoring

It is possible that other types of vessels will anchor independently or otherwise employ Anchor-Handling Tugboats (AHT), to support the proposed operations. There is a risk that anchors could initiate UXO if they were to come into direct contact with it, either as they are positioned and especially emplaced. However, the deployment and post-tensioning of anchor catenaries are considered much less likely to inadvertently initiate UXO. In the latter case, this is due to a number of factors, namely: the cable forces are comparatively longer in duration and of lower magnitude; the risk is generally confined to surface UXO only (as the cables may be deployed under tension and may not generally sweep extensive areas of the seabed); nonetheless, any cable contact with UXO is likely to be linear (i.e., along the cable/UXO length rather than as a "point" force), which is considered less aggressive when compared with a point induced force.

### 4.6.3 Jack-Up Barges

A jack-up barge is a type of mobile platform that consists of a buoyant hull fitted with a number of movable legs, capable of lifting it over the surface of the sea, thus affording a stable work platform for *inter alia*, the installation of WTG foundations. The buoyant hull facilitates relatively easy transportation of the barge between operations and once it is at the desired location, the hull is raised (jacked-up on legs), to the required elevation above the sea and its legs are supported by the seabed.

From a UXO risk perspective, the legs of such barges may be designed to penetrate the seabed, and/or may be fitted with enlarged sections or footings. Generally, jack-up barges are not self-propelled and rely on AHT for positioning and upon its anchors for stability and movement. Nonetheless, if the jack-up barge leg or its anchor (deployed by an AHT) encounters UXO, then a risk pathway might be generated.

### 4.6.4 Diving Operations

There is no indication that divers are currently being considered to assist or undertake GI, nor installation operations.

Nonetheless, divers are especially vulnerable to the types of underwater shock generated by UXO detonations and, subject to UXOs' NEQ, diver fatalities can easily be generated hundreds of metres from the seat of an underwater high explosive event. Therefore, divers should not be deployed where there is a risk of occurrence of such a detonation event.

If divers are to be used, then the risks associated with diving operations must be reassessed by *6 Alpha*.

# 5 Study Site Characterisation

## 5.1 Local Sea Bed Conditions

The study Site's local seabed conditions are important influencing factors when assessing the potential for UXO burial and/or migration and the potential consequences of an unplanned encounter and initiation of UXO during GI, cable installation and WTG foundation installation operations.

### 5.1.1 Bathymetry

A body of water will both absorb and transmit energy, generated by either a bomb entering the water and/or a high explosive event of the sort that might be generated by a UXO detonation. In general, the consequences of a through-water UXO detonation will reduce, as the "stand-off" – or separation distance – increases between prospective receptors and the UXO either buried in or lying upon the seabed.

The water depths reported in the *Bay of Biscay*, within the bounds of the export cable corridors, range from landfall (i.e., 0m LAT) up to 94m LAT. Within the proposed OWF area itself, the water depths range from 50m to 109m LAT. Due to the (relatively), deep-water within much of the proposed OWF area, the consequences of potential UXO initiation are likely to be significantly mitigated by the ameliorative effect of that body of water, on UXO initiation effects especially. However, in areas of shallower water, notably across parts of the export cable corridors, this is unlikely to be the case.

The water depths (in LAT) across the Study Site are presented at Appendix 13.

### 5.1.2 Seabed Sediments and Shallow Soils

The nature of local seabed sediments and shallow soils also need to be considered to determine the prospect for UXO burial in general and unexploded bomb UXB) burial in particular, upon their initial deployment and/or subsequently by seabed sediment movement. UXO scour and/or migration may also be influenced by seabed sediments.

Although detailed shallow soil and seabed sediment information for the Study Site has not yet been collected, an analysis of *European Marine Observation and Data Network* data has noted that muddy-sand sediments are present across the majority of the *A05 Brittany* Site.

As the export cable corridors approach the shore, a wider variety of seabed sediments are recorded, including rock, sand and fine mud. Mud sediments are generally less likely to form a mobile seabed than one comprising solely of sandy sediments but, it is still possible that UXO may have become shallow buried (after their initial deployment, having come to rest upon the surface of the seabed), by mobile seabed sediment, particularly within sandy seabed areas.

## 5.2 UXO Burial and Munitions Migration

### 5.2.1 Initial Burial

As with impact burial of UXO on land, only those munitions travelling at a high terminal velocity at the point of impact (e.g. and typically aerially delivered iron bombs and/or gun/mortar launched projectiles), have the potential to penetrate the seabed upon their initial deployment. Historically, studies of typical bomb penetration depths have been undertaken for the terrestrial environment based upon *inter alia*, the soil type in general and its shear strength in particular, as well as the UXO type, size and mass and their angle/speed of initial impact. Such studies are not directly applicable in the offshore environment, given the mitigative effects of water (e.g. in slowing and reducing the impact of munitions on the seabed). Nonetheless and in general, UXO penetration into the seabed beyond 2m below seabed level, is considered highly unlikely in water depths of more than 20m, with initial impact burial in deeper waters considered highly unlikely.

### 5.2.2 Munitions Migration Effects

If geophysical UXO survey data is more than one year old from its date of capture, it may compromise the subsequent production of an ALARP safety sign-off certificate in general and the positional accuracy of pUXO (designated for avoidance) in particular, because of the risk of prospective munitions migration effects.

In order to address this issue and to extend the longevity of ALARP safety sign-off certification, a Munitions Migration and Burial Assessment can be undertaken, that models the potential for UXO migration based upon *inter alia* seabed geomorphology in general and the Site's seabed characteristics in particular (e.g. the seabed sediments, current direction, and strengths).

Further background information regarding UXO scour, burial and migration is presented separately at Annex D.


www.6alpha.com
+44 (0) 2033 713 900
enquiry@6alpha.com

# 6 UXO Risk Assessment

## 6.1 Overarching Methodology

A Semi Quantitative Risk Assessment (SQRA) has been undertaken and it is presented separately at Appendix 14. The SQRA is specifically designed to assess the probability of an unplanned discovery and initiation of UXO, as well as their prospective consequences upon a range of potential sensitive receptors (e.g. vessels and any associated underwater equipment), in order to determine the level of UXO risk for GI, cable installation and WTG foundation installation methodologies. This assessment is achieved by employing the following formula: Risk **(R)** = Probability **(P)** x Consequence **(C)**. The core elements of this formula and its variables are further described at Section 6.3.

The risk assessment has been conducted for all types of operations, irrespective of the prospective risk mitigative effect of any prior operations which by then, may have preceded them.

However, the assessment not only evaluates the level of UXO risks generated but also highlights the effect of the recommended risk mitigation measures - benchmarked with reducing risks ALARP. A full explanation of *6 Alpha's* SQRA process is presented at Annex E.

## 6.2 The Precautionary Principle

Making predictions about the yet unobserved states of UXO, generates uncertainties within the risk assessment, especially when determining the probability of UXO initiation. The probability of UXO encounter and of its initiation is therefore steered by the precautionary principle that, for risk assessment and mitigation purposes, informs risk-mitigating actions in such circumstances.

The principle concludes that if there is uncertainty about the nature of the risk (e.g. but not limited to, the condition and viability of UXO), then a proportionate, transparent, and consistent approach must be taken during the decision-making process that aligns with industry best practice. Therefore, for risk assessment and precautionary purposes, it is assumed any direct, kinetic energy encounter with UXO is likely to cause its initiation.

## 6.3 Risk Assessment Variables

The UXO risk level at the Study Site has been determined by considering the following factors:

### 6.3.1 Probability

Probability is determined by considering the likelihood of both encountering and initiating UXO.

The probability of encountering UXO is a function of the prospective nature, scope and extent of the prospective UXO contamination sources within the Site (which have been evidenced separately at Section 3) and the juxtaposition of any and all sub-seabed, intrusive activities with respect to it. Nonetheless, the numbers, extent and locations of all prospective UXO threats are difficult to accurately quantify due to the lack of detailed historical records associated with depositional events (such as, and especially; unrecorded and abandoned ordnance; and/or AAA fire; and/or jettisoned aerial HE bombs that cannot be spatially defined with either certainty or accuracy). Such uncertainty is accounted for by employing the precautionary principle (and see Section 6.2).

The likelihood of initiating underwater UXO is generally, but not exclusively, dependent upon kinetic energy; therefore, the planned operations that might generate it have been considered within Section 4, in order to determine if the kinetic energy associated with such activities that might create a viable UXO risk pathway.

### 6.3.2 Consequence

The consequences of an unplanned UXO initiation are a function of the mass of high explosives in the UXO and their proximity to, and robustness of, sensitive receptors - including the support vessels, their crews as well as GI, cable installation and WTG foundation installation equipment/tools.

The mass of high explosives and their underwater and/or surface effects can generally be either estimated or accurately modelled. Other assessment factors include but are not limited to; the prospective position of the UXO on the seabed at the moment of its encounter (i.e., on the surface or partially/completely shallow buried - and in the latter case to what depth), the soil type, the through soil and through water/air separation distances between the UXO; and the robustness of such receptors.

The likely through-water and/or through-air effects upon such receptors are dependent upon their juxtaposition with reference to the UXO, as well as their robustness in general and their capacity to withstand such a high-explosive event in particular. Generally, personnel are very vulnerable to high explosive fragmentation, as well as underwater shock and to a reduced extent surface-blast. As long as workers are not jeopardised, limited adverse effects upon vessels, barges and GI, cable installation and/or wind turbine installation equipment, might be tolerated.

Further detailed information, detailing both the effects of high explosive detonation events in the marine environment and the way in which these are modelled by *6 Alpha*, is included at Annex F.

## 6.4 Risk Assessment Key Findings

The findings of the risk assessment are presented at Table 6.4:

| Intrusive Operation | UXO | UXO Risk (10m WD) | UXO Risk (26m WD) | UXO Risk (40m WD) | UXO Risk (60m WD) |
|---|---|---|---|---|---|
| Geotechnical Investigation | Aerial Bombs | HIGH | HIGH | MEDIUM | MEDIUM |
| | Naval Mines | HIGH | HIGH | HIGH | MEDIUM |
| | Projectiles | MEDIUM | LOW | LOW | LOW |
| Pre-Lay Operations | Aerial Bombs | VERY HIGH | VERY HIGH | HIGH | HIGH |
| | Naval Mines | VERY HIGH | VERY HIGH | HIGH | HIGH |
| | Projectiles | HIGH | MEDIUM | MEDIUM | LOW |
| Cable Installation and Burial | Aerial Bombs | VERY HIGH | VERY HIGH | HIGH | HIGH |
| | Naval Mines | VERY HIGH | VERY HIGH | HIGH | HIGH |
| | Projectiles | HIGH | MEDIUM | MEDIUM | LOW |
| Wind Turbine Installation | Aerial Bombs | HIGH | HIGH | HIGH | MEDIUM |
| | Naval Mines | HIGH | HIGH | HIGH | HIGH |
| | Projectiles | HIGH | MEDIUM | MEDIUM | LOW |
| Protection Operations | Aerial Bombs | HIGH | HIGH | HIGH | MEDIUM |
| | Naval Mines | HIGH | HIGH | HIGH | HIGH |
| | Projectiles | HIGH | MEDIUM | MEDIUM | LOW |
| Enabling Operations | Aerial Bombs | HIGH | HIGH | HIGH | MEDIUM |
| | Naval Mines | HIGH | HIGH | HIGH | HIGH |
| | Projectiles | HIGH | MEDIUM | MEDIUM | LOW |

**Table 6.4:** Representative UXO Risk Assessment Summary

An unexpurgated project SQRA has been included at Appendix 14, which presents the complete risk assessment for each individual sub-seabed intrusive activity as well as each UXO threat group.

In addition, Table 6.4 is intended as an indicative summary. Torpedoes were not included for presentation purposes based on the fact that they have been categorised as a MEDIUM level of UXO risk and they do not therefore require bespoke UXO risk mitigation because, those risk mitigation measures associated with UXO that is considered more prevalent (e.g. HE bombs and naval mines), will also account for torpedoes and their like.

### 6.4.1 GI Operations

GI operations (including bore-holing, CPT and vibro-coring) are considered less likely to directly encounter UXO (as benchmarked with other types of sub seabed intrusive activities), given the juxtaposition of UXO threats, the limited spatial extent of the methodologies employed and the likely level of disturbance of the seabed.

GI operations are considered a HIGH UXO risk in general, although this risk is reduced to MEDIUM in deeper waters (>26m LAT) accounting for most types of UXO threat sources, due partially to the concentration and scope of the UXO contamination threats across the Study Site and the amelioration effect of the deep water, upon a high explosive UXO detonation event.

### 6.4.2 Pre-Lay Operations

Any PLGR and/or RC operations that are undertaken along the export cable corridor routes and in advance of cable installation, is likely to generate significant UXO risks. This is because PLGR is considered may encounter UXO as it covers a significant linear extent, and the grapnels have prolonged contact with the seabed. Therefore, unmitigated UXO risks associated with pre-lay operations in general and with PLGR in particular, are categorised as VERY HIGH risks in areas associated with WWII mine deployment and aerial bombing.

### 6.4.3 Cable Installation and Burial Operations

Surface lay and subsequent burial of cables are likely to generate different categories of UXO risks owing to the amount of seabed interaction involved with the various installation and burial methodologies under consideration.

Where cables are laid on the surface of the seabed and they are not then to be subsequently buried, UXO risks are categorised HIGH, although this risk may be reduced to MEDIUM in deeper water (>26m LAT) accounting for most UXO threat sources – assuming that the cable will be installed upon the surface of the seabed in a controlled fashion.

Where however, either jetting or ploughing cable burial techniques are to be employed, then such UXO risks are categorised as HIGH or VERY HIGH due to the comparatively large footprint of such installation tools (especially a subsea cable plough) and the significant forces exerted into the seabed by such cable burial tools.

### 6.4.4 WTG Foundation Installation Operations

The installation of WTG foundations are categorised as HIGH UXO risk in all water depths. This is because the common installation methodologies employ significant levels of kinetic energy to drive monopiles into the seabed. Any UXO encountered either directly or close proximity to such operations is considered highly likely to be initiated.

### 6.4.5 Protection Operations

The emplacement of rock to protect unburied cables or to prevent scour at wind turbine foundations may also generate HIGH UXO risks. Dumping rock either over the side of a rock dumping support vessel or through a pipe-fall system, may result in significant kinetic energy being transferred (in comparison with more controlled installation methods), which may cause a UXO initiation event should the rock come into direct contact with it or if rocks impact the seabed in their close proximity.

### 6.4.6 Enabling Operations

Anchoring is considered unlikely to directly encounter UXO, given the reduced spatial extent of the anchoring and the likely point-disturbance of the seabed. Nonetheless, anchoring is categorised a HIGH UXO risk, although it may be reduced to MEDIUM level in deeper water (>26m LAT), due partially to the comparative concentration and scope of the UXO contamination threats across the Study Site and the amelioration effect of the deep water upon a high explosive UXO detonation event.

Jack-up barge operations also pose a HIGH UXO risk in all depths of water as a result of the kinetic energy and penetration of the seabed associated with the deployment of their legs.

### 6.4.7 Surface Vessels and Personnel

Although there is evidence to suggest that a UXO encounter could occur across significant swaths of the OWF area and its export cable corridors, such an encounter is generally considered a low probability-high consequence event. Therefore, the consequences of exposing the vessel and its crew to the kind of forces associated with an underwater initiation of an indicative selection of high, medium and low NEQ threat spectra UXO has been modelled and is presented separately at Table 6.4.7.

| UXO | Estimated Ferrous Mass | NEQ | Consequence at 10m WD | Consequence at 26m WD | Consequence at 40m WD | Consequence at 60m WD |
|---|---|---|---|---|---|---|
| A Mark I-IV Mine | 340kg | 340kg | Vessel Sinking / Fatalities | Vessel Sinking / Fatalities | Serious Structural Damage / Fatalities | Mechanism Damage / Minor Injuries |
| 1,000lb GP Bomb | 325kg | 161.9kg | Vessel Sinking / Fatalities | Vessel Sinking / Fatalities | Mechanism Damage / Minor Injuries | Minor Damage |
| 250lb GP Bomb | 82kg | 30kg | Vessel Sinking / Fatalities | Mechanism Damage / Minor Injuries | Minor Damage | Acceptable |
| 15cm AAA Projectile | 40kg | 3.9kg | Mechanism Damage / Minor Injuries | Acceptable | Acceptable | Acceptable |

**Table 6.4.7:** Consequences of UXO Initiation

Table 6.4.7 has been compiled using *6 Alpha's* in-house through-water, shockwave calculator, which is based on a variety of open source academic and military studies concerning military ordnance detonations underwater, the peak pressure generated, and the effects of pressure (with the effects measured in Mega Pascals (MPa)) on vessels and indirectly, their crews. Although the probability of initiating UXO varies between the types of GI and installation operations, the consequences of an initiation of each type of UXO is not driven by how such an initiation event might be caused. Therefore, the table remains applicable to GI as well as installation operations. The calculations presented within Table 6.4.7 are also employed within the SQRA (at Appendix 14) in order to assess and grade potential UXO detonation consequences based upon the peak pressure exposure of the vessel and its crews. Further explanation of the methodology for calculating UXO detonation consequences is presented at Annex E.

### 6.4.8 Underwater Equipment

If any size of UXO is inadvertently encountered and initiated, it is likely that underwater equipment or tools employed in close proximity of such an event are likely to be significantly damaged and/or completely destroyed.

### 6.4.9 Vessel and Diver Safety Distances

The SQRA assesses the risk of an unplanned initiation of UXO with reference to relevant sensitive receptors (e.g. including but not limited to, vessels and their crews and/or underwater equipment), resulting from underwater explosive shock waves and to a reduced extent, fragmentation effects.

Such underwater detonation effects are determined the energy that might be generated by detonating high explosive UXO. TNT is employed as a representative baseline high explosive for the likely UXO threat items within the Site (regardless of their precise high-explosive fill), as well as estimating the distances separating the source (UXO) and the sensitive receptors.

The following formula is applied to calculate peak pressure with the resultant shockwave output generated in MPa, (Reid, 1996):

$$Peak\ Pressure\ (MPa) = 52.4.\left(\frac{M^{\frac{1}{3}}}{R}\right)^{1.18}$$

Using this formula, Table 6.4.9 summarises the distances at which point the prospective consequences of an underwater encounter and initiation of a selection of threat spectrum UXO to the vessel(s) and their crew(s) become intolerable (e.g. where injuries are sustained from exposure to more than 4MPa of peak pressure). In addition, the table also summarises the minimum safety distance for divers - if they are to be employed (these distances have been calculated by *6 Alpha's* UXO experts).

| UXO Type | UXO NEQ | TARA Consequence Score Peak Pressure Exposure (MPa) and Vessel Safety Distance | | Swimmers and Divers Safety Distance |
|---|---|---|---|---|
| | | 1<br>0 – 2 (MPa) | 2<br>2 – 4 (MPa) | Burst on seabed with diver on seabed |
| A Mark I-IV Mine | 340kg | 112m | 62m | 1,736m |
| 250lb GP Bomb | 30kg | 50m | 28m | 1,121m |
| 15cm AAA Projectile | 3.9kg | 26m | 14m | 777m |

**Table 6.4.9:** Underwater Explosion Consequences

For the consequences of an initiation of high NEQ UXO to be completely ameliorated in terms of its effects upon the vessel (<2 MPa and see consequence column 1), the minimum vessel safety stand-off distance must be not less than 112m (this may be reduced to 50m and 26m for medium and low NEQ items, respectively).

Consequence column 2 articulates the depths of water at which light superficial damage to the vessel may be caused and the exposure of the vessel and its crew to intolerable and dangerous high-explosive effects is likely to occur at depths of less than 62m, if a large NEQ UXO is initiated. If the vessel(s) and its crew(s) are exposed to greater than 4MPa of pressure, the likely effects are damage to electronics, injuries sustained by crew members and partial loss of vessel steering and control. Vessel damage becomes more severe as the peak pressure exposure increases, with fatalities highly likely to be caused at 8MPa pressure and greater. These consequences have been calculated without accounting for the specific characteristics of the vessels that will eventually undertake the proposed GI and installation operations. Therefore, the precise consequence modelling might change as additional factors such as vessel draught are introduced.

In addition, divers are highly vulnerable if they are exposed to the kind of underwater shock generated by UXO initiation. As Table 6.4.9 evidences, swimmers and divers are required to be located at between 777m and 1,736m from the seat of a seabed initiation of threat spectrum UXO (smallest to largest respectively), to be considered safe, which further evidences the risks involved with deploying divers during sub-seabed operations, wherever UXO contamination might be expected.

## 6.5 UXO Risk Zones

*6 Alpha* have zoned the whole of the study area according to the level of risk generated by a variety of sub-seabed activities and sources of UXO. UXO risks have therefore been zoned, based on one, or a combination of, the following factors:

- The nature and scope of sub-seabed activities and the distances from pertinent UXO threat sources;
- The varying water depths (LAT) throughout the OWF array and export cable corridors;
- The project stakeholders' assumed appetite for the carriage of residual UXO risks.

Given the distribution of UXO threat sources (identified in Section 3) and their various NEQ, juxtaposed with the expected water depths, it is possible to split the Study Site into UXO risk zones at a high-level, as presented in Figure 5 and Appendix 15.

VERY HIGH UXO risks have been evidenced in the nearshore sectors associated with both export cable corridors, based upon *inter alia* but not limited to; the historical evidence of high-NEQ naval mining and munitions dumping, in conjunction with the relatively shallow water depths near to *Lorient* and *Île de Groix*.

Furthermore, HIGH UXO risks are posed in along the remainder of the nearshore areas. Such risks are primarily driven by HE bombing, WWII-era naval mines and AAA projectiles in relatively shallow waters.

The remainder of the Study Site presents MEDIUM UXO risks where a combination of deeper water depths and the absence of evidence to suggest large NEQ UXO may be present, both reduce the overall level of risk.

The UXO risk zones are presented at Figure 5.

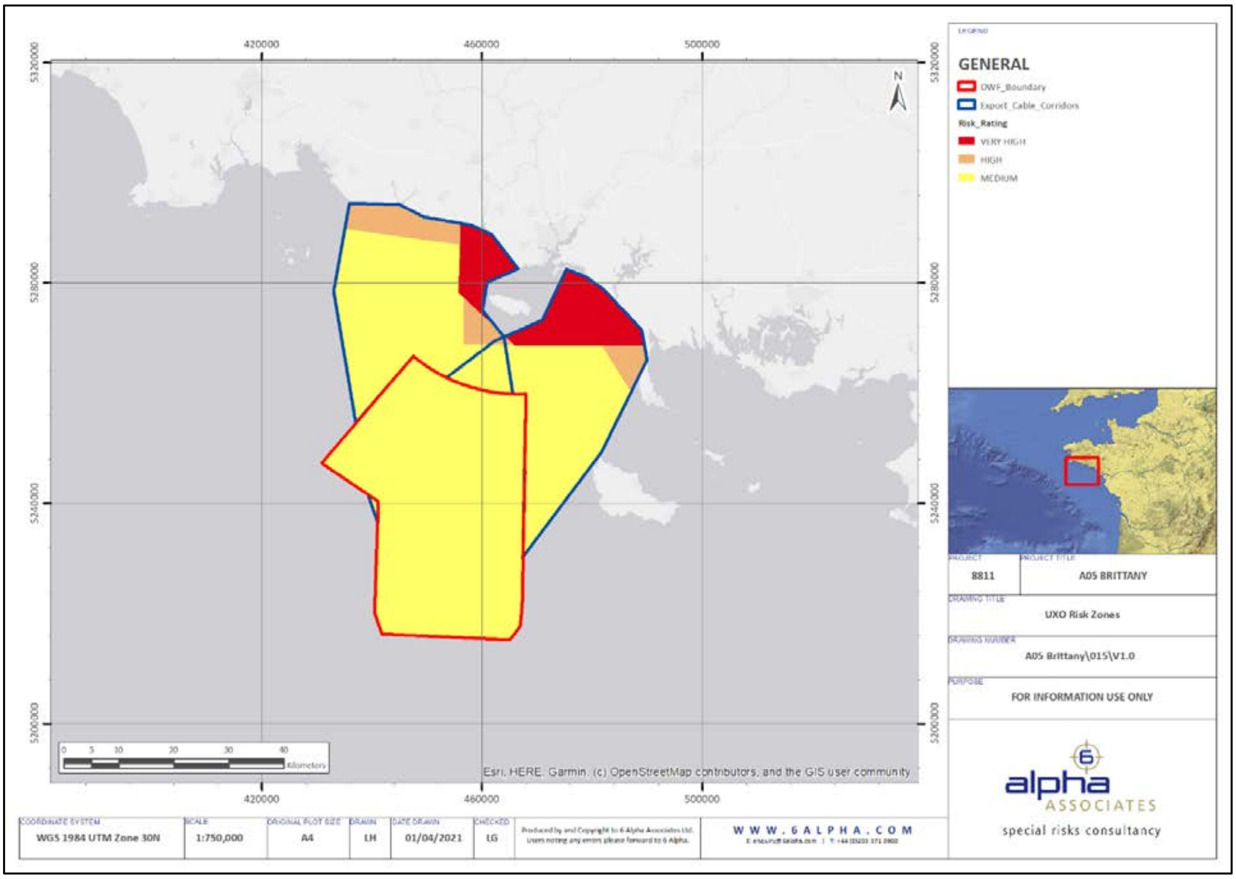



**Figure 5 – UXO Risk Zones: All Operations**

*6 Alpha* have also zoned the UXO risk associated with GI works only, those risk zones are presented at Figure 6 and Appendix 16.

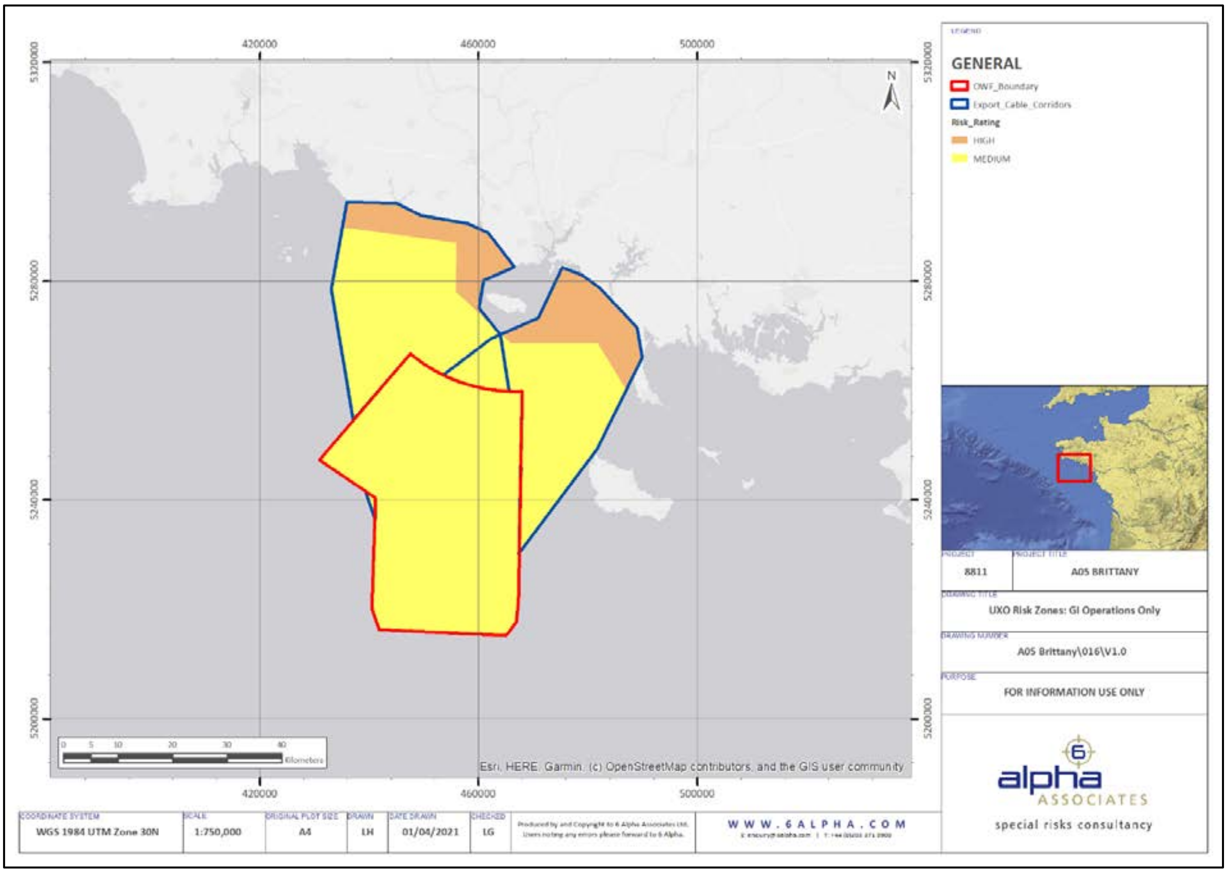



**Figure 6 – UXO Risk Zones: GI Only**

It is possible that the UXO risk zones could be refined further within the body of a tactical level risk mitigation design document and through further risk analysis. However, the precise types and locations of any intrusive GI operations would need to be considered, together with the water depths and likely shallow sub-seabed conditions, in order to further refine the UXO risk zoning, in either the OWF array or its export cable corridors.

# 7 Conclusions and Recommendations

## 7.1 Conclusions

### 7.1.1 Generally

The nature and scope of the UXO risks vary across the OWF area and for each export cable corridor, based upon a source-pathway-receptor review in general, as well as an analysis of the probability of encountering and of initiating UXO and the prospective consequences of doing so, in particular. The nature and extent of the risks posed are partly predicated by *6 Alpha's* assessment of the type, extent and aggressiveness of the proposed intrusive operations.

In the offshore environment, the effects of the depth of water upon potential UXO initiation consequences (and *inter alia* the resultant through seabed and through-water shock wave), will be partly or wholly risk mitigative with the exception of large Net Explosive Quantity (NEQ) UXO threats and in such circumstances, where the risk is partly and sufficiently mitigated, the residual risks might well be tolerated.

Nonetheless, some UXO risks posed by the proposed operations have been categorised as either VERY HIGH or HIGH because they are generally associated with the unplanned initiation of large NEQ UXO in the nearshore sectors – such as naval mines and aerial bombs, with the generation of prospective risks by sub-seabed operations such as GI, cable installation and WTG foundation installation, as well as similar enabling or supporting operations. Such risks are considered intolerable. MEDIUM category UXO risks are also posed by certain other types of UXO and/or intrusive sub-seabed operations in deeper water.

As a result, *6 Alpha* have zoned such offshore UXO risks into different categories and have defined the requirements for their mitigation, based upon underwater explosive effects modelling and the variable likelihood that UXO may be encountered within different areas of the OWF.

### 7.1.2 UXO Risks to Surface Vessels and their Crew

UXO risks that are posed to vessels and their crew are most severe in shallow water (defined for the purposes of UXO risk analysis as 26m water depth, or shallower). Although the UXO risk is generally greater during prospective installation operations than it is during point-focal GI operations.

In addition, the prospective consequences for surface vessels generally reduces as the depth of water between the vessel and the point of a UXO initiation increases, the water depths throughout the OWF area and the export cable corridors are expected to be sufficient to wholly mitigate threat spectrum NEQ UXO risks posed by medium sized naval mines, and therefore, the level of UXO risk is generally categorised as MEDIUM in the OWF and offshore sectors of the export cable corridors.

Furthermore, the UXO risk to point-focal GI operations is reduced, particularly in deeper water. For example, the UXO risk during GI operations in water depths of 60m Lowest Astronomical Tide (LAT) is categorised as MEDIUM, whereas installation operations at the same depth may still generate a HIGH level of UXO risk depending on the types of UXO likely to be present and their NEQ.

If divers are deployed to facilitate subsea operations, then they may also be exposed to significant UXO risks, because divers are especially vulnerable to UXO if it is initiated underwater and fatalities can be generated hundreds of meters from the seat of such explosions (subject to the NEQ in the UXO).

#### 7.1.3 UXO Risks to Underwater Equipment

Underwater equipment and, subject to water depths, their support vessels, are unlikely to be sufficiently robust to withstand the consequences of an initiation of most threat spectrum UXO. The prospective UXO risks posed to underwater equipment are therefore classified as at least HIGH in all depths of water.

### 7.2 Recommendations

*6 Alpha* recommends that the UXO risk is mitigated within the bounds of the ALARP risk reduction principal. For example, if project stakeholders are willing and able to tolerate some low NEQ UXO risks associated with subsea equipment, then better value for money solutions may be afforded in terms of UXO risk mitigation by avoiding those costly and time-consuming risk mitigation measures that reduce the risks associated with low NEQ UXO threats in deep water especially. Therefore, *6 Alpha* has recommended that only specific and intolerable risks (i.e. those categorised as HIGH and VERY HIGH) are mitigated in order to reduce them to ALARP, in accordance with *EU* and national laws.

The following UXO risk mitigation recommendations have therefore been made in order to reduce UXO risks to ALARP:

#### 7.2.1 UXO Risk Mitigation Strategy for GI - Overview

The UXO risk mitigation strategy has been designed for GI operations only, and there are three main options to consider in order to reduce these UXO risks ALARP, based upon the source-pathway-receptor model.

*6 Alpha*'s approach is that UXO risk can effectively be reduced to ALARP, by removing one (or more) element(s) of the model or otherwise mitigating the risks associated with a single element of the model. The three main strategic options based upon source-pathway-receptor modelling are, in priority order:

#### 7.2.1.1 Avoidance

A strategy of pUXO detection and avoidance is proposed as the most cost effective and efficient method of reducing UXO risks to ALARP. By surveying for and avoiding direct or indirect contact with any pUXO by moving the locations of GI operations where necessary, such risks are appropriately and effectively reduced.

An overview of the different methods available to detect UXO is presented at Annex G.

#### 7.2.1.2 Removal of Risk Receptors

A second option is to remove the receptor element (of the source-pathway-receptor model), by moving certain sensitive and vulnerable receptors (typically crews of offshore vessels), to a safe distance from the point of the intrusive activity and thus the pUXO hazard, so that it will diminish sufficiently the prospective blast, fragmentation and/or shock wave consequences to reduce UXO risks to ALARP. Clearly, this is not always achievable and such a course of action is commonly impractical.

#### 7.2.1.3 Removal of Threat Sources

Where GI operations cannot be moved in order to avoid pUXO, an alternative (but commonly, time consuming and costlier) option, is to verify pUXO by investigation and where it is confirmed UXO (cUXO), to remove it (effectively removing the source element of the source-pathway-receptor model) Either by moving it to a position where it can do no harm (but only when it is safe to do so and wherever permit licencing and consent condition allow such actions), and/or destroying it or otherwise rendering it safe.

#### 7.2.1.4 Residual Risk Tolerance

Following the implementation of the risk mitigation strategy, UXO risks will not be reduced to "zero". Residual UXO risks will likely remain in the offshore environment due to *inter alia*, the limits of geophysical UXO survey technology, data interpretation limitations and the fact that small scale low NEQ UXO threats might be tolerated which is acceptable under the auspices of the ALARP risk reduction principle. Such residual risks have been tolerated on many other projects, in very similar circumstances. Such an approach, therefore, is likely to be deemed acceptable by a wide variety of project stakeholders and regulators and is consistent with all agreed upon risk management standards, practices and frameworks.

### 7.2.2 UXO Risk Mitigation Measures

The GI risk mitigation strategy should be enacted through the design and implementation of risk mitigation measures, as follows:

- Proactive Measures:
    - **Geophysical UXO Survey**; a geophysical UXO survey is to be designed (and subsequently undertaken) to detect threat spectrum UXO as follows:
        - **SSS**; high-resolution Side Scan Sonar should be employed (>600kHz frequency);
        - **MBES**; Multi-Beam Echo-Sounder survey is often corroborative and helpful in delivering UXO target discrimination; its outputs should therefore be employed to compliment SSS data;
        - **MAG**; subject to the locations and type of GI being undertaken, the juxtaposition of GI work vessel(s) and the water depths, geophysical UXO survey by magnetometer (or in combination gradiometer) may or may not be required. *6 Alpha* can better advise when the details of the GI operations are known;
    - **Anomaly Selection**; geophysical UXO survey data (is to be employed in order to select those anomalies that model as pUXO. *6 Alpha* can discriminate pUXO from benign seabed (or sub-seabed) detritus. Our recommendation is that pUXO should be avoided (see below); or, where it cannot be avoided, it may have to be verified by investigation (also see below);
    - **pUXO Avoidance**; pUXO is to be avoided either by 15m (the latter is a baseline and *6 Alpha* standard safety distance but may be reduced through the medium of a Technical Advisory Note), measured from the edge of any sub seabed GI tool;
    - **pUXO Investigation**; where pUXO avoidance criteria cannot be met (which is not expected to be an issue for the GI campaign), then target investigation must be undertaken to verify and classify pUXO as either cUXO, or as seabed debris. Any Target Investigation ought to be undertaken, remotely where possible;


www.6alpha.com
+44 (0) 2033 713 900
enquiry@6alpha.com

  - **UXO Disposal**; following the inspection of pUXO, those items verified as cUXO will require either: movement (e.g. to the edge of the consent corridor – where it is permitted and safe to do so) and/or render safe either by low-order/deflagration or by sympathetic detonation.

- Reactive Measures:
  - **Emergency Management Plans;** are to be written and distributed to all vessels involved with GI operations;
  - **Tool-Box Briefs**; are to be delivered to all personnel intimately involved with GI activities;
  - **On-Call UXO Response;** an office based, on-call UXO response option can provide rapid assistance and advice, if UXO is unexpectedly discovered - even after proactive risk mitigation measures have been executed - during any and all subsequent activities associated with GI operations.

#### 7.2.3 Minimum UXO Threat Item

The recommendation for the minimum threat items to be detected by geophysical UXO survey is variable throughout the Study Site depending on a number of factors including but not limited to; water depth, likely GI methodology, the nature of the UXO threat, prospective vessel slant range and vessel robustness. It should also be noted that the minimum threat item is based on a UXO threat item's ferrous metal content rather than its physical dimensions or any other factor.

In water depths of up to 10m LAT, the minimum UXO threat item to be detected by geophysical UXO survey is:

- 10.5 cm leFH 18 Artillery Projectile with a ferrous metal mass of 13kg.

In water depths of between 10m and 26m LAT, the minimum UXO threat item for survey is:

- *US* AN-M30 100lb HE Bomb with a ferrous metal mass of 26kg.

In water depths of between 26m and 40m LAT, the minimum UXO threat item for survey is:

- *British* 500lb MC Bomb with a ferrous metal mass of 111kg.

Where water depths exceed 40m LAT, the minimum UXO threat item for geophysical UXO survey should instead be the following:

- *British* Mark XVII Naval Mine with a ferrous metal mass of 68kg.

In general, the types of UXO threat spectrum items that need to be detected (and either: avoided by a minimum approved safety distance, or else verified by target investigation) in a variety of water depths, is presented in Figure 7. However, this figure is presented as an indicative guide and the precise detection requirements at each water depth may vary following based on the site-specific UXO threat assessment.

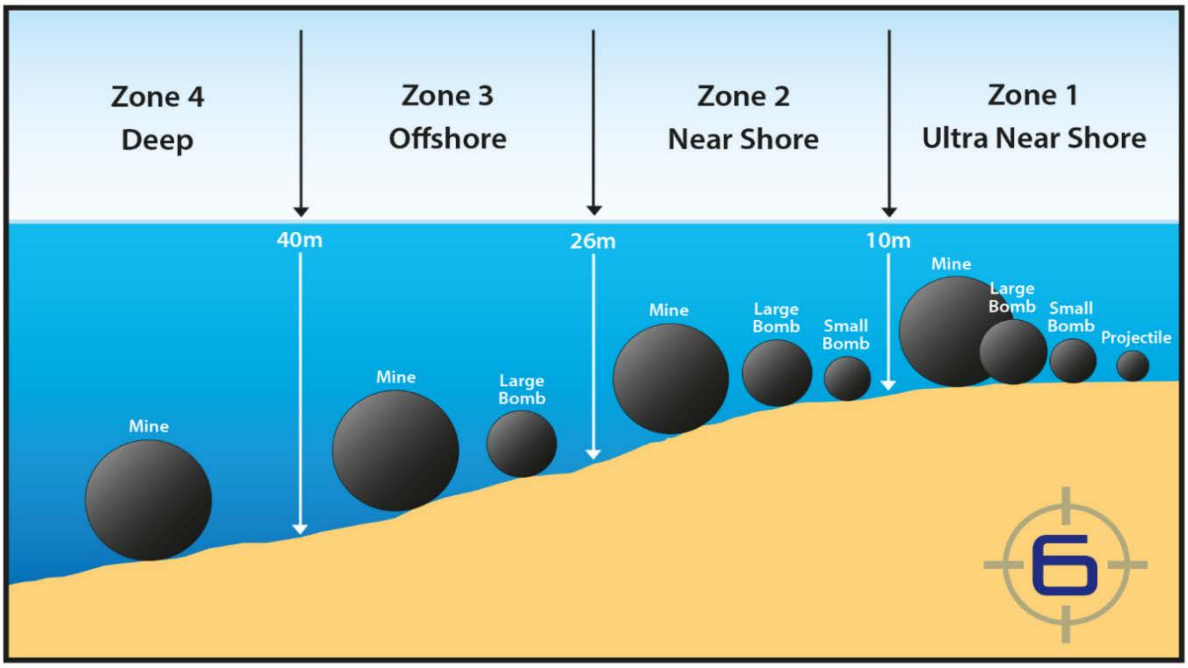



**Figure 7 – UXO Detection Requirement with Respect to Water Depths (LAT)**

#### 7.2.3.1 Minimum UXO Threat Item Selection Methodology

The diagram presented at Figure 7 is intended as a general guide to minimum threat detection at those specified depths that is generally correct across all types of projects. However, as a general guide it is not bespoke to this project as the specific ferrous masses, NEQs and potential detonation consequences associated with project specific UXO threats, as identified and evidenced within the threat assessment element at Section 3 of this report, may vary from the general guidance on UXO threat item detection presented at Figure 7.

For example, in water depths up to 10m LAT, the minimum UXO threat item to be detected by UXO geophysical survey is a 10.5cm artillery projectile with a ferrous mass of 13kg. Whilst Table 3.10.5 shows that other projectiles with a smaller ferrous mass may be encountered, the selection of the minimum UXO threat item has taken into account the likelihood of encountering each item, the UXO's NEQ in order to assess detonation consequences, the limitations of geophysical survey techniques and the recommended UXO risk tolerance in order to select the UXO with the lowest ferrous mass that ought to be detected by geophysical UXO survey in order to reduce the UXO risk to the vessels and its crews to ALARP.

In addition, whilst Figure 7 suggests that generally, small and medium HE bombs are unlikely to require detecting by geophysical UXO survey in depths above 26m LAT, on this project a *British* 500lb MC bomb with a ferrous mass of 111kg has been selected as the minimum UXO threat item for detection in depths of between 26m LAT and 40m LAT because its NEQ is sufficient to cause prospective damage to the vessel and its crews if it were to be inadvertently initiated in depths up to 40m LAT. Although the *British* Mark XVII Naval Mine has a lower estimated ferrous mass, based on the threat assessment it was not historically deployed within waters of this depth within the Study Site.

Where water depths exceed 40m LAT, a *British* Mark XVII Naval Mine has been selected as the minimum UXO threat to be detected by geophysical UXO survey. Whilst other mines may pose a UXO threat, the Mark XVII naval mine has been selected as the minimum threat to be detected by geophysical UXO survey because it is the UXO threat item with the lowest ferrous mass that is likely to be encountered during GI activities that contains sufficient NEQ to potentially cause damage to the vessel and harm to vessel crews.

### 7.2.4 UXO Risk Tolerance and Residual Risks

*6 Alpha's* risk mitigation strategy is based around the principle that whilst damage/destruction to the any underwater GI equipment is undesirable, in certain circumstances it could be tolerated - where the vessel and any personnel are not endangered - as a residual UXO risk, under the auspices of the ALARP principle. Such a recommendation is common for offshore GI projects of this nature.

Specifically, *6 Alpha* also recommends that the UXO risks associated with a prospective initiation of low NEQ UXO risks in deeper waters, such as the risks associated with AAA or small naval gun projectiles only, in water depths greater than 26m LAT, need not to be reduced with proactive risk mitigation measures ahead of GI operations. This recommendation is driven by the fact that attempting to mitigate low NEQ UXO risks in deep water through UXO geophysical survey is especially challenging, time consuming and costly without the benefit of corresponding risk mitigation reduction.

With this in mind, *6 Alpha* would encourage the Client and their stakeholders to consider and confirm our assumed tolerance for UXO risks with respect to the risk mitigation strategy in general and with reference to the recommended level of GI UXO risk tolerance that is outlined and presented at Option 2 in Table 7.2.4, in particular.

| UXO Risk Tolerance | Prospective Residual UXO Risk | Cost Implications |
|---|---|---|
| Option 1 – Very Conservative | Damage to subsea GI equipment of any kind will not be tolerated. | Very expensive and time-consuming option but the risk of damaging the GI equipment is reduced. There is also a significantly reduced risk of project delay due to UXO initiation but, project delay due to the difficulties of ameliorating low ferrous-low NEQ UXO risks in deep water will increase. |
| Option 2 – 6 Alpha Recommended (within ALARP threshold) | Damage/Destruction of subsea GI equipment is tolerable – if undesirable. Damage to the vessel that endangers personnel (either directly or indirectly) is intolerable and will require proactive UXO risk mitigation. | Time and cost efficient, although such tolerance carries the risk of repair and/or replacement of the subsea GI equipment in the event of unplanned low NEQ UXO detonation. |

**Table 7.2.4:** UXO Risk Tolerance Options

### 7.2.5 ALARP Safety Sign-Off Certification

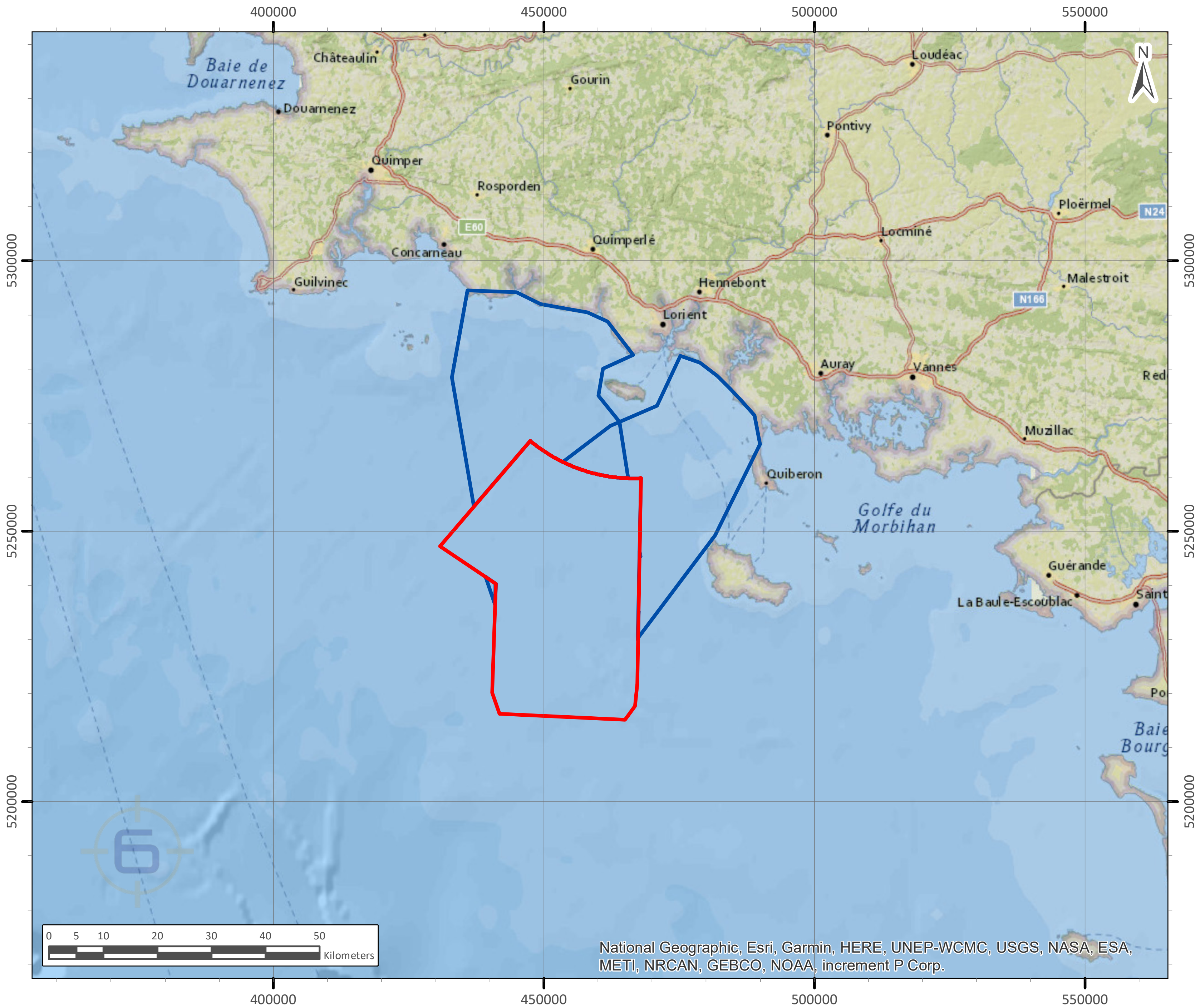
In order to evidence that the UXO risk during forthcoming GI operations has been appropriately reduced by the implementation of a recommended and agreed UXO risk mitigation strategy, ALARP safety sign-off certificates can be delivered warranting that the GI campaign can be undertaken safely and in accordance with all national and regional safety and legal standards.

*6 Alpha* recommend that the UXO risk mitigation strategy is subsequently updated and expanded to encompass risk mitigation measures for OWF foundation and all cable installation works, which are expected to be scheduled later in the project cycle.

# Appendices

# Appendix 1

## Site Location




LEGEND

## GENERAL

- OWF_Boundary
- Export_Cable_Corridors

| PROJECT | PROJECT TITLE |
|---|---|
| 8811 | A05 BRITTANY |

DRAWING TITLE

Site Location

DRAWING NUMBER

A05 Brittany\001\V1.0

PURPOSE

FOR INFORMATION USE ONLY

alpha ASSOCIATES

special risks consultancy

| COORDINATE SYSTEM | SCALE | ORIGINAL PLOT SIZE | DRAWN | DATE DRAWN | CHECKED |
|---|---|---|---|---|---|
| WGS 1984 UTM Zone 30N | 1:1,000,000 | A4 | LH | 24/03/2021 | LG |



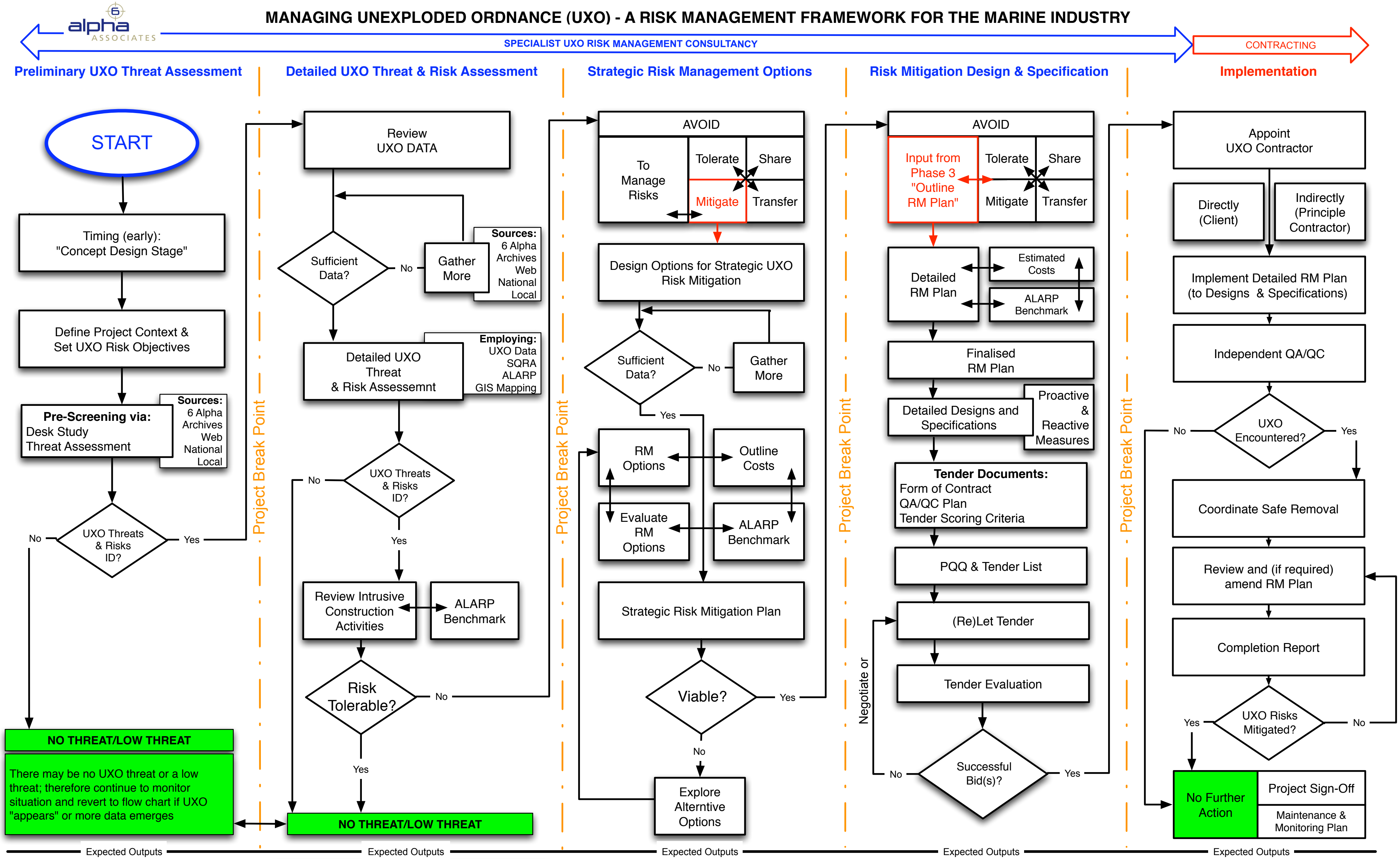
W W W . 6 A L P H A . C O M

E: enquiry@6alpha.com | T: +44 (0)203 371 3900

# Appendix 2

## Marine Risk Management Framework

# MANAGING UNEXPLODED ORDNANCE (UXO) - A RISK MANAGEMENT FRAMEWORK FOR THE MARINE INDUSTRY




**Preliminary UXO Threat Assessment**
**Expected Consultancy Outputs:**
Concise Report
Supported by:
GIS Mapping &
Research Data
Conclusions
Recommendations - move to next step (or not)?

**Detailed UXO Risk Assessment**
**Expected Consultancy Outputs:**
UXO Threat Assessment employing:
Comprehensive UXO Data Sources
Semi-Quantitative Risk Assessment (SQRA) & ALARP
GIS Mapping
Independent/Robust/Transparent Assessment
Comprehensive & Informative Report

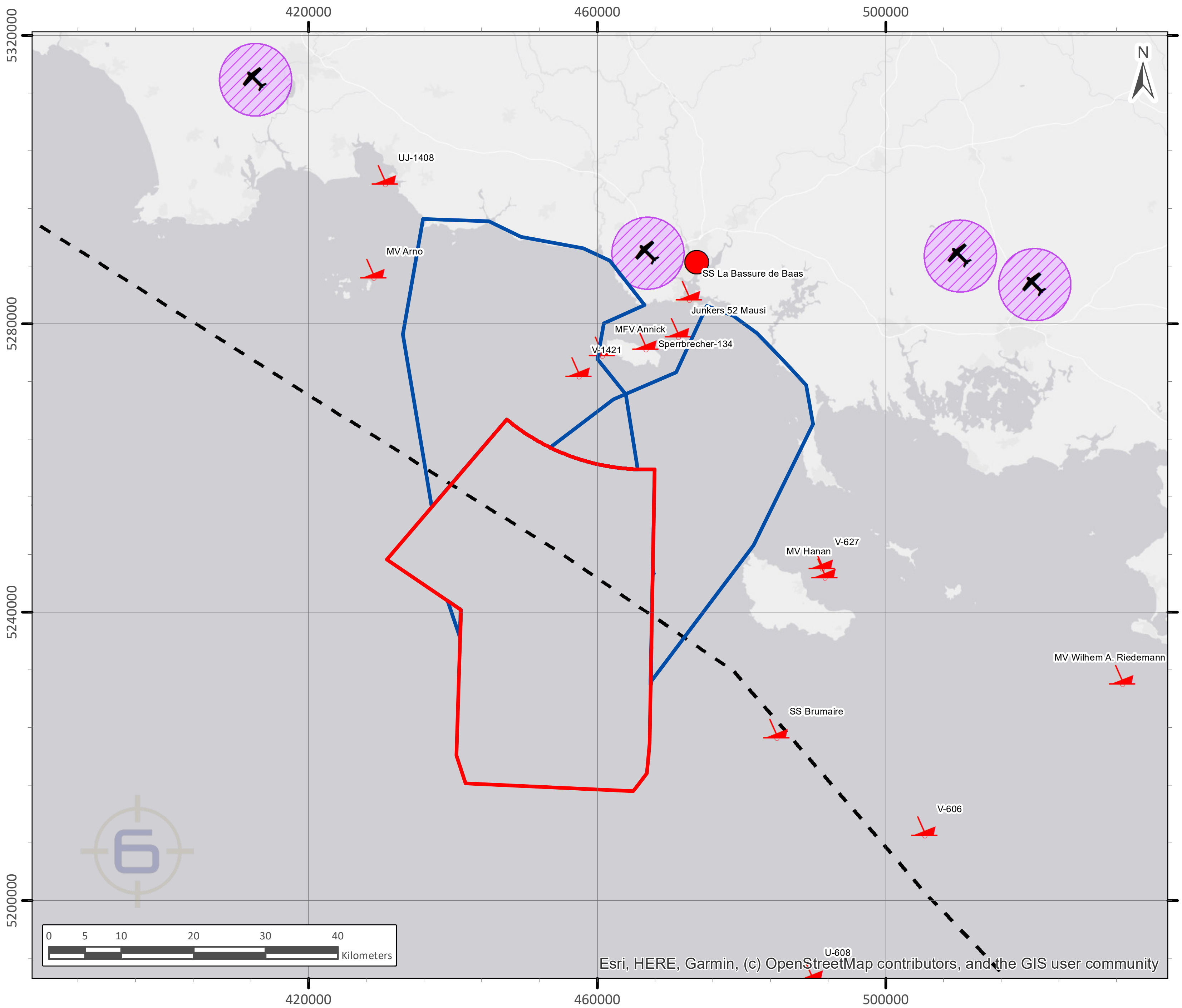
**Strategic Risk Management Options**
**Expected Consultancy Outputs:**
Strategic Risk Mitigation (RM) options
Criteria for selection of mix of options
Selection of best mix of options
Benchmark with Client's Tolerance of UXO Risk
Strategic Risk Mitigation Plan

**Risk Mitigation Design & Specification**
**Expected Consultancy Outputs:**
Detailed Risk Mitigation Design
Accompanying Risk Mitigation Specifications
Sufficient for Incorporation into Tender Documents

**Implementation**
**Expected Consultancy & Contractor Outputs:**
Safe Removal of UXO
Independent QA/QC on Contractor
Completion Reposts
Independent Consultancy Sign-off
Post Construction Maintenance/ Monitoring Plan

# Appendix 3

## Aerial Bombing Threat




LEGEND

## GENERAL

OWF_Boundary

Export_Cable_Corridors

## UXO THREATS

Allied_Bombing_Target

WWII_Air-Raid_Wreck

WWII_German_ROSA_Route

Luftwaffe_Airfield

Airfield_5km_Buffer

| PROJECT | PROJECT TITLE |
|---|---|
| 8811 | A05 BRITTANY |

DRAWING TITLE
**Aerial Bombing Threat**

DRAWING NUMBER
**A05 Brittany\003\V1.0**

PURPOSE
**FOR INFORMATION USE ONLY**

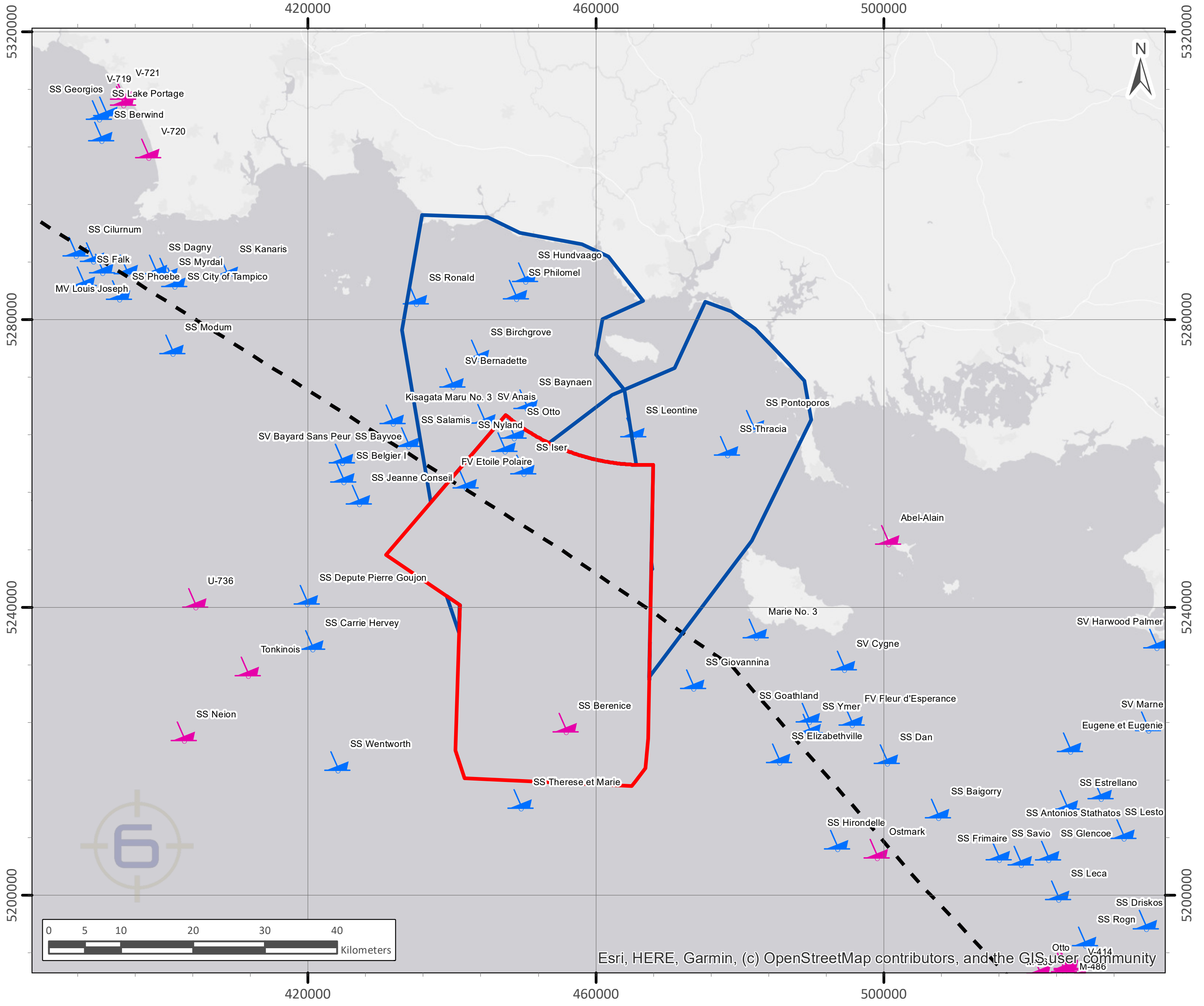
6 alpha ASSOCIATES
special risks consultancy

| COORDINATE SYSTEM | SCALE | ORIGINAL PLOT SIZE | DRAWN | DATE DRAWN | CHECKED | | |
|---|---|---|---|---|---|---|---|
| WGS 1984 UTM Zone 30N | 1:750,000 | A4 | LH | 24/03/2021 | LG | Produced by and Copyright to 6 Alpha Associates Ltd. Users noting any errors please forward to 6 Alpha. | W W W . 6 A L P H A . C O M<br>E: enquiry@6alpha.com \| T: +44 (0)203 371 3900 |

# Appendix 4

## Naval Engagements


www.6alpha.com
+44 (0) 2033 713 900
enquiry@6alpha.com




LEGEND

## GENERAL

OWF_Boundary

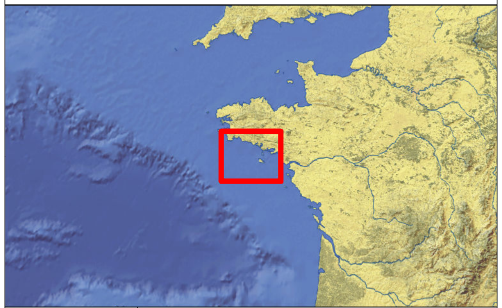
Export_Cable_Corridors

## UXO THREATS

WWII_German_ROSA_Route

WWI_Naval_Wreck

WWII_Naval_Wreck



| PROJECT | PROJECT TITLE |
|---|---|
| 8811 | A05 BRITTANY |

DRAWING TITLE

Naval Engagements

DRAWING NUMBER

A05 Brittany\004\V1.0

PURPOSE

FOR INFORMATION USE ONLY

6 alpha ASSOCIATES

special risks consultancy

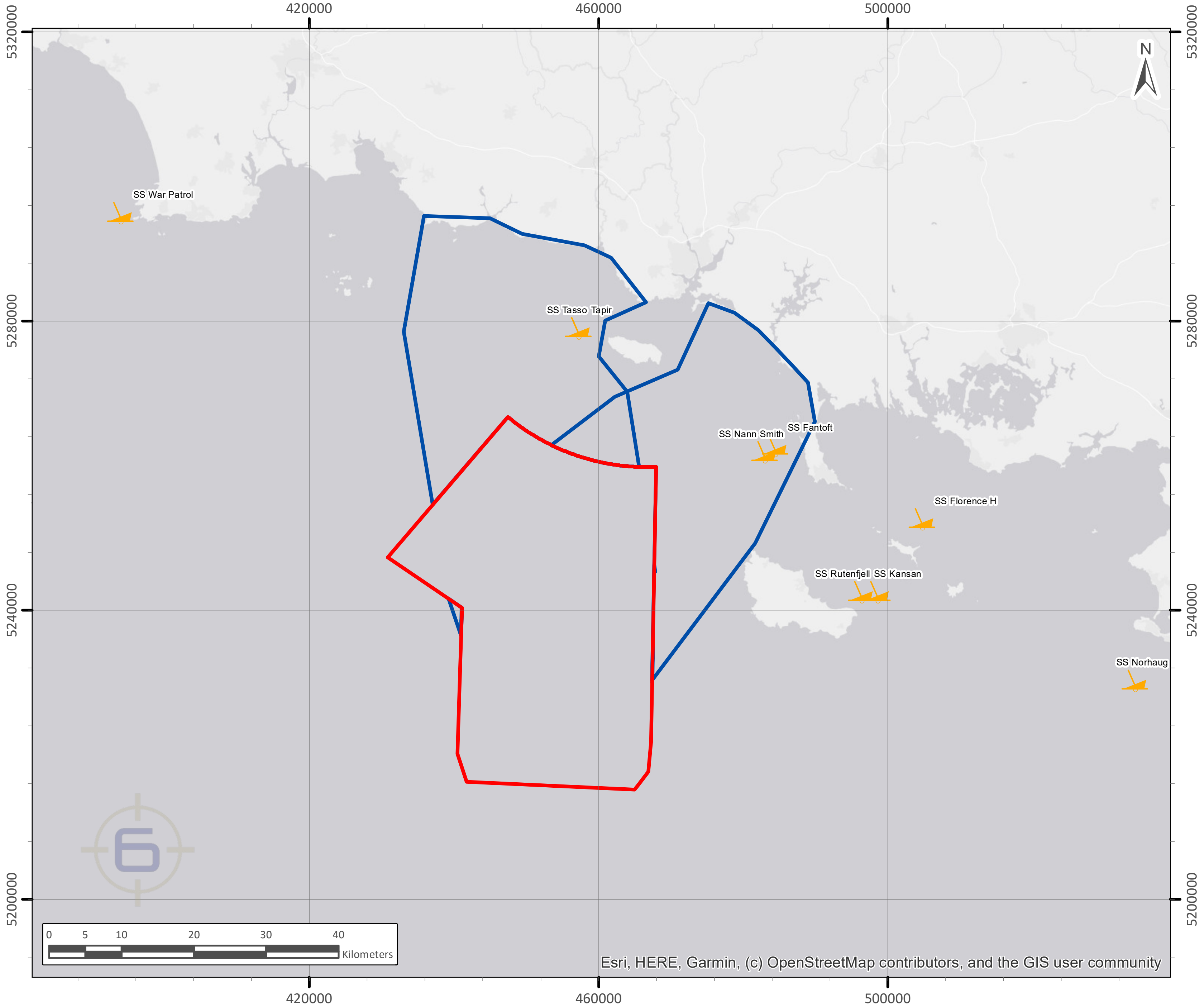
| COORDINATE SYSTEM | SCALE | ORIGINAL PLOT SIZE | DRAWN | DATE DRAWN | CHECKED |
|---|---|---|---|---|---|
| WGS 1984 UTM Zone 30N | 1:750,000 | A4 | LH | 24/03/2021 | LG |



W W W . 6 A L P H A . C O M
E: enquiry@6alpha.com | T: +44 (0)203 371 3900

# Appendix 5

## WWI Minefields




LEGEND

## GENERAL

OWF_Boundary
Export_Cable_Corridors

## UXO THREATS

WWI_Mined_Wreck

| PROJECT | PROJECT TITLE |
|---|---|
| 8811 | A05 BRITTANY |

DRAWING TITLE
**WWI Minefields**

DRAWING NUMBER
**A05 Brittany\005\V1.0**

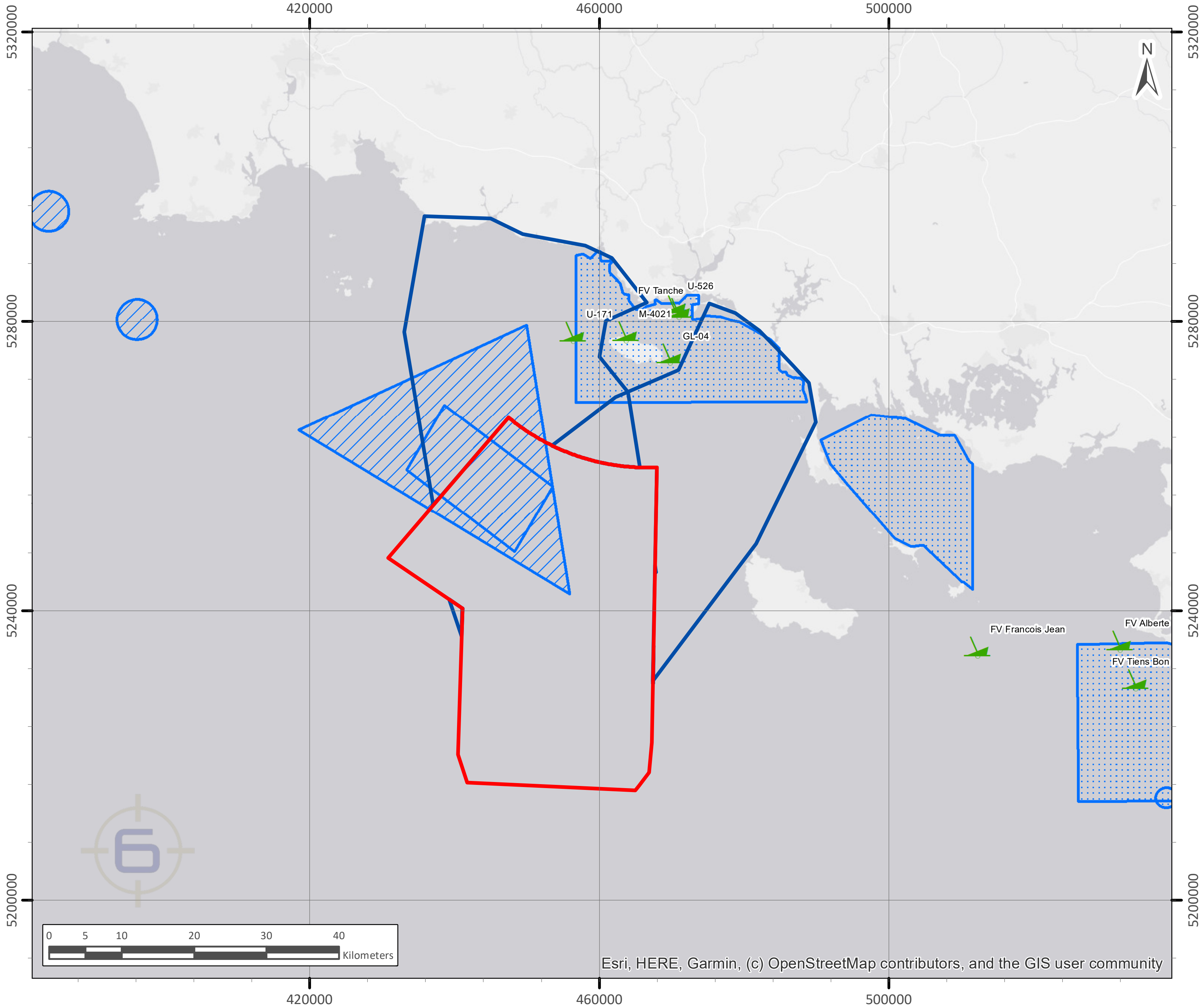
PURPOSE
**FOR INFORMATION USE ONLY**

alpha ASSOCIATES
special risks consultancy

| COORDINATE SYSTEM | SCALE | ORIGINAL PLOT SIZE | DRAWN | DATE DRAWN | CHECKED | | |
|---|---|---|---|---|---|---|---|
| WGS 1984 UTM Zone 30N | 1:750,000 | A4 | LH | 24/03/2021 | LG | Produced by and Copyright to 6 Alpha Associates Ltd. Users noting any errors please forward to 6 Alpha. | W W W . 6 A L P H A . C O M<br>E: enquiry@6alpha.com \| T: +44 (0)203 371 3900 |

# Appendix 6

WWII Minefields



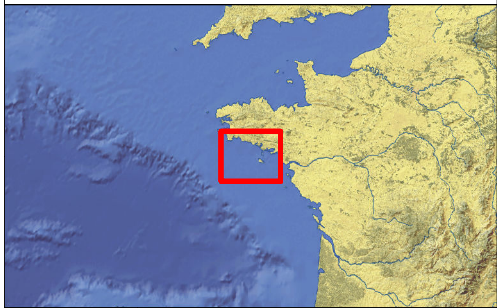

LEGEND

## GENERAL

OWF_Boundary
Export_Cable_Corridors

## UXO THREATS

WWII_Mined_Wreck
Allied_WWII_Minefield
Allied_WWII_Mine_Garden



| PROJECT | PROJECT TITLE |
|---|---|
| 8811 | A05 BRITTANY |

DRAWING TITLE
WWII Minefields

DRAWING NUMBER
A05 Brittany\006\V1.0

PURPOSE
FOR INFORMATION USE ONLY

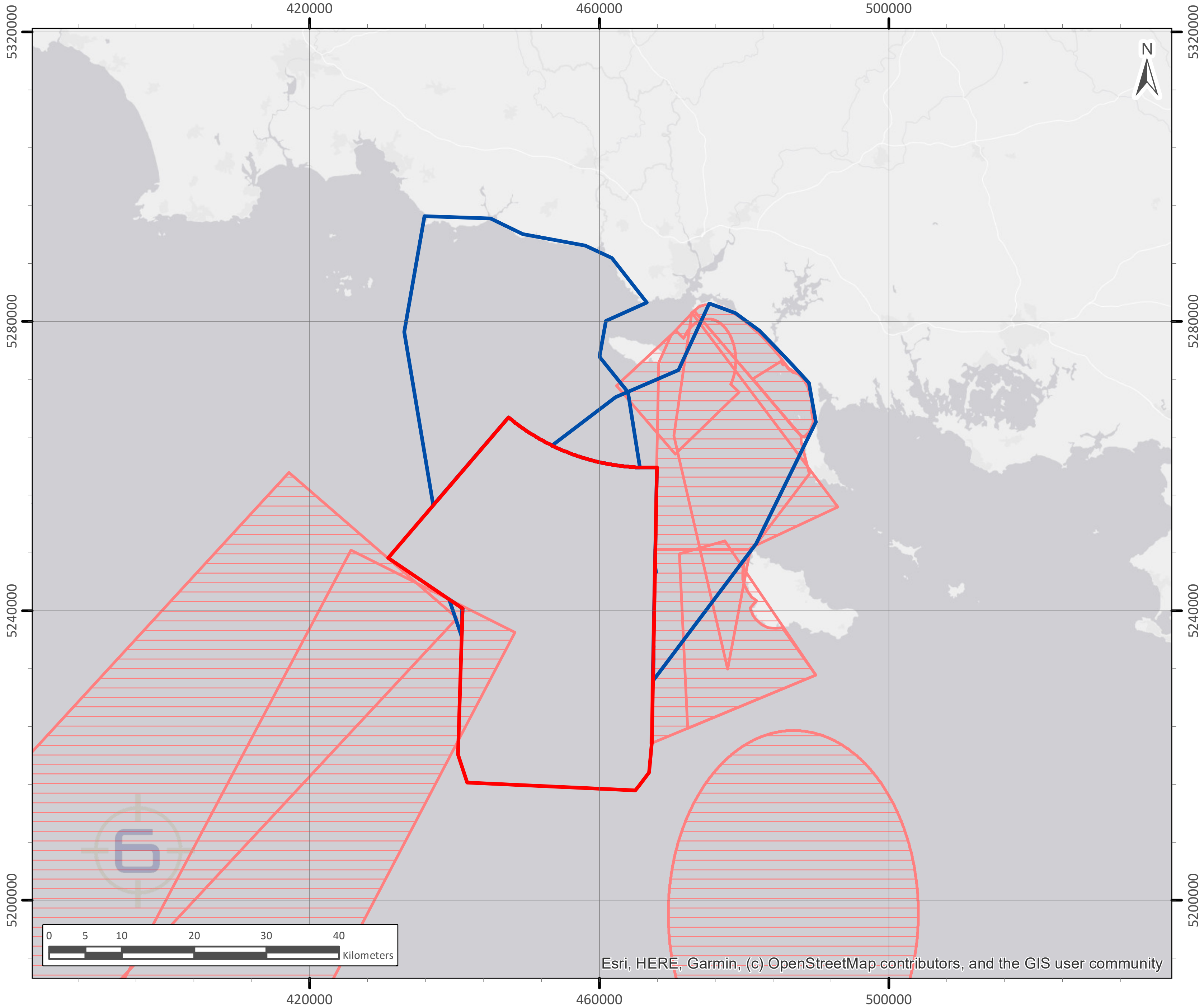
alpha ASSOCIATES
special risks consultancy

| COORDINATE SYSTEM | SCALE | ORIGINAL PLOT SIZE | DRAWN | DATE DRAWN | CHECKED | | |
|---|---|---|---|---|---|---|---|
| WGS 1984 UTM Zone 30N | 1:750,000 | A4 | LH | 30/03/2021 | LG | Produced by and Copyright to 6 Alpha Associates Ltd. Users noting any errors please forward to 6 Alpha. | WWW.6ALPHA.COM E: enquiry@6alpha.com \| T: +44 (0)203 371 3900 |

# Appendix 7

Modern PEXA


www.6alpha.com
+44 (0) 2033 713 900
enquiry@6alpha.com




LEGEND

## GENERAL

OWF_Boundary

Export_Cable_Corridors

## UXO THREATS

Firing_Exercise_Area

| PROJECT | PROJECT TITLE |
|---|---|
| 8811 | A05 BRITTANY |

DRAWING TITLE
**Modern PEXA**

DRAWING NUMBER
**A05 Brittany\007\V1.0**

PURPOSE
**FOR INFORMATION USE ONLY**

alpha ASSOCIATES

special risks consultancy

| COORDINATE SYSTEM | SCALE | ORIGINAL PLOT SIZE | DRAWN | DATE DRAWN | CHECKED |
|---|---|---|---|---|---|
| WGS 1984 UTM Zone 30N | 1:750,000 | A4 | LH | 24/03/2021 | LG |

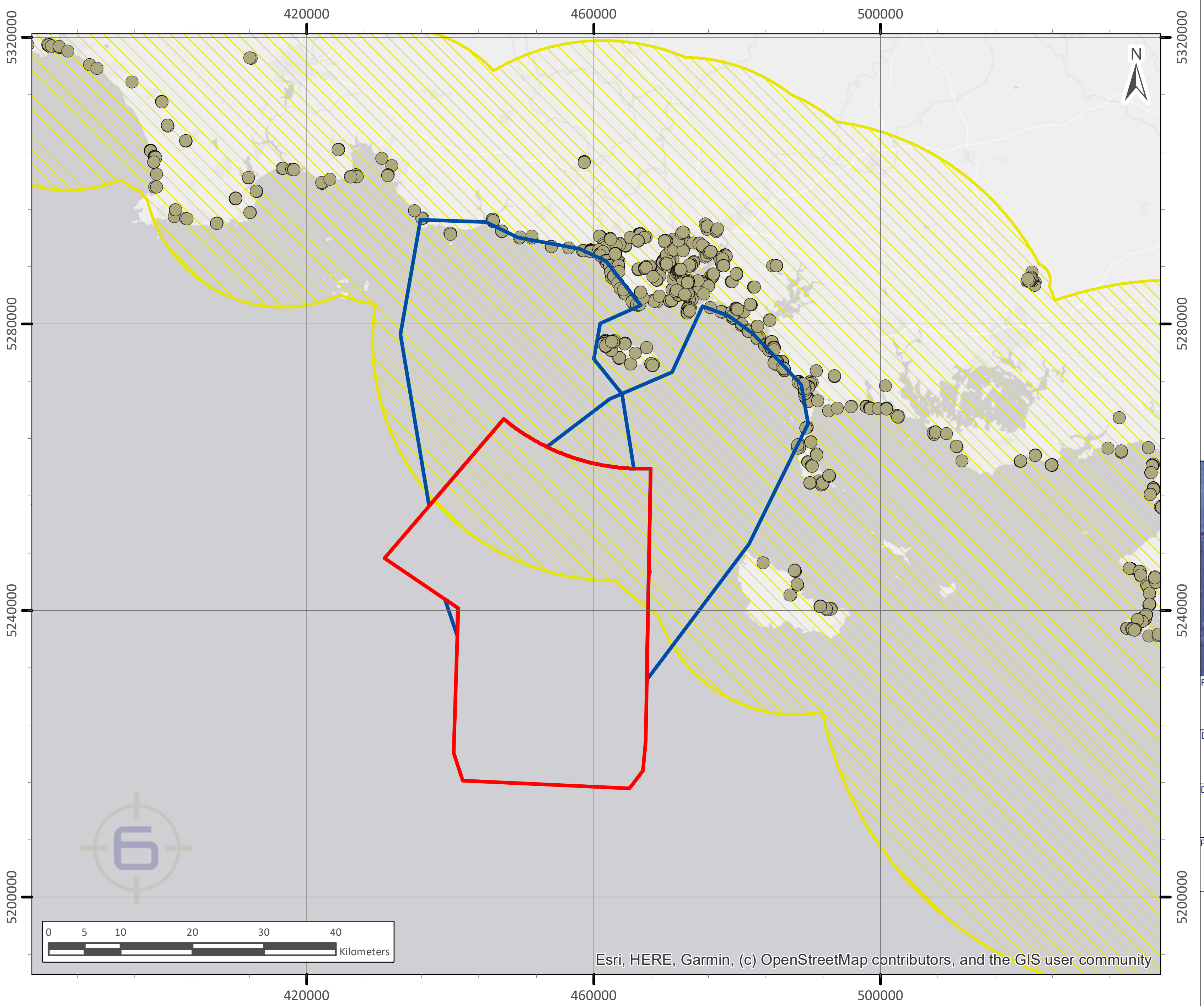


W W W . 6 A L P H A . C O M
E: enquiry@6alpha.com | T: +44 (0)203 371 3900

# Appendix 8

## Atlantikwall


www.6alpha.com
+44 (0) 2033 713 900
enquiry@6alpha.com




LEGEND

## GENERAL

- OWF_Boundary
- Export_Cable_Corridors

## UXO THREATS

- Atlantikwall_Installation
- Atlantikwall_Range

| PROJECT | PROJECT TITLE |
|---|---|
| 8811 | A05 BRITTANY |

DRAWING TITLE
Atlantikwall

DRAWING NUMBER
A05 Brittany\008\V1.0

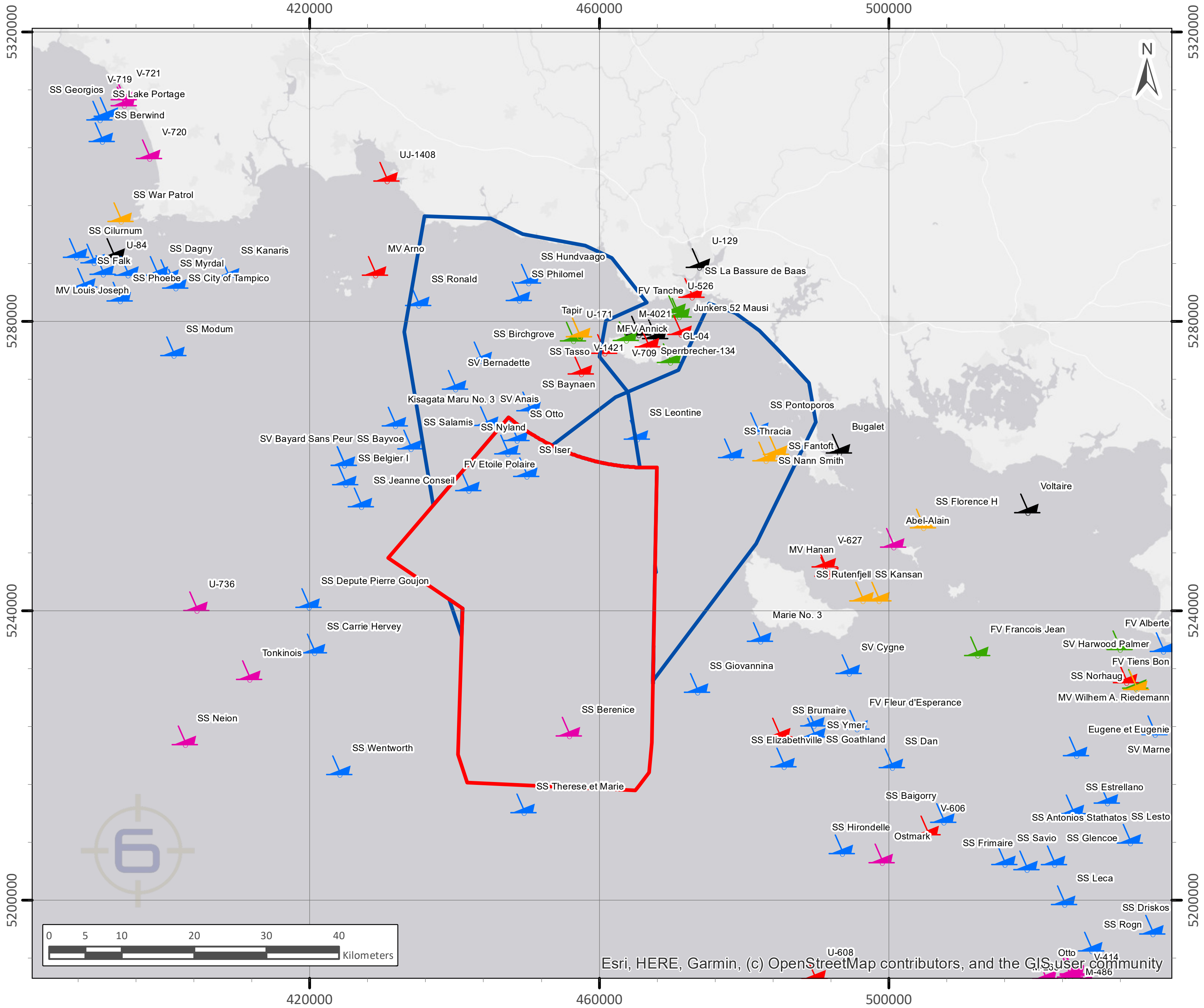
PURPOSE
FOR INFORMATION USE ONLY

alpha ASSOCIATES
special risks consultancy

| COORDINATE SYSTEM | SCALE | ORIGINAL PLOT SIZE | DRAWN | DATE DRAWN | CHECKED | | |
|---|---|---|---|---|---|---|---|
| WGS 1984 UTM Zone 30N | 1:750,000 | A4 | LH | 24/03/2021 | LG | Produced by and Copyright to 6 Alpha Associates Ltd. Users noting any errors please forward to 6 Alpha. | W W W . 6 A L P H A . C O M<br>E: enquiry@6alpha.com \| T: +44 (0)203 371 3900 |

# Appendix 9

## Munitions Related Shipwrecks




LEGEND

## GENERAL

- OWF_Boundary
- Export_Cable_Corridors

## UXO THREATS

- WWI_Naval_Wreck
- WWI_Mined_Wreck
- WWII_Air-Raid_Wreck
- WWII_Naval_Wreck
- WWII_Mined_Wreck
- Other_Munitions_Wreck

| PROJECT | PROJECT TITLE |
|---|---|
| 8811 | A05 BRITTANY |

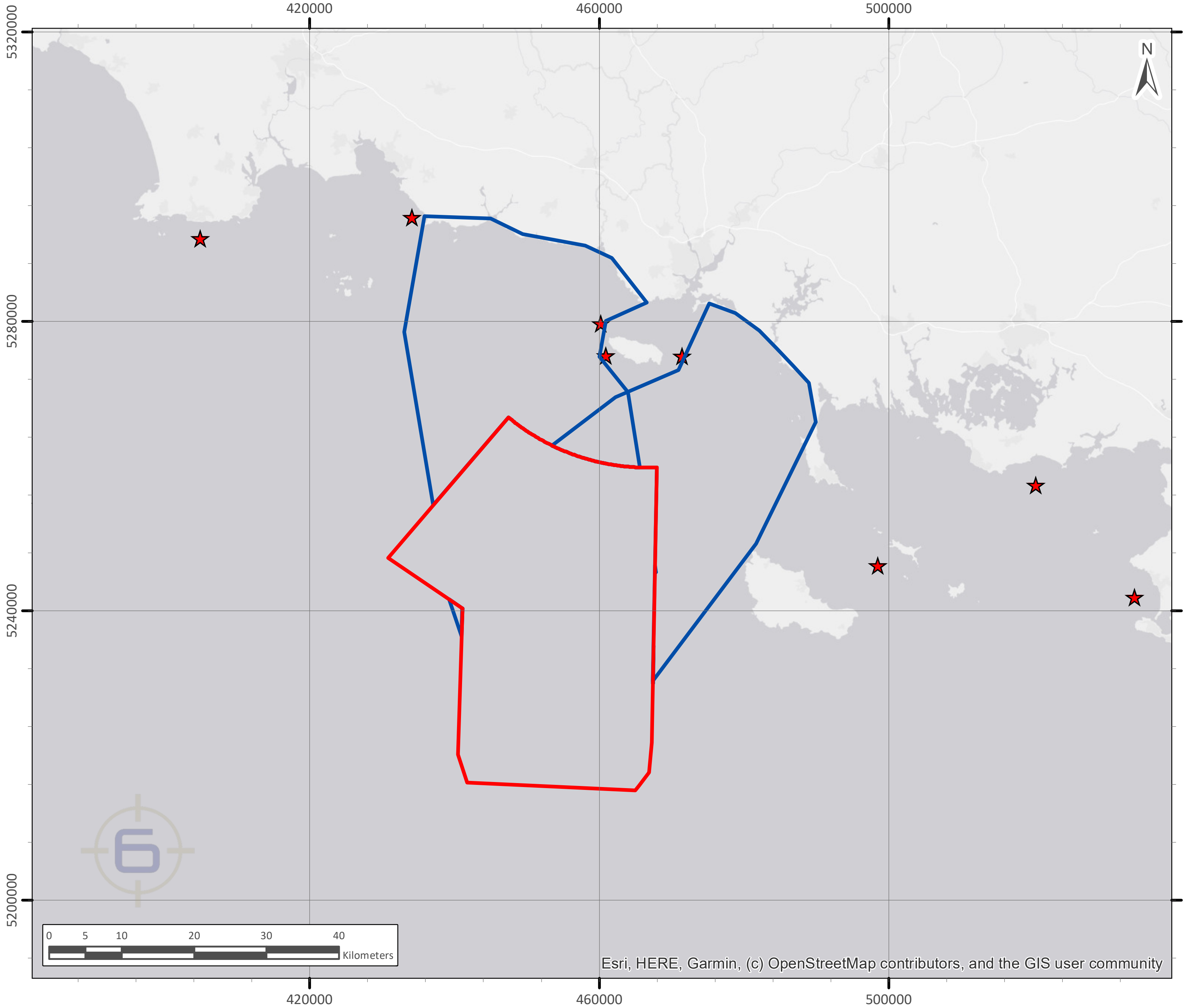
| | |
|---|---|
| DRAWING TITLE | Munitions Related Shipwrecks |
| DRAWING NUMBER | A05 Brittany\009\V1.0 |
| PURPOSE | FOR INFORMATION USE ONLY |

alpha ASSOCIATES
special risks consultancy

| COORDINATE SYSTEM | SCALE | ORIGINAL PLOT SIZE | DRAWN | DATE DRAWN | CHECKED | | |
|---|---|---|---|---|---|---|---|
| WGS 1984 UTM Zone 30N | 1:750,000 | A4 | LH | 24/03/2021 | LG | Produced by and Copyright to 6 Alpha Associates Ltd. Users noting any errors please forward to 6 Alpha. | WWW.6ALPHA.COM E: enquiry@6alpha.com \| T: +44 (0)203 371 3900 |

# Appendix 10

## Munitions Dumping




LEGEND

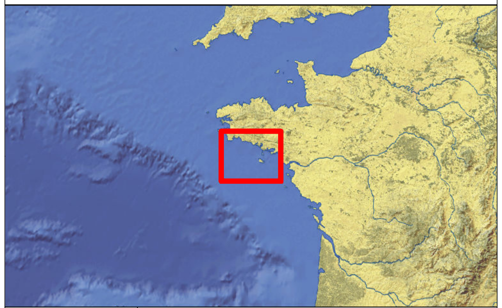
## GENERAL

OWF_Boundary

Export_Cable_Corridors

## UXO THREATS

Conventional_Munitions_Dump



| PROJECT | PROJECT TITLE |
|---|---|
| 8811 | A05 BRITTANY |

DRAWING TITLE

**Munitions Dumping**

DRAWING NUMBER

**A05 Brittany\010\V1.0**

PURPOSE

**FOR INFORMATION USE ONLY**

alpha ASSOCIATES

special risks consultancy

| COORDINATE SYSTEM | SCALE | ORIGINAL PLOT SIZE | DRAWN | DATE DRAWN | CHECKED |
|---|---|---|---|---|---|
| WGS 1984 UTM Zone 30N | 1:750,000 | A4 | LH | 24/03/2021 | LG |

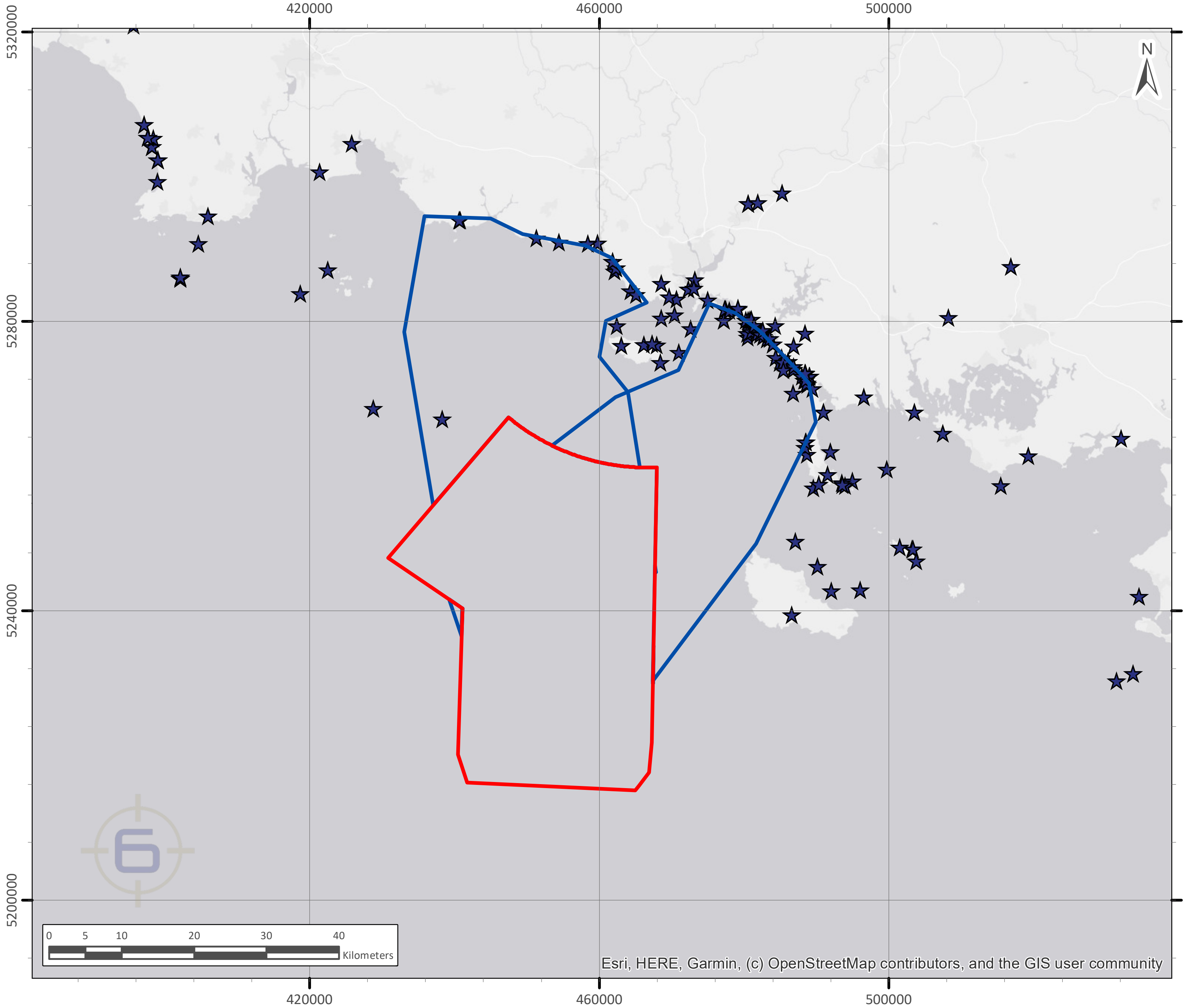


W W W . 6 A L P H A . C O M

E: enquiry@6alpha.com | T: +44 (0)203 371 3900

# Appendix 11

## Munitions Encounters



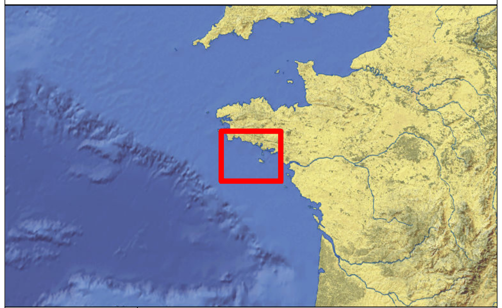

LEGEND

## GENERAL

OWF_Boundary
Export_Cable_Corridors

## UXO THREATS

OSPAR_Munitions_Encounters



| PROJECT | PROJECT TITLE |
|---|---|
| 8811 | A05 BRITTANY |

DRAWING TITLE
Munitions Encounters

DRAWING NUMBER
A05 Brittany\011\V1.0

PURPOSE
FOR INFORMATION USE ONLY

alpha ASSOCIATES
special risks consultancy

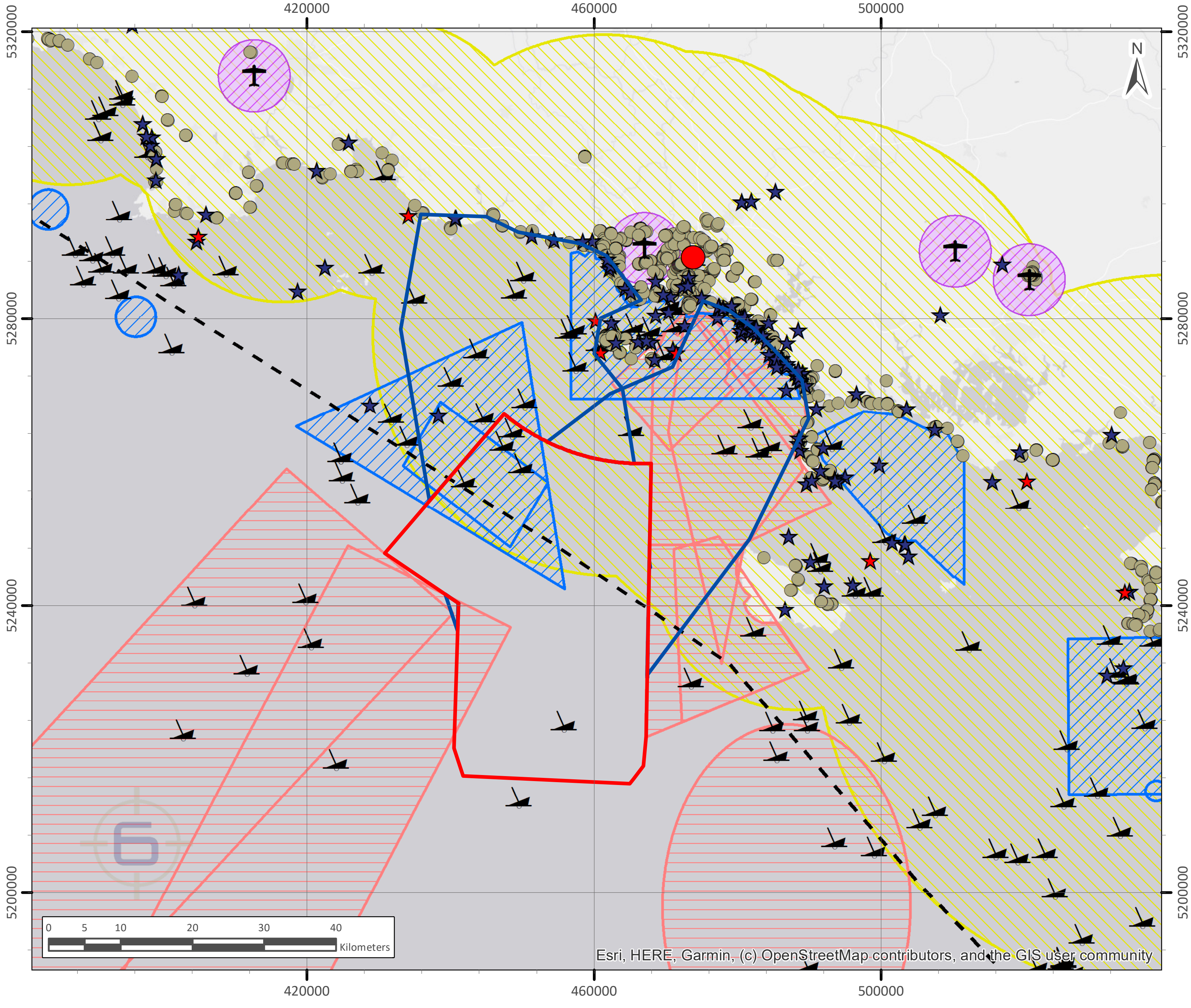
| COORDINATE SYSTEM | SCALE | ORIGINAL PLOT SIZE | DRAWN | DATE DRAWN | CHECKED |
|---|---|---|---|---|---|
| WGS 1984 UTM Zone 30N | 1:750,000 | A4 | LH | 24/03/2021 | LG |



W W W . 6 A L P H A . C O M
E: enquiry@6alpha.com | T: +44 (0)203 371 3900

# Appendix 12

## Consolidated UXO Threat




LEGEND

## GENERAL

- OWF_Boundary
- Export_Cable_Corridors

## UXO THREATS

- Allied_Bombing_Target
- Luftwaffe_Airfield
- Conventional_Munitions_Dump
- OSPAR_Munitions_Encounters
- Atlantikwall_Installation
- WWII_German_ROSA_Route
- Munitions_Related_Shipwreck
- Airfield_5km_Buffer
- Allied_WWII_Minefield
- Firing_Exercise_Area
- Atlantikwall_Range

| PROJECT | PROJECT TITLE |
|---|---|
| 8811 | A05 BRITTANY |

DRAWING TITLE
**Consolidated UXO Threat**

DRAWING NUMBER
**A05 Brittany\012\V1.0**

PURPOSE
**FOR INFORMATION USE ONLY**

6 alpha ASSOCIATES
special risks consultancy

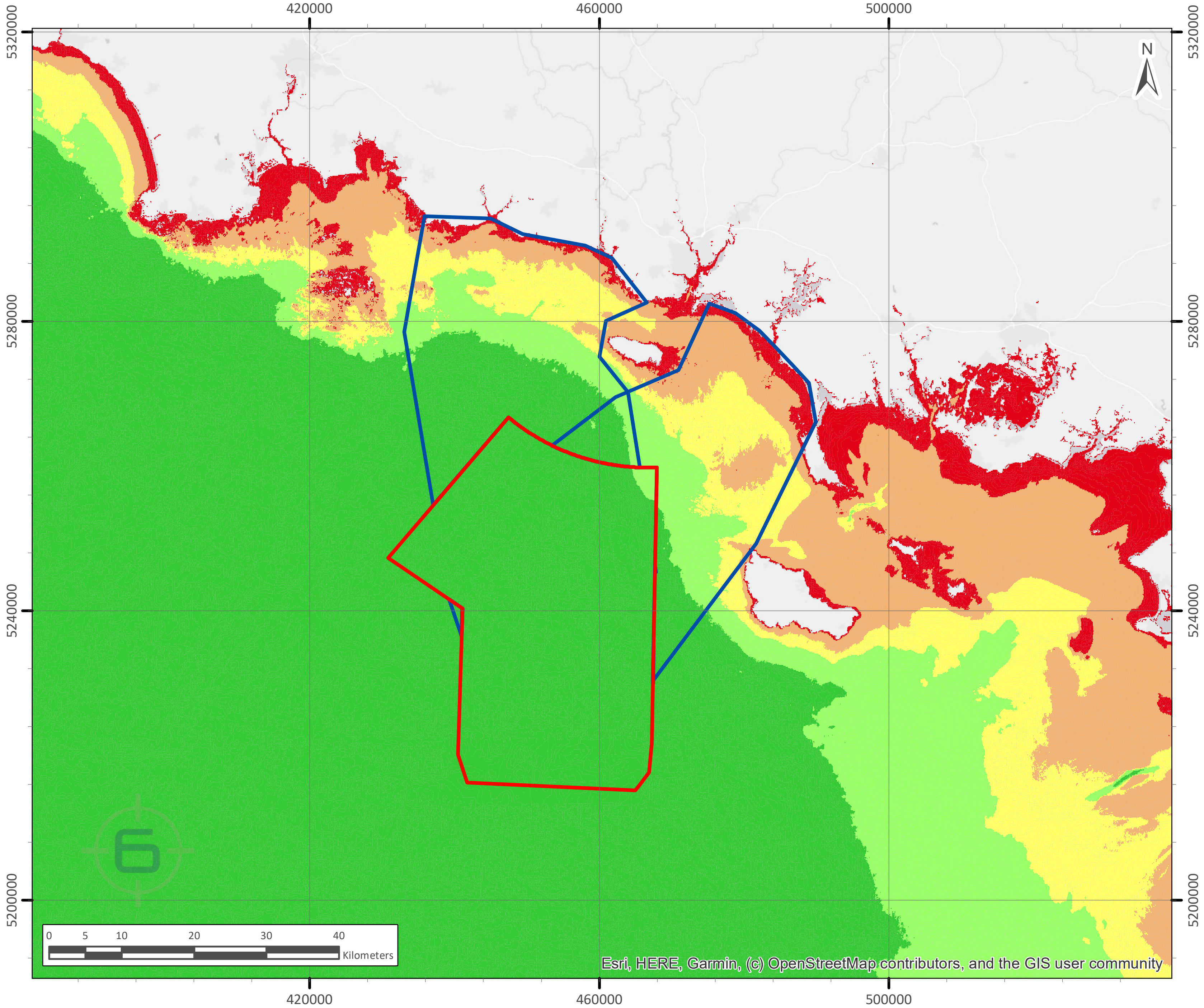
| COORDINATE SYSTEM | SCALE | ORIGINAL PLOT SIZE | DRAWN | DATE DRAWN | CHECKED |
|---|---|---|---|---|---|
| WGS 1984 UTM Zone 30N | 1:750,000 | A4 | LH | 31/03/2021 | LG |



W W W . 6 A L P H A . C O M
E: enquiry@6alpha.com | T: +44 (0)203 371 3900

# Appendix 13

## Bathymetry



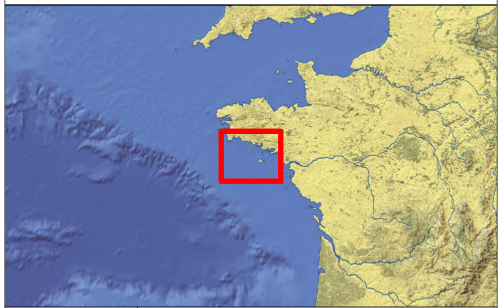

LEGEND

## GENERAL

- OWF_Boundary
- Export_Cable_Corridors

**Water_Depth (LAT)**

- <10m
- <26m
- <40m
- <60m
- >60m



| PROJECT | PROJECT TITLE |
|---|---|
| 8811 | A05 BRITTANY |

DRAWING TITLE

**Bathymetry**

DRAWING NUMBER

**A05 Brittany\013\V1.0**

PURPOSE

**FOR INFORMATION USE ONLY**

alpha ASSOCIATES

special risks consultancy

| COORDINATE SYSTEM | SCALE | ORIGINAL PLOT SIZE | DRAWN | DATE DRAWN | CHECKED | | |
|---|---|---|---|---|---|---|---|
| WGS 1984 UTM Zone 30N | 1:750,000 | A4 | LH | 31/03/2021 | LG | Produced by and Copyright to 6 Alpha Associates Ltd. Users noting any errors please forward to 6 Alpha. | W W W . 6 A L P H A . C O M<br>E: enquiry@6alpha.com \| T: +44 (0)203 371 3900 |

# Appendix 14

## Semi-Quantitative Risk Assessment Tables

The tables produced on the following pages outline and display the numeric scored assessment for the project as well as the initial and residual UXO risk to each specific operation after mitigation measures have been appropriately applied. It is also important to note that the risk assessment for the GI, cable installation and wind turbine installation operations is conducted for each individual activity, irrespective of prior operations which may have taken place.

An explanation of the SQRA process and Azimuth risk matrix used by 6 Alpha Associates is presented at Annex E.

Risk (R) is calculated as a function of probability of encounter and initiation (P) and consequence of initiation (C), where R = P x C.

## Geotechnical Investigation Operations

| Activity | UXO Threat Item | Assessed NEQ (kg TNT) | UXO Risk to Vessel/Personnel | | | | | | UXO Risk to Underwater Equipment | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Initial UXO Risk Level | | | Recommended Mitigated UXO Risk Level | | | Initial UXO Risk Level | | | Recommended Mitigated UXO Risk Level | | |
| | | | P | C | R | P | C | R | P | C | R | P | C | R |
| All GI (10m) | Large Naval Mines | 340 | 3 | 5 | 15 | 1 | 5 | 5 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Medium HE Bombs | 161.9 | 3 | 5 | 15 | 1 | 5 | 5 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Small HE Bombs | 30 | 3 | 5 | 15 | 1 | 5 | 5 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Large HE Bombs | 507 | 2 | 5 | 10 | 1 | 5 | 5 | 2 | 5 | 10 | 1 | 5 | 5 |
| | Medium Naval Mines | 227 | 2 | 5 | 10 | 1 | 5 | 5 | 2 | 5 | 10 | 1 | 5 | 5 |
| | Large AAA Projectiles | 21.7 | 2 | 5 | 10 | 1 | 5 | 5 | 2 | 5 | 10 | 1 | 5 | 5 |
| | Medium AAA Projectiles | 3.94 | 2 | 3 | 6 | 1 | 3 | 3 | 2 | 3 | 6 | 1 | 3 | 3 |
| | Small AAA Projectiles | 0.17 | 2 | 1 | 2 | 1 | 1 | 1 | 2 | 1 | 2 | 1 | 1 | 1 |
| | Torpedoes | 364 | 1 | 5 | 5 | 1 | 5 | 5 | 1 | 5 | 5 | 1 | 5 | 5 |

| Activity | UXO Threat Item | Assessed NEQ (kg TNT) | UXO Risk to Vessel/Personnel | | | | | | UXO Risk to Underwater Equipment | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Initial UXO Risk Level | | | Recommended Mitigated UXO Risk Level | | | Initial UXO Risk Level | | | Recommended Mitigated UXO Risk Level | | |
| | | | P | C | R | P | C | R | P | C | R | P | C | R |
| All GI (26m) | Large Naval Mines | 340 | 3 | 5 | 15 | 1 | 5 | 5 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Medium HE Bombs | 161.9 | 3 | 5 | 15 | 1 | 5 | 5 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Small HE Bombs | 30 | 3 | 3 | 9 | 1 | 3 | 3 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Large HE Bombs | 507 | 2 | 5 | 10 | 1 | 5 | 5 | 2 | 5 | 10 | 1 | 5 | 5 |
| | Medium Naval Mines | 227 | 2 | 5 | 10 | 1 | 5 | 5 | 2 | 5 | 10 | 1 | 5 | 5 |
| | Large AAA Projectiles | 21.7 | 2 | 2 | 4 | 1 | 2 | 2 | 2 | 5 | 10 | 1 | 5 | 5 |
| | Medium AAA Projectiles | 3.94 | 2 | 1 | 2 | 1 | 1 | 1 | 2 | 3 | 6 | 1 | 3 | 3 |
| | Small AAA Projectiles | 0.17 | 2 | 1 | 2 | 1 | 1 | 1 | 2 | 1 | 2 | 1 | 1 | 1 |
| | Torpedoes | 364 | 1 | 5 | 5 | 1 | 5 | 5 | 1 | 5 | 5 | 1 | 5 | 5 |



www.6alpha.com
+44 (0) 2033 713 900
enquiry@6alpha.com

| Activity | UXO Threat Item | Assessed NEQ (kg TNT) | UXO Risk to Vessel/Personnel | | | | | | UXO Risk to Underwater Equipment | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Initial UXO Risk Level | | | Recommended Mitigated UXO Risk Level | | | Initial UXO Risk Level | | | Recommended Mitigated UXO Risk Level | | |
| | | | P | C | R | P | C | R | P | C | R | P | C | R |
| All GI (40m) | Large Naval Mines | 340 | 3 | 4 | 12 | 1 | 4 | 4 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Medium HE Bombs | 161.9 | 3 | 3 | 9 | 1 | 3 | 3 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Small HE Bombs | 30 | 3 | 2 | 6 | 1 | 2 | 2 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Large HE Bombs | 507 | 2 | 4 | 8 | 1 | 4 | 4 | 2 | 5 | 10 | 1 | 5 | 5 |
| | Medium Naval Mines | 227 | 2 | 3 | 6 | 1 | 3 | 3 | 2 | 5 | 10 | 1 | 5 | 5 |
| | Large AAA Projectiles | 21.7 | 2 | 2 | 2 | 1 | 2 | 2 | 2 | 5 | 10 | 1 | 5 | 5 |
| | Medium AAA Projectiles | 3.94 | 2 | 1 | 2 | 1 | 1 | 1 | 2 | 3 | 6 | 1 | 3 | 3 |
| | Small AAA Projectiles | 0.17 | 2 | 1 | 2 | 1 | 1 | 1 | 2 | 1 | 2 | 1 | 1 | 1 |
| | Torpedoes | 364 | 1 | 4 | 4 | 1 | 4 | 4 | 1 | 5 | 5 | 1 | 5 | 5 |



www.6alpha.com
+44 (0) 2033 713 900
enquiry@6alpha.com

| Activity | UXO Threat Item | Assessed NEQ (kg TNT) | UXO Risk to Vessel/Personnel | | | | | | UXO Risk to Underwater Equipment | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Initial UXO Risk Level | | | Recommended Mitigated UXO Risk Level | | | Initial UXO Risk Level | | | Recommended Mitigated UXO Risk Level | | |
| | | | P | C | R | P | C | R | P | C | R | P | C | R |
| All GI (60m) | Large Naval Mines | 340 | 3 | 3 | 9 | 1 | 3 | 3 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Medium HE Bombs | 161.9 | 3 | 2 | 6 | 1 | 2 | 2 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Small HE Bombs | 30 | 3 | 1 | 3 | 1 | 1 | 1 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Large HE Bombs | 507 | 2 | 3 | 6 | 1 | 3 | 3 | 2 | 5 | 10 | 1 | 5 | 5 |
| | Medium Naval Mines | 227 | 2 | 2 | 4 | 1 | 2 | 2 | 2 | 5 | 10 | 1 | 5 | 5 |
| | Large AAA Projectiles | 21.7 | 2 | 1 | 2 | 1 | 1 | 1 | 2 | 5 | 10 | 1 | 5 | 5 |
| | Medium AAA Projectiles | 3.94 | 2 | 1 | 2 | 1 | 1 | 1 | 2 | 3 | 6 | 1 | 3 | 3 |
| | Small AAA Projectiles | 0.17 | 2 | 1 | 2 | 1 | 1 | 1 | 2 | 1 | 2 | 1 | 1 | 1 |
| | Torpedoes | 364 | 1 | 3 | 3 | 1 | 3 | 3 | 1 | 5 | 5 | 1 | 5 | 5 |



www.6alpha.com
+44 (0) 2033 713 900
enquiry@6alpha.com

### Pre-Lay Operations

| Activity | UXO Threat Item | Assessed NEQ (kg TNT) | UXO Risk to Vessel/Personnel | | | | | | UXO Risk to Underwater Equipment | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Initial UXO Risk Level | | | Recommended Mitigated UXO Risk Level | | | Initial UXO Risk Level | | | Recommended Mitigated UXO Risk Level | | |
| | | | P | C | R | P | C | R | P | C | R | P | C | R |
| PLGR + RC (10m) | Large Naval Mines | 340 | 5 | 5 | 25 | 1 | 5 | 5 | 5 | 5 | 25 | 1 | 5 | 5 |
| | Medium HE Bombs | 161.9 | 5 | 5 | 25 | 1 | 5 | 5 | 5 | 5 | 25 | 1 | 5 | 5 |
| | Small HE Bombs | 30 | 5 | 5 | 25 | 1 | 5 | 5 | 5 | 5 | 25 | 1 | 5 | 5 |
| | Large HE Bombs | 507 | 4 | 5 | 20 | 1 | 5 | 5 | 4 | 5 | 20 | 1 | 5 | 5 |
| | Medium Naval Mines | 227 | 4 | 5 | 20 | 1 | 5 | 5 | 4 | 5 | 20 | 1 | 5 | 5 |
| | Large AAA Projectiles | 21.7 | 4 | 5 | 20 | 1 | 5 | 5 | 4 | 5 | 20 | 1 | 5 | 5 |
| | Medium AAA Projectiles | 3.94 | 4 | 3 | 12 | 1 | 3 | 3 | 4 | 3 | 12 | 1 | 3 | 3 |
| | Small AAA Projectiles | 0.17 | 4 | 1 | 4 | 1 | 1 | 1 | 4 | 1 | 4 | 1 | 1 | 1 |
| | Torpedoes | 364 | 2 | 5 | 10 | 1 | 5 | 5 | 2 | 5 | 10 | 1 | 5 | 5 |



www.6alpha.com
+44 (0) 2033 713 900
enquiry@6alpha.com

| Activity | UXO Threat Item | Assessed NEQ (kg TNT) | UXO Risk to Vessel/Personnel | | | | | | UXO Risk to Underwater Equipment | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Initial UXO Risk Level | | | Recommended Mitigated UXO Risk Level | | | Initial UXO Risk Level | | | Recommended Mitigated UXO Risk Level | | |
| | | | P | C | R | P | C | R | P | C | R | P | C | R |
| PLGR + RC (26m) | Large Naval Mines | 340 | 5 | 5 | 25 | 1 | 5 | 5 | 5 | 5 | 25 | 1 | 5 | 5 |
| | Medium HE Bombs | 161.9 | 5 | 5 | 25 | 1 | 5 | 5 | 5 | 5 | 25 | 1 | 5 | 5 |
| | Small HE Bombs | 30 | 5 | 3 | 15 | 1 | 3 | 3 | 5 | 5 | 25 | 1 | 5 | 5 |
| | Large HE Bombs | 507 | 4 | 5 | 20 | 1 | 5 | 5 | 4 | 5 | 20 | 1 | 5 | 5 |
| | Medium Naval Mines | 227 | 4 | 5 | 20 | 1 | 5 | 5 | 4 | 5 | 20 | 1 | 5 | 5 |
| | Large AAA Projectiles | 21.7 | 4 | 2 | 8 | 1 | 2 | 2 | 4 | 5 | 20 | 1 | 5 | 5 |
| | Medium AAA Projectiles | 3.94 | 4 | 1 | 4 | 1 | 1 | 1 | 4 | 3 | 12 | 1 | 3 | 3 |
| | Small AAA Projectiles | 0.17 | 4 | 1 | 4 | 1 | 1 | 1 | 4 | 1 | 4 | 1 | 1 | 1 |
| | Torpedoes | 364 | 2 | 5 | 10 | 1 | 5 | 5 | 2 | 5 | 10 | 1 | 5 | 5 |



www.6alpha.com
+44 (0) 2033 713 900
enquiry@6alpha.com

| Activity | UXO Threat Item | Assessed NEQ (kg TNT) | UXO Risk to Vessel/Personnel | | | | | | UXO Risk to Underwater Equipment | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Initial UXO Risk Level | | | Recommended Mitigated UXO Risk Level | | | Initial UXO Risk Level | | | Recommended Mitigated UXO Risk Level | | |
| | | | P | C | R | P | C | R | P | C | R | P | C | R |
| PLGR + RC (40m) | Large Naval Mines | 340 | 5 | 4 | 20 | 1 | 4 | 4 | 5 | 5 | 25 | 1 | 5 | 5 |
| | Medium HE Bombs | 161.9 | 5 | 3 | 15 | 1 | 3 | 3 | 5 | 5 | 25 | 1 | 5 | 5 |
| | Small HE Bombs | 30 | 5 | 2 | 10 | 1 | 2 | 2 | 5 | 5 | 25 | 1 | 5 | 5 |
| | Large HE Bombs | 507 | 4 | 4 | 16 | 1 | 4 | 4 | 4 | 5 | 20 | 1 | 5 | 5 |
| | Medium Naval Mines | 227 | 4 | 3 | 12 | 1 | 3 | 3 | 4 | 5 | 20 | 1 | 5 | 5 |
| | Large AAA Projectiles | 21.7 | 4 | 2 | 8 | 1 | 2 | 2 | 4 | 5 | 20 | 1 | 5 | 5 |
| | Medium AAA Projectiles | 3.94 | 4 | 1 | 4 | 1 | 1 | 1 | 4 | 3 | 12 | 1 | 3 | 3 |
| | Small AAA Projectiles | 0.17 | 4 | 1 | 4 | 1 | 1 | 1 | 4 | 1 | 4 | 1 | 1 | 1 |
| | Torpedoes | 364 | 2 | 4 | 8 | 1 | 4 | 4 | 2 | 5 | 10 | 1 | 5 | 5 |



www.6alpha.com
+44 (0) 2033 713 900
enquiry@6alpha.com

| Activity | UXO Threat Item | Assessed NEQ (kg TNT) | UXO Risk to Vessel/Personnel | | | | | | UXO Risk to Underwater Equipment | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Initial UXO Risk Level | | | Recommended Mitigated UXO Risk Level | | | Initial UXO Risk Level | | | Recommended Mitigated UXO Risk Level | | |
| | | | P | C | R | P | C | R | P | C | R | P | C | R |
| PLGR + RC (60m) | Large Naval Mines | 340 | 5 | 3 | 15 | 1 | 3 | 3 | 5 | 5 | 25 | 1 | 5 | 5 |
| | Medium HE Bombs | 161.9 | 5 | 2 | 10 | 1 | 2 | 2 | 5 | 5 | 25 | 1 | 5 | 5 |
| | Small HE Bombs | 30 | 5 | 1 | 5 | 1 | 1 | 1 | 5 | 5 | 25 | 1 | 5 | 5 |
| | Large HE Bombs | 507 | 4 | 3 | 12 | 1 | 3 | 3 | 4 | 5 | 20 | 1 | 5 | 5 |
| | Medium Naval Mines | 227 | 4 | 2 | 8 | 1 | 2 | 2 | 4 | 5 | 20 | 1 | 5 | 5 |
| | Large AAA Projectiles | 21.7 | 4 | 1 | 4 | 1 | 1 | 1 | 4 | 5 | 20 | 1 | 5 | 5 |
| | Medium AAA Projectiles | 3.94 | 4 | 1 | 4 | 1 | 1 | 1 | 4 | 3 | 12 | 1 | 3 | 3 |
| | Small AAA Projectiles | 0.17 | 4 | 1 | 4 | 1 | 1 | 1 | 4 | 1 | 4 | 1 | 1 | 1 |
| | Torpedoes | 364 | 2 | 3 | 6 | 1 | 3 | 3 | 2 | 5 | 10 | 1 | 5 | 5 |

## Cable Installation and Burial Operations

| Activity | UXO Threat Item | Assessed NEQ (kg TNT) | UXO Risk to Vessel/Personnel | | | | | | UXO Risk to Underwater Equipment | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Initial UXO Risk Level | | | Recommended Mitigated UXO Risk Level | | | Initial UXO Risk Level | | | Recommended Mitigated UXO Risk Level | | |
| | | | P | C | R | P | C | R | P | C | R | P | C | R |
| Surface Lay (10m) | Large Naval Mines | 340 | 3 | 5 | 15 | 1 | 5 | 5 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Medium HE Bombs | 161.9 | 3 | 5 | 15 | 1 | 5 | 5 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Small HE Bombs | 30 | 3 | 5 | 15 | 1 | 5 | 5 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Large HE Bombs | 507 | 2 | 5 | 10 | 1 | 5 | 5 | 2 | 5 | 10 | 1 | 5 | 5 |
| | Medium Naval Mines | 227 | 2 | 5 | 10 | 1 | 5 | 5 | 2 | 5 | 10 | 1 | 5 | 5 |
| | Large AAA Projectiles | 21.7 | 2 | 5 | 10 | 1 | 5 | 5 | 2 | 5 | 10 | 1 | 5 | 5 |
| | Medium AAA Projectiles | 3.94 | 2 | 3 | 6 | 1 | 3 | 3 | 2 | 3 | 6 | 1 | 3 | 3 |
| | Small AAA Projectiles | 0.17 | 2 | 1 | 2 | 1 | 1 | 1 | 2 | 1 | 2 | 1 | 1 | 1 |
| | Torpedoes | 364 | 1 | 5 | 5 | 1 | 5 | 5 | 1 | 5 | 5 | 1 | 5 | 5 |



www.6alpha.com
+44 (0) 2033 713 900
enquiry@6alpha.com

| Activity | UXO Threat Item | Assessed NEQ (kg TNT) | UXO Risk to Vessel/Personnel | | | | | | UXO Risk to Underwater Equipment | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Initial UXO Risk Level | | | Recommended Mitigated UXO Risk Level | | | Initial UXO Risk Level | | | Recommended Mitigated UXO Risk Level | | |
| | | | P | C | R | P | C | R | P | C | R | P | C | R |
| Surface Lay (26m) | Large Naval Mines | 340 | 3 | 5 | 15 | 1 | 5 | 5 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Medium HE Bombs | 161.9 | 3 | 5 | 15 | 1 | 5 | 5 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Small HE Bombs | 30 | 3 | 3 | 9 | 1 | 3 | 3 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Large HE Bombs | 507 | 2 | 5 | 10 | 1 | 5 | 5 | 2 | 5 | 10 | 1 | 5 | 5 |
| | Medium Naval Mines | 227 | 2 | 5 | 10 | 1 | 5 | 5 | 2 | 5 | 10 | 1 | 5 | 5 |
| | Large AAA Projectiles | 21.7 | 2 | 2 | 4 | 1 | 2 | 2 | 2 | 5 | 10 | 1 | 5 | 5 |
| | Medium AAA Projectiles | 3.94 | 2 | 1 | 2 | 1 | 1 | 1 | 2 | 3 | 6 | 1 | 3 | 3 |
| | Small AAA Projectiles | 0.17 | 2 | 1 | 2 | 1 | 1 | 1 | 2 | 1 | 2 | 1 | 1 | 1 |
| | Torpedoes | 364 | 1 | 5 | 5 | 1 | 5 | 5 | 1 | 5 | 5 | 1 | 5 | 5 |



www.6alpha.com
+44 (0) 2033 713 900
enquiry@6alpha.com

| Activity | UXO Threat Item | Assessed NEQ (kg TNT) | UXO Risk to Vessel/Personnel | | | | | | UXO Risk to Underwater Equipment | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Initial UXO Risk Level | | | Recommended Mitigated UXO Risk Level | | | Initial UXO Risk Level | | | Recommended Mitigated UXO Risk Level | | |
| | | | P | C | R | P | C | R | P | C | R | P | C | R |
| Surface Lay (40m) | Large Naval Mines | 340 | 3 | 4 | 12 | 1 | 4 | 4 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Medium HE Bombs | 161.9 | 3 | 3 | 9 | 1 | 3 | 3 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Small HE Bombs | 30 | 3 | 2 | 6 | 1 | 2 | 2 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Large HE Bombs | 507 | 2 | 4 | 8 | 1 | 4 | 4 | 2 | 5 | 10 | 1 | 5 | 5 |
| | Medium Naval Mines | 227 | 2 | 3 | 6 | 1 | 3 | 3 | 2 | 5 | 10 | 1 | 5 | 5 |
| | Large AAA Projectiles | 21.7 | 2 | 2 | 2 | 1 | 2 | 2 | 2 | 5 | 10 | 1 | 5 | 5 |
| | Medium AAA Projectiles | 3.94 | 2 | 1 | 2 | 1 | 1 | 1 | 2 | 3 | 6 | 1 | 3 | 3 |
| | Small AAA Projectiles | 0.17 | 2 | 1 | 2 | 1 | 1 | 1 | 2 | 1 | 2 | 1 | 1 | 1 |
| | Torpedoes | 364 | 1 | 4 | 4 | 1 | 4 | 4 | 1 | 5 | 5 | 1 | 5 | 5 |


www.6alpha.com
+44 (0) 2033 713 900
enquiry@6alpha.com

| Activity | UXO Threat Item | Assessed NEQ (kg TNT) | UXO Risk to Vessel/Personnel | | | | | | UXO Risk to Underwater Equipment | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Initial UXO Risk Level | | | Recommended Mitigated UXO Risk Level | | | Initial UXO Risk Level | | | Recommended Mitigated UXO Risk Level | | |
| | | | P | C | R | P | C | R | P | C | R | P | C | R |
| Surface Lay (60m) | Large Naval Mines | 340 | 3 | 3 | 9 | 1 | 3 | 3 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Medium HE Bombs | 161.9 | 3 | 2 | 6 | 1 | 2 | 2 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Small HE Bombs | 30 | 3 | 1 | 3 | 1 | 1 | 1 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Large HE Bombs | 507 | 2 | 3 | 6 | 1 | 3 | 3 | 2 | 5 | 10 | 1 | 5 | 5 |
| | Medium Naval Mines | 227 | 2 | 2 | 4 | 1 | 2 | 2 | 2 | 5 | 10 | 1 | 5 | 5 |
| | Large AAA Projectiles | 21.7 | 2 | 1 | 2 | 1 | 1 | 1 | 2 | 5 | 10 | 1 | 5 | 5 |
| | Medium AAA Projectiles | 3.94 | 2 | 1 | 2 | 1 | 1 | 1 | 2 | 3 | 6 | 1 | 3 | 3 |
| | Small AAA Projectiles | 0.17 | 2 | 1 | 2 | 1 | 1 | 1 | 2 | 1 | 2 | 1 | 1 | 1 |
| | Torpedoes | 364 | 1 | 3 | 3 | 1 | 3 | 3 | 1 | 5 | 5 | 1 | 5 | 5 |

| Activity | UXO Threat Item | Assessed NEQ (kg TNT) | UXO Risk to Vessel/Personnel | | | | | | UXO Risk to Underwater Equipment | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Initial UXO Risk Level | | | Recommended Mitigated UXO Risk Level | | | Initial UXO Risk Level | | | Recommended Mitigated UXO Risk Level | | |
| | | | P | C | R | P | C | R | P | C | R | P | C | R |
| Jetting (10m) | Large Naval Mines | 340 | 4 | 5 | 20 | 1 | 5 | 5 | 4 | 5 | 20 | 1 | 5 | 5 |
| | Medium HE Bombs | 161.9 | 4 | 5 | 20 | 1 | 5 | 5 | 4 | 5 | 20 | 1 | 5 | 5 |
| | Small HE Bombs | 30 | 4 | 5 | 20 | 1 | 5 | 5 | 4 | 5 | 20 | 1 | 5 | 5 |
| | Large HE Bombs | 507 | 3 | 5 | 15 | 1 | 5 | 5 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Medium Naval Mines | 227 | 3 | 5 | 15 | 1 | 5 | 5 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Large AAA Projectiles | 21.7 | 3 | 5 | 15 | 1 | 5 | 5 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Medium AAA Projectiles | 3.94 | 3 | 3 | 9 | 1 | 3 | 3 | 3 | 3 | 9 | 1 | 3 | 3 |
| | Small AAA Projectiles | 0.17 | 3 | 1 | 3 | 1 | 1 | 1 | 3 | 1 | 3 | 1 | 1 | 1 |
| | Torpedoes | 364 | 1 | 5 | 5 | 1 | 5 | 5 | 1 | 5 | 5 | 1 | 5 | 5 |



www.6alpha.com
+44 (0) 2033 713 900
enquiry@6alpha.com

| Activity | UXO Threat Item | Assessed NEQ (kg TNT) | UXO Risk to Vessel/Personnel | | | | | | UXO Risk to Underwater Equipment | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Initial UXO Risk Level | | | Recommended Mitigated UXO Risk Level | | | Initial UXO Risk Level | | | Recommended Mitigated UXO Risk Level | | |
| | | | P | C | R | P | C | R | P | C | R | P | C | R |
| Jetting (26m) | Large Naval Mines | 340 | 4 | 5 | 20 | 1 | 5 | 5 | 4 | 5 | 20 | 1 | 5 | 5 |
| | Medium HE Bombs | 161.9 | 4 | 5 | 20 | 1 | 5 | 5 | 4 | 5 | 20 | 1 | 5 | 5 |
| | Small HE Bombs | 30 | 4 | 3 | 12 | 1 | 3 | 3 | 4 | 5 | 20 | 1 | 5 | 5 |
| | Large HE Bombs | 507 | 3 | 5 | 15 | 1 | 5 | 5 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Medium Naval Mines | 227 | 3 | 5 | 15 | 1 | 5 | 5 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Large AAA Projectiles | 21.7 | 3 | 2 | 6 | 1 | 2 | 2 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Medium AAA Projectiles | 3.94 | 3 | 1 | 3 | 1 | 1 | 1 | 3 | 3 | 9 | 1 | 3 | 3 |
| | Small AAA Projectiles | 0.17 | 3 | 1 | 3 | 1 | 1 | 1 | 3 | 1 | 3 | 1 | 1 | 1 |
| | Torpedoes | 364 | 1 | 5 | 5 | 1 | 5 | 5 | 1 | 5 | 5 | 1 | 5 | 5 |



www.6alpha.com
+44 (0) 2033 713 900
enquiry@6alpha.com

| Activity | UXO Threat Item | Assessed NEQ (kg TNT) | UXO Risk to Vessel/Personnel | | | | | | UXO Risk to Underwater Equipment | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Initial UXO Risk Level | | | Recommended Mitigated UXO Risk Level | | | Initial UXO Risk Level | | | Recommended Mitigated UXO Risk Level | | |
| | | | P | C | R | P | C | R | P | C | R | P | C | R |
| Jetting (40m) | Large Naval Mines | 340 | 4 | 4 | 16 | 1 | 4 | 4 | 4 | 5 | 20 | 1 | 5 | 5 |
| | Medium HE Bombs | 161.9 | 4 | 3 | 12 | 1 | 3 | 3 | 4 | 5 | 20 | 1 | 5 | 5 |
| | Small HE Bombs | 30 | 4 | 2 | 8 | 1 | 2 | 2 | 4 | 5 | 20 | 1 | 5 | 5 |
| | Large HE Bombs | 507 | 3 | 4 | 12 | 1 | 4 | 4 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Medium Naval Mines | 227 | 3 | 3 | 9 | 1 | 3 | 3 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Large AAA Projectiles | 21.7 | 3 | 2 | 6 | 1 | 2 | 2 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Medium AAA Projectiles | 3.94 | 3 | 1 | 3 | 1 | 1 | 1 | 3 | 3 | 9 | 1 | 3 | 3 |
| | Small AAA Projectiles | 0.17 | 3 | 1 | 3 | 1 | 1 | 1 | 3 | 1 | 3 | 1 | 1 | 1 |
| | Torpedoes | 364 | 1 | 4 | 4 | 1 | 4 | 4 | 1 | 5 | 5 | 1 | 5 | 5 |

| Activity | UXO Threat Item | Assessed NEQ (kg TNT) | UXO Risk to Vessel/Personnel | | | | | | UXO Risk to Underwater Equipment | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Initial UXO Risk Level | | | Recommended Mitigated UXO Risk Level | | | Initial UXO Risk Level | | | Recommended Mitigated UXO Risk Level | | |
| | | | P | C | R | P | C | R | P | C | R | P | C | R |
| Jetting (60m) | Large Naval Mines | 340 | 4 | 3 | 12 | 1 | 3 | 3 | 4 | 5 | 20 | 1 | 5 | 5 |
| | Medium HE Bombs | 161.9 | 4 | 2 | 8 | 1 | 2 | 2 | 4 | 5 | 20 | 1 | 5 | 5 |
| | Small HE Bombs | 30 | 4 | 1 | 4 | 1 | 1 | 1 | 4 | 5 | 20 | 1 | 5 | 5 |
| | Large HE Bombs | 507 | 3 | 3 | 9 | 1 | 3 | 3 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Medium Naval Mines | 227 | 3 | 2 | 6 | 1 | 2 | 2 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Large AAA Projectiles | 21.7 | 3 | 1 | 3 | 1 | 1 | 1 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Medium AAA Projectiles | 3.94 | 3 | 1 | 3 | 1 | 1 | 1 | 3 | 3 | 9 | 1 | 3 | 3 |
| | Small AAA Projectiles | 0.17 | 3 | 1 | 3 | 1 | 1 | 1 | 3 | 1 | 3 | 1 | 1 | 1 |
| | Torpedoes | 364 | 1 | 3 | 3 | 1 | 3 | 3 | 1 | 5 | 5 | 1 | 5 | 5 |



www.6alpha.com
+44 (0) 2033 713 900
enquiry@6alpha.com

| Activity | UXO Threat Item | Assessed NEQ (kg TNT) | UXO Risk to Vessel/Personnel | | | | | | UXO Risk to Underwater Equipment | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Initial UXO Risk Level | | | Recommended Mitigated UXO Risk Level | | | Initial UXO Risk Level | | | Recommended Mitigated UXO Risk Level | | |
| | | | P | C | R | P | C | R | P | C | R | P | C | R |
| Ploughing (10m) | Large Naval Mines | 340 | 5 | 5 | 25 | 1 | 5 | 5 | 5 | 5 | 25 | 1 | 5 | 5 |
| | Medium HE Bombs | 161.9 | 5 | 5 | 25 | 1 | 5 | 5 | 5 | 5 | 25 | 1 | 5 | 5 |
| | Small HE Bombs | 30 | 5 | 5 | 25 | 1 | 5 | 5 | 5 | 5 | 25 | 1 | 5 | 5 |
| | Large HE Bombs | 507 | 4 | 5 | 20 | 1 | 5 | 5 | 4 | 5 | 20 | 1 | 5 | 5 |
| | Medium Naval Mines | 227 | 4 | 5 | 20 | 1 | 5 | 5 | 4 | 5 | 20 | 1 | 5 | 5 |
| | Large AAA Projectiles | 21.7 | 4 | 5 | 20 | 1 | 5 | 5 | 4 | 5 | 20 | 1 | 5 | 5 |
| | Medium AAA Projectiles | 3.94 | 4 | 3 | 12 | 1 | 3 | 3 | 4 | 3 | 12 | 1 | 3 | 3 |
| | Small AAA Projectiles | 0.17 | 4 | 1 | 4 | 1 | 1 | 1 | 4 | 1 | 4 | 1 | 1 | 1 |
| | Torpedoes | 364 | 2 | 5 | 10 | 1 | 5 | 5 | 2 | 5 | 10 | 1 | 5 | 5 |

| Activity | UXO Threat Item | Assessed NEQ (kg TNT) | UXO Risk to Vessel/Personnel | | | | | | UXO Risk to Underwater Equipment | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Initial UXO Risk Level | | | Recommended Mitigated UXO Risk Level | | | Initial UXO Risk Level | | | Recommended Mitigated UXO Risk Level | | |
| | | | P | C | R | P | C | R | P | C | R | P | C | R |
| Ploughing (26m) | Large Naval Mines | 340 | 5 | 5 | 25 | 1 | 5 | 5 | 5 | 5 | 25 | 1 | 5 | 5 |
| | Medium HE Bombs | 161.9 | 5 | 5 | 25 | 1 | 5 | 5 | 5 | 5 | 25 | 1 | 5 | 5 |
| | Small HE Bombs | 30 | 5 | 3 | 15 | 1 | 3 | 3 | 5 | 5 | 25 | 1 | 5 | 5 |
| | Large HE Bombs | 507 | 4 | 5 | 20 | 1 | 5 | 5 | 4 | 5 | 20 | 1 | 5 | 5 |
| | Medium Naval Mines | 227 | 4 | 5 | 20 | 1 | 5 | 5 | 4 | 5 | 20 | 1 | 5 | 5 |
| | Large AAA Projectiles | 21.7 | 4 | 2 | 8 | 1 | 2 | 2 | 4 | 5 | 20 | 1 | 5 | 5 |
| | Medium AAA Projectiles | 3.94 | 4 | 1 | 4 | 1 | 1 | 1 | 4 | 3 | 12 | 1 | 3 | 3 |
| | Small AAA Projectiles | 0.17 | 4 | 1 | 4 | 1 | 1 | 1 | 4 | 1 | 4 | 1 | 1 | 1 |
| | Torpedoes | 364 | 2 | 5 | 10 | 1 | 5 | 5 | 2 | 5 | 10 | 1 | 5 | 5 |




www.6alpha.com
+44 (0) 2033 713 900
enquiry@6alpha.com

| Activity | UXO Threat Item | Assessed NEQ (kg TNT) | UXO Risk to Vessel/Personnel | | | | | | UXO Risk to Underwater Equipment | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Initial UXO Risk Level | | | Recommended Mitigated UXO Risk Level | | | Initial UXO Risk Level | | | Recommended Mitigated UXO Risk Level | | |
| | | | P | C | R | P | C | R | P | C | R | P | C | R |
| Ploughing (40m) | Large Naval Mines | 340 | 5 | 4 | 20 | 1 | 4 | 4 | 5 | 5 | 25 | 1 | 5 | 5 |
| | Medium HE Bombs | 161.9 | 5 | 3 | 15 | 1 | 3 | 3 | 5 | 5 | 25 | 1 | 5 | 5 |
| | Small HE Bombs | 30 | 5 | 2 | 10 | 1 | 2 | 2 | 5 | 5 | 25 | 1 | 5 | 5 |
| | Large HE Bombs | 507 | 4 | 4 | 16 | 1 | 4 | 4 | 4 | 5 | 20 | 1 | 5 | 5 |
| | Medium Naval Mines | 227 | 4 | 3 | 12 | 1 | 3 | 3 | 4 | 5 | 20 | 1 | 5 | 5 |
| | Large AAA Projectiles | 21.7 | 4 | 2 | 8 | 1 | 2 | 2 | 4 | 5 | 20 | 1 | 5 | 5 |
| | Medium AAA Projectiles | 3.94 | 4 | 1 | 4 | 1 | 1 | 1 | 4 | 3 | 12 | 1 | 3 | 3 |
| | Small AAA Projectiles | 0.17 | 4 | 1 | 4 | 1 | 1 | 1 | 4 | 1 | 4 | 1 | 1 | 1 |
| | Torpedoes | 364 | 2 | 4 | 8 | 1 | 4 | 4 | 2 | 5 | 10 | 1 | 5 | 5 |



www.6alpha.com
+44 (0) 2033 713 900
enquiry@6alpha.com

| Activity | UXO Threat Item | Assessed NEQ (kg TNT) | UXO Risk to Vessel/Personnel | | | | | | UXO Risk to Underwater Equipment | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Initial UXO Risk Level | | | Recommended Mitigated UXO Risk Level | | | Initial UXO Risk Level | | | Recommended Mitigated UXO Risk Level | | |
| | | | P | C | R | P | C | R | P | C | R | P | C | R |
| Ploughing (60m) | Large Naval Mines | 340 | 5 | 3 | 15 | 1 | 3 | 3 | 5 | 5 | 25 | 1 | 5 | 5 |
| | Medium HE Bombs | 161.9 | 5 | 2 | 10 | 1 | 2 | 2 | 5 | 5 | 25 | 1 | 5 | 5 |
| | Small HE Bombs | 30 | 5 | 1 | 5 | 1 | 1 | 1 | 5 | 5 | 25 | 1 | 5 | 5 |
| | Large HE Bombs | 507 | 4 | 3 | 12 | 1 | 3 | 3 | 4 | 5 | 20 | 1 | 5 | 5 |
| | Medium Naval Mines | 227 | 4 | 2 | 8 | 1 | 2 | 2 | 4 | 5 | 20 | 1 | 5 | 5 |
| | Large AAA Projectiles | 21.7 | 4 | 1 | 4 | 1 | 1 | 1 | 4 | 5 | 20 | 1 | 5 | 5 |
| | Medium AAA Projectiles | 3.94 | 4 | 1 | 4 | 1 | 1 | 1 | 4 | 3 | 12 | 1 | 3 | 3 |
| | Small AAA Projectiles | 0.17 | 4 | 1 | 4 | 1 | 1 | 1 | 4 | 1 | 4 | 1 | 1 | 1 |
| | Torpedoes | 364 | 2 | 3 | 6 | 1 | 3 | 3 | 2 | 5 | 10 | 1 | 5 | 5 |

## Wind Turbine Installation Operations

| Activity | UXO Threat Item | Assessed NEQ (kg TNT) | UXO Risk to Vessel/Personnel | | | | | | UXO Risk to Underwater Equipment | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Initial UXO Risk Level | | | Recommended Mitigated UXO Risk Level | | | Initial UXO Risk Level | | | Recommended Mitigated UXO Risk Level | | |
| | | | P | C | R | P | C | R | P | C | R | P | C | R |
| Piling (10m) | Large Naval Mines | 340 | 4 | 5 | 20 | 1 | 5 | 5 | 4 | 5 | 20 | 1 | 5 | 5 |
| | Medium HE Bombs | 161.9 | 4 | 5 | 20 | 1 | 5 | 5 | 4 | 5 | 20 | 1 | 5 | 5 |
| | Small HE Bombs | 30 | 4 | 5 | 20 | 1 | 5 | 5 | 4 | 5 | 20 | 1 | 5 | 5 |
| | Large HE Bombs | 507 | 3 | 5 | 15 | 1 | 5 | 5 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Medium Naval Mines | 227 | 3 | 5 | 15 | 1 | 5 | 5 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Large AAA Projectiles | 21.7 | 3 | 5 | 15 | 1 | 5 | 5 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Medium AAA Projectiles | 3.94 | 3 | 3 | 9 | 1 | 3 | 3 | 3 | 3 | 9 | 1 | 3 | 3 |
| | Small AAA Projectiles | 0.17 | 3 | 1 | 3 | 1 | 1 | 1 | 3 | 1 | 3 | 1 | 1 | 1 |
| | Torpedoes | 364 | 1 | 5 | 5 | 1 | 5 | 5 | 1 | 5 | 5 | 1 | 5 | 5 |


www.6alpha.com
+44 (0) 2033 713 900
enquiry@6alpha.com

| Activity | UXO Threat Item | Assessed NEQ (kg TNT) | UXO Risk to Vessel/Personnel | | | | | | UXO Risk to Underwater Equipment | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Initial UXO Risk Level | | | Recommended Mitigated UXO Risk Level | | | Initial UXO Risk Level | | | Recommended Mitigated UXO Risk Level | | |
| | | | P | C | R | P | C | R | P | C | R | P | C | R |
| Piling (26m) | Large Naval Mines | 340 | 4 | 5 | 20 | 1 | 5 | 5 | 4 | 5 | 20 | 1 | 5 | 5 |
| | Medium HE Bombs | 161.9 | 4 | 5 | 20 | 1 | 5 | 5 | 4 | 5 | 20 | 1 | 5 | 5 |
| | Small HE Bombs | 30 | 4 | 3 | 12 | 1 | 3 | 3 | 4 | 5 | 20 | 1 | 5 | 5 |
| | Large HE Bombs | 507 | 3 | 5 | 15 | 1 | 5 | 5 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Medium Naval Mines | 227 | 3 | 5 | 15 | 1 | 5 | 5 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Large AAA Projectiles | 21.7 | 3 | 2 | 6 | 1 | 2 | 2 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Medium AAA Projectiles | 3.94 | 3 | 1 | 3 | 1 | 1 | 1 | 3 | 3 | 9 | 1 | 3 | 3 |
| | Small AAA Projectiles | 0.17 | 3 | 1 | 3 | 1 | 1 | 1 | 3 | 1 | 3 | 1 | 1 | 1 |
| | Torpedoes | 364 | 1 | 5 | 5 | 1 | 5 | 5 | 1 | 5 | 5 | 1 | 5 | 5 |

| Activity | UXO Threat Item | Assessed NEQ (kg TNT) | UXO Risk to Vessel/Personnel | | | | | | UXO Risk to Underwater Equipment | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Initial UXO Risk Level | | | Recommended Mitigated UXO Risk Level | | | Initial UXO Risk Level | | | Recommended Mitigated UXO Risk Level | | |
| | | | P | C | R | P | C | R | P | C | R | P | C | R |
| Piling (40m) | Large Naval Mines | 340 | 4 | 4 | 16 | 1 | 4 | 4 | 4 | 5 | 20 | 1 | 5 | 5 |
| | Medium HE Bombs | 161.9 | 4 | 3 | 12 | 1 | 3 | 3 | 4 | 5 | 20 | 1 | 5 | 5 |
| | Small HE Bombs | 30 | 4 | 2 | 8 | 1 | 2 | 2 | 4 | 5 | 20 | 1 | 5 | 5 |
| | Large HE Bombs | 507 | 3 | 4 | 12 | 1 | 4 | 4 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Medium Naval Mines | 227 | 3 | 3 | 9 | 1 | 3 | 3 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Large AAA Projectiles | 21.7 | 3 | 2 | 6 | 1 | 2 | 2 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Medium AAA Projectiles | 3.94 | 3 | 1 | 3 | 1 | 1 | 1 | 3 | 3 | 9 | 1 | 3 | 3 |
| | Small AAA Projectiles | 0.17 | 3 | 1 | 3 | 1 | 1 | 1 | 3 | 1 | 3 | 1 | 1 | 1 |
| | Torpedoes | 364 | 1 | 4 | 4 | 1 | 4 | 4 | 1 | 5 | 5 | 1 | 5 | 5 |



www.6alpha.com
+44 (0) 2033 713 900
enquiry@6alpha.com

| Activity | UXO Threat Item | Assessed NEQ (kg TNT) | UXO Risk to Vessel/Personnel | | | | | | UXO Risk to Underwater Equipment | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Initial UXO Risk Level | | | Recommended Mitigated UXO Risk Level | | | Initial UXO Risk Level | | | Recommended Mitigated UXO Risk Level | | |
| | | | P | C | R | P | C | R | P | C | R | P | C | R |
| Piling (60m) | Large Naval Mines | 340 | 4 | 3 | 12 | 1 | 3 | 3 | 4 | 5 | 20 | 1 | 5 | 5 |
| | Medium HE Bombs | 161.9 | 4 | 2 | 8 | 1 | 2 | 2 | 4 | 5 | 20 | 1 | 5 | 5 |
| | Small HE Bombs | 30 | 4 | 1 | 4 | 1 | 1 | 1 | 4 | 5 | 20 | 1 | 5 | 5 |
| | Large HE Bombs | 507 | 3 | 3 | 9 | 1 | 3 | 3 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Medium Naval Mines | 227 | 3 | 2 | 6 | 1 | 2 | 2 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Large AAA Projectiles | 21.7 | 3 | 1 | 3 | 1 | 1 | 1 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Medium AAA Projectiles | 3.94 | 3 | 1 | 3 | 1 | 1 | 1 | 3 | 3 | 9 | 1 | 3 | 3 |
| | Small AAA Projectiles | 0.17 | 3 | 1 | 3 | 1 | 1 | 1 | 3 | 1 | 3 | 1 | 1 | 1 |
| | Torpedoes | 364 | 1 | 3 | 3 | 1 | 3 | 3 | 1 | 5 | 5 | 1 | 5 | 5 |

**Cable and Wind Turbine Protection Operations**

| Activity | UXO Threat Item | Assessed NEQ (kg TNT) | UXO Risk to Vessel/Personnel | | | | | | UXO Risk to Underwater Equipment | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Initial UXO Risk Level | | | Recommended Mitigated UXO Risk Level | | | Initial UXO Risk Level | | | Recommended Mitigated UXO Risk Level | | |
| | | | P | C | R | P | C | R | P | C | R | P | C | R |
| Rock Emplacement (10m) | Large Naval Mines | 340 | 4 | 5 | 20 | 1 | 5 | 5 | 4 | 5 | 20 | 1 | 5 | 5 |
| | Medium HE Bombs | 161.9 | 4 | 5 | 20 | 1 | 5 | 5 | 4 | 5 | 20 | 1 | 5 | 5 |
| | Small HE Bombs | 30 | 4 | 5 | 20 | 1 | 5 | 5 | 4 | 5 | 20 | 1 | 5 | 5 |
| | Large HE Bombs | 507 | 3 | 5 | 15 | 1 | 5 | 5 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Medium Naval Mines | 227 | 3 | 5 | 15 | 1 | 5 | 5 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Large AAA Projectiles | 21.7 | 3 | 5 | 15 | 1 | 5 | 5 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Medium AAA Projectiles | 3.94 | 3 | 3 | 9 | 1 | 3 | 3 | 3 | 3 | 9 | 1 | 3 | 3 |
| | Small AAA Projectiles | 0.17 | 3 | 1 | 3 | 1 | 1 | 1 | 3 | 1 | 3 | 1 | 1 | 1 |
| | Torpedoes | 364 | 1 | 5 | 5 | 1 | 5 | 5 | 1 | 5 | 5 | 1 | 5 | 5 |

| Activity | UXO Threat Item | Assessed NEQ (kg TNT) | UXO Risk to Vessel/Personnel | | | | | | UXO Risk to Underwater Equipment | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Initial UXO Risk Level | | | Recommended Mitigated UXO Risk Level | | | Initial UXO Risk Level | | | Recommended Mitigated UXO Risk Level | | |
| | | | P | C | R | P | C | R | P | C | R | P | C | R |
| Rock Emplacement (26m) | Large Naval Mines | 340 | 4 | 5 | 20 | 1 | 5 | 5 | 4 | 5 | 20 | 1 | 5 | 5 |
| | Medium HE Bombs | 161.9 | 4 | 5 | 20 | 1 | 5 | 5 | 4 | 5 | 20 | 1 | 5 | 5 |
| | Small HE Bombs | 30 | 4 | 3 | 12 | 1 | 3 | 3 | 4 | 5 | 20 | 1 | 5 | 5 |
| | Large HE Bombs | 507 | 3 | 5 | 15 | 1 | 5 | 5 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Medium Naval Mines | 227 | 3 | 5 | 15 | 1 | 5 | 5 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Large AAA Projectiles | 21.7 | 3 | 2 | 6 | 1 | 2 | 2 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Medium AAA Projectiles | 3.94 | 3 | 1 | 3 | 1 | 1 | 1 | 3 | 3 | 9 | 1 | 3 | 3 |
| | Small AAA Projectiles | 0.17 | 3 | 1 | 3 | 1 | 1 | 1 | 3 | 1 | 3 | 1 | 1 | 1 |
| | Torpedoes | 364 | 1 | 5 | 5 | 1 | 5 | 5 | 1 | 5 | 5 | 1 | 5 | 5 |



www.6alpha.com
+44 (0) 2033 713 900
enquiry@6alpha.com

| Activity | UXO Threat Item | Assessed NEQ (kg TNT) | UXO Risk to Vessel/Personnel | | | | | | UXO Risk to Underwater Equipment | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Initial UXO Risk Level | | | Recommended Mitigated UXO Risk Level | | | Initial UXO Risk Level | | | Recommended Mitigated UXO Risk Level | | |
| | | | P | C | R | P | C | R | P | C | R | P | C | R |
| Rock Emplacement (40m) | Large Naval Mines | 340 | 4 | 4 | 16 | 1 | 4 | 4 | 4 | 5 | 20 | 1 | 5 | 5 |
| | Medium HE Bombs | 161.9 | 4 | 3 | 12 | 1 | 3 | 3 | 4 | 5 | 20 | 1 | 5 | 5 |
| | Small HE Bombs | 30 | 4 | 2 | 8 | 1 | 2 | 2 | 4 | 5 | 20 | 1 | 5 | 5 |
| | Large HE Bombs | 507 | 3 | 4 | 12 | 1 | 4 | 4 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Medium Naval Mines | 227 | 3 | 3 | 9 | 1 | 3 | 3 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Large AAA Projectiles | 21.7 | 3 | 2 | 6 | 1 | 2 | 2 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Medium AAA Projectiles | 3.94 | 3 | 1 | 3 | 1 | 1 | 1 | 3 | 3 | 9 | 1 | 3 | 3 |
| | Small AAA Projectiles | 0.17 | 3 | 1 | 3 | 1 | 1 | 1 | 3 | 1 | 3 | 1 | 1 | 1 |
| | Torpedoes | 364 | 1 | 4 | 4 | 1 | 4 | 4 | 1 | 5 | 5 | 1 | 5 | 5 |



www.6alpha.com
+44 (0) 2033 713 900
enquiry@6alpha.com

| Activity | UXO Threat Item | Assessed NEQ (kg TNT) | UXO Risk to Vessel/Personnel | | | | | | UXO Risk to Underwater Equipment | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Initial UXO Risk Level | | | Recommended Mitigated UXO Risk Level | | | Initial UXO Risk Level | | | Recommended Mitigated UXO Risk Level | | |
| | | | P | C | R | P | C | R | P | C | R | P | C | R |
| Rock Emplacement (60m) | Large Naval Mines | 340 | 4 | 3 | 12 | 1 | 3 | 3 | 4 | 5 | 20 | 1 | 5 | 5 |
| | Medium HE Bombs | 161.9 | 4 | 2 | 8 | 1 | 2 | 2 | 4 | 5 | 20 | 1 | 5 | 5 |
| | Small HE Bombs | 30 | 4 | 1 | 4 | 1 | 1 | 1 | 4 | 5 | 20 | 1 | 5 | 5 |
| | Large HE Bombs | 507 | 3 | 3 | 9 | 1 | 3 | 3 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Medium Naval Mines | 227 | 3 | 2 | 6 | 1 | 2 | 2 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Large AAA Projectiles | 21.7 | 3 | 1 | 3 | 1 | 1 | 1 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Medium AAA Projectiles | 3.94 | 3 | 1 | 3 | 1 | 1 | 1 | 3 | 3 | 9 | 1 | 3 | 3 |
| | Small AAA Projectiles | 0.17 | 3 | 1 | 3 | 1 | 1 | 1 | 3 | 1 | 3 | 1 | 1 | 1 |
| | Torpedoes | 364 | 1 | 3 | 3 | 1 | 3 | 3 | 1 | 5 | 5 | 1 | 5 | 5 |



www.6alpha.com
+44 (0) 2033 713 900
enquiry@6alpha.com

## Enabling Operations

| Activity | UXO Threat Item | Assessed NEQ (kg TNT) | UXO Risk to Vessel/Personnel | | | | | | UXO Risk to Underwater Equipment | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Initial UXO Risk Level | | | Recommended Mitigated UXO Risk Level | | | Initial UXO Risk Level | | | Recommended Mitigated UXO Risk Level | | |
| | | | P | C | R | P | C | R | P | C | R | P | C | R |
| Anchoring (10m) | Large Naval Mines | 340 | 3 | 5 | 15 | 1 | 5 | 5 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Medium HE Bombs | 161.9 | 3 | 5 | 15 | 1 | 5 | 5 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Small HE Bombs | 30 | 3 | 5 | 15 | 1 | 5 | 5 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Large HE Bombs | 507 | 2 | 5 | 10 | 1 | 5 | 5 | 2 | 5 | 10 | 1 | 5 | 5 |
| | Medium Naval Mines | 227 | 2 | 5 | 10 | 1 | 5 | 5 | 2 | 5 | 10 | 1 | 5 | 5 |
| | Large AAA Projectiles | 21.7 | 2 | 5 | 10 | 1 | 5 | 5 | 2 | 5 | 10 | 1 | 5 | 5 |
| | Medium AAA Projectiles | 3.94 | 2 | 3 | 6 | 1 | 3 | 3 | 2 | 3 | 6 | 1 | 3 | 3 |
| | Small AAA Projectiles | 0.17 | 2 | 1 | 2 | 1 | 1 | 1 | 2 | 1 | 2 | 1 | 1 | 1 |
| | Torpedoes | 364 | 1 | 5 | 5 | 1 | 5 | 5 | 1 | 5 | 5 | 1 | 5 | 5 |


www.6alpha.com
+44 (0) 2033 713 900
enquiry@6alpha.com

| Activity | UXO Threat Item | Assessed NEQ (kg TNT) | UXO Risk to Vessel/Personnel | | | | | | UXO Risk to Underwater Equipment | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Initial UXO Risk Level | | | Recommended Mitigated UXO Risk Level | | | Initial UXO Risk Level | | | Recommended Mitigated UXO Risk Level | | |
| | | | P | C | R | P | C | R | P | C | R | P | C | R |
| Anchoring (26m) | Large Naval Mines | 340 | 3 | 5 | 15 | 1 | 5 | 5 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Medium HE Bombs | 161.9 | 3 | 5 | 15 | 1 | 5 | 5 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Small HE Bombs | 30 | 3 | 3 | 9 | 1 | 3 | 3 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Large HE Bombs | 507 | 2 | 5 | 10 | 1 | 5 | 5 | 2 | 5 | 10 | 1 | 5 | 5 |
| | Medium Naval Mines | 227 | 2 | 5 | 10 | 1 | 5 | 5 | 2 | 5 | 10 | 1 | 5 | 5 |
| | Large AAA Projectiles | 21.7 | 2 | 2 | 4 | 1 | 2 | 2 | 2 | 5 | 10 | 1 | 5 | 5 |
| | Medium AAA Projectiles | 3.94 | 2 | 1 | 2 | 1 | 1 | 1 | 2 | 3 | 6 | 1 | 3 | 3 |
| | Small AAA Projectiles | 0.17 | 2 | 1 | 2 | 1 | 1 | 1 | 2 | 1 | 2 | 1 | 1 | 1 |
| | Torpedoes | 364 | 1 | 5 | 5 | 1 | 5 | 5 | 1 | 5 | 5 | 1 | 5 | 5 |



www.6alpha.com
+44 (0) 2033 713 900
enquiry@6alpha.com

| Activity | UXO Threat Item | Assessed NEQ (kg TNT) | UXO Risk to Vessel/Personnel | | | | | | UXO Risk to Underwater Equipment | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Initial UXO Risk Level | | | Recommended Mitigated UXO Risk Level | | | Initial UXO Risk Level | | | Recommended Mitigated UXO Risk Level | | |
| | | | P | C | R | P | C | R | P | C | R | P | C | R |
| Anchoring (40m) | Large Naval Mines | 340 | 3 | 4 | 12 | 1 | 4 | 4 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Medium HE Bombs | 161.9 | 3 | 3 | 9 | 1 | 3 | 3 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Small HE Bombs | 30 | 3 | 2 | 6 | 1 | 2 | 2 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Large HE Bombs | 507 | 2 | 4 | 8 | 1 | 4 | 4 | 2 | 5 | 10 | 1 | 5 | 5 |
| | Medium Naval Mines | 227 | 2 | 3 | 6 | 1 | 3 | 3 | 2 | 5 | 10 | 1 | 5 | 5 |
| | Large AAA Projectiles | 21.7 | 2 | 2 | 2 | 1 | 2 | 2 | 2 | 5 | 10 | 1 | 5 | 5 |
| | Medium AAA Projectiles | 3.94 | 2 | 1 | 2 | 1 | 1 | 1 | 2 | 3 | 6 | 1 | 3 | 3 |
| | Small AAA Projectiles | 0.17 | 2 | 1 | 2 | 1 | 1 | 1 | 2 | 1 | 2 | 1 | 1 | 1 |
| | Torpedoes | 364 | 1 | 4 | 4 | 1 | 4 | 4 | 1 | 5 | 5 | 1 | 5 | 5 |

| Activity | UXO Threat Item | Assessed NEQ (kg TNT) | UXO Risk to Vessel/Personnel | | | | | | UXO Risk to Underwater Equipment | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Initial UXO Risk Level | | | Recommended Mitigated UXO Risk Level | | | Initial UXO Risk Level | | | Recommended Mitigated UXO Risk Level | | |
| | | | P | C | R | P | C | R | P | C | R | P | C | R |
| Anchoring (60m) | Large Naval Mines | 340 | 3 | 3 | 9 | 1 | 3 | 3 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Medium HE Bombs | 161.9 | 3 | 2 | 6 | 1 | 2 | 2 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Small HE Bombs | 30 | 3 | 1 | 3 | 1 | 1 | 1 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Large HE Bombs | 507 | 2 | 3 | 6 | 1 | 3 | 3 | 2 | 5 | 10 | 1 | 5 | 5 |
| | Medium Naval Mines | 227 | 2 | 2 | 4 | 1 | 2 | 2 | 2 | 5 | 10 | 1 | 5 | 5 |
| | Large AAA Projectiles | 21.7 | 2 | 1 | 2 | 1 | 1 | 1 | 2 | 5 | 10 | 1 | 5 | 5 |
| | Medium AAA Projectiles | 3.94 | 2 | 1 | 2 | 1 | 1 | 1 | 2 | 3 | 6 | 1 | 3 | 3 |
| | Small AAA Projectiles | 0.17 | 2 | 1 | 2 | 1 | 1 | 1 | 2 | 1 | 2 | 1 | 1 | 1 |
| | Torpedoes | 364 | 1 | 3 | 3 | 1 | 3 | 3 | 1 | 5 | 5 | 1 | 5 | 5 |

| Activity | UXO Threat Item | Assessed NEQ (kg TNT) | UXO Risk to Vessel/Personnel | | | | | | UXO Risk to Underwater Equipment | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Initial UXO Risk Level | | | Recommended Mitigated UXO Risk Level | | | Initial UXO Risk Level | | | Recommended Mitigated UXO Risk Level | | |
| | | | P | C | R | P | C | R | P | C | R | P | C | R |
| Jack-Up Barge (10m) | Large Naval Mines | 340 | 4 | 5 | 20 | 1 | 5 | 5 | 4 | 5 | 20 | 1 | 5 | 5 |
| | Medium HE Bombs | 161.9 | 4 | 5 | 20 | 1 | 5 | 5 | 4 | 5 | 20 | 1 | 5 | 5 |
| | Small HE Bombs | 30 | 4 | 5 | 20 | 1 | 5 | 5 | 4 | 5 | 20 | 1 | 5 | 5 |
| | Large HE Bombs | 507 | 3 | 5 | 15 | 1 | 5 | 5 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Medium Naval Mines | 227 | 3 | 5 | 15 | 1 | 5 | 5 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Large AAA Projectiles | 21.7 | 3 | 5 | 15 | 1 | 5 | 5 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Medium AAA Projectiles | 3.94 | 3 | 3 | 9 | 1 | 3 | 3 | 3 | 3 | 9 | 1 | 3 | 3 |
| | Small AAA Projectiles | 0.17 | 3 | 1 | 3 | 1 | 1 | 1 | 3 | 1 | 3 | 1 | 1 | 1 |
| | Torpedoes | 364 | 1 | 5 | 5 | 1 | 5 | 5 | 1 | 5 | 5 | 1 | 5 | 5 |



www.6alpha.com
+44 (0) 2033 713 900
enquiry@6alpha.com

| Activity | UXO Threat Item | Assessed NEQ (kg TNT) | UXO Risk to Vessel/Personnel | | | | | | UXO Risk to Underwater Equipment | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Initial UXO Risk Level | | | Recommended Mitigated UXO Risk Level | | | Initial UXO Risk Level | | | Recommended Mitigated UXO Risk Level | | |
| | | | P | C | R | P | C | R | P | C | R | P | C | R |
| Jack-Up Barge (26m) | Large Naval Mines | 340 | 4 | 5 | 20 | 1 | 5 | 5 | 4 | 5 | 20 | 1 | 5 | 5 |
| | Medium HE Bombs | 161.9 | 4 | 5 | 20 | 1 | 5 | 5 | 4 | 5 | 20 | 1 | 5 | 5 |
| | Small HE Bombs | 30 | 4 | 3 | 12 | 1 | 3 | 3 | 4 | 5 | 20 | 1 | 5 | 5 |
| | Large HE Bombs | 507 | 3 | 5 | 15 | 1 | 5 | 5 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Medium Naval Mines | 227 | 3 | 5 | 15 | 1 | 5 | 5 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Large AAA Projectiles | 21.7 | 3 | 2 | 6 | 1 | 2 | 2 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Medium AAA Projectiles | 3.94 | 3 | 1 | 3 | 1 | 1 | 1 | 3 | 3 | 9 | 1 | 3 | 3 |
| | Small AAA Projectiles | 0.17 | 3 | 1 | 3 | 1 | 1 | 1 | 3 | 1 | 3 | 1 | 1 | 1 |
| | Torpedoes | 364 | 1 | 5 | 5 | 1 | 5 | 5 | 1 | 5 | 5 | 1 | 5 | 5 |



www.6alpha.com
+44 (0) 2033 713 900
enquiry@6alpha.com

| Activity | UXO Threat Item | Assessed NEQ (kg TNT) | UXO Risk to Vessel/Personnel | | | | | | UXO Risk to Underwater Equipment | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Initial UXO Risk Level | | | Recommended Mitigated UXO Risk Level | | | Initial UXO Risk Level | | | Recommended Mitigated UXO Risk Level | | |
| | | | P | C | R | P | C | R | P | C | R | P | C | R |
| Jack-Up Barge (40m) | Large Naval Mines | 340 | 4 | 4 | 16 | 1 | 4 | 4 | 4 | 5 | 20 | 1 | 5 | 5 |
| | Medium HE Bombs | 161.9 | 4 | 3 | 12 | 1 | 3 | 3 | 4 | 5 | 20 | 1 | 5 | 5 |
| | Small HE Bombs | 30 | 4 | 2 | 8 | 1 | 2 | 2 | 4 | 5 | 20 | 1 | 5 | 5 |
| | Large HE Bombs | 507 | 3 | 4 | 12 | 1 | 4 | 4 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Medium Naval Mines | 227 | 3 | 3 | 9 | 1 | 3 | 3 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Large AAA Projectiles | 21.7 | 3 | 2 | 6 | 1 | 2 | 2 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Medium AAA Projectiles | 3.94 | 3 | 1 | 3 | 1 | 1 | 1 | 3 | 3 | 9 | 1 | 3 | 3 |
| | Small AAA Projectiles | 0.17 | 3 | 1 | 3 | 1 | 1 | 1 | 3 | 1 | 3 | 1 | 1 | 1 |
| | Torpedoes | 364 | 1 | 4 | 4 | 1 | 4 | 4 | 1 | 5 | 5 | 1 | 5 | 5 |

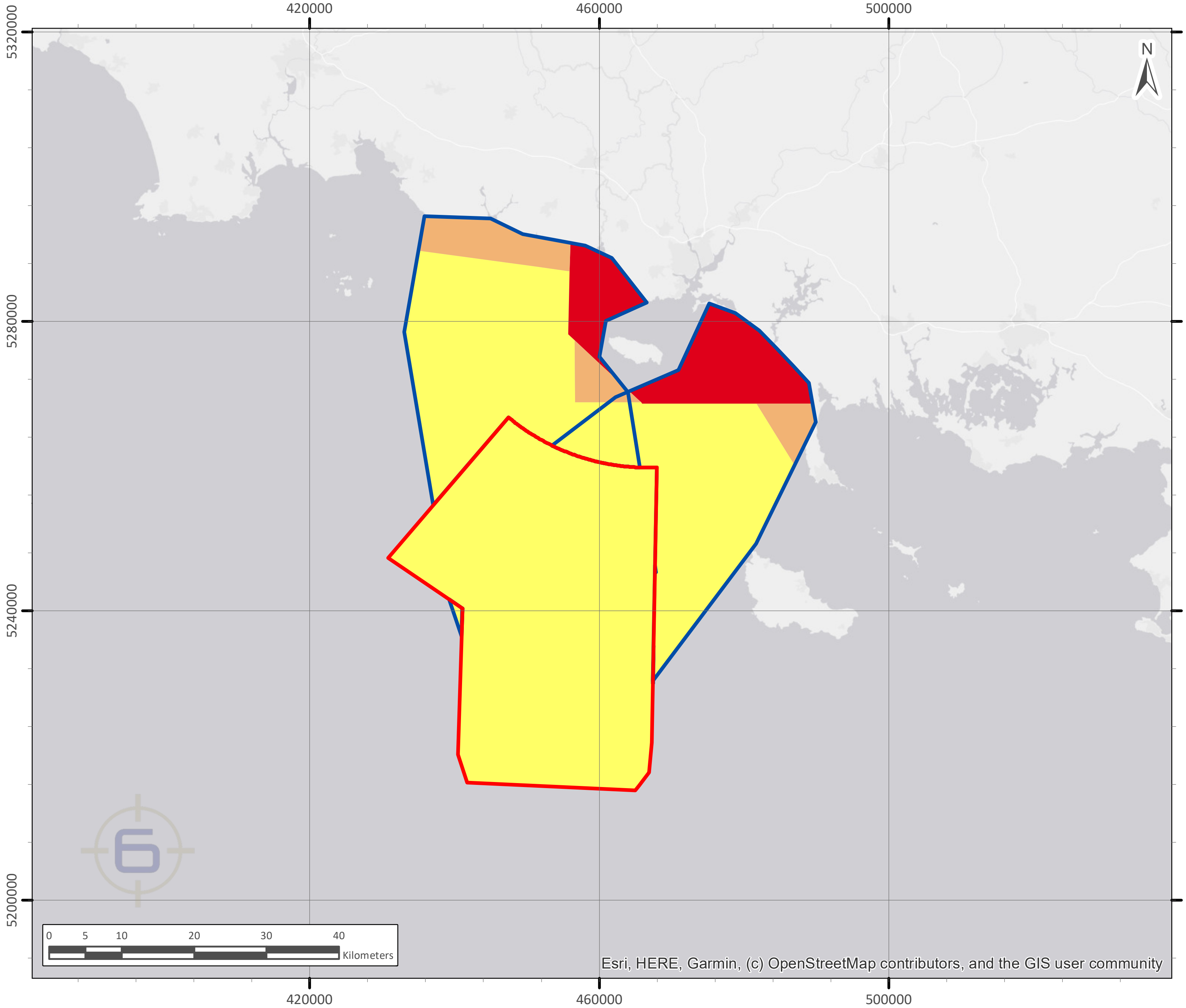
| Activity | UXO Threat Item | Assessed NEQ (kg TNT) | UXO Risk to Vessel/Personnel | | | | | | UXO Risk to Underwater Equipment | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Initial UXO Risk Level | | | Recommended Mitigated UXO Risk Level | | | Initial UXO Risk Level | | | Recommended Mitigated UXO Risk Level | | |
| | | | P | C | R | P | C | R | P | C | R | P | C | R |
| Jack-Up Barge (60m) | Large Naval Mines | 340 | 4 | 3 | 12 | 1 | 3 | 3 | 4 | 5 | 20 | 1 | 5 | 5 |
| | Medium HE Bombs | 161.9 | 4 | 2 | 8 | 1 | 2 | 2 | 4 | 5 | 20 | 1 | 5 | 5 |
| | Small HE Bombs | 30 | 4 | 1 | 4 | 1 | 1 | 1 | 4 | 5 | 20 | 1 | 5 | 5 |
| | Large HE Bombs | 507 | 3 | 3 | 9 | 1 | 3 | 3 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Medium Naval Mines | 227 | 3 | 2 | 6 | 1 | 2 | 2 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Large AAA Projectiles | 21.7 | 3 | 1 | 3 | 1 | 1 | 1 | 3 | 5 | 15 | 1 | 5 | 5 |
| | Medium AAA Projectiles | 3.94 | 3 | 1 | 3 | 1 | 1 | 1 | 3 | 3 | 9 | 1 | 3 | 3 |
| | Small AAA Projectiles | 0.17 | 3 | 1 | 3 | 1 | 1 | 1 | 3 | 1 | 3 | 1 | 1 | 1 |
| | Torpedoes | 364 | 1 | 3 | 3 | 1 | 3 | 3 | 1 | 5 | 5 | 1 | 5 | 5 |



www.6alpha.com
+44 (0) 2033 713 900
enquiry@6alpha.com

# Appendix 15

## UXO Risk Zones: GI and Installation Operations




LEGEND

## GENERAL

- OWF_Boundary
- Export_Cable_Corridors

**Risk_Rating**

- VERY HIGH
- HIGH
- MEDIUM

| PROJECT | PROJECT TITLE |
|---|---|
| 8811 | A05 BRITTANY |

DRAWING TITLE
**UXO Risk Zones**

DRAWING NUMBER
**A05 Brittany\015\V1.0**

PURPOSE
**FOR INFORMATION USE ONLY**

| COORDINATE SYSTEM | SCALE | ORIGINAL PLOT SIZE | DRAWN | DATE DRAWN | CHECKED |
|---|---|---|---|---|---|
| WGS 1984 UTM Zone 30N | 1:750,000 | A4 | LH | 01/04/2021 | LG |

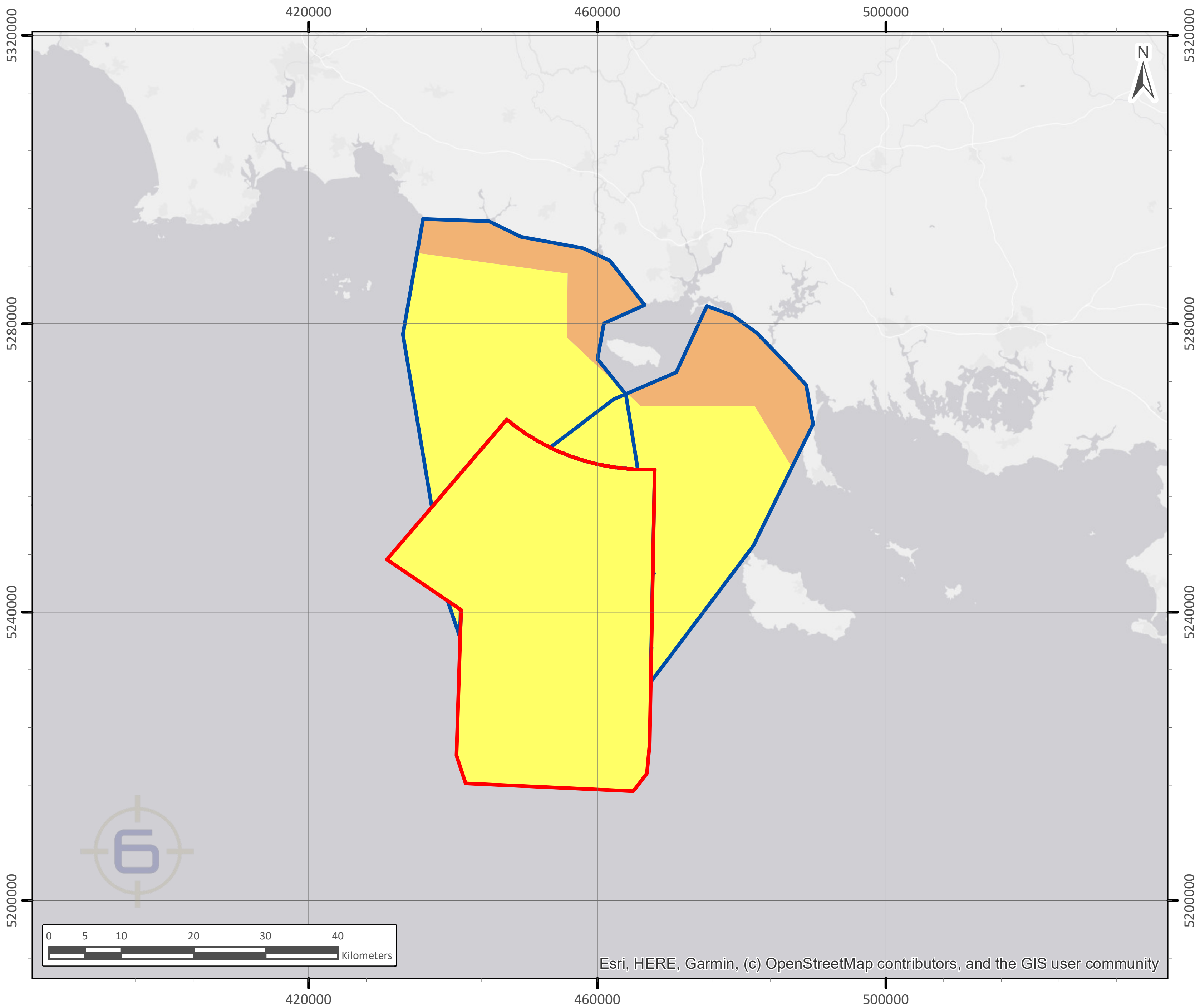


W W W . 6 A L P H A . C O M
E: enquiry@6alpha.com | T: +44 (0)203 371 3900

alpha ASSOCIATES
special risks consultancy

# Appendix 16

UXO Risk Zones: GI Operations Only




LEGEND

## GENERAL

- OWF_Boundary
- Export_Cable_Corridors

**Risk_Rating**

- HIGH
- MEDIUM

| PROJECT | PROJECT TITLE |
|---|---|
| 8811 | A05 BRITTANY |

DRAWING TITLE: **UXO Risk Zones: GI Operations Only**

DRAWING NUMBER: **A05 Brittany\016\V1.0**

PURPOSE: **FOR INFORMATION USE ONLY**

alpha ASSOCIATES
special risks consultancy

| COORDINATE SYSTEM | SCALE | ORIGINAL PLOT SIZE | DRAWN | DATE DRAWN | CHECKED |
|---|---|---|---|---|---|
| WGS 1984 UTM Zone 30N | 1:750,000 | A4 | LH | 01/04/2021 | LG |



W W W . 6 A L P H A . C O M
E: enquiry@6alpha.com | T: +44 (0)203 371 3900

# Appendix 17

## Holistic UXO Risk Management Process


www.6alpha.com
+44 (0) 2033 713 900
enquiry@6alpha.com

## CONCEPT

There are generally, three sequential strands of Unexploded Ordnance (UXO) risk management work to consider in order to reduce risks ALARP and they have been depicted (at Figure 1) and grouped together, at the Strategic, Tactical and Operational levels.

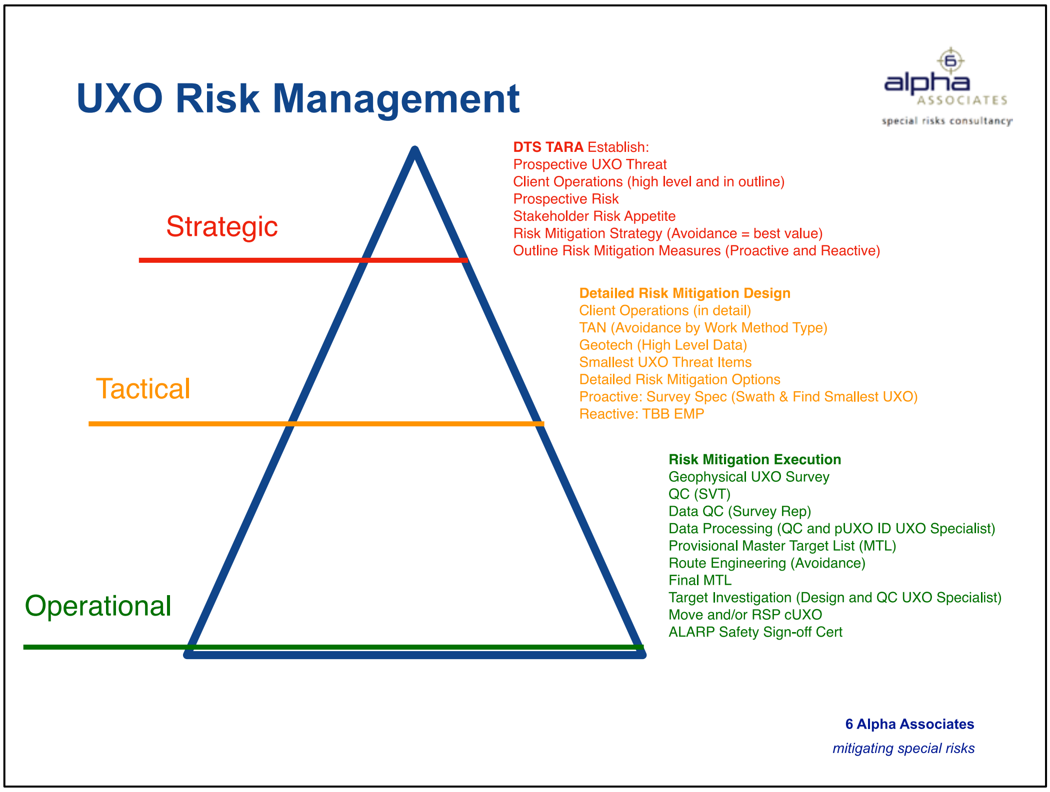



**Figure 1: 6 Alpha UXO Risk Management - Concept**

## DETAIL

### Strategic Level - A Holistic Perspective of UXO Threat, Risk and Risk Management

A UXO Desk Top Study (DTS) will establish the prospective UXO threat and risk in sequence, as follows:

- **Operations**; it will establish the nature of prospective Client operations (at high level and in outline) for example and typically:
  - Geotechnical Investigation (GI);
  - Cable Installation;
  - OWF Installation;
- **Risk**; establish prospective UXO risk by examining (using Semi Quantitative Risk Assessment), two key factors:

    - **Probability**; of UXO encounter and of its initiation (the former is driven by UXO/civil engineering juxtaposition; the latter by kinetic energy);
    - **Consequence**; of UXO initiation, which is driven by the Net (High) Explosive Quantity (NEQ) in each type of UXO. And (critically); the proximity and robustness of sensitive receptors (e.g. people, GI and/or installation equipment);
- **Stakeholder Risk Appetite**; what risks can stakeholders reasonably and legally tolerate? What cannot be tolerated (e.g. risk of injury to personnel)?;
- **Risk Mitigation Strategy**; e.g. UXO avoidance which delivers the best value for money solution;
- **Risk Mitigation Measures**; divided typically into proactive and reactive categories.

**Tactical Level - Detailed Risk Mitigation Design**

Following GI and/or installation solution has been designed (or concurrent with it), 6 Alpha then deliver a "Detailed UXO Risk Mitigation Design", considering the following factors, in sequence:

- The Client's and Principal Contractor's installation operations (in detail);
- Technical Advisory Notes (TAN) that deliver potential UXO (pUXO) avoidance by work method type. Benefits: reduced pUXO avoidance (initially 15m radius, but typically ~10m radii, post TAN); therefore, more freedom of pipeline manoeuvre, micro-routing and micro siting, in advance of installation; fewer pUXO to be avoided; less investigation; thus save time, reduce schedule and save money;
- Geotech input in the form of high level data on soil types and shear strengths. Detailed geotech will enable more accurate and better focussed TAN;
- Smallest UXO threat items for detection v stakeholder appetite for risk?
- Therefore, outline risk mitigation measures are typically sub-divided into the following categories:
    - **Proactive Measures** e.g.:
        - Geophysical UXO survey (accounting for the smallest UXO threat) and its avoidance
        - If pUXO cannot be avoided, then verify it by investigation;
        - If it is confirmed UXO (cUXO) then move it (if it both safe and practical to do so) and/or destroy it;
    - **Reactive Measures** eg:
        - Site Emergency Management Plans (EMP);
        - Tool Box Briefs (TBB) for site workers.

**Operational Level - Delivery of UXO Risk Management and Mitigation Solutions**

UXO risk mitigation execution might typically include, sequentially:

- Geophysical UXO Survey pre-installation;
- Survey Quality Control (QC) via a Survey Verification Test (SVT);
- Data QC;
- Data Processing (QC and pUXO ID - by a UXO Specialist, such as 6 Alpha), concurrent with survey operations;
- Provisional Master Target List (MTL) generated by UXO Specialist consisting of all pUXO;
- Micro-siting and/or route engineering (thus avoidance) is undertaken (benefit - saves time and money);
- Final MTL produced, which ensured that the following activities are reduced to the minimum in order to reduce risk ALARP and to save time and money:
    - Target Investigation (designed, and QC'd by a UXO Specialist such as 6 Alpha);
    - Move and/or Redner Safe Procedure (RSP) on confirmed UXO (cUXO);
    - ALARP Safety Sign-off Certs delivered for all installation methods.

www.6alpha.com
+44 (0) 2033 713 900
enquiry@6alpha.com

# Annex A

## Legislation and UXO Risk Management

## Contents

# 1 Legislation and UXO Risk Management

## 1.1 Introduction

The law requires that the client fulfils both their statutory and legal duties to protect those that may be exposed to harm. In the event of an UXO incident that causes harm, failure to adequately manage the UXO risk may lead to the prosecution and imprisonment of those deemed responsible for breaching their duty of care. The following sections outline national legislation, industry good practice, the ALARP principle, the assumptions made of the client's risk tolerance, as well as the expected behavioural responses of the project stakeholders when confronted with the UXO risk.

## 1.2 European Union Directives and National Legislation

The primary regulation, and minimum standard requirement for all European Union (EU) countries and businesses, residing in and/or working within the EU, is the Council Directive 89/391/EEC – OSH "Framework Directive" of 12th June 1989, on the introduction of measures to encourage improvements in the safety and health of workers at work. This framework directive contains basic obligations for employers and workers, with emphasis on the employer's obligation to ensure the safety and health of workers in every aspect related to work, without imposing financial costs on the worker to achieve this aim. From this legally binding EU directive, the minimum standards and fundamental principles (such as risk assessment) were passed into national law and enforced by the EU member states.

By contracting a UXO risk management consultant, the client has drawn upon help from a competent person to perform a risk assessment and to assess and advise upon the UXO risk posed to the client's employees and contractors. In doing so, the client has acted in compliance with the legal duties required as dictated in the above legislation. 6 Alpha Associates has acted based on the guidance of industry good practice, professional risk management, explosive ordnance disposal (EOD) experience, and its interpretation of the law.

In the end, it is for both national and EU courts to decide whether the client has acted in compliance with the law, and to determine if sufficient risk management and mitigation measures were undertaken and effectively applied.

## 1.3 UXO Industry Guidance and Good Practice

The construction industry research and information association (CIRIA) has published guidance on the assessment and management of unexploded ordnance risk in the marine environment (CIRIA C754, published 2016, London). CIRIA is a neutral, non-government, non-profit body linking organisations with common interests, that collaborate with the aim of improving and setting an agreed level of minimum industry standards.

The CIRIA C754 guide therefore represents an industry agreed standard for the assessment and management of UXO risk, which has been judged and recognised by the Health and Safety Executive (HSE) of the UK as a minimum standard or source of good practice, that satisfies the law when applied in an appropriate manner.

For UXO assessment and risk management, 6 Alpha Associates assesses itself against the CIRIA C754 guide to ensure compliance with the minimum legal requirements of industry good practice to manage UXO risks to as low as reasonably practicable (ALARP).

## 1.4 Reducing Risks to ALARP

Reducing risks to ALARP is the concept of weighing a risk against the resources (effort, time, and money) required to a level that adequately control the risks. The law sets this level of what is reasonably practicable, whilst stakeholders determine what is considered tolerable to the project, whilst also fulfilling their legal obligations.

Industry good practice in the form of CIRIA C754 guide, offers the direction as to assessing both ALARP and the risk tolerance, so that an agreement amongst the stakeholders can be reached as to what the ALARP level is, and what resources are required to achieve it. ALARP therefore describes the level to which risks are controlled, as determined by good practice.

Confirming that the UXO risks have been reduced to ALARP involves weighing the residual risk against the resources to further reduce it. If it can be demonstrated that the resource requirement is grossly disproportional to the benefits of further risk reduction, then risks have been reduced to ALARP. Consequently, the principle of reducing risks to a reasonably practicable level will usually result in a residual level of risk, as well as *de minimis* risks that must be either shared, transferred, mitigated, and/or tolerated.

A diagrammatic representation for meeting with ALARP is presented at Figure 1.

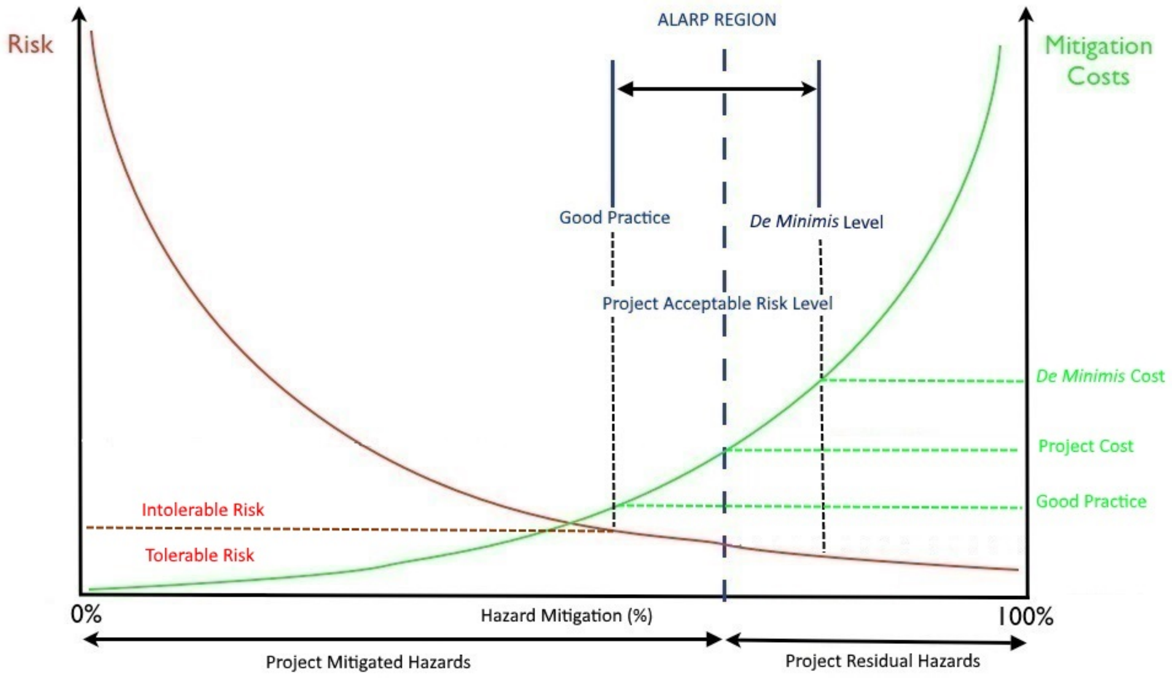



**Figure 1**: The ALARP principle of managing risk.

## 1.5 UXO Risk Tolerance

6 Alpha Associates have made certain assumptions about the client's tolerance of UXO risk. Our assumptions include that the following interrelated elements are to be considered when determining the projects UXO risk tolerances:

- **Corporate Governance** – is the system of rules, practices, and processes by which companies are managed and controlled. It is assumed that the client will wish to adhere to the highest international standards of corporate governance. Discharge of corporate responsibility is expected to be on risk based criteria and it is expected that the client will have in place a framework for managing risk for good governance. It is anticipated that safety and risk management are integrated in the client's business culture and be actively applied throughout the project.
- **Risk Management** – the client will expect the highest standard of risk and safety management to be applied to this project and will have a risk management system in place for responding to business, programme, and project risks. The client will rely upon help from a competent person to identify UXO risks, but also to design appropriate UXO risk management solutions in accordance with industry good practice. Any risks posed by UXO must be assessed based upon probability and consequence criteria. Potential UXO targets must be avoided or otherwise

mitigated not only in accordance with the law, but also with CIRIA C754 industry guidelines. A competent person will oversee the UXO geophysical survey and the UXO risk mitigation contractors who are responsible for the subsequent execution of those works, ensuring they are performed to appropriate quality and meet good practice standards.

- **Safety** – personnel safety will assume the highest priority for the project. The protection and preservation of equipment, property, and the environment, although important, will remain a secondary priority to that of the prevention of harm to personnel involved with the project.

## 1.6 UXO Risk Behaviour

UXO incidents that result in harm to construction personnel, are generally termed an extreme, or a low probability-high consequence (LP-HC) event. Given the ambiguity and uncertainty surrounding such events, project stakeholders may respond to the risk in an extreme manner, and demand a disproportionate level of risk mitigation. The client should be aware of the following common responses and attitudes to LP-HC risks, to manage stakeholder expectations of the UXO risk throughout the project's life cycle. There are three general behavioural patterns for dealing with LP-HC events (Kunreuther, 1995):

1) Individuals do not think probabilistically and demand zero risk when costs do not need to be absorbed. Alternatively, when individuals do need to absorb the cost themselves, they are more likely to tolerate very high probability risks.

2) Risk is a multidimensional problem which cannot be simply measured quantitively, such as the number of fatalities per year. Risk tends to be influenced by people's attitudes to catastrophic situations, fear, lack of familiarity, or situations they perceive to be beyond their control. By nature, humans are risk averse when exposed to uncertainty and will enhance the level of risk accordingly.

3) Given the lack of knowledge over the probability of these event, people are more likely to use simple decision making measures, such as threshold values. The general perception is, that the probability of LP-HC risks is too low to possibly occur, and as a result not take adequate steps to protect themselves.

Such behaviour patterns typically lead to one or more of the following common responses from project stakeholders:

- A desire for zero risk;
- A concern for future generations;

- Denial that the event can ever happen to them;
- A perception that the situation is under their control and therefore can never happen;
- That the hazard is perceived to be benign after a certain amount of time;
- Short sighted behaviour and an aversion to spend today to reap the potential benefits later.

## 1.7 References

1) Kunreuther, H., 1995, Protection against low probability high consequence events.

# Annex B

## Classification of UXO

# Contents

# 1 Classification of Unexploded Ordnance

## 1.1 General

Unexploded ordnance (UXO) is any munition, weapon delivery system or ordnance item that contains explosives, propellants, or chemical agents, after they are either:

- Armed and prepared for action;
- Launched, placed, fired, thrown, or released in a way that they cause a hazard;
- Remain unexploded either through malfunction or through design.

## 1.2 Classification of Unexploded Ordnance

Unexploded ordnance items can be classified into 11 broad categories which are detailed below:

### 1.2.1 Small Arms Ammunitions (SAA)

Small arms ammunition (SAA) is a generic catchall term for projectiles that are generally less than 13mm in diameter and less than 100mm in length. SAA is fired from various sizes of weapon, such as pistols, shotguns, rifles, machine guns. Generally, the outer casings comprise either brass or steel. As UXO, they present a minimal risk compared to other high net explosive quantity (NEQ) UXO, although SAA may explode if subjected to extreme heat, or if struck with a sharp object.

### 1.2.2 Hand Grenades

Hand grenades are small bombs thrown by hand and come in various sizes and shapes. Typical types of hand grenades include fragmentation, smoke, incendiary, chemical, training, and illumination. As UXO, they present a risk if mishandled, subjected to a high impact or sufficient pressure resulting in crushing or piercing of the case, and/or exposed to extreme heat.

### 1.2.3 Projectiles

Projectiles are munitions generally ranging in diameter from 20mm to 406mm and can vary in length from 50mm to 1,219mm. All projectiles are fired from some type of launcher or gun barrel and may comprise either an explosive, chemical, smoke, illumination, or inert/training fill. Projectiles may also be fitted with stabilising fins and their fuzes are typically located either in the nose or located at the base. As UXO, they present a risk if mishandled, subjected to a high impact or sufficient pressure resulting in crushing or piercing of the case, and/or exposed to extreme heat.

### 1.2.4 Mortar Bombs

Mortar bombs come in a range of shapes, sizes, and types, typically ranging between 25mm to 280mm in diameter and typically fired from a mortar; a short smooth barrelled tube. Mortar bomb types and functions can vary to include fragmentation, smoke, incendiary, chemical, training, and illumination. Mortar bombs may be found with or without stabilising fins and they present a risk if mishandled, subjected to a high impact or sufficient pressure resulting in crushing or piercing of the case, and/or exposed extreme heat.

### 1.2.5 Landmines

Landmines are an explosive device typically shallow buried or concealed on the ground and used to defend vulnerable areas or to deny the area completely for any use. After WWII, the defensive minefields around the coastlines were swept clear and the munitions either buried or dumped at sea. Landmines come in various sizes, shapes and types including fragmentation, incendiary, chemical, training and illumination. The cases of landmines are typically made of metal but can comprise any non-magnetic material such as wood, clay, glass, concrete, or plastic so that they are harder to detect. As UXO, they present a risk if mishandled, subjected to a high impact or sufficient pressure resulting in crushing or piercing of the case, and/or exposed extreme heat.

### 1.2.6 Bombs

Bombs come in a range of size and types, generally weighing from 0.5kg to 10,000kg with typical components of a metal casing, a mechanical or electrical fuze, a main charge, a booster charge, and stabilising fins. The metal casing contains the explosive or chemical fill and may be compartmentalised. Bomb types include high explosive, incendiary, chemical, training, and concrete. As UXO, they present a risk if mishandled, subjected to a high impact or sufficient pressure resulting in crushing or piercing of the case, and/or exposed extreme heat.

### 1.2.7 Sea Mines

Sea mines are self-contained explosive devices either placed on the seabed or moored in the water column to damage or destroy surface ships or submarines. Like land mines, they are typically used to defend vulnerable areas or to deny the area completely for any use. After WWI and WWII, sea minefields were swept, with surface vessels working in tandem to cut the mooring tether so that the sea mine would float to the surface. The sea mine was then shot with SAA so that it either exploded or flooded and sank to the seabed. Some sea mines were also simply lost or were not recovered and remain unaccounted for. Sea mines come in all shapes and sizes and as UXO, they present a risk mishandled, subjected to a high impact or sufficient pressure resulting in crushing or piercing of the case, and/or exposed extreme heat.

### 1.2.8 Rockets

Rockets are self-propelled unguided munitions that generally vary in diameter from 37mm to more than 380mm and can vary in length from 300mm to 2,743mm. All rockets comprise a warhead, fuze and motor section, with the warhead typically containing either an explosive or chemical fill. As UXO, they may or may not be present with tail fins and present a risk if mishandled, subjected to a high impact or sufficient pressure resulting in crushing or piercing of the case, and/or exposed extreme heat.

### 1.2.9 Depth Charge

A depth charge is a container, typically barrel or drum shaped, of high explosive fitted with a hydrostatic pistol, designed to trigger at a pre-programmed depth. As UXO, they present a risk if mishandled, subjected to a high impact or sufficient pressure resulting in crushing or piercing of the case, and/or exposed extreme heat.

### 1.2.10 Torpedo

Torpedoes are guided or unguided, underwater, self-propelled weapons typically fitted with a high explosive warhead. The dimensions of complete torpedoes vary but are generally between 400mm to 600mm in diameter and between 4,500mm to 7,500mm in length. As UXO, torpedoes are they are rarely found completely intact with the warhead and propulsion stages often discovered separated. Both the warhead and propulsion stages of the torpedo present a hazard if mishandled, subjected to a high impact or sufficient pressure resulting in crushing or piercing of the case, and/or exposed extreme heat.

### 1.2.11 Guided Missiles

Guided missiles are similar in design to rockets, with the exception being that they are guided to their targets by some form of guidance system and can be either self-adjusting or operator controlled. Guided missiles can be found in a variety of size, shape and colour and may be found with or without stabilising fins attached. As UXO, they present a hazard if mishandled, subjected to a high impact or sufficient pressure resulting in crushing or piercing of the case, and/or exposed extreme heat.

# Annex C

## UXO Discovery, Detonation and Sympathetic Detonation Risks


www.6alpha.com
+44 (0) 2033 713 900
enquiry@6alpha.com

# 1 UXO Discovery, Detonation and Sympathetic Detonation Risks

## 1.1 Introduction

A host of theoretical and empirical studies have provided strong evidence that Unexploded Ordnance (UXO) becomes more sensitive to trigger events that transfer kinetic energy (such as a physical impact or shock) and/or chemical energy (such as heat) as they age. Theoretically, a spontaneous detonation of UXO may occur but such instances are exceptionally rare. Therefore, UXO risk management focuses on the avoidance of known trigger events, even those of small magnitude, that may cause UXO to detonate.

Subject to its size and Net Explosive Quantity (NEQ), significant risks may be present by the discovery and accidental detonation of a singular item of UXO. Additionally, it is not uncommon for UXO to be discovered in close proximity to one another, in the offshore environment especially. For example, UXO might be found in very close proximity in munitions dumps, within the body of a shipwreck, or clustered together due to underwater topography. These circumstances are not unusual, with numerous 20th century shipwrecks and munitions dumps having been discovered around the world. Given that UXO becomes more sensitive to trigger events as they age, it is reasonably foreseeable that one detonation may trigger others in close proximity to explode in a chain reaction, a process known as sympathetic detonation.

## 1.2 Objectives

The objective of this annex is to present open-source examples of UXO discovery in individual and group circumstances that evidences the longevity and severity of UXO threats in the marine environment. Secondly, this annex aims also to highlight the potential hazards associated with a prospective UXO detonation and/or a sympathetic detonation event and the emergency reaction of the authorities to such discoveries.

## 1.3 Open Source Examples

The *North Atlantic Ocean* and the *Bay of Biscay* proved to be a crucial naval theatre of war in both WWI and WWII. Numerous naval engagements and offensive and defensive mine campaigns have specifically involved the deployment of munitions across the region. With its access to the *North Atlantic* Ocean, the western coast of *France* comprised vital trading and supply routes and consequently, was heavily targeted by covert submarine operations. During WWII, the region was also home to several submarine bases and significant military installations, which also resulted in deliberate air-to-surface vessel attacks, air mining and bomb jettisoning at sea. As such, both WWI and WWII have left a legacy of unexploded munitions in the *North Atlantic Ocean* which are still encountered to the present day. Although almost 75 years have passed since the end of the WWII, associated UXO are still located and discovered within the coastline and offshore environments of the *Bay of Biscay* to this day, as demonstrated by the following publicly accessible news article summarising encounters with historic munitions.

# WWII bomb found near French town

Thu, Apr 12, 2001, 01:00

Some 10,000 people had to leave the centre of Lorient on France's Atlantic coast today after workers found an unexploded World War Two bomb while digging a foundation for a new cultural centre.

Experts were due to defuse the bomb later today.

Local officials said the 250 kilogramme bomb was probably British - one of many dropped on the city by Allied bombers when Lorient had the largest submarine base in German-occupied France.

The bomb, which disposal experts classified as very dangerous, was found about two kilometres from the submarine base, which survived the wartime attacks intact while the city was destroyed.

The Irish Times, *WWII bomb found near French town*, 12th April 2001.
https://www.irishtimes.com/news/wwii-bomb-found-near-french-town-1.380418

# Ile de Groix : une explosion fait un mort et un blessé grave

Dimanche 7 septembre 2014 à 7:21 - Mis à jour le dimanche 7 septembre 2014 à 14:50 - Par Nathalie Delpeyrat, Germain Arrigoni, France Bleu

**Une explosion, provenant vraisemblablement d'un feu de camp, a fait un mort et un blessé très grave dans la nuit de samedi à dimanche sur une plage de l'île de Groix (Morbihan) où campaient dix personnes. Les services de déminages sont sur place, il s'agit sans doute d'une munition datant de la seconde guerre mondiale, remontée près de la surface avec les grandes marées.**

La plage de l'île de Groix où a eu lieu l'explosion © Maxppp

L'explosion, dont l'origine se trouve sous le feu de camp selon les premiers éléments de l'enquête, a eu lieu vers 2h dimanche matin, alors que les jeunes, âgés d'une vingtaine d'années et arrivés samedi par bateau sur cette plage, partaient se coucher.

## Une bombe à l'origine de l'explosion ?

Un périmètre de sécurité a été installé sur la plage ainsi qu'en mer. Outre des sapeurs-pompiers et une vingtaine de gendarmes, le Groupe Plongeurs Démineurs de Brest est aussi engagé ainsi que le GRID (démineurs de la sécurité (civile). Le parquet de Lorient, qui s'est aussi rendu sur place *"diligente une enquête pour homicide involontaire"* , selon la gendarmerie.L'une des hypothèses évoquée est la présence sous le feu de camp d'un explosif oublié de la Seconde Guerre mondiale. Cette thèse a été renforcée par la découverte sur les lieux par les enquêteurs de la gendarmerie et les techniciens en investigations criminelles de Vannes d'un "morceau de munition". *"Des analyses scientifiques auront lieu pour déterminer l'origine de ce morceau métallique".*

Nathalie Delpeyrat and Germain Arrigoni, *Ile de Groix : une explosion fait un mort et un blessé grave*, 7th September 2014.
https://www.francebleu.fr/infos/faits-divers-justice/ile-de-groix-une-explosion-fait-un-mort-et-un-blesse-grave-1410067301

Publié le 15 octobre 2020 à 18h04 Modifié le 16 octobre 2020 à 16h21

# Explosion d'une mine anglaise, près de l'île de Groix

**Une opération de contre-minage d'un explosif anglais datant de la deuxième guerre mondiale s'est déroulée ce mercredi à proximité de l'île de Groix. Elle était conduite par une équipe du GPD Atlantique.**

Partager
Agrandir
Imprimer
Version journal PRO

Une mine anglaise de type Mark, datant de la Deuxième Guerre mondiale et représentant un poids de charge de 400 kg équivalent TNT, a été découverte par la société Neotek, le 14 septembre dernier, entre le continent et l'île de Groix.

Ce mercredi, les plongeurs-démineurs du GPD Atlantique ont procédé au relevage de cette munition historique. Elle a ensuite été déplacée vers le sud-est sur une distance de six kilomètres jusqu'à la zone de contre-minage où elle a été détruite à la mi-journée.

## Le secteur réglementé de 9 h à 17 h

Pour des raisons de sécurité, les activités maritimes dans ce secteur ont été réglementées durant l'opération. La pratique des activités nautiques, subaquatiques, de la baignade et de toute autre activité impliquant la présence humaine en mer était donc interdite entre 9 h et 17 h. La présence des navires de commerce de forts tonnages était interdite dans un rayon de 1 100 m autour de la munition. Enfin, la présence des navires de commerce, des navires de pêche et des navires de plaisance à moteur était interdite dans un rayon de 540 m.


Le Télégramme, *Explosion d'une mine anglaise, près de l'île de Groix*, 16th October 2020.
https://www.letelegramme.fr/morbihan/lorient/explosion-d-une-mine-anglaise-pres-de-l-ile-de-groix-15-10-2020-12639158.php

MAIB
MARINE ACCIDENT INVESTIGATION BRANCH

# PRELIMINARY ASSESSMENT

SERIOUS MARINE CASUALTY

December 2020

**Extract from The United Kingdom Merchant Shipping (Accident Reporting and Investigation) Regulations 2012 – Regulation 5:**

"The sole objective of a safety investigation into an accident under these Regulations shall be the prevention of future accidents through the ascertainment of its causes and circumstances. It shall not be the purpose of such an investigation to determine liability nor, except so far as is necessary to achieve its objective, to apportion blame."

**NOTE**

This report is not written with litigation in mind and, pursuant to Regulation 14(14) of the Merchant Shipping (Accident Reporting and Investigation) Regulations 2012, shall be inadmissible in any judicial proceedings whose purpose, or one of whose purposes is to attribute or apportion liability or blame.



All reports can be found on our website:
www.gov.uk/maib

For all enquiries:

Email: maib@dft.gov.uk
Tel: 023 8039 5500

## Preliminary assessment of the explosion resulting in damage and abandonment of the potting fishing vessel *Galwad-Y-Mor* (BRD116) 22 nautical miles north of Cromer, Norfolk on 15 December 2020

***The information contained in this preliminary assessment is based on investigations to date. Readers are cautioned that new evidence may become available that might alter the circumstances as depicted in this statement, and the MAIB's final report of this accident.***

## NARRATIVE

On 15 December 2020, *Galwad-Y-Mor* was operating in potting fishing grounds east of the Wash **(Figure 1)**. At about 1120, the crew was in the process of hauling in a string of crab pots; the skipper was in the wheelhouse with other crew members below decks working the pots. The hauler was being used to heave in the back rope, and the crew had let the skipper know that there was a lot of tension on the line, when there was an unexpected explosion.

*Galwad-Y-Mor* was thrown up from the sea surface, then landed heavily back down; all propulsion and electrical power was immediately lost. The skipper was injured and dazed, but conscious, and saw that the wheelhouse had been completely wrecked. As he became aware that other crew members had been badly injured and that the engine room was flooding, the skipper ordered the crew to abandon ship. He also raised the alarm by texting the skipper of a sister vessel and activating the electronic position indicating radio beacon.

Image courtesy of Macduff Ship Designs


*Galwad-Y-Mor*

Reproduced from Admiralty Charts 0002 and 2182A by permission of HMSO and the UK Hydrographic Office

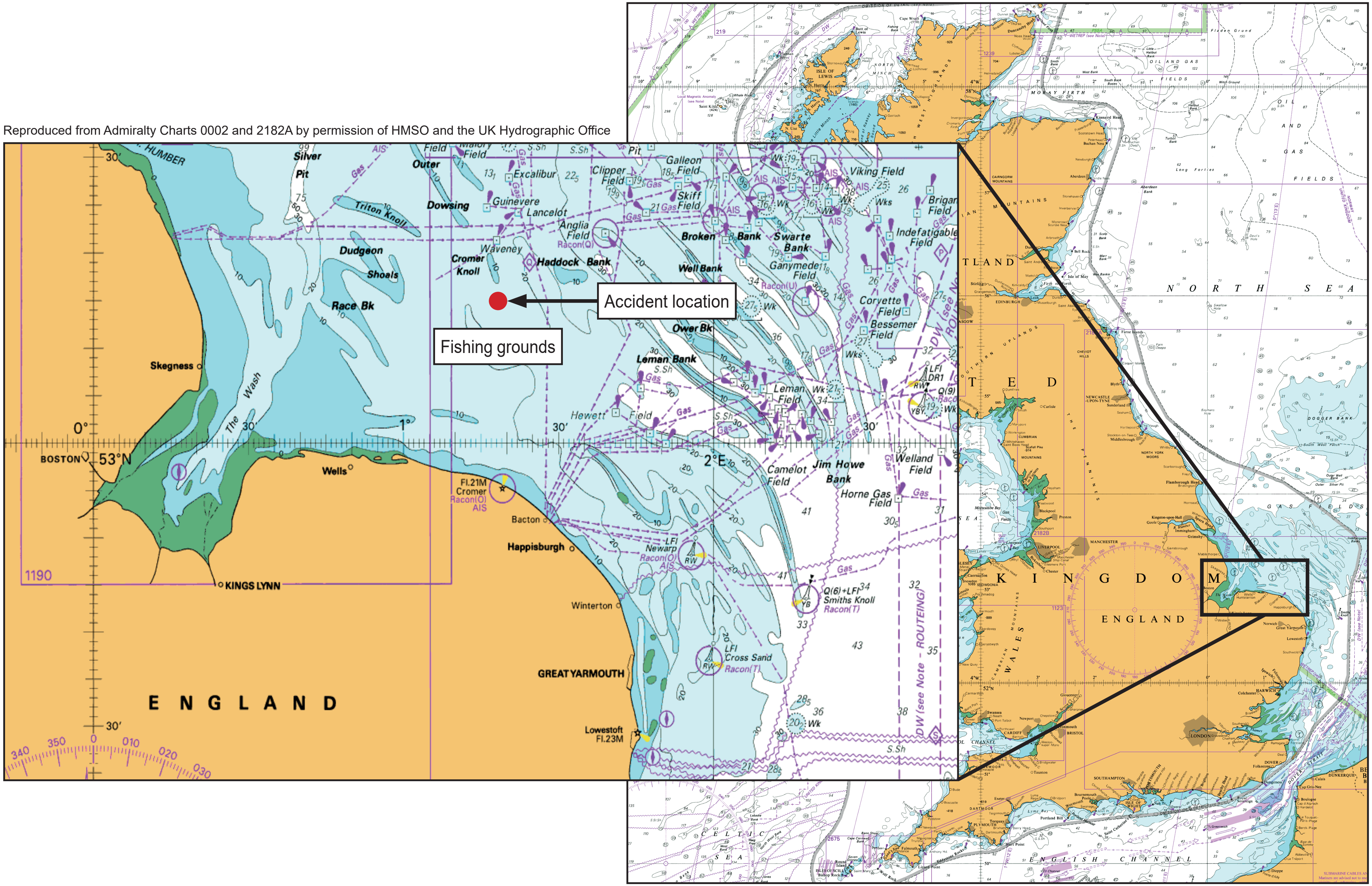



**Figure 1:** Charts showing the fishing grounds and accident location

Although the liferaft had been manually activated, all crew members were initially rescued by the offshore support vessel, *Esvagt Njord*, then transferred ashore to hospital by helicopter and lifeboat. The abandoned *Galwad-Y-Mor*, which had settled low in the water **(Figure 2)**, was towed to Grimsby by the tug, *GPS Avenger*, then lifted out of the water.


**Figure 2:** *Galwad-Y-Mor*, low in the water, after the abandonment

## VESSEL AND CREW

*Galwad-Y-Mor* was a 12.9m registered length, potting fishing vessel built in 2007. It was powered by a 268kW main engine driving a single, fixed-pitch propeller; deck machinery included a crane and hauler for handling pots.

There were seven crew on board, two UK nationals and five Latvians. All crew members suffered injuries, some life-changing, during the explosion.

## INVESTIGATION

MAIB inspectors attended *Galwad-Y-Mor* once it had been lifted ashore in Grimsby. A summary of the key areas of damage was:

- Extensive shell plating indentation between frames **(Figure 3)**
- Shell plating ruptures and shearing of a seawater suction
- Main engine displaced from bedplate
- Widespread and significant levels of destruction of the wheelhouse **(Figure 4)** and other internal compartments
- Buckling of internal bulkheads and warping of decks
- Widespread damage to upper deck fittings.

There was no evidence of an internal explosion.


**Figure 3:** Detail of shell plating damage showing coating loss and indentation between internal frames

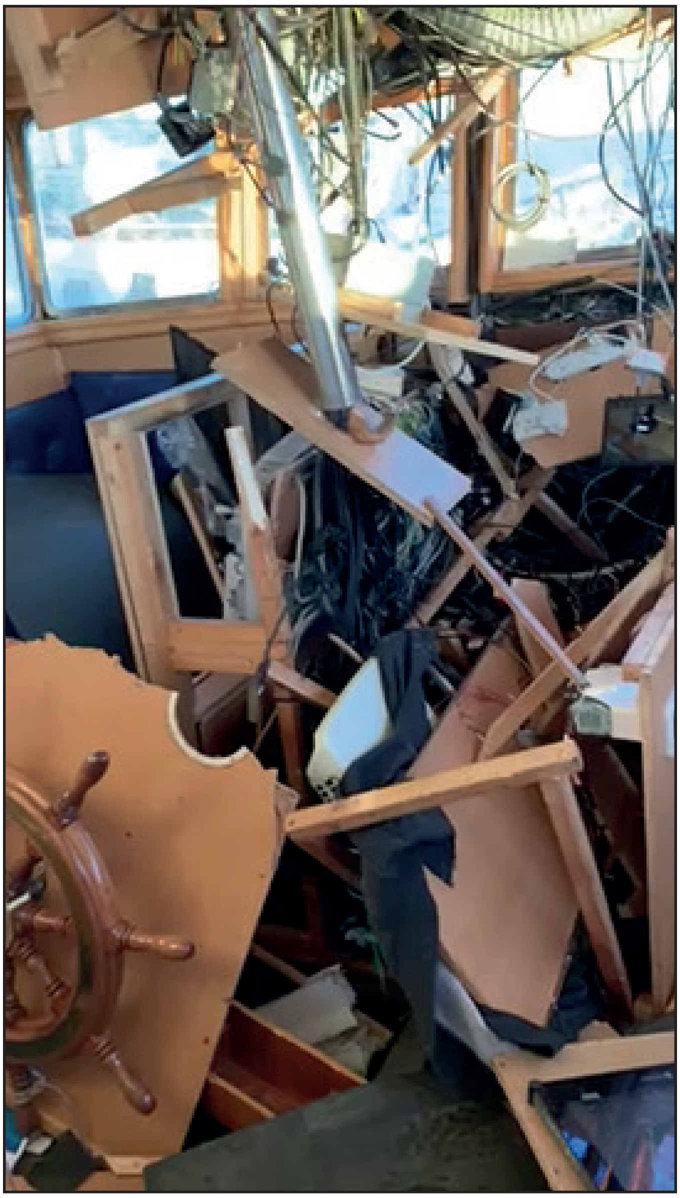


**Figure 4:** Wheelhouse destruction by shock damage

## PRELIMINARY ASSESSMENT

While recovering crab pots using its hauler, *Galwad-Y-Mor* was extensively damaged and serious injuries were inflicted on the crew by an explosion. The explosion was in the water and external to the vessel. There was nothing that the crew could have done to prevent the accident. The source of the explosion has not been determined, but it was possible that old munitions on the seabed were disturbed as the vessel hauled its pots. Although extensively damaged and flooded, it is almost certain that *Galwad-Y-Mor* stayed afloat because the bulkheads either side of the engine room maintained their watertight integrity, containing the flood.

## ONGOING ACTION

The MAIB has notified other relevant agencies including: the Maritime and Coastguard Agency, the Receiver of Wreck and the Ministry of Defence. The MAIB investigation is ongoing and a report of the accident will be published in due course.

| SHIP PARTICULARS | |
|---|---|
| Vessel's name | *Galwad-Y-Mor* |
| Flag | United Kingdom |
| Fishing numbers | BRD116 |
| Type | Potting fishing vessel |
| Registered owner | Galwad-Y-Mor Shellfish Limited |
| Construction | 2007 |
| Year of build | Steel |
| Length overall | 14.95m |
| Registered length | 12.90m |
| Authorised cargo | Shellfish |

| VOYAGE PARTICULARS | |
|---|---|
| Port of departure | Grimsby |
| Port of arrival | Grimsby |
| Type of voyage | Commercial |
| Cargo information | Shellfish |
| Manning | 7 |

| MARINE CASUALTY INFORMATION | |
|---|---|
| Date and time | 15 December 2020, 1120 UTC |
| Type of marine casualty or incident | External explosion (Serious Marine Casualty) |
| Location of incident | 53°18.53'N 001°13.25'E |
| Place on board | Hull and all compartments |
| Injuries/fatalities | Significant, including life-changing injures – full details not being disclosed with this report |
| Damage/environmental impact | Extensive damage to hull, including shell plating breaches, engine room flooded and severe shock damage in all internal compartments |
| Ship operation | Fishing, recovering crab pots |
| Voyage segment | In operation |
| External and internal environment | Wind, south-westerly force 3-4; sea state, slight/moderate; visibility good. |
| Persons on board | 7 |

# Annex D

## Ordnance Burial, Scour and Migration


www.6alpha.com
+44 (0) 2033 713 900
enquiry@6alpha.com

# 1 Ordnance Scour, Burial and Migration

## 1.1 Overview

Unexploded ordnance (UXO) is typically found washed up on the coastlines, typically during severe weather periods, that strongly suggests movement from their originally deployed position. Consequently, any item of UXO detected during the geophysical UXO survey will be subjected to similar forces and processes and may therefore migrate and change position over time. The following annex provides an overview of the forces and processes to be considered for the assessment of UXO migration, to inform the UXO consultant of the longevity of the UXO risk ALARP sign-off certificate, as well as the expansion size of the avoidance radii.

## 1.2 Physical Environment

### 1.2.1 Bathymetry

Both the local bathymetry and the seabed morphology have a significant influence on where munitions are likely to be situated, as well as their prospective mobility. For instance, ordnance located in shallower water depths will be exposed to higher wave generated forces than in deeper water depths. High seabed gradients will also promote migration downslope under the force of gravity.

Whilst it may take relatively little force for an item of UXO to roll or slide downslope into a topographic low, such as a depression or a channel, an increased amount of force will be required to transport the UXO item back upslope. It is widely accepted that any UXO items found in such areas will effectively become trapped and is highly unlikely to move any further.

### 1.2.2 Tidal Currents

The force generated at the seabed by the tidal current flow will determine the rate and direction of movement of mobile sediments and hence bedform features, but also any debris on the seabed including UXO items.

Tides may be semi-diurnal (generating two low and two high tides within a 24-hour period) or diurnal (generating one high and one low tide during a 24-hour period). Localised tidal variations vary by the alignment of the Sun and Moon, by the pattern of tides in the deep ocean, by the amphidromic systems of the oceans and by the shape of the coastline and near-shore bathymetry. Analysis of metocean data is necessary to fully understand the localised tides and currents which operate within a region to understand the potential for UXO migration.

Depending on the local region, a tidal system will generate either a stronger ebb or flood tide and, dependent on the tidal current vector (magnitude and direction), will influence the predominant direction and rate of movement of an item of UXO.

### 1.2.3 Wind Generated Surface Waves and Storm Events

Long periods of high wind speeds associated with storm events, which can generate large surface waves, have the highest potential to mobilise items of UXO on the seabed.

The frequency, direction and duration of these storm events is difficult to predict, and therefore there is no proven way to accurately predict the net rate of mobility of UXO on Site without direct observation. Nonetheless, if a 1:50 year storm was to take place on the site after a geophysical UXO survey had already been undertaken, then some form of confirmatory geophysical survey (and investigation) may be required to evidence that the potential UXO targets have not moved, or to scope the magnitude and direction of any such movement.

### 1.2.4 Seabed Sediments

The nature of the sediments on any site is important for understanding the prospective movement of UXO. The ability of sediments to allow for either full or partial burial of such objects, is key to understanding the potential for scour, burial and the future mobility of the UXO item.

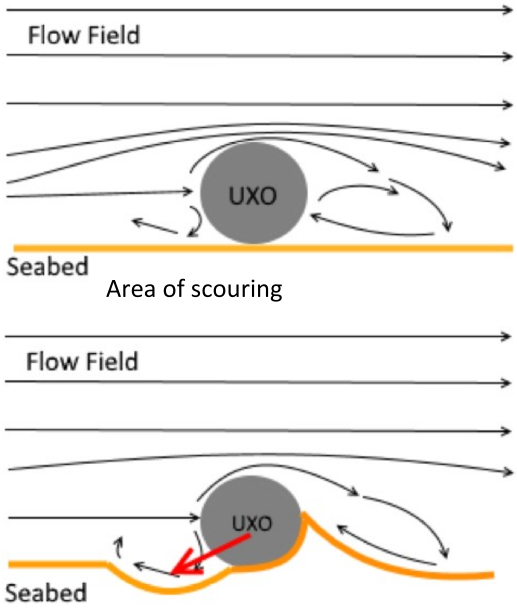
UXO can become buried, either by penetrating the seabed upon its initial deployment (subject to its residual energy upon impact with the seabed) or subsequently, over time, because of scour. UXO items that do become partially or fully buried are unlikely to migrate any further, due to requiring a significantly greater force to mobilise them from their partially buried position. If a UXO item is situated above the mean seabed level and covered by mobile bedforms, such as megaripples or sand waves, they may potentially become uncovered if the bedform position migrates over time.

UXO items are likely to be found on the surface of the seabed of consolidated cohesive sediments as well as bedrock. In comparison, UXO items located on granular soils or unconsolidated cohesive soils may be subjected to greater a potential of scouring and subsequent burial.

The disturbance of the water flow across the UXO item itself causes scouring. Vortices are generated in front of the UXO item, which in turn exerts a shear force at the seabed and mobilise the seabed sediments away from the UXO item. This process is periodic, accelerating with energetic wave and tidal current conditions, and will continue until the UXO item is of a similar roughness to the surrounding seabed. Eventually, the UXO item will be undermined by the scouring action and fall into its own scour pit as shown in Figure 1.

1. Vortices are produced in the front of the UXO scouring sediment away.

2. The UXO is eventually undermined by the scouring action and rolls/slides into the scour pit.




3. Scour – burial cycle begins again until vortices are too weak to transport the seabed sediments.

Figure 1: Vortex scouring and burial mechanism for UXO.

## 1.3 Human Factors - Fishing

Commercial fishing activities have the capability to inadvertently snag and move items of UXO, particularly in areas where dredging, beam and pair trawling is prevalent and nets are in contact with the seabed. These snagged UXO items may have been transported with the movements of the vessel's nets for considerable distances before they are returned to the seabed or recovered to the vessel.

Fishing boats which accidentally recover items of UXO have also been known to dispose of them/cut them free once they have been brought up to the surface, rather than inform the authorities (which involves considerable delay, but reduced risk).

## 1.4 Munitions Properties - Size, Shape and Density

The density, which is dependent on the mass and volume of the ordnance item, the cross-sectional area presented to the residual flow direction, and the hydrodynamic shape are primary factors considering an ordnance item's propensity to migrate.

In general, the denser and smaller an item of UXO is, the less likely it is to migrate. A large cross-sectional area will experience a higher hydrodynamic drag force than a smaller cross-sectional area, and a more streamlined body will experience a lower hydrodynamic drag force than a non-streamlined body.

Items of UXO, particularly high explosive bombs, are effectively hollow cases filled with an explosive fill. A large proportion of the bomb’s volume is therefore dedicated to this low-density explosive fill. In comparison, a heavy anti-aircraft artillery projectile is significantly smaller and lighter, but is also denser, with a larger proportion of the volume dedicated to the casing to maximise the fragmentation effect. The projectile will also have a much smaller area exposed to the water flow. Given these circumstances, it is likely that the heavy anti-aircraft projectile will have a lower propensity to migrate than the high explosive bomb.

# Annex E

## Semi-Quantitative Risk Assessment Methodology

# Contents

# 1 Semi-Quantitative Risk Assessment

## 1.1 Overview

*6 Alpha Associates* use a Semi-Quantitative Risk Assessment (SQRA) approach to assess the prospective unexploded ordnance (UXO) risk for each of the project's intrusive investigation, installation and/or construction operations that interacts with the seabed. The SQRA process relies upon *6 Alpha's* risk matrix, which is used to provide guidance on the required risk mitigation measures to be implemented, in order to manage the UXO risk to As Low As Reasonably Practicable (ALARP).

The following sections transparently outline *6 Alpha's* SQRA methodology. The risk assessment tables for each of the project's investigation, installation and/or construction operations are presented separately within the report appendices.

## 1.2 Risk Matrix

For the purposes of this report, **Risk** (**R**) is calculated as a function of **Probability** (**P**) of encounter and initiation of UXO and **Consequence** (**C**) of initiation:

**R = P x C**.

For each investigation, installation and/or construction activity that interacts with the seabed, the probability and consequence of the identified UXO threats has been assessed on a scale of 1 to 5. (Where 1 = Very Low, & 5 = Very High). These ratings are multiplied together (with a maximum of twenty-five) in order to determine a risk rating based on *6 Alpha's* UXO risk matrix. Not only does this allow relative weighting and comparison of UXO risk across the project's seabed intrusive operations, but it also ensures that *6 Alpha* assesses UXO risk in a way that is consistent across projects which is a key responsibility of a UXO consultant. 6 Alpha's risk matrix is shown below in Table 1.

| Likelihood | Probability of Encounter and Initiation | Consequences – Consequence of Initiation | | | | | |
|---|---|---|---|---|---|---|---|
| | | | **1** Negligible | **2** Minor | **3** Moderate | **4** Major | **5** Severe |
| | | **5** Highly Likely | 5 Low | 10 Medium | 15 High | 20 High | 25 Very High |
| | | **4** Likely | 4 Low | 8 Medium | 12 High | 16 High | 20 High |
| | | **3** Possible | 3 Low | 6 Medium | 9 Medium | 12 High | 15 High |
| | | **2** Unlikely | 2 Low | 4 Low | 6 Medium | 8 Medium | 10 Medium |
| | | **1** Highly Unlikely | 1 Very Low | 2 Low | 3 Low | 4 Low | 5 Low |

**Table 1: *6 Alpha Associates*' UXO Risk Matrix**

The numerical values assigned to the UXO risk are compared to Table 2, which shows *6 Alpha's* risk grading and describes the recommended best practice strategic risk mitigation measures required in order to satisfactorily manage the UXO risk to ALARP.

Whilst this risk matrix is aligned with *6 Alpha's* standards in providing a UXO risk mitigation strategy, we also recognise that other UXO risk management consultancies may differ in their own assessment of the UXO risk and their recommended UXO risk mitigation measures.

| Risk Rating (P x C) | Grading | Risk Tolerance | Action Required to Achieve UXO Risks ALARP |
|---|---|---|---|
| 1 | Very Low Risk | Tolerable | The risk is at, or below the *de minimis* level with no further action required to reduce the UXO risk to ALARP. Operations may proceed without proactive UXO risk mitigation measures in place. Nonetheless, reactive mitigation measures might be recommended in order to mitigate residual UXO risks and to align with industry best practice. Risks will be reviewed periodically to ensure risk mitigation controls remain effective. |
| 2-5 | Low Risk | | |
| 6-10 | Medium Risk | Potentially Tolerable | The UXO risk may be tolerable depending on the specific nature of the UXO risk and the potential consequences of a UXO initiation and the project stakeholder's risk tolerance. Where vessel crews and/or other personnel may be exposed to harm, then the UXO risk is intolerable. |
| 12-20 | High Risk | Intolerable | Operations may not proceed without proactive risk mitigation measures being implemented prior to intrusive investigation, installation and/or construction works. Reactive risk mitigation measures must also be implemented. |
| 25 | Very High Risk | | |

**Table 2: *6 Alpha Associates*' Project Risk Tolerability**

## 1.3 Calculating the Project's Probability of Encounter and Initation

At the strategic level, and for risk assessment purposes, *6 Alpha Associates* applies the precautionary principle to all prospective UXO encounters within a Study Site. For example, the probability of initiating an item of UXO upon an encounter is considered certain, whereas in practice factors such as the kinetic energy transfer and UXO sensitivity will impact whether direct or indirect contact with UXO will cause an initiation event. Therefore, the probability of encountering and initiating UXO is primarily influenced by the likely level of UXO contamination within the Study Site, but also subsequently through the application of a methodology modifier (the value of which is determined by the spatial extent of the soil intrusion). Further details of *6 Alpha's* guidance on the scoring of the probability of UXO contamination can be found in Table 3 below.

| Probability of UXO Contamination | Likelihood Score | Description<br>(Based on a 5km Assessment Distance) |
|---|---|---|
| **Highly Unlikely** | 1 | There is no indication of historical or modern ordnance activity or discovered ordnance **within 5km of the Study Site.**<br>Potential ordnance discoveries are, therefore, likely to be from unquantifiable sources and/or from subsequent UXO migration. |
| **Unlikely** | 2 | There is evidence of historical or modern ordnance activity or discovered ordnance **within 2km to 5km** (or 4km to 10km for an ordnance dump) of the Study Site's boundary. |
| **Possible** | 3 | There is evidence of historical or modern ordnance activity **within 1km to 2km** (or 2km to 4km for an ordnance dump) of the Study Site's boundary. |
| **Likely** | 4 | There is evidence of historical or modern ordnance activity or discovered ordnance **either on-site or within 1km of it**. If the prospective UXO threat source intersects the Study Site, then the precise nature of the threat source and/or the proximity and concentration of any previous UXO encounters may influence whether the assessment concludes a "Likely" or "Highly Likely" probability of contamination. |
| **Highly Likely** | 5 | There is significant evidence of historical or modern ordnance activity, **within the Study Site** that is corroborated with evidence that **UXO has been encountered previously** either on-site or in the immediate vicinity. |

**Table 3: *6 Alpha Associates'* Probability of UXO Contamination Assessment Criteria**

The categorisation of UXO threats may not always be straightforward, and multiple additional factors might also be considered that result in a potential threat source being classified as a higher or lower threat than indicated by Table 3. For example, WWI-era ordnance is rarely encountered in the marine environment in the 21st Century and therefore, the likelihood of encountering such ordnance may be reduced.

Additionally, the categorisation of potential threat sources such as Anti-Aircraft Artillery projectiles (or similar) might also be influenced by the total number of artillery batteries in any given area that possess a firing arc template that encompasses a Study Site and/or the likelihood that they were fired for training or operational purposes (amongst other things).

In order to calculate the overall probability of encounter, the probability of UXO contamination at the Site is modified based upon the likely spatial extent of the seabed disturbance, caused by the proposed investigation, installation or construction activity. This provides the final calculation for the probability of encounter and initiation, which is used for the risk assessment.

## 1.4 Calculating the Projects Consequences

The risk assessment performed by *6 Alpha* assesses the risk of an unplanned initiation of UXO to the relevant sensitive receptors (e.g. human life, the vessel(s) and/or underwater equipment), resulting from explosive shockwave and/or fragmentation effects.

This is achieved by calculating the resulting peak pressure for an equivalent mass of trinitrotoluene (TNT) representative of the likely UXO threat items within the Site, as well as estimating the distances separating the source (UXO) and the sensitive receptors.

The following formula is applied to calculate peak pressure in megapascals (MPa), of the resultant shockwave (Reid, 1996):

$$Peak\ Pressure\ (MPa) = 52.4.\left(\frac{M^{\frac{1}{3}}}{R}\right)^{1.18}$$

For SQRA calculations, R is the separation distance in metres between the source and the receptor and M is the mass of TNT explosive equivalent in kilograms.

The resulting peak pressure calculated is compared to Table 5, which provides the final consequence calculation for entry into the risk matrix (Szturomski, 2015).

| Peak Pressure (MPa) | Consequence Rating | Consequence Score | Description |
|---|---|---|---|
| 0 – 2 | **Negligible** | 1 | Damage to the vessel is likely to be negligible and vessel crews are highly unlikely to be hurt. Damage to underwater equipment will be influenced by the robustness of such equipment and its internal mechanisms. |
| 2– 4 | **Minor** | 2 | There may be minor damage to brittle materials and to the sensitive electronics. The vessel crews are unlikely to be injured. Damage to underwater equipment will be influenced by the robustness of such equipment and its internal mechanisms. |
| 4 – 6 | **Moderate** | 3 | More significant damage to vessel is likely and may impact vessel steering and control and light injuries might be sustained by the crew. There is also the prospect of light damage to underwater equipment. |
| 6 – 8 | **Major** | 4 | Serious damage to the vessels electronics, generators and control systems is likely and serious injuries and/or fatalities amongst the vessel crew are possible. Serious damage to underwater equipment is also likely. |
| More than 8 | **Severe** | 5 | Catastrophic structural vessel damage is likely and it is also likely that there will be multiple injuries and fatalities to personnel aboard. Catastrophic damage to underwater equipment is likely. |

**Table 5: Consequence Rating of an unplanned UXO initiation based on shockwave peak pressure.**

## 1.5 References


1) Reid, W.D., 1996, The response of surface ships to underwater explosions.

2) Szturomski, B., 2015, The effect of an underwater explosion on a ship. Scientific Journal of Polish Naval Academy.

# Annex F

## Explosives and Detonation Effects

# Contents

# 1 Explosives and Detonation Effects

## 1.1 Introduction

Explosives can be categorised into two broad categories, namely: those designed to be detonating (or high explosives) and those designed to be deflagrating (or low explosives). In the case of unexploded ordnance (UXO) risk management in the marine environment, the primary concern is associated with ordnance comprising high explosive content.

Due to the infrequency of UXO initiation events that cause harm, it is a commonly held notion that World War One and Two (WWI and WWII) ordnance devices may have deteriorated and no longer function as designed, presenting a false sense of tolerable risk to project stakeholders. The precautionary principle of risk management prevents this misplaced assumption from being carried throughout the risk assessment and project life cycle. Ordnance must, for the purposes of risk management, be assumed to be fully functional until determined safe by an explosive ordnance disposal (EOD) operative.

This annex describes the classification of explosives, the generic design of the explosives train and the effects of a detonation in the marine environment.

## 1.2 Classification of Explosives

### 1.2.1 Detonating or High Explosives

Detonating or High Explosive (HE) compounds are characterised by their very rapid decomposition and development of a high-pressure shock wave. These explosives detonate at velocities ranging from 1,000m/s to 9,000m/s and may be subdivided into two explosives classes, differentiated by their respective sensitivity or ease with which an explosive may be ignited or initiated:

- **Primary Explosives** – are extremely sensitive to impact, friction, sparks, flames or other methods of generating heat to which they will respond by burning rapidly or detonating. Examples include mercury fulminate and lead azide. This high sensitivity to initiation makes them unsuitable to use as a base explosive (i.e. main-fill explosive in military ordnance).
- **Secondary Explosives** – are relatively insensitive to impact, friction, sparks, flame or other methods of producing heat. They may burn when exposed to heat in small-unconfined quantities, although the risk of initiation is always present especially when they are confined and/or burnt in bulk. Dynamite, trinitrotoluene (TNT), RDX and HMX are classed as secondary high explosives, which are commonly used as base explosives in military ordnance.

Pentaerythritol tetranitrate (PETN) is the benchmark compound for comparative purposes, with those explosives that are more sensitive to initiation than PETN classified as primary explosives.

### 1.2.2 Deflagrating or Low Explosives

A low explosive is usually a mixture of a combustible substance and an oxidant that decomposes rapidly, a process known as deflagration which produces a relatively low pressure, shock wave. Under normal conditions, low explosives undergo deflagration at rates that vary from a few centimetres per second to approximately 400m/s, yet when concentrated and confined may be caused to detonate and produce a relatively high-pressure shock wave.

Deflagration processes of low explosives are easier to control than the detonations of high explosive, that they are typically used as ballistic propellants for rockets, artillery projectiles and bullets. Typical ballistic propellants include the family of smokeless propellants known as cordite which was used extensively during WWII.

## 1.3 Generic Design of Ordnance

In general, explosive ordnance items, such as bombs or sea mines tend to have the following basic components:

- **Case** – the casing or body of the ordnance item is typically manufactured from a ferrous metal such as steel. The *German* Luftmine A and B (LMA and LMB respectively) parachute mines used during WWII, were however manufactured from aluminium. The case shatters during detonation of the high explosive fill, fragmenting at high velocity to increase the potential damage and harm.
- **Main Charge** – the main charge makes up most of the explosive mass of the ordnance item comprising a high explosive fill with a relatively low sensitivity to initiation.
- **Booster** – a secondary high explosive booster charge is used to ignite the main charge component and comprises a more sensitive, albeit smaller quantity of high explosive.
- **Fuze** – a small quantity, high explosive charge is usually incorporated into the device which is sensitive to initiation. The fuze acts as the primary explosive which is used to ignite the booster. The fuze is relatively small when compared to the booster and housed with a fuze pocket within the casing of the ordnance item, located immediately adjacent to the booster charge.

- **Trigger** – a mechanical, electrical, or chemical mechanism is used to initiate the fuze at the appropriate time, such as upon impact, hydrostatic depth, magnetic field distortion or time. The trigger is the most sensitive component to the firing train and the primary method of ignition, that if interfered with may cause an inadvertent detonation.

An explosive chain reaction is therefore started when the sufficient energy (kinetic, electrical, or chemical) is generated to initiate the explosive content of the fuze, which in turn detonates the booster and finally the main charge. These components form the explosive train of the ordnance device.

## 1.4 Underwater High Explosive Detonations

An explosion underwater differs from that within air due to the formation of a gas bubble within the water in addition to the fragmentation and shockwave effects. Upon detonation, the ordnance case will fragment and cause damage to proximal receptors such as underwater equipment, with the main hazard to the surface vessel, personnel aboard, and underwater equipment being from the resulting gas bubble and shockwave.

An underwater explosion results in the change of solid matter (the main charge) into a gas of high temperature and pressure (the gas bubble) as well as a spherical shockwave. The pressure acting outwards from the gas bubble is opposed by the hydrostatic pressure of the surrounding water, which causes an oscillating effect of expansion and contraction as the gas bubble moves towards the water surface.

Each expansion of the gas bubble causes a shockwave that is propagated outwards throughout the water in all directions. Although these shockwaves gradually become weaker as the gas bubble rises through the water column, it may close with nearby receptors such as surface vessels, situated offset or directly above the gas bubble causing damage. When the gas bubble reaches the surface, a columnar plume is formed from the sudden release of the gas into the atmosphere as well as carrying water. Should a vessel be directly in the path of the gas bubble as it contracts, the vessel may be subjected to bubble jetting loads; a high-energy jet of water capable of rupturing the vessel's hull.

The shockwave from an underwater explosion propagates radially outwards from the source location. Possessing an initial high velocity, the shock wave decelerates over distance from the source location, eventually decreasing to the underwater speed of sound. As the distance from the source location increases, the peak pressure of the shockwave decreases reducing the damage potential of the shockwave.

A surface vessel must therefore be kept a safe distance away from a source of an explosion so that resultant shockwave causes no damage.

If a nearby surface vessel is struck by the shockwave, the vessel can experience significant vibrations resulting in the damage to underwater hull mounted equipment and the dislodgment of loose objects, machinery, and power cables on board the vessel. Both the initial vibrations and secondary effects resulting from the vessel damage, have the capacity to cause disabling injuries to personnel aboard, from being struck by loose objects, trips and falls, and joint damage (ankles, knees, hips, spine, and neck) from a sudden acceleration.

A second damage mechanism may arise from the whipping effect. The whipping effect occurs when the frequency of the expansion and contraction of the gas bubble matches the vessels natural oscillating frequency. The vessel's hull will be driven to vibrate at its natural resonating frequency, vibrating at a greater amplitude than that of the initial pressure wave from the expanding gas bubble.

A badly affected ship usually sinks quickly due to cracking and deformation of the hull, resulting in flooding across the length of the ship and eventual sinking.

Divers, as well as marine mammals, are especially vulnerable to underwater shockwave effects and can be seriously injured or killed by the detonation of relatively small, high explosive charges.

# Annex G

UXO Detection Methods

# Contents

# 1 UXO Detection Methods

## 1.1 Overview

There are several systems and underwater tools available on the commercial market for detecting unexploded ordnance (UXO). Generally, UXO detection methods rely on either one or more of the following ordnance properties: the known physical dimensions of the threat items likely to be encountered upon the site, whether the ordnance casing is metallic, and/or whether the ordnance casing comprises a ferrous metal for most ordnance types. The other property that an item of UXO has which classifies it from benign debris, is the explosive content. However, marine explosive detectors are still at the experimental stage and currently not widely utilised.

UXO detection is accomplished by utilising one or more of the following methods:

- Visual detection methods;
- Magnetic methods;
- Electromagnetic methods;
- Acoustic methods.

## 1.2 Visual Detection

A visual inspection typically employs a remotely operated vehicle (ROX) or diver, to inspect the seabed at the site of the intrusive investigation, installation or construction operation and detect any UXO present. The classification of any potential UXO targets found is performed simultaneously during the visual inspection. An ROV or diver is typically equipped with a pulse induction metal detector, to detect any shallow buried potential UXO targets, or to search for and relocate any marked potential UXO targets. The costs of performing a visual inspection across an extensive area of the seabed makes visual detection of UXO a more appropriate method for small specific locations.

## 1.3 Magnetic Methods

Magnetic methods for UXO detection, relies on the ferrous metal content of the UXO item producing a local magnetic distortion/anomaly of the Earth's magnetic field. This magnetic distortion will occur even when the ferrous source is buried under the seabed. Magnetometer sensors are typically employed to provide a scalar or vector measurement of the Earth's magnetic field. A suitably qualified interpreter may then record the positions of these anomalies for further target classification.

Magnetometers for UXO detection are generally regarded as the main detection methods for UXO and allow flexibility in the towing arrangement for rapid geophysical acquisition of extensive survey areas. Diurnal fluctuations of the Earth's magnetic field may be eliminated by towing two or more magnetometers in a gradiometer arrangement. As a gradiometer, the magnetometers measure the rate of change of the magnetic field distortion in one or more axial planes and have the benefit over a conventional single magnetometer of an improved signal to noise ratio, permitting the detection of smaller ferrous sources. Geology with a high susceptibility to magnetisation, will act as a source of magnetic noise potentially masking potential UXO targets from detection. Ordnance casing made from non-ferrous metals, such as aluminium, are undetectable by magnetometers as are any other non-ferrous debris occurring upon the site.

## 1.4 Electromagnetic Methods

UXO detection using electromagnetic methods classifies UXO targets by their electrical conductivity and will detect both ferrous and non-ferrous metallic targets. Pulse induction is an electromagnetic method, commonly employed for the detection of UXO, although the system is generally mounted upon an ROV during relocation of potential UXO targets.

Pulse induction works by generating a pulse of electrical current, within a few microseconds through a coil of wire. Each pulse produces a brief magnetic field which collapses with the stoppage of the current resulting in a large voltage spike across the coil and a second current or reflected pulse flowing through the coil. If there is a conductor present, the pulsing magnetic field induces eddy currents. These eddy currents produce a second magnetic field which propagates back to the detector inducing a small voltage within the coil. The eddy currents generated by a conductor are scaled with the item's inherent conductivity, which is dependent on the item's material, thickness, and length.

If a target is purely magnetic and non-conductive (e.g. a boulder), no eddy current would be generated and nothing would be detected on the sensor. One of the advantages of electromagnetic methods over magnetic methods is that geology is not detected, removing a potential source of false positive potential UXO targets to be investigated.

However, the range of detection is inferior to that of magnetic methods with EM methods possessing a faster signal falloff rate proportional to $1/r^6$ compared to a total magnetic field falloff rate of $1/r^3$ (r being the separation distance between the detector and the target). Boat towed metal detectors are commercially available; however, they are required to be flown very close to the seabed which may prove difficult. For increased control, pulse induction detectors are generally mounted on an ROV, making this method suitable for potential UXO target relocation, and to limited survey areas where there is a threat of non-ferrous UXO.

## 1.5 Acoustic Methods

Acoustic methods for UXO detection rely on the distinguishable contrasts in reflected acoustic energy between a UXO item and the surrounding seabed.

Sound navigation and ranging (sonar) is a method of using acoustic energy to determine distance and direction. Single and multi-beam echo sounders (MBES) use this method to determine distance to the seabed. Side scan sonars (SSS) are used to insonify and produce an image of the seafloor. SSS is generally used during geophysical surveys for the locating of boulders and debris, as well as mapping the boundaries of sediment types and bedforms. Classification of potential UXO targets from non-UXO targets is typically based on matching the SSS contacts' dimensions to the physical dimensions of possible UXO threat items.

Although SSS is used to detect potential UXO (pUXO) items on the seabed, sonar methods are unable to detect fully buried targets. Instead, seismic reflection methods are used, specifically 3D chirp and other high-resolution seismic systems, which rely on variations of density and therefore acoustic impedance, to detect buried contacts.

Acoustic methods of UXO detection are susceptible to error during the classification of contacts, particularly when using SSS and/or MBES. Partial burial of the UXO within the seabed may reduce the dimensions of targets (length and width), resulting in pUXO targets being incorrectly graded as benign debris. Further errors may also be introduced via human error during the measuring process of the contacts' dimensions, leading to false classifications of targets.

For UXO detection, acoustic methods are ideally combined with either magnetic or electromagnetic methods to provide a further method of target classification. Without a second method to classify between targets, the client may be overwhelmed by the sheer number of SSS contacts that have dimensions like that of UXO, which are subsequently graded by the UXO consultant as pUXO targets and would require either avoiding or further target investigation.