UXO DESK STUDY

OFFSHORE WIND FARM BORNHOLM II EAST

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NjordIC B.V.

Mr. J. Bakker
UXO consultant & EOD manager

Image front page: Location of the Bornholm East Offshore Wind Farms and its respective export cable route (source: Energinet).

ABBREVIATIONS

Abbreviation	Definition
A Mk	Designation for aircraft-launched mines
AAA	Anti Aircraft Artillery
AC	Accelerations
ALARP	As Low As Reasonably Practicable
AP	Armour Piercing
Ar	Arado Flugzeugwerke was a German aircraft manufacturer
BaMa	Bundesarchiv-Militärarchiv in Freiburg, Germany
BHD	BackHoe Dredger
BV	Blohm & Voss, a German military factory holding an aircraft division
cm	Centimetre
CPT	Cone Penetration Test
CSD	Cutter Suction Dredger
DF	Deformation
DP	Dynamic Positioning
EEZ	Exclusive Economic Zone
EM	Electromagnetic
EMA	Einheitsmine A, a German moored contact mine
EMC	Einheitsmine C, a German moored contact mine
EOD	Explosive Ordnance Disposal
FLAK	Flugabwehrkanone, German Anti Aircraft Artillery
FLUWA	Flug-Melde-Organisation, German listening posts
FLWS	Fliegerwaffenschule
GBPP	Gas bubble Proximity Parameter
GIS	Geografic Information System
GP	General Purpose
GRT	Gross Register Tonnage
HC	High Capacity
He	Heinkel Flugzeugwerke, a German aircraft manufacturing company
HE	High Explosive
HELCOM	Helsinki Commission, an intergovernmental organization bridging policy and science on matters related to the environment of the Baltic Sea
HS	Significant wave height
HSE	Health, Safety and Environment
IAC	Inter-Array Cable
IWM	Imperial War Museum in London, United Kingdom
Ju	Junkers Flugzeug- und Motorenwerke AG more commonly Junkers, a major German aircraft and aircraft engine manufacturer
KG	Kampfgruppe, battle group of the German Luftwaffe during World War II
kJ	Kilo joule
km	Kilometre
kV	Kilo Volt
lb	Pound, unit of avoirdupois weight, equal to 0.454 kg
LtCdr	Lieutenant commander

Abbreviation	Definition
m	Metre
m/s^{-1}	Metres per second
m/s^2	Metres per square second
MAG	Magnetometer
MBES	Multi Beam Echo Sounder
MC	Medium Capacity
MCM	Mine Counter Measure
MI	Mechanical Impact
Mk	Mark
mm	Millimetre
MO	Movement
MW	Megawatt
NARA	National Archives and Records Administration in Maryland, USA
NATO	North Atlantic Treaty Organization
NEQ	Net Explosive Quantity
nm	Nautical Mile
OSP	Offshore Substation Platforms
OSPAR	OSlo and PARis Convention, OSPAR is the mechanism by which 15 Governments and the EU cooperate to protect the marine environment of the North-East
OWF	Offshore Wind Farm
PLGR	Pre-Lay Grapnel Run
pUXO	Potential UXO
UXO	UneXploded Ordnance
RAF	Royal Air Force
ROTV	Remotely Operated Towed Vehicle
ROV	Remotely Operated Vehicle
RPL	Route Position List
s	Second
SAGr	Seeaufklärungsgruppe, Maritime Reconnaissance Group
SAP	Semi Armour Piercing
SBP	Sub Bottom Profiler
Sgt	Sergeant
SKC	SC = Schiffkanone (naval gun), C = Konstruktionsjahr (year of construction)
SIT	Surrogate Items Trial
Sqn	Squadron
SQRA	Semi-Quantitative Risk Assessment
SSS	Side Scan Sonar
S/Sgt	Staff sergeant
TNA UK	The National Archives at Kew, London, United Kingdom
TNO	The Netherlands Organisation for applied scientific research. TNO was founded by law in 1932 to enable business and government to apply knowledge. As an organisation regulated by public law, TNO is independent.
TNT	2,4,6-trinitrotolueen
TROV	Tracked Remotely Operated Vehicle
TSHD	Trailing Suction Hopper Dredger
T/Sgt	Technical sergeant

Abbreviation	Definition
UK	United Kingdom
US	United States of America
USAAF	United States Army Air Forces
U-boat	Unterseeboot, a German submarine
V-1	Vergeltungswaffen 1, a pulsejet-powered cruise missile designed for strategic bombing during World War II
V-2	Vergeltungswaffen 2, the world's first long-range guided ballistic missile designed for strategic bombing during World War II
W	TNT equivalent explosive weight
WROV	Working class Remotely Operated Vehicle
WTG	Wind Turbine Generator
WWI	World War One
WWII	World War Two

SUMMARY

Following a decision in the Danish Parliament June 2020 Denmark is on the path to establish offshore energy infrastructure in the Danish North Sea and in the Danish Baltic Sea to connect offshore wind energy to the Danish mainland and to neighbouring countries via offshore energy hubs.

In the Baltic Sea, the offshore part of the project includes the following main components:

- 2 offshore wind farms (Bornholm I West and II East),
- Subsea cables from the energy island (Bornholm) to the offshore wind farms.

NjordIC was commissioned for the preparational Unexploded Ordnance (UXO) consultancy services for the Energy Island in the Baltic Sea. The contracted services comprise of a UXO threat assessment, a UXO risk assessment and a UXO risk mitigation strategy. This resulted in revision 3.0 of this report.

After delivery of revision 3.0 if this report, Energinet commissioned a geophysical and geotechnical campaign. In this revision, the results of these campaigns are incorporated into chapter 3.

OBJECTIVES

The main objectives of this study are:

1. Quantify of the UXO risks that may occur during the installation of the Bornholm II East OWF and the export cable.
2. Perform a UXO risk assessment to determine the tolerability of the UXO related risks.
3. Provide recommendations on the ALARP requirements ultimately resulting in a UXO risk management strategy for the Bornholm II East OWF and the export cable route.

UXO THREAT ASSESSMENT

A UXO threat assessment was performed to provide an assessed and reasoned answer to the question: "Is there a realistic chance of encountering UXO from WWI/WWII in the area of investigation, during the installation of the Bornholm II East OWF and its export cables?

In context of the research question above, several sources have been consulted. The consultation of historical sources showed that there are several war related activities relevant to the area of investigation. Also, post war military activities may have contributed to the UXO contamination in the area. The information gathered and assessed provides a reliable indication of the types of UXO that may be left behind and the qualitative likelihood.

To indicate the likelihood of presence of UXO the classification indicated in Table S-1 is used.

Presence term	Meaning
Highly unlikely	No evidence pointing to the presence of this type of UXO within an area but it cannot be discounted completely.
Unlikely	Some evidence of this type of UXO in the wider region but it would be unusual for it to be present within the area of investigation.
Possible	Evidence suggests that this type of UXO could be present within the area of investigation.
Likely	Strong evidence [1] that this type of UXO is likely to be present within the area of investigation.

[1] Strong evidence means there are several reliable and verifiable indications from primary sources indicating the likely presence of UXO in the area of investigation.

Presence term	Meaning
Highly likely	Indisputable evidence [2] that this type of UXO is present within the area of investigation.

Table S-1: Definitions of terminology used for the likely presence of UXO.

In Table S-2 the likelihood of presence of remnants of war is presented for all war related and post war military activities. For all UXO with a likelihood of presence ranging from possible to highly likely a UXO risk area is demarcated (see paragraph 2.3).

Event	UXO type	Type	Likelihood of presence
Minelaying by aircraft	Ground mines	A Mk I-IV and A Mk VI	Likely
Minelaying by submarines	Ground and buoyant mines	Unknown	Highly unlikely
Airplane crashes	Air dropped bombs	All common types of UK and US HE and incendiary bombs	Possible
V-1 crashes	Rocket	V-1	Unlikely
Aerial attacks on Rønne	Air dropped bombs	Unknown	Highly unlikely
Dumping of chemical warfare materials	Chemical warfare materials	Solidified sulphur mustard	Unlikely
Military training areas	Artillery shells	7.5cm, 8.8cm, 10.5cm, and 15cm	Unlikely

Table S-2: Definitions of terminology used for the likely presence of UXO.

UXO RISK ASSESSMENT

In assessing the overall UXO risks for the project a Semi-Quantitative Risk Assessment (SQRA) process was applied. The applied risk management matrix divides risks into three bands, LOW, MEDIUM, and HIGH. Regarding the assessment of UXO related risks, the 'As Low As Reasonably Practicable' (ALARP) principle is applied. This means mitigation measures are required to reduce the risks to 'As Low As Reasonably Practicable' (ALARP).

The concept of "reasonably practicable" involves weighing a risk against the trouble, time and money needed to control it. Thus, ALARP describes the level to which we expect to see workplace risks controlled.

The ALARP principle relates to risk management matrix as follows.

LOW	: Adequate mitigation measures in place. Acceptable risks, no further action required.
MEDIUM	: Further assessment for additional controls may be required to reduce the risk.
HIGH	: Further assessment is required to identify additional controls and reduce the risk (ALARP).

Table S-3: Criteria for determining risk tolerability.

For all assumed installation operations, the so-called naked risks regarding UXO are assessed. The naked risk is the risk without any form of risk mitigation. For the assessment of the risks the site-specific information, the planned operations (chapter 4) and their accompanying factors of influence on UXO (chapter 5) and detonation/exposure effects (chapter 6) were considered.

[2] In case of indisputable evidence these UXO are encountered in the area of investigation in the past.

The main driver for the risk assessment results is the severity/consequence of a detonation, and in particular the gas bubble effect. The likelihood of initiation is assessed to be rare to possible, depending on the installation activity and type of UXO.

The risk assessment shows that intolerable (HIGH and MEDIUM) risks may occur during the installation of the Bornholm II East OWF and export cables. This means mitigation measures should be considered.

RECOMMENDED MITIGATION MEASURES

To mitigate the risks identified, proactive and reactive mitigation measures are recommended.

Proactive mitigation measures.

It is recommended to perform a UXO geophysical survey of the CPT, vibrocore, and borehole locations, and all locations/areas where installation activities will be executed (WTG and OSP foundation locations, and the export cable corridor). The recommended areas to be subjected to this survey comprise of:

1. A magnetometer line for all shallow seabed investigations for cable route reconnaissance to ensure avoidance of anomalies on the survey line. [3]
2. A 'box' measuring approximately 30m x 30m centred on all CPT, vibrocore, and borehole locations for deep seabed investigations. [4]
3. all IAC and export cable corridors with a width of 60m (30m either side of the cable), and
4. a circular area with a radius of 250m surrounding each foundation location.

It is recommended to survey the abovementioned area by means of a ROTV magnetometer (MAG) array using a system with a fixed offset of sensors in a gradiometer array.

<u>Threshold</u>

With regards to the survey threshold, it is recommended to divide the area of investigations in two zones:

1. Areas with water depths < 25m
   In water shallower than 25m, it is recommended to apply a threshold of 50kg ferrous mass for the design and execution of the UXO geophysical survey. For the evaluation of acoustic survey data, a size threshold is recommended of 0.25 x 0.60 (shape: cylindrical).
2. Areas with water depths > 25m
   In water deeper than 25m, it is recommended to apply a threshold of 100kg ferrous mass for the design and execution of the UXO geophysical survey. For the evaluation of acoustic survey data, a size threshold is recommended of 0.35 x 1.10 (shape: cylindrical).

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[3] The maximum sensor altitude of the magnetometer above the seabed is to be determined on the ferrous mass threshold applicable to the area, depended on the water depth.

[4] The recommended box size considers DPII operations and deployment of a seabed frame, in case of jack-up operations the size of the box is to be determined based on the footprint of the intrusions. The size of the boxes should consider sufficient space to avoid any pUXO targets.

Required detection range

Considering the assessed UXO burial depths, the required survey detection range for the export cable route and most of the wind farm site is assessed to be -2.0m below the current seabed. Locally, a higher depth of penetration of UXO may occur, depending on the thickness of the layer of soft mud. However, the available data does not allow for demarcation of these areas.

The current seabed level is to be derived from the MBES data that will be collected by the contractor selected for the execution of the survey.

Avoidance of potential UXO objects

It is recommended to avoid potential targets or pUXO resulting from the UXO geophysical survey by means of relocation (CPT, borehole, vibrocore and grab sampling) or (micro) re-routing (inter array and export cables).

For relocation and the re-routing process, a standoff distance is to be implemented around all geophysical survey anomalies above the applicable detection threshold that has not yet been confirmed as UXO through investigation by WROV. The standoff distances applicable to encountered pUXO targets during cable burial operations is dependent on the installation method, equipment, side effects on the seabed, and positional errors. It is recommended to determine the final standoff distances for the actual equipment deployed in the project.

Intermediate survey

All threshold pUXO targets on the target list which are unavoidable, require positive identification by WROV intervention. Depending on the number of pUXO targets, conducting an intermediate survey can be considered using acoustic survey techniques with classification capabilities (e.g., SBI). Using such a survey system, accurate information can be acquired regarding the depth of burial and the size and shape of pUXO targets.

Previous experiences show that an intermediate survey may result in a significant reduction (up to 60%-80%) of the number of false positive pUXO targets to be identified by WROV intervention.

Identification of unavoidable pUXO objects

All pUXO targets that cannot be avoided require positive identification by WROV intervention. Non-UXO items are to be removed to enable an as left survey if applicable, ensuring no pUXO targets are left behind in the magnetic masking zone of the object identified.

In Denmark the Royal Danish Navy EOD is responsible for all identification and disposal operations. Therefore, Royal Danish Navy EOD personnel must be present onboard the pUXO identification campaign.

Provision of ALARP certification

Upon finalisation of the UXO risk mitigation campaign (a) UXO ALARP certificate(s) is (are) to be issued. Based on the assessed information, UXO migration by natural causes can be excluded. The only factor possibly resulting in UXO migration is through human intervention.

This factor is considered part of the baseline residual risk. The recommended validity of the ALARP-certificate is 5 years minimum.

This enables the installation of the export cables and OSPs within the validity of the ALARP certificates. In case UXO migration due to human intervention is excluded in the UXO ALARP certificates the validity can be indefinite.

Reactive mitigation measures

NjordIC recommend the following reactive risk mitigation measures to be considered to mitigate the residual risk of encountering below threshold UXO:

- UXO safety and awareness briefing
  It is recommended to provide a UXO safety and awareness briefing to all personnel conducting intrusive works. A project specific briefing is recommended.
- UXO safety instructions
  These written instructions contain information detailing actions to be taken if (suspected) a (potential) UXO is discovered.
- Implementation of safe working procedures
  It is recommended to draft, issue and brief specific UXO safe working procedures for the recovery of equipment to deck (risk of entrapment of below threshold UXO) detailing the actions to be undertaken to ensure safe operations.
- UXO banksman
  Deployment of a UXO banksman on call to support operations in case of encounter of a suspicious object/substance should be considered for the project. On call support can respond immediately to reports of any suspected items of ordnance that have been recovered on site.

TABLE OF CONTENT

1 INTRODUCTION

Following a decision in the Danish Parliament June 2020 Denmark is on the path to establish offshore energy infrastructure in the Danish North Sea and in the Danish Baltic Sea to connect offshore wind energy to the Danish mainland and to neighbouring countries via offshore energy hubs.

In the Baltic Sea, the offshore part of the project includes the following main components:

- 2 offshore wind farms (Bornholm I West and II East),
- Subsea cables from the energy island (Bornholm) to the offshore wind farms.

In preparation for the Offshore Wind Farm (OWF) and export cable installation, Energinet will launch a preliminary study project, comprising of several specific studies, pursuant to the Danish environmental legislation, etc. Amongst others, a grab sampling campaign will be launched in October/November 2021.

NjordIC was commissioned for the preparational Unexploded Ordnance (UXO) consultancy services for the Energy Island in the Baltic Sea. The contracted services comprise of a UXO threat assessment, a UXO risk assessment and a UXO risk mitigation strategy.

1.1 OBJECTIVES

The main objectives of this study are:

1. Quantify of the UXO risks that may occur during the installation of the Bornholm II East OWF and the export cable.
2. Perform a UXO risk assessment to determine the tolerability of the UXO related risks.
3. Provide recommendations on the ALARP requirements ultimately resulting in a UXO risk management strategy for the Bornholm II East OWF and the export cable route.

1.2 AREA OF INVESTIGATION

The OWF Bornholm II East will be installed 20 km from the coast south of Rønne, Bornholm. The OWF location and its respective export cable route are displayed in Figure 1.

Note: The OWF boundaries and export cable corridor may be subjective to change over time. The illustrations in this report and the GIS-files accompanying this report are based on the GIS-files provided by Energinet, dated October 7 (OWF site) and October 25 (export cable corridor).

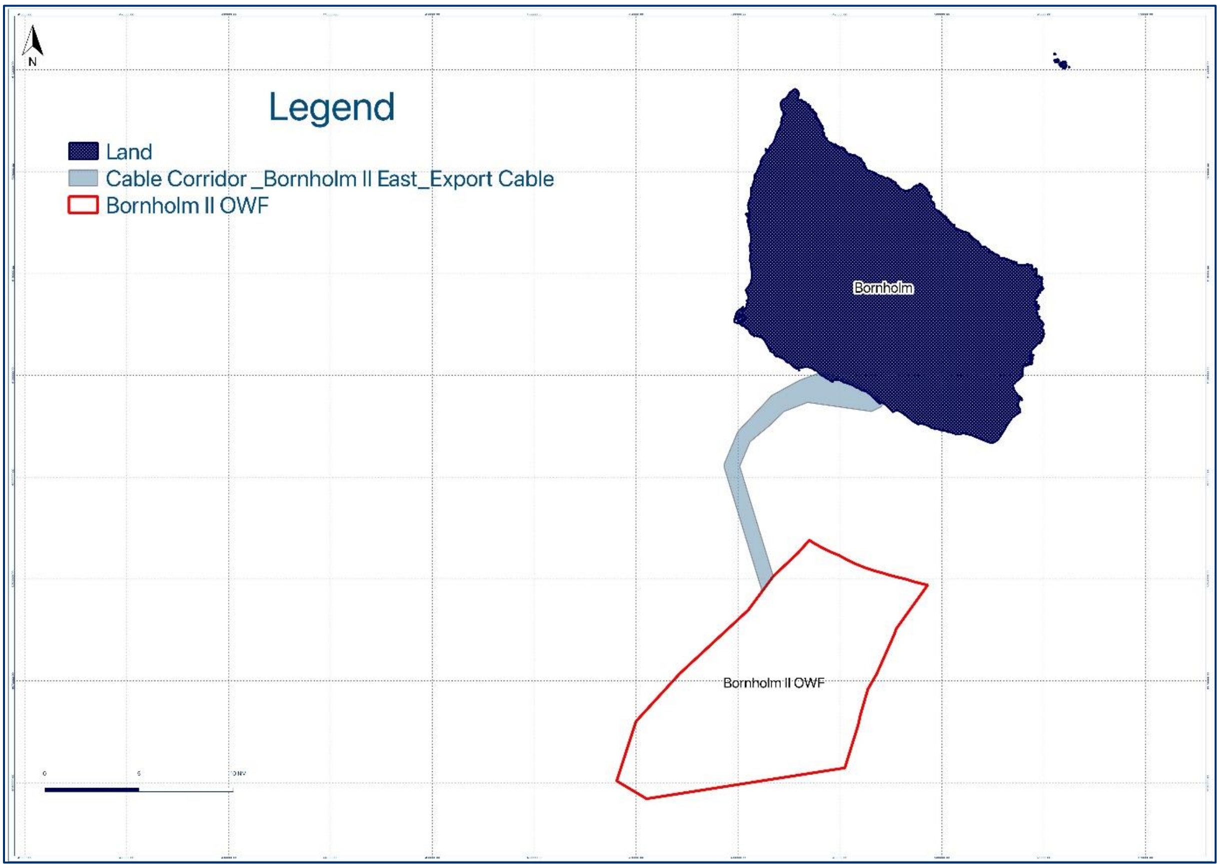

Figure 1: Location of Bornholm II East Offshore Wind Farm and the export cable route (source: Energinet).

1.3 CONTENT GUIDE

In chapter 2 the results of the performed UXO threat assessment are detailed.

The site-specific data relevant for the UXO risk assessment are presented in chapter 3.

The planned OWF and export cable installation operations are outlined in chapter 4.

During the execution of the installation operations, the intrusions into the seabed may affect and influence a UXO located on/in the seabed. In chapter 5 the influences on UXO (explosive contents and their associated fusing systems) that can initiate a detonation are assessed.

In the situation of a “High Order” detonation of a UXO, a vast amount of energy is released in an extremely short period of time. In chapter 6 the effects of underwater detonations are presented.

In chapter 7, the tolerability of risks is assessed based on the factors of influence on UXO and the effects of detonations.

Finally, chapter 8 provides recommendations on the mitigation measures required to reduce the assessed risks to a level that is considered ALARP.

2 UXO THREAT ASSESSMENT

A UXO threat assessment was performed to provide an assessed and reasoned answer to the question: "Is there a realistic chance of encountering UXO from WWI/WWII in the area of investigation, during the installation of the Bornholm II East OWF and its export cables?

2.1 SOURCES

In context of the research question above, several sources have been consulted. These are: literature, websites, The National Archives in London, The National Archives and Records Administration in Washington, and the collections of the Imperial War Museum in London.

This paragraph gives an overview of the sources that have been consulted in the context of the UXO threat assessment, referring to titles and archival records and inventory numbers.

2.1.1 Literature

A literature study was carried out. The overview below lists the reference works consulted for the area of investigation.

- Bertke, Donald A., Don Kindell, *World War II Sea War. Volume 1: The Nazis Strike First: Day-to-Day Naval Actions August 1939 through March 1940* (Bertke Publications 2011).
- Bertke, Donald A., Don Kindell, *World War II Sea War. Volume 4: Germany sends Russia to the Allies: Day-to-Day Naval Actions June 1941 through November 1941* (Bertke Publications 2012).
- Bertke, Donald A., Don Kindell, *World War II Sea War. Volume 7: The Allies Strike Back: Day-to-Day Naval Actions September through November 1942* (Bertke Publications 2014).
- Butter, Prit, *Between Giants. The Battle for the Baltics in World War II* (Osprey Publishing 2013).
- Davis, R., *RAF-AAF Bomber Operations by Day. Jan 1942 - May 1945 – Max-well Air Force Base, Alabama* (Air University Press 2006).
- Dopheide, R., *Kiel, Mai 1945. Britische Truppen besetzen die Kriegsmarinestadt: Mit einer Filmdokumentation von Kay Gerdes* (Ludwig 2007).
- Golücke, F., *Schweinfurt und der strategische Luftkrieg 1943* (Schöningh 1980).
- Gosztonyi, P., *Die Rote Armee. Geschichte und Aufbau der sowjetischen Streitkräfte seit 1917* (Molden 1980).
- Greaf, D., "Hake". *Angriffsziel Giessen 1944/45* (Selbstverl. d. Oberhessischen Geschichtsvereins Gießen 1991).
- Grooss, Poul, *The Naval War in the Baltic, 1939-1945* (Pen & Sword Books 2017).
- Groot, B. de, *Zeemijnen: De Mijnenoorlog in Noord- en Oostzee 1914-18 en 1939-45* (ASPEKT 2017).
- Grove, Eric J. *The Defeat of the Enemy Attack upon Shipping, 1939-1945: A Revised Edition of the Naval Staff History* (Routledge Revivals 1957).
- Haupt, W., *Das Ende im Westen, 1945. Bildchronik vom Kampf in Westdeutschland* (Podzun Dornheim 1972).
- Hupp, K., *Bei der Marineflak zur Verteidigung der Stadt und Festung Kiel im 2. Weltkrieg: Ein Beitrag zur Kieler Stadtgeschichte* (Husum Verlag 1998).
- Jackson, Robert, *Battle of the Baltic: The Wars 1918-1945* (Pen & Sword Books 2007).
- Jung, H., *Panzerregiment Grossdeutschland im Einsatz. Der Eliteverband der deutschen Panzerwaffe* (DS Verlag 2005).

- Kutzleben, K. v., Wilhelm Schroeder, Jochem Brennecke, *Minenschiffe: 1939-1945* (Koehler 2002).
- Mehner, K., *1. Dezember 1942 - 31. Mai 1943* (Osnabrück 1989).
- Middlebrook, M. & Everitt, C., *The Bomber Command War Diaries. An operational reference book, 1939-1945* (Penn & Sword Aviation 1990).
- Neufeld, Michael J., *The Rocket and the Reich: Peenemünde and the Coming of the Ballistic Missile Era* (Harvard University Press 1996).
- Paul, W., *Der Heimatkrieg. 1939 bis 1945* (Bechtermünz/Weltbild Verlag 1980).
- Ransted, Chris, *Disarming Hitlers V Weapons: Bombs Disposal, the V1 and V2 rockets* (Pen & Sword Books 2013).

2.1.2 Websites

In addition to literature, various websites were also consulted in the first weeks of October 2021. The overview below lists the websites consulted for the research area:

- http://www.flensted.eu.com/ (Aerial war over Denmark).
- https://aviation-safety.net/database/dblist.php?Country=OY (Airplane crashes around Denmark).
- https://bunkermuseumhanstholm.dk/en/learn-more/german-coastal-batteries-in-denmark-1940-45/german-seacoast-defenses-1945-amerikansk/ (Coastal defense of Denmark).
- https://digital-commons.usnwc.edu/cgi/viewcontent.cgi?article=1423&context=ils (Making Law of War Treaty's).
- https://encyclopedia.1914-1918-online.net/article/military_and_strategy_denmark (International encyclopedia of the First World War).
- https://helcom.fi/media/publications/Chemical-Munitions-Dumped-in-the-Baltic-Sea-Report-of-the-ad-hoc-Expert-Group.pdf (Chemical munitions dumped in the Baltic Sea).
- https://maps.helcom.fi/website/mapservice/?datasetID=e54e0cc7-c646-4b82-87bf-9a1132712ae7 (Map and data service of HELCOM).
- https://uboat.net/allies/warships/ship/9984.html (Index of U-boats)
- https://uboat.net/boats.htm (Index of U-boats).
- https://uboat.net/maps/ (Index of U-boats and corresponding maps).
- https://www.historynet.com/ (History Net).
- https://www.ibiblio.org/hyperwar/USN/SubLosses/SS_losses-german.html (German U-boat casualties in World War II).
- https://www.nationalarchives.gov.uk/cabinetpapers/themes/german-invasions-fall-france.htm (German invasion of Denmark and Norway).
- https://www.naval-history.net/WW1Book-World_War_1_Timeline_or_Chronology_1917.htm (Political and military background to the war at sea).
- https://www.naval-history.net/WW1Book-World_War_1_Timeline_or_Chronology_1918.htm (Political and military background to the war at sea).
- https://www.wrecksite.eu/ (Wreck database & collection of Baltic maritime charts).

2.1.3 The National Archives, London (TNA UK)

Archive research was carried out in the National Archives at Kew, London (UK). TNA UK hold interpretation reports and the daily logs of various units of the British and Commonwealth of Nations combat forces. The following files were consulted:

Reference	Title	Inventory number	Year	Description
ADM234	Admiralty Reference Books	560	*1939-1945*	*Mining Operations Vol.1*
ADM234	Admiralty Reference Books	561	*1939-1945*	*Mining Operations Vol. 2*
AIR14	Air Ministry: Bomber Command	2676	*1943*	*Night Bomb Raid Sheets, January-May 1943*
AIR14	Air Ministry: Bomber Command	2678	*1943-1944*	*Night Bomb Raid Sheets, December 1943-May 1944*
AIR14	Air Ministry: Bomber Command	3101	*1943*	*Group Operations Orders, April 1943*
AIR14	Air Ministry: Bomber Command	3116	*1944*	*Group Operations Orders, April 1944*
AIR27	Air Ministry: Squadrons	203	*1941-1943*	*Operations Record Book 15 Squadron, 1941-1943*
AIR27	Air Ministry: Squadrons	816	*1944*	*Operations Record Book 103 Squadron, 1944*
AIR41	Air Historical Branche Narratives and Monographs	47	*1941-1943*	*The RAF in Maritime War Vol. III Jul 1941-Feb 1943*
AIR41	Air Historical Branche Narratives and Monographs	48	*1943-1944*	*The RAF in Maritime War Vol. IV Feb 1943-May 1944*
AIR41	Air Historical Branche Narratives and Monographs	73	*1939-1941*	*The RAF in Maritime War Vol. II Sep 1939-Jun 1941*
AIR41	Air Historical Branche Narratives and Monographs	74	*1944-1945*	*The RAF in Maritime War Vol. V Jun 1944-May 1945*
AIR41	Air Historical Branche Narratives and Monographs	79	*1939-1945*	*The RAF in Maritime War Vol. VIII Statistics*

Table 1: Files consulted at the National Archives, London, United Kingdom.

2.1.4 Bundesarchiv-Militärarchiv (BaMa) Freiburg

Archive research was carried out at the Bundesarchiv-Militärarchiv (BaMa) in Freiburg, Germany. The following files were consulted:

Reference	Title	Inventory number	Year	Description
RM7	Seekriegsleitung der Kriegsmarine	5-71	*1939-1945*	*Kriegstagebuch Teil A: Täglicher verlauf und Lagebeurteilungen*

Table 2: Files consulted at the Bundesarchiv-Militärarchiv, Freiburg, Germany.

2.1.5 National Archives and Records Administration, Washington (NARA)

Archive research was carried out at the American National Archives and Records Administration at NARA II, College Park (Maryland, USA). The following files were consulted:

Reference	Title	Inventory number	Year	Description
RG 242 T1022	Marinegruppekommando Ost	4039-4040	*1940*	*Kriegstagebuch, 1 Mai-31 Juli 1940*
RG 242 T1022	Marinegruppekommando Nord	3938-3939	*1940-1941*	*Kriegstagebuch 1 August 1940-31 Oktober 1941*
RG 242 T1022	Marinegruppekommando Nord	3946-3948	*1941-1942*	*Kriegstagebuch 16 November 1941-11 Juli 1942*
RG 242 T1022	Marinegruppekommando Nord	3971	*1943*	*Kriegstagebuch 16 -28 Februar 1943*
RG 242 T1022	Marinegruppekommando Nord	3939	*1943*	*Kriegstagebuch 15 April-15 Juli 1943*
RG 242 T1022	Marinegruppekommando Nord	2109-2111		*Kriegstagebuch, Anlagen*
RG 242 T1022	Marinegruppekommando Nord	2148-2149		*Kriegstagebuch, Anlagen*
RG 242 T1022	Marinegruppekommando Nord	2150-2153		*Kriegstagebuch, Anlagen*
RG 242 T1022	Marinegruppekommando Nord	2171-2174		*Kriegstagebuch, Anlagen*
RG 242 T1022	Marinegruppekommando Nord	2177		*Kriegstagebuch, Anlagen*
RG 242 T1022	Marinegruppekommando Nord	2178-2181		*Kriegstagebuch, Anlagen*
RG 242 T1022	Marinegruppekommando Nord	2181-2185		*Kriegstagebuch, Anlagen*
RG 242 T1022	Marinegruppekommando Nord	2195-2198		*Kriegstagebuch, Anlagen*
RG 242 T1022	Marinegruppekommando Nord	2201-2211		*Kriegstagebuch, Anlagen*
RG 242 T1022	Marinegruppekommando Nord	2219		*Kriegstagebuch, Anlagen*
RG 242 T1022	Marinegruppekommando Nord	2220		*Kriegstagebuch, Anlagen*
RG 242 T1022	Marinegruppekommando Nord	2221-2223		*Kriegstagebuch, Anlagen*
RG 242 T1022	Marinegruppekommando Nord	2224-2226		*Kriegstagebuch, Anlagen*
RG 242 T1022	Marinegruppekommando Nord	2227-2228		*Kriegstagebuch, Anlagen*
RG 242 T1022	Marinegruppekommando Nord	2229		*Kriegstagebuch, Anlagen*
RG 242 T1022	Marinegruppekommando Nord	2261		*Kriegstagebuch, Anlagen*
RG 242 T1022	Marinegruppekommando Nord	2262		*Kriegstagebuch, Anlagen*
RG 242 T1022	Marinegruppekommando Nord	2263		*Kriegstagebuch, Anlagen*
RG 242 T1022	Marinegruppekommando Nord	2264		*Kriegstagebuch, Anlagen*

Reference	Title	Inventory number	Year	Description
RG 242 T1022	Marinegruppekommando Nord	2265-2266		*Kriegstagebuch, Anlagen*
RG 242 T1022	Marinegruppekommando Nord	2267		*Kriegstagebuch, Anlagen*
RG 242 T1022	Marinestation Ostsee	4045-4046	*1940-1941*	*Kriegstagebuch, 1 Juni 1940-31 Dezember 1941*
RG 242 T1022	Marinestation Ostsee	4242	*1939-1943*	*Kriegstagebuch, 1 Dezember 1939-31 Januar 1943*
RG 242 T1022	Marineoberkommando Ostsee	4042	*1943*	*Kriegstagebuch, 1 Februar-31 Juli 1943*
RG 242 T1022	Marineoberkommando Ostsee	2650	*1943*	*Kriegstagebuch, 17 August-31 Dezember 1943*
RG 242 T1022	Marineoberkommando Ostsee	3842-3843	*1944*	*Kriegstagebuch, 1 Januar-31 August 1944*
RG 242 T1022	Marineoberkommando Ostsee	2650	*1944*	*Kriegstagebuch, 1-30 September 1944*
RG 242 T1022	Marineoberkommando Ostsee	4043-4044	*1943-1944*	*Kriegstagebuch, 1 August 1943-31 Dezember 1944*
RG 242 T1022	Küstenbefehlshaber der westlichen Ostsee	4055	*1939-1940*	*Kriegstagebuch, 23 August 1939-31 Dezember 1940*
RG 242 T1022	Küstenbefehlshaber der westlichen Ostsee	4296-4297	*1941-1942*	*Kriegstagebuch, 1 Januar 1941-15 November 1942*
RG 242 T1022	Küstenbefehlshaber der westlichen Ostsee	2626-2627	*1942-1943*	*Kriegstagebuch, 16 November 1942-15 Oktober 1943*
RG 242 T1022	Küstenbefehlshaber der westlichen Ostsee	2629	*1943-1944*	*Kriegstagebuch, 16 Oktober 1943-30 November 1944*
RG 242 T1022	Kommandierende Admiral der westlichen Ostsee	2630	*1944-1945*	*Kriegstagebuch, 1 Dezember 1944-31 Januar 1945*
RG 242 T1022	Kommandierende Admiral der westlichen Ostsee	3744	*1945*	*Kriegstagebuch, 1-28 Februar 1945*
RG 242 T1022	Marinebefehlshaber Dänemark	2614-2617	*1940-1944*	*Kriegstagebuch, 10 April 1940-31 März 1944*
RG 242 T1022	Admiral Dänemark	2617	*1944*	*Kriegstagebuch, April-Juni 1944*
RG 242 T1022	Admiral Dänemark	3941-3942	*1944*	*Kriegstagebuch, Juli-Dezember 1944*
RG 242 T1022	Admiral Dänemark	3744	*1945*	*Kriegstagebuch, Januar-Februar 1945*
RG 242 T1022	Seekommandant der Dänische Inseln	2667	*1943-1944*	*Kriegstagebuch 1 Juli 1943-30 November 1944*
RG 242 T1022	Inselkommandant Bornholm	2668	*1943*	*Kriegstagebuch, 1 März-30 Juni 1943*
RG 242 T1022	Inselkommandant Bornholm	2803	*1943-1944*	*Kriegstagebuch, 1 Juli-31 August 1944*
RG 242 T1022	Befehlshaber der Sicherung der Ostsee	4058	*1939-1940*	*Kriegstagebuch, 22 August 1939-15 März 1940*

Reference	Title	Inventory number	Year	Description
RG 242 T1022	Befehlshaber der Sicherung der Ostsee	4295	*1940*	*Kriegstagebuch, 16 März-30 Juni 1940*
RG 242 T1022	Befehlshaber der Sicherung der Ostsee	4058-4059	*1940*	*Kriegstagebuch, 1 Juli 1940-1 Januar 1941*
RG 242 T1022	Befehlshaber der Sicherung der Ostsee	4058-4059	*1940*	*Kriegstagebuch, 1 Juli 1940-1 Januar 1941*
RG 242 T1022	Befehlshaber der Sicherung der Ostsee	4055-4058	*1941*	*Kriegstagebuch, 2 Januar-15 Oktober 1941*
RG 242 T1022	Befehlshaber der Sicherung der Ostsee	2609	*1941*	*Kriegstagebuch, 16-31 Oktober 1941*
RG 242 T1022	Befehlshaber der Sicherung der Ostsee	4050-4053	*1941-1942*	*Kriegstagebuch, 1 November 1941-31 Dezember 1942*
RG 242 T1022	Befehlshaber der Sicherung der Ostsee	4295	*1943*	*Kriegstagebuch, 1-15 Januar 1943*
RG 242 T1022	Befehlshaber der Sicherung der Ostsee	4059-4060	*1943*	*Kriegstagebuch, 16 Januar-14 April 1943*
RG 242 T1022	Befehlshaber der Sicherung der Ostsee	2610-2611	*1943*	*Kriegstagebuch, 15 April-15 August 1943*
RG 242 T1022	Befehlshaber der Sicherung der Ostsee	2644-2645	*1943-1944*	*Kriegstagebuch, 16 August 1943-15 April 1944*
RG 242 T1022	Befehlshaber der Sicherung der Ostsee	2763-2764	*1944*	*Kriegstagebuch, 1 May-15 November 1944*
RG 242 T1022	Befehlshaber der Sicherung der Ostsee	2611-2614		*Kriegstagebuch, Anlagen*
RG 242 T1022	Befehlshaber der Sicherung der Ostsee	2658-2664		*Kriegstagebuch, Anlagen*
RG 242 T1022	Befehlshaber der Sicherung der Ostsee	2679-2683		*Kriegstagebuch, Anlagen*
RG 242 T1022	Befehlshaber der Sicherung der Ostsee	2688-2691		*Kriegstagebuch, Anlagen*
RG 242 T1022	Befehlshaber der Sicherung der Ostsee	2692		*Kriegstagebuch, Anlagen*
RG 242 T1022	Befehlshaber der Sicherung der Ostsee	2736-2737		*Kriegstagebuch, Anlagen*
RG 242 T1022	Befehlshaber der Sicherung der Ostsee	2764-2765		*Kriegstagebuch, Anlagen*
RG 242 T1022	Befehlshaber der Sicherung der Ostsee	3907		*Kriegstagebuch, Anlagen*
RG 242 T1022	Befehlshaber der Sicherung der Ostsee	3908		*Kriegstagebuch, Anlagen*
RG 242 T1022	Führer der Minensuchverbände Nord	4001-4004	*1940-1941*	*Kriegstagebuch, -30 Juni 1941*
RG 242 T1022	Führer der Minensuchverbände Nord	3943-3946	*1941-1942*	*Kriegstagebuch, 1 Juli 1941-11 März 1942*
RG 242 T1022	Führer der Minensuchverbände Ost	4053-4055	*1942-1943*	*Kriegstagebuch, 12 März 1942-15 Mai 1943*
RG 242 T1022	Führer der Minensuchverbände Ost	4311	*1943*	*Kriegstagebuch, 16 May-31 Dezember 1943*
RG 242 T1022	Führer der Minensuchverbände Ost	2640-2641	*1944*	*Kriegstagebuch, 1 Januar-15 Juni 1944*

Reference	Title	Inventory number	Year	Description
RG 242 T1022	9./Sicherungsdivision	3559-3561	*1944*	*Kriegstagebuch, 30 Juni-15 Januar 1945*
RG 242 T1022	2./Sicherungsflottille	3526-3527	*1943-1944*	*Kriegstagebuch 1 October 1943-15 Dezember 1944*

Table 3: Files consulted at the American National Archives and Records Administration, College Park, Maryland, USA.

2.1.6 Imperial War Museum, London (IWM)

The collections of the Imperial War Museum hold information about the British armed forces from the First World War onwards. On the website of the IWM (digitized) photos and films from the First and Second World War and other post 1945 conflicts are available. The online database of the IWM has been accessed to find more information about Bornholm and its surroundings during the First and Second World War.

2.1.7 Royal Swedish Navy

The Royal Swedish Navy Maritime Warfare Data Centre was requested to provide information on naval minefields and military training areas relevant to the area of investigation. The Maritime Warfare Data Centre is specialised in supporting the Navy with information, data, and assessments to enhance the efficiency of Underwater Warfare. The Data Centre has built a comprehensive database on minefields laid in the Baltic Sea during both World Wars.

Lieutenant Commander G. Möller provided the requested data on behalf of the Royal Swedish Navy.

2.2 RESULTS OF THE INVENTORY

This paragraph displays the results of the research of the sources listed in the previous paragraph. Based on the sources, a chronological overview has been drawn up of events which took place within and near the area of investigation.

2.2.1 First World War

During the First World War (WWI), not many major fleet encounters have occurred between the German and Russian (or other allied) marines. [**historical context**]

August 2, 1914

On August 2, 1914, two German light cruisers, the Augsburg and the Magdenburg, received an order to attack the former Russian city of Libau (now the Latvian city of Liepāja). The cruisers laid all their mines in this vicinity [**380km east**], after which they first headed a northern course and then a western course to Bornholm. They finally moored in Swinemünde (Świnoujście), Poland. [5] [**historical context**]

August 9, 1914

On August 9, 1914, orders were issued for the Russians to lay a minefield in Köge Bay aimed to be an obstacle for a coastal bombardment of Copenhagen. The operation was carried out by the 1st Squadron from the 11th to the 12th of August. The minefield consisted of two mine lines with a total of 246 mines. Only a few sunken mines, and probably mine anchors are assessed to remain today. [6] [**180km west**]

5 Groot, B. de, *Zeemijnen: De Mijnenoorlog in Noord- en Oostzee 1914-18 en 1939-45* (ASPEKT 2017), p. 132-133

6 LtCdr G. Möller, Royal Swedish Navy.

December 14-15, 1914

During the Russian offensive mining operations of 1914, the British submarines E 1 and E 9 provided cover West of Bornholm. Goal of this offensive was to interrupt the German connections with the Southern part of the Baltic Sea. [7] [**historical context**]

January 12, 1915

The Russian offensive mining operations continued into 1915 and in the evening of January 12th, the Oleg (96 mines) and the Bogatyr (100) dropped their mines east of Bornholm. [8] [**unknown location**]

March-April 1915

During a German mine sweeping activity, the II. Minensuchdivision searched the sea for enemy submarines at Bornholm for two days between March5 and 6. Between April 11 and 13 it searched for mines in the area West of Bornholm. [9] [**historical context**]

April 26, 1915

The Soviets laid a large minefield East of Bornholm. This field was only discovered after the war. [10] [**unknown location**]

2.2.2 Second World War

While military operations around the Baltic Sea included surface and sub-surface combat, aerial combat, amphibious landings, and support of large-scale ground fighting, the most significant feature of Baltic Sea operations was the scale and size of mine warfare. [**historical context**]

August 30, 1939

One and a half days before World War II broke out, the Polish destroyers Blyskawica, Burza and Grom were escorted past Bornholm by four German destroyers Z8 Bruno Heinemann, Z14 Friedrich Ihn, Z15 Erich Steinbrinck and Z16 Friederich Eckoldt. [11] [**historical context**]

September 8, 1939

All five Polish submarines Orzeł, Wilk, Rys, Zbik and Sęp were ordered to patrol between Bornholm and Danzig Bay. No rewarding targets for the Polish submarine torpedoes appeared here. The submarines were to patrol as long as possible. They were then ordered to sail to the UK or to a neutral country, though not the Soviet Union. [12] [**historical context**]

March 19, 1940

On March 19, 1940, the Hörnum Air Base on Sylt became the target of British sea planes. This undertaking did not meet the desired results because some of the bombers had attacked the Danish Island of Bornholm in the Baltic Sea due, among other things, to misorientation. [13] [**historical context, location Bornholm Island**]

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[7] Groot, B. de, *Zeemijnen: De Mijnenoorlog in Noord- en Oostzee 1914-18 en 1939-45* (ASPEKT 2017), p. 137-139

[8] Ibid., p. 140.

[9] Ibid., p. 142-143.

[10] Ibid., p. 145.

[11] Grooss, Poul. *The Naval War in the Baltic, 1939–1945* (Pen & Sword Books 2017), p. 82.

[12] Ibid., p. 92.

[13] Greaf, D., "Hake". *Angriffsziel Giessen 1944/45* (Selbstverl. d. Oberhessischen Geschichtsvereins Gießen 1991), p. 8.

May 9, 1940

On the 9th of May 1940, a German landing force arrived at Rønne on the island of Bornholm. From the beginning, the Germans wanted to gain control over the Danish-controlled minefields, and, on April 9, 100 men deployed in sixteen ships began the process of locating and capturing the four control stations from where the controlled minefields in the Great Belt and the Little Belt could be activated and deactivated. [14] [**historical context**]

April 21, 1940

He 111P-2 belly landed in the sea just of the beach at Dueodde on the island of Bornholm. The He 111 was part of a formation of three aircrafts that at 19:15 hours had been fired at by FLAK when over the Swedish island of Gotland. The aircraft belonged to 4. / KG 54 and was coded B3+LM. The crew remained unharmed and the He 111 which was nicknamed "Lümmel" was not damaged much. It was dismantled and brought to the harbour of Rønne where it was loaded aboard the Luftwaffe ship "Günther Plüschow" and brought to Germany. [15] [**historical context, location east of export cable landfall**]

July 1, 1940

A He 60 emergency landed in the Baltic near Bornholm. The aircraft belonged to FLWS (See)2 and was coded TT+HY. It was reported at 02:42 hours that the aircraft had been towed to Christiansø island. The crew were unharmed. [16] [**>35km northeast**]

October 15, 1940

He 60 serial number 1408 made an emergency landing near Bornholm due to engine problems. It was damaged for 40% and the crew was unharmed. The aircraft belonged to Fliegerwaffenschule (See)1 and was coded ZU+HS. [17] [**unknown location**]

Late 1940

Beam testing was done with aircraft flying out across the Baltic to the occupied Danish Island of Bornholm. By late 1940 Hoelzer and his assistant, Otto Hirschler, had managed to develop an electronic "mixing device" to calculate additional mathematical terms to modify the guide beam signal. Steinhoff piloted many of the flights himself.

Even with that experience, perfecting a stable and workable system to be tested on the A-5 was difficult, and the first launch was not attempted until the spring of 1941. After working out innumerable problems in A-5 and A-4 launches, this guide beam was later used in some launches in the V-weapons campaign. [18] [**historical context**]

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[14] Grooss, Poul, *The Naval War in the Baltic, 1939–1945* (Pen & Sword Books 2017), p. 139.

[15] *He 111P-2 belly landed on the island of Bornholm 21/4 1940* (http://www.flensted.eu.com/), accessed on October 4, 2021.

[16] *He 60 emergency landed in the Baltic near Bornholm 1/7 1940* (http://www.flensted.eu.com/), accessed on October 5, 2021.

[17] *Ar 196A-2 serial number 0047 crashed near the island of Bornholm 7/1 1941* (http://www.flensted.eu.com/), accessed on 4-10-2021.

[18] Neufeld, Michael J., *The Rocket and the Reich: Peenemünde and the Coming of the Ballistic Missile Era* (Smithsonian 2013), p. 105.

7 January 1941
Ar 196A-2 serial number 0047 crashed near the island of Bornholm. An aircraft crashed during landing in sea near the island of Bornholm. It was 35% damaged. The aircraft belonged to 1./ Bordfliegergruppe 196. [19] [**unknown location**]

March 7, 1941
He 60 made an emergency landing in the sea 2 to 3 miles southwest of Rønne in the morning. It was towed to the beach at Korsodde by Verkehrsboot Hafen Kapitän Rønne. It hit rocks and one float was damaged and the aircraft ended up with the nose in the water. The crew was unharmed. [20] [**>4km north**]

Summer 1941
A German coastal battery named Bornholm-Süd was completed in the summer of 1941. It was a battery with two 40,6 cm S.K.C/34 f guns. [21] [**historical context**]

Summer 1941
During the German-Soviet collaboration between 1939 and 1941, the Soviet Union had ordered some 15-inch/380mm battleship guns from Germany. When the war against the Soviet Union broke out in the summer of 1941, it was instead decided to put these guns in a German position at Dueodde on the south coast of the occupied Danish Island of Bornholm, which would then be able to fire on large Soviet vessels which were either trying to break out of the Baltic Sea or wanted to fight the Kriegsmarine in the western Baltic Sea. [22] [**historical context, location northeast of export cable landfall**]

June 24, 1941
He 111H serial number 6866 made an emergency landing at Rutsker Højlyng on the island of Bornholm. The crew experienced an engine fire and the aircraft burned out and was a 100% loss. The crew remained unharmed. The aircraft belonged to 9./ KG 40. [23] [**Bornholm Island, >15km north**]

July 3, 1941
He 60 made an emergency landing on the sea near the island of Bornholm. The aircraft is believed to have belonged to 1./SAGr 125 and to be coded 7R+MH. The aircraft made an emergency landing in the sea 2 to 3 miles southwest of Rønne in the morning. It was towed to the beach at Korsodde by Verkehrsboot Hafen Kapitän Rønne. It hit the rocks and one float was damaged and the aircraft ended up with the nose in the water. The crew was unharmed. [24] [**>4km north**]

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[19] *Ar 196A-2 serial number 0047 crashed near the island of Bornholm 7/1 1941* (http://www.flensted.eu.com/), accessed October 4, 2021.
[20] *He 60 made emergency landing on the sea near the island of Bornholm 3/7 1941* (http://www.flensted.eu.com/), accessed on October 4, 2021.
[21] *List of the German coastal batteries in Europe, January 1941* - Museumscenter Hanstholm Denmark (https://bunkermuseumhanstholm.dk/), accessed on October 5, 2021.
[22] Grooss, Poul, *The Naval War in the Baltic, 1939-1945* (Pen & Sword Books 2017), p. 230.
[23] *He 111H serial number 6866 emergency landed on the island of Bornholm 24/6 1941* (http://www.flensted.eu.com/), accessed on October 4, 2021.
[24] *He 60 made emergency landing on the sea near the island of Bornholm 3/7 1941* (http://www.flensted.eu.com/), accessed on October 5, 2021.

July 5 - August 7 1941
Six Russian submarines were lost between the 5th of July and the 7th of August. The Russian K-3 was lost on a mine block West of Bornholm. [25] [**unknown location**]

August 1941
In early August, the Soviet submarines Lembit and Kalev left Tallinn. Kalev laid its twenty mines southwest of Ventspils and they sank two German ships. Lembit passed west of Bornholm and laid mines off one of the German ports. On 25 August 1941, both submarines were back in Tallinn to take more mines on board, but this was during the evacuation of the city. [26] [**historical context**]

August 17, 1941
On August 17, 1941, the Soviet-Estonian submarine Lembit carried out minelaying "west of Bornholm". According to Russian (Soviet) sources, the mines were laid in three groups, while post-war documentation indicates two minelines. A total of 20 mines of the Estonian type A (1930) were laid in these groups/lines. [27] [**>35km southwest, also see February 26, 1942**]

19 October 1941
On October 1941 the aircraft He 114B serial number 2289 was reported lost. On 19/10 the wreckage was found washed ashore at Stenodde on the island of Bornholm. The aircraft belonged to Grosse Kampfliegerschule 5 and was coded TV+HX. [28] [**>8km east**]

February 9, 1942
On the night of 9 February 1942, 9 flights were undertaken into the Reich territory through the Skagerrak, 5 of them in Gdansk Bay and 4 on Bornholm. [29] [**historical context**]

February 26, 1942
The Swedish ferry Starke (2459 GRT) is mined and damaged west of Bornholm in position 54°35'N, 13°45'E. She may have hit a mine laid by Lembit on 17 August 1941. [30] [**>40km southwest**]

April 3 and 4, 1942
On April 3 and 4, 1942, Werner von Braun was on the island with two technicians, Dr. Ernst Steinhoff, and the engineer Gerhard Reisig. They were going to set up radar stations which could follow the V-2 launches from Peenemünde. [31] [**historical context**]

June 22, 1942
The Swedish ship Ada Gordon, loaded with 4,000 tonnes of iron ore to Germany, was torpedoed and sunk east of Öland [**German Bight**]. Both ships had been hit by torpedoes from the Soviet submarine Shch-317, which then went on patrol north of Bornholm. [32] [**unknown location**]

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25 Groot, B. de, *Zeemijnen: De Mijnenoorlog in Noord- en Oostzee 1914-18 en 1939-45* (ASPEKT 2017), p. 320.
26 Grooss, Poul, *The Naval War in the Baltic, 1939-1945* (Pen & Sword Books 2017), p. 211.
27 Ibid., p. 211.
28 *He 114B serial number 2289 washed ashore on the island of Bornholm 19/10 1941* (http://www.flensted.eu.com/), accessed on October 4, 2021.
29 Mehner, K., *1. Dezember 1942 - 31. Mai 1943* (Osnabrück 1989), p. 142.
30 https://uboat.net/allies/warships/ship/9984.html, accessed on October 13, 2021.
31 Grooss, Poul, *The Naval War in the Baltic, 1939-1945* (Pen & Sword Books 2017), p. 291.
32 Ibid., p. 258.

July 13, 1942
The German merchant Kathe O (1,854 GRT, built 1903, former Latvian Ausma) is mined and damaged west of Bornholm in position 54°36'N, 13°46'E. She may have hit a mine laid by Lembit on 17 August 1941. [33] [**>35km south**]

September 1943

Figure 2: The German destroyer Z31 with 6in/ 150mm guns in Rønne harbour on Bornholm in September 1942. [34]

September 18, 1942
The Russian submarines SHCH-310, D-2 and SHCH-406 patrolled the area between Rixhöft and Bornholm. [35] [**historical context**]

November 6, 1942
A Soviet submarine attack was reported about twenty-five nautical miles east of Bornholm. [**location unknown**] This attack was aimed at Swedish tankers that travelled the northern part of the Eastern Front with fuel. [36] [**historical context**]

October 3, 1942
At the Luftwaffe base at Peenemünde, the Germans were developing the Vergeltungswaffe 1 (or V-1). Churchill's scientific adviser, Professor R. V. Jones, traced the 14th and 15th companies from the Luftwaffe's experimental signals regiment to the island of Rügen, and to Dueodde and Svaneke on the occupied Danish Island of Bornholm, and these units had just received the latest version of the Würzburg radar. Germany had a wide range of different monitoring stations on Bornholm. Some were related to the extensive submarine construction and others related to activities in Peenemünde. [37] [**historical context**]

October 5, 1942
SHCH-406 patrolled between Rixhöft (Cape Rozewie), Poland, and Bornholm, Denmark. [38] [**historical context**]

[33] https://uboat.net/allies/warships/ship/9984.html, accessed on 13-10-2021.
[34] Grooss, Poul, *The Naval War in the Baltic, 1939-1945* (Pen & Sword Books 2017), p. 263.
[35] Bertke, Donald A., Don Kindell, *World War II Sea War. Volume 7: The Allies Strike Back: Day-to-Day Naval Actions September through November 1942* (Bertke Publications 2014) p. 65.
[36] Grooss, Poul, *The Naval War in the Baltic, 1939-1945* (Pen & Sword Books 2017), p. 264.
[37] Ibid., p. 291.
[38] Bertke, Donald A., Don Kindell, *World War II Sea War. Volume 7: The Allies Strike Back: Day-to-Day Naval Actions September through November 1942* (Bertke Publications 2014), p. 173.

October 14, 1942
Russian submarine D-2 sank German steamer JACOBUS FRITZEN (4090grt) off Bornholm, Denmark on position 55.10N, 13.38,5E. [39] [**50km northeast**]

October 19, 1942
Russian submarine D-2 hit German steamer DEUTSCHLAND (2,972grt) off Bornholm, Denmark. It was hit by a torpedo and could still enter Trelleborg. On the same day, Russian submarine SHCH-406 (Capt 3rd Class Osipov) sank Finnish steamer AGNES (2,983grt) off Bornholm [40] on position 55 ° 14' " N, 018 ° 12' " E. [41] [**7km north**]

November 1, 1942
Russian submarines SHCH-310, D-2, and SHCH-406 patrolled the area between Rixhöft, Poland, and Bornholm, Denmark. [42] [**historical context**]

January 17, 1943
FW 58C serial number 3851 crashed in the Baltic Sea. The aircraft belonged to Flg. Waffenschule (See) Parow and was coded CB+GH. The aircraft crashed in the Baltic See between Parow and the island of Bornholm and was a 100% loss. [43] [**unknown location**]

February 11, 1943
A German seaplane emergency landed in the Baltic sea west of the island of Bornholm. The plane emergency landed 5 to 6 miles west of Hammerhavn Harbour and was towed to Allinge by a Danish steam ship. The seaplane had entered Swedish territorial area and FLAK had been fired that had apparently damaged the sea plane. [44] [**>15km north**]

March 14, 1943
Lancaster III ED494 crashed in the Baltic Sea. The aircraft belonged to RAF 9 Sqn. Bomber Command and was coded WS-G. At 00:10 an aircraft was shot down by FLAK and fell burning in the Baltic Sea west of Rønne on the island of Bornholm. During the next day's wreckage from the aircraft was found in the area and a dead flyer with an attached parachute was observed in the water but disappeared before he could be retrieved. There have been found nothing which could identify the aircraft, but the only one which it can possibly be is Lancaster ED404. [45] [**unknown location**]

April 28 – 29, 1943
A Royal Air Force mine-dropping area, codenamed 'Pollock', existed near Bornholm. The area was bounded on the north by a from Hammeren Point to 55.00N, 14.27E. On the east side, the area was bounded by 14.46E and 5 fathoms depth. On the south side, the area was bounded by 54.48N and on the west by 14.27E.

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[39] Ibid., p. 174; NARA, RG242 T1022 Roll 4292.
[40] Ibid., p. 174.
[41] http://www.balticwrecks.com/en/wrecks/agnes/, accessed on November 15, 2021.
[42] Bertke, Donald A., Don Kindell, *World War II Sea War. Volume 7: The Allies Strike Back: Day-to-Day Naval Actions September through November 1942* (Bertke Publications 2014), p. 311.
[43] *FW 58C serial number 3851 crashed in the Baltic Sea 27/1 1943* (http://www.flensted.eu.com/), accessed on October 5, 2021.
[44] *German seaplane emergency landed in the Baltic Sea west of the island of Bornholm 11/2 1943* (http://www.flensted.eu.com/), accessed on October 4, 2021.
[45] *Lancaster III ED494 crashed in the Baltic Sea 14/3-1943* (http://www.flensted.eu.com/), accessed on October 5, 2021.

On the night of 28th to 29th April 1943, 12 mines in the Pollock area were dropped for the first time by four of the five British Short Stirlings deployed from 3 Group heavy bombers. The mines dropped were of type F616, exact drop locations are not indicated. [46] [**mine garden Pollock, coinciding with export cable corridor**]

June 3, 1943
Ju 88C-6 serial number 360433 emergency landed at Vester Marie. The aircraft belonged to 4/II./ NJG 3 and was coded D5+BM. The JU 88 took part in the defense of Berlin but lost orientation due to thunderstorms and at 06:00 hours Pilot Unteroffizier Günter Liersch emergency landed at Vestergaard farm near Vester Marie on the island of Bornholm. One of the three-man crew was slightly injured and the aircraft was 40% damaged. [47] [**Bornholm Island**]

July 18, 1943
Bornholm lay close to the test firings at Peenemünde, and on 18 July 1943, the German anti-aircraft guns in Svaneke had shot down an unidentified aircraft. The search for the aircraft was stopped on the orders of Suchleitung Swinemünde (the search headquarters at Swinemünde – now Polish Świnoujście). It had been a stray V-1 rocket. [48] [**unknown location**]

July 23, 1943
Five days after the bombing raid of the RAF on Peenemünde, the commanding officer of Bornholm's naval district, Kaptajnløjtnant Christian W T Hasager Christiansen, was called out to something that looked like a crashed aircraft. He managed to photograph the object before German troops arrived at the scene. [49] [**historical context**]

July 28, 1943
In the summer of 1943, the threat of invasion was again felt in Sweden. On 28 July 1943, which was just a few days before Sweden cancelled all German transit through its territory, secret Swedish reconnaissance flights started between the Kalmar Strait and Bornholm. [50] [**historical context**]

22 August 1943
A V-1 landed near Bodilsker on the island of Bornholm. The V-1 was fired from a He 111 for testing purpose and landed two kilometres west northwest of Bodilsker church at 13:05 hours. The yellow painted V-1 touched down in a grass field and bounced across a small road to end up in a turnips field belonging to Klippedam farm owned by Farmer Svend Å. Kofoed. [51] [**Bornholm Island, 10km northeast**]

August 22, 1943
On 22 August 1943, an early prototype of the V-1 had crashed at Bodilsker and Hasager Christiansen's photographs and report reached Professor R.V. Jones. Five copies of the report and photographs were made: Professor Jones received three sets via different channels.

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[46] TNA UK, AIR41/48.

[47] *Ju 88C-6 serial number 360433 emergency landed at Vester Marie 3/6 1943* (http://www.flensted.eu.com/), accessed on October 5, 2021.

[48] Grooss, Poul, *The Naval War in the Baltic, 1939-1945* (Pen & Sword Books 2017), p. 293.

[49] Ibid., p. 293.

[50] Ibid., p. 273.

[51] *V 1 landed near Bodelsker on the island of Bornholm 22/8 1943* (http://www.flensted.eu.com/), accessed on October 4, 2021.

He noted drily that someone must have been determined that the information should reach the British. [52] [**Bornholm Island, 10km northeast**]

<u>August 22, 1943</u>
The first of the V-1's fell on Bornholm on 22 August 1943 and was investigated by Lieutenant Commander Christiansen, a Danish mine disposal officer. The missile had apparently crashed 2 kilometers west-north-west of Bodilsker Church, having just missed the tops of the trees close to a house some 250 meters away. Christiansen photographed the wreckage and sent a report and drawing to the Ministry of Marine. He also sent four photographs to the intelligence section of the Naval Staff. When the Germans asked if he had taken photographs he denied it, but unfortunately, they found one of the reports he had written in the possession of a 'messenger', a sailor working on the Elsinore–Helsingborg (Sweden) ferry. [53] [**Bornholm Island, 10km northeast**]

<u>Date unknown</u>
According to contemporary British records, after the Bornholm missile a second one was recovered from the sea by the Swedes (date unknown). It was given a cursory examination and then blown up as a mine. [54] [**unknown location**]

<u>November 18 1943</u>
After a collision with U-476, U-718 (Oblt. Helmut Wieduwilt) sank on the 18th of November 1943, north-east of Bornholm. The exact position is: 55.21N, 15.24E. [55] [**>30km northwest**]

<u>December 20, 1943</u>
BV 138 damaged in Rønne Harbour on the island of Bornholm. At 23:10 hours on the evening of 20/12 it was reported by Oberleutnant that BV 138 6H+PH had lost its moorings due to a storm and had drifted ashore and was under partial water. At 09:30 hours on the morning of 21/12 he reported that BV 138 coded 6H+NH had lost its mooring and had drifted towards land and had hit 6H+PH. The aircraft belonged to 1./ Küstenfliegerergänzungsgruppe (See) and was coded 6H+PH. On 30/12 both aircrafts were salvaged by Bergungsprahm BP 45. 6H+PH was transported to Travemünde on 5/1 1944 and 6H+NH followed later. [56] [**9km north**]

<u>March 13, 1944</u>
Si 204 serial number 0012 made an emergency landing in a field between Kiledgård farm and Hjuleregård farm near Blemmelyng about one kilometer northwest of the church of Nylars on the island of Bornholm. The aircraft belonged to Erprobungsstelle d. Lw. Rechlin. It was damaged 90%, but the crew remained unharmed. [57] [**Bornholm Island, 5km north**]

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[52] Grooss, Poul, *The Naval War in the Baltic, 1939-1945* (Pen & Sword Books 2017), p. 293.
[53] Ransted, Chris. *Disarming Hitlers V Weapons: Bomb Disposal, the V1 and V2 rockets* (Pen & Sword Books 2013), p. 23.
[54] Ibid., p. 23.
[55] *The Baltic - The U-boat War in Maps* (https://uboat.net/maps/baltic_sea.htm), accessed on October 4, 2021; Grove, Eric J. *The Defeat of the Enemy Attack upon Shipping, 1939–1945: A Revised Edition of the Naval Staff History* (Routledge Revivals 1957), p. 263.
[56] *BV 138 damaged in Rønne Harbour on the island of Bornholm 20/12 1943* (http://www.flensted.eu.com/), accessed on October 5, 2021.
[57] *Si 204 serial number 0012 emergency landed on the island of Bornholm 13/3 1944* (http://www.flensted.eu.com/), accessed October 4, 2021.

8 April 1944

V-1 crashed at Østermarie on the island of Bornholm. The V-1 is believed to have been fired from a He 111 and should probably have crashed into the Baltic Sea. At 15:45 hrs it was seen flying from a south southwesterly direction towards north northeast. It hit some trees between the farms Stamperegaard and Kofoedgaard and crashed in a field, jumped back up and continued for another 400 metres before it hit the ground and exploded. It disintegrated and parts of it set fire to a barn belonging to Stamperegaard. Apparently, there had been no explosives in the V-1 and the explosion had been caused by the fuel. The German Inselkommandant was informed and collected the wreckage. [58] [**Bornholm Island, 12km northeast**]

April 8, 1944

On 8 April 1944, a fourth V-1 crashed 20 metres from Stampere Farm, near Stamperegaarden in Ostermarie on Bornholm. [59] [**Bornholm Island, 12km northeast**]

April 11, 1944

B-17G 42-37876 crashed in the Baltic Sea south of the island of Bornholm. The aircraft belonged to USAAF, 8th Air Force, 95th Bomb Group, 412th Bomb Squadron and was coded QW-S. MACR 3804 states: B-17G 42-37876 piloted by 2nd Lt Eugene T. Schiappacasse was hit by a T/EE/A (= Twin engined enemy aircraft) from 2 o`clock high using rockets. A/c winged over to the left and climbed a little in control. No fire or damage visible. Ten chutes were seen to leave aircraft at 54`15N 15`00E at 12:18 hours. Co-pilot 2nd Lt David Janofsky was picked up from the sea by the German fishing trawler "Josef Stadtland" but not until the next day did it radio Hasle, Bornholm and requested that a boat come and pick up a wounded flyer. Olaf Thorsen in his fishing boat "Anna" picked Janofsky, who was still alive, up and took him to Svanike where he was handed over to the Germans. The next morning Janofsky was dead, and he was laid to rest in Svanike cemetery on 14/4 1944. [60] **[>50km north**]

April 11, 1944

B-17G 42-31427 ditched in the Baltic Sea. The aircraft belonged to USAAF, 8th Air Force, 305th Bomb Group, 364th Bomb Squadron. 42-31427 was hit by FLAK over the target and had to feather a propeller. On the return flight it left the formation and headed for Sweden. 25 miles east southeast of Tejn on the island of Bornholm Pilot 1st Lt Calvin Vanee found necessary to ditch the B-17. At 15:00 hours he made a perfect landing after which the crew entered the B-17`s two dinghies.

The ditching had been observed from the Danish fishing boat RØ 40 "Dannebrog" of Tejn and at 15:30 Skipper Gaarde Jensen was beside the dinghies. The flyers transferred to the fishing boat and the dinghies were taken in tow. Due to the presence of a German patrol boat guarding the fishing place it was not possible for Jensen to sail the flyers to Sweden and at 19:00 hours "Dannebrog" arrived at Tejn harbour. After about 1½ hour the flyers were picked up by a Wehrmacht truck and taken to Rønne. [61] [**unknown location**]

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58 *V-1 crashed at Østermarie on the island of Bornholm 8/4 1944* (http://www.flensted.eu.com/), accessed on October 4, 2021; Grove, Eric J., *The Defeat of the Enemy Attack upon Shipping, 1939–1945: A Revised Edition of the Naval Staff History* (Routledge Revivals 1957), p. 267.

59 Ransted, Chris., *Disarming Hitlers V Weapons: Bomb Disposal, the V1 and V2 rockets* (Pen & Sword Books 2013), p. 23.

60 *B 17G 42-37876 crashed in the Baltic Sea south of the island of Bornholm 11/4 1944* (http://www.flensted.eu.com/), accessed on October 5, 2021.

61 *B 17G 42-31427 ditched in the Baltic Sea 11/4 1944* (http://www.flensted.eu.com/), accessed on October 5, 2021.

April 11, 1944

B-17F 42-29939 crashed in the Baltic Sea. The aircraft belonged to USAAF, 8th Air Force, 96th Bomb Group, 338th Bomb Squadron and was coded BX-X. 42-29939 was attacked by German fighters and crashed into the Baltic Sea not far from the island of Bornholm. Four crew members managed to bail out of the aircraft before the crash. Left waist gunner Sgt Wilfred A. Dennis landed in the sea and was picked up by a German patrol boat. He was taken to the captain and requested that the captain searched for survivors. He denied that, saying that he had to report back to port immediately. It is not known to which prisoner of war camp he was sent. [62] [**unknown location**]

April 11, 1944

B-17G 42-31156 crash landed near Nexø. The aircraft belonged to USAAF, 8th Air Force, 447th Bomb Group, 708th Bomb Squadron. When approaching the Focke Wulf aircraft factory at Arminswalde it was found to be covered by clouds and the alternative target in Stettin was bombed. After having dropped its load 42-31156 was hit by FLAK and Pilot 1st Lt Howard S. Pauling and Co-pilot 2nd Lt Lauren M. Davis had to feather the two inboard engines. They then left the formation at 12.000 feet and headed towards Sweden. Believing that they were over Sweden they belly landed the Flying Fortress named “Big Stoop” at “Skyttegaard” farm near Ibsker 3 kilometres north of Nexø on the island of Bornholm at 14:52 hours. [63] [**Bornholm Island, 10km east**]

April 12, 1944

Ar 196A-3 serial number 1021 crash landed at Rø plantation. The aircraft belonged to 4./Erg.Gr.(See) and was coded 6H+LM. Somewhere around nine o`clock in the morning the aircraft attempted an emergency landing in Rø plantation on the island of Bornholm. Pilot Unteroffizier Theo Vernhofen failed, and the aircraft came down in some rather large pine trees where it ploughed its way for about a hundred metres. The aircraft broke up killing Vernhofen and Wop Unteroffizier Eduard Knab and a fire started. One crew member was found in the wreck when the fire ended, and one was found to have been thrown clear in the crash. [64] [**Bornholm Island, 17km north**]

April 23 and 24, 1944

During the night of 23/24 April 1944, 12 naval mines were dropped for the second and last time in the Pollock area by two British Avro Lancaster heavy bombers of 1 Group. [65] The exact drop locations of the 1,500 lbs mines are not shown. [**mine garden Pollock, coinciding with export cable corridor**]

April 29, 1944

B-24H 41-29479 crashed near Poulsker. The aircraft belonged to USAAF, 8th Air Force, 448th Bomb Group, 715th Bomb Squadron. Three engines were shot out by FLAK and the nose turret as well as the top turret and the tail plane was badly damaged by FLAK. The plane was losing height by 600 feet pr. minute, and it was decided to leave the aircraft as soon as they were over the island of Bornholm.

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[62] *B 17F 42-29939 crashed in the Baltic Sea 11/4 1944* (http://www.flensted.eu.com/), accessed on October 5, 2021.

[63] *B 17G 42-31156 crash landed near Neksø 11/4 1944* (http://www.flensted.eu.com/), accessed on October 5, 2021.

[64] *Ar 196A-3 serial number 1021 crash landed at Rø plantation 12/4 1944* (http://www.flensted.eu.com/), accessed on October 5, 2021.

[65] TNA UK, AIR14/2678; TNA UK, AIR27/816; TNA UK, AIR14/3116.

Bombardier 2nd Lt Laurin M. Derosier, Top turret gunner T/Sgt Harry J. Ambrosini, Right waist gunner S/Sgt William L. Hutchins, left waist gunner S/Sgt Harold W. Nininger, nose turret gunner S/Sgt Stanley E. Jones and tail gunner Sgt Albert L. Heikkila bailed out through the waist escape hatch at 3,000 feet. When they had left, Radio operator T/Sgt Russell D. Leonard, Navigator 2nd Lt Robert L. Bobst, Co-Pilot F/O Thonas J. Verran and Pilot 2nd Lt Orland T. Howard bailed out through the bomb bay. At 14:22 hours the Liberator crashed in a field belonging to "Jomfrugaard" farm near Povlsker on the island of Bornholm. [66] [**Bornholm Island, 10km east**]

May 5, 1944

He 111 emergency landed near Nylars. A He 111 made an emergency landing in a field belonging to Klintegaard farm north of Nylars church on the island of Bornholm early in the evening. An engine and a landing gear were damaged while the crew were unharmed. Apparently, the aircraft was repaired on the spot and later flown out. [67] [**Bornholm Island, 5km north**]

May 19, 1944

Two experts, a radio specialist by the name of Squadron Leader Calvert and armament specialist Flight Lieutenant Heath, were flown over to Sweden on 19 May with the intention of examining the wreckage of a V1 in Sweden. During discussions between the two British and the Swedish technical officers, it emerged that the Swedes had previously recovered two similar projectiles, and there were two others known to have crashed on the German-occupied Danish Island of Bornholm. All five had come down as part of the V1 test program. [68] [**unknown location**]

May 24, 1944

B-17G 42-31619 belly landed at Sosegaard on the island of Bornholm. The aircraft belonged to USAAF, 8th Air Force, 615th Bomb Group, 401st Bomb Squadron. Over Germany 42-31619, called "BTO in the ETO", was hit by FLAK and number four engine stopped as did number two engine turbocharger. At 12:45 hours the B-17 left the formation at 55`00N 13`10E and headed for Sweden. Apparently believing that the Danish Island of Bornholm was Swedish "BTO in the ETO" came low over Rønne airport from the sea after having dropped the radio equipment in the water and belly landed in a field belonging to "Sosegaard". The time was 14:12 hours. [69] [**Bornholm Island**]

June 15, 1944

Do 24T-2 serial number 3351 damaged near Bornholm Island. The aircraft belonged to Erprobungsstelle der Luftwaffe and was coded KT+MU. The seaplane was damaged when attempting to salvage a dinghy. [70] [**unknown location**]

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[66] *B 24H 41-29479 crashed near Poulsker 29/4 1944* (http://www.flensted.eu.com/), accessed on October 5, 2021.

[67] *He 111 emergency landed near Nylars 5/5 1944* (http://www.flensted.eu.com/), accessed on October 5, 2021.

[68] Ransted, Chris. *Disarming Hitlers V Weapons: Bomb Disposal, the V1 and V2 rockets* (Pen & Sword Books 2013), p. 22.

[69] *B 17G 42-31619 belly landed at Sosegaard on the island of Bornholm 24/5 1944* (http://www.flensted.eu.com/), accessed on October 5, 2021.

[70] *Do 24T-2 serial number 3351 damaged near Bornholm Island 15/6 1944* (http://www.flensted.eu.com/), accessed on October 5, 2021.

August 17, 1944
Lancaster III NE167 crashed in the Baltic Sea near Swinemünde. The aircraft belonged to RAF 97Sqn. Bomber Command and was coded OF-Y. A message was received from the aircraft at 01:22 hours while still over the target area, stating that the aircraft was on fire and that the crew were preparing to bail out. The body of Rear gunner Sgt T M. Twomey was found washed ashore at Dueodde on the island of Bornholm on 27/9 by the German Fluwa based there. [71] [**historical context**]

January-February 1945
The evacuations of German divisions were centred on Gotenhafen, Danzig and Hel, and in order that embarkations could be carried out, an effective air defence system had to be established to keep the large numbers of Soviet aircraft at a distance. This became a task for the Kriegsmarine's FLAK guns. In the coastal areas, the Baltic Fleet's aircraft from the 9th Air Support Division under Lieutenant-Colonel 30 Slepenkov were on patrol, along with the 8th Minelaying and Torpedo Aircraft Regiment under Colonel Kurochkin. Slepenkov later had a role in connection with the air raids on Bornholm. [72] [**historical context**]

February 14, 1945
Halifax III MZ793 crashed at Sdr. Asmindrup. The aircraft belonged to RAF 10 Sqn. Bomber Command and was coded ZA-X. When MX793 was flying outbound over the island of Sjælland it was attacked by a German Ju 88 G-6 nightfighter coded D5+ZB of I./ NJG 3 piloted by Gruppenkommandeur Major Werner Husemann and with the crew of Bordfunker Hans-Georg Schierholz, Bordschütze Feldwebel Willi Möller and Second Bordfunker Feldwebel Hein Fehmann. [73] [**>50km west**]

March 6 and 7, 1945
Lancaster I NG396 crashed in the Baltic Sea. The aircraft belonged to RAF 44 Sqn. Bomber Command and was coded KM-G. The Lancaster is believed to have been hit by FLAK and to have crashed into the Baltic Sea. On 18/6 1946 fisherman Carl Jensen of the fishing boat K 1235 "Narhvalen" of Vordingborg was fishing in the Baltic Sea between the island of Møn and Bornholm. At about midday he was trawling at approximately 50 meters when the trawl fouled a heavy object. On pulling the net up to the surface he discovered, in the net, the body of an airman. It was the body of Flt. Engr. Sgt William C. Thornton. [74] [**unknown location**]

March 23, 1945
On March 23, 1945, one of the most important units of the Kriegsmarine, Ausbildungsgruppe für Front-U-Boote, moved to Rønne on the island of Bornholm while torpedo firings were moved to Travemünde. The submarines were ordered partly to the waters around Bornholm and partly to Norwegian waters, while some of the staff were evacuated in three ships that put in at German Baltic ports further west. That same day, five new Type XXIII submarines sailed to Rønne. These were the U-2334, U-2356, U-2357, U-2359 and U-4701. U-2361 (Type XXIII) arrived later due to rudder problems. [75] [**historical context**]

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[71] *Lancaster III NE167 crashed in the Baltic Sea near Swinemünde 17/8-1944* (http://www.flensted.eu.com/), accessed on October 5, 2021.
[72] Grooss, Poul, *The Naval War in the Baltic, 1939-1945* (Pen & Sword Books 2017), p. 418.
[73] *Halifax III MZ793 crashed at Sdr. Asmindrup 14/2 1945* (http://www.flensted.eu.com/), accessed on October 5, 2021.
[74] *Lancaster I NG396 crashed in the Baltic Sea 6-7/3 1945* (http://www.flensted.eu.com/), accessed on October 5, 2021.
[75] Grooss, Poul, *The Naval War in the Baltic, 1939-1945* (Pen & Sword Books 2017), p. 422.

<u>March 28, 1945</u>

The submarines U-2533, U-3522, U-3025 (Type XXI) and U-1007 (Type VIIC) arrived at Rønne on 28 March with a total of 185 Hitler Youth members on board in addition to their own crews. One of the group's other submarines struck a mine on its way out and all the crew were lost. It turned out later that on board the submarine were the submarine commander's wife and several relatives of the other crew members. This was not normally permitted, but the situation could not be described as normal. Three Type XXI submarines, U-3012, U-3013 and U-3529, brought fifty FLAK soldiers and an unknown number of refugees to Bornholm. [76] [**historical context**]

<u>April 16, 1945</u>

Figure 3: The Norwegian freighter Goya from the shipping company J Ludwig Mowinkel A/ S in Bergen, sailing in home waters. Goya was seized and requisitioned for German refugee transports. On 16 April 1945, she was sunk east of Bornholm by the Soviet submarine L-3. About 6,220 people went down with the ship. [77]

<u>May 1945</u>

The German forces withdrew as slowly as possible, partly to ensure the relocation and training of the new submarine crews and production of the new submarines of Type XXI and Type XXIII. Submarine training had to be moved from Memel and Gotenhafen. It was first moved to Bornholm, and from here most of it was transferred to Norway in the final phase of the war. [78] [**historical context**]

<u>May 4, 1945</u>

Bf 109K-4 landed north of Rønne. The aircraft belonged to III./ JG 51 and was coded Black 1. The Bf 109K-4 made a normal landing in a field at Langebjerg north of Rønne on the island of Bornholm. [79] [**Bornholm Island**]

<u>May 7, 1945</u>

Bf 109G-8 Werk number 201143 belly landed near Nyker. Oberleutnant Leibnitz had taken off from Kurland to escape the Russian forces. He belly landed the Bf 109G in a field belonging to the farm "Buldregård" south of Nyker on the island of Bornholm. [80] [**Bornholm Island**]

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[76] Grooss, Poul, The Naval War in the Baltic, 1939-1945 (Pen & Sword Books 2017), p. 422-423.

[77] Ibid, p. 437.

[78] Ibid, p. 333.

[79] *Bf 109K-4 landed north of Rønne 4/5 1945* (http://www.flensted.eu.com/), accessed on October 5, 2021.

[80] *Bf 109G-8 Wreck number 201143 belly landed near Nyker 7/5-1945* (flensted.eu.com), accessed on October 4, 2021.

May 7, 1945

A little before noon, Soviet naval aircraft from the 51st Mine and Torpedo Air Regiment bombed Rønne and Nexø. From a Soviet point of view, it was a natural thing to do, because before a major attack 'the main objectives had to be softened up', either by artillery bombardment or bombs. In the evening, the Russians dropped more bombs on the towns, as well as leaflets with Russian text. They contained a call for the island's German commander to surrender to the Russians the next morning. To that end, he had to come to Kolberg before ten o'clock. The sea journey would be made safe, it said. The flyer was signed by 'Lieutenant-Colonel Slepenkov, Commander of the air units'. [81] [**Bornholm Island, >5km northwest and >5km east**]

May 8, 1945

When the surrender had not taken place, a renewed bombardment of Rønne and Nexø came on 8 May, but by now the towns had been evacuated. Ten Bornholm civilians died. The bombing raid came around nine o'clock, since the Russians were not aware of the time difference, and that their ultimatum had not yet expired. The bombardment of Rønne and Nexø, and the subsequent Soviet capture of the island was an opportunity the Russians just suddenly grabbed. [82] [**Bornholm Island, >5km northwest and >5km east**]

May 9, 1945

On 9 May, a lot of ships sailed close to Christiansø, an island off the east coast of Bornholm. Many of them came from Libau and Ventspils, but there were also some from the pockets at Hel and on the estuary of the Vistula. When passing Christiansø, they were subjected to an air raid – after the end of the war – by a large number of Soviet aircraft. The fighting could be followed from Christiansø and Bornholm. The tanker Liselotte Friederich and the artillery ferry barge F517 were sunk off Christiansø with the loss of ten and five men respectively. Throughout the following summer, countless bodies drifted up onto the shores of Bornholm from all the ships sunk during the previous months. [83] [**>20km northeast**]

May 9, 1945

The Russian landing took place after the war had ended. It was on the afternoon of 9 May, when five Soviet motor torpedo boats with about a hundred marines on board took Rønne harbour without a fight. The German forces did not put up any resistance. Among the German officers on the quay was Wuthmann's chief of staff. The war had ended the previous evening at 21:00 on 8 May. [84] [**historical context**]

June 1, 1945

On 1 June 1945, one of the ships that shuttled back and forth between Rønne and Kolberg was sunk. This was the rescue ship Vesterhavet, which struck a mine just outside Kolberg harbour. Only eight of the 225 Soviet soldiers on board, and only one of the Danish crew of twelve, were rescued. The ships being used sailed German POWs away from Rønne and brought Soviet troops in the opposite direction. [85] [**>65km southeast**]

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[81] Grooss, Poul, *The Naval War in the Baltic, 1939-1945* (Pen & Sword Books 2017), p. 453-454.
[82] Ibid., p. 454.
[83] Ibid., p. 449.
[84] Ibid., p. 455.
[85] Ibid., p. 469.

August 1945 – December 1946

Towards the end of the war chemical munitions were dumped to remove dangerous munitions from areas subject to imminent attacks, to prevent munitions from being seized by attacking troops and to demilitarize before surrender. In the post-war period, dumping at sea was chosen by the Allies to allow for the swift demilitarisation and removal of dangerous war materials from Germany.

During the period between August 1945 and December 1946 chemical munitions were dumped in the Bornholm Basin dumping area on behalf of the British Military Administration in Germany. [86] [**>50km northeast**]

1946

In 1946, according to witness reports, four ships containing around 15,000 tonnes of chemical munitions were scuttled south-west of Bornholm. These dumping's have not been confirmed by other sources. [87] [**unknown location**]

August 1947 – January 1948

During the period between August 1947 and January 1948 chemical munitions were dumped in the Bornholm Basin dumping area on behalf of the Soviet Military Administration in Germany. [88]

Between August 1947 and January 1948, an alleged 32,000 tonnes of chemical warfare materials, later reported to have contained altogether about 11,000 tonnes of chemical warfare agent payload, were shipped to the area. [89] [**>50km northeast**]

1959 – July 1965

Even after the official conclusion of the demilitarisation campaign, chemical warfare materials were discovered on German territory. In the early 1950s, the German Democratic Republic (GDR) disposed of these materials by chemical treatment, while in the late 1950s and most decidedly in the first half of the 1960s dumping activities were resumed, mainly by using the old dumping area east of Bornholm. [90] [**>50km northeast**]

1994 - to the present

Since 1994 112 cases of chemical warfare materials caught by fishermen were reported in the wider area around Bornholm, accounting for altogether about 5,410kg of warfare agent payload. In 80% of cases (about 4,140kg of warfare agent payload; net weight), the material has been relocated to designated emergency relocation areas. In total, 93 cases were related to sulphur mustard warfare materials, including more than 80 lumps of solidified sulphur mustard. [91] [**adjacent to export cable route corridor**]

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[86] HELCOM, 2013, *Chemical Munitions Dumped in the Baltic Sea. Report of the ad hoc Expert Group to Update and Review the Existing Information on Dumped Chemical Munitions in the Baltic Sea* (HELCOM MUNI), Baltic Sea Environment Proceeding (BSEP) No. 142 Number of pages: 128, p. 43.

[87] Ramboll, *Baltic Pipe Offshore Pipeline: Permitting and Design, UXO Desk Study*, (October 2019), p. 5.

[88] HELCOM, 2013, *Chemical Munitions Dumped in the Baltic Sea. Report of the ad hoc Expert Group to Update and Review the Existing Information on Dumped Chemical Munitions in the Baltic Sea* (HELCOM MUNI), Baltic Sea Environment Proceeding (BSEP) No. 142 Number of pages: 128, p44.

[89] Ibid., p. 44.

[90] Ibid., p. 43.

[91] Ibid., p. 54.

2016

During the UXO clearance campaign for Wikinger Süd OWF a Russian ground mine and a Russian contact mine were encountered and disposed of. [92] These mines were submarine laid. [**south of OWF**]

2.3 WAR RELATED ACTIVITIES RELEVANT TO THE AREA OF INVESTIGATION

The consultation of historical sources showed that there are several war related activities relevant to the area of investigation. Also, post war military activities may have contributed to the UXO contamination in the area.

In this section the relevance of the identified war related events for the area of investigation is determined. The information gathered and assessed provides a reliable indication of the types of UXO that may be left behind and the qualitative likelihood. However, it is not possible to demarcate the exact areas where different types of UXO are to be expected. The historical sources often lack reliable location information.

To indicate the likelihood of presence the classification indicated in Table 4 is used.

Presence term	Meaning
Highly unlikely	No evidence pointing to the presence of this type of UXO within an area but it cannot be discounted completely.
Unlikely	Some evidence of this type of UXO in the wider region but it would be unusual for it to be present within the area of investigation.
Possible	Evidence suggests that this type of UXO could be present within the area of investigation.
Likely	Strong evidence [93] that this type of UXO is likely to be present within the area of investigation.
Highly likely	Indisputable evidence [94] that this type of UXO is present within the area of investigation.

Table 4: Definitions of terminology used for the likely presence of UXO.

For all UXO with a likelihood of presence ranging from possible to highly likely a UXO risk area is demarcated. The colours indicating the UXO risk areas display the likelihood of presence for that particular type of UXO.

2.3.1 Minelaying by aircraft

During the Second World War "gardening" was the British Royal Air Force (RAF) term given to the dropping of mines from Bomber Command aircraft into the sea. The mines were laid at strategic positions near ports, inland waterways, estuaries, and shipping lanes. Throughout Europe the coastline was split into various targets. These targets were given distinct code names; the majority (but not all) were given names of trees and plants.

The key issue was that to successfully place the mines in the correct position, a bomber would have to fly considerably lower than a usual bombing sortie over, say, a German city. Accuracy was essential and the bomber would generally fly under 1,500 feet. This would make them an obvious target for FLAK.

[92] Source: STASCHEIT Kampfmittelräumung GmbH.

[93] Strong evidence means there are several reliable and verifiable indications from primary sources indicating the likely presence of UXO in the area of investigation.

[94] In case of indisputable evidence these UXO are encountered in the area of investigation in the past.

The crucial part of 'gardening' was to ensure the mines landed in an area that was being used as a shipping lane. This would necessitate mine-sweeping and cause considerable delays to vessels either entering or leaving ports.

The export cable route crosses the former mining area codenamed 'Pollock'. Here minelaying was conducted by RAF Bomber Command during the years 1942-1943. In 'Pollock' a total of 104 A Mk I-IV and A Mk VI ground mines were laid in 1942 and 1943. [95]

Military mine clearance in modern time (1996-2021) shows that approximately 70% of the number of mines laid normally remain today in the areas the mines were laid. [96]

Considering the number of mines laid and the effectiveness of the post war mine clearance operations, the likelihood of presence of ground mines is assessed to be likely.

UXO type	Type	Likelihood of presence
Ground mines	A Mk I-IV and A Mk VI	Likely

Table 5: Likelihood of presence for UXO originating from minelaying by aircraft.

The likelihood for ground mines to remain is limited to the Mine Danger Area (MDA) of the Pollock gardening zone (see Figure 4).

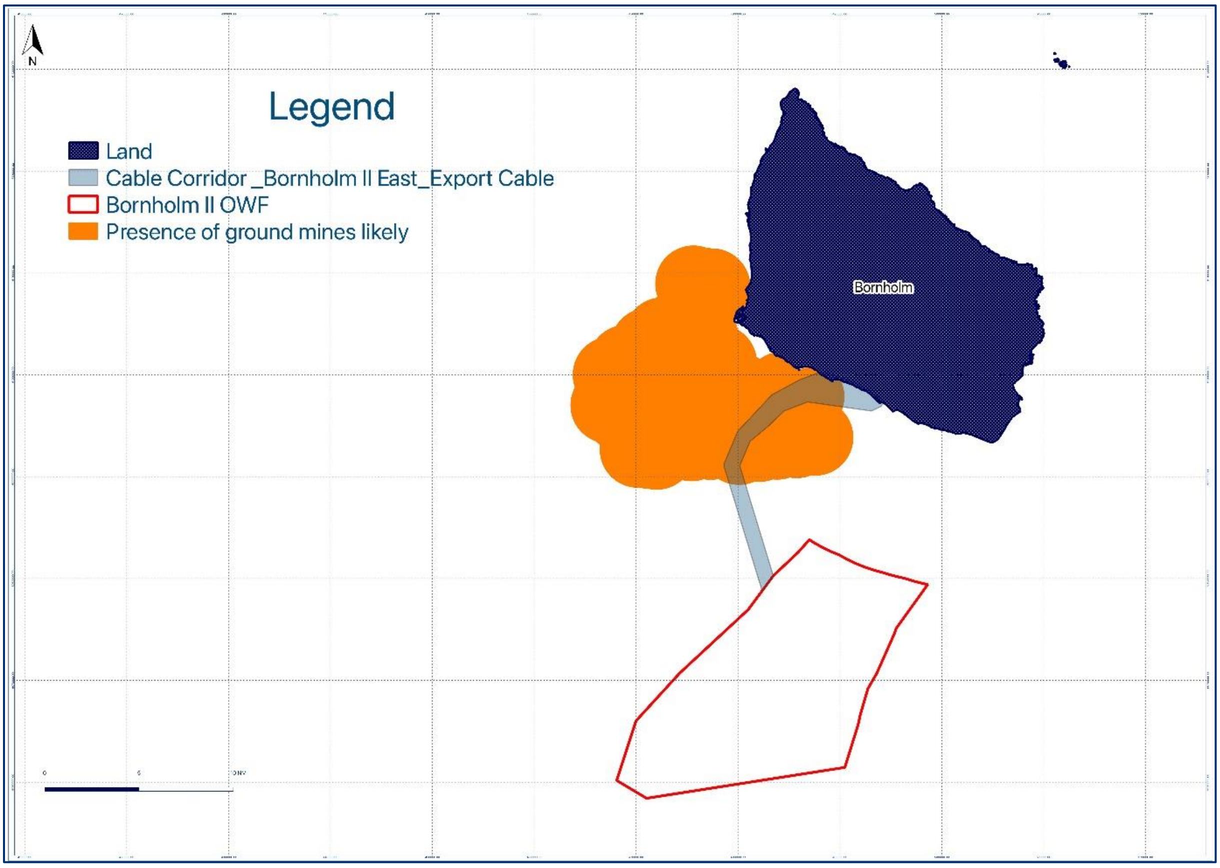

Figure 4: Demarcation of the area Mine Danger Area where the presence of ground mines is likely.

95 Source: LtCdr G. Möller, Royal Swedish Navy.
96 Idem.

2.3.2 Minelaying by submarines

During the UXO clearance campaign conducted for the Wikinger Süd OWF two submarine laid Russian mines were encountered. The UXO threat assessment showed that there were mines laid by the Russian naval forces during WWII. The exact positions of these minefields however are often not known. There are no known Russian minefields coinciding with the area of investigation. [97] The minefields are believed to be located west of Bornholm. Therefore, the likelihood of presence of submarine laid Russian mines is assessed to be highly unlikely.

UXO type	Type	Likelihood of presence
Ground and buoyant mines	Unknown	Highly unlikely

Table 6: Likelihood of presence for UXO originating from minelaying by submarines.

2.3.3 Airplane crashes

During the war many aircraft crashed in the Baltic Sea. In the first years of the war several German aircraft crashed in the Baltic Sea and at Bornholm Island.

From February 1942 onward, the British bombing campaign not only targeted military targets. Industrial sites and civilian areas were increasingly being targeted during the Allied strategic bombing campaign. The flight paths of several bombing raids on northern German and Polish cities were positioned north of the German Coast. Here, the allied planes were within reach of the German Night Fighters and German FLAK (Flugabwehrkanone, anti-aircraft artillery) positions. [98]

When under attack or damaged by German Night fighters or anti-aircraft artillery, the bombers often jettisoned their bombs to reduce weight and, increase the chance of reaching friendly territory. Bomb loads could be jettisoned in a safe or armed condition. Safe condition means the initiation device fitted within the bombs were not in their armed state. Specific information about the positions of these jettisons is often lacking.

The consultation of the historical sources did not yield any indications for bomb jettisons. However, since 1943 several allied bombers crashed in the Baltic Sea surrounding Bornholm Island. Therefore, the presence of jettisoned bombs cannot be excluded. The likelihood of presence is assessed to be possible.

UXO type	Types	Likelihood of presence
Air dropped bombs	All common types of UK and US HE and incendiary bombs	Possible

Table 7: Likelihood of presence for UXO originating from bomb jettisons by allied aircraft.

It is not possible to reliably demarcate the area where bomb jettisons may have occurred. Therefore, the likelihood of presence of jettisoned bombs applies to the entire area of investigation (see Figure 5).

97 Source: LtCdr G. Möller, Royal Swedish Navy.

98 The UXO threat assessment indicated that on February 14, 1945, Halifax III MZ793 crashed after it was attacked by a German Ju 88 G-6 night fighter coded D5+ZB of I./ NJG 3.

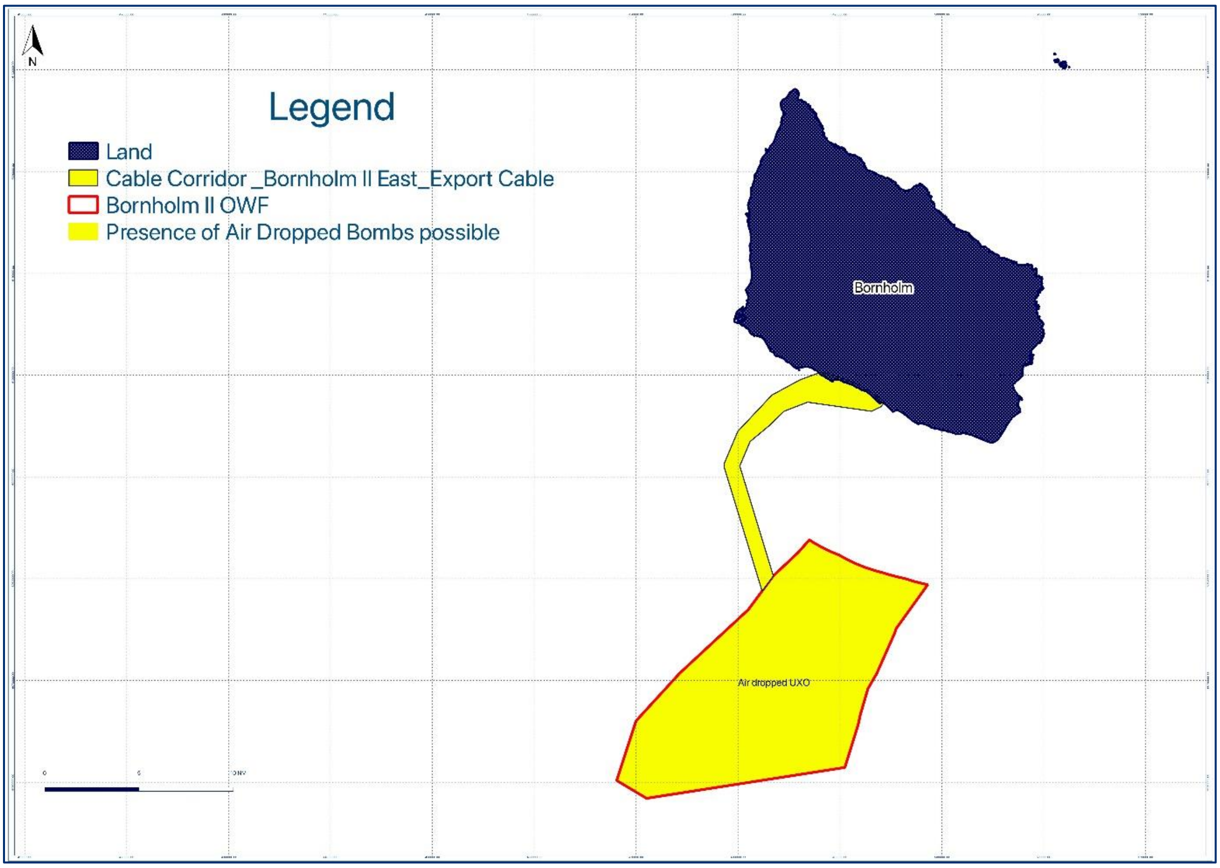

Figure 5: Area within the area of investigation where the presence of jettisoned bombs is possible.

2.3.4 V-1 crashes

The Peenemünde Army Research Facility was established by the Nazi regime in the late 1930's. The site included an electric power plant, later used after the closure of the research center for supplying energy to the East German power grid, an airport, later converted into an air base and operated by the Air Force of East Germany, a seaport, a series of technical facilities for testing and producing all that was needed to assemble rockets, their systems, and engines, as well as for preparing propellants. There were also several launch pads for missiles and V-1 rockets. Peenemünde was never an operative launch site, but a testing and production site of the V-1 rockets.

The consultation of historical sources showed that several V-1 rockets crashed on Bornholm and in the Baltic Sea near Bornholm during the testing of this weapon system. Reliable information on locations of V-1 crashes in the Baltic Sea is lacking.

The historical sources suggest that the German Inselkommandant soon arrived at the crash sites to collect the wreckages of the V-1s. It is assumed that also in case of a crash in the Baltic Sea, German forces tried to locate and recover the wreckage. This was to prevent that any information on the V-1 reached the allied forces. Therefore, the likelihood of presence of V-1 rockets is assessed to be unlikely.

UXO type	Types	Likelihood of presence
Rocket	V-1	Unlikely

Table 8: Likelihood of presence for UXO originating from V-1 testing by the Peenemünde Army Research Facility.

2.3.5 Aerial attacks on Rønne

On May 8 and 9 Rønne was heavily bombed by the Soviet Air Force. Given the distance between the target (Rønne harbour) and the export cable corridor of the Bornholm II East OWF this event is assessed not to impact the area of investigation. The likelihood of presence of Russian air dropped bombs is assessed to be highly unlikely.

UXO type	Types	Likelihood of presence
Air dropped bombs	Unknown	Highly unlikely

Table 9: Likelihood of presence for UXO originating from the aerial attacks on Rønne on May 8 and 9, 1945.

2.3.6 Dumping of chemical warfare materials in the Baltic Sea

The Bornholm Basin dumping area is situated in deep water to the northeast of Bornholm. The dumping area itself does not coincide with the area of investigation. One of the transport routes to the dumpsite crosses the Bornholm II East OWF. Over the post war period chemical warfare materials were discovered (e.g., by fisherman) well outside the designated dumpsite. The area where chemical warfare materials were encountered is demarcated by the Helsinki Commission (HELCOM). This area extends to the southeast of Bornholm, west of the Rønne ban, but does not coincide with the Bornholm II East OWF.

Chemical warfare materials can be found south-west of Bornholm in an emergency relocation area. This emergency relocation is bordering the Bornholm II East export cable route. The area has been assigned by the Bornholm-located Danish Navy Maritime Surveillance Centre South in the vicinity of the Bornholm dumpsite for the emergency disposal of netted warfare materials too unsafe to be brought and handled ashore. The area has a diameter of 0.5 nautical miles.

On the GIS-charts provided by the Royal Swedish Navy the emergency relocation area is shown. On this chart the area is considerably larger than the area with a diameter of 0.5 nautical mile. In Figure 6 the location of the emergency relocation area is presented.

The likelihood of presence of chemical warfare materials within the emergency relocation area is assessed to be possible. However, the emergency relocation area is not coinciding with the area of investigation. Within the area of investigation, the likelihood of presence of chemical warfare materials is assessed to be unlikely.

UXO type	Types	Likelihood of presence
Chemical warfare materials	Solidified sulphur mustard	Unlikely

Table 10: Likelihood of presence for chemical warfare materials in the area of investigation.

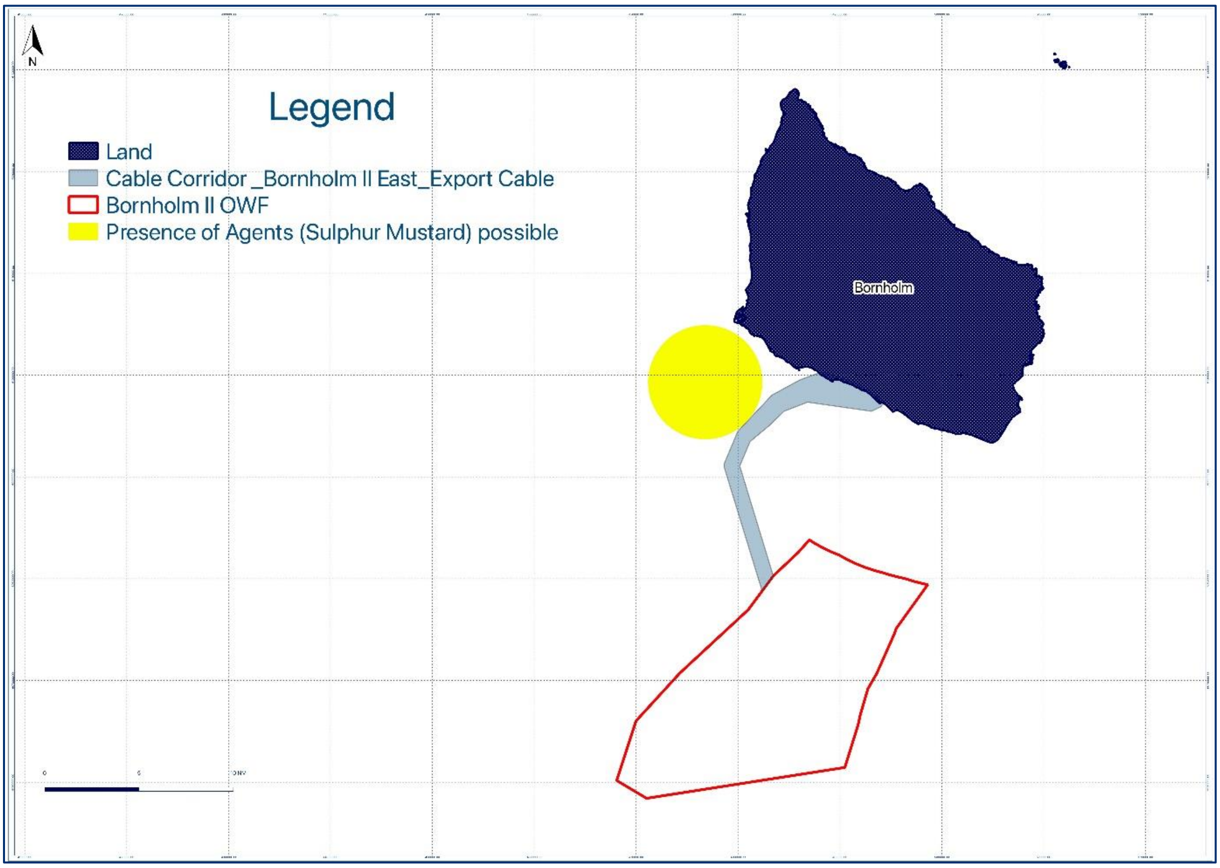

Figure 6: Emergency relocation area for encountered chemical warfare agents.

2.3.7 Military training areas

The Royal Swedish Navy provided GIS-charts showing the military training areas near the area of investigation.

There is one military training area in Danish waters that is relevant to the Bornholm II East OWF. The Danish training area “Dueodde” is situated at the south coast of Bornholm Island. The training areas overlaps with the export cable corridor. In this area firing practice may have been conducted.

There are also some military training areas in the German EEZ west of the Bornholm II East OWF. Most training areas are NATO training areas for submarine and air force training. These areas are not allowed for firing. Approximately 8km west of the area of investigation lies the artillery firing area ‘Artillerieschießgebiet Pommersche Bucht’. In this area artillery firing training is conducted. The training involves both inert practice ammunition and ammunition with a High Explosive (HE) fill.

During the UXO clearance campaigns conducted in preparation to the installation of the German OWFs Wikinger, Wikinger Süd, Arcadis Ost, and Arkona a significant number of artillery shells were encountered. The calibres encountered were 7.5cm, 8.8cm, 10.5cm, and 15cm. Some shells were fitted with mechanical delayed fuzes (zeitzunder). [99]

[99] Source: STASCHEIT Kampfmittelräumung GmbH.

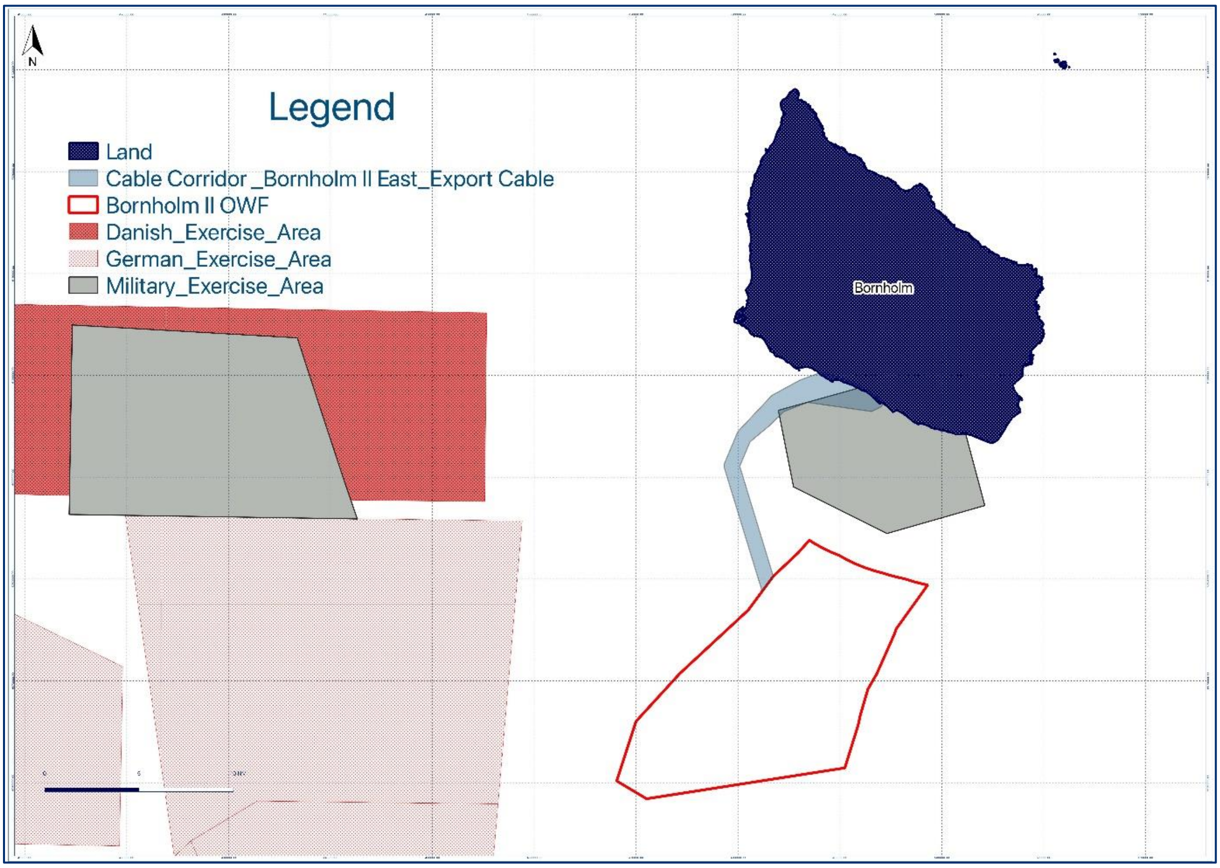

Figure 7: Military training areas.

The likelihood of presence for artillery shells area of investigation is assessed to be unlikely.

UXO type	Types	Likelihood of presence
Artillery shells	7.5cm, 8.8cm, 10.5cm, and 15cm	Unlikely

Table 11: Likelihood of presence for artillery shells because of artillery firing training.

3 SITE SPECIFIC DATA

In this chapter the site-specific data relevant to the UXO risk assessment are provided.

3.1 BATHYMETRY

To the Southwest of Bornholm, a shallow water area with Adler Grund and Rønne Banke separates the Arkona and Bornholm Basins. The Water depths on Rønne Banke is about 20m, and on Adler Grund the shallowest area is about 10m deep. The maximum water depth in the Bornholm Basin is 92m and the average depth in the Arkona Basin is 48m. In the Bornholm II East OWF site the water depth ranges from approximately 15m to 57m.

An overview of the bathymetry is shown in Figure 8.

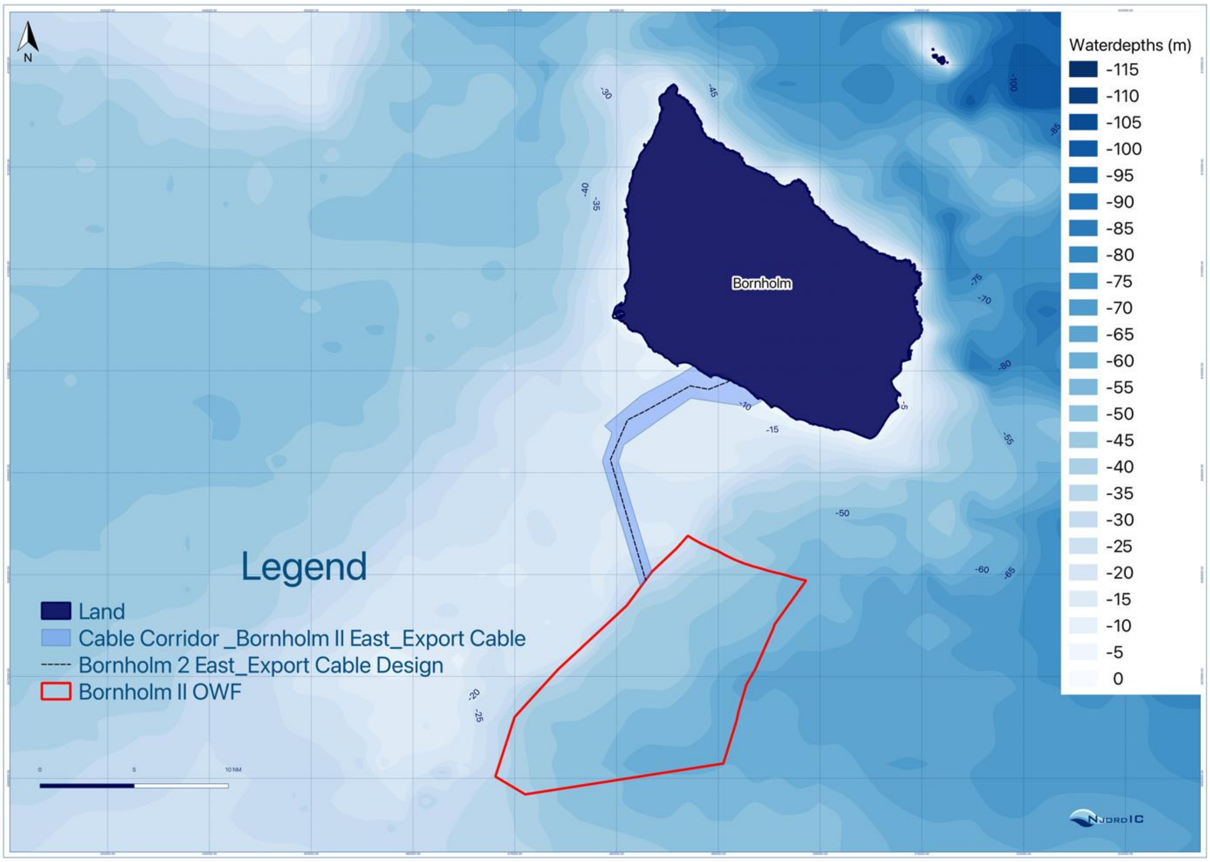

Figure 8: Bathymetry overview. [100]

3.2 EXPORT CABLE ROUTE

In this section the site-specific information for the export cable route is presented. The export cable route comprises part of the cable route Bornholm-Sjælland (KP 0.000 – KP 9.206), and the export cable route to Bornholm II OWF (KP 9.206 – KP 27.600).

[100] Source: *Geological Survey of Denmark and Greenland* (https://eng.geus.dk/, accessed October 8, 2021).

Figure 9: Overview of the Bornholm II East export cable route. [101]

3.2.1 Bathymetry

Cable route Bornholm-Sjællan (KP 0.000 – KP 9.206)

From KP 0.050 to KP 3.350 the seabed slopes gently down from an elevation of 1.63 m to a depth of 12.79 m. Between KP 3.350 and KP 4.250 the route crosses a raised rocky outcrop with ridges. From KP 3.350 to KP 9.206 the seabed continues slowly deepening westward with a very irregular bathymetry and moderate to very steep slopes due to seabed formations. [102]

Export cable route Bornholm II (KP 9.206 – KP 27.600)

The route starts at KP 9.206 moving over high-density boulder fields and outcrops. From KP 9.206 to approximately KP 17.0 the seafloor slope varies between very gentle and very steep. Within this section the maximum gradient of 26.2° is located at KP 12.868 and the shoal depth of 10.16 m is located at KP 13.145. Between approximately KP 17.0 and KP 19.0 the seafloor is very gentle and shoaling until KP 19.206 where the seafloor undulates until KP 22.206.

From KP 22.206 until KP 26.30 the seafloor is flat. At KP 26.30 there is very steep break in seafloor off the Ronne Bank from 15 m to 27 m depth over approximately 25 m distance: a slope of approximately 25°. For the remainder of the route the seafloor is gently deepening from KP 26.50 to 27.60; where the maximum depth of 33.44 m is located. [103]

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[101] Ocean Infinity, *Energy Island Cable Route Survey Baltic Sea*, reference 103971-ENN-OI-SUR-REP- SURVLOT1, revision 05, April 11, 2023.

[102] Idem.

[103] Idem.

3.2.2 Seabed surface geology

Cable route Bornholm-Sjællan (KP 0.000 – KP 9.206)

The surficial geology between KP 0 and KP 9.206 is highly variable characterised by outcrops of sedimentary rock with areas of sand, gravel, and coarse sand and diamicton. Diamicton is composed of sand, gravel and clay with cobbles and boulders. The outcropping sedimentary rock forms ridges at seabed and sediments infill the erosional surface of the bedrock. Glacial debris is prevalent between KP 0 and KP 9.206, with high density boulder fields. [104]

Export cable route Bornholm II (KP 9.206 – KP 27.600)

The start of the route between KP 9.206 and KP 13.957 is highly variable characterised by outcrops of sedimentary rock with areas of sand, gravel, and coarse sand and diamicton. The diamicton is composed of sand, gravel, clay with cobbles and boulders. The sedimentary rock forms ridges at seabed and sediments infill the erosional surface of the bedrock. Glacial debris is prevalent between KP 9.206 and KP 14.372, with high density boulder fields. A large area of gravel and coarse sand occurs between KP 13.957 to KP 26.367 extending across the entire width of the corridor, north-south trending ribbons of sand break up this area. There is a seabed ridge at KP 26.367, following the ridge the seabed sediment is composed primarily of sand. Areas of ripples occur within the areas of gravel and coarse sand; ripple crests are orientated north to south in line with the prevailing storm wave base. [105]

3.3 BORNHOLM II EAST OWF

In this section the site-specific information for the Bornholm II East wind farm site is presented

3.3.1 Bathymetry

The depth varies moderately across Bornholm II, except in the central-west area of the site. The minimum surveyed depth is 15.04 m at 476326 m E, 6072604 m N in the western part of the site. The maximum surveyed depth is 57.30 m at 493100 m E, 6070045 m N in the northern part of the site. The mean depth across the site is 46.41 m.

Figure 10 shows an overview of the bathymetry within Bornholm II East.

[104] Ocean Infinity, *Energy Island Cable Route Survey Baltic Sea*, reference 103971-ENN-OI-SUR-REP- SURVLOT1, revision 05, April 11, 2023.

[105] Idem.

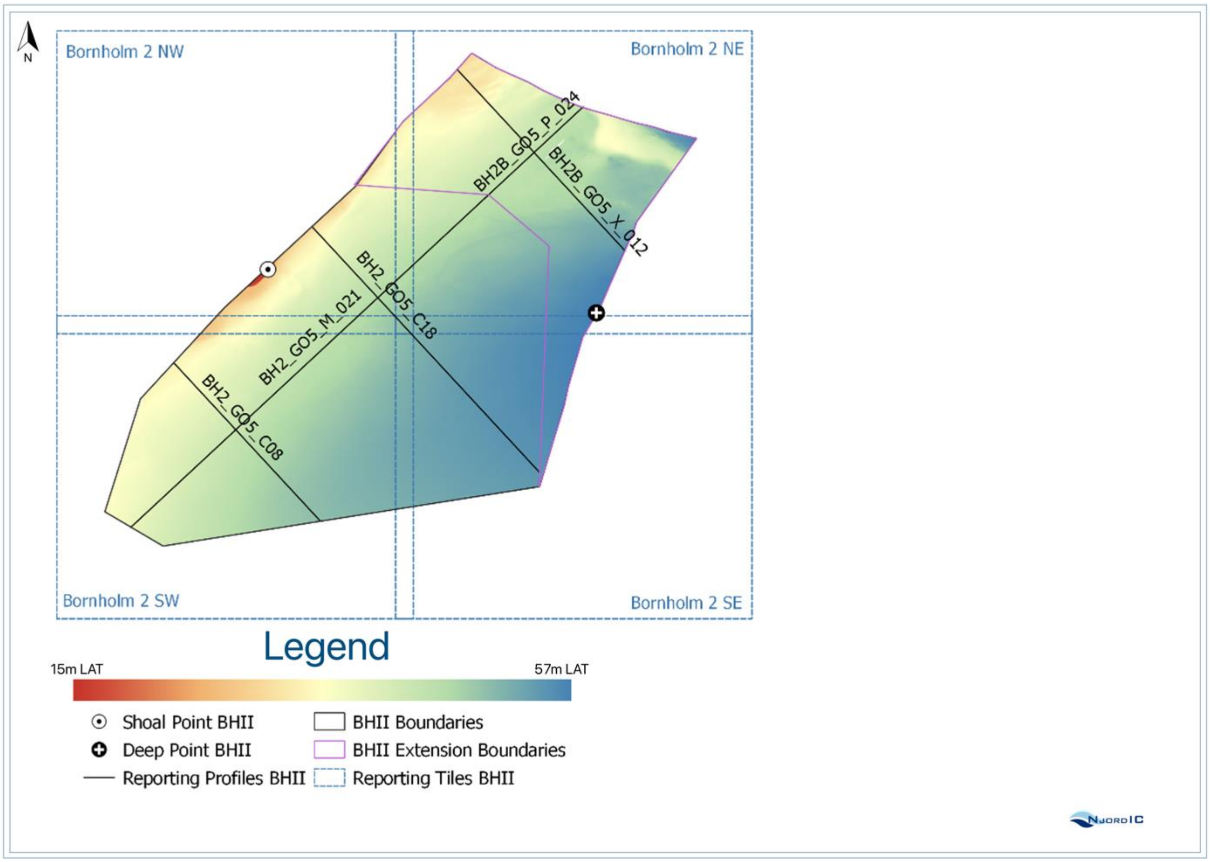

Figure 10: Bathymetry overview. [106]

3.3.2 Seabed surface geology

GEOxyz evaluated the seabed geology from the interpretation of the low frequency SSS data and backscatter datasets. [107] The geological interpretation using geophysical data was guided by the grab sampling campaign. The resultant seabed surface geology interpretation is highlighted in Figure 11.

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[106] Source: GEOxyz, *Geophysical Survey Report BHII - Work Package A*, reference BE4240H-771, revision 4.0, 10/03/2023.

[107] Idem.

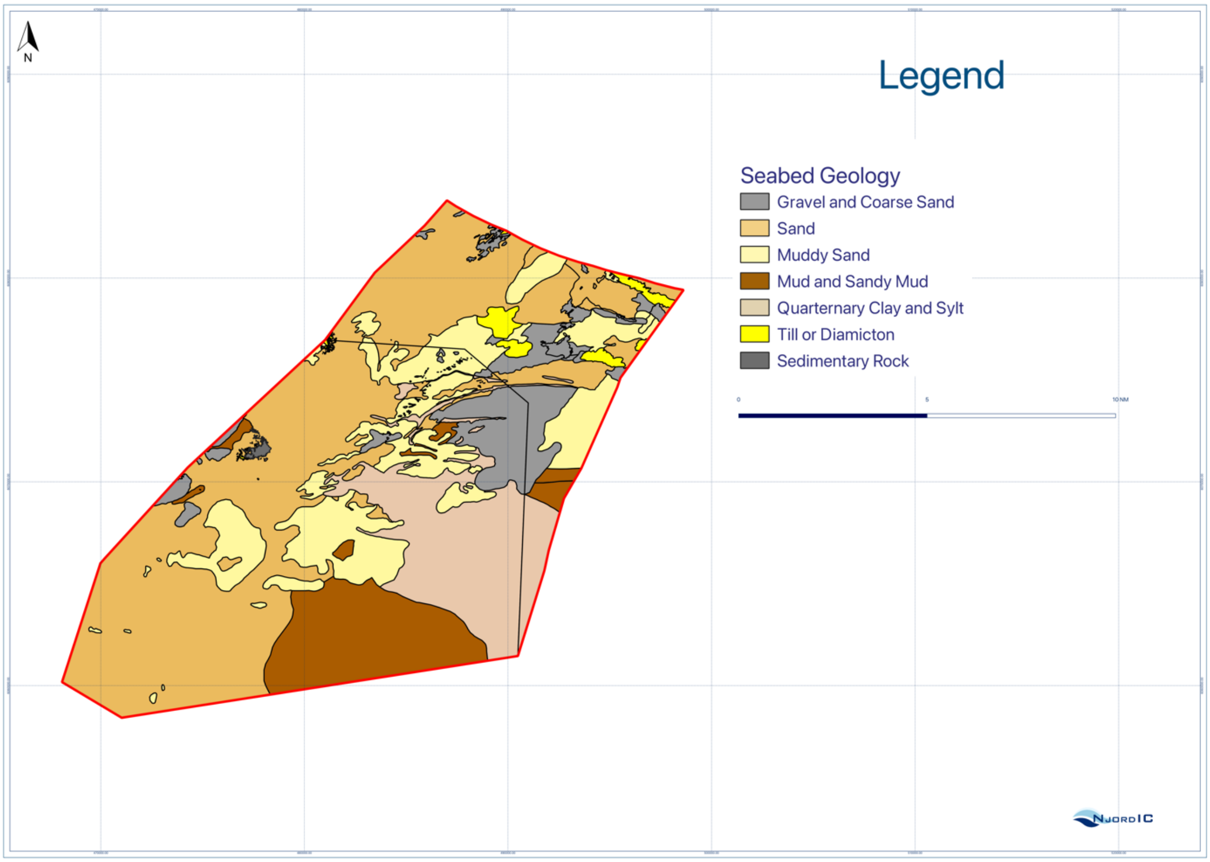

Figure 11: Bornholm II East seabed surface geology classification. [108]

The seabed surface geology is characterized by clayey sand and silt. Bands of clayey and silty sand with some areas of gravel are found in the north-eastern section of the site. The south of the site is dominated by sand and silt areas. An area of outcrop is found in the north-west of the site with some areas of clayey, silty sand with gravel.

3.3.3 Seabed surface morphology

GEOxyz evaluated the seabed morphology from the interpretation of the low frequency SSS data and backscatter imagery. [109]

The northeast, the southeast and the southwest sections of the OWF site are dominated by heavily trawl scarred areas interspersed by pitted parts. Regions of disturbed sediment are likely associated with the construction of the Nordstream 1 and Baltic Pipe pipelines that cross the site and the construction of Nordstream 2 that is close to the southern part of the site. Boulder fields are generally restricted to the north and north-east. Limited areas of mobile bedforms, mainly ripples but also large ripples, mega-ripples, and sand waves, [110] extend at the western and northern areas (see Figure 12).

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[108] Source: GEOxyz, *Geophysical Survey Report BHII - Work Package A*, reference BE4240H-771, revision 4.0, 10/03/2023.

[109] Idem.

[110] Ripples: wavelength <5m, height <0.01 - 0.1m, large ripples: wavelength of 5m - 15m, height <0.1 - 1m, mega ripples: wavelength 15m - 50m, height 1m - 3m, sand waves: wave length 50m - 200m, height 3m - 5m.

![NjordIC logo]

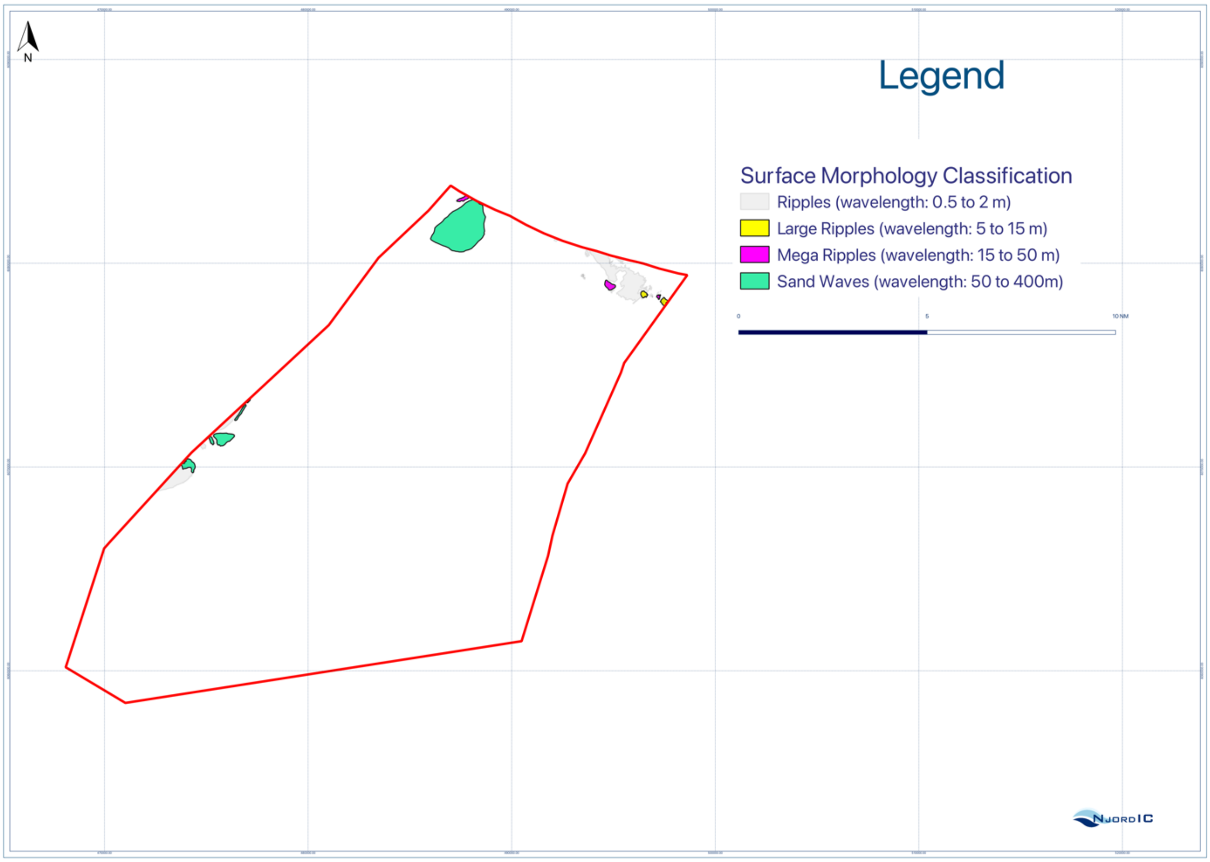

Figure 12: Seabed surface morphology classification.[111]

3.3.4 Seabed surface substrate types

GEOxyz evaluated the seabed substrate from the interpretation of the low frequency SSS data and backscatter imagery. The surficial geology was considered, and the resultant seabed surface substrate interpretation is highlighted into particle size subdivisions in Figure 13. The western and southern areas of the OWF site are predominately sand, whereas the eastern part is characterised by clay areas to the east and gravel and larger stone areas to the north. [112]

[111] Source: GEOxyz, *Geophysical Survey Report BHII - Work Package A*, reference BE4240H-771, revision 4.0, 10/03/2023.

[112] Idem.

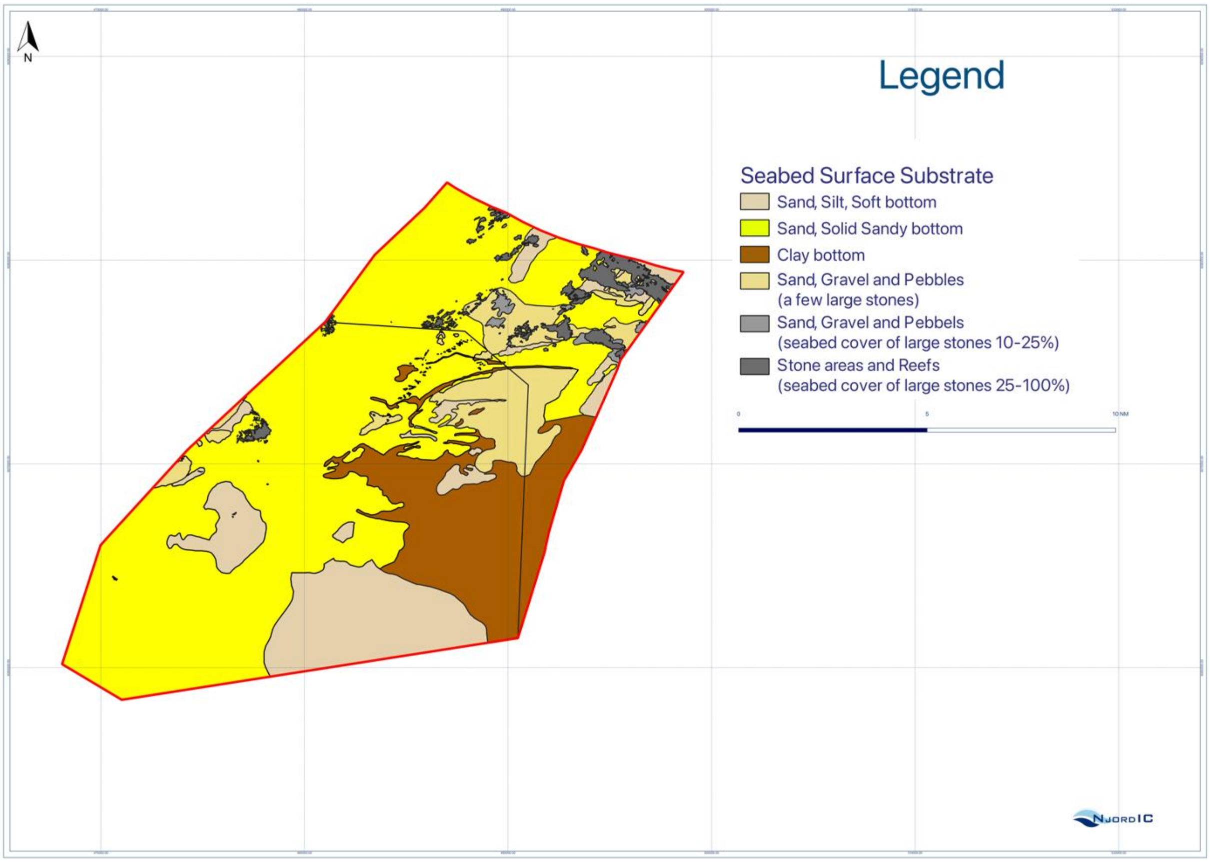

Figure 13: Bornholm II East seabed surface substrate classification. [113]

3.3.5 Sub-surface geology

On a regional basis Unit I (organic-rich post-glacial marine clay) is a thin package of organic-rich post-glacial marine clay. The desk study performed by GEOxyz indicates that it is thin or absent within the Bornholm II OWF area. Profiler data indicate that Unit I is not present as a distinct seismostratigraphic package. However, Unit IIa (clay, laminated towards top) does show a near seabed lateral facies transition to a lower amplitude acoustic character. In the most distal south-eastern parts of the area the seabed reflection displays a very low amplitude and acoustic transparency immediately below seabed. These characteristics are like those of Unit I in Bornholm I West OWF where Unit I is more clearly defined. The Unit I type facies occurs in water depths greater than ~45 m. Some settlement of seabed equipment was reported from this area during geotechnical acquisition.

Unit 1 facies are interpreted to be thin, probably less than 1 m thick, perhaps reaching a thickness of 2 m in easternmost parts of the area.

[113] Source: GEOxyz, *Geophysical Survey Report BHI - Work Package A*, reference BE4240H-771, revision 4.0, 10/03/2023.

3.4 HYDRODYNAMICS IN THE AREA OF INVESTIGATION

The Baltic Sea is a semi-enclosed marginal sea consisting of a series of sills and basins. Shallow and narrow connections at the entrance between the Danish islands and Sweden limit the water exchange with the North Sea. This leads, together with the distinct thermo- and haloclines to a highly stratified water column and the presence of gravity currents.

The hydrodynamics of the Baltic Sea are highly dependent on the salinity exchange with the North Sea. There are two distinct surface and bottom flow layers with significant variations in salinity and temperature. The surface layer is dominated by the low salinity freshwater inflows from the rivers and the bottom layer by saline water. The bottom layer transports the saline and warmer waters of the Belt Sea and Kattegat into the Arkona Basin (see Figure 14 for location).

Near bottom flow velocities range from 0 to approximately 60cm/s^{-1} in the main flow direction. [114]

The wind speeds have a strong seasonal character with standard deviations that are roughly half of the mean values. The maximum wind speed range is 20-25m/s that mostly occurs during the autumn periods. The dominant wind direction is from the southwest. [115]

The wave climate has a combination of the relatively modest long-term average wave height (0.76m) and the heights of most typical seas (0.25–0.5m) with the predominance of relatively short waves. A specific feature is the narrow range for typical wave periods (2.6s - 4s). Extreme wave heights of the order of HS ≈ 4m occur on average once a decade. [116]

[114] Lass, H. U. and Mohrholz, V. (2003): *On dynamics and mixing of inflowing saltwater in the Arkona Sea*, Journal of geophysical research, vol. 108, no. C2, 3042, doi:10.1029/2002JC001465, 2003.

[115] Dargahi, B and Cvetkovic, V. (2014): *Hydrodynamic and Transport Characterization of the Baltic Sea 2000-2009*, TRITA-LWR.REPORT 2014:03, ISSN 1650-8610, ISBN: 978-91-7595-215-4.

[116] Soomere, T. et al (2012): *Wave climate in the Arkona Basin, the Baltic Sea*, Ocean Science 8, 287–300, 2012

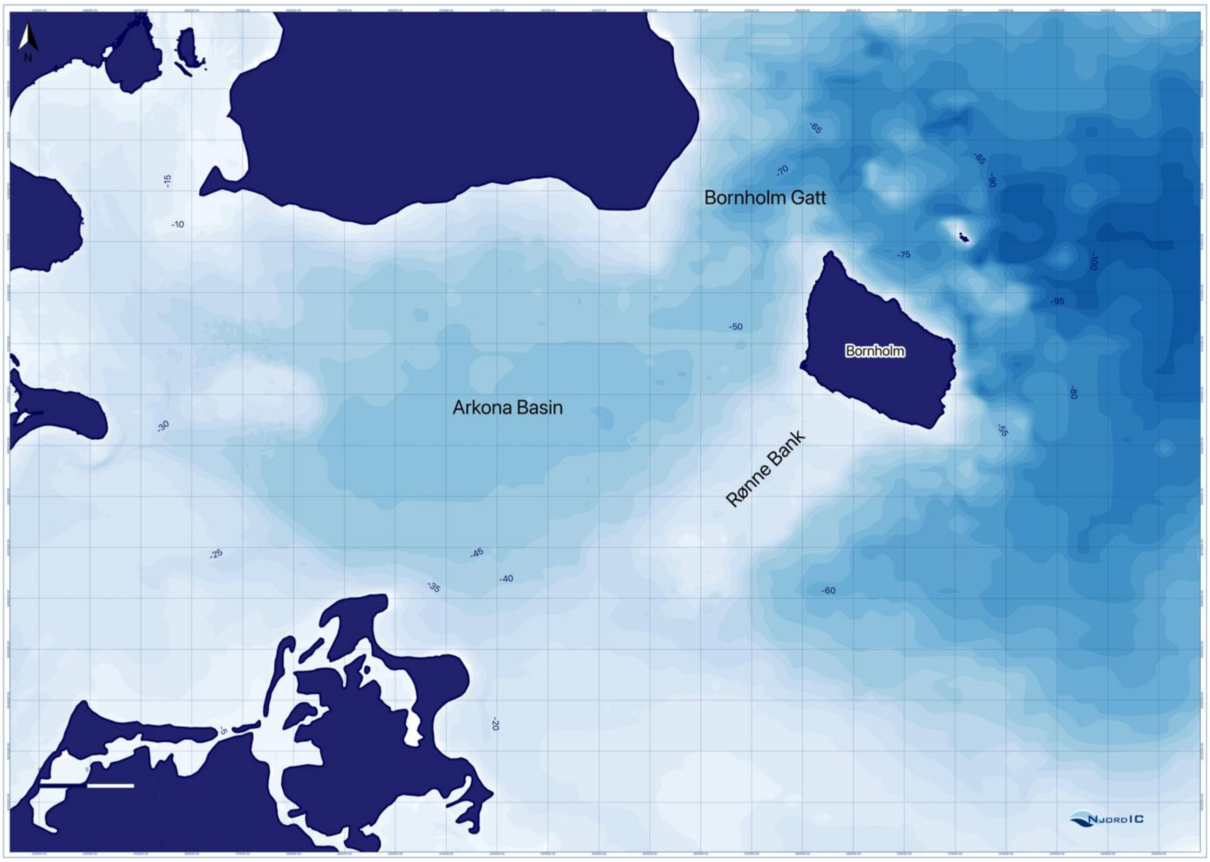

Figure 14: Location of the Arkona Basin.

3.5 UXO BURIAL ASSESSMENT

In dynamic sediment conditions, UXO items are likely to become buried. The depth of burial is dependent on several variables that will be explored below.

3.5.1 Burial on impact

The first mechanism for UXO burial to consider is that due to initial impact. Burial on impact is applicable to air dropped UXO (e.g., air dropped bombs and ground mines).

In the marine environment, a bomb's kinetic energy is rapidly attenuated by the water it passes through, and its geometry is changed substantially. The depth of water, therefore, is a crucial factor in estimating the likely burial depth on impact.

Experiments on Mk84 bombs in the USA show that the trajectory of a bomb falling into water at an angle of entry of ~90° is rapidly altered by the new medium (see Figure 15). The bomb rotates and orientates to near parallel to the seabed by a water depth of around 5-6m. Its burial in sandy soils due to impact will be minimal in water depths over 5m. [117]

Because of the water depths at the OWF site and most of the export cable corridor, burial on impact can be excluded. Potentially, in water depths shallower than 5m LAT, UXO burial on impact is possible. However, at the export cable landfall location, the seabed consists of sedimentary rock.

[117] Based on: Chu P.C. et al (May 2008): *Semi Empirical Formulas of Drag/Lift Coefficients for High Speed Rigid Body Maneuvering in Water Column*.

Based on the seabed conditions in the area with water depths shallower than 5m LAT significant UXO burial can be excluded.

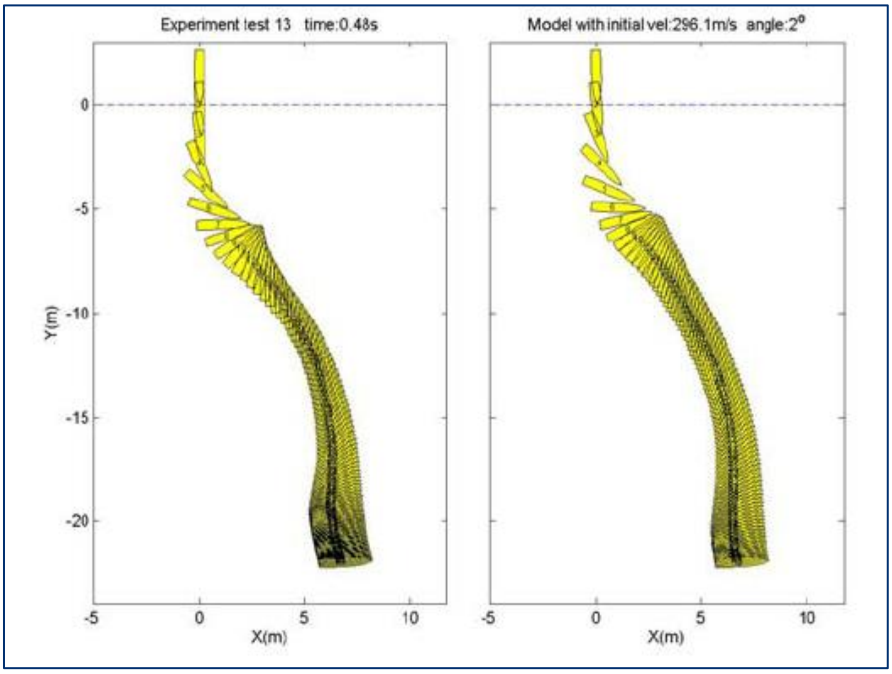

Figure 15: Comparison between modelled and observed Mk84 bomb trajectories. [118]

3.5.2 Scour-burial

Scour related burial is to be expected in non-cohesive sediments that are exposed to tidal or wave induced currents. Due to scour around an object (such as a UXO), the object may become (partly) buried. This effect is called self-burial or scour-burial. Due to this effect, the objects may become buried to a maximum of 1.15 times their diameter. [119] The horizontal displacement is limited and in the order of the diameter of the object. [120]

Non-cohesive sediments are present in the northern and eastern part of the site (see Figure 13). In parts of these areas mobile seabed features are present (see Figure 12 and paragraph 3.5.3). It is assessed that in the areas with non-cohesive bedforms, scour-burial may have occurred. The scour related burial is assessed to be 1.15 times the diameter of the UXO. The largest UXO has a diameter of 45cm. Therefore, scour-burial up to approximately 0.5m below seabed is assessed to be possible.

In areas with cohesive sediments (clay) and sedimentary rock, scour-burial will not have occurred.

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[118] Chu, P.C. et al. (2010): *Underwater Bomb Trajectory Prediction for Stand-off Assault (Mine/IED) Breaching Weapon Fuse Improvement* (SOABWFI).

[119] Whitehouse, R. (1998). *Scour at marine structures - A manual for practical applications*. London: Thomas Telford.

[120] Menzel, P. et al, *Prediction of the initial movement of objects on the sea floor*. In: OCEANS 2017-Aberdeen, Menzel P. et al, *Towards a general prediction-model for the current-induced mobilisation of objects on the sea floor*, In Ocean Engineering 164 (2018), Menzel P. et al, *Mobilisation of UXO, caused by hydrodynamics*, 2019.

3.5.3 Bedform migration

Ripples, large ripples, mega ripples, and sand waves have been identified mainly in the western and northern areas of the site (see Figure 12). The presence of mobile bed forms is limited to a few relatively small areas.

A morphodynamical analysis is not available. Therefore, the migration direction and rate of the bedforms is unknown. In assessing the maximum burial depth, it is assumed that since the war, the large and mega ripples have migrated more than a full wavelength, and that all UXO are located on the base of the active layer (see Figure 16). This is a worst-case assumption.

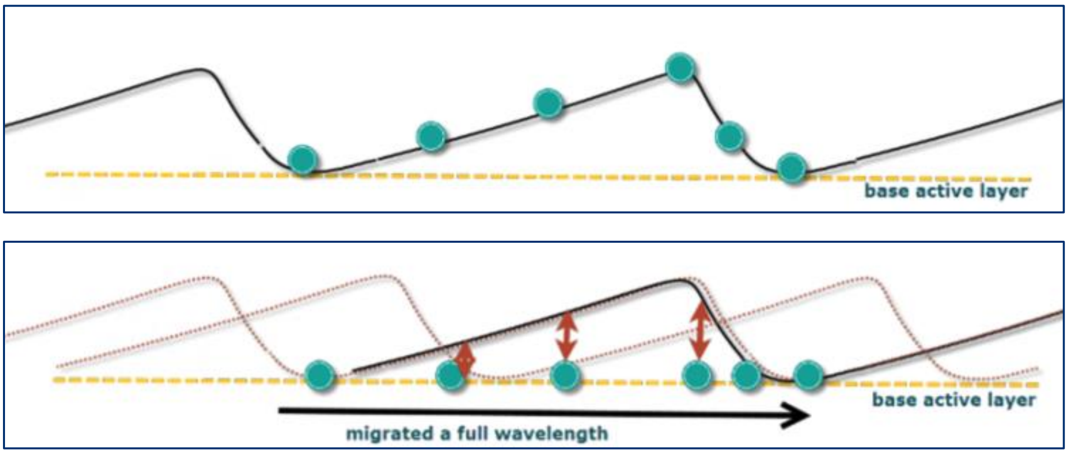

Figure 16: Schematic representation of mobile bedform migration and burial of UXO's to the base of the active layer (cross section of bathymetry). [121]

In areas with large ripples, burial because of bedform migration is limited to 1.0m below seabed (at the crests of the large ripples). In areas with mega ripples, the maximum burial depth may be as much as 3.0m below seabed, and in areas with sand waves as much as 5m below seabed.

Scour-burial (see paragraph 3.5.2) may have added to the UXO burial depth. Scour-burial may have occurred when a UXO was exposed in a through between the ripples.

3.5.4 Creep

In very low strength soils UXO may become buried because of the weight of the UXO, causing it to slowly sink down. These very low strength soils are concentrated along the eastern border of the site, mainly in water depths exceeding 40m.

The extent to which an object like a UXO is slowly sinking into the seabed depends on how the object's density compares to the density of the seabed layer it is embedded in.

To assess whether a UXO object is likely to slowly sink into the supporting seabed layer, the net weight of the UXO object needs to be calculated because if the bomb floats (equal specific gravity as the surrounding soil), the object will not sink.

[121] Based on Deltares, *Hindcast seabed levels S4 sand mining area*, reference 11209827-002-HYE-0002, August 4, 2023.

This can be determined using the formula:

$$F_{netto} = m_{\mathrm{UXO}} * g - V_{\mathrm{UXO}} * p(z) * g$$

Equation 1: Formula for calculating the UXO weight corrected for floating. [122]

In which:

F_{netto}	: The weight of the UXO corrected for floating [N]
m_{UXO}	: The mass of the UXO object [kg]
g	: The gravitational acceleration (9.81 m/s^2)
V_{UXO}	: The volume of the UXO object [m^3] [123]
p	: The specific gravity of the surrounding soil [kg/m^3]

F_{netto} was determined for a 500lbs bomb and an A Mk I-IV ground mine to assess the potential for the objects to sink into the supporting seabed layer. The specific gravity of the surrounding soil was derived from the geotechnical report. [124] For the specific gravity, the bulk density of the soil samples was used. Bulk densities of soil samples were measured by weighing samples of known volume immediately following sample extrusion. Therefore, the bulk density is considered the most representative parameter.

The borehole logs of sample locations with a seabed surface layer comprising (extremely low strength) gyttja and/or clay were examined. The most critical density was encountered in borehole log BH-204. The bulk density of the surface layer in this sample was approximately 1.1Mg/m^3 (1,100kg/m^3). This density was used for the calculation of F_{netto} . In the other borehole logs, the bulk density is generally 1.3 - 1.8Mg/m^3.

Parameter	500lbs GP	A Mk I-IV
m_{UXO} [kg]	227	681
g [m/s^2]	9.81	9.81
V_{UXO} [m^3]	0.12	0.63
p [kg/m^3]	1,100	1,100
F_{netto} [N]	931,95	-104,55

Table 12: F_{netto} for 500lbs GP bombs and A Mk I-IV ground mines.

Based on the calculation of F_{netto} , the conclusion can be drawn that A Mk I-IV ground mines will not sink into the supporting seabed layer. Only air dropped bombs can potentially sink into the supporting seabed layer because $F_{netto} > 0$.

[122] Deltares, Ontwerp Voorschrift Bepaling Indringingsdiepte Conventionele Explosieven, reference 1210497-000, 2015.

[123] When determining the volume of a UXO object, the volume of the tail section is not included, as it usually breaks off when passing through the water column.

[124] Gardline, *Preliminary Geotechnical Investigation for Energy Island - Bornholm I and Bornholm II OWF, Volume II: Measured and Derived Geotechnical Parameters and Final Results*, Energinet reference 21/07851-01, 24/04/2023.

For F_{netto} >0, the rate of sinking can be determined with:

$$v_{\text{creep}} = v^0 * \frac{D}{D^0} * \left(\frac{F_{netto}}{A * q_c * 10^6}\right)^{\frac{1}{y}}$$

Equation 2: Formula for calculating the rate of sinking of a UXO in the supporting seabed layer. [125]

In which:

v_{creep}	: The rate of sinking further [m/s]
v^0	: The CPT probing speed [0.02 m/s]
D	: The diameter of the UXO [m]
D^0	: The diameter of the CPT cone [m]
F_{netto}	: The weight of the UXO corrected for floating [N]
A	: The minimum projected surface area of the UXO [m^2]
q_c	: The cone resistance of the supporting seabed layer [MPa]
y	: Empirically determined constant: 0,1 [-]

In Equation 2, D needs to be corrected because the formula assumes that the UXO that is positioned vertically in the soil. Any UXO deployed in the area will be positioned horizontally. The surface area of a 500lbs GP bomb is 1.184 x 0,36 = 0.42624. When this surface area is assumed to be a circle, the diameter can be calculated. This results in a diameter of 0.736m.

For A, half the surface area of a cylinder with a length of 1.184m and diameter of 0.36m was assumed (0.77m^2). This considers a horizontal position of the UXO.

For a cone resistance of 0,01 MPa, v_{creep} = 2.8 * 10^{-10}.

The depth of sinking of a UXO can be determined using:

$$z_{creep} = v_{creep} * t$$

Equation 3: Formula to determine the depth of sinking (z_{creep}) after initial deployment of a UXO.

In Equation 3, t stands for the number of seconds passed after initial deployment of the UXO (78 years = 2,461,440,228 seconds). This results in z_{creep} = 0.679m.

Based on the above sinking of a bomb into the supporting seabed layer can be expected in the areas with very soft sediments (sand, silty soft bottom, and clay bottom).

[125] Deltares, Ontwerp Voorschrift Bepaling Indringingsdiepte Conventionele Explosieven, reference 1210497-000, 2015.

3.5.5 Soft mud

On several locations very soft ground conditions were encountered during the execution of the geotechnical investigations resulting in excessive sinking of the seabed frame. The reported seabed sinkage [126] was assessed and compared to the geophysical data. [127]

However, a clear correlation between the reported seabed sinkage and the surface geology and seabed surface substrate types could not be found. The average reported seabed sinkage of the seabed frame is approximately 0.2m, with a maximum of >1m for the CPT frame (CPT-206) and >4m for the borehole frame (BH-206).

Considering the specific gravity of bombs, any remaining bombs will rest on the supporting seabed layer below the layer of soft mud. Based on the reported seabed sinkage of the seabed frame the UXO burial under a layer of soft mud is assumed to be generally 1m below seabed. Locally, any bombs remaining may have sunken deeper into the soft mud. The available information does not allow for demarcation of the areas where excessive sinkage of bombs is likely. However, assessment of the backscatter data does show that the darker backscatter areas (indicating a seabed surface of soft mud) are mainly located in the southeastern section of the OWF site.

Part of the soft mud layer may be deposited post war. Parts of the area are subject to sediment accumulation. The sedimentation rate in the Arkona basin was calculated for anthropogenically undisturbed mud cores for a period over 100 years. The accumulation rate was calculated to be 2.3 - 2.9mm/year. [128]

3.5.6 Conclusion

The UXO burial depth is depending on the seabed substrate and the presence of mobile bedforms. In Table 13, the assessed UXO burial depth is differentiated based on seabed substrate and the presence of mobile bedforms.

Seabed substrate	Mobile bedforms	UXO burial depth [m below seabed]
Sand, silty soft bottom	Featureless	0 – 1.7 *
Sand, solid sandy bottom	Featureless	0 – 0.5
	Ripples	0.1 – 0.6
	Large ripples	1.0 – 1.6
	Mega ripples	3.0 – 3.6
	Sand waves	5.0 – 5.6
Clay bottom	Featureless	0 – 1.7 *
Sand gravel and pebbles a few large stones	Featureless	0 – 0.5
	Ripples	0.1 – 0.6
	Large ripples	1.0 – 1.6
	Mega ripples	3.0 – 3.6

126 Gardline, *Preliminary Geotechnical Investigation for Energy Island - Bornholm I and Bornholm II OWF, Volume II: Measured and Derived Geotechnical Parameters and Final Results*, Energinet reference 21/07851-01, 24/04/2023.

127 GEOxyz, *Geophysical Survey Report BHII - Work Package A*, reference BE4240H-771, revision 4.0, 10/03/2023.

128 Bunke, D. et al (2019): *Natural and Anthropogenic Sediment Mixing Processes in the South-Western Baltic Sea*, Front. Mar. Sci., 12 November 2019

Seabed substrate	Mobile bedforms	UXO burial depth [m below seabed]
	Sand waves	5.0 – 5.6
Sand gravel and pebbles seabed cover of large stones 10-25%	Featureless	0 – 0.5
	Ripples	0.1 – 0.6
	Large ripples	1.0 – 1.6
	Mega ripples	3.0 – 3.6
	Sand waves	5.0 – 5.6
Stone areas and reefs seabed cover of large stones 25-100%	Featureless	0 – 0.5
* Locally, a higher depth of penetration may occur, depending on the thickness of the layer of soft mud.		

Table 13: Differentiation of UXO burial depth bases on seabed substrate and the presence of mobile bedforms.

3.6 UXO MIGRATION ASSESSMENT

In this paragraph the potential for horizontal UXO migration within the area of investigation is assessed. The result will be used as input for determining the ALARP certification requirements (e.g., survey corridor width, ALARP certificate validity).

3.6.1 Hydrodynamics

Past experiences have shown that man-made objects, such as UXO, can move around on the seafloor because of extreme weather events. Especially small calibre UXO in sandy energetic environments are known to migrate. [129] Research has demonstrated that even heavy objects (500 kg cylinders, like the characteristics of naval ground mines) may shift under strong enough wave conditions. [130]

Offshore experiments showed that the largest movements of UXO surrogates occurred in the first two days after deployment on the seabed. In this stage scour related burial is still minimal, making the UXO particularly susceptible to mobility if sufficiently large waves occur. The high rate of initial migration was observed to be abruptly halted by burial lock-down.

Once a UXO is fully buried, subsequent movement is assessed to only be possible if bottom profile variation result in re-exposure to a sufficient degree that releases the UXO from burial lock-down and permits it to undergo additional scour and roll progressions. [131]

In Germany, the requirements of initial movement of objects on the sea floor were investigated and a model was developed and validated allowing prediction of the incident fluid velocity that is necessary for an inertial motion of defined cylindrical and spherical objects. [132]

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[129] Traykowski, Peter (2015): MR-2319 *Continuous Monitoring of Mobility, Burial, and Re-exposure of Underwater Munitions in Energetic Near-Shore Environments*. Appendix D. in: Second Workshop on Burial and Mobility Modelling of Munitions in the Underwater Environment (2015), Final Report, SERDP

[130] Papili, Sonia; Thomas Wever et al. (2014): *Storm influence on the burial of objects in a shallow sandy shelf environment*. Marine Geology, DOI: 10.1016/j.margeo.2014.01.004, Guyonic, Stéphane; Mathieu Mory et al. (2007): *Full-Scale Mine Burial Experiments in Wave and Current Environments and Comparison with Models*. IEEE Journal of Oceanic Engineering, DOI: 10.1109/JOE.2007.890951 and Bower, Grant R.; Michael D. Richardson et al. (2007): *Measured and Predicted Burial of Cylinders During the Indian Rocks Beach Experiment*. IEEE Journal of Oceanic Engineering, DOI: 10.1109/JOE.2007.890950

[131] Wilson, Jeffry V., et al (2008): *Predicting the Mobility and Burial of Underwater Munitions and Explosives of Concern Using the VORTEX Model*, ESTCP Project MM-0417.

[132] Menzel, Peter, et al (2017): *Laboratory experiments and numerical simulations on the wave- and flow-induced migration of munition from WW1 and WW2 as a risk assessment for offshore construction*.

Conservative assumptions were made on the critical near bottom current velocities needed to move certain UXO objects at various degrees of burial. The items considered were:

- British Depth Bomb Mark I.
- British 250 lb General Purpose bomb.
- German EMA mine (British designation GU).
- German EMC mine (British designation GY).

The critical near bottom current velocities assumed are displayed in Table 14 for various degrees of burial.

Item	Critical near bottom current velocity [m/s^{-1}]			
	5% burial	15% burial	30% burial	50% burial
British Depth Bomb Mark I	1.2	1.5	1.9	2.2
British 250 lb GP bomb	1.6	2.0	2.4	2.7
German EMA mine	1.8	2.1	2.5	3.3
German EMC mine	2.2	2.7	2.9	3.9

Table 14: Critical near bottom current velocities for various stages of UXO burial. [133]

The table shows that current velocities required for migration increase as the objects and the degree of burial increases.

The Bornholm II East OWF site is dominated by muddy sand. UXO deployed during World War I and II are likely to have become largely buried (> 50% of the UXO diameter) because of the UXO weight, the assumed bearing strength of the muddy seabed sediments and proceeding sediment accretion (up to approximately 30cm/100a). [134] This means that near bottom current velocities exceeding 2.2m/s^{-1} are required to uncover the UXO and potentially cause migration.

The gravity current induced near bottom current velocities are in the order of decimetres per second. Also, the water depths at the OWF site and the extreme wave heights (HS ≈ 4m) are such that wave induced currents will not result in above threshold current velocities (> 2.2m/s^{-1}). Therefore, it is concluded that seabed currents are not sufficient to cause migration of UXO.

3.6.2 Morphodynamical behaviour

The area of investigation appears to be relatively stable (see paragraph **Error! Reference source not found.**). Mobile bedforms (e.g., sand waves) and migrating tidal channels are absent. The seabed in the Arkona basin is subjective to slow sediment accretion. The rate of sediment accretion is estimated to be up to approximately 30cm/100annum. [135] Therefore, UXO migration by morphodynamical processes can be excluded.

3.6.3 Human activity

Human activity will have a more significant impact on UXO migration than natural causes. Specifically fishing activities have the capacity to move items of UXO over considerable distances.

133 Idem.

134 Bunke, D. et al (2019): *Natural and Anthropogenic Sediment Mixing Processes in the South-Western Baltic Sea*, Front. Mar. Sci., 12 November 2019.

135 Bunke, D. et al (2019): *Natural and Anthropogenic Sediment Mixing Processes in the South-Western Baltic Sea*, Front. Mar. Sci., 12 November 2019.

Large areas of the Baltic Sea are affected by bottom trawling. This also applies to the eastern part of the Bornholm II East site (see paragraph 3.3.3).

Beam and otter trawlers use strong outrigger booms to tow their fishing gear. These techniques are used to fish for shrimp and flatfish. Beam trawlers are known to also trap UXO accidentally in their nets. This is because the beam is intrusive to the seabed through contact of the gear components with the sediment. In the soft sediments the trawl marks remain visible for a long time and the furrows may reach a penetration depth of up to 30cm. [136]

The UXO in the parts of the area where trawling marks are visible and boulder fields are present are likely to only be partly buried, making them potentially susceptible to entrapment in fishing gear. The UXO in areas with a soft mud layer and mobile bed forms are less likely to be entrapped in fishing gear because they are more likely to be completely buried.

It is not possible to quantify the UXO migration due to human interaction. Therefore, human interaction is not a factor in the ALARP sign off certification process. This migration factor is part of the baseline residual risk.

3.6.4 Conclusion

Based on the assessed information, UXO migration by natural causes can be excluded. The only factor possibly resulting in UXO migration is through human intervention. This factor is considered part of the baseline residual risk.

[136] Krost, P., et al (1990): *Otter trawl tracks in Kiel Bay (Western Baltic) mapped by side-scan sonar*, Meeresforschung 32, 344–353.

4 PLANNED INTRUSIVE OPERATIONS

In this chapter the planned intrusive operations are detailed. Since a design of the OWF and export cable is not yet available, several installation options are considered.

4.1 PRELIMINARY SITE INVESTIGATIONS

Preliminary geotechnical cable route and site investigations are planned to be conducted, comprising of:

- Cone penetration tests
  The cone penetration test (CPT) is a in situ testing method used to determine the geotechnical engineering properties of soils and assessing subsurface stratigraphy. The test is carried out by first pushing the cone into the ground at a standard velocity of 1 to 2cm/s^{-1} while keeping the sleeve stationary.
- Vibrocore sampling
  Vibrocoring is a technique for collecting core samples of the seabed sub-strata sediments. It consists of a vibrating mechanism attached to a metallic core which is driven into the sediment by the force of gravity, enhanced by vibration energy.
- Borehole sampling
  The drilling method for borehole sampling involves a powered rotary cutting head on the end of a shaft, which is driven into the ground as it rotates. The sample is recovered using an inner barrel or a removable tube or liner to be recovered and brought to the surface.
- Grab sampling
  Sampling will be undertaken using a Van Veen grab, day grab or similar sample apparatus. The grab is lowered vertically towards the sea floor, at an even rate of speed. Between approximately 5 and 10m above the sea floor, the lowering speed is reduced to a complete stop, followed by slow lowering (< 0.5m/s^{-1}) for the last few meters allowing the grab to set down on the seabed as gently as possible.

<u>Potential UXO risks</u>

Potential UXO risks are:

- Direct contact between a UXO and jacks, anchors and/or suction anchors of the vessels conducting the site investigations.
- Direct contact between a UXO and the cone, drill, vibrocore, or grab sampler during the geotechnical investigations
- Exposure of personnel to a UXO entrapped in the soil sample (borehole, vibrocore, and grab sampling).
- Mechanical impact to a UXO entrapped in the soil sample because of uncontrolled handling during sample handling.

4.2 INSTALLATION OF THE WIND TURBINE GENERATORS

A Wind Turbine Generator (WTG) consists of a nacelle with rotor blades, a support structure, and a foundation. For the UXO risk assessment only intrusive activities (all activities that influence the soil) are relevant. There are several suitable foundation options. The decision for a foundation type will be based on a range of factors, including soil characteristics, water depth, tidal, wind and wave conditions, logistical practicalities, commercial factors, ease of construction and installation, and the type and size of turbine chosen. Possible foundation types are for example:

- Monopile
  This is a long steel pile driven into the seabed to the target penetration depth using a hydraulic piling hammer.
- Gravity based structure
  This is a large diameter steel or concrete structure that is often internally ballasted after placement on the seabed.
- Space frame foundation
  This is a 3- or 4-legged steel lattice structure that is secured to the seabed with piles at each leg position. The piles will be driven into the seabed to the target penetration depth using a hydraulic piling hammer.
- Suction caisson jacket support structure
  This is a 3- or 4-legged jacket structure with X-braced bays. The structure is secured to the seabed by suction caissons. The suction caissons are lowered to the seabed and will initially self-penetrate. Subsequently the suction operation will start to drive the suction caissons to the target penetration depth.

<u>Potential UXO risks</u>

Potential UXO risks are:

- Direct contact between a UXO and jacks, anchors and/or suction anchors of the vessels installing the foundation.
- Direct contact between a UXO and dredging equipment and/or gravel or rock during the removal of obstructions, the preparation of the seabed and/or gravel/rock dumping.
- Direct contact between a UXO and the foundation during the placement of the foundation.
- Accelerations with an amplitude > 1 m/s^2 in the soil surrounding a UXO during the placement or removal of the foundation (depending on the type of foundation, there are techniques that are vibration-free).
- Direct contact between a UXO and divers during cable connection operations.
- Direct contact between a UXO and divers/ROV's during inspections and as-built checks.

4.3 INSTALLATION OF THE OFFSHORE SUBSTATION PLATFORM (OSP) SUPPORT STRUCTURE(S)

The Offshore Substation Platforms (OSPs) will be the heart of the Bornholm II East OWF. The energy of all wind turbines will be transferred via the OWF's 66kV subsea cables to the OSP. There the voltage will be transformed via grid transformers. The energy will then be transmitted further via the export cables to the energy island (Bornholm).

The Offshore substation will comprise of an upper part - the topside -, and a lower part, the jacket foundation. The jacket will be held in place by several piles that will be driven into the seabed.

The installation of the OSP support structure(s) potentially comprises of the following activities:

- Pre-installation ROV visual as-found seabed survey.
- Offshore installation of the OSP consisting of:
    - Lifting operation from the cargo barge.
    - Set down jacket structure on seabed at target location(s).
    - Installation of a quantity of piles (e.g., four).
    - Levelling of the jacked if needed.
    - Installation of the remaining piles.
    - Post completion activities (i.e.: jacket leg cut-offs, etc.).
- Post-installation ROV visual seabed survey.
- Rock dumping around foundation locations (if required).

It is assumed that the jacket and piles will be installed by a DPII offshore installation vessel. The jacket will be lowered through the splash zone until it is hovering a few meters above the seabed. Then the vessel will manoeuvre on DP to adjust the jacket position and heading over the target location.

Once the jacket and vessel's motions have stabilized, the jacket is slowly lowered to the seabed. Once the position and orientation of the jacket are within tolerances a quantity of piles (e.g., four) piles will be stabbed and driven in the seabed using a hydro hammer. If required, the jacket will be levelled prior to installing the remaining piles.

<u>Potential UXO risks</u>

Potential UXO risks are:

- Direct contact between a UXO and the jacket during the installation of the OSP support structure(s).
- Direct contact between a UXO and a pile during the installation of the OSP support structure(s).
- Direct contact between a UXO and rocks during the installation of the scour protection (if required).

4.4 INSTALLATION OF INTER ARRAY AND EXPORT CABLES

The Inter Array Cables (IAC) connect the WTGs with the OSP. The export cables are high voltage cables that connect the OSP to the onshore network. The installation of the IAC and export cables comprises of cable route clearance and trenching operations.

4.4.1 Cable route clearance

Prior to the start of marine operations, it is essential to ensure the cable route is clear of obstructions that may hinder the operation. Seabed debris such as scrap trawler warps or ships' crane wires that may have been jettisoned by vessels onto the seabed, abandoned communications cables and other debris can be detrimental to the burial machine. Therefore, a Pre-Lay Grapnel Run (PLGR) operation is likely to be carried out.

The PLGR involves a vessel towing a grapnel train arrangement over the seabed. The grapnel wire pulling the grapnel train will have a length of at least 4-5 times the water depth. The vessel follows the cable route to hook in and recover all small debris such as lost fishing nets, ropes, and wires from the seabed, following the centre line of the planned cable routes with a certain tolerance either side of the planned cable route. The grapnel train configuration will only slightly penetrate the surface of the seabed. Penetration of the seabed will be limited to approximately 0.15m.

<u>Potential UXO risks</u>

Potential UXO risks are:

- Direct contact between a UXO and the grapnel train arrangement.
- UXO getting entrapped in the grapnel train and being brought to deck.

4.4.2 Boulder relocation campaign

Since the area of investigation has been subjected to land ice during the glaciations, the presence of boulder fields is likely. If boulder fields are present, this can pose a risk to trenching. To mitigate this risk boulder clearance of boulders exceeding a size threshold (to be determined, if any) may be conducted to mitigate this risk before trenching the cables. Boulders to be relocated are probably identified based on Sub-Bottom Profiler (SBP) data evaluation.

A boulder relocation campaign will be executed using a Remotely Operated Vehicle (ROV) support vessel. This vessel is likely to be operating on DPII during the relocation campaign. Boulders within the cable corridors will be picked up using an orange peel grab mounted on a utility ROV and will be relocated outside the cable corridors.

<u>Potential UXO risks</u>

Potential UXO risks are:

- Direct contact between a UXO and the orange peel grab mounted on a ROV.

4.4.3 Trenching

The export cables will likely be installed by a trencher that is supported by a DPII class offshore cable installation vessel. Given the assumed soil characteristics along the export cable route, a jet trencher is likely to be used for the southern half of the cable route (muddy sand). A jet trencher is a self-propelled tracked cable trenching system. Burial is achieved by using jet water on two parallel jet swords to fluidise the seabed sediments.

The cable runs through a cable guide between the jetting swords. As the soil is fluidised and displaced the swords penetrate the seabed to the required depth of lowering and the cable is laid at the rear. The soil refills the cable trench covering the laid cable as the trencher passes.

This methodology uses water jetting which has a relatively low energy. The estimated water pressure is approximately 10 bar. The burial speed is typically 200 to 250m per hour.

In the northern half of the export cable route, sedimentary rock is present. Here a chain cutter is likely to be deployed. This also is a self-propelled tracked cable trenching system. As the cutter chain excavates the trench, the cable runs through a cable guide behind the chain cutter. The cable trench will normally backfill, covering the laid cable. Since the rate of backfilling in the area of investigation is very limited, the trench might be filled after the cable is installed.

It is also possible that a Backhoe Dredger (BHD) in the area with sedimentary rock. A BHD is a stationary dredger with a hydraulic excavator installed on a pontoon. A BHD can precisely dredge a wide range of materials and can be operated in shallow water. A BHD is anchored firmly with spuds. Possibly a transport barge is moored alongside the BHD for the disposal of the excavated materials. The bucket excavates soil in a combined backward and upward movement of the boom, stick and bucket. When the bucket is full, an upward movement of the boom and stick lifts the bucket above the water to start swinging. The filled bucket is positioned above the barge by rotating the excavator on the turntable. The dredged material is discharged into the transport barge. The full barge transports the dredged material to a designated dump site for offshore disposal.

Deployment of a Cutter Suction Dredger (CSD) is not assessed to be likely given the large trench width that is required when using a CSD.

Potential UXO risks

Potential UXO risks are:

- Direct contact between a UXO and the tracks and/or jet swords/chain cutter during cable installation operations.
- An increase of the pressure because of the cable installation tool passing over a UXO.
- Direct contact between a UXO and the excavation bucket (only applicable for BHD operations).
- Direct contact between a UXO and the hull of the barge in which the dredged materials are loaded (only applicable for BHD operations).
- Direct contact between a UXO and divers/ROV’s during inspections and as-built checks.

4.4.4 Cable protection activities

Rock berms or concrete mattresses are applied for protection of shallow buried, surface laid or crossing pipelines and cables. Also, cable protection might be required at the different cable entry configurations, such as bell mouths at the substation, J-tubeless cable entries in the monopiles, situations with or without preinstalled scour protection, etc.

<u>Potential UXO risks</u>

Potential UXO risks are:

- Direct contact between a UXO and jacks, anchors and/or suction anchors of the vessels installing the cable protection.
- Direct contact between a UXO and rocks/cable mattresses during the installation of the cable protection.
- Direct contact between a UXO and divers/ROV’s during inspections and as-built checks.

5 IDENTIFYING FACTORS OF INFLUENCE ON UXO

During the installation of the Bornholm II East OWF and the export cable, several potential UXO risks are identified (see chapter 3). In this chapter, the influences on UXO (charges and fuzes) that can initiate a detonation are assessed. Subsequently the influences of the planned operations on UXO possibly left behind are assessed. The information presented in this chapter is derived from the 'Informatiepakket-CE'. [137]

5.1 FACTORS OF INFLUENCE

The UXO threat assessment (see chapter 2) revealed that UXO with a main charge of high explosive are likely to be left behind in the area of investigation. The identified potential UXO threats in the area are:

- Ground mines: Type A Mk I-IV, and A Mk VI
- Air dropped bombs: Various types (e.g., 250lb GP/MC, 500lb GP/MC, and 1,000lb GP/HC)[138]

For all UXO with a main charge of high explosive, a distinction can be made between factors of influence to the internal explosives of a UXO and factors of influence to the fuzes fitted to the UXO. In the following paragraphs the factors of influence on both components of UXO are substantiated.

5.2 EXPLOSIVES

Detonating high explosives are usually sub-divided into (a) primary, and (b) secondary explosives. The primary high explosives nearly always detonate as intended by simple shock, heat of friction. The secondary explosives require, at least in practical application, the use of a primary high explosive such as a detonator and frequently a booster. A detonator contains amongst others a primary explosive as an essential element in the explosive train.

The main factor that can influence explosives is deformation of the explosive (primary and/or secondary explosives) located in the fuze and/or the main body of the UXO.

Deformation of the body of ground mines, air dropped bombs, and artillery shells, due to the cable installation activities (PLGR, trenching) and OWF installation (piling) is unlikely. These UXO items have a solid construction and are generally encountered in a very good condition. Some of these UXO (e.g., air dropped bombs) can be fuzed with fuzes protruding from the UXO body. The explosives in fuzes protruding from UXO may be susceptible to deformation.

5.3 FUZES

The types of UXO possibly remaining in the area of investigation can be fitted with different types of fuzes. The factors of influence to these fuses are dependent on the working principle of the fuze. In Table 15 an overview is presented indicating the different working principles that applied in the fuzes fitted to the types of UXO possibly left behind.

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[137] Van den Berg, et al., *Informatiepakket-CE*, reference RO-180223, date September 14, 2018. This is an information package holding relevant information for the conduction of UXO risk assessments for offshore sand borrow operations in the Dutch sector of the North Sea.

[138] These are the most commonly used types of bombs. Other types and sizes of bombs however cannot be excluded.

The UXO possibly present, can be fuzed with mechanical and chemical delayed fuzes as well as hydrostatical fuzes. The working principle of these fuzes however, is based on a cocked striker. Therefore, in Table 15, these types of fuzes are detailed under the working principle 'cocked striker'.

Working principle fuze	Air dropped bombs	Ground mines
Tearing wire	X	
Retainer spring	X	
Diaphragm	X	
Cocked striker	X	X
Pyrotechnical	X	
Electrical	X	X

Table 15: Overview of working principles of fuzes on UXO assumed to possibly be left behind in the area of investigation.[139]

The factors of influence to these fuses are dependent on the working principle of the fuze. In general, during offshore construction operations, the following factors of influence may occur:

- Mechanical Impact on the body of a UXO causing a shock wave (kinetic energy) to travel through the UXO body into the fuze (MI).
- Deformation of the UXO body and in particular the fuze mounted onto the UXO (DF).
- Movement of a UXO with an armed fuze based on the cocked striker principle (MO).
- Accelerations traveling through the seabed in which a UXO with an armed fuze based on the cocked striker principle is located (AC).

In Table 16 the factors of influence on fuzes of different types are summarized.

Working principle fuze	MI	DF	MO	AC
Tearing wire	X	X		
Retainer spring	X	X		
Diaphragm	X	X		
Cocked striker	X	X	X	X
Pyrotechnical		X		
Electrical		X		

Table 16: Possible influences on fuzes of different types.
MI = Mechanical Impact, DF = Deformation Fuze, MO = Movement, AC = accelerations.

Table 16 shows that all UXO may be susceptible to deformation and most UXO may be susceptible to mechanical impact.

[139] Source: Van den Berg, et al., *Informatiepakket-CE*, reference RO-180223, date September 14, 2018.

5.4 INFLUENCE OF THE PLANNED OPERATIONS ON UXO

The information presented in Table 16 is used to assess the possible influence of the planned operations on the UXO that possibly remained in the area. It is assessed which influences may cause initiation of the main charge and/or on the various fuzes fitted on the UXO.

5.4.1 Ground mines

The ground mines are initiated by the magnetic or acoustic influences of their target (vessel). Due to the lack of battery power normal initiation of the electrical fuze in the main charge due to the magnetic or acoustic firing mechanism will not occur.

Given the construction of ground mines and the good condition they are usually encountered in, these mines are not very susceptible for deformation of the mine body.

Because of the potential presence of a fuze based on the cocked striker principle, ground mines may be susceptible to mechanical impact. It is assessed that the impact of interaction with a spudcan, anchor, rock, pile, track, or jet sword onto an air dropped bomb may transfer sufficient energy into the fuze to cause initiation.

5.4.2 Air dropped bombs

Fuzes can have various timer devices to make the timing of the blast more effective. Some function at a given time after arming, e.g., a chemical long delay pistol or a mechanical clockwork fuze. More common are short de-lay or instantaneous pistol/fuzes to delay the detonation for a few fractions of a second. Long delay fuzes were mainly fitted on bombs designated for attacks on targets such as airfields and factories. [140]

TNO's Defence, Safety and Security department [141] assessed that fuzes of the diaphragm, retainer spring and cocked-striker-type may be sensitive to accelerations. Therefore, it is assessed that these types of fuzes are also sensitive to motion and mechanical impact on the UXO-body. It is assessed that the impact of interaction with a spudcan, anchor, rock, pile, track, or jet sword onto an air dropped bomb may transfer sufficient energy into the fuzes to cause initiation.

Air dropped bombs can be fitted with a large variety of fuzes, some of which partly protrude outside the bomb body. These fuzes can be receptive to deformation by mechanical impact. The likelihood of an external part of a fuze being struck during the installation operations, is assessed to be negligible.

Air dropped bombs have a solid construction and are predominantly encountered in good condition. Therefore, deformation of the main charge is not likely to occur. The bomb is more likely to be pushed aside on impact.

[140] The UXO threat assessment indicated the potential jettisons of bombs. Locations of jettisons, however, are not known. The presence of air dropped bombs fitted with chemical long delay pistol can therefore not be excluded

[141] TNO, the Netherlands Organisation for applied scientific research, was founded by law in 1932 to enable business and government to apply knowledge. As an organisation regulated by public law, TNO is independent.

6 EFFECTS OF INTERACTION WITH UXO

In the case of a "High Order" detonation of a UXO, a vast amount of energy is released in an extremely short period of time. During the installation of the export cable there also is a chance on interaction with chemical warfare agents. In this chapter the possible effects of an interaction with a UXO and/or chemical warfare agents are presented.

The effects on vessels, equipment, crew members and surroundings will determine the level of risk during the installation of the Bornholm II East OWF and the export cable.

6.1 LETHALITY OF FRAGMENTS

The mechanical energy of a detonation will disintegrate the UXO body into numerous fragments. These hot fragments are projected away by the pressure of the detonation at an exceptionally high speed. With regards to fragmentation, a distinction is made between primary and secondary fragments. Primary fragments originate from the UXO body. Secondary fragments originate from materials located in the immediate vicinity of the detonation, such as rubble, scour protection, monopiles, etc. In case of a detonation under water on a seabed consisting of sand, secondary fragmentation will not be a hazard.

The lethality of primary fragments depends on the water depth and the Net Explosive Quantity (NEQ) of the UXO. TNO has researched the effects of underwater detonations in shallow water. The results of this research are presented in the 'HB EOD'. [142] The minimum water depths in which in case of a detonation no "lethal" fragments ($D_{min\ no\ lethal\ frags}$) or no fragments ($D_{min\ no\ frags}$) are ejected above water can be determined by means of approximative equations based on TNT equivalent explosive weight ($W_{exp\ TNT\ equiv}$):

$$D_{min\ no\ lethal\ frags} = 1.14 \times (W_{exp\ TNT\ equiv})^{0.38}$$

Equation 4: Approximative equation for determining the minimum water depth preventing lethal fragments to be ejected above the water line.[143]

$$D_{min\ no\ frags} = 1.58 \times (W_{exp\ TNT\ equiv})^{0.34}$$

Equation 5: Approximative equation for determining the minimum water depth preventing fragments to be ejected above the water line. [144]

In Figure 17, the results of the performed research are presented for UXO with an NEQ up to 1,000kg TNT equivalent weight. The UXO with the largest NEQ that can be left behind based on the historical research is a British ground mine type A Mk VI with a maximum NEQ of 431kg (Amatol).

Figure 17 shows that a water depth exceeding approximately 12.5m, will contain all fragments in case of a detonation at the seafloor of all UXO that are possibly left behind in the area of investigation.

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142 Defensie Expertise Centrum EODD, *Handboek Explosive Ordnance Disposal Support to National Operations*, reference LAND-ENG-EOD-01, June 12, 2020.

143 Source: Defensie Expertise Centrum EODD, *Handboek Explosive Ordnance Disposal Support to National Operations*, reference LAND-ENG-EOD-01, June 12, 2020.

144 Idem.

The displayed values are worst-case values based on spear-shaped fragments and a vertical fragment course (perpendicular to the water line). In case of a non-vertical course of the fragments the distance travelled by the fragments through the water column is larger.

The displayed values are worst-case values based on spear-shaped fragments and a vertical fragment course (perpendicular to the water line). In case of a non-vertical course of the fragments the distance travelled by the fragments through the water column is larger.

It should also be noted that the bodies of underwater ammunition (the main group of UXO with large explosive content) are not designed for fragmentation. Therefore, fragments of these type of UXO will be larger and irregularly shaped causing them to be sufficiently slowed down by a smaller water column.

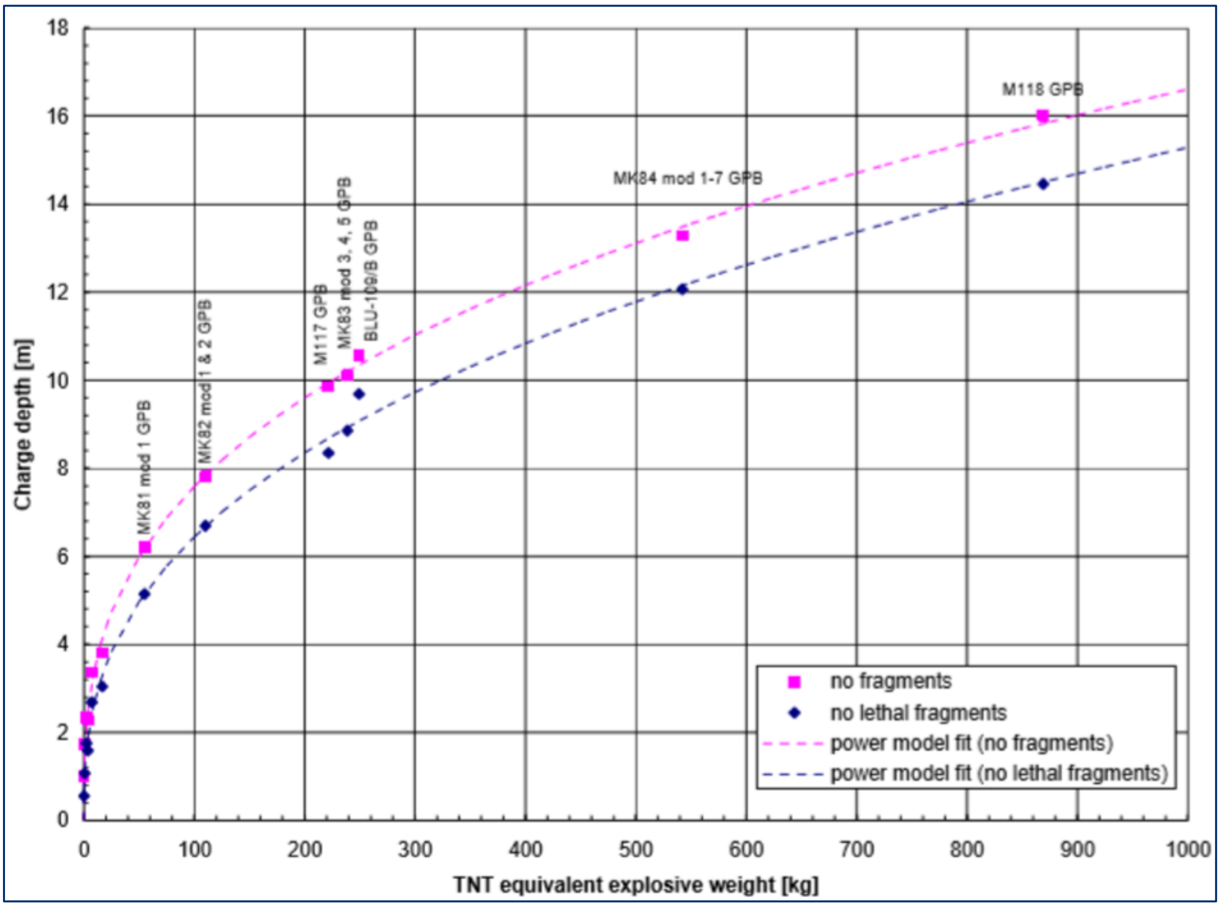

Figure 17: Minimal water depths to suppress fragments for 0-1000 kg. [145]

Considering the water depths in Bornholm II East OWF (ranging between 15m to 57m) no risks will occur due to fragmentation in case of a detonation at the seafloor. Only in the shallow parts of the export cable corridors, in water depths under 12.5m, fragmentation may pose a HSE risk.

[145] Defensie Expertise Centrum EODD, *Handboek Explosive Ordnance Disposal Support to National Operations*, reference LAND-ENG-EOD-01, June 12, 2020.

6.2 GAS BUBBLE EFFECT

An underwater detonation also results in a gas bubble, which contains about half of the explosive energy.[146] The detonation gases are enclosed in a gas bubble that alternately grows and shrinks during an upward movement to the water surface. The gas bubble energy decreases with an increase of the number of oscillations.[147] When the detonation happens close to the ship hull, there may be additional gas bubble effects influencing the ship.

The maximum gas bubble radius during its first oscillation R_b can be estimated from:

$$R_b = 3.4\sqrt[3]{\frac{W}{d+10}}$$

Equation 6: Equation to determine maximum gas bubble radius during its first oscillation.[148]

In the equation R_b stands for the maximum gas bubble radius during its first oscillation, where d is the depth of detonation. For the planned maintenance operations d equals the water depth. W represents the charge weight in kilograms TNT-equivalent.

The gas bubble may migrate towards the hull, which may result in overall hull failure.[149] Furthermore, at the first bubble minimum a devastating water jet directed toward the ship may result in even more global damage to the ship. These effects are called 'close proximity underwater explosion effects'. Although not completely accurate, a rule of thumb is that such effects may occur when the so-called gas bubble proximity parameter (GBPP) meets the following condition:

$$GBPP = \frac{Rb}{R} \geq 0.33$$

Equation 7: Equation to determine the GBPP-value.[150]

In the equation R_b stands for the maximum gas bubble radius during its first oscillation. R stands for the smallest distance between the charge (UXO) and the hull of the vessel. This distance is determined by subtracting the draft of the vessel from the water depth. This is a conservative value since there will be some horizontal spacing between the detonation point and the vessel's hull, especially during cable installation operations.

In Table 17 the calculated GBPP-values are provided for different combinations of NEQ and water depths. Since it is not yet known which vessels will be deployed for the installation activities a vessel draft of 8m is assumed.

Intolerable GBPP-values (> 0.33) are printed in red. A GBPP-value >0.9 means that severe whipping and jetting are bound to occur (printed red underlined).

146 Source: TNO (Aanhold van, J.E. et al), *Effects of an explosion on a trailing suction head dredger*, date February 20, 2018, page 13 (confidential).

147 Idem.

148 Idem.

149 Idem.

150 Idem.

The fact that detonation occurs at the sea bottom will probably provide some mitigation, because the gas bubble may stick to the sea bottom and jet into the bottom instead of the ship or the bubble may split, where only one of the two bubbles generates a water jet toward the ship. [151] Values ≥ 0.9 are displayed in red and underlined.

NEQ [kg]	Water depth						
	15	20	25	30	35	40	45
5	0.28	0.16	0.10	0.08	0.06	0.05	0.04
10	0.36	0.20	0.13	0.10	0.08	0.06	0.05
15	0.41	0.22	0.15	0.11	0.09	0.07	0.06
20	0.45	0.25	0.17	0.12	0.10	0.08	0.07
25	0.49	0.27	0.18	0.13	0.10	0.08	0.07
30	0.52	0.28	0.19	0.14	0.11	0.09	0.08
40	0.57	0.31	0.21	0.15	0.12	0.10	0.08
50	0.61	0.34	0.23	0.17	0.13	0.11	0.09
75	0.70	0.38	0.26	0.19	0.15	0.12	0.10
100	0.77	0.42	0.28	0.21	0.16	0.13	0.11
150	0.88	0.48	0.32	0.24	0.19	0.15	0.13
200	0.97	0.53	0.36	0.26	0.21	0.17	0.14
250	1.05	0.57	0.39	0.28	0.22	0.18	0.15
300	1.11	0.61	0.41	0.30	0.24	0.19	0.16
400	1.22	0.67	0.45	0.33	0.26	0.21	0.18

Table 17: GBPP-values for different combinations of NEQ and water depths. Intolerable GBPP-values (≥0.33) are printed in red (≥0.33) or red underlined (≥0.9).

With regards to the gas bubble effects, the installation of the WTG foundations and the OSP support structure is normative. During the installation of the foundations the vessel will be next to the detonation point in the event of a detonation. The WTGs and OSP support structures will be installed in water depths ranging from 35m to 45m. In these water depths intolerable GBPP-values do not occur.

The GBPP-values for vessels deployed for the PLGR and trenching are not calculated because in case of a detonation the point of detonation is situated at some horizontal distance (at least 30m) of the vessel. A study commissioned by TenneT [152] has shown that in case of a detonation point at 20m horizontal distance of the vessel, no intolerable damage to the ship occurs in case of a detonation of a GP 500lb bomb.

In water depths under 15m post lay burial is most likely to be the preferred installation method. In this case the cable is first laid at the seabed. Subsequently the trencher will bury the cable. In this situation the distance between the trencher and the vessel is likely to be larger than for simultaneous lay and burial.

In case a BHD is deployed to bury the export cables in sedimentary rock the vessel will very close to the detonation point. In the area with sedimentary rock the water depth is less than 25m. This means that intolerable gas bubble effects are to be expected.

[151] Source: TNO (Aanhold van, J.E. et al), *Effects of an explosion on a trailing suction head dredger*, date February 20, 2018, page 13 (confidential).

[152] DNV.GL, *Full-ship and local structure UXO response simulation*, reference MRGDE719 2017.107, Rev. 1, date February 7, 2020.

6.3 SHOCK WAVE

A detonation of an UXO at the seabed will lead to a shock wave in the water that will impact the hull of the vessel. The shock wave is a direct result of the rapid expansion of the hot, gaseous reaction products that are formed during the detonation. Due to the rapidly expanding gas bubble, pressure is exerted on the surrounding water. Because water is not compressible, the surrounding water is displaced by the gas bubble. Several oscillations can occur depending on the water depth. Each expansion causes a shock wave that travels through the water in all directions.

Due to the characteristics of water, the maximum pressure of the initial phase of the shock wave will be much higher than when it takes place in soil or air. However, the peak pressure is shorter. The shock wave decreases in force with an increase of the number of oscillations as the gas bubble rises.

6.3.1 Hull failure

Commissioned by Rijkswaterstaat, TNO carried out research into the expected damage to Trailing Suction Hopper Dredgers (TSHD) because of a detonation. [153] The study shows that failure of hull plating due to the shock wave only occurs at combinations of low water depths (10m) and high charge weights (> 75kg). At water depths over 20 m no failure of hull plating is assessed to occur for the charge weights up to 200kg assessed in the study. Based on the outcome of this study failure of hull plating in the Bornholm II East OWF is not expected due to the water depths.

In the export cable corridor hull failure is likely in case a BHD is deployed to bury the cable. In this area ground mines (NEQ up to 431kg) and air dropped bombs (NEQ up to 238kg) may be present.

6.3.2 Failure of appendages

The main concern for the vessels involved in the installation operations is rupture of the seals around the driving shafts.

The research conducted by TNO on behalf of offshore dredging operations using a TSHD [154] shows that even when the hull remains intact, flooding of the engine rooms may occur when appendages rupture. In TSHDs i.e., hull valves or their attached seaside piping may break off and/or the hull entry and hull entry valve of the trailing suction pipe ruptures. TNO assumes that this happens when accelerations exceed 100g. On the assessed TSHD (Boskalis Strandway) for a draught of 6.8m and a water depth of 20m failure is expected for charge weights of 20kg and above. In case of dredging the detonation occurs under or just next to the vessel near the main engine room.

Appendage failure of the vessels involved in the OWF and cable installation operations is assessed to have a less significant effect than appendage failure on a TSHD. The amount of water entering the vessel will be less than for a TSHD. It is assumed that the vessel bilge pump systems can discharge the entering water.

[153] Source: TNO (Aanhold van, J.E. et al), *Effects of an explosion on a trailing suction head dredger*, date February 20, 2018 (confidential).

[154] Idem.

6.3.3 Crew/personnel injury

The shock wave that is caused by an underwater detonation, results in accelerations, which in their turn may lead to crew injuries. TNO defined the injury criteria in terms of peak acceleration and peak velocity of superstructure shock pulse, based on applied research.[155]

Risk of crew injury is assumed for vertical peak accelerations beyond 33g in the superstructure. TNO assessed the risk on crew injury for dredging with a trailer suction hopper for several combinations of charge weight, water depth and draught. The cases, for which this condition occurs, are marked red in Table 18.

It is seen that there is only a risk of crew injury for larger charge weights in lower water depths. This fits well in the general experience with steel naval ships for increasing shock levels, that equipment fails first, followed by crew injury and at last by hull rupture.

Charge weight [kg TNT]	Water depth 10 m		Water depth 20 m		Water depth 30 m	
	Draft		Draft		Draft	
	3.8 m	6.8 m	3.8 m	6.8 m	3.8 m	6.8 m
10	4-12 g	3-13 g	3-7 g	4-8 g	3-4 g	3-5 g
20	5-17 g	5-18 g	5-10 g	5-12 g	4-6 g	4-7 g
25	6-19 g	5-21 g	5-11 g	6-13 g	4-7 g	5-8 g
30	6-21 g	6-23 g	6-12 g	6-14 g	5-8 g	5-9 g
40	7-24 g	7-26 g	7-14 g	7-17 g	5-9 g	6-10 g
50	8-27 g	8-29 g	8-16 g	8-19 g	6-10 g	7-11 g
75	10-33 g	9-36 g	9-20 g	10-23 g	7-12 g	8-14 g
100	11-38 g	11-41 g	11-23 g	11-26 g	9-14 g	9-16 g
150	14-47 g	13-51 g	13-28 g	14-32 g	10-17 g	11-20 g
200	16-54 g	15-58 g	15-32 g	16-37 g	12-20 g	13-23 g

Table 18: Overview of vertical peak accelerations in the superstructure for different combinations of parameters. Risk of crew injury is assumed for vertical peak accelerations beyond 33g in the superstructure. These values are printed in red. For vertical peak accelerations beyond > 50g crew injury is likely. These values are underlined.

The water depths in the OWF range from 15 up to 57m. The maximum draught of the vessels that will be deployed is 8.0m. Based on this information the conclusion is drawn that unacceptable accelerations with regards to crew injury only occur in case of charge weights ≥ 75kg and shallow water depths.

In the export cable corridors intolerable accelerations may occur in case of deployment of a BHD for charge weights ≥ 50kg (depending on water depths).

6.3.4 Failure of equipment

A simplified damage scale is assumed for equipment failure assessment, as shown in Table 19. The table is based on a dated review of shock test data for about 450 pieces of equipment for shipboard applications, which were rigidly mounted, and shock tested in the period 1970-1980 by TNO. It must be warned that the levels of Table 19 are a rough indication only. Finally, note that broken parts flying around may cause injury to crew members and/or damage to other equipment, an effect that is not incorporated in the damage scale used.

155 Regoord, *Report by the Norwegian Delegation on the effect of shock waves on the human organism*, NATO document AC/23 (CD/SH)D/62, 1967 (confidential).

Damage scale no.	Peak acceleration range	Estimated equipment status
0	0-10g	No damage
1	10-20g	First failures of electronic equipment
2	20-50g	First failures of electrical equipment More failures of electronic equipment
3	50-100g	First failures of heavy machinery items More failures of electronic and electrical equipment
4	100-500g	First failures of small to medium weight machinery items More failures of all other equipment
5	>500g	Large scale equipment failure

Table 19: Equipment damage scale. Warning: this is a rough indication only! [156]

Based on Table 18, the expected accelerations in the OWF are in the range of 13 to 23 for the UXO items with charge weight up to 200kg and a water depth of 30m. This means failure of electronical and electrical equipment is possible in case of a detonation of a large NEQ UXO item (> 200kg). In water depths over 35m the damage scale will likely be 0 or 1, dependent on the NEQ of the UXO item.

In the export cable corridor and the OWF areas with shallower water depths equipment damage (damage scale no. 3) is highly likely.

6.4 EFFECTS ON SEA LIFE

In case of an uncontrolled detonation the high sound pressure and explosion-related shock waves can lead to severe injury and hearing impairment in marine mammals at considerable (kilometres) distance from detonation sites. Based on experimental data from terrestrial mammals held under water it is assumed that smaller animals are more vulnerable than larger ones. [157, 158]

The shock wave results in primary blast injury originating from the compression of tissues or organs by the incoming wave front. High-amplitude pressure pulses may cause differential tissue displacement disrupting cells and tissues of different density such as muscle and fat. [159]

Especially at the interface with gas-filled cavities capable of compression, molecules are displaced resulting in damage to these tissues.

Tissues at these interfaces are torn or shredded by instantaneous compression of the gas. Hence, massive damage can occur in the lungs, intestines, sinuses, and ear cavities. [160]

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[156] Source: TNO (Aanhold van, J.E. et al), *Effects of an explosion on a trailing suction head dredger*, date February 20, 2018 (confidential).

[157] Source: *Draft HELCOM Thematic Assessment on Hazardous Submerged Objects*, code 3-1, November 12, 2018, paragraph 3.4.1.

[158] Source: K. Baker, et al., *Assessment and Mitigation of Marine Explosives: Guidance for Protected Species in the Southeast U.S.*, version 1, date February 2008, page 4.

[159] Source: *Draft HELCOM Thematic Assessment on Hazardous Submerged Objects*, idem.

[160] Ibidem.

This document 'Assessment and Mitigation of Marine Explosives: Guidance for Protected Species in the Southeast U.S' provides several formulas to estimate the potential area affected by underwater detonations. For the area of investigation, the danger zone for Porpoise and Dolphins is considered the most relevant.

For unconfined blasts, such as an uncontrolled detonation on the seabed, the danger zone for Porpoise and Dolphin can be estimated by:

Porpoise/Dolphin danger zone (ft) = 578 (charge weight in lb)$^{0.28}$

Equation 8: Formula for estimating the danger zone for Porpoise and Dolphin. [161]

The equation is considered to provide a very conservative predictor to avoid serious injury and mortality. [162] In Table 20 the danger zone is provided for the types of UXO possibly left behind in the area of investigation (1lb = 0.4536kg 1ft = 0.3048m).

UXO type	NEQ [163] [kg]	NEQ [lb]	Danger zone [m]
Air dropped bomb 250lb	30.8	68	574
Air dropped bomb 500lb	120	264	839
Air dropped bomb 1,000lb	238	525	1,017
Ground mine A Mk I-IV and VI	431	948	1,202

Table 20: Porpoise/Dolphin danger zone for the types of UXO possibly left behind.

The danger zone for fish is dependent on the weight of the fish and the depth of the detonation and therefore not provided.

The outcome of the estimation of the danger zone was cross checked using the formula to calculate the radius surrounding a detonation point where swimming and diving is prohibited provided in the 'HB EOD'. [164]

$$R = 270 \sqrt[3]{W}$$

Equation 9: Formula for calculating the radius around the detonation point in case of a controlled in which swimming and diving is prohibited. [165]

In the equation R stands for the radius of the zone in which swimmers and divers are not allowed. W stands for the charge weight of the UXO in TNT-equivalents. Using Equation 9 the danger zone radius for swimmers and divers is 1,760m.

The outcome is in line with the outcome of the danger zone for Porpoise and dolphins considering that for swimmers/divers additional safety is likely to be taken into account.

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[161] Source: K. Baker, et al., *Assessment and Mitigation of Marine Explosives: Guidance for Protected Species in the Southeast U.S.*, version 1, date February 2008, page 13.

[162] Ibidem.

[163] For the calculation of the danger zones the largest explosive content deployed in the different UXO types is used.

[164] Defensie Expertise Centrum EODD, *Handboek Explosive Ordnance Disposal Support to National Operations*, reference LAND-ENG-EOD-01, June 12, 2020.

[165] Source: idem.

6.5 EFFECTS ON INSTALLATION AND OWF ASSETS

In case of a detonation during installation activities the detonation is likely to affect the installation equipment (vessel, trencher) and OWF assets (IAC, export cable, foundations). Adverse effects are to be expected for even the smallest threat items possibly left behind in the area of investigation.

In this risk assessment, the health and safety risks for personnel involved in the installation operations are assessed. Mitigation measures are recommended to reduce the intolerable risks to a level that is considered ‘as low as reasonably practicable’ (ALARP).

The tolerability of damage to installation equipment and OWF assets cannot be assessed by the UXO consultant since it is not primarily a health and safety aspect. The tolerability of damage to installation and OWF assets is primarily impacting the project schedule and costs and is to be agreed upon between employer and contractor.

7 UXO RISK ASSESSMENT

In this chapter, the tolerability of risks is assessed based on the factors of influence on UXO and the effects of detonations. In assessing the overall UXO risks for the project a Semi-Quantitative Risk Assessment (SQRA) process was applied. SQRA is widely considered best practice in the offshore industry. The risk factor values assigned in the SQRA are determined by UXO experts and are consequently subjective and open to different interpretation.

7.1 RISK ASSESSMENT MATRIX

The assessment of the effects of underwater detonations shows that some detonation effects lead to unacceptable risks for the personnel involved in the installaton operations. The matrix shown in Table 21 is used to quantify the risks. Each generic UXO hazard is assessed for severity/consequence and likelihood of occurrence. This model is generally considered best practice for assessing risk in the marine environment, although it has been modified where required to ensure it is UXO centric. The likelihood of risk event is related to the factors of influence to UXO (see chapter 5) and the severity/consequence class to the effects of detonations/exposure to chemical warfare agents (see chapter 6).

			Likelihood of Risk Event (%)				
			A	B	C	D	E
			Rare (< 1%)	Unlikely (1% - 10%)	Possible (10% - 25%)	Likely (25% - 50%)	Almost Certain (> 50%)
Severity/consequence class	1	Trivial	LOW 1	LOW 2	LOW 3	LOW 4	MEDIUM 5
	2	Minor	LOW 2	LOW 4	LOW 6	MEDIUM 8	MEDIUM 10
	3	Moderate	LOW 3	MEDIUM 6	MEDIUM 9	MEDIUM 12	MEDIUM 15
	4	Major	MEDIUM 4	MEDIUM 8	HIGH 12	HIGH 16	HIGH 20
	5	Severe	HIGH 5	HIGH 10	HIGH 15	HIGH 20	HIGH 25

Table 21: UXO Risk Assessment Matrix.

7.2 CRITERIA FOR DETERMINING RISK TOLERABILITY

The applied risk management matrix divides risks into three bands, LOW, MEDIUM and HIGH. Regarding the assessment of UXO related risks, the 'As Low As Reasonably Practicable' (ALARP) principle is applied. This means mitigation measures are required to reduce the risks to 'As Low As Reasonably Practicable' (ALARP).

The concept of "reasonably practicable" involves weighing a risk against the trouble, time and money needed to control it. Thus, ALARP describes the level to which we expect to see workplace risks controlled. Please note there will always be a residual risk that cannot be further controlled.

The ALARP principle relates to risk management matrix as follows.

LOW	: Adequate mitigation measures in place. Acceptable risks, no further action required.
MEDIUM	: Further assessment for additional controls may be required to reduce the risk.
HIGH	: Further assessment is required to identify additional controls and reduce the risk (ALARP).

Table 22: Criteria for determining risk tolerability.

7.3 RISK ASSESSMENT RESULTS

In this paragraph the so-called naked risks for the assumed installation operations regarding UXO are presented. The naked risk is the risk without any form of risk mitigation. For the assessment of the risks the site-specific information, the planned operations (chapter 4) and their accompanying factors of influence on UXO (chapter 5) and detonation/exposure effects (chapter 6) were considered.

The main driver for the risk assessment results is the severity/consequence of a detonation, and in particular the gas bubble effect. The likelihood of initiation is assessed to be rare to possible, depending on the installation activity and type of UXO.

7.3.1 Preliminary site investigations

Preliminary geotechnical site investigations are planned to be conducted, comprising of:

- Cone penetration tests
- Vibrocore sampling
- Borehole sampling
- Grab sampling

In Table 23 the risk assessment results for the abovementioned activities are presented. It is assumed the samples will be distributed to adequately sample the anticipated distribution of seabed sediments and seabed morphology in the OWF and along the export cable corridor. Therefore, in the risk assessment results the consequence of a risk event reflects the consequence in shallow water depths.

The normative activities are cone penetration testing, vibrocore, and borehole sampling. The impact of a grab sampler that is lowered on the seabed in a controlled manner is assessed to be too small to cause deformation or sufficient mechanical impact to initiate a detonation (see substantiation below). Therefore, the risk assessment results are not presented in a table.

For vibrocore sampling, borehole, and grab sampling entrapment of UXO is an additional risk to be considered. The risk of exposure to UXO during sample handling is described below.

Cone penetration test, vibrocore, and borehole sampling

Main type UXO	Sub type UXO	NEQ [kg]	Water depth [m]	Likelihood	Consequence	Risk result
Air dropped bombs	GP, 250lb (UK)	30.8	0-50	Rare (A)	Major (4)	MEDIUM (4)
	GP, 250lb (US)	58.8	0-50	Rare (A)	Major (4)	MEDIUM (4)
	GP, 500lb (US)	120	0-50	Rare (A)	Severe (5)	HIGH (5)
	GP, 1,000lb (UK)	171	0-50	Rare (A)	Severe (5)	HIGH (5)
	HC, 1,000lb (UK)	238	0-50	Rare (A)	Severe (5)	HIGH (5)
Ground mines	A Mk I-IV	352	0-30	Rare (A)	Severe (5)	HIGH (5)
	A Mk VI	431	0-30	Rare (A)	Severe (5)	HIGH (5)

Table 23: Naked risks of detonation effects cone penetration testing, vibrocore, and borehole sampling.

Grab sampling

The impact of a grab sampler that is lowered on the seabed in a controlled manner is assessed to be too small to cause deformation or sufficient mechanical impact to initiate a detonation. Normally the main driver for the risk assessment results is the severity/consequence of a detonation, and in particular the gas bubble effect. A detonation of a large Net Explosive Quantity (NEQ) UXO item is likely to have a severe effect on the vessel and its crew. However, given the combined likelihood of interaction and initiation the overall UXO related risks are assessed to lie within the ALARP region. Conduction of e.g., a magnetometer survey with the single purpose to avoid UXO is deemed a disproportionate mitigation measure to further reduce the risk. The time and costs involved are not proportionate against the reduction of the risk.

Note:
The abovementioned assessment does not consider anchoring of the vessels conducting the operations. In case anchoring of the vessels is required the risk assessment results are different. In this case the likelihood of interaction is still very low, but the likelihood of initiation is elevated to Unlikely (B) due to the increase of the depth of intrusion and the potential transfer of energy onto a UXO. The impact of a detonation is assessed to be major (4) to severe (5). This will result in a risk score of 8 (MEDIUM) to 10 (HIGH).

7.3.2 Installation of the Wind Turbine Generators and the Offshore Substation Platform

The WTG and OSP support structure installation can be subdivided into two distinct intrusive activities:

1. Foundation installation
2. Scour protection installation

In Table 24 and Table 25 the risk assessment results for the abovementioned activities are presented. The normative activity regarding the tolerability of the detonation effects is jacking operations. The point of intrusion for this activity is below the vessel and the amount of energy potentially transferred onto a UXO is high. During piling the point of intrusion is located several meters to the side of the vessel, reducing the detonation effects impacting the vessel.

Piling

Main type UXO	Sub type UXO	NEQ [kg]	Water depth [m]	Likelihood	Consequence	Risk result
Air dropped bombs	GP, 250lb (UK)	30.8	30-50	Possible (C)	Minor (2)	LOW (6)
	GP, 250lb (US)	58.5	30-50	Possible (C)	Minor (2)	LOW (6)
	GP, 500lb (US)	120	30-50	Possible (C)	Minor (2)	LOW (6)
	GP, 1,000lb (UK)	171	30-50	Possible (C)	Moderate (3)	MEDIUM (9)
	HC, 1,000lb (UK)	238	30-50	Possible (C)	Moderate (3)	MEDIUM (9)

Table 24: Naked risks of detonation effects for the installation of the foundation for WTGs and the OSP support structure.

Scour protection installation

Main type UXO	Sub type UXO	NEQ [kg]	Water depth [m]	Likelihood	Consequence	Risk result
Air dropped bombs	GP, 250lb (UK)	30	30-50	Unlikely (B)	Minor (2)	LOW (4)
	GP, 250lb (US)	58.5	30-50	Unlikely (B)	Minor (2)	LOW (4)
	GP, 500lb (US)	120	30-50	Unlikely (B)	Minor (2)	LOW (4)
	GP, 1,000lb (UK)	171	30-50	Unlikely (B)	Moderate (3)	MEDIUM (6)
	HC, 1,000lb (UK)	238	30-50	Unlikely (B)	Moderate (3)	MEDIUM (6)

Table 25: Naked risks of detonation effects for the scour protection installation of WTGs and the OSP support structure.

7.3.3 Installation of inter array cables

The installation of the IAC can be subdivided into three distinct intrusive activities:

1. Cable route clearance
2. Boulder relocation
3. Trenching

In Table 26, Table 27, and Table 28 the risk assessment results for the abovementioned activities are presented.

Cable route clearance

Main type UXO	Sub type UXO	NEQ [kg]	Water depth [m]	Likelihood	Consequence	Risk result
Air dropped bombs	GP, 250lb (UK)	30	30-50	Possible (C)	Minor (2)	LOW (6)
	GP, 250lb (US)	58.5	30-50	Possible (C)	Minor (2)	LOW (6)
	GP, 500lb (US)	120	30-50	Possible (C)	Minor (2)	LOW (6)
	GP, 1,000lb (UK)	171	30-50	Possible (C)	Moderate (3)	MEDIUM (9)
	HC, 1,000lb (UK)	238	30-50	Possible (C)	Moderate (3)	MEDIUM (9)

Table 26: Naked risks of detonation effects for the cable route clearance prior to IAC installation.

Note:
During PLGR operations there is a (small) risk of recovering UXO to deck if they become entrapped in the grapnel train. In this situation a detonation of even the smallest calibre UXO poses a high HSE risk.

Boulder relocation

Main type UXO	Sub type UXO	NEQ [kg]	Water depth [m]	Likelihood	Consequence	Risk result
Air dropped bombs	GP, 250lb (UK)	30	30-50	Unlikely (B)	Minor (2)	LOW (4)
	GP, 250lb (US)	58.5	30-50	Unlikely (B)	Minor (2)	LOW (4)
	GP, 500lb (US)	120	30-50	Unlikely (B)	Minor (2)	LOW (4)
	GP, 1,000lb (UK)	171	30-50	Unlikely (B)	Moderate (3)	MEDIUM (6)
	HC, 1,000lb (UK)	238	30-50	Unlikely (B)	Moderate (3)	MEDIUM (6)

Table 27: Naked risks of detonation effects for the boulder relocation prior to IAC installation.

Note:
In case the boulders are recovered to deck, there is a risk of recovering UXO to deck. This poses a high HSE risk.

Trenching

Main type UXO	Sub type UXO	NEQ [kg]	Water depth [m]	Likelihood	Consequence	Risk result
Air dropped bombs	GP, 250lb (UK)	30	30-50	Unlikely (B)	Minor (2)	LOW (4)
	GP, 250lb (US)	58.5	30-50	Unlikely (B)	Minor (2)	LOW (4)
	GP, 500lb (US)	120	30-50	Unlikely (B)	Minor (2)	LOW (4)
	GP, 1,000lb (UK)	171	30-50	Unlikely (B)	Moderate (3)	MEDIUM (6)
	HC, 1,000lb (UK)	238	30-50	Unlikely (B)	Moderate (3)	MEDIUM (6)

Table 28: Naked risks of detonation effects for trenching of the IACs.

7.3.1 Installation of export cables

The installation of the export cables can be subdivided into three distinct intrusive activities:

1. Cable route clearance
2. Boulder relocation
3. Trenching (jet trencher, chain cutter or BHD)

In Table 29, Table 30, Table 31, and Table 32 the risk assessment results for the abovementioned activities are presented. The risks for the export cable installation are generally higher than for IAC installation. This is because of the shallower water depths, higher NEQ UXO items and potentially different installation techniques.

Cable route clearance

Main type UXO	Sub type UXO	NEQ [kg]	Water depth [m]	Likelihood	Consequence	Risk result
Air dropped bombs	GP, 250lb (UK)	30	0-30	Possible (C)	Minor (2)	LOW (6)
	GP, 250lb (US)	58.5	0-30	Possible (C)	Minor (2)	LOW (4)
	GP, 500lb (US)	120	0-30	Possible (C)	Moderate (3)	MEDIUM (9)
	GP, 1,000lb (UK)	171	0-30	Possible (C)	Moderate (3)	MEDIUM (9)
	HC, 1,000lb (UK)	238	0-30	Possible (C)	Moderate (3)	MEDIUM (9)
Ground mines	A Mk I-IV	352	0-30	Possible (C)	Major (4)	HIGH (12)
	A Mk VI	431	0-30	Possible (C)	Major (4)	HIGH (12)

Table 29: Naked risks of detonation effects for the cable route clearance prior to export cable installation.

Note:
During PLGR operations there is a (small) risk of recovering UXO to deck if they become entrapped in the grapnel train. In this situation a detonation of even the smallest calibre UXO poses a HSE risk.

Boulder relocation

Main type UXO	Sub type UXO	NEQ [kg]	Water depth [m]	Likelihood	Consequence	Risk result
Air dropped bombs	GP, 250lb (UK)	30	0-30	Unlikely (B)	Minor (2)	LOW (4)
	GP, 250lb (US)	58.5	0-30	Unlikely (B)	Minor (2)	LOW (4)
	GP, 500lb (US)	120	0-30	Unlikely (B)	Moderate (3)	MEDIUM (6)
	GP, 1,000lb (UK)	171	0-30	Unlikely (B)	Major (4)	MEDIUM (8)
	HC, 1,000lb (UK)	238	0-30	Unlikely (B)	Major (4)	MEDIUM (8)
Ground mines	A Mk I-IV	352	0-30	Unlikely (B)	Severe (5)	HIGH (10)
	A Mk VI	431	0-30	Unlikely (B)	Severe (5)	HIGH (10)

Table 30: Naked risks of detonation effects for the boulder relocation prior to export cable installation.

Note:
In case the boulders are recovered to deck there is a risk of recovering UXO to deck. This poses a HSE risk.

Trenching using a chain cutter

Main type UXO	Sub type UXO	NEQ [kg]	Water depth [m]	Likelihood	Consequence	Risk result
Air dropped bombs	GP, 250lb (UK)	30	0-30	Possible (C)	Minor (2)	LOW (4)
	GP, 250lb (US)	58.5	0-30	Possible (C)	Minor (2)	LOW (4)
	GP, 500lb (US)	120	0-30	Possible (C)	Moderate (3)	MEDIUM (9)
	GP, 1,000lb (UK)	171	0-30	Possible (C)	Major (4)	MEDIUM (8)
	HC, 1,000lb (UK)	238	0-30	Possible (C)	Major (4)	HIGH (12)
Ground mines	A Mk I-IV	352	0-30	Possible (C)	Major (4)	HIGH (12)
	A Mk VI	431	0-30	Possible (C)	Major (4)	HIGH (12)

Table 31: Naked risks of detonation effects for trenching of the export cables with a chain cutter.

Trenching using a BHD

Main type UXO	Sub type UXO	NEQ [kg]	Water depth [m]	Likelihood	Consequence	Risk result
Air dropped bombs	GP, 250lb (UK)	30	0-30	Possible (C)	Major (4)	HIGH (12)
	GP, 250lb (US)	58.5	0-30	Possible (C)	Major (4)	HIGH (12)
	GP, 500lb (US)	120	0-30	Possible (C)	Severe (5)	HIGH (15)
	GP, 1,000lb (UK)	171	0-30	Possible (C)	Severe (5)	HIGH (15)
	HC, 1,000lb (UK)	238	0-30	Possible (C)	Severe (5)	HIGH (15)
Ground mines	A Mk I-IV	352	0-30	Possible (C)	Severe (5)	HIGH (15)
	A Mk VI	431	0-30	Possible (C)	Severe (5)	HIGH (15)

Table 32: Naked risks of detonation effects for trenching of the export cables with a BHD.

7.3.2 Cable protection activities

In both the OWF and the export cable corridor, cable protection may be required.

In Table 33 the risk assessment results for cable protection activities are presented. The risks within the export cable corridor are generally higher than in the OWF. This is because of the shallower water depths and higher NEQ UXO items.

<u>Cable protection activities</u>

Main type UXO	Sub type UXO	NEQ [kg]	Water depth [m]	Likelihood	Consequence	Risk result
Air dropped bombs	GP, 250lb (UK)	30.8	0-50	Unlikely (B)	Major (4)	MEDIUM (8)
	GP, 250lb (US)	58.8	0-50	Unlikely (B)	Major (4)	MEDIUM (8)
	GP, 500lb (US)	120	0-50	Unlikely (B)	Severe (5)	HIGH (10)
	GP, 1,000lb (UK)	171	0-50	Unlikely (B)	Severe (5)	HIGH (10)
	HC, 1,000lb (UK)	238	0-50	Unlikely (B)	Severe (5)	HIGH (10)
Ground mines	A Mk I-IV	352	0-30	Unlikely (B)	Severe (5)	HIGH (10)
	A Mk VI	431	0-30	Unlikely (B)	Severe (5)	HIGH (10)

Table 33: Naked risks of detonation effects for cable protection activities.

8 MITIGATION MEASURES

The risk assessment shows that intolerable (HIGH and MEDIUM) UXO related risks may occur during the installation of the Bornholm II East OWF and export cables. This means mitigation measures should be considered. The mitigation measures are to be reasonable, practical, and affordable (ALARP). In this chapter, the recommended mitigation measures are provided.

Note: A UXO detonation caused by offshore installation operations a typical Low-Probability High-Consequence event, comparable to e.g., a plane crash. These are events that are unexpected, with few similar historical events; however, when they do happen the impact is severe.

8.1 PROACTIVE MITIGATION MEASURES

It is recommended to assign the responsibility for the final UXO ALARP Clearance certification to a UXO consultant. To be able to take responsibility for the UXO ALARP clearance certificates the UXO consultant must be approved by Energinet to act as UXO manager and sign off authority.

8.1.1 UXO geophysical survey

It is recommended to perform a UXO geophysical survey of the CPT, vibrocore, and borehole locations, and all locations/areas where installation activities will be executed (WTG and OSP foundation locations, and the export cable corridor). The recommended areas to be subjected to this survey comprise of:

1. A magnetometer line for all shallow seabed investigations for cable route reconnaissance to ensure avoidance of anomalies on the survey line. [166]
2. A 'box' measuring approximately 30m x 30m centred on all CPT, vibrocore, and borehole locations for deep seabed investigations. [167]
3. all IAC and export cable corridors with a width of 60m (30m either side of the cable), and
4. a circular area with a radius of 250m surrounding each foundation location.

The recommended size of the survey boxes for CPT, vibrocore, and borehole sampling considers re-location of the planned sample locations within the box to a location free of potential UXO objects (pUXO).

The recommended IAC and export cable corridor considers re-routing to avoid as many pUXO as possible. This may ultimately result in a reduction of unavoidable targets that require positive identification by WROV intervention.

It is recommended to survey the abovementioned areas by means of ROTV magnetometers (MAG) using a system with a fixed offset of sensors in a gradiometer array.

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[166] The maximum sensor altitude of the magnetometer above the seabed is to be determined on the ferrous mass threshold applicable to the area, depended on the water depth.

[167] The recommended box size considers DPII operations and deployment of a seabed frame, in case of jack-up operations the size of the box is to be determined based on the footprint of the intrusions. The size of the boxes should consider sufficient space to avoid any pUXO targets.

8.1.1.1 Threshold

With regards to the survey threshold, it is recommended to divide the area of investigations in two zones:

1. Areas with water depths < 25m
2. Areas with water depths > 25m

Areas with water depths < 25m

The smallest UXO item to mitigate against for the export cable installation in water shallower than 25m is assessed to be the 250lb bomb. This UXO has a minimum ferrous mass of 58.8kg (GP 250lb US, depending on type). Based on the above, it is recommended to apply a threshold of 50kg ferrous mass for the design and execution of the UXO geophysical survey. For the evaluation of acoustic survey data, a size threshold is recommended of 0.25 x 0.60 (shape: cylindrical). If acoustic survey systems are to be utilised for this purpose they must be proven to be fit for purpose and capable of this appropriate threshold dimensioning.

Areas with water depths > 25m

The smallest UXO item to mitigate against for all activities in water deeper than 25m is assessed to be the 500lb bomb. This UXO has a minimum ferrous mass of 107kg (GP 500lb Mk I – III and Mk IV – VII US, depending on type). Based on the above, it is recommended to apply a threshold of 100kg ferrous mass for the design and execution of the UXO geophysical survey. For the evaluation of acoustic survey data, a size threshold is recommended of 0.35 x 1.10 (shape: cylindrical). If acoustic survey systems are to be utilised for this purpose they must be proven to be fit for purpose and capable of this appropriate threshold dimensioning.

Data evaluation

The UXO magnetometer survey data is to be assessed and processed to identify pUXO targets which meet the minimum ferrous mass threshold and meet the target picking criteria derived from the Surrogate Items Trial (SIT) which shall be conducted prior to the UXO magnetometer survey phase.

8.1.1.2 Required detection range

Considering the assessed UXO burial depths (see Table 13), the required detection range for the export cable route and most of the wind farm site is assessed to be -2.0m below the current seabed. The current seabed level is to be derived from the MBES data that will be collected by the contractor selected for the execution of the survey.

Locally, a higher depth of penetration of UXO may occur, depending on the thickness of the layer of soft mud. The available data does not allow for demarcation of these areas. However, assessment of the backscatter data does show that the darker backscatter areas (indicating a seabed surface of soft mud) are mainly located in the southeastern section of the OWF site.

8.1.1.3 Data evaluation

As part of the mitigation strategy to manage the UXO risk, a Surrogate Items Trial (SIT) for all detection equipment is recommended to be conducted by the survey spreads prior to the commencement of any field operations. The objective is to quantify the performance of the detection equipment and the quality of the positioning.

The UXO magnetometer survey data is to be assessed and processed to identify potential UXO (pUXO) targets which meet the minimum ferrous mass threshold and meet the target picking criteria derived from the SIT.

The presence of numerous boulders and glacial deposits in the area may result in a significant number of false positives. To minimise the number of false positives (e.g., boulders/deposits with a magnetic signature) as much as possible, it is recommended to use an Artificial Intelligence classifier in the pUXO target picking process.

8.1.2 Avoidance of potential UXO objects

In the geotechnical survey boxes, it is recommended to avoid pUXO by relocating the sample location within the box to a location free of pUXO. For this purpose, a standoff distance is to be applied to all pUXO. The standoff distance is dependent on the footprint of the sample apparatus, the positioning accuracy thereof and the positional accuracy of the pUXO. Generally, a standoff distance of 10m suffices.

In the IAC and export cable corridors, it might be possible to avoid potential targets or pUXO resulting from the UXO geophysical survey by means of (micro) re-routing. The re-routing process is driven by optimisation for project costs in relation to the acceptable level of remaining UXO risks when executing the cable installation works.

The avoidance process can start as soon as the UXO geophysical survey data becomes available after processing, QC and interpretation and ends with the definition of the final re-routed Route Position Lists (RPLs) of the ex-port cables and a Final Master Target List which details all pUXO objects that cannot be avoided by the re-routing process.

For the re-routing process, a standoff distance is to be implemented around all pUXO geophysical survey anomalies above the applicable detection threshold that has not yet been confirmed as UXO through investigation by WROV. Thus, the risk of a detonation caused by intrusive activities will be prevented if the object proves to be UXO.

The standoff distances applicable to encountered pUXO targets during cable burial operations is dependent on the installation method, equipment, side effects on the seabed, and positional errors.

The standoff distance for cable trenching can be calculated by the following formula:

Standoff distance = PT + M + (0.5 x WT) + LAC

Where:

PT = Estimated positional accuracy of the target

M = An additional safety margin based on the dimensions of the UXO to be expected

WT = Width of the trencher

LAC = Laying accuracy of the cable relative to the planned RPL

Equation 10: Formula for determining the standoff distance for trenching.

The estimated positional accuracy of the targets is approximately 2m. The recommended additional safety margin based on the dimensions of the UXO is 1.5m. This is approximately half the length of the largest UXO (A Mk ground mine). The intrusion influence zone is assessed to be 3m.

This is based on a maximum trench width (outer side of the swords) of 1m, a burial depth of 1.5m and an influence zone on both sides of the trench of 1m. Finally, the laying accuracy of the cable is assessed to be 1m. The width of the trencher is not yet known but is assumed to be in the order of 6 to 8m.

It is recommended to determine the final standoff distances for the actual equipment deployed in the project.

8.1.3 Intermediate survey

All threshold pUXO targets on the target list which are unavoidable, require positive identification by WROV intervention. Depending on the quantity of pUXO targets, it may be highly beneficial to consider performing an intermediate survey using acoustic survey techniques with classification capabilities (e.g., SBI). Using such a survey system, accurate information can be acquired regarding the depth of burial and the size and shape of pUXO targets.

Previous experiences show that an intermediate survey may result in a significant reduction (up to 60%-80%) of the quantity of pUXO targets to be identified by WROV intervention.

As the site contains large numbers of boulders, conduction of an intermediate survey may add to a more cost effective UXO risk mitigation campaign. Especially because the types of UXO possibly remaining are limited to ground mines and bombs, with a specific size and shape.

8.1.4 Identification of unavoidable pUXO objects

All pUXO targets that cannot be avoided require positive identification by WROV intervention. Non-UXO items are to be removed to enable an as left survey if applicable, ensuring no pUXO targets are left behind in the magnetic masking zone of the object identified.

In Denmark the Royal Danish Navy EOD is responsible for all identification and disposal operations. Therefore, Royal Danish Navy EOD personnel must be present onboard the pUXO identification campaign. The developer is to provide all resources, including vessels, equipment, and personnel.

The Royal Danish Navy EOD team will perform their duties from the vessels of the UXO contractor selected by Energinet. Therefore, these vessels should be able to accommodate Royal Danish Navy EOD personnel, have sufficient deck space for containers and crane for launch and recovery of the EOD’s Rigid Inflatable Boat (RIB) as well as deck space for equipment related to removal/disposal of UXO. All costs involved are to be paid by the developer (Energinet).

8.1.5 Provision of ALARP certification

Upon finalisation of the UXO risk mitigation campaign (a) UXO ALARP certificate(s) is (are) to be issued. Based on the assessed information, UXO migration by natural causes can be excluded. The only factor possibly resulting in UXO migration is through human intervention. This factor is considered part of the baseline residual risk. The recommended validity of the ALARP-certificate is 5 years minimum. This enables the installation of the export cables and OSPs within the validity of the ALARP certificates. In case UXO migration due to human intervention is excluded in the UXO ALARP certificates the validity can be indefinite.

8.2 RESIDUAL RISK

The risk mitigation strategy proposed will not eliminate 100 per cent of the potential UXO risk and so a residual risk will remain. It is important to recognise that a residual risk will always remain, as it is simply not possible to reliably detect all UXO possibly remaining on/in the seabed up to their maximum burial depth (e.g., artillery shells).

The residual risk is a financial risk as a detonation of a under threshold UXO may result in damage to installation equipment and OWF and export cable assets resulting in project delay. It is recommended to share the residual risk among project stakeholders through contractual arrangements or to transfer the risk to third parties, for example an insurer. The decision as to whether a suitable insurance policy should be (or can be) used for this purpose is a commercial one and should be considered between the client, the legal advisors, and the insurance brokers.

8.3 REACTIVE MITIGATION MEASURES

NjordIC recommend the following reactive risk mitigation measures should be considered to mitigate the residual risk of encountering below threshold UXO.

8.3.1 UXO safety and awareness briefing

It is recommended to provide a UXO safety and awareness briefing to all personnel conducting intrusive works. A project specific briefing is recommended. It is an essential component of the Project Health & Safety Plan. All personnel working on the site should be instructed on the recognition features of UXO, actions to be taken to alert project management, employer, and Danish Royal Navy EOD authorities and to keep people and equipment safe from the hazard.

8.3.2 UXO safety instructions

These written instructions contain information detailing actions to be taken if a (potential) UXO is discovered. They are to be retained on site and will both assist in making a preliminary assessment of a suspect object and provide guidance on the immediate steps to be taken if ordnance is believed to have been found.

8.3.3 Implementation of safe working procedures

It is recommended to draft, issue and brief specific UXO safe working procedures for the recovery of equipment to deck (risk of entrapment of below threshold UXO) detailing the actions to be undertaken to ensure safe operations.

For soil sample handling a work instruction was already compiled (NjordIC, *UXO Risk Assessment Grab sample operations OWF Bornholm I West and II East*, reference 2021.03.214/UP0-336, September 23, 2021). This work instruction is appended in Appendix A.

8.3.4 UXO banksman

Deployment of a UXO banksman on call to support operations in case of encounter of a suspicious object/substance should be considered for the project. On call support can respond immediately to reports of any suspected items of ordnance or substances that have been recovered on site. UXO support can also provide the UXO safety and awareness briefings to any staff that have not received them earlier and advise staff of the need to modify working practices to take account of the ordnance threat, and finally to aid Incident Management which would involve liaison with the local authorities should ordnance be identified and present an HSE hazard.

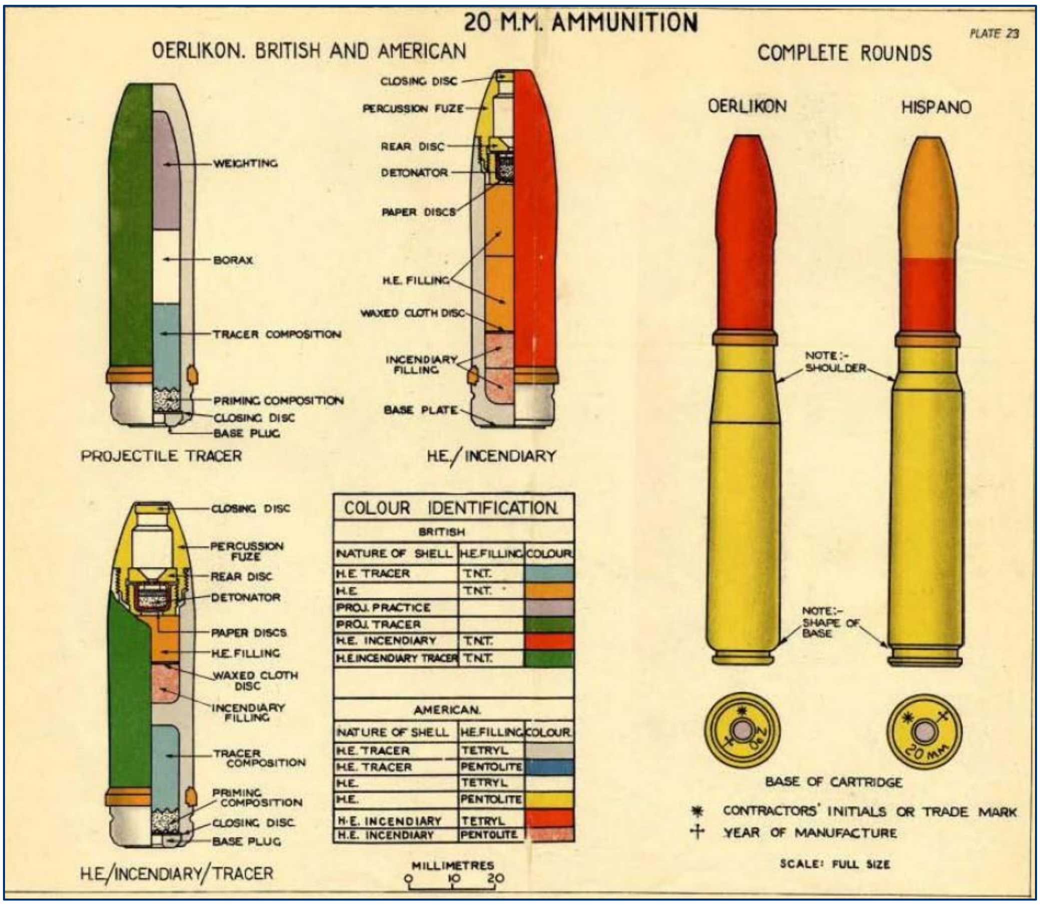
APPENDIX A: WORK INSTRUCTION FOR THE VISUAL INSPECTION OF SAMPLES

This work instruction is to be used for the visual inspection of the borehole, vibrocore, and grab samples collected prior to processing the samples.

<u>Risk</u>
When collecting the grab samples there is a (very) low risk on entrapment of small calibre UXO (e.g., 20 mm shells used in cannons of aircraft) and/or chemical warfare agents.

<u>Mitigation</u>
The low risk can easily be reduced further by applying a visual inspection procedure prior to sample handling. The visual inspection procedure is to be followed during sample handling. **Make sure that the amount of personnel during opening of the grab is kept to minimal/essential personnel only.**

<u>Visual identification of possible UXO</u>
The small calibre UXO projectiles that can potentially be entrapped in the sample are fired from aircraft cannons. They can be of German and British origin. The projectiles are cigar shaped with a diameter of 2 cm/20 mm (German and British) or 3 cm (German) and a length of approximately 8 (2 cm projectile) to 13 cm (3 cm projectile). Below some illustrations of the projectiles are provided for reference as well as some photographs. Since the rounds are fired it is likely that the cartridge case and the projectiles may be encountered separately. The projectiles can be armour piercing, high-explosive or incendiary and may pose a threat to personnel.



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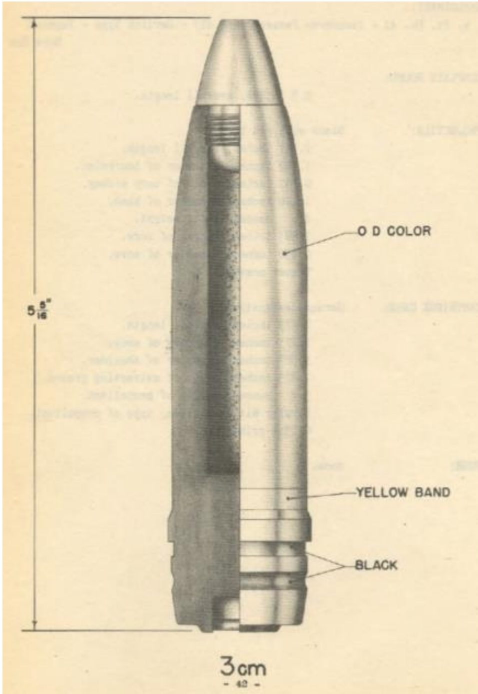
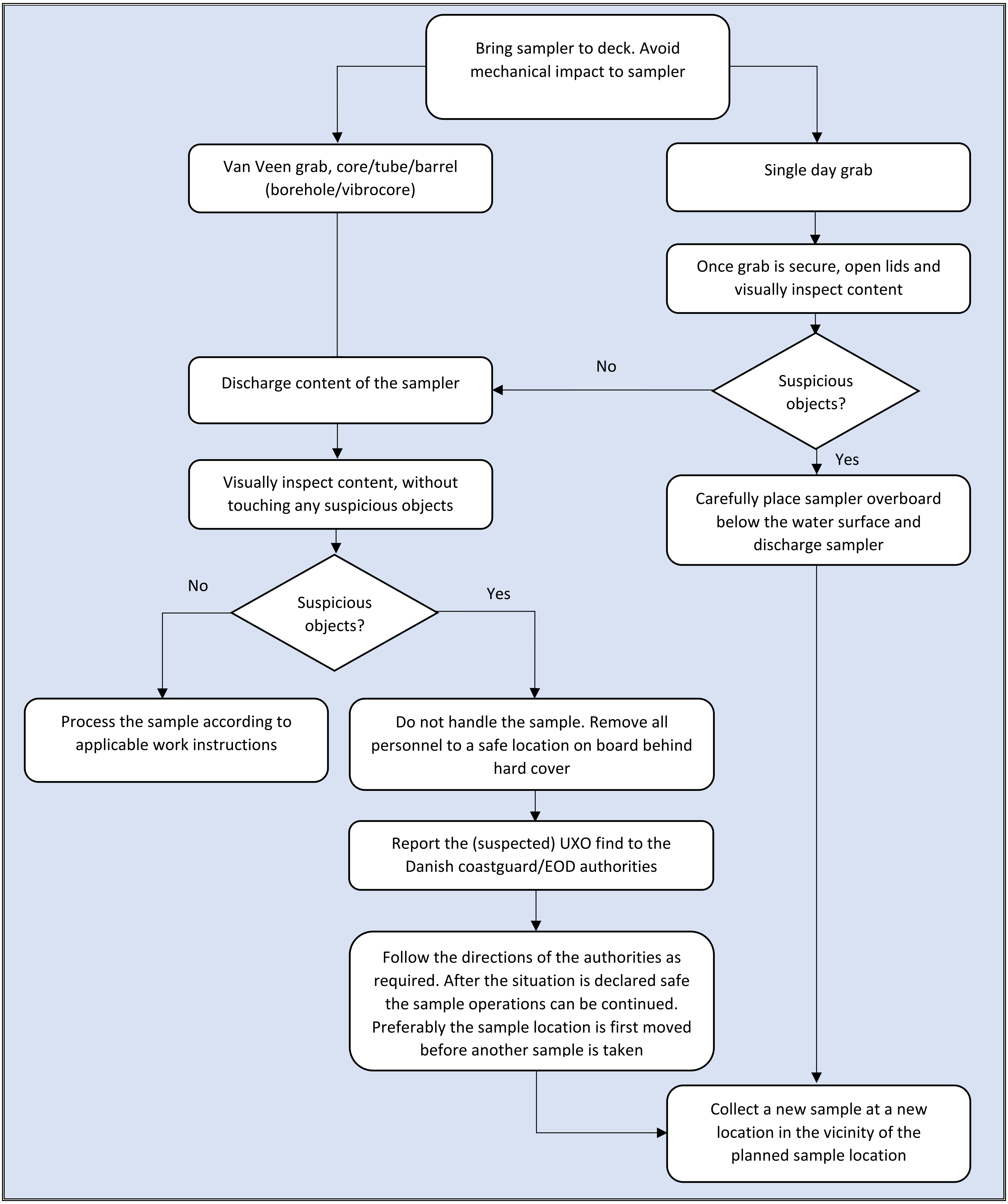
<td>
</td>
</tr>
<tr>
<td>20 mm cartridge case (left) and projectile (right)</td>
<td>20 mm round</td>
<td>3 cm projectile</td>
</tr>
</table>


Bring sampler to deck. Avoid mechanical impact to sampler
Van Veen grab, core/tube/barrel (borehole/vibrocore)
Single day grab
Once grab is secure, open lids and visually inspect content
Suspicious objects?
No
Yes
Discharge content of the sampler
Carefully place sampler overboard below the water surface and discharge sampler
Visually inspect content, without touching any suspicious objects
Suspicious objects?
No
Yes
Process the sample according to applicable work instructions
Do not handle the sample. Remove all personnel to a safe location on board behind hard cover
Report the (suspected) UXO find to the Danish coastguard/EOD authorities
Follow the directions of the authorities as required. After the situation is declared safe the sample operations can be continued. Preferably the sample location is first moved before another sample is taken
Collect a new sample at a new location in the vicinity of the planned sample location