NNB GENERATION COMPANY (HPC) LIMITED

HINKLEY POINT C PROJECT

CASE FOR REMOVAL OF THE REQUIREMENT TO INSTALL AN ACOUSTIC FISH DETERRENT

Summary of the Engineering Optioneering Process

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ACRONYMS

The following acronyms will be used in the report.

Acronym	Definition
AC	Alternating Current
AFD	Acoustic Fish Deterrent
AOD	Above Ordnance Datum
AODC	Association of Offshore Diving Contractors
BEEMS	British Energy Estuarine and Marine Studies
C1 / C2	Safety Class 1 / Safety Class 2
CAPEX	Capital Expenditure
CCGT	Combined Cycle Gas Turbine
CD	Chart Datum
CFD	Computational Fluid Dynamics
dB	Decibel, used in acoustics as a unit of Sound Pressure Level
DC	Direct Current
DCO	Development Consent Order
DP	Dynamically Positioned
Draft	The vertical distance between the waterline and the bottom of a ship's hull
EA	Environment Agency
EDF	Électricité de France
EPR	UKEPRTM Unit
FRR	Fish Recovery and Return
FTU	Formazan Turbidity Unit
HAT	Highest Astronomical Tide
HCB	Filtering Debris Recovery Pit (abbreviation of French term for this item of plant)
HCF	Fish Return System (abbreviation of French term for this item of plant)

HDD	Horizontal Directional Drilling
HDPE	High Density Poly-Ethylene
Heat Sink	The means by which the station loses the heat from its condensers
HLSF	High Level Safety Function
HMI	Human Machine Interface
HP	Cooling Water Pump House (abbreviation of French term for this item of plant)
HPA	Hinkley Point A
HPB	Hinkley Point B
HPC	Hinkley Point C
HPF	Forebay
HW	High Water
Hz	Hertz, unit of frequency defined as one cycle per second
IMCA	International Marine Contractors Association
LAT	Lowest Astronomical Tide
LF	Low Frequency
LVSE	Low-Velocity Side-Entry
LW	Low Water
MSC	Mediterranean Shipping Company
MTTF	Mean Time to Failure
MW(e)	Mega Watt (electric)
Neap Tide	a tide just after the first or third quarters of the moon when there is least difference between high and low water.
NNB	NNB Generation Company (Hinkley Point C) Limited
NPP	Nuclear Power Plant
PrISM	Acoustic model used to predict sound pressure and particle-movement field
RMS	Root Mean Square
ROV	Remotely Operated Vehicle

SC1 / SC2	Seismic Class 1 / Seismic Class 2
SP	Sound Projector
SP cluster	Cluster of 6 Sound Projectors
SPA	Sound Projector Array
SPL	Sound Pressure Level
Spring Tide	a tide just after a new or full moon, when there is the greatest difference between high and low water.
SQEP	Suitably Qualified and Experienced Persons
Turbidity	A measure of the degree that water loses its transparency due to the presence of suspended particulates
UXO	Unexploded Ordnance

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1 INTRODUCTION

1.1 Hinkley Point C Nuclear Power Station

1.1.1 On 18 March 2013, the Secretary of State granted a Development Consent Order (DCO) to NNB Generation Company (Hinkley Point C) Limited (NNB) to build and operate a nuclear power station at Hinkley Point. The new power station will comprise 2 UKEPRTM Units (hereafter, referred to as EPR) that will operate for 60 years, each with the capacity to produce 1650 MW(e). The new station (the 'C' station) will be the third nuclear power station to be built at Hinkley Point, and will be built immediately to the west of the existing 'A' station (which is now being decommissioned), which itself lies to the west of the 'B' station (still in operation).

1.1.2 Hinkley Point C (HPC) will be 'direct-cooled', that is, it will abstract water from the sea in Bridgwater Bay to cool its steam condensers (and other heat exchangers), before returning that same water back into Bridgwater Bay at an elevated temperature (11.8°C higher than at the intake). In order to abstract the combined 130 cubic meters per second (m3 s-1) required for both Units for this cooling process, a large system of cooling water tunnels will extend out into Bridgwater Bay, under the sea bed, before linking to the sea via vertical shafts and associated headworks. As part of the design of the cooling water system, a Fish Recovery and Return (FRR) system will be built, which will include a tunnel extending approximately 600 metres under the foreshore, to return entrapped fish back to the sea.

1.2 Purpose of this report

1.2.1 Since the Secretary of State issued the DCO NNB, has continued to develop the detailed design for the various systems consented under the DCO. Design work on the cooling water system and its various components has advanced, including for the Acoustic Fish Deterrent (AFD) system.

1.2.2 To develop the AFD system NNB committed to an intensive process of optioneering and design to deliver a reliable and effective AFD system. This report provides an overview of this process and the conclusions NNB have drawn.

1.2.3 Due to the unique nature of this project it is important to bear in mind whilst reading this report, much of the technology and techniques being discussed are only at the concept stage of development. This will change over time, but at the stage when NNB are making decisions about how to proceed, the approach outlined and resulting conclusions are the most accurate possible, considering all requirements, at the time of decision.

1.2.4 NNB's commitment to developing a reliable and safe AFD system is demonstrated by the level of effort applied to reach the conclusions presented in this report.

2 BACKGROUND TO THE HPC COOLING WATER SYSTEM

2.1 Introduction

2.1.1 Design of the heat sink (the means by which the station loses the heat from its condensers) is an extremely important aspect of system design for nuclear power stations, in terms of both safety and efficiency as well as environmental impacts.

2.1.2 Considerable work preceded the selection of the preferred cooling water system that was ultimately consented in the DCO, Marine Licence and Water Discharge Permit. The following is a brief overview of this work and description of the selected system, of which the AFD is a component.

2.1.3 The overview presented here is largely based on the detailed scheme description given in the Report to Discharge DCO requirement CW1 (Paragraph 1) and Marine Licence Condition 5.2.31 (NNB GenCo, 2017a).

2.2 Selection of cooling option

2.2.1 As outlined in detail in the HPC 2011 Environmental Statement (EDF, 2011), Volume 2, Chapter 6, there are a number of potential alternative means of cooling the water used to condense steam after it has passed through power station turbines. Of the three principal cooling options considered suitable for new nuclear power plants in the United Kingdom, outlined in **Table 2.1**, direct cooling was selected as the best option for HPC. Reasons why direct cooling are considered the best option for some nuclear power stations, including HPC, is outlined by the EA in their 2010 Guidance (EA, 2010).

Table 2.1 Main types of cooling options for new nuclear power stations.

Cooling option	Circuit type	Cooling option description
Air cooling	Closed circuit	Utilises an array of radiators across which air is forced at high volume to effect heat loss directly to the atmosphere
Tower cooling	Closed circuit	Involves the dispersion and cooling of water in direct contact with incoming air, within a large tower (or towers), involving some evaporative heat loss from the cooling water circuit and the need to make-up for this loss
Direct cooling	Open circuit	Involves the transfer of heat directly from the condensers to a large volume of water which is typically abstracted from the sea or a major river by passing the water once through the condensers before returning to the environment.

2.2.2 Once selected, NNB developed the design of the direct cooling, cooling water system.

2.3 Components of the HPC cooling water system

2.3.1 The components of the HPC cooling water system are outlined in **Table 2.2**.

Table 2.2 Components of the cooling water system.

Description	**HPC building / system**
Acoustic Fish Deterrent (AFD)	Cooling water intakes
Low Velocity, Side-Entry (LVSE) intake head	
Intake shaft	
Intake tunnel	
Forebay (HPF)	Forebay (HPF)
Debris rack and rake	Cooling water pump house (HP)
Bandscreen	
Drum screen	
Connection gutters	
Filtering debris recovery pit (HCB) basin	Filtering debris recovery pit (HCB)
Debris rack and rake	
Archimedes' screw	
Fish return gutter	Fish return system (HCF)
Fish return transition structure	
Fish return tunnel	
Fish return outfall structure	
Outfall tunnel	Cooling water outfalls
Outfall shaft	
Outfall head	

2.3.2 The optimisation of the design of the cooling water system buildings, structures, systems and components has been carried out to ensure that they perform their primary functions (i.e. provision of adequate and reliable supply of cooling water to meet all plant operating states) taking into account a range of other variables including:

- Nuclear safety;
- Industrial safety;
- Fish protection;
- Other environment and sustainability concerns;

- Constructability;
- Operability and operator burden;
- Maintenance burden;
- Supplier experience; and
- Cost (proportionality assessment).

2.3.3 The location of the intakes was established prior to the selection of the AFD technology.

2.4 Location of the intakes

2.4.1 Establishing cooling water intake and outfall locations is an activity that must be carried out very early in the concept development for a large, direct cooled power station as the provision of adequate volumes of cooling water and safe dispersion of the thermal plume are critical to the safe operation and siting of a new facility.

2.4.2 The two key requirements for the appropriate positioning of the cooling water intake structures are:

- The need for safe and efficient operation (including the requirement to incorporate redundancy against hazards in the design); and
- The consideration of environmental sensitivities.

2.4.3 In addition to these key requirements, the intake structures must also:

- Be sufficiently robust to provide a supply of suitable water that will be constant and consistent for the duration of the power plant operation (60 years) in the harsh physical environment of the Severn Estuary, with limited opportunity for maintenance;
- Abstract water at a sufficient depth so as to not draw in air during extreme tidal conditions or in wave troughs;
- Avoid interactions with bed sediment transport to avoid entraining solids that may accumulate and block the cooling water system;
- Limit the number of fish entrained with the water intake;
- Avoid abstracting large amounts of aquatic fauna, including larval or egg life-stages;
- Be geologically suitable (i.e. comprises suitable bedrock for construction and is inactive[1] in respect of faulting or tectonic movements);
- Not cause a hazard to navigation by ships (to minimise risk of impact on the headworks);

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[1] Even though geologically inactive locations are chosen, the headworks and tunnels are built to be able to withstand earthquakes.

- Be sufficiently far away from the associated cooling water outfall headworks, so that water discharged from the outfall is not taken in by the intake[2]; and
- Be as close to the station as possible to reduce the pumping capacity required by the system cooling water system.

2.4.4 Taking into account all the requirements for the cooling water system, NNB considered both the inshore and offshore environments for placement of the intake structures.

2.4.5 Extensive coastal modifications would be required to secure a cross-shore intake that would provide sufficient depth of water at all times (so as to not draw in air during the extreme tidal changes). Due to the significant environmental impacts of such a structure, an inshore intake location was not considered further.

2.4.6 An offshore intake position was therefore selected as the preferred option.

2.4.7 Detailed siting of the intake structures

2.4.8 Accepting that the constant and reliable supply of water over the operational lifetime of the station can only be generated offshore, a suitable location for the intake heads was established using data from several offshore investigations conducted over a large area of the Bristol Channel.

2.4.9 A number of options for positioning the intake and outfall heads has been analysed through thermal plume studies to prevent thermal recirculation between the outfall and the intake.

2.4.10 Based on these studies two main options have been considered for the location of the intake heads: along the -10 m Chart Datum (CD) contour line, corresponding to a distance roughly 5.3 km from the coast (BEEMS, 2011a), and along the -7 m CD, corresponding to a distance 3.3 km from the coast (BEEMS, 2011b). As it is believed there is a sufficient depth of water at both distances, the key benefit to locating the intake heads further from the shore is in reducing the level of sediments on the seafloor and hence reducing the potential for clogging in the cooling water system. Conversely, the main drawbacks to siting the intake heads such a distance from the coast are the cost of construction and the head loss of the associated tunnel.

2.4.11 The head loss of the tunnel has a high impact on the pumping cost, and directly informs the height of the pumping station and pumping requirements. An additional metre of head loss would require the pumping station to be lowered, and the drum screens and band screen to be increased by a similar amount.

2.4.12 For comparison, the HPB intake heads are located 600 m from the station, just outside of the tidal zone. At this location the sea level can reach depths as shallow as 2 m at Lowest Astronomical Tide (LAT) and it has been observed that in these situations large numbers of fish and shellfish are entrained (EDF, 2011b). By siting the intake heads further out, the threat of low seawater level and the associated

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[2] Water discharged by the outfall will be approximately 11.8° C warmer than ambient, and so if this water is 're-circulated' into the intake it has less cooling capacity than ambient seawater, making the heat sink cooling process less efficient

impact on fish entrainment are expected to be reduced. Furthermore, it is believed that seaweed remains concentrated within a region 300 m to 400 m from the shore (HRW, 2013). Therefore, the threat of clogging due to drifting seaweed is minimised by siting the intake heads a significant distance beyond this zone.

2.4.13 In summary, thermal recirculation, low seawater level related hazards and sedimentation are generally believed to become less hazardous with distance from the shore. However, the cost and critically the head loss become prohibitive with large tunnel lengths. A location 3.3 km from the shore has been chosen as the most appropriate solution taking into account the requirements to reduce the hazards associated with low seawater level and head loss. This specific location has been chosen as a local minimum in sediment depths and one that avoids the tunnels from crossing any major faults (Turnpenny Horsfield 2015a).

2.4.14 As shown in **Figure 2.1**, each Unit has a separate intake tunnel, to which two intake heads are connected. The intakes on each tunnel are approximately 200 m apart. The two tunnels are approximately 450 m apart.

2.4.15 It is important to note that there has been a vast amount of work carried out over the last 10 years to identify and develop the optimal intake and outfall locations for the HPC cooling water system (intake and outfall locations are intrinsically linked). In order to provide adequate levels of cooling water at all tidal states, the intake heads need to be in a depth of water that would provide equal challenges to those experienced 3.3km offshore. To avoid these challenges, the intake heads would need to be located onshore which would require massive coastal engineering works to create an intake canal or lagoon. This is not an acceptable option primarily due to the destruction of habitats and impacts on the local environment that would result.

2.4.16 Taking all the above points into consideration, it can be concluded that there is no scope to move the intake heads closer to shore.

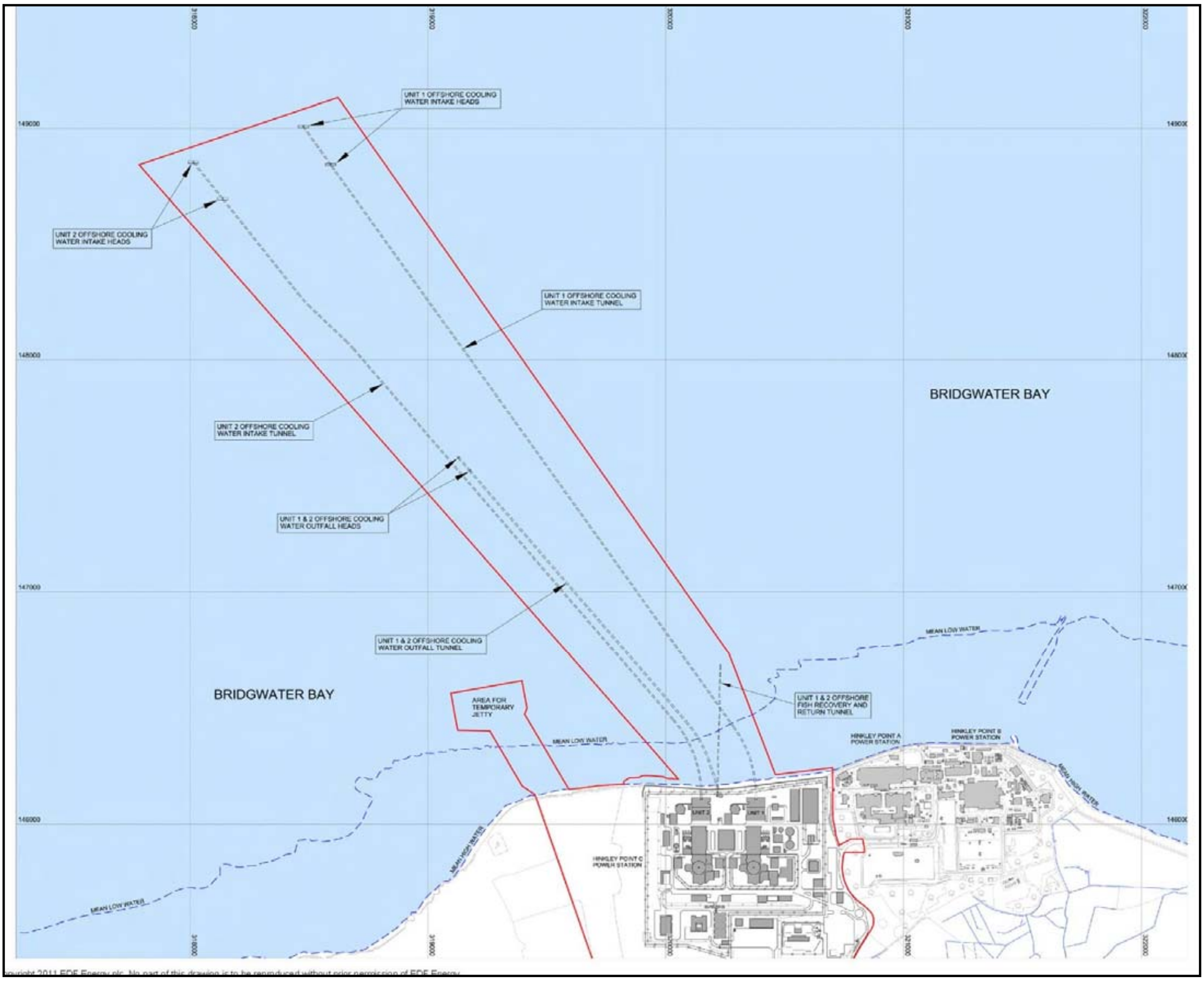
2.5 Intake heads

2.5.1 The HPC intake head design remains identical to that described in the DCO Environmental Statement. It is a rectangular, Low-Velocity Side-Entry (LVSE) intake, which was designed using principles described in the EA ‘Best Practice’ for screening at intakes and outfalls (EA, 2005).

2.5.2 The structure is rectangular with a total size of 43.90 m x 10.00 m x 2.80 m and has an isometric wedge-shaped ‘nose’ structure at each end. The distribution chamber (the intake section) itself is 35.50 m long. Along the two sides are apertures for water to enter the structure; these apertures have baffles within them to prevent the entry of large pieces of debris. The lower sill of the intake apertures will be approximately 1 m above the sediment level of the seabed.

2.5.3 The combined (mean[3]) abstraction rate of the two Units at HPC will be approximately 132 m^3 s^{-1} (depending on tidal state), so each individual intake head will abstract approximately 33 m^3 s^{-1}.

Figure 2.1 Locations of the intake headworks and intake tunnels (also showing outfall headworks and tunnels and Fish Return System (HCF) tunnel and outfall).



2.5.4 The LVSE design is based on three key principles to allow fish in the vicinity the maximum opportunity to escape being drawn in with the water:

- intake flow rates should be slow (i.e. slower than the ‘burst’ swimming speed of fish) so that they can swim away from the intake, provided they are able to detect it and chose to do so;

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[3] Abstraction rate varies according to tidal state.

- in addition to (i) the apertures to the intake head should be perpendicular to the current flow, so that intake velocities are not added to by current/tidal flow; and
- the intake should draw in water sideways, because fish are better able to escape from a horizontal current than they are from a vertical current.

2.5.5 The HPC intake head design achieves all three of these objectives.

2.5.6 The design for the installation of an Acoustic Fish Deterrent (AFD) system must take account of the intake head design objectives and be designed in such a manner that it does not impact the performance of the intake heads.

3 APPROACH TO THE DETAILED AFD ENGINEERING PROCESS

3.1 Introduction

3.1.1 Once the location of the cooling water intakes and the design of the intake heads had been established, NNB commenced detailed consideration of the design, construction, operation and maintenance of the AFD system.

3.1.2 It should be noted that the decision regarding the location of the cooling water intakes was made, following significant investment, prior to the DCO decision in 2013. The DCO process validated the decision regarding the location, so the engineering process and decisions made up to that point were not re-visited as part of this process. When developing nationally significant infrastructure projects it is important to recognise the requirement to make and essentially freeze design decisions. This is essential to allow robust assessment of the environmental impacts of the proposals and enables work to move forward whilst minimising costs associated with re-design.

3.1.3 This section provides an overview of the engineering process, stakeholders and timeline which has been followed by NNB to develop an optimised concept design of the AFD system for HPC.

3.2 The AFD design and optioneering team

3.2.1 NNB engaged Costain, engineering consultants, to develop the AFD system design and plan the AFD system implementation and operation. Costain were selected for this work by NNB as they were, at the time, also retained as the contractor responsible for construction and delivery of the Cooling Water System. Essentially, Costain were tasked with designing a system they would then have to build. This would ensure that the AFD interface with the intake heads would be optimal. Utilising Costain also brought the benefit of their extensive knowledge of operations in marine environments and delivering offshore platform and subsea solutions for the oil and gas industries.

3.2.2 Prior to Costain’s involvement and then working alongside Costain, a large team of engineers from both NNB and the responsible designer, EDF CNEPE, have been involved in various elements of the process. Multiple disciplines have been involved in both the design and critical review, including: civil engineers, structural engineers, subsea engineers, electrical engineers, mechanical engineers, marine ecologists and CDM-advisor. Where required all specialists have been confirmed as Suitably Qualified and Experienced Persons (SQEP).

3.2.3 Supporting the core team, specific activities have also been subcontracted to different specialised companies like ROVCO for Remotely Operated Vehicle (ROV) expertise, James Fisher for diving expertise, HR Wallingford for hydraulic modelling and FGS for acoustic modelling. Each of these organisations were selected for their expertise in the given subject.

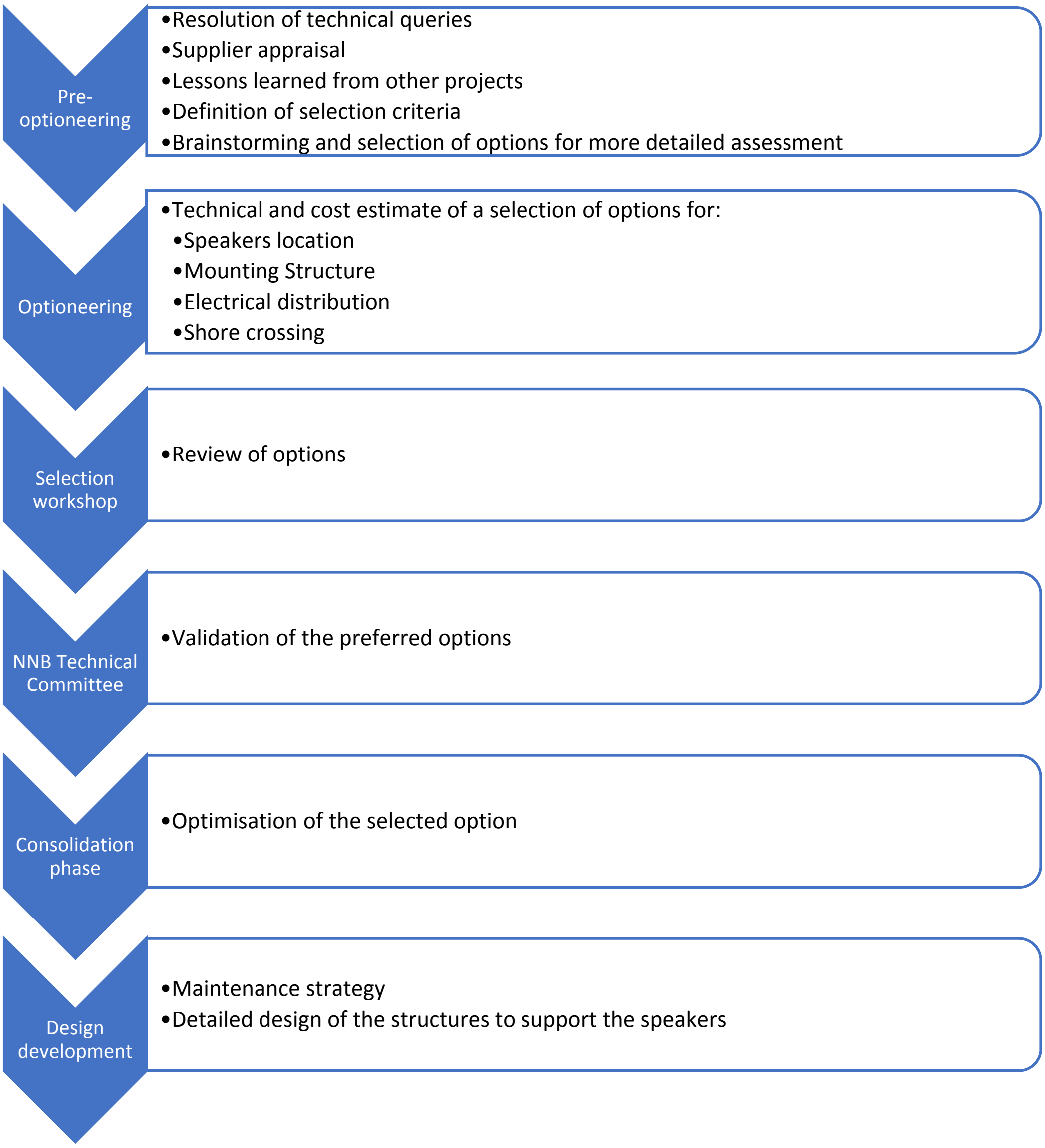
3.3 Detailed design timeframe

3.3.1 The detailed AFD optioneering and design development phase lasted approximately 2 years, and proceeded in a phased approach:

- Pre-optioneering phase – From December 2015 to April 2016
- Optioneering phase – From April to October 2016
- Consolidation/ design development phase – From November 2016 to December 2017.

3.3.2 The simplified schematic in **Figure 3.1** presents the different phases and the key aims for the phase.

Figure 3.1 Key phases of the AFD engineering process



4 ESTABLISHING THE DESIGN AND FUNCTIONAL REQUIREMENTS FOR THE HPC AFD SYSTEM

4.1 Background to requirements and best practice

4.1.1 The EA Screening for Intakes and Outfalls 'Best Practice' Guide11 proposes the following requirements regarding the frequency and Sound Pressure Level (SPL) for a Low Frequency (LF) Sound Projector Array (SPA) Acoustic Fish Deterrent (AFD) systems, installed to deter hearing specialist fish species:

> "*The sound signal should be within the frequency spectrum 10 Hz – 3 kHz*."

4.1.2 The nature of the signal should be repellent to hearing specialist fish. Pure tones do not deter fish, except at very low frequencies that are difficult to generate (e.g. 10 Hz) or at very high SPL, which are expensive to generate. The most cost-effective deterrent signals use either a blend of different frequencies applied as a pulse or crescendo, or a 'chirp' comprising sweep across a frequency band.

4.1.3 The sound level received by the fish at the required point of deflection should be sufficiently above ambient noise level (typically at least ten times, or >20 dB), although this depends on the species of fish and the type of signal).

4.1.4 Regarding the SPL, the EA guidance (EA, 2005) adds that recent research suggests:

> "*… that the degree of reaction to sound in fish cannot be predicted from just the received sound level and the background noise level without knowledge of the hearing sensitivity of the fish, as expressed by an audiogram (plot of hearing sensitivity on a decibel or dB scale versus sound frequency). Based on field trials, the following approximate levels in relation to fish behaviour have been proposed (the levels shown are the peak sound pressure levels calculated when the audiogram values are subtracted from the received noise spectrum and are known as dB(ht)species levels)*" (**Table 4.1**)

Table 4.1 Fish behaviours to varying sound levels.

Sound Level (dB(ht)$_{species}$)	**Fish behaviour**
+30dB	Threshold of visible reaction in more sensitive individuals
+50dB	Most fish swim away from the sound
+70dB	Strong aversive reaction

4.1.5 Regarding the positioning of the Sound Projectors (SP) relative to the intake and the form of the sound field generated, the guide (EA, 2005) also proposes the following requirements:

> *"For best results, the sound projectors are located close to the intake opening, so as to yield high signal particle velocities in the paths of incoming fish. The optimum number and positioning of sound projectors can be determined using an acoustic model such as PrISM to predict the resulting sound pressure and particle-movement field…. The ideal sound field should form a steep acoustic gradient approaching the entrance, free from acoustic nulls caused by destructive interference within the sound field. The presence of such nulls could cause fish to be guided into, rather than away from the intake (Lambert et al., 1998)*".

4.1.6 The specific performance targets for the AFD at HPC in terms of fish species deflection efficiencies (calculated from DCO targets) are as shown in **Table 4.2**.

Table 4.2 Deflection performance targets.

Species	**Predicted efficiency of AFD (% deterred)**
Sprat	88
Whiting	55
Sole	16
Cod	55
Herring	95
Plaice	16
Blue Whiting	55
Eel	0
Twaite shad	88
Allis shad	88
River Lamprey	0
Sea Lamprey	0

4.2 Site specific constraints

4.2.1 A significant factor to consider when setting out the AFD requirements for HPC is the constraints particular to the site and the ambient conditions, which represent a major challenge. The following outlines the key constraints for the construction, operation and maintenance of any AFD system.

4.2.2 Operational function and nuclear safety

4.2.3 The intake heads are nuclear safety classified structures and as such, the AFD system must not adversely impact on the ability of the intake heads to fulfil the Design Basis High Level Safety Function (HLSF) of providing the safety critical cooling water to the land based power generating plant. This has the following implications for the design of the SP mounting structures with regard to the seismic stability element of nuclear safety:

- If the units are sufficiently compact and lightweight such that they are unable to cause damage to the intake heads and impair the HLSF in the event of collapse, seismic qualification of the structures is not required; or
- If the structures are of a size and mass which are capable of impairing the HLSF, the structures must either be seismically qualified, or installed a sufficient distance from the head such that they are unable to impact the head in the event of collapse. However, this has an impact on the effectiveness of the sound field generated, discussed in Paragraphs **4.3.10** to **0**.

4.2.4 Location

4.2.5 The intake heads will be situated approximately 3.5 km from the shoreline on the seabed. This presents two major challenges:

- **Powering the AFD**: as the AFD needs to be powered from the shore, the power supply has to be transmitted over a long distance and then distributed to each of the four intake heads, which increases the complexity of the power transmission and limits the number of possible transmission options (discussed further in **Section 5.4**).
- **Accessing the AFD**: the distance from the shoreline renders access to the AFD possible only by boat, making maintenance and inspection much more time and labour intensive than at other sites already equipped with AFD systems (see **Section 4.4**), thus exposing personnel to the unique and hazardous conditions encountered in the Severn Estuary.

4.2.6 Tidal range

4.2.7 The tidal range in the Severn Estuary, where the HPC intakes are located, is the second largest in the world. The tidal range between the Highest Astronomical Tide (HAT) and Lowest Astronomical Tide (LAT) is over 13 m, as shown in **Table 4.3**.

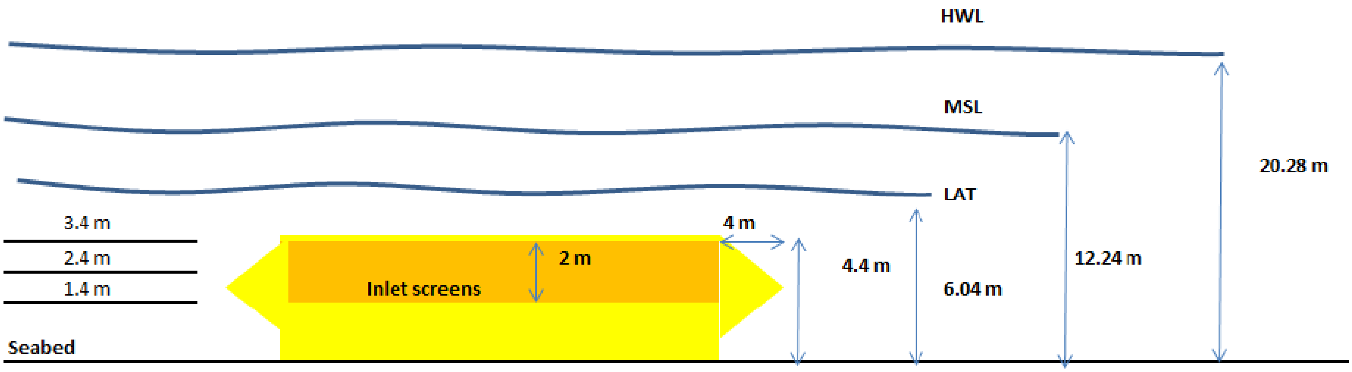
Table 4.3 Tidal range at HPC

Tidal state	Tidal height
High Water Level (HWL)	8.14 mOD
Highest Astronomical Tide (HAT)	7.20 mOD
Mean High Water Spring (MHWS)	6.00 mOD

Tidal state	Tidal height
Mean High Water Neap (MHWN)	3.00 mOD
Mean Sea Level (MSL)	0.30 mOD
Mean Low Water Neap (MLWN)	-2.30 mOD
Mean Low Water Spring (MLWS)	-5.10 mOD
Lowest Astronomical Tide (LAT)	-6.10 mOD

4.2.8 Figure 4.1 shows the tidal states relative to the seabed and intake heads and the resulting submergence depth (i.e. the depth of water above the top of the intake heads), with a maximum of around 15 m at HAT, dropping to less than 2 m at LAT.

Figure 4.1 Tidal states relative to the seabed and intake heads.



4.2.9 Water velocity

4.2.10 The water velocities in the Severn Estuary are a result of the tide. The range of water velocities encountered at HPC is extremely high and vary between 0 – 1.5 m/s for the majority of the time (over 95%), although velocities can occasionally (< 5% of the time) peak at around 1.8 m/s under certain circumstances.

4.2.11 Water turbidity

4.2.12 The waters around HPC contain very high concentrations of suspended solids, resulting in zero or near zero visibility conditions for the vast majority of the time (see Paragraphs **7.4.35** to **7.4.42**). The impact of the high concentrations of suspended solids on the operation and reliability of the SP units will need to be investigated further.

4.3 Transposition into finalised HPC works information

4.3.1 The challenge for NNB was then to transpose these general requirements into a set of requirements for HPC to allow the delivery of finalised works information to the AFD contractor. This involved various steps, with the technical specification continually evolving as more information was gathered.

4.3.2 The AFD subsystems

4.3.3 The overall AFD system comprises three subsystems; the SPs, the SP mounting structure, and the power and communications supply. The role of each subsystem and the interdependencies are described here.

4.3.4 Sound projectors

4.3.5 The SPs are responsible for generating the sound waves which deter the fish. The SPs need to be able to output sound across the required frequency range and the larger the SPL the fewer the number of SPs required to achieve the target sound levels. The reliability of the SPs is important and the Mean Time to Failure (MTTF) determines the number of additional (spare) SPs required to meet the requirements of maintenance operations to replace failed units, ensuring maintenance of the correct sound field.

4.3.6 Sound projector mounting structures

4.3.7 The individual SPs need to be mounted in banks or arrays on mounting structures and the number of SPs will be constrained by the size of the mounting structure. The size, shape and positioning of the mounting structures determines the shape of the sound field produced and the acoustic gradient. A key consideration for the mounting structure is the impact of these structures on the operation of the intake heads, nuclear safety classified structures, and how these mounting structures will be retrieved during maintenance operations.

4.3.8 Power and communications supply

4.3.9 The AFD system requires an electrical power supply, as well as the relevant communications and diagnostics links. Continuity of supply is important and cannot be intermittent. Reliability of all the components making up the power supply system is essential to maximise availability and minimise maintenance.

4.3.10 Estimation of required sound levels

4.3.11 An important step in designing an AFD system is determining the sound levels required to achieve the necessary efficiency in terms of the percentage of fish deterred for each species. This determines the required SP numbers and layout.

4.3.12 Fish reaction to sound is a complex topic and a thorough literary review of academic papers revealed evidence of fish response being linked to sound levels and particle motion, although research in both areas (sound level and particle motion) is still very much an ongoing field.

4.3.13 Nedwell et al. 2007 research on fish reaction to sound levels proposes a linear relationship between the dBht level and the reaction level in fish. This is based on data from various field trials around the world, including Doel Nuclear Power Plant (NPP) in Belgium. **Table 4.4** shows the deflection efficiencies that were achieved for a given dBht level for each species.

Table 4.4 The sound in dBht units vs the percentage avoidance

Common name	Species	Data source	dB_{ht} level	Efficiency
Herring	*Clupea harengus*	Doel	82	94.7
Bass	*Dicentrarchus labrax*	Doel	56	58.5
Perch	*Perca fluviatilis*	Doel	55	51.2
Goby	*Pomatoschistus sp.*	Doel	44	46.1
Flounder	*Platichthys flesus*	Doel	37	37.7
Bighead carp	*Aristichthys nobilis*	Illinois	55	57.0

4.3.14 As stated in Nedwell et al.2007: "*When plotted as a graph, it appears to indicate a clear and near linear dependence of the avoidance on the level of the noise above the species "threshold", i.e. the dBht(Species) level. An extrapolation of the fit implies that at levels of 90 dBht(Species) and above virtually all of a species will avoid the sound. Similarly, at levels of 10 dBht(Species) and below, no reaction occurs.*"

4.3.15 This leads to the following best fit line equation for the data set, where ø is the percentage avoiding a noise of dBht(Species) level L:

- Ø = 100 (L > 90)
- Ø = 1.3 L – 13 (10 < L < 89)
- Ø = 0 (L < 10)

4.3.16 This relationship is summarised in **Table 4.5**.

Table 4.5 Criteria for the effects of noise given in Nedwell *et al.* 2007

Level in dBht (Species)	Effect
Less than 0	None
0 to 50	Mild reaction in minority of individuals, probably not sustained
50 to 90	Stronger reaction by majority of individuals, but habituation may limit effect

Level in dBht (Species)	**Effect**
90 and above	Strong avoidance reaction by virtually all individuals
Above 110	Tolerance limit of sound; unbearably loud
Above 130	Possibility of traumatic hearing damage from single event

4.3.17 Coupling the data on reaction levels with audiograms for the hearing sensitivity thresholds for different species as a function of frequency, between 10 – 1000 Hz (as an example two key HPC species are shown in Table 4.6), the sound levels necessary to achieve the observed efficiency level can be inferred.

Table 4.6 Sensitivity thresholds for herring and bass

	Herring	**Bass**
Data source	Doel	Doel
AFD frequency range	20 – 600 Hz	20 – 600 Hz
Hearing threshold across frequency range	circa. 75 – 80 dB	100 – 105 dB
dBht level	82	56
Approximate sound level	[75 + 82] – [80 + 82] = **157 – 162 dB**	[100 + 56] – [105 + 56] = **156 – 161 dB**

4.3.18 The information detailed in this section led to NNB taking the decision to target a SPL of at least 160 dB across the intake screens in order to maximise the likelihood of the AFD meeting its required efficiency targets in terms of percentage of fish deflected.

4.3.19 Analysis of available AFD technology from potential AFD suppliers

4.3.20 NNB conducted extensive research and analysis of potential AFD suppliers between March 2016 and July 2017. In order to maximise the likelihood of the AFD meeting the required performance levels during the life of the plant, an AFD supplier should have a proven track record of designing and installing effective AFD systems, which encompasses, as a minimum, the following criteria:

- Acoustic modelling capabilities
- Knowledge of sound signal patterns effective in deterring fish

- Proven and robust SP technology able to meet the minimum HPC maintenance intervals
- Experience of large scale power and communications distribution systems

Table 4.7 Summary of potential suppliers

Potential Supplier	Core Business and Location	Communications
Fish Guidance Systems Ltd	Fish deterrent systems. Southampton, UK	Face-to-face meetings, telephone calls, e-mails. http://www.fish-guide.com/
Aquatic Control Engineering Ltd partnered with Fish Flow Innovations BV	ACE Ltd: supply and installation of specialist equipment for the water industry, Nottinghamshire, UK FFI BV: fish migration facilities and protections systems, Medemblik, Netherlands	Face-to-face meetings, telephone calls, e-mails. https://www.aquaticcontrol.co.uk/ www.fishflowinnovations.nl
ACE Aquatec Ltd partnered with Neptune Sonar	ACE Aquatec Ltd: partnership with experts in different scientific fields to apply breakthrough technology developments to aquaculture and marine industries, Dingwall, UK Neptune Sonar: Undersea Defence and Commercial transducers, Kelk, UK	Telephone calls, e-mails https://aceaquatec.com/ http://www.neptune-sonar.co.uk/
Systems Engineering and Assessment Ltd	Delivery of electronic systems to the defence, transport and offshore energy markets using skills and knowledge in Naval Combat Systems, Dismounted Soldier Operations, Traffic Enforcement and Subsea Engineering, Frome, UK	Face-to-face meetings, telephone calls, e-mails https://www.sea.co.uk/
GeoSpectrum Technologies Ltd	Underwater acoustic transducers and systems supplied to the defence and homeland security, oil and gas, and environmental sectors, Dartmouth, Nova Scotia, Canada	Telephone calls, e-mails https://geospectrum.ca/
Smith-Root	Solutions for aquatic ecosystems management with a focus on fisheries investigation products, Vancouver, WA, USA.	N/A – internet research only. https://www.smith-root.com/

4.3.21 The conclusions of the supplier research and analysis exercise is that the number of viable suppliers is extremely limited.

4.3.22 Given the scale and complexity of the HPC project and the severe environmental conditions encountered in the estuary, no supplier (even those with previous experience) is currently able to meet all of the HPC Project's minimum criteria.

4.3.23 Analysis of available AFD SP technology

4.3.24 Although there are some suppliers who have developed or are willing to develop different types of AFD SP unit, most of the development is experimental and there is only one supplier who has provided long term and permanent installations with effective fish deflection results.

4.3.25 Given that this supplier also has acoustic modelling capabilities and knowledge of sound signal patterns effective in deterring fish, NNB have based their optioneering analysis and development on the supplier's existing LF SP technology which operates within the 10 – 3000 Hz range and typically covers 20 – 600 Hz.

4.3.26 The technology used to generate these frequencies is similar in principle to a normal SP, with an electromagnetic coil which is excited by an electrical current in order to move a flexible diaphragm, generating sound waves (**Figure 4.2**). So that the SP can operate underwater, they are equipped with an internal pressure compensation bladder or 'airbag' which acts to balance the inward pressure on the diaphragm generated by the hydrostatic water pressure (which increases linearly with water depth) (shown in **Figure 4.2**).

4.3.27 Although this technology has been employed at numerous sites (the estuarine sites of Pembroke and Doel being the largest examples of operational sites on a commercial scale), it is not suitable for implementation at HPC in its current state and requires significant design development and improvement before it could be considered robust enough.

4.3.28 A key improvement required is the development of the power and communications system. With the large number of SPs required to cover the four intake heads at HPC, located a long distance offshore, the available power and communications systems are not sufficient and need major development.

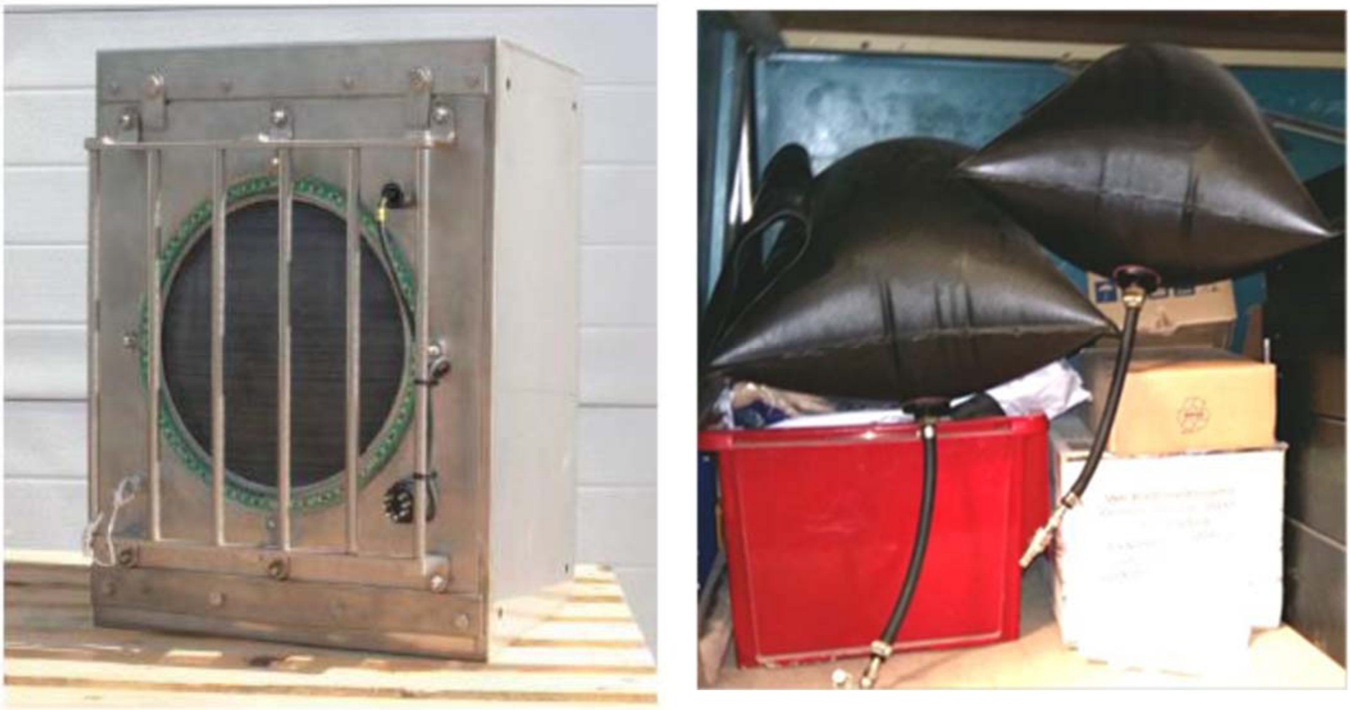
4.3.29 Development would need to focus on (but not be limited to):

- Human Machine Interface (HMI) Control – HPC will require dual control from land and from the offshore hub
- Control software - upgrading and improving to cope with the size of the HPC system
- Capability to change sound signals remotely
- Cable connectors – wet mate versions will be required instead of the current dry mate connectors

- Improved diagnostics feedback to provide more information on system performance

4.3.30 The robustness of the SP unit would also need to be substantially improved. Available evidence from installations at Doel and notably Pembroke shows that in environmental conditions much more benign than those encountered at HPC (lower water depth, tidal range, waves, current, etc.), the current SP technology is susceptible to failure (in particular the airbags), even when cleaned every 6 – 9 months and replaced every 12 months.

Figure 4.2 Example of AFD SP (left) and 'airbag' (right)



4.3.31 To be able to fulfil requirements this means that significant improvements in the robustness of the SP units would be required. The SP units need to withstand the environmental conditions at HPC sufficiently to ensure the service and/or replacement interval for each SP unit is 18 months (not 12 months). The 18 month replacement schedule is explained further in **Section 7.4**.

4.3.32 **Improvements required to available SP technology to enable it to withstand environmental conditions at HPC**

4.3.33 Available SP technology will require substantial upgrading to withstand the environmental conditions at HPC.

4.3.34 The following outlines the key environmental considerations and the parameters that would need to be addressed in any SP upgrading exercise. Where practical solutions are available these are noted.

4.3.35 Water depths and wave loading issues

4.3.36 The large tidal range, resulting in significant variations in water depth and velocity have a number of impacts on the design, construction, operation and maintenance of the AFD.

4.3.37 At HPC the tidal range and frequently encountered wave heights mean the water depth can reach up to 25 m (2.5 bar in water pressure). This large pressure range, that the SP housing and airbag would have to cope with throughout the tidal cycle, is greater than the SP housing and airbag unit are currently designed to withstand. Considerable design improvement is required to enable the SP housing and airbag to withstand these conditions over the operational window.

4.3.38 Tidal flow

4.3.39 The high water velocity at HPC relative to other sites (up to and sometimes in excess of 1.5 m/s) means that the SPs cannot be positioned perpendicular to the flow as this would impede the diaphragms' active displacement range. The only mitigation measure is to ensure that the SPs are positioned parallel to the flow.

4.3.40 In addition to this, the water velocities are such that further research and design is required to ensure that the SPs are not affected by flow induced turbulence.

4.3.41 Turbulence

4.3.42 The SP pressure compensation systems are designed to accommodate slow changes in external pressure associated with tidal height. Long-wavelength pressure variations, associated with surface waves, are well accommodated by the available systems. Short wavelength pressure variations, caused by turbulence, may excessively stress the moving components, especially if it results in uneven loads on the diaphragm causing misalignment of the moving coil. Given the high current velocities at HPC, the only mitigation measure is to ensure that the flow around the SPs and their associated structures does not generate excessive turbulence through careful consideration in the design phase, followed by confirmation through Computational Fluid Dynamics (CFD) analysis.

4.3.43 Silt

4.3.44 The SP outer casing is open to the sea and there is the high possibility of silt ingress, which could limit the effective airbag expansion volume. Although this has not proved a problem in existing AFD systems and no loss of sound output has been attributed to this cause, the extremely high suspended sediment loadings in the Severn Estuary around HPC and the more limited opportunities for rising and cleaning SP units at HPC means that some pilot-scale testing would be needed to rule out the risk of failure (or adapt the design to improve robustness in the event it does prove problematic).

4.3.45 Biofouling

4.3.46 Biofouling within the SP outer housing can include crabs, barnacles, limpets and other marine life, and can cause abrasion leading to airbag leakage/failure. Although HPC has not been identified as a site with a high risk of biolfouling, as per silting, the limited opportunities for raising and cleaning SPs at HPC mean that some pilot-scale testing would need to be performed to rule out the risk of failure (or adapt the design to improve robustness in the event that it does prove problematic).

4.3.47 Summary of analysis of current AFD suppliers

4.3.48 There is no technology currently available on the market which is suitable for implementation at HPC. Even the most viable LF SP will require significant design improvement by its supplier to meet the requirements of the AFD at HPC (to withstand the environmental conditions and allow an 18-month service interval). Any process of improvement will take considerable time and cannot be guaranteed.

4.4 Lessons learnt from other sites using AFD technology

4.4.1 There are a number of cooling water abstraction locations that have AFD systems installed, however Doel and Pembroke are the only two known sites in Europe with operational AFD systems on a commercial scale. NNB therefore sought information regarding the operation of AFD systems at these two sites to help inform ongoing design considerations for the AFD system at HPC.

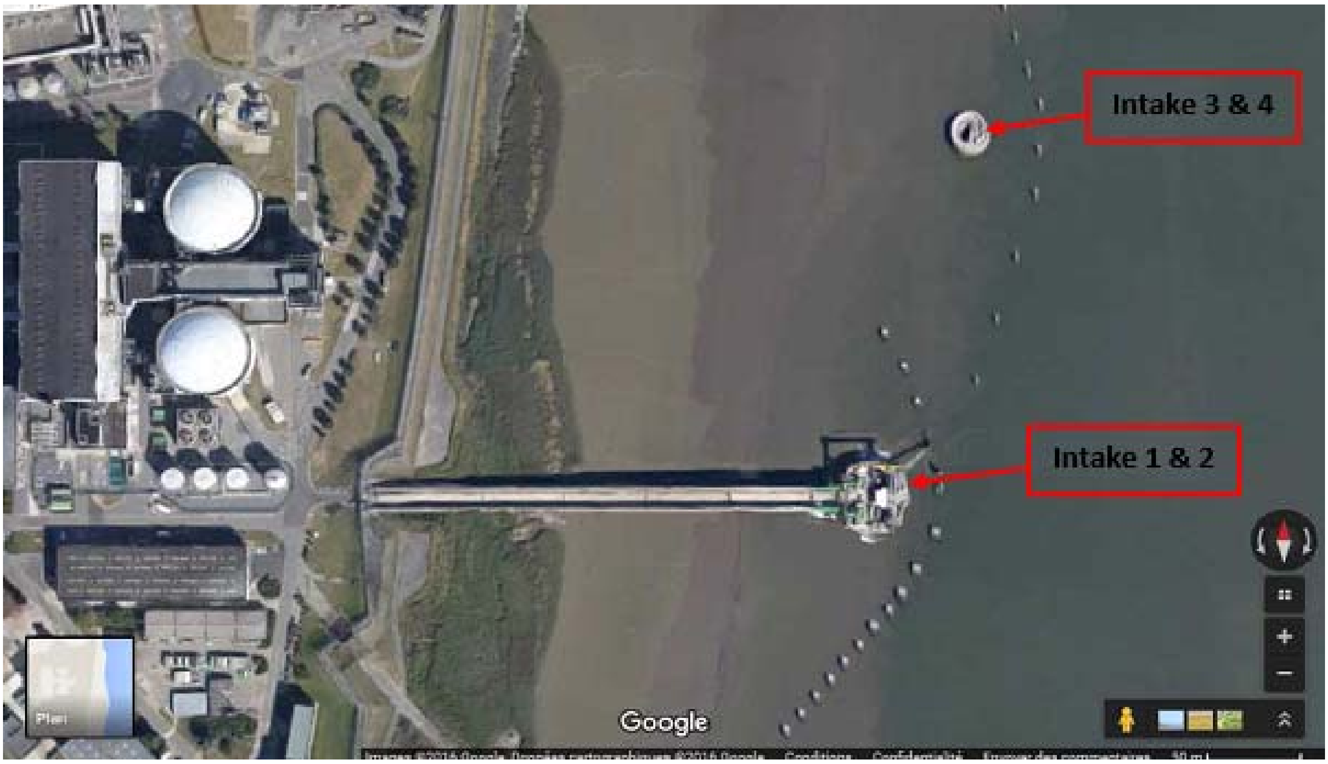
4.4.2 Information about the operation of the AFD system at Doel and Pembroke is not publicly available. NNB approached both operators and both operators gave information about the systems installed. Due to the commercial nature of these discussions the following sections provide an outline of the key information available and relevant to the considerations presented in this report.

4.4.3 **Doel**

4.4.4 System overview

4.4.5 Doel NPP is situated on the Scheldt Estuary, near Antwerp, Belgium. The plant and its water intake structures can be seen in **Figure 4.3**.

Figure 4.3 Aerial photograph of DOEL NPP on the Scheldt Estuary near Antwerp, Belgium, showing location of the water intake structures



4.4.6 Intake 1 & 2, situated to the south, is accessible by foot from the shore and houses the AFD system's amplifier units. The AFD SP array is fitted to intake 3 & 4, which is situated between 50 – 200 m from the shore (depending on the tide) and is only accessible by boat.

4.4.7 The intake 3 & 4 structure is fitted with 20 large (600 W) pressure-compensated LF SP units, sweeping a frequency range of 20 – 600 Hz every 0.2 seconds. The system was initially commissioned in 1997 with the SP units mounted around 5 m away from the intake heads. A preliminary trial of the system in 1997-1998 yielded no significant reduction in the number of fish entering the intake. As a result, the SP units were relocated and installed on the intake structure. Since being installed on the intake heads, trials have shown a reduction in the number of fish entering the intake.

4.4.8 Reliability, redundancy and maintenance

4.4.9 Routine maintenance is required on all parts of the intake system at Doel, however the highest maintenance burden is attributed to the SP units. The SP units can only be reached by boat however access for maintenance and the maintenance duration is helped by:

- the short distance from the shoreline (of the order of 200 m maximum, depending on the tide);
- the relatively low number of SPs (20); and

- the SP mounting units being surface retrievable: as shown in **Error! Reference source not found.**, the SPs are mounted on a carriage-rail system, with a manually operated winch to raise and lower the units.

Figure 4.4 Diagram showing the SP mounting units at Doel and the remote retrieval mechanism

4.4.10 The 20 SPs are raised every six months for cleaning. This timeframe is required otherwise issues are encountered with bio-fouling from marine flora and fauna growth which reduces the effectiveness of the SPs and jams the winch system (which requires diver intervention to repair). The cleaning and SP replacement takes around two to three days and is performed at low tide.

4.4.11 During the six monthly cleaning operations, eight SPs are completely removed and replaced with refurbished units. The units removed are then refurbished by the supplier. Refurbishment work can be minor, such as replacing seals, or more significant and involved, such as replacing electronics or airbags.

4.4.12 Information on the redundancy rate of the SP units at Doel is not available.

4.4.13 Pembroke

4.4.14 System overview

4.4.15 Pembroke Combined Cycle Gas Turbine (CCGT) power plant is located near Milford Haven in Wales and was commissioned in 2012. **Figure 4.5** shows an aerial view of the power plant and water intake.

4.4.16 Pembroke CCGT intake is located in a sheltered bay with a tidal range of around 8 m. The water intake velocity is low at around 0.2 m/s. The intake head is situated on land and is therefore accessible by foot.

4.4.17 Pembroke CCGT intake is fitted with a total of 72 pressure-compensated LF SP units (250 W), arranged in 18 columns of four SPs. This arrangement covers the whole rectangular shaped intake opening.

Figure 4.5 Aerial view of Pembroke CCGT

4.4.18 Reliability, redundancy and maintenance

4.4.19 The AFD system at Pembroke CCGT is designed to accommodate a redundancy (failure) of one SP per column of four SPs, giving 25% redundancy (this is in the event of single failures regularly spaced across the columns as opposed to losing entire groups of SPs).

4.4.20 As per Doel NPP, by far the largest maintenance burden for the AFD system is the SPs. Each column of four SPs can be raised out of, and lowered back into, the water via a motorised travelling crane. **Figure 4.6** shows SP columns both lifted out of the water and in the process of being raised or lowered.

4.4.21 The plant operator maintains two SP columns (eight SP units) every month. The accessible nature of the intake and motorised crane allow the maintenance of two columns by two personnel in a single shift. Each column is raised in order to both clean the SPs and remove and replace any SPs which are due to be serviced. This rolling monthly cycle means that each SP is cleaned every nine months and replaced, with a refurbished unit, every 12 months.

4.4.22 Despite the regular maintenance, unexpected failures still occur. The principle reasons for failure of the SPs are the cable connectors to the SP's speakers and the SP's internal pressure compensation bladder.

Figure 4.6 Diagram showing the location of the SPs at Pembroke being raised / lowered

4.4.23 The regular raising and cleaning of the SPs limits marine growth (no special measures are implemented in this regard) and as a result no lifting operation failure has been reported, meaning no diver intervention has been required since commissioning.

4.4.24 Conclusions of lessons learnt from other sites

4.4.25 **Table 4.8** gives a comparison of the key AFD information of Doel NPP, Pembroke CCGT and HPC.

Table 4.8 Comparison of the AFD systems at Doel NPP, Pembroke CCGT and HPC

	Doel NPP	Pembroke CCGT	HPC
Number of SPs	20	72	288
Scale (number of SPs relative to Pembroke)	0.3	1	4
Intake distance from shoreline (m)	50 – 200 (depending on tide)	0	3000
Means of access	Boat	Foot	Boat
Means of SP retrieval	Surface (via manual winch)	Surface (via motorised crane)	Subsea (via diver or ROV)
SP cleaning cycle	6 months	9 months	18 months
SP replacement cycle	15 months	12 months	18 months (target)
Redundancy (failure) allowance	No redundancy in the Doel AFD system but the system is oversized. Fish are deterred even when some SPs are not working (depending on where the failed SPs are)	25%	> 16% (although precise percentage would depend on further sound modelling to determine number of SPs which can fail before acoustic field drops below the required 160 dB)

4.4.26 From the review of existing operational AFD systems at Doel NNP and Pembroke CGGT it can be seen that the AFD system at HPC would be much larger than any existing system, at a much greater distance from the shoreline, with greater access and SP retrieval difficulties to overcome.

4.4.27 The key learning points taken from Doel NNP and Pembroke CGGT are outlined in Table 4.8 with an overview of what the implications for HPC AFD system are.

Table 4.9 Key learning points from Doel NPP and Pembroke CCGT and the implications for HPC.

Key learning point from Doel and Pembroke	Implications / applicability for HPC
In order to deflect fish effectively, the SPs must be located as close as possible to the intakes.	The design of the HPC intakes allows for the SP's to be close to the intake structure.
Without regular cleaning (every six months at Doel and every nine months at Pembroke) or other special measures, marine growth can cause potential maintenance issues.	Whilst HPC is not expected to be a site which is sensitive to bio-fouling issues, this remains an unknown factor. The impact of regular cleaning on the MTTF of the SPs is not known, and this could be problematic for HPC as regular raising of the SPs for cleaning will not be feasible.

Key learning point from Doel and Pembroke	Implications / applicability for HPC
For an AFD system, the LF pressure-compensated SPs represent the majority of the maintenance burden and are generally replaced around once every 12 months. However, even at this replacement rate, unexpected failures still occur.	The unexpected failure rate for Doel and Pembroke are in conditions that are much less severe than those encountered at HPC therefore failure rate will likely be higher.
Maintenance of the AFD system is a very significant undertaking.	Given the larger scale of the HPC AFD system in harsher environmental conditions at a greater distance from shore, the maintenance burden of the HPC AFD system is likely to be significantly greater than other sites.

4.5 NNB requirements for an AFD system

4.5.1 Taking into account the information collected about the currently available AFD SP technology and suppliers, power supply options, site constraints and lessons learnt from other sites, a list of requirements for any AFD system installed at HPC has been created. The key requirements are:

- The sound envelope must maintain a strong acoustic gradient with SPLs reducing with distance from the intake screens;
- SPL generated has to be > 160 dB Re 1 μpa across the whole surface of the intake screens (at the entrance to the intake heads) with minimal interference and acoustic nulls;
- SPL has to be maintained for all states of tide, demonstrated by use of an appropriate acoustic model such as PrISM;
- The sound signal should be within the frequency range of 30 – 600 Hz, with the capability of operating up to 2000 Hz;
- The AFD's control system needs to be programmable so that it can emit different sound patterns (chirp, sweep, etc.);
- To ensure the AFD system meets operational needs the AFD system design should be based on proven technologies;
- The entire AFD system (including SPs) must be designed to withstand fluctuating water depths between 0 – 25 m (tide + wave height) and current speeds between 0 – 1.8 m/s;
- The entire AFD system is to be powered from onshore via submarine cable(s);
- To ensure the AFD system acts as a deterrent, as planned, the entire AFD system must meet a minimum availability of 90%, including downtime for both planned and unplanned maintenance
- The system needs to be designed to ensure operability on an 18-month replacement cycle for SPs;
- Maintenance activities of the AFD systems and associated mechanical and electrical power supply infrastructure should not interfere with, or risk damage to, the cooling water intake structures;

- Diving activities should be minimised where possible; and
- The water intake heads and tunnels are classified safety class C1[4] and seismic class SC1[5]. It is, therefore, necessary to apply C2 SC2 seismic requirements to any building or structure which itself is not required to remain robust against earthquake, but whose failure could have unacceptable impact on a structure or component with an SC1 seismic requirement. In particular, if the collapse of a structure/building can directly or indirectly have unacceptable impact on an adjacent structure or component designed with an SC1 seismic requirement, this structural/building must be designed with an SC2 seismic requirement.

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[4] In the classification scale C1 is the highest safety classification for a structure or building.

[5] In the classification scale SC1 is the highest seismic classification class for a structure or building.

5 ENGINEERING OPTIONEERING PROCESS

5.1 Introduction

5.1.1 Having established the requirements for an AFD system at HPC, defined in **Section 4.5**, NNB considered the viability of a number of engineering options against these requirements. To simplify the engineering optioneering process the analysis was broken down into four work packages:

a) SP location for acoustic field generation;

b) AFD mounting structures (onto which the individual SPs are mounted);

c) Electrical power supply/distribution and communications; and

d) Shore crossing (the connection between the power supply on land and the submarine cable feeding the AFD).

5.1.2 The following sections provide an overview of the optioneering process that was undertaken for each work package and the conclusions drawn.

5.2 SP location for acoustic field generation

5.2.1 In order to examine the influence of SP location in relation to the intake head on the acoustic field generated, sound modelling was performed using PrISM software.

5.2.2 The different SP locations and configurations modelled were to test the feasibility of two different deflection principles:

- Deflection Principle 1: as shown in **Figure 5.1**, the SPs are mounted at ends of the intake heads - this method consists of mounting SPs in clusters upstream and downstream of the intakes, with the clusters either operating at both ends simultaneously or only at the upstream end. The deflection principle is that the fish being carried in the tidal stream (which reaches up to around 1.5 m/s) encounter the sound field and are deflected to a distance which is sufficiently far from the intakes that they are unable to swim back within a radius where they risk being entrained.
- Deflection Principle 2: as shown in **Figure 5.2**, the SPs are mounted along sides of intakes - this method consists of mounting SPs along the sides of the intakes to deflect fish to a distance from the intake where they do not risk being entrained. In this scenario, unless the SPs are mounted directly on or very close to the intake heads, some degree of upstream deflection may be required to ensure that fish remain on the correct side of the SPs and the sound pressure gradient when they are carried towards the intake heads at higher tidal velocities (as the distance between the SPs and the intake heads increases, the upstream deflection distance increases).

5.2.3 The two deflection principles were then modelled using different base cases, with each case subsequently being modelled in a variety of configurations in an attempt to optimise the SP layout and generate the most robust sound field.

Figure 5.1 Deflection Principle 1 – SPs mounted at the end of intakes

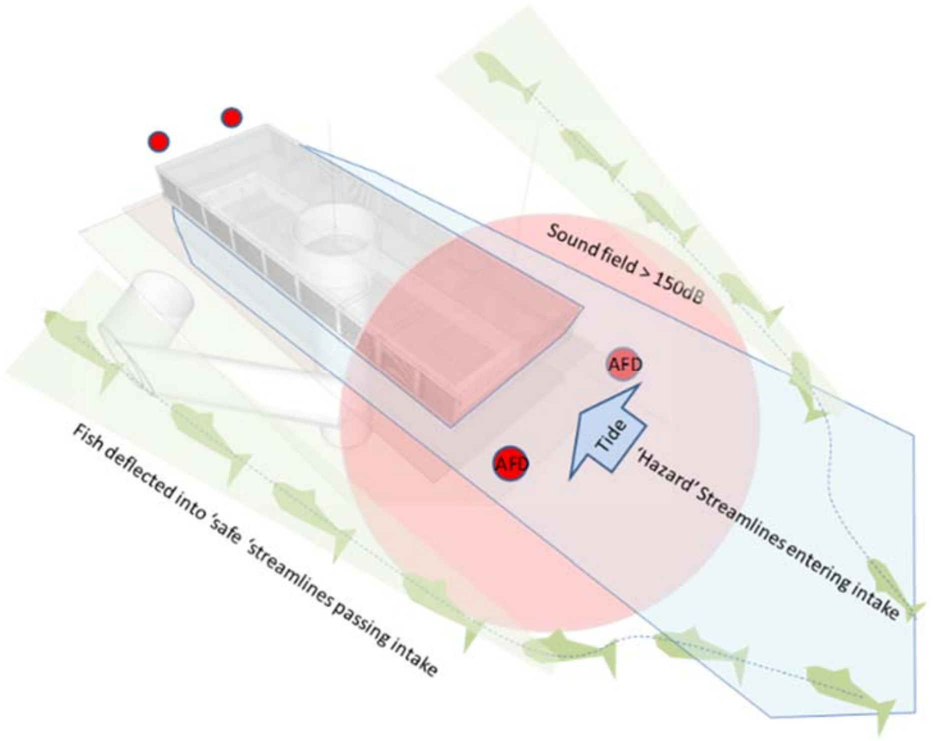
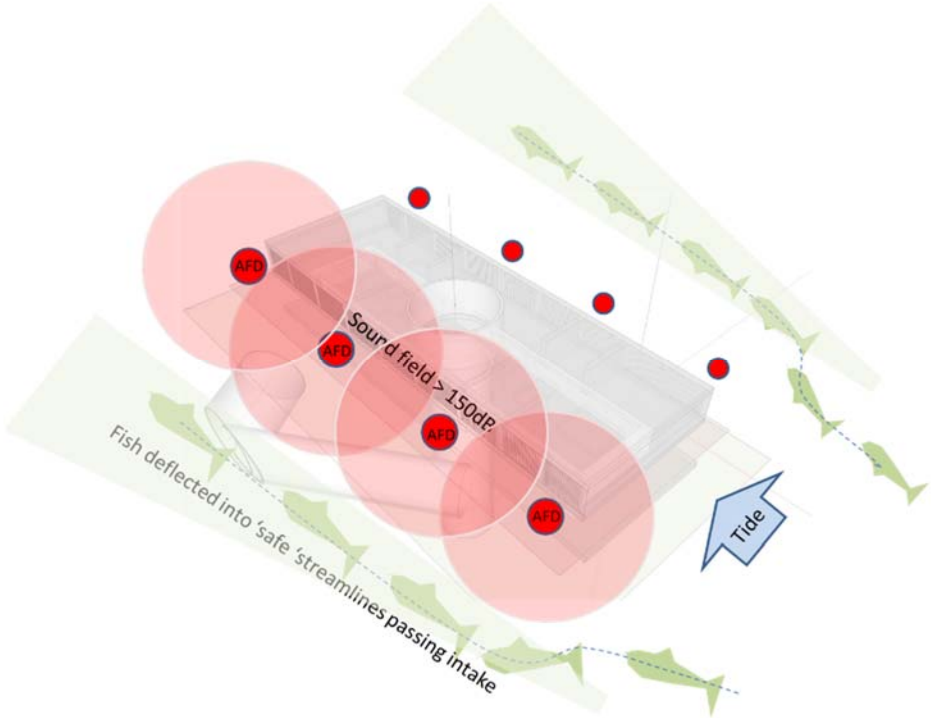


Figure 5.2 Deflection Principle 2 – SPs mounted along the sides of the intake



5.2.4 Deflection Principle 1

5.2.5 For Deflection Principle 1, the SPs were arranged in clusters, lines and V-shaped configurations, with each arrangement being modelled with the SPs operating simultaneously at both ends and at the upstream end only. This is the proposed SP layout given in the HPC Environmental Statement1, prior to any detailed modelling.

5.2.6 All of the Deflection Principle 1 modelling cases were deemed unsatisfactory and eliminated. All configurations lead to poor sound coverage over the intake screens, leading to decreased protection at lower tidal velocities when fish are less likely to be carried along in the tidal streamlines past the intakes. Each configuration also suffered from a variety of different drawbacks such as the creation of acoustic nulls, insufficient lateral deflection, risk of trapping fish between the two sound fields and funnelling them into the intakes, risk of fish swimming over the SP array at higher tidal levels and dropping back towards the intake or simply requiring too many SPs.

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Figure 5.4 give examples of snapshots from the modelling. The configuration in **Error! Reference source not found.**, based on previous modelling carried out in 2011 and described in BEEMS Technical Report 194 (BEEMS, 2011d), highlights the insufficient lateral deflection, acoustic nulls and poor sound coverage over the intake screens. The configuration in

5.2.7 **Figure 5.4** generates sufficient lateral deflection; however, again, sound coverage is poor over the intake screens and there is also a risk of trapping fish between the two sound fields. In both cases, some of these issues can be resolved by only operating SPs at the upstream end of the intake heads but this leads to an even greater reduction in sound coverage over the intake screens themselves.

Figure 5.3 Sound modelling results for SP clusters at either end of the intake head. The sound field is shown in red – yellow and the intake head in grey.

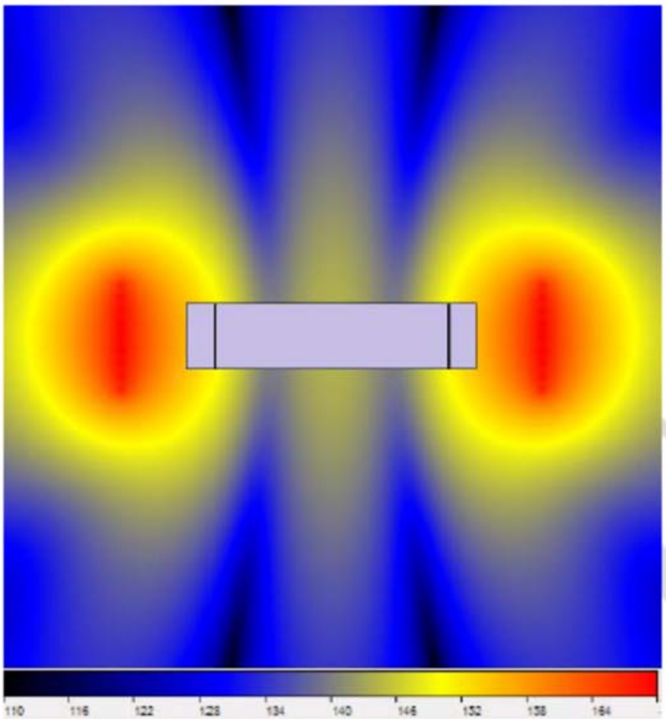
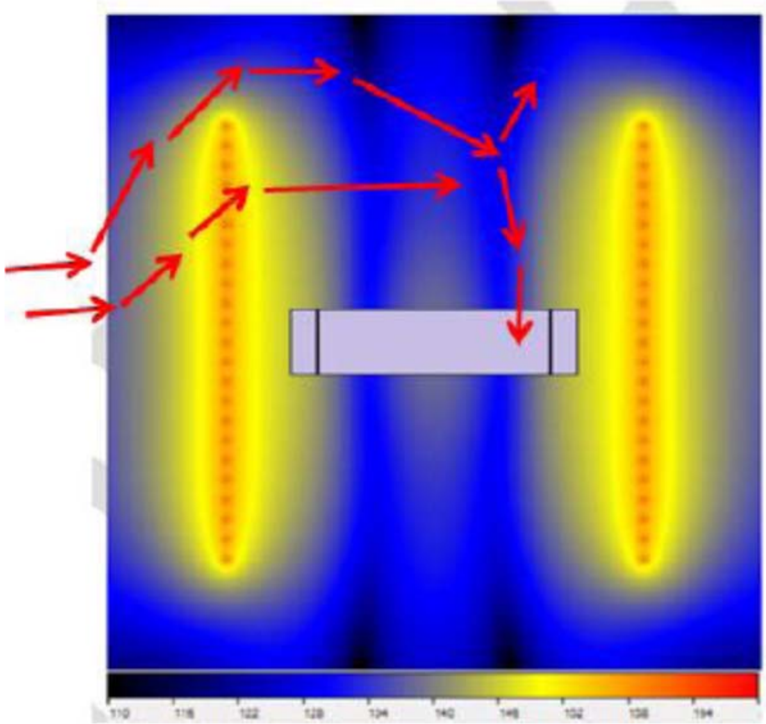


Figure 5.4 Sound modelling results for SP line array at either end of the intake head. The sound field is shown in red- yellow and the intake head in grey.



5.2.8 Deflection Principle 2

5.2.9 For Deflection Principle 2 the SPs were arranged in a single row parallel to the intake screens. Two offset distances were selected to evaluate the general sound field generated by the SPs:

- a close proximity scenario where the SPs are mounted 2.5m from the intake head foundation chamber (**Figure 5.5**); and

an offset proximity scenario where the SPs are mounted 8m from the intake head (

- **Figure 5.6**).

Figure 5.5 and

5.2.10 **Figure 5.6** show the sound modelling results with a 2.5 m and 8 m SP offset respectively. Both offset distances generated strong sound fields over the intake screens.

In the case of the 8 m offset there is a decreasing sound pressure gradient between the SPs and the intake, as seen in

5.2.11 **Figure 5.6**. Additional SPs would be required upstream in order to deflect fish onto the correct side of the sound field to avoid fish being ‘funnelled’ towards the intake.

5.2.12 Various upstream SP configurations were modelled with the 8 m offset scenario; however, it was concluded that the 8 m offset would be less effective than 2.5 m offset.

5.2.13 The preferred configuration from the Deflection Principle 2 scenario was therefore the 2.5 m offset, and that the SPs should be mounted as close to the intakes as is feasible

Figure 5.5 Sound modelling results for 2.5 m SP offset. The sound field is shown in red-yellow and the intake head in grey

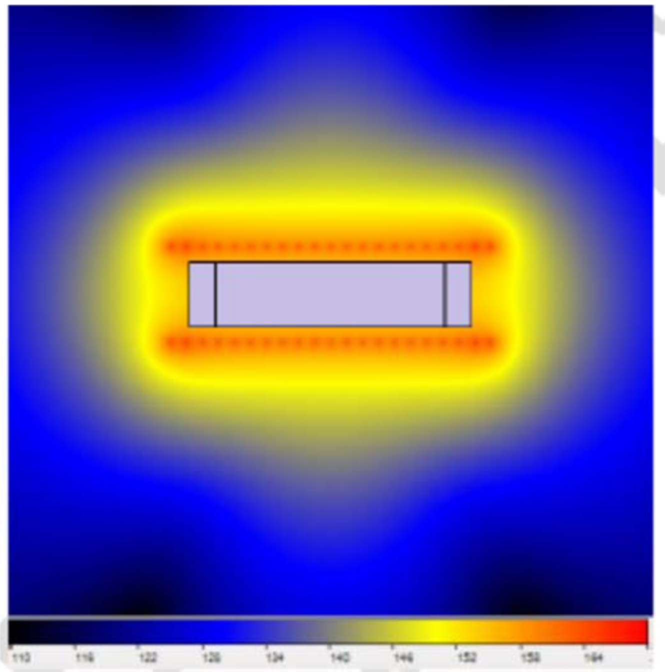
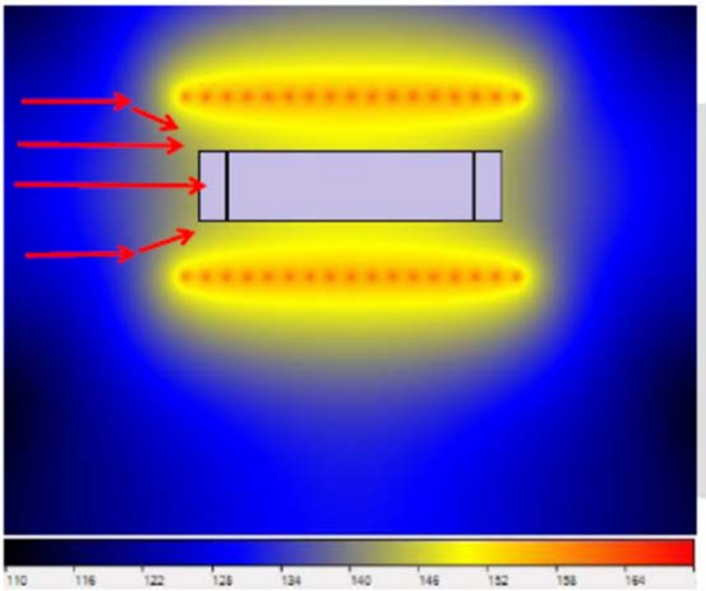


Figure 5.6 Sound modelling results for 8 m SP offset. The sound field is shown in red- yellow and the intake head in grey



5.2.14 Conclusions of the SP location for acoustic field generation optioneering process.

5.2.15 The conclusion of the initial sound modelling was that Deflection Principle 2 should be taken forward, with a focus on trying to reduce the offset between the SPs and the intake head as far as possible to improve the sound field around the intakes and maximise the probable effectiveness of the AFD.

5.2.16 This decision was taken for the following reasons:

- Deflection Principle 1 differs from EA best practice (EA, 2005), which recommends SPs are located closed to the intake opening, forming a steep acoustic gradient, free from acoustic nulls.
- All the SP configurations associated with Deflection Principle 1 performed poorly in sound modelling and did not provide an adequate sound field compared with the SP configurations associated with Deflection Principle 2, which performed well in sound modelling and provide a good sound field (on the proviso that the offset distance between the SPs and the intakes is kept as low as possible).
- The real world performance of Deflection Principle 1 is based on fish reacting to sound and swimming laterally to a distance great enough to avoid being able to drift back towards the intake. Given the high and fluctuating current speeds at the HPC intake location, not only does this lead to a very large sound field envelope requirement (long at high current speeds to provide sufficient upstream deflection and wide at low current speeds to provide sufficient lateral deflection), but it is also reliant on being able to accurately predict both the fishes' swimming direction and speed in response to the sound and there is no available evidence that this technique would be effective.
- Operational AFD systems installed at Pembroke and Doel power stations, which have proven efficiency in deflecting fish, are based on Deflection Principle 2. There are currently no operational AFD systems based on Deflection Principle 1. In addition, the AFD at Doel initially had the SP arrays

mounted away from the intake heads and proved ineffective, with the current performance levels only being attained once the SPs were relocated on to the intake heads.

5.3 AFD mounting structures

5.3.1 This stage considered the options for the structures upon which the SPs would be mounted. There were two stages of optioneering and the scope for the initial optioneering phase was left extremely open in order to examine all potential SP mounting options, structure types and SP retrieval modes before taking forward the most promising solutions to the more detailed optioneering phase, from which the best option would be taken forward to the basic design phase.

5.3.2 The key considerations for the optioneering process and the solutions taken forward were the following:

- Minimise the impact on the intake head structures.

  The intake head structures are nuclear safety classified and therefore the AFD system must not in any way impact on the intake heads' capacity to draw the safety critical flow rate.

- Minimise the impact on intake head hydraulics.

  The intakes at HPC are designed to provide a smooth, low turbulence, low velocity intake profile as close to 0.3 m/s as possible. The solution should therefore avoid restricting the inlet screens and disrupting streamlines/creating turbulence as much as possible.

- Maximise the performance of the AFD in deterring fish.

  The required performance for the AFD at HPC in terms of the percentage of fish deflected for each species are extremely challenging, given the scale of HPC relative to the systems from which the targets are derived. The AFD should, therefore, aim to provide a higher level of performance than the target levels in order to avoid the risk of the system falling short of requirements.

- Facilitate maintenance.

  With the AFD system being situated over 3 km offshore in an area with high tidal ranges and currents, access for maintenance is not straightforward and will involve the use of marine vessels for intervention. This will not only incur high operational and maintenance costs, but also expose personnel to a hazardous environment. In addition, the minimum required availability for the AFD is 90% and although specific reliability data for the system components is not available, the information obtained from operational systems in more benign conditions (such as Pembroke), suggests that frequent maintenance will be required. Therefore, a system which facilitates easy and safe access to the AFD is deemed highly advantageous.

- Maximise availability.

This criterion is strongly linked to maintenance as a system which is designed for maximum reliability not only increases availability (which is set at ≥90% for HPC), but also reduces the need for maintenance operations.

- Good track record/minimal risk.

  At present there are a limited number of AFD systems that have been installed, and as far as known none in a configuration similar to HPC where the majority of the components are located offshore. It is expected that the current equipment available will require to be modified to suit this application. A solution which minimises any modification may be considered as involving less risk.

- Maximise expandability/future proofing.

  The AFD is to be designed to operate for 70 years. It is, therefore, likely that the system may be subject to alterations sometime in the future for a variety of reasons. These may include improvements in technology, component obsolescence and suppliers exiting/entering the market. Additionally, the system may require to be expanded if the installed number of SPs does not deter the expected number of fish.

- Minimise Capital Expenditure (CAPEX).

  The solution should minimise cost, subject to satisfying all of the above criteria.

5.3.3 For detail on the priority and weighting of the criteria used for both optioneering stages please see Section 3.1 of NNB’s Appraisal of Options Report (NNB GenCo, 2016).

5.3.4 Initial AFD mounting structure optioneering phase

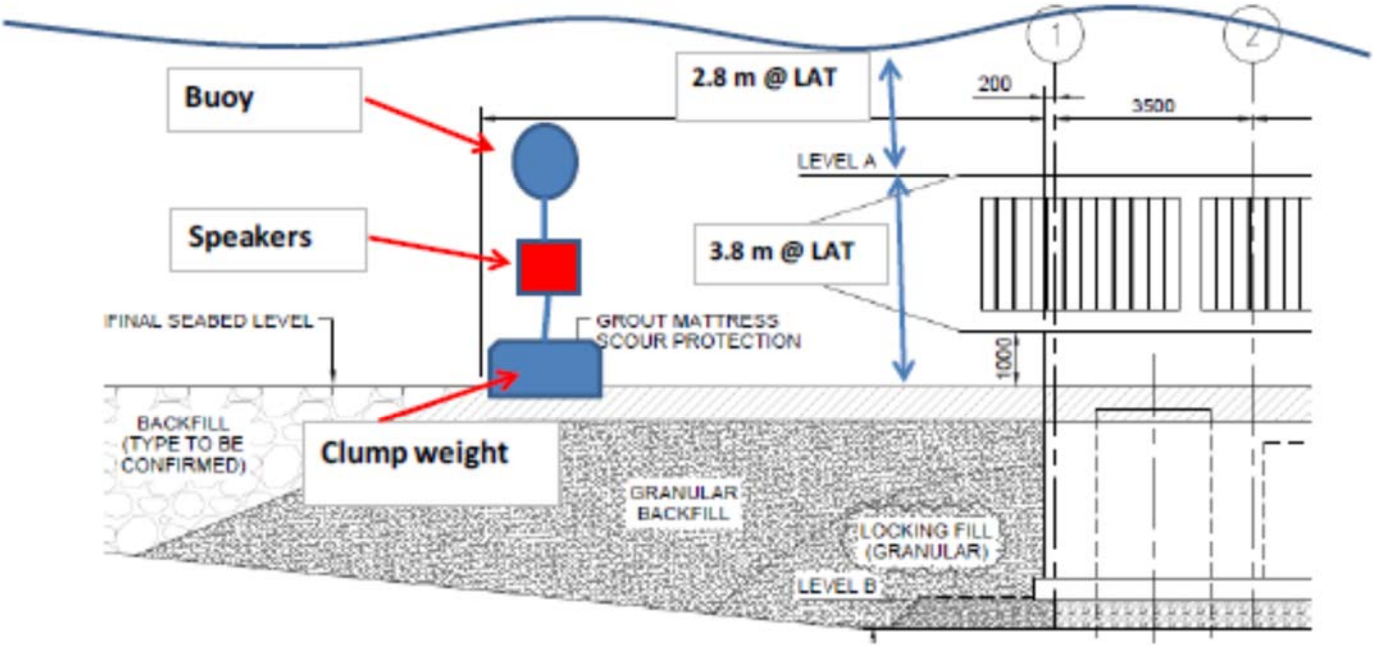
5.3.5 During the initial optioneering phase, 12 structural solutions were examined, with five options taken through to the detailed optioneering phase.

5.3.6 The seven options not taken through to the detail optioneering phase were:

5.3.7 SPs suspended from subsea buoy

5.3.8 **Figure 5.7** shows a depiction of a subsea buoy set up. In order to maintain line tension between the buoy and the clump weight to minimise the effect of the tidal current on the SPs the buoy must remain at least partially submerged at all times. As the SPs only have to be suspended approximately two metres above the seabed no advantages can be seen for this option over mounting them on a rigid structure. This option was therefore not taken further.

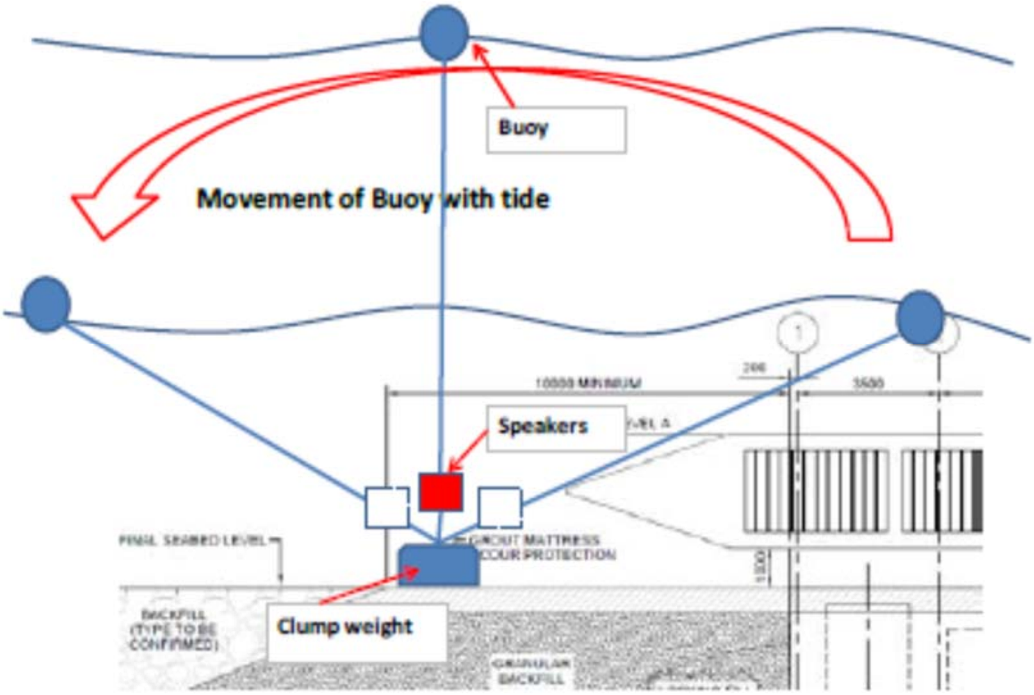
Figure 5.7 Depiction of SPs suspended from subsea buoy.



5.3.9 SPs suspended from surface buoy

5.3.10 **Figure 5.8** shows a SP suspended from a surface buoy system. This is a variation of the subsea buoy system, the difference being that the buoy is on the surface. As the tidal range at the HPC intake location is over 13 m, the buoy will move markedly with the tide. To design the buoy system and mooring so that the buoy would not affect the inlet head under extreme conditions would present design challenges. It was apparent that this option was not viable and was therefore not taken further.

Figure 5.8 Depiction of SPs suspended from surface buoy.

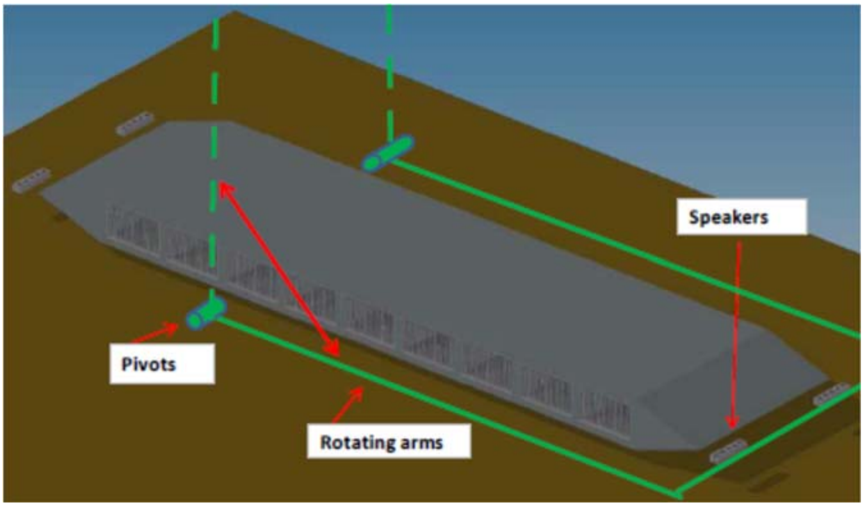


5.3.11 SPs on articulated arms

This option involves mounting the acoustic components on arms which rotate around pivots, as shown in

5.3.12 **Figure 5.9**. This has the advantage that the SPs can be lifted out of the water for maintenance. However, the system has numerous drawbacks including being a complex subsea pivot structure, susceptible to possible issues with marine growth jamming the mechanism. The large structure could impact intake hydraulics and structural collapse could impact intake heads. Due to the number of drawbacks the option was not taken further.

Figure 5.9 Depiction of SPs on articulated arms.



5.3.13 SPs mounted on tie-bars cast into intake head

5.3.14 In this option, the SPs would be attached to the beam by quick release fixings, as shown in

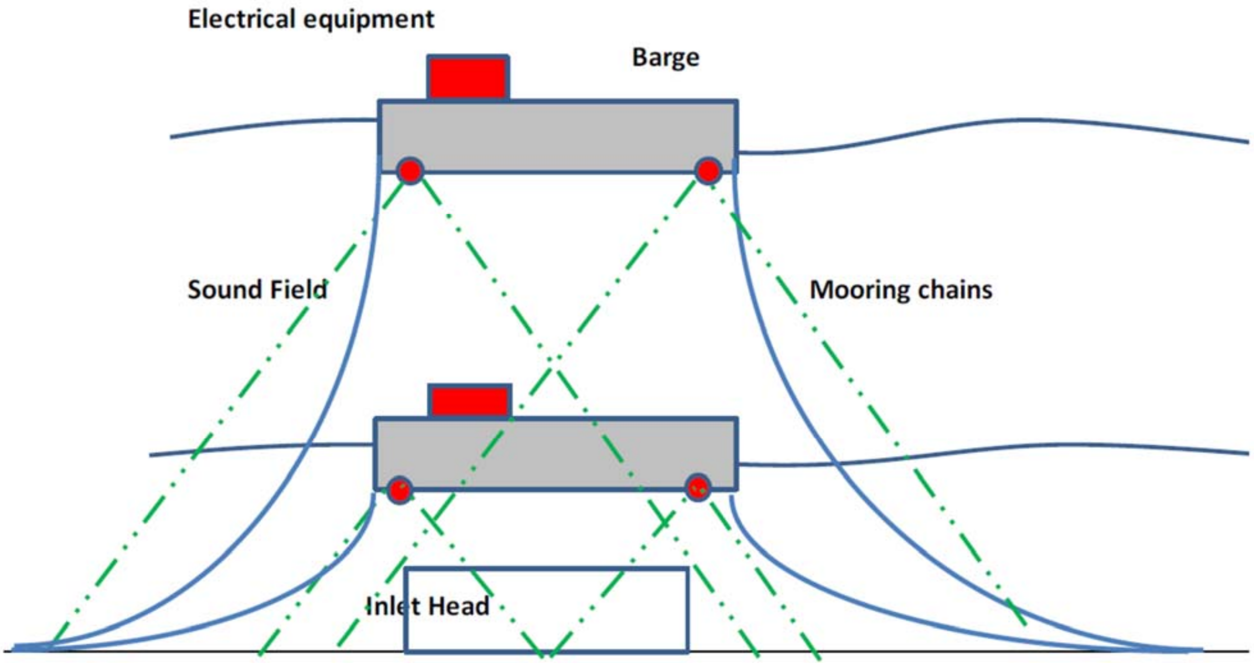
5.3.15 **Figure 5.10**, requiring subsea diver or ROV intervention for maintenance. Although relatively simple and by far the lowest CAPEX option, access to the SPs and associated cabling would be restrictive, any damage to the intake head concrete (safety classified) would be difficult to repair and expanding the system or repairing/replacing damaged or corroded tie-bars would be extremely challenging. For these reasons this option was not taken further.

Figure 5.10 Depiction of the tie-bars cast into the intake head and the SP fixing.

5.3.16 SPs supported from a barge

5.3.17 In this option the SPs are mounted on the underside of a shallow bottomed barge, as shown in **Figure 5.11**. The control equipment is mounted on the barge and so can be easily accessed. The barge is held in position by a mooring system utilising mooring chains, with one barge per intake head. There is only 2.7 m clearance with the top of the intake head at LAT. Even for a shallow bottomed barge if LAT coincided with anything but very small waves, the barge would impact the head. The sound field over the heads would also vary greatly with the tidal fluctuations. For these reasons this option was not taken further.

Figure 5.11 Depiction of barge supported SPs

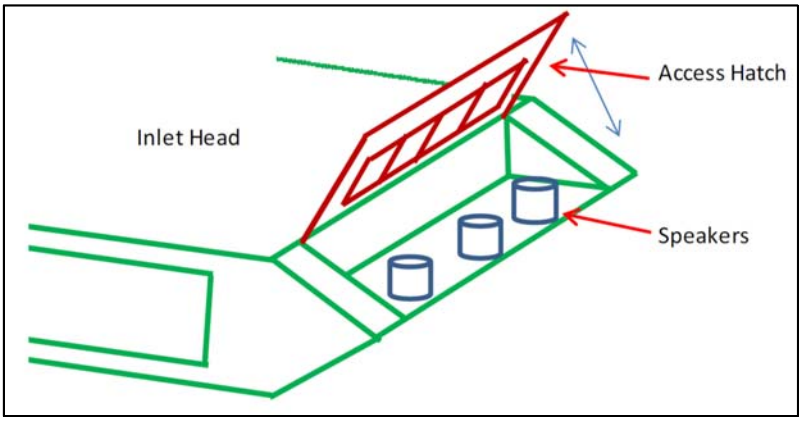


5.3.18 Modify intake head nose to incorporate AFD

This option consists of modifying the nose of the intake head structure to incorporate the AFD equipment, as shown in

Figure 5.12. A maintenance access hatch would be provided to improve the streamlining of the head and minimise the impact on the inlet velocity. As this configuration aligns with Deflection Principle 1 (see **Section 5.2**) the AFD system in this location would be unable to generate an effective sound field and intake head design would require major modification. For these reasons this option was not taken further.

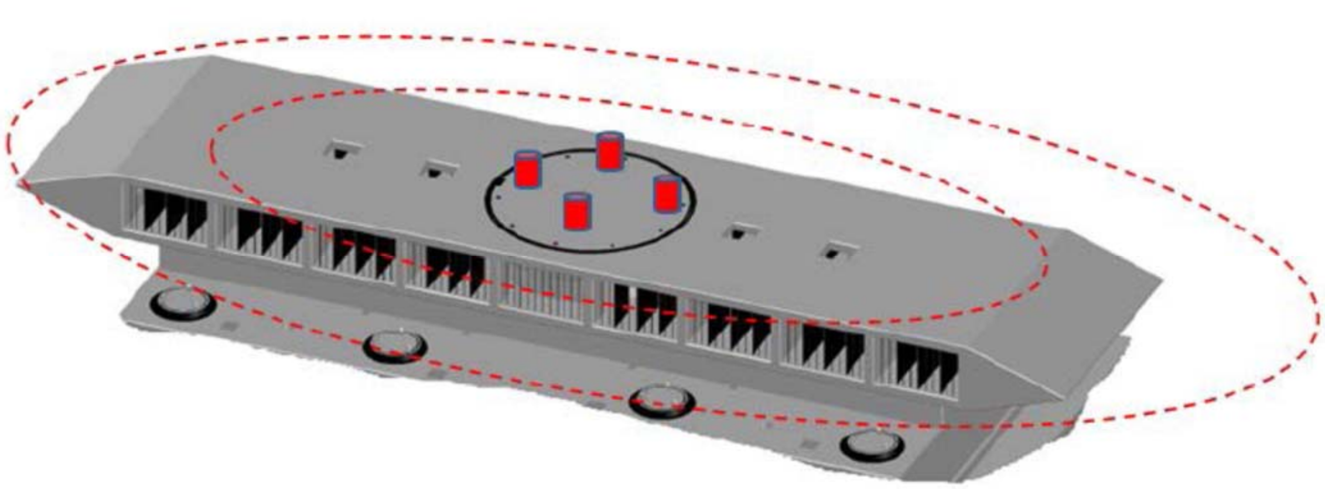
Figure 5.12 Depiction of SPs incorporated in the nose of the intake head



5.3.19 SPs mounted on top of the intake head

5.3.20 In this option the SP units are mounted on the top of the intake head isolation disc, as shown in **Error! Reference source not found.**. Due to the location of the SP units the generated sound field is unlikely to be sufficient, particularly at low water, due to the proximity of the sea surface not allowing the sound field to establish. For these reasons this option was not taken further.

Figure 5.13 Depiction showing four SP clusters mounted on top of the intake head



5.3.21 **Detailed AFD mounting structure optioneering phase**

5.3.22 Following the initial optioneering phase five structural SP mounting options were taken forward to the detailed optioneering phase.

5.3.23 These options were assessed against the key considerations in greater detail, considering the viability of each option and comparing with the other options to determine the best feasible option to meet the demands of the system. The following sections provide an overview of the detailed optioneering phase. For further detail please see Section 6 of the NNB Optioneering report (NNB GenCo, 2017b).

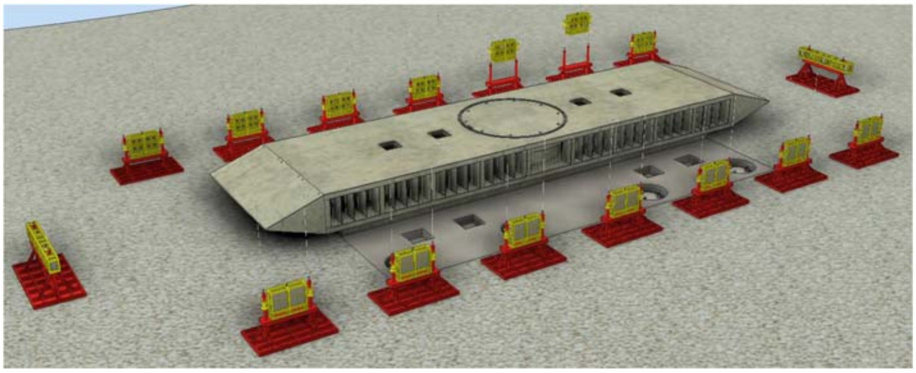
5.3.24 Subsea gravity base AFD mounting structures

5.3.25 This option consists of the SP units being mounted on gravity base (mudmat) structures which are lowered into position and are held in place by their own weight (Figure 5.14). The SP units would be retrieved with diver or ROV intervention to a vessel for maintenance.

5.3.26 This option was not considered viable for the following reasons:

- Gravity bases cannot be mounted on the intake head foundation chamber, severely limiting the proximity of the SPs to the intake heads, resulting in a sub-optimal sound field.
- The area immediately around the foundation chamber is back-filled with suitable material such as rock, which would create potential stability issues for the gravity base. Moving the gravity bases out of the back-filled area would further reduce their proximity to the head and the effectiveness of the sound field.

Figure 5.13 Depiction of SPs mounted on subsea gravity base

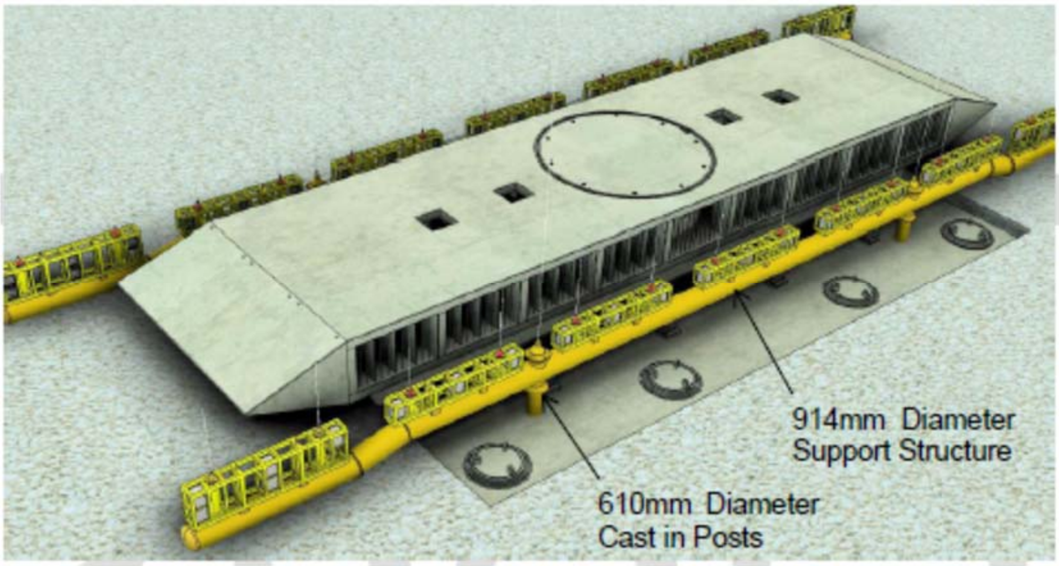


5.3.27 Subsea beam structure anchored to intake head foundation chamber

5.3.28 This option consists of the SPs mounted on a large beam structure which is anchored to the intake head foundation chamber (**Figure 5.14**). The SP units would be retrieved with diver or ROV intervention to a vessel for maintenance.

5.3.29 The option was not considered viable as the piles of this additional structure would transmit very high loads to the intake head foundation chambers, impacting the seismic response and integrity of the intake heads.

Figure 5.14 Depiction of SPs mounted on subsea beam structure anchored to the intake head foundation chamber



5.3.30 Subsea discrete lightweight structures

5.3.31 In this option, the SPs are mounted on discrete lightweight structures, supported by posts cast into the intake head foundation chamber (**Figure 5.15**). The SP units would be retrieved, with diver or ROV intervention, to a vessel for maintenance.

5.3.32 This option was deemed viable and to be the best solution overall. The key advantages of this option are:

- Lowest footprint and impact on intake hydraulics of all the solutions with greatest potential for mounting the structures close to the intake screens to achieve an effective sound field;
- Small size and low mass mean that the structures do not require seismic qualification; and
- Similar to structures used extensively in the oil and gas industry, meaning less technological risk as the technology is already proven in another industry and is not the first of a kind.

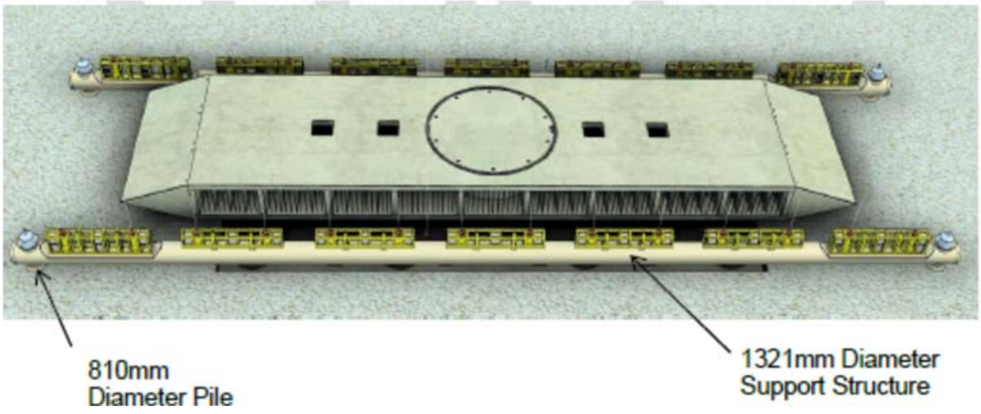
Figure 5.15 Depiction of SPs mounted on discrete subsea structures supported by posts cast into the intake head foundation chamber.

5.3.33 Subsea piled beam structure

5.3.34 Whilst similar to the option of the subsea beam structure anchored to the intake head foundation chamber, in this option the beam is supported on stubs piled into the seabed (**Figure 5.16**). These stub piles are at either end of the beam structure and away from the intake head foundation to avoid any design interaction with the intake head. The beam is therefore remote from the intake head structure and consequently the beam structure is larger and heavier due to the increased span between the supports. The SP units would be retrieved from the beam with diver or ROV intervention to a vessel for maintenance.

5.3.35 This option was not considered viable due to its large footprint and the need to seismically qualify the beam structure (given its size, mass and location). The structure also has a greater impact on intake hydraulics and therefore reduces the potential for mounting the SPs close enough to the intake screens to achieve an effective sound field.

Figure 5.16 Depiction of SPs mounted on subsea piled beam structure



5.3.36 Non-subsea piled structure

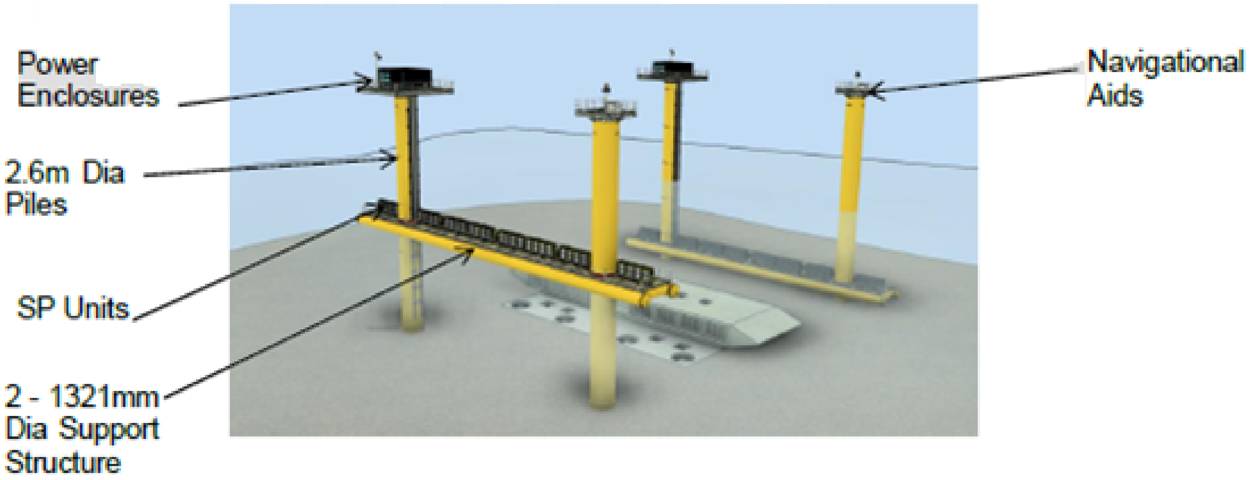
5.3.37 This option consists of the SP units being mounted on a beam type structure, supported by piles. The beam is designed to be submerged and remain at seabed level until maintenance of the SPs are required, when the beam can then be floated to sea level. The piles would be around 30 m high to ensure that the power and communications equipment, hosed on a platform on top of the piles, is always above sea level (**Figure 5.17**). The intention of this option is to remove the requirement of subsea diver or ROV intervention for the recovery of the SPs.

5.3.38 To float the beam, the ballast system would be filled with air, then flooded with sea water to sink. It is envisaged that the structure would have multiple chambers so that a single or small number of failures would not render the ballast system un-operable. The ballast chambers would need to have controlled flooding and dewatering to avoid jamming during ascent and descent.

5.3.39 This option has some advantages over the others considered, notably removing the need for diver or ROV intervention, the power and communications equipment being integrated into the structures and having the greatest scope for expandability of all of the structures. However, the option was not considered viable due to having some serious drawbacks, including:

- high potential for disruption in the event of jamming or malfunctioning of the buoyant structure;
- the concept design would be challenging to install given the size of the structures;
- the concept design has a very large footprint which would have a high impact on intake hydraulics and greatly reduced the potential for mounting the SPs close enough to the intake screens to achieve an effective sound field; and
- the structures would need to be seismically qualified due to their size and proximity to the intake heads. They could only be installed if they can be prevented from collapsing and damaging the intake heads.

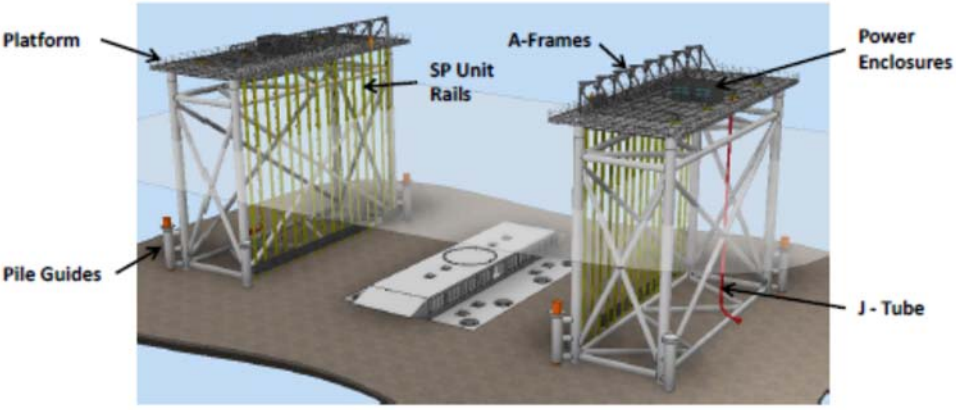
Figure 5.17 Depiction of SPs mounted on non-subsea piled beam structure



5.3.40 Non-subsea lattice / jacket structure

5.3.41 This option consists of the SP units mounted on a frame supported by a lattice framework structure (**Figure 5.18**). The SPs are raised by winch to the surface and lowered back along rails running the height of the structure. The motorised winch is housed on the platform at the top of the lattice structure, which would also house the power and communications equipment. To ensure that the platform is always above sea level, the structures would need to be around 30 m high.

Figure 5.18 Depiction of SPs mounted on lattice framework structure



5.3.42 This option has some advantages over the others considered, notably removing the need for diver or ROV intervention, the power and communications equipment being integrated into the structures and having scope for expansion. However, the option was not considered viable due to having some serious drawbacks, including:

- the concept design would be challenging to install given the size and weight of the structures. At 30 m high x 40 m wide and weighing in excess of 1000 tonnes safe installation in close proximity to the intake heads would be challenging;
- access to the platform could be challenging due to the large tidal range;
- the concept design has a very large footprint which would have a high impact on intake hydraulics and greatly reduced the potential for mounting the SPs close enough to the intake screens to achieve an effective sound field; and
- the structures would need to be seismically qualified due to their size and proximity to the intake heads. They could only be installed if they can be seismically qualified to prevent collapse and subsequent damage to the intake heads.

5.3.43 Conclusions of the AFD mounting structure optioneering phase

5.3.44 The twelve possible solutions were evaluated in a two phase process against the key considerations. Of the five designs taken forward for consideration in the detailed optioneering stage, the subsea discrete lightweight structures (**Figure 5.15**) was considered the most viable option. Acknowledging that the maintenance challenge would need to be addressed, this option was the only design that allowed the SPs to be mounted close enough to the intake heads to provide effective fish deterrence, and also the most acceptable from a nuclear safety perspective with regard to the impact of having large, heavy structures around the intake heads.

5.4 Electrical power supply and communications

5.4.1 The AFD system requires a constant and reliable power supply. Early work on power generation and supply for the AFD examined a variety of onshore and offshore options to find the most suitable technology including:

- Shore derived power supply with either subsea or platform mounted electrical equipment (transformers, etc.)
- Offshore platform mounted diesel generators
- Marine turbine with offshore battery and distribution platform
- Wind turbine with offshore battery and distribution platform
- Photo-voltaic (solar) with offshore battery and distribution platform
- Autonomous buoys with photo voltaic panels and wind generators

5.4.2 Of the given options, a shore derived power supply was judged to be the only proven, low maintenance technology that could reliably provide the large amounts of power required (of the order of 250 kW total). With the type of power supply identified, the pre-optioneering and optioneering exercises which followed consisted of examining the different supply voltage levels, distribution configurations, etc. to find the optimal basic design solution.

5.4.3 For the retained shore based supply, different electrical supply options from the electrical switchboards located onshore were investigated. To consider the power supply options robustly the process considered the two key aspects of the supply system separately and in the following order:

- the power supply voltage level; and
- the electrical network

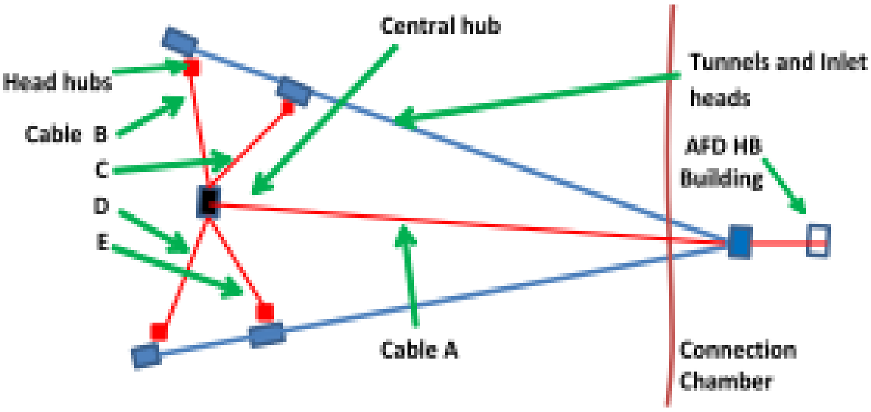
5.4.4 Power supply voltage level

5.4.5 Various supply voltage levels, both Alternating Current (AC) and Direct Current (DC), were considered ranging from 10 kV 3-phase high voltage down to 230 V single-phase low voltage. The advantage of low supply voltages is that they do not require step-down transformers to convert the voltage down to the level required for distribution to each intake head and the individual SP clusters. However, given the very large total power requirements for the AFD (in the region of 250 kW) and the long transmission distance (over 3000 m), only the 10 kV 3 phase high voltage, with step-down transformers, can meet the AFD power requirements. This would result in a voltage drop of less than 8%, in accordance with The Wiring Regulations BS 7671.

5.4.6 Electrical network

5.4.7 For all subsea AFD mounted structures a central hub with ‘star’ distribution, as shown in **Figure 5.19** is considered to be the optimal design. The electricity passes along a high voltage line from the shore to the central hub (**Figure 5.19** Cable A). At the central hub it is then transformed down to a lower voltage before being distributed to the intake heads via cables (**Figure 5.19** Cables B, C, D & E).

Figure 5.19 Diagram showing proposed star distribution network



5.4.8 Central hub

5.4.9 Two options were considered for the central hub:

- A subsea hub with an underwater transformer (**Figure 5.20**); or

An offshore monopile platform to house the transformer out of the water (

- **Figure 5.21**).

Figure 5.20 Depiction of a subsea central hub with underwater transformer

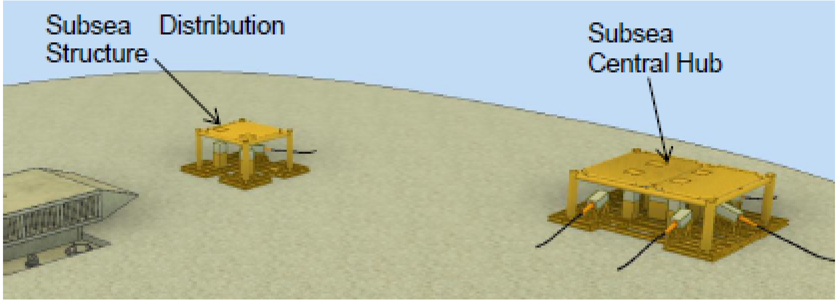


Figure 5.21 Depiction of a monopole central hub with transformer housed on a platform.

5.4.10 The advantages and disadvantages of the two central hub options were considered. The subsea hub with an underwater transformer has the advantages of having no visible structures above water, a lower routine maintenance burden than the other option and requires no transfer of personnel to a platform. However, it was not considered a viable option when compared to the monopile option for the following reasons:

- Market available subsea transformers are large structures, generally used by the oil and gas industries. The subsea transformer required at HPC would be much smaller than market available units so this would mean developing a prototype specific for the HPC site requirements.
- The subsea transformer would be a single unit with no back up, introducing a single point of possible failure for the entire AFD system. Repair would not be an easy task as the subsea transformer could only be accessed and repaired by diver or ROV.
- The monopile platform would have the space to accommodate a backup transformer.
- The subsea transformer is much more limited in terms of future expandability than the monopile.

5.4.11 As a result of these considerations the monopole central hub was taken forward.

5.4.12 Communications

5.4.13 The AFD system needs to be controlled remotely and this would be done by a communications system. Work on the communication transmission method (fibre optic, copper wire, etc.) would need to be completed in partnership with the SP supplier.

5.4.14 Conclusion of the electrical power supply and communications optioneering phase

5.4.15 The optioneering completed identified that the most viable AFD power supply network consists of a shore based power source linked to a monopile central hub by submarine cable capable of carrying a 10 kV 3 phase high voltage power supply. The monopile central hub would house the transformer, and its back up. The transformer would convert the voltage down to the level required for distribution to each intake head and the individual SP clusters via submarine cable.

5.4.16 However, given the size and scale of the AFD system at HPC and the large number of SPs, routing and managing all the cables required for power and communications from the monopile to each intake head and then down to the individual SP clusters and then each discrete SP represents a real challenge, especially in terms of reliability, to which solutions would need to be found.

5.5 Power supply shore crossing

5.5.1 As a shore based power supply has been selected there is the need to consider the portion of the electricity supply network that connects the power supply on land and the submarine cable connecting the AFD system. Marine vessels will be used to lay the submarine cable but as they are unable to operate in the intertidal area, a method of installing the section of the AFD power supply that crosses the shoreline out to approximately 600m offshore needs to be considered. Two options were taken forward:

- Conventional trench excavation and backfill; and
- Horizontal Directional Drilling (HDD).

5.5.2 Conventional trench excavation and backfill

5.5.3 This method consists of excavating a trench into which a High Density Poly-Ethylene (HDPE) duct is laid (**Figure 5.22**). Once completed, the electrical cables are then pulled though and the excavation is backfilled, burying the duct. This would extend to a distance at which the water depth is sufficient for marine vessels to take over the operation (approximately 600m from the shore).

Figure 5.22 Photograph of conventional trench excavation and backfill operation.

5.5.4 Horizontal Directional Drilling (HDD)

With HDD, a drilling rig (

Figure 5.23), situated inside the HPC site, is used to drill a tunnel through which an HDPE duct can be pulled. Once completed, the electrical cables are then pulled though. As per the trenching option, this would extend to a distance where marine vessels can take over the operation (approximately 600 m from the shore).

Figure 5.23 Photograph of HDD drilling rig.

5.5.5 Conclusions of the shore crossing optioneering process

5.5.6 The optioneering completed identified that the most viable method for installing the section of the AFD power supply that crosses the shore is HDD. The key reasons HDD was selected over conventional trenching were:

- Environmental impact:

  The foreshore in front of the HPC site is an environmentally designated area, which trenching would disturb, possibly detrimentally. HDD, however, is performed from inside the HPC site, with the drill passing under the seawall and foreshore, leaving the area completely untouched.

- Potential synergies:

  Other construction activities occurring at the HPC site will also be utilising HDD, notably the HCF Fish Return Tunnel, improving the ease of the site construction phase.

5.6 Further design development

5.6.1 Since the optioneering exercise outlined in **Section 5** was undertaken, the preferred concepts from all four stages of the process have been developed and refined further. This work has mainly focused on refining the positions of the AFD SP structures, with associated alterations to the other AFD elements as appropriate.

5.6.2 The key issues this further design development sought to address were:

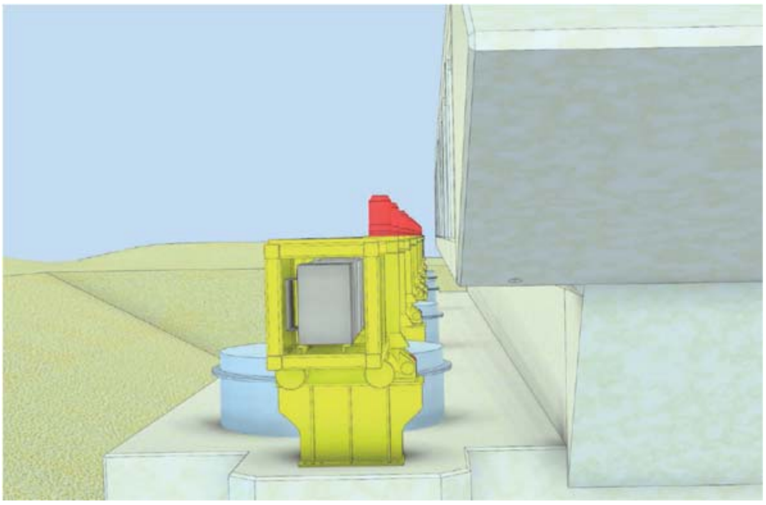
- Siting the SPs as close to the intake screens and with as regular a spacing as possible (i.e. fewer discrete clusters) to generate the best possible sound field;

- Analysing the interface between the AFD SP structures and the intake heads in greater detail to enable the integration of the AFD with the intake head structures and ensure that the AFD SP structures do not hinder access for maintenance of the intake heads;
- Minimising the impact of the AFD SP structures on intake hydraulics; and
- Minimising the number of SP clusters to facilitate maintenance of the AFD.

5.6.3 More detailed analysis of the access requirements for maintaining and inspecting both the AFD and the intake heads revealed that the preferred concept of subsea discrete lightweight mounting structures at a 2.5 m offset from the intake head presented a number of obstacles to maintenance of both the SP clusters and the intake head. It was, therefore, decided to try and move the structures closer to the intake screens, sitting them just below the bottom of the intake screens. It was assumed that this would improve the coverage and effectiveness of the sound field. This change in design would be implemented subject to verifying the sound field requirements were met and that there was no impact on the intake hydraulics. The new locations for the AFD SP mounting structures are shown in .

5.6.4 **Figure 5.24** and **Figure 5.25**.

Figure 5.24 Image showing AFD SP mounting structure (yellow) in new location (i.e. no offset).



The sound modelling confirmed the benefits of moving the SPs closer, with **Figure 5.26** and

5.6.5 **Figure 5.27** showing the improvement in the sound field between a 2.5 m offset and a 0.2 m offset, with the latter generating in excess of 160 dB across the intake screens, in accordance with NNB requirements.

Figure 5.25 Plan and profile view showing siting of SP clusters (yellow objects) next to intake structure

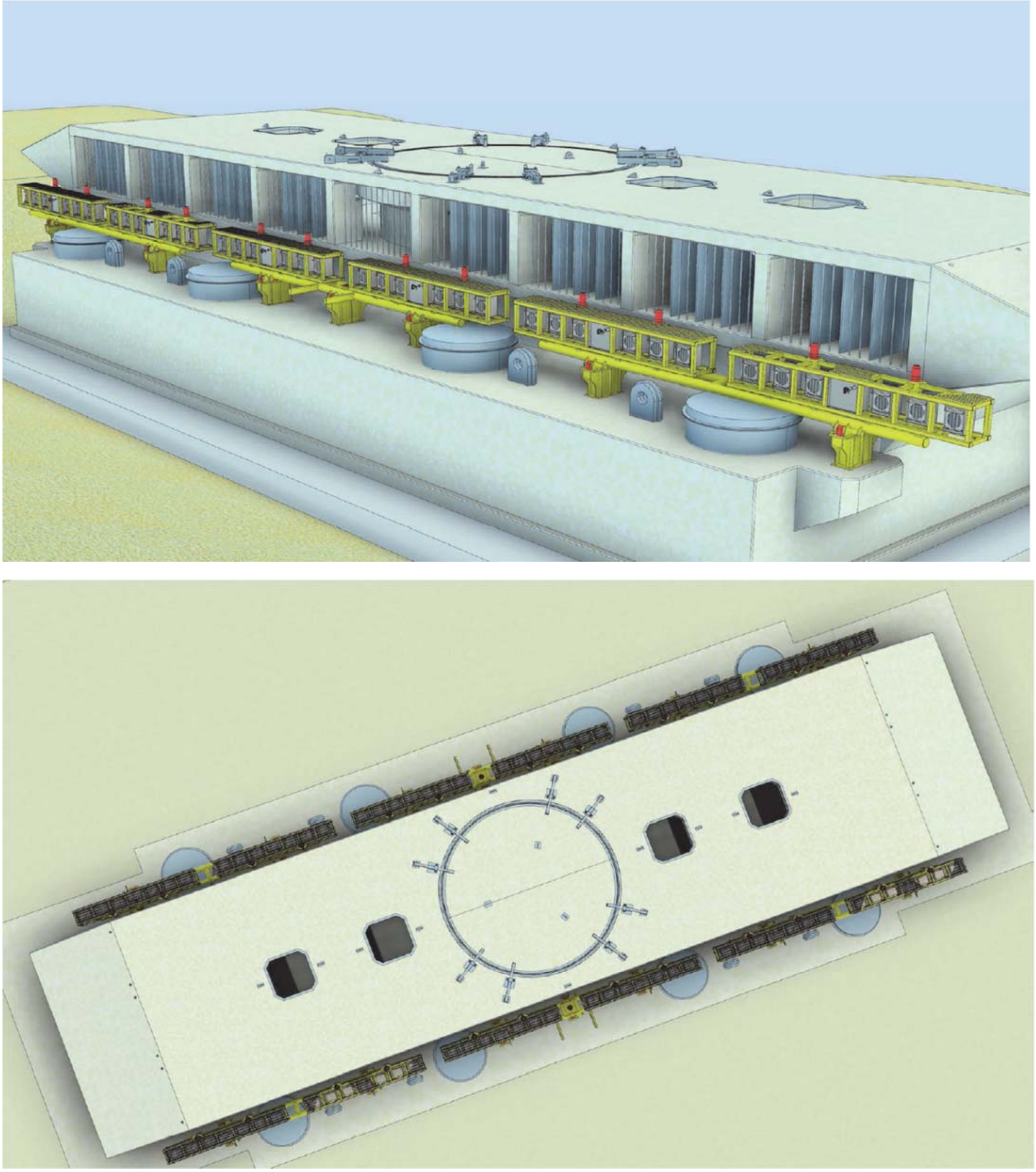


Figure 5.26 Sound modelling results for SP clusters offset from the intake head by 2.5m. The sound field is shown in red – yellow and the intake head in grey

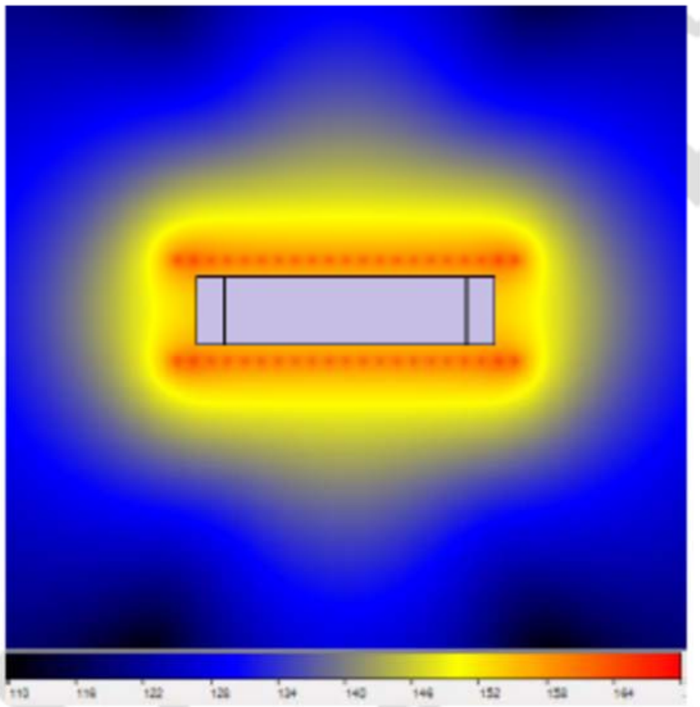
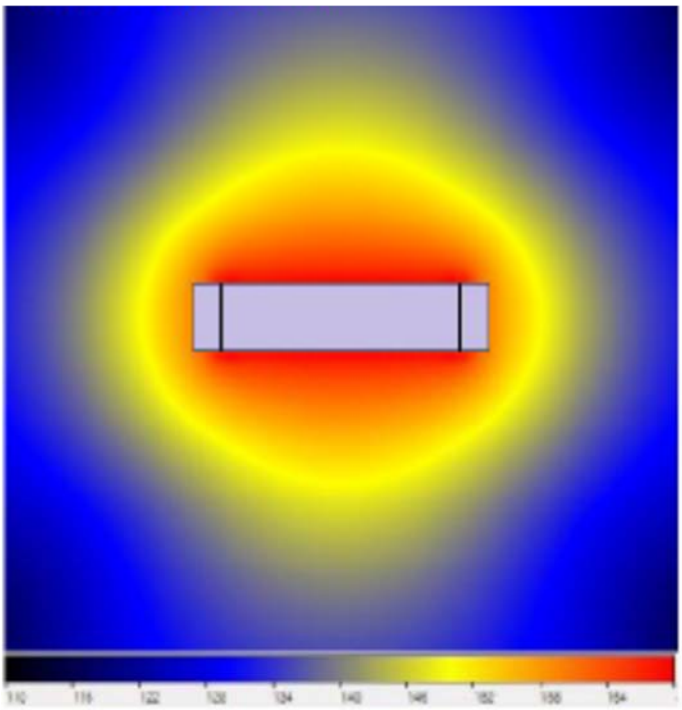


Figure 5.27 Sound modelling results for SP clusters offset from the intake head by 0.2m. The sound field is shown in red – yellow and the intake head in grey



5.6.6 Conclusions of the further design development

5.6.7 The finalised basic design is shown in Figure 5.29. This design incorporates the following modifications:

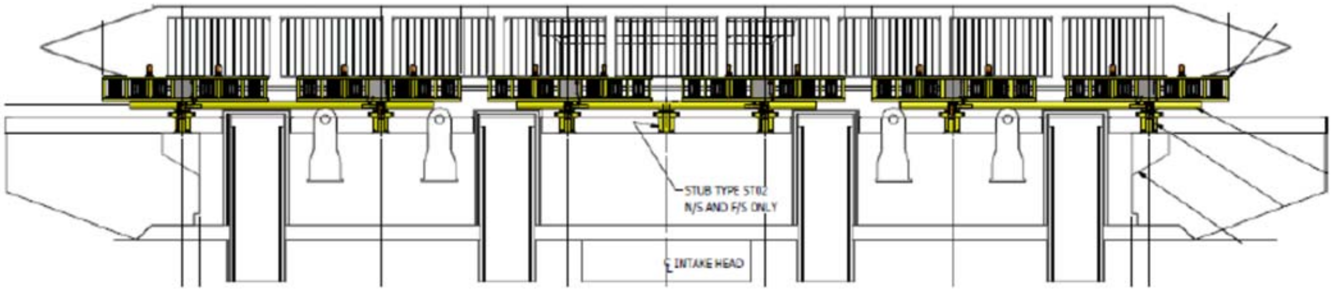
- Reduced number of cast-in stubs (7 versus 10 per side) following more detailed examination of the number of possible stub locations along the intake head foundation chamber (this reduces the number of structures that need to be installed, but increases the span and the size of each structure that needs to be transported and manoeuvred into position (see maintenance **Section 7**).
- The SP offset of 0.5m.

The offset has increased slightly from the 0.2 m offset modelled to 0.5 m. It has been confirmed that this has no appreciable impact on the acoustic field generated and should not adversely impact the intake hydraulics (however, this would need to be confirmed through further hydraulic modelling). Additionally, the following modification further ensures the effectiveness of the sound field.

- The number of SP clusters has increased from five to six per side due to spatial constraints and to improve sound coverage across the entire length of the intake screens. This means that the maximum number of SPs possible per intake side has increased by over 20% from 29 to 36 SPs.

This increase in potential SP number that can be accommodated on the AFD SP mounting structure introduces additional flexibility to be able to reinforce the sound field by introducing more SP's if required.

Figure 5.28 Finalised AFD mounting structure design



5.7 Conclusions of the engineering optioneering process

5.7.1 The optioneering completed identified that the most viable SP configuration that could fulfil the requirements for an AFD system at HPC would consist of subsea discrete lightweight structures employing Deflection Principle 2, with a shore based power source linked to a monopile central hub by submarine cable that crosses the shore via HDD.

5.7.2 This decision was taken for the following reasons:

- SP location for acoustic field generation

  Sound modelling concluded that Deflection Principle 2 should be taken forward, with an aim to reduce the offset between the SPs and the intake head as far as possible to improve the sound field around the intakes and maximise the probable effectiveness of the AFD.

- AFD mounting structures (onto which the individual SPs are mounted).

  Subsea discrete lightweight structures were the only option which allowed the SPs to be mounted close enough to the intake heads to provide effective fish deterrence and was also the most acceptable with regards to the structural impact in an earthquake situation, for the safety classifies intake head structures.

- Electrical power supply/distribution and communications.

  Since a subsea transformer is not viable, a shore based power source linked to a monopile central hub by submarine cable carrying a 10 kV 3 phase high voltage power supply was chosen. The monopile central hub would house the transformer, which would convert the voltage down for distribution to each intake head and the individual SP clusters via submarine cable.

- Shore crossing (the connection between the power supply on land and the submarine cable feeding the AFD).

  The optioneering completed identified that the most viable method for installing the section of the AFD power supply that crosses the shore is HDD due to the detrimental environmental impact of trenching and the possible synergies with other activities also employing HDD.

6 CONCLUSIONS OF THE AFD DESIGN PROCESS

6.1.1 A large scale research, optioneering and design exercise has been undertaken by NNB to find the optimal solution for the AFD system at HPC, involving:

- Examining EA requirements and best practice;
- Literary review of academic papers and liaising with experts in the field;
- Analysing sites with operational AFD systems;
- Analysing the market for potential suppliers;
- Producing a set of requirements for the AFD at HPC, taking into account both the nature and scale of the project, as well as the environmental conditions encountered at the site;
- A pre-optioneering phase to determine the most viable concepts for each of the four work packages making up the overall AFD system (SP location and acoustic field, the AFD structures, the electrical power supply and distribution and the shore crossing);
- An optioneering phase to select the finalised concept for each work package; and
- Design development of the finalised overall concept.

6.1.2 From this extensive and exhaustive exercise, the following conclusions were reached:

- The SPs must be mounted along the intake screens at as low an offset distance as possible;
- The sound level across the intake screens must be at least 160 dB across a frequency range of 30 – 600 Hz, with the capability of operating at up to 2 kHz;
- There is only one SP supplier on the market with commercial scale installations that have proven efficiency in deterring fish. As this supplier additionally has acoustic modelling capabilities and knowledge of sound signal patterns effective in deterring fish, pre-optioneering and optioneering analysis were performed on the basis of the their existing LF SP technology;
- The LF SP technology, which is used at Doel and Pembroke, requires frequent cleaning and replacement in environmental conditions which are far more benign than those encountered at HPC. The maintenance of SPs at these sites is a major undertaking, which are on a much smaller scale than HPC with a much greater ease of access. The SP technology will require significant design development and improvement both to render it suitable for the conditions at HPC and also to extend the service life to an interval which is compatible with the scale of the plant and the limited access. However, even if this is achieved, it would still mean exposing personnel to frequent maintenance operations in hazardous conditions;
- During the pre-optioneering and optioneering phases, different AFD structure types were analysed with both surface and subsea ROV or diver retrieval of SP clusters. However, none of the surface retrieval structural options was found to be feasible for implantation at HPC, from both a technical and acoustic field perspective. Although the retained concept (subsea discrete lightweight structures) presents a greater challenge in terms of maintenance due to the requirement for diver or ROV

intervention, it was the only solution allowing the SPs to be mounted close enough to the intake heads to ensure effective fish deterrence, and presenting an acceptable nuclear safety impact with regard to having large, heavy structures around the intake heads; and

- The retained concept was then further developed to arrive at the finalised basic design, which has been shown to generate a highly effective acoustic field with no adverse impact on intake flow hydraulics.

6.1.3 The next section of this report explores in greater detail the challenges associated with maintaining the AFD system at HPC.

7 AFD MAINTAINENCE

7.1 Overview

7.1.1 As outlined in **Section 5.2**, the engineering optioneering phase ensured that the selected AFD system accommodated SP mounting structures and SP retrieval modes that were considered viable in engineering terms at the HPC location. Once the design of the AFD system had been selected work was then undertaken looking into the detailed maintenance requirements of this system and how a realistic maintenance schedule could be achieved.

7.1.2 The AFD system selected is a sub-sea system retrievable to a vessel, located at the surface, with sub-sea assistance from a diver or ROV.

7.1.3 Subsea operations are both time consuming and have safety implications so it was recognised that the selected AFD system required optimisation to minimise the need for diving activities and allow the use of ROV if or when possible.

7.1.4 The further design development, outlined in **Section 5.6**, started to consider maintenance requirements and reduction of maintenance burden. However, this was secondary to ensuring the intake head functions properly with the AFD in place and that the AFD generates the best possible sound field. Following conclusion of the further design development process, the maintenance requirements for the selected design, shown in **Figure 5.28**, were considered.

7.1.5 As with the engineering optioneering process, the environmental conditions at the HPC intake locations (**Section 4.2**) are an important consideration and constraint, resulting in significant challenges for the establishment of a viable maintenance regime. It is important to note that there are currently no AFD systems operating in conditions like those experienced at the HPC intake locations. The maintenance regime required to ensure the AFD technology operates as required is therefore completely un-tested. This means the feasibility of any maintenance regime put forward would need to be demonstrated and would need to go through a series of developmental stages before confidence can be given regarding its ability to maintain the AFD system and give a 90% reliability.

7.1.6 The following sections outline the inspection and maintenance operations considered necessary for the selected AFD system at the HPC intake location, how specific site constraints affect these operations and how they could be mitigated.

7.2 Description of main maintenance activities

7.2.1 Maintenance of the whole AFD system will be required and different components of the system will require differing amounts of intervention during the lifetime of the power station. The exact maintenance requirements will need to be established with the equipment suppliers in due course, once all design and testing has been undertaken, however it is envisaged the following will be the main inspection and maintenance activities:

- Maintenance and testing of the offshore monopile central hub and equipment; and
- SP maintenance and replacement.

7.2.2 In addition to these preventative inspection and maintenance activities, there will be the need to repair and replace elements of the AFD system during the lifetime of the power station, such as:

- the structural frame that supports the SP clusters;
- electrical equipment and cabling; and
- submarine cabling, either from the hub to the intake head locations, or from the shore based power supply to the distribution hub.

7.2.3 The repair and replace operations will require substantial mechanical intervention and how this would be accomplished has not yet been determined by NNB. The necessary planning and design work would be undertaken in due course once the suppliers of the components had been selected and it is confirmed the AFD system was to be installed.

7.2.4 As the repair and replacement operations have not been considered in detail at this stage the following sections only describe the main inspection and maintenance activities in more detail.

7.3 Maintenance and testing of the offshore monopile central hub and equipment

7.3.1 The maintenance and testing activities that will need to occur at the central hub can be broken down into three discrete phases, each with different frequencies:

- visual inspection and testing of offshore monopile central hub and equipment;
- maintenance and testing of the offshore monopile central hub equipment; and
- major maintenance of offshore monopile central hub and equipment.

7.3.2 <u>Visual inspection and testing of offshore monopole central hub and equipment</u>

7.3.3 Anticipated frequency – six months.

7.3.4 Visual inspections of the central hub, inspection and testing of certain equipment and minor routine preventative maintenance tasks such as lubrication and navigational aid testing will be carried out every six months.

These are not complicated tasks, but will require mobilisation of a vessel and crew. Due to the large tidal variation at the monopile site, the platform on the monopile would need to be accessible at all states of tide (as depicted on

7.3.5 **Figure 5.21**).

7.3.6 Primary access to the AFD hub platform shall be by vessel transfer onto a vertical ladder leading up to the deck levels. This will be by ‘fendering’ whereby a vessel pushes up against the structure to allow persons to step over to a ladder. To facilitate this, fenders shall be installed at either side of the access ladder capable of withstanding vessel impact.

7.3.7 The access ladder shall be appropriately positioned to take into account prevailing wind, wave and tidal conditions. This system shall be accessible to use at all tidal levels between LAT and HAT. A suitable fall arrest system shall be installed to protect personnel using the platform access ladder.

7.3.8 The requirement for a heli-hoist area is to be determined. This would not be intended to be the primary means of access to the installation but would provide an alternative evacuation route in the event of an emergency.

7.3.9 **Maintenance and testing of the offshore monopile central hub and equipment**

7.3.10 Anticipated frequency – every 12 months.

7.3.11 Maintenance and testing of the central hub equipment will be carried out every 12 months. The vessel mobilised will be larger than that needed for the six-monthly maintenance activities due to the need to transport parts and lifting equipment to the monopile location.

7.3.12 Due to the duration of maintenance an additional small inshore vessel for transferring personnel would be required. This assumes that no accommodation facilities will be implemented on the offshore monopole central hub.

7.3.13 **Major maintenance of offshore monopile central hub and equipment**

7.3.14 Anticipated frequency – every 10 years.

7.3.15 Every 10 years major maintenance activity will be carried out at the monopile location, on both the structure and the equipment. Activities will include replacement of some equipment and painting of structures.

7.3.16 An underwater survey will be carried out by ROV to inspect the pile and also the cable joins. Repair or replacement of underwater elements may be required depending upon the survey results. For the underwater work a dive vessel, a support vessel and a transfer vessel will be required.

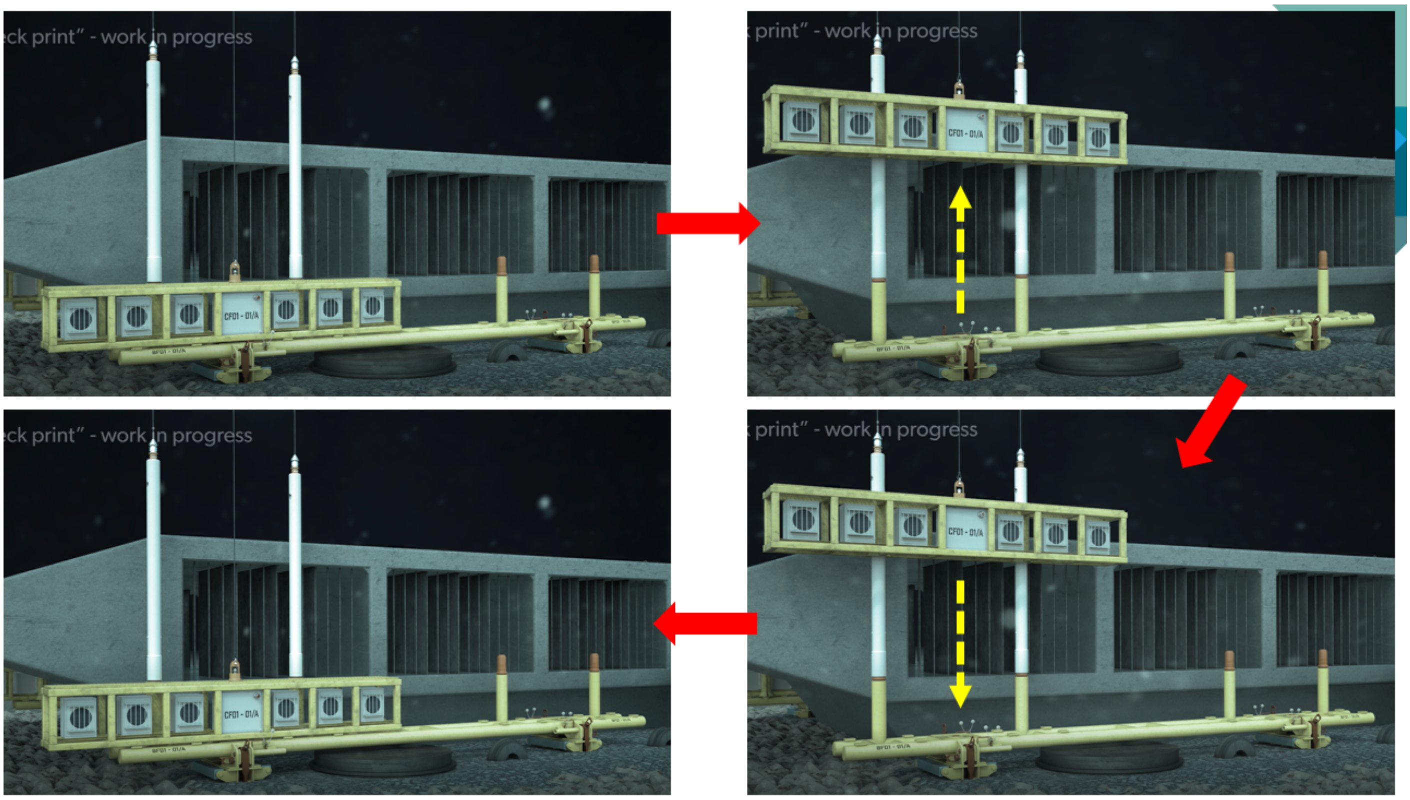
7.3.17 The duration of this maintenance activity is expected to be a minimum of five days, requiring multiple personnel transfer to the monopile and platform.

7.4 SP Maintenance

7.4.1 In line with the approach taken at other sites (**Section 4.4**), NNB propose to maintain the SPs by working on a single SP cluster at a time, removing SPs and replacing with refurbished units. As the intake heads are subsea, NNB will use a vessel to deploy divers or ROV. The diver or ROV will locate the SP cluster of six SPs, attach the necessary lifting gear and then the lifting gear aboard the vessel will raise the SP cluster on to the vessel deck. To ensure that operations aboard the vessel are kept to a minimum, refurbishment of SP units will be undertaken back at the manufacturer’s shore based facilities. NNB will replace the full cluster of SPs by a cluster which has been refurbished and prepared at a shore based facilities. This means there needs to be a large number of ‘spare’ SP units which will be undergoing refurbishment and then storage prior to replacement activities.

7.4.2 Once replaced, the refurbished SP cluster will be lowered back into its position on the intake head. **Figure 7.1** gives the main underwater steps for the lifting and replacement of the SP cluster.

Figure 7.1 Graphic depiction of stages of speaker removal and replacement. The white uprights are the guide posts that require diver intervention to attach.



7.4.3 The following sections outline the key considerations for the SP maintenance and replacement regime proposed for HPC.

7.4.4 <u>SP maintenance and replacement frequency</u>

7.4.5 A SP cluster is made up of six SP's and the selected design, shown in **Figure 5.28**, has been optimised to house six SP clusters on each side of the intake head. This equates to 12 SP clusters per intake head and 48 SP clusters in total for the four intake heads. This is a total of 288 individual SPs.

7.4.6 Required replacement frequency

7.4.7 As outlined in **Section 4.4**, NNB have considered the maintenance requirements for SP units at other sites where AFD systems have been installed. In general, the maintenance and replacement frequency of an individual SP unit at these other sites is once every 12 months. However, the HPC intake location and site conditions are not comparable to these other sites. The harsher conditions at HPC will put more strain on the equipment, requiring more frequent maintenance and replacement to avoid failure. This means the existing SP design will require significant design development and testing to raise the reliability of the SP units sufficiently to make a 12 or 18 month maintenance frequency viable.

7.4.8 From discussions with suppliers it is expected that following an extensive period of SP development and testing, the time between SP maintenance could be increased to 18 months. There is no guarantee that this could be extended to 24 months or more. Therefore, for the preliminary SP maintenance strategy NNB assumed that the replacement of the SP clusters will need to be carried out every 18 months.

7.4.9 Based on the assumption that each SP unit would need to be replaced every 18 months, it means that 32 SP clusters, a total of 192 SPs, would need to be replaced each year.

7.4.10 Alignment of maintenance with power station operation

7.4.11 The EPR outage strategy is based on an outage period every 18 months. The duration and the constraint associated to the maintenance described later in the document is not compatible with the maintenance strategy of the UKEPR^{TM}; therefore, the replacement of SP clusters would have to be performed when the plant is in operation, with a live intake. Risk assessment for diving (and also ROV operation) would need to consider the risk associated for intervention in front of a live intake.

7.4.12 Development of the maintenance schedule

7.4.13 Lifting operations offshore and diving or ROV operations require specific conditions and sea state to be conducted safely. Due to the increase in adverse weather during the winter and the resultant increase in safety risks and weather downtime, NNB will avoid any offshore maintenance activities during these months.

7.4.14 This seasonal constraint is not compatible with the 18 months SP maintenance and replacement frequency. NNB investigated different strategies for SP replacement to avoid working in the winter.

7.4.15 Within the limitations imposed due to seasonal and environmental constraints, in particular the restriction to intervene during neap tides (discussed further in Paragraphs **7.4.22** to **7.4.34**) a limited period will be available for SP maintenance.

7.4.16 The strategy replaces the SP clusters located at the ends of each intake head every year, as they are more critical in producing an efficient sound field. Those SP clusters located in the centre of each head, which are less critical, will be replaced only every two years.

7.4.17 The dive time required to conduct the retrieval of the SP cluster and the subsequent maintenance tasks has been evaluated by assessment of the duration of every single task to be performed, using the following assumptions:

- The diver shall return to the basket during lifting and lowering operations (Paragraphs **7.4.54** to **7.4.66**);
- The visibility is minimal and therefore standard durations for tasks are not valid;
- Dive work will only take place at high tides, since sufficient clearance between the vessel and the guidepost top must be maintained (Paragraphs **7.4.67 to 7.4.72**); and

- Divers cannot be deployed and recovered in the baskets at tidal velocities exceeding the threshold values.

7.4.18 The task list and duration is given in **Figure 7.2**. These durations have been verified with the diving supervisor involved during the 2017 UXO survey. With the assumption that maintenance could also be carried out during night time, only one SP cluster could be replaced per day.

7.4.19 Due to water velocity constraints (Paragraphs **7.4.22** to **7.4.34**), especially during spring tides, the available window for diving operations is too small (covered in detail in Paragraphs **7.4.54** to **7.4.66**), so there are days where no SP replacement is possible. On this basis a maintenance programme was developed.

7.4.20 Detail of the maintenance programme is presented in **Figure 7.3**, which covers two of the four intake heads. The programme shows that replacement of 32 SP clusters per year, avoiding winter and taking water velocity and depth constraints into account, along with the duration of the tasks required, would require a minimum of 72 days of offshore operation. The 72-day timeframe excludes time for mobilisation and demobilisation and any allowance for weather downtime or unforeseen delays (such a mechanical failure).

7.4.21 The following sections outline the main constraints for SP maintenance activities.

7.4.22 Water velocity constraints

7.4.23 The extreme tidal range at the HPC intake head locations results in high water velocities which will restrict the time that divers or ROVs will be able to operate. The high water velocities also contribute to poor visibility due to disturbance of seabed sediment.

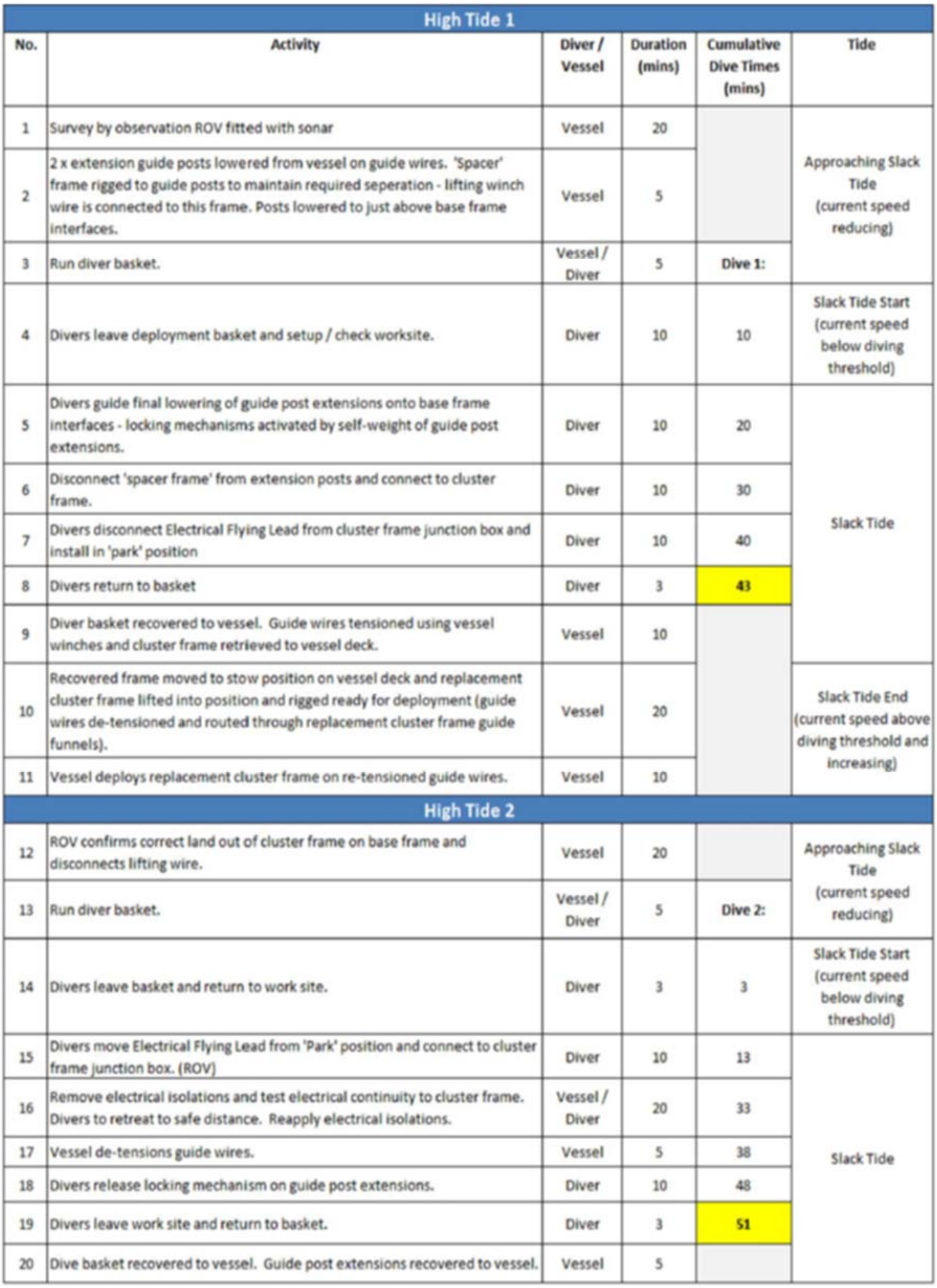
7.4.24 Key considerations, associated with water velocities attributable to states of tide, are:

- The maximum velocity on an ebbing tide is approximately 1.5 m/s;
- The maximum velocity on the flood tide is approximately 1.25 m/s; and
- Maximum turbidity values occur at just after low water as the tide begins to flow.

7.4.25 The allowable working limits for divers performing light work, as stated in the International Marine Contractors Association (IMCA) guidelines (AODC, 1987) is 0.5 m/s (1.0 knot).

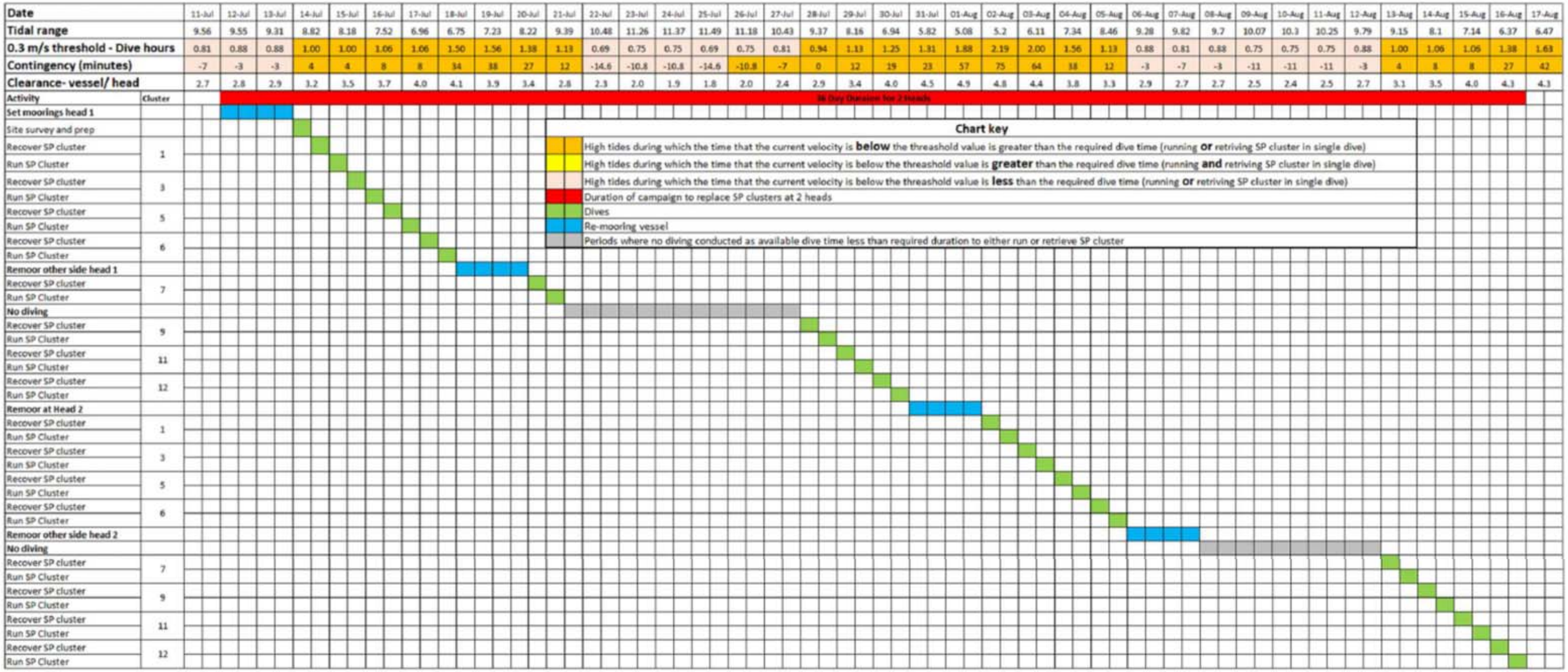
7.4.26 ROVs are capable of working in greater water velocities than divers. ROV manufacturers were contacted regarding the performance of their ROVs. At the time of these discussions small work class ROVs are capable of working in water velocities up to 1.3 m/s (2.5 knots), however these small ROVs are not suitable for the type of work required at HPC. ROVs that are suitable for the type of work required at HPC are larger and are capable of working in water velocities up to 0.75 m/s. Several manufacturers have ROVs in development and it is hoped the development will result in an increase in the ROVs abilities to operate in water velocities up to 1.5 to 2.05 m/s (3 - 4 knots). The capabilities of the ROVs will also depend upon their ability to operate in different positions and therefore thruster technology is also an important consideration. It is not possible to guarantee when this solution will be commercially available.

Figure 7.2 Assessment of the duration of every task to be performed.



No.	Activity	Diver / Vessel	Duration (mins)	Cumulative Dive Times (mins)	Tide
High Tide 1					
1	Survey by observation ROV fitted with sonar	Vessel	20		Approaching Slack Tide (current speed reducing)
2	2 x extension guide posts lowered from vessel on guide wires. 'Spacer' frame rigged to guide posts to maintain required seperation - lifting winch wire is connected to this frame. Posts lowered to just above base frame interfaces.	Vessel	5		
3	Run diver basket.	Vessel / Diver	5	Dive 1:	
4	Divers leave deployment basket and setup / check worksite.	Diver	10	10	Slack Tide Start (current speed below diving threshold)
5	Divers guide final lowering of guide post extensions onto base frame interfaces - locking mechanisms activated by self-weight of guide post extensions.	Diver	10	20	Slack Tide
6	Disconnect 'spacer frame' from extension posts and connect to cluster frame.	Diver	10	30	
7	Divers disconnect Electrical Flying Lead from cluster frame junction box and install in 'park' position	Diver	10	40	
8	Divers return to basket	Diver	3	43	
9	Diver basket recovered to vessel. Guide wires tensioned using vessel winches and cluster frame retrieved to vessel deck.	Vessel	10		
10	Recovered frame moved to stow position on vessel deck and replacement cluster frame lifted into position and rigged ready for deployment (guide wires de-tensioned and routed through replacement cluster frame guide funnels).	Vessel	20		Slack Tide End (current speed above diving threshold and increasing)
11	Vessel deploys replacement cluster frame on re-tensioned guide wires.	Vessel	10		
High Tide 2					
12	ROV confirms correct land out of cluster frame on base frame and disconnects lifting wire.	Vessel	20		Approaching Slack Tide (current speed reducing)
13	Run diver basket.	Vessel / Diver	5	Dive 2:	
14	Divers leave basket and return to work site.	Diver	3	3	Slack Tide Start (current speed below diving threshold)
15	Divers move Electrical Flying Lead from 'Park' position and connect to cluster frame junction box. (ROV)	Diver	10	13	Slack Tide
16	Remove electrical isolations and test electrical continuity to cluster frame. Divers to retreat to safe distance. Reapply electrical isolations.	Vessel / Diver	20	33	
17	Vessel de-tensions guide wires.	Vessel	5	38	
18	Divers release locking mechanism on guide post extensions.	Diver	10	48	
19	Divers leave work site and return to basket.	Diver	3	51	
20	Dive basket recovered to vessel. Guide post extensions recovered to vessel.	Vessel	5		

Figure 7.3 SP unit maintenance and replacement programme for two intake units (the overall duration for the maintenance of the 4 heads will double). Note that maintenance cannot take place during periods of spring tides.



Date	11-Jul	12-Jul	13-Jul	14-Jul	15-Jul	16-Jul	17-Jul	18-Jul	19-Jul	20-Jul	21-Jul	22-Jul	23-Jul	24-Jul	25-Jul	26-Jul	27-Jul	28-Jul
Tidal range	9.56	9.55	9.31	8.82	8.18	7.52	6.96	6.75	7.23	8.22	9.39	10.48	11.26	11.37	11.49	11.18	10.43	9.37
0.3 m/s threshold - Dive hours	0.81	0.88	0.88	1.00	1.00	1.06	1.06	1.50	1.56	1.38	1.13	0.69	0.75	0.75	0.69	0.75	0.81	0.94
Contingency (minutes)	-7	-3	-3	4	4	8	8	34	38	27	12	-14.6	-10.8	-10.8	-14.6	-10.8	-7	0
Clearance- vessel/ head	2.7	2.8	2.9	3.2	3.5	3.7	4.0	4.1	3.9	3.4	2.8	2.3	2.0	1.9	1.8	2.0	2.4	2.9

Date	29-Jul	30-Jul	31-Jul	01-Aug	02-Aug	03-Aug	04-Aug	05-Aug	06-Aug	07-Aug	08-Aug	09-Aug	10-Aug	11-Aug	12-Aug	13-Aug	14-Aug	15-Aug	16-Aug	17-Aug
Tidal range	8.16	6.94	5.82	5.08	5.2	6.11	7.34	8.46	9.28	9.82	9.7	10.07	10.3	10.25	9.79	9.15	8.1	7.14	6.37	6.47
0.3 m/s threshold - Dive hours	1.13	1.25	1.31	1.88	2.19	2.00	1.56	1.13	0.88	0.81	0.88	0.75	0.75	0.75	0.88	1.00	1.06	1.06	1.38	1.63
Contingency (minutes)	12	19	23	57	75	64	38	12	-3	-7	-3	-11	-11	-11	-3	4	8	8	27	42
Clearance- vessel/ head	3.4	4.0	4.5	4.9	4.8	4.4	3.8	3.3	2.9	2.7	2.7	2.5	2.4	2.5	2.7	3.1	3.5	4.0	4.3	4.3

36 Day Duration for 2 Heads

Activity	Cluster
Set moorings head 1	
Site survey and prep	
Recover SP cluster	1
Run SP Cluster	
Recover SP cluster	3
Run SP Cluster	
Recover SP cluster	5
Run SP Cluster	
Recover SP cluster	6
Run SP Cluster	
Remoor other side head 1	
Recover SP cluster	7
Run SP Cluster	
No diving	
Recover SP cluster	9
Run SP Cluster	
Recover SP cluster	11
Run SP Cluster	
Recover SP cluster	12
Run SP Cluster	
Remoor at Head 2	
Recover SP cluster	1
Run SP Cluster	
Recover SP cluster	3
Run SP Cluster	
Recover SP cluster	5
Run SP Cluster	
Recover SP cluster	6
Run SP Cluster	
Remoor other side head 2	
No diving	
Recover SP cluster	7
Run SP Cluster	
Recover SP cluster	9
Run SP Cluster	
Recover SP cluster	11
Run SP Cluster	
Recover SP cluster	12
Run SP Cluster	

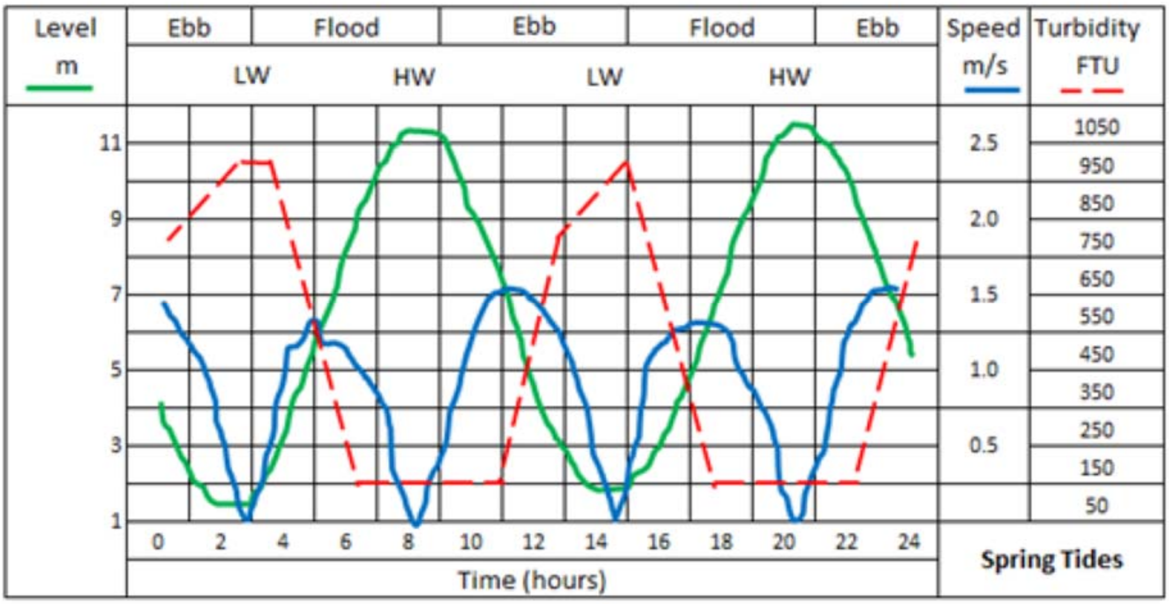
Chart key

🟧	High tides during which the time that the current velocity is **below** the threashold value is greater than the required dive time (running **or** retriving SP cluster in single dive)
🟨	High tides during which the time that the current velocity is below the threashold value is **greater** than the required dive time (running **and** retriving SP cluster in single dive)
▨	High tides during which the time that the current velocity is below the threashold value is **less** than the required dive time (running **or** retriving SP cluster in single dive)
🟥	Duration of campaign to replace SP clusters at 2 heads
🟩	Dives
🟦	Re-mooring vessel
⬜	Periods where no diving conducted as available dive time less than required duration to either run or retrieve SP cluster

7.4.27 The tidal velocities over a tidal cycle at HPC have been extracted from data taken over a six week period (from 17 August to 26 September 2008), which comprised three tidal cycles (**Figure 7.4**). The tide height, speed, and turbidity data was extracted at the highest tide in this period.

7.4.28 In order to assess the effect of the tidal water velocities on the time that both divers and ROVs are able to work, historical oceanographic data for the area around HPC was used to generate a graph of time available at high water and low water.

Figure 7.4 Graph showing the relation between tide level, current velocity and turbidity.



7.4.29 **Figure 7.5** shows the time where the tidal velocity was under the working limits, assuming 0.5 m/s and 0.75 m/s limits for divers and ROVs respectively.

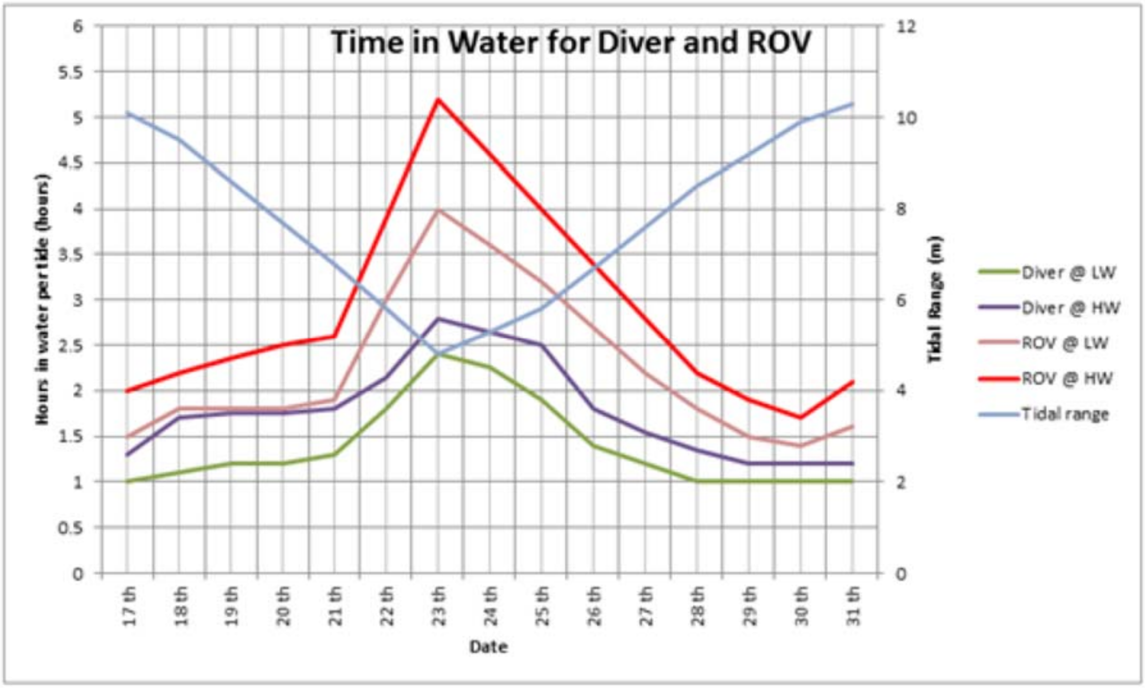
7.4.30 From this the following conclusions may be drawn:

- ROVs have significantly greater working time than divers (approximately 60% greater);
- For all cases there is significantly greater working time at High Water (HW) than at Low Water (LW) (approximately 30%); and
- Working time is significantly greater at neap tides than spring tides (approximately 30%).

7.4.31 Even though **Figure 7.5** shows that the working time is greater for ROVs, the limitations of the ROV technology means that time will be lost as a result of the ROV's 'lack of feel', which would lead to a large time increase for all tasks the ROV carries out.

7.4.32 As a result of this constraint, the time available per day and seasonally for performing the replacement of SP units will be highly reduced. This is a very significant issue for establishing a viable maintenance schedule for technology with unknown reliability.

Figure 7.5 Time in water for diver and ROV where the current speed was under the working limits.



7.4.33 As this limitation is critical with regards to the feasibility of the maintenance of the SPs, NNB performed additional analysis using available data by JBA consultants who used their “ForeCoastRMarine” metocean risk management software to predict the conditions found at the intake head position. This software was used to produce predictions of the subsurface current versus the predicted tide heights at the intake heads. This data was cross referred to the published tide tables and the data recorded from the current meter used during the Unexploded Ordnance (UXO) Survey performed by NNB around the intake heads during summer 2017.

7.4.34 A good correlation was found between published tide tables, software generated forecast and actual measurements during the UXO survey.

7.4.35 Turbidity constraints

7.4.36 Turbidity is a measure of the degree that water loses its transparency due to the presence of suspended particulates; essentially, the higher the turbidity the murkier the water. Turbidity is an important consideration for SP maintenance activities at HPC as both diver and ROV operations will be restricted by high turbidity.

7.4.37 A survey carried out in 2008 measured turbidity close to the HPC intake locations during both spring and neap tides using turbidity tubes. A turbidity tube is a simple device for measuring the turbidity of water samples (**Figure 7.6**). It consists of a clear tube with a disc at the bottom divided into alternating black/white quadrants. Water is poured into the tube until the point at which the disc cannot be seen when viewed from above. A measurement is then taken of the distance between the disc and the water level in the tube.

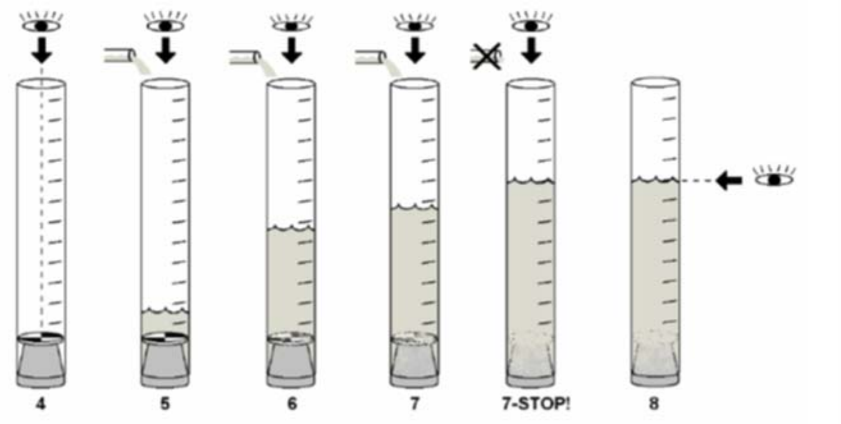
7.4.38 The highest level found during the survey was around 950 Formazan Turbidity Unit (FTU)[6] and the key results were:

- Spring Tide:
    - Peak flood tide turbidity: 950 FTU at HW–4hrs
    - Peak ebb tide turbidity: 750 FTU at HW+5hrs
    - Period of relatively low turbidity (<100 FTU): HW-2hrs to HW+2.5hrs
- Neap Tide:
    - Peak flood turbidity: 870 FTU at HW–4.8hrs
    - Peak ebb turbidity: 650 FTU at HW+5.7hrs
    - Period of relatively low turbidity between peaks

7.4.39 There is an exponential relationship between the measured depth and turbidity which can be quantified using the following equation:

- Depth in cm = 244.13 x (Turbidity in NTU)^-0.662

Figure 7.6 Example of turbidity tube for measuring the turbidity of water samples.



7.4.40 Although there is no simple relation between turbidity and visibility, the values shown in **Table 7.1** demonstrate that the in-water visibility close to the HPC intake structures is very poor. In terms of practical visibility for diver or ROV operations, the mean and

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[6] 1 NTU (Nephlometric Turbidity Unit) = 1 FTU (Formazin Turbidity Unit). FTUs were the units used for the Turbidity measurements during the survey at Hinkley Point

maximum turbidity levels would be considered as ‘no-visibility’ conditions, with only a few centimetres of turbid water required to obscure a high contrast object. Even at minimum turbidity levels, low visibility conditions (of less than 0.4 m) still arise.

7.4.41 These results have been confirmed by feedback obtained from the UXO survey performed at the location of the intake heads in 2017.

7.4.42 Low to no visibility conditions have significant implications for operations underwater. Both diver and ROV operations will be significantly restricted and this will result in increased time requirements for maintenance operations.

Table 7.1 Estimate of visibility based on FTU measurement at HPC

	Turbidity (FTU)	**Visibility (cm)**
Spring Tide – Min. Turbidity	27	27.3
Spring Tide – Max Turbidity	962	2.6
Spring Tide – Mean Turbidity	243	6.4
Neap Tide – Min Turbidity	20	33.2
Neap Tide – Max Turbidity	632	3.4
Neap Tide – Mean Turbidity	103	11.4

7.4.43 Other environmental constraints

7.4.44 There are a number of other environmental constraints which could significantly affect the activities required to maintain the SP Units.

7.4.45 Silt

7.4.46 HPC is characterized by a high level of sediment. It is not expected that silt would affect the performance of the system, as the SP unit itself will be fully sealed. There is a significant risk however that silt deposition in some areas of the AFD structure will complicate the maintenance operation. For example, silt deposition at the location of the stubs (that fix the SP clusters to the frame, and need to be released prior to cluster removal) will restrict ROV intervention, and the ROV will not be able to perform the task until a diver has cleared the silt. This will impact on the duration of the operation and increase safety risks.

7.4.47 Marine growth

7.4.48 HPC is not considered as critical in terms of marine growth, but it is likely that some marine growth will develop on parts of the AFD structure, potentially complicating the maintenance operation. Marine growth on the AFD system components will result in the need for:

- Cleaning of the top of the guide posts before lifting activities can begin. Without this cleaning there is a high risk the SP clusters will jam on the wires whilst being lifted;
- Growth around electrical connectors restricting mating / unmating;
- Obscuring of subsea identification markings; and
- Covering lifting points.

7.4.49 Consideration of the use of ROVs

7.4.50 NNB worked with a company specialised in ROV operation in severe conditions (RovCo), to evaluate the suitability of ROVs to operate under the extreme tidal velocity and visibility conditions at HPC. An image of an ROV is shown in **Figure 7.7**. This collaboration generated the following conclusions:

- The visibility conditions at HPC will severely limit the effectiveness of standard ROV cameras and therefore a high reliance on sonar systems will be required.
- Although multibeam sonar solutions could 'see' with sufficient resolution they could not be mounted in the traditional position between the ROV manipulators as the sonars have an inherent blind spot at close range. It was therefore recommended that alternative mounting arrangements for the sonars are investigated to overcome the 'blind spot' problems
- From the desktop evaluation of sonar systems, it was concluded that there are multibeam sonar systems under development. However, this technology is not yet available and the use of sonar technology to provide adequate visibility, in order to carry out the ROV manipulator tasks at HPC, is at the limits of technology currently available due to the inherent close quarter 'blind spot' of such systems.
- On the market there is currently no existing ROV that operates with the addition of Sonar. The ability of the manipulation tasks to be carried out by the ROV using sonar in the conditions at HPC will therefore require extensive testing.

Figure 7.7 Image of type of ROV technology considered for HPC project.

7.4.51 In practice, the use of ROVs in zero visibility environments results in a high risk of entanglement between the ROV, its tether and the structure. Should entanglement or entrapment of the ROV occur, its recovery would be restricted by the tidal velocities and visibility conditions. If ROVs are to be used safely, and without a high risk of tether snagging, all tether traps will need to be designed so that their profiles are smooth. Even with the best design, it would not be possible to remove all the risk of entanglement.

7.4.52 With the absence of visibility, knowing the location of the ROV relative to the inlet heads and SP equipment is fundamental to ensuring that maintenance operations can be executed within the tidal water velocity window, and also without difficulty. Development of ROVs would have to include addition of acoustic positioning to enable the location of the ROV and its umbilical to be known at all times.

7.4.53 In conclusion the use of ROV technology in the zero visibility conditions at HPC for the tasks required for the maintenance of AFD system, together with high water velocity, and presence of obstacles and snagging hazards is a major technical challenge which would have to be overcome before the use of ROV's could be considered viable. Extensive development and testing of the ROVs and the SONAR and positioning equipment would be required before the technology could be considered viable for use during SP maintenance activities at HPC.

7.4.54 Consideration of diving operations

7.4.55 As explained in Paragraphs **7.4.49** to **7.4.53**, there is no guarantee at this stage of the project, that the future development of ROV technology will be able to produce a reliable ROV, equipped with sonar camera capable of performing the necessary tasks during SP maintenance at HPC. Even if ROV technologies became available there will still be occasion[7] where use of ROVs will not be practicable, and diving operations will be required, so NNB have undertaken a feasibility review of the diving operations that will be required at HPC.

7.4.56 Description of diving operations at HPC intake location

7.4.57 Diving operations during maintenance activities associated with the SP clusters will involve a diver being deployed from the dive vessel. The diver will be connected to the dive vessel via an umbilical cord which carries communications and air supply (**Figure 7.8**).

7.4.58 A second diver will remain onboard the dive vessel, in a basket, to be deployed in the case of emergency. This diver will also manage the deployment of the first diver's umbilical, allowing the length and movement of the umbilical to be carefully managed as the diver moves into position by the intake head.

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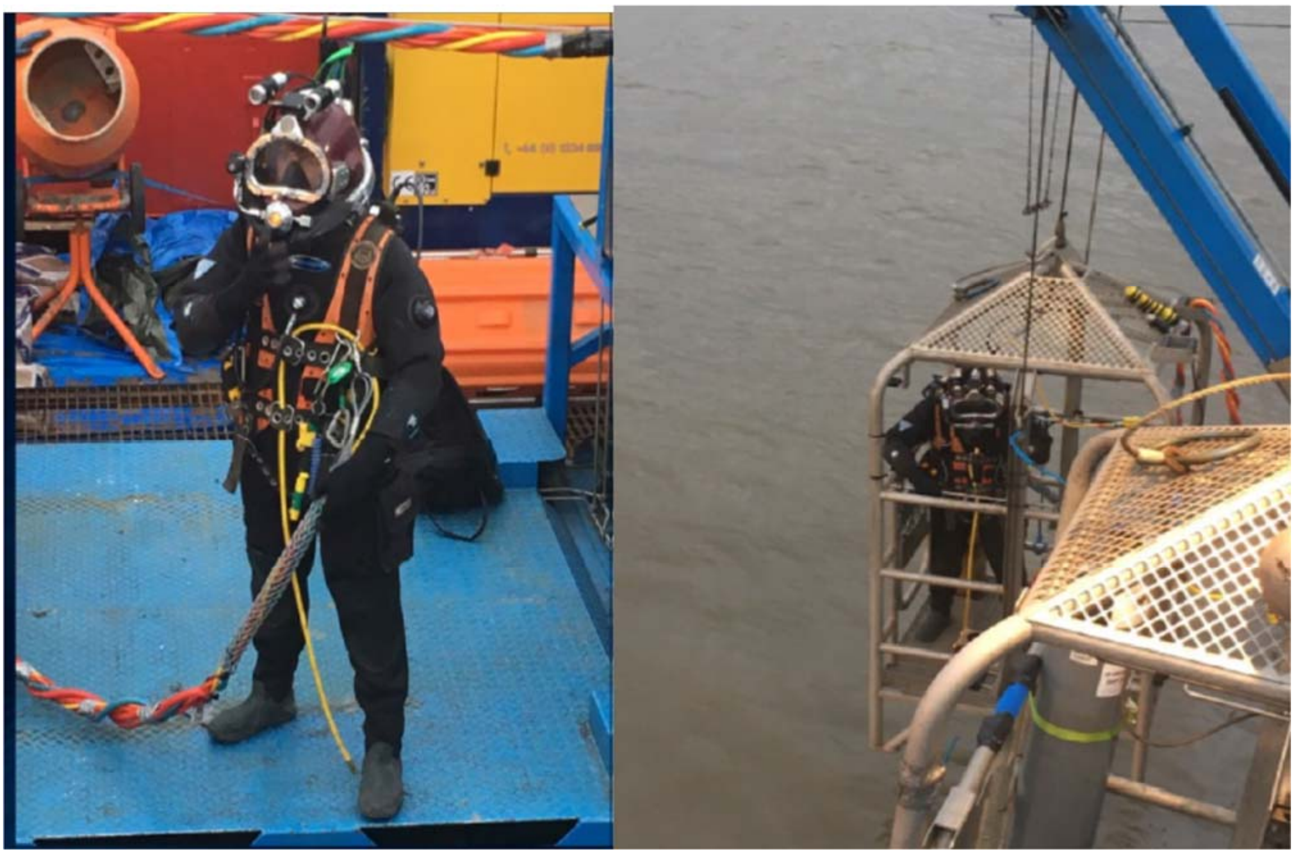
[7] Occasions would include the need to clear marine growth, determine silt levels and clear these, release jams etc. Operations have been designed to enable ROV's to carry them out however there are unforeseen events that will require human (diver) intervention.

7.4.59 The dive vessel will be supplied with a decompression chamber as evacuation from this location to a shore based decompression chamber will take longer than the two hours limit.

7.4.60 Divers will be fitted with SONAR equipment. Images will be relayed to the operator on board the dive vessel who will guide the diver.

Figure 7.8 Image of diver dressed with umbilical (left) and diver in the basket (right) from 2017 UXO survey.



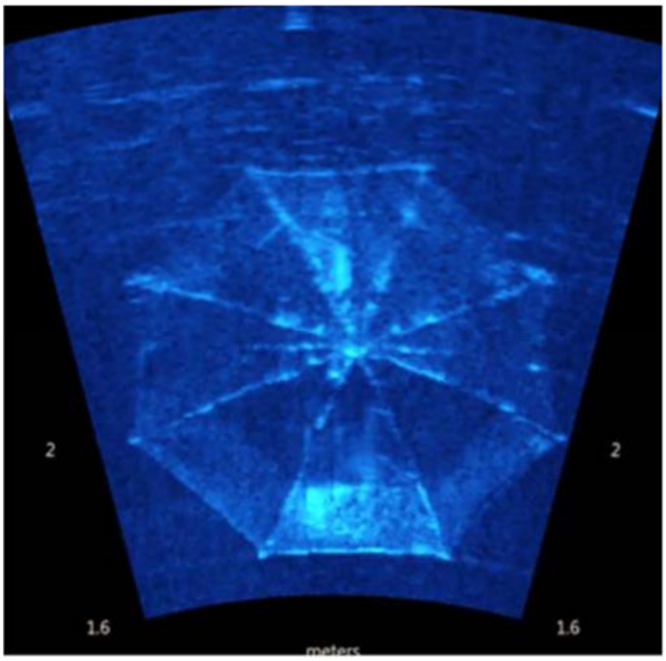
7.4.61 Findings from NNB diving feasibility review

7.4.62 The individual maintenance tasks that would be performed by divers has been examined by a diving specialist, James Fisher. The specialist confirmed that these tasks could feasibly be performed by divers, however any complication, such as blockage of equipment by silt or marine growth, will lead to difficulties and will restrict the diver given the zero visibility conditions at HPC.

7.4.63 Diving in zero visibility conditions presents major difficulties. The diver will be equipped with sonar equipment but will not get any direct view. The diver will therefore be guided by someone on board the vessel. The image the vessel will see will be comparable to that shown in **Figure 7.9**. The quality of the images provided by acoustic camera are fairly accurate, but they do not give any perspective and are difficult to interpret with relation to the distance. When the diver is in position, the task can only be performed by touch.

7.4.64 The risk of entanglement described for ROV's also applies during diving operations. As the diver will be working in close proximity to the active intake head, there is a significant risk of entanglement with the AFD structure or intake head, or entrapment on the intake heads itself. This risk is heightened due to the low visibility conditions. Emergency divers will be ready on board the vessel and will be deployed in the event that the divers underwater encounter difficulties.

Figure 7.9 Typical view of Sound Metrics ARIS 3000 image.



7.4.65 NNB have considered the lessons learned from the 2017 UXO survey performed at the intake locations. Key findings that have helped inform the feasibility assessment for diving operations were:

- The turbidity of the water was confirmed by samples taken at different depths as well as verbal accounts given by the divers, with the water being described as "coffee water". The UXO dive team confirmed that were no significant variations in visibility during the four-month period of the UXO survey. Even in the best conditions, the best visibility was 30 cm, with no visibility at arm's length;
- During the UXO survey, water velocities were consistently monitored due to the 0.5 m/s diving limit. This data confirmed that predicted current speeds (from tide tables) were accurate, though times differed slightly. The average duration of a single dive period during the UXO survey was one hour;

- Divers reported significant difference in the seabed conditions between the four intake locations and also at the same location during different dive periods. Seabed conditions varied from rock to fine muds, with up to 800 mm of silt reported in places, where divers could sink in; and
- The UXO survey was conducted during summer 2017 when weather downtime[8] was minimal and aborted diving operations due to swell conditions were limited.

7.4.66 The tidal window for diving operations at HPC will be approximately one hour. Once in the water, divers will be restricted by poor conditions, including low visibility. Any delays resulting from these restrictions, weather downtime or any unexpected issues (such as marine growth etc.) will impact the maintenance programme and could therefore limit the reliability of the AFD system.

7.4.67 Consideration of vessel requirements

7.4.68 Vessel operational requirements and water depth constraints

7.4.69 The tidal range at HPC is significant (Paragraphs **4.2.6** to **4.2.8**) and is approximately 11 m during spring tides. The top of the intake head structures is at a height of around 4.4 m above the seabed.

7.4.70 As the maintenance vessel will be operating over live intake heads, the under vessel clearance is an important consideration and at LAT there will be less than 2 m of clearance between the intake head and the hull of the maintenance vessel (**Figure 7.10**).

7.4.71 The vessel will need to be of a specific type as it has to perform a number of tasks. The vessel will need to:

- transport and store the refurbished SP units until needed;
- position and re-position above the intakes according to maintenance requirements;
- act as a stable lifting platform for divers and/or ROVs;
- act as a stable platform for the safe operation of the lifting equipment required to lift the SP clusters;
- provide sufficient deck space for maintenance activities once the SP cluster is onboard; and
- provide accommodation for crew and engineers (approximately 20 people).

7.4.72 The type of vessel selected for maintenance will ultimately determine the associated operational risks. NNB undertook a feasibility review of available vessel types most suited to the maintenance activities at HPC in order to establish the operational risks. The two main types considered were:

- jack-up barges that can elevate the working platform above the water line; and
- free-floating vessels (work boats, barges etc.), either:
    - dynamically positioned;

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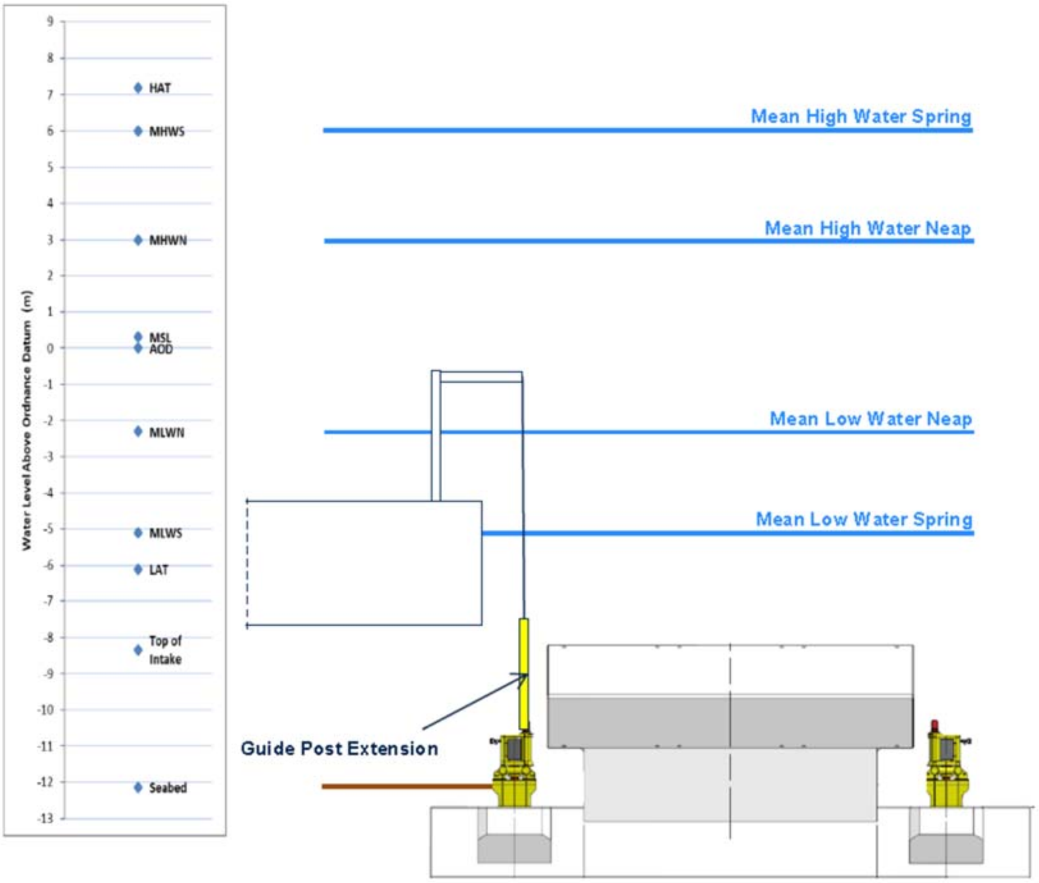
[8] Weather downtime is time lost in waiting out unfavourable conditions until operations can recommence due to strong winds or high waves'

- positioned via anchor

Figure 7.10 Position of intake head relative to tidal states and water depths



7.4.73 **Consideration of the use of a Jack-up barge for SP maintenance activities**

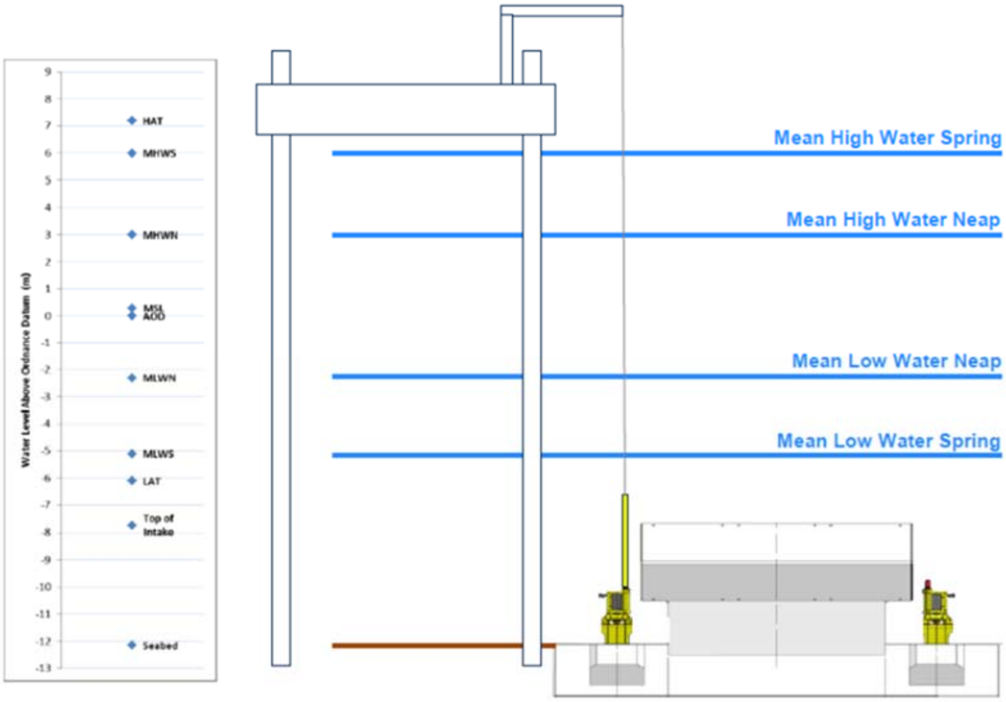
7.4.74 A jack-up barge consists of a platform that can be elevated on legs once the vessel is in the desired position. A typical jack up barge s shown in **Figure 7.11**.

7.4.75 Once in position with the legs safely deployed and platform elevated, a jack-up barge offers a stable working platform from which lifting equipment can be safely deployed. The fixed platform can also be raised to a height to ensure it is not affected by tidal variations and wave action (as shown in **Figure 7.12**).

7.4.76 Whilst the jack-up barge offers stability benefits, the time it takes to position, deploy the legs and raise the platform to working height has to be considered alongside the maintenance schedule. It is estimated that the jack-up barge would have to position itself and then reposition itself at least once whilst at an intake head, even for clusters on the same side of the intake.

Figure 7.11 Image of a jack up barge

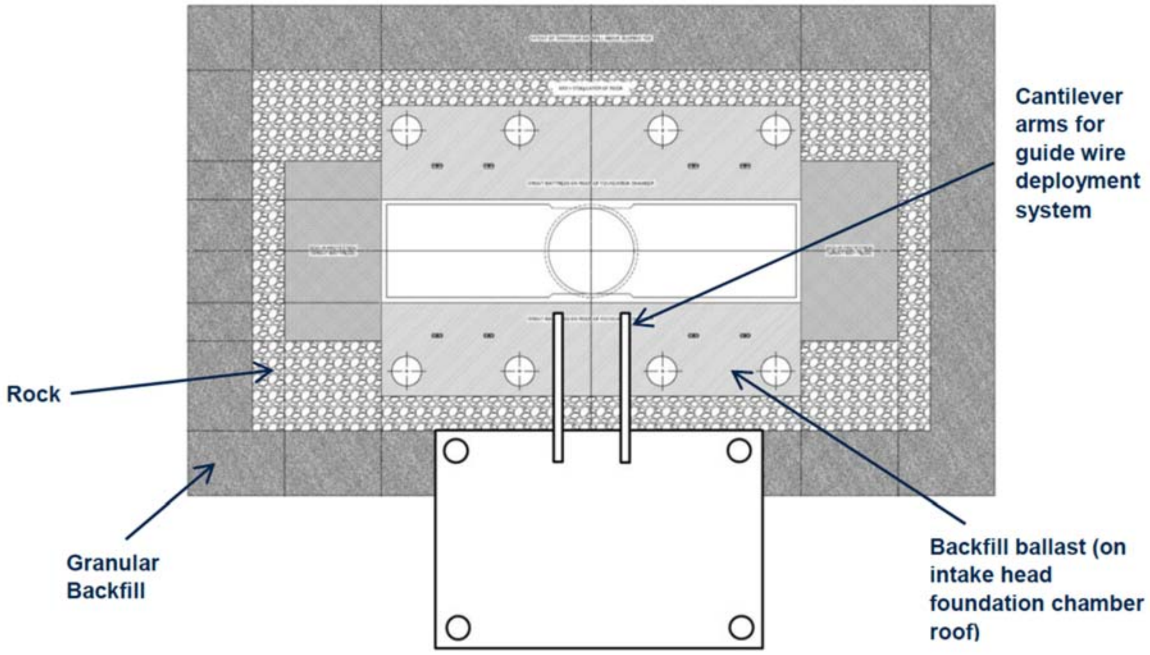
Figure 7.12 Position of jack-up barge above the intake heads



7.4.77 A jack-up will require particular seabed conditions for the legs to provide adequate support and specific requirements would need to be determined in consultation with vessel operators. For example, punch-through of jack-up footings can occur where there is strong soil overlying a softer soil, causing instability and meaning the vessel cannot be deployed in the necessary position. Due to the very localised nature of such seabed conditions it is not possible to survey and select locations at this scale.

7.4.78 Assuming that the legs could not be set down in the rock surrounding the intake head, a cantilever (beam) approximately 9 m long, extended over the side of vessel (as shown in **Figure 7.13**) would be required for safe deployment of the lifting gear associated with lifting of the SP clusters during SP maintenance.

Figure 7.13 Position of jack-up barge above the intake heads



7.4.79 NNB determined that the option of deploying a jack-up barge was not realistic due to the impacts it would have on schedule and the unrealistic safe deployment distances required.

7.4.80 Consideration of the use of a free floating Dynamically Positioned (DP) vessel for SP maintenance activities

7.4.81 A DP vessel is a free floating vessel, which holds station by computer controlled thrusters based on inputs from a number of position referencing systems. A free-floating vessel will have a constantly changing vertical position above the seabed as a result of tidal and wave conditions. A major risk in using this type of vessel will be collision with fixed infrastructure on the seabed in low water conditions.

7.4.82 DP systems are typically installed on larger conventional hull type construction vessels, which have a larger draft[9] than barge type vessels, which imposes on them the associated difficulty of working in shallow water. The major risk associated with diving or ROV deployment from a DP vessel is diver umbilical entanglement in vessel thrusters, mitigated by ensuring a minimum separation is always maintained. IMCA guidance states that a divers umbilical must be physically restrained to prevent it coming within 5m of any physical hazard identified by risk assessment (such as vessel thrusters, propellers, water intakes etc.). With the restriction of water depth and the risk associated with diving or ROV operation from a DP vessel, NNB will not further consider the use of a DP vessel for the SP maintenance.

7.4.83 Consideration of the use of a free floating vessel positioned via anchors for SP maintenance activities

7.4.84 A free-floating vessel will have a constantly changing vertical position above the seabed as a result of tidal and wave conditions. A major risk in using this type of vessel will be collision with fixed infrastructure on the seabed in low water conditions.

7.4.85 During the lifting activities required for SP maintenance, the top of the guide post extensions[10] would be the shallowest point a vessel could strike. **Figure 7.10** shows how a typical barge type vessel would sit in the water at mean low water spring. Assuming a 2.5 m vessel draft, the bottom of the vessel would be below the level of the top of the guide post extension and only 14 cm above the top of the intake head. Obviously for this arrangement, any uncontrolled horizontal movement of the vessel coupled with action of waves could lead to collision with the guide post extension and/or the intake head.

7.4.86 To mitigate the risk of collision, limits could be placed on the water depths at which it would be acceptable to carry out the installation activities. For example, considering the same vessel with 2.5 m draft, applying a minimum 2 m compulsory vertical clearance between the vessel and guide post extension would give a minimum operational water level of -2.15 m Above Ordnance Datum (AOD) (slightly above mean low water neap). This would reduce the operational window for installation activities as demonstrated (for example only) in **Figure 7.14**.

7.4.87 **Figure 7.14** shows the water level variations over a number of spring and neap tides (based on historical survey data at Hinkley Point) with the area highlighted in red representing when the water depth would be too shallow to carry out maintenance activities (for the 2.5 m draft vessel with 2 m vertical clearance example). As can be seen, a proportion of the tidal cycle falls within this zone and therefore there will be key periods during spring tides where the vessel cannot operate and SP maintenance activities will have to cease. When in this non-operational zone, the vessel may be required to move out of the vicinity of the intake head. Depending upon the method of securing the vessel in position, this could present a significant constraint with regard to programme and being

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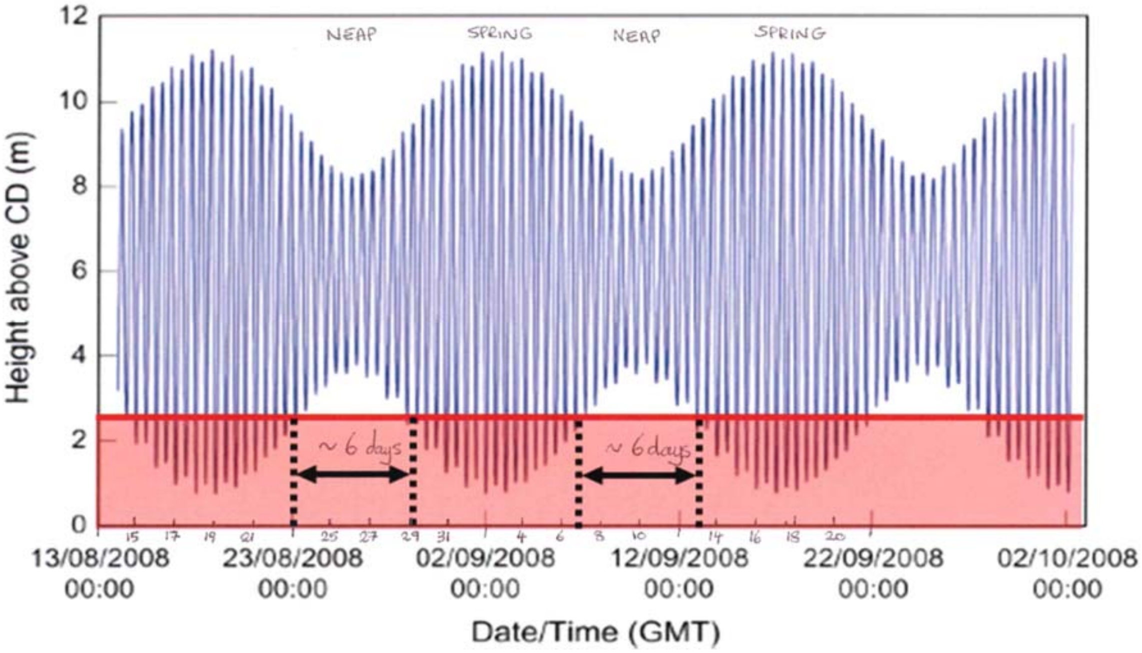
[9] The draft of a ship's hull is the vertical distance between the waterline and the bottom of the hull.

[10] Guide post extensions are required during maintenance activities to help guide the SP cluster safely from and then back to its seat on the intake head.

able to maximise the limited windows where maintenance activities can be carried out safely.

Figure 7.14 Water Depth constraint on installation operation (example only)



7.4.88 Neither the use of a jack-up barge or free floating DP vessel are considered viable options for use at HPC for SP maintenance activities. The solution of anchoring a free floating vessel is therefore considered as the only appropriate option to manage the risk of collision with fixed structures and enable SP maintenance activities to be carried out. This has been analysed in more detail by NNB through a anchoring study.

7.4.89 Anchoring studies

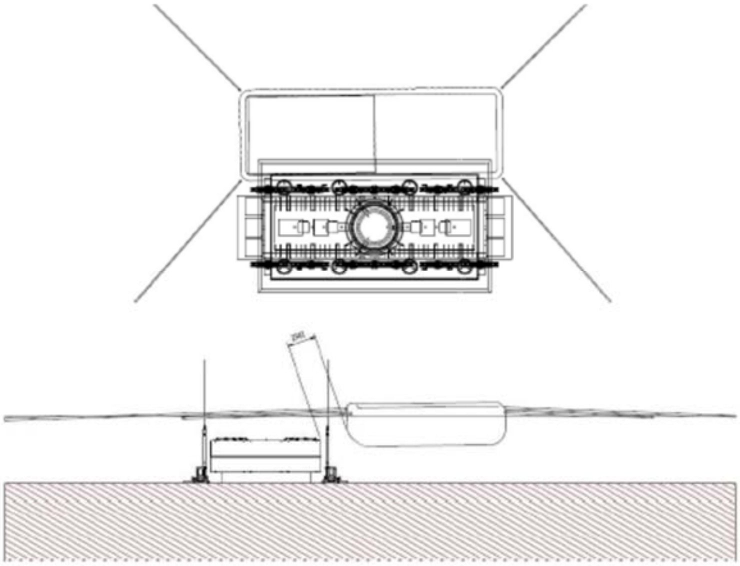
7.4.90 In order to evaluate the constraints associated with anchoring, the size of vessel required has been estimated by looking to the deck size required to fit ROV equipment, diving support, lifting gear for lifting the SP cluster and the spare SP units. The result of this analysis shows that a large barge would be required. Vessels are available that meet the requirements and the MSC Ailsa has been used as the example vessel for the mooring study. **Figure 7.15** shows the MCS Ailsa and her dimensions.

7.4.91 To establish how the vessel could be anchored safely alongside the intake heads, a number of four- point anchoring configurations were analysed using one-year return wind and wave conditions and peak water velocities during spring tides. A four point anchoring layout is shown in **Figure 7.16**. Four anchoring points are considered necessary to ensure the vessel is held in position, away from the intake head yet close enough to enable the maintenance activities.

Figure 7.15 Typical mooring vessel used for mooring studies – MCS Ailsa

MCS Ailsa dimensions	
Length	41.5 m
Beam	14.0 m
Draft	2.0 m

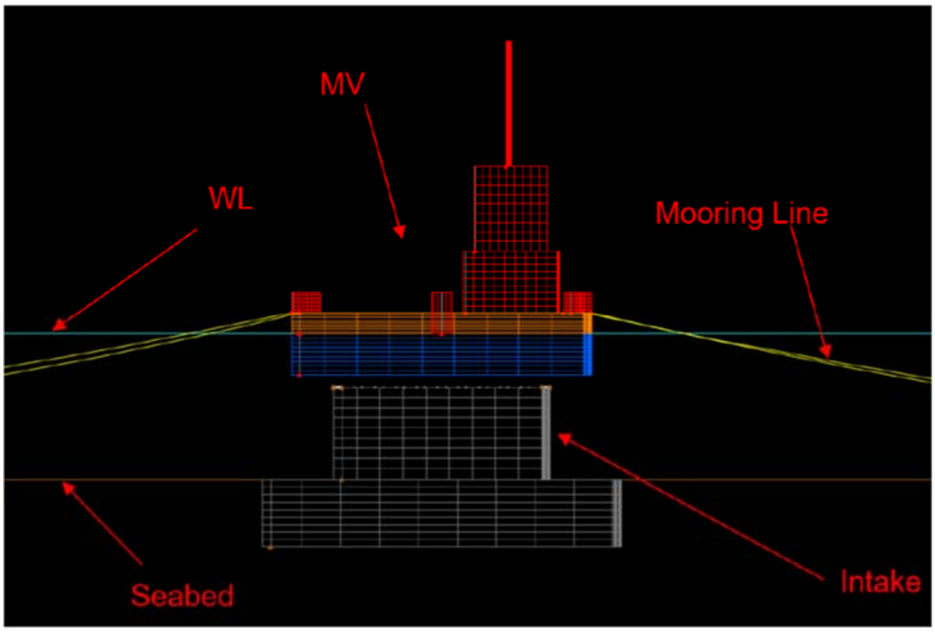
Figure 7.16 Depiction of a four-point anchoring layout, with profile view at LAT



7.4.92 A specialized static and dynamic analysis software for modelling the behaviour of marine and offshore systems (Orcina Orcaflex 10.1) was used to evaluate the anchor chain length, pattern and the tension into the anchoring lines. **Figure 7.17** shows an extract from the modelling system. This analysis considered the constraints for the positioning of the vessel at each SP maintenance location including the length of the anchoring lines, accuracy of positioning and how the vessel positions at each location. It has been concluded that an anchoring line length of 300 m is required to ensure the vessel is safely secured. The requirement for a 300 m long anchoring line results in the need for an extensive area available around the intake heads to position the vessel. As a result of this constraint, the offshore monopile central hub will need to be repositioned at a larger distance from the intake heads.

7.4.93 The anchor line pattern would also need to avoid the position of buried cables linking the offshore monopile central hub with each intake head.

Figure 7.17 Extract of the model used to evaluate anchoring (mooring) pattern / tension



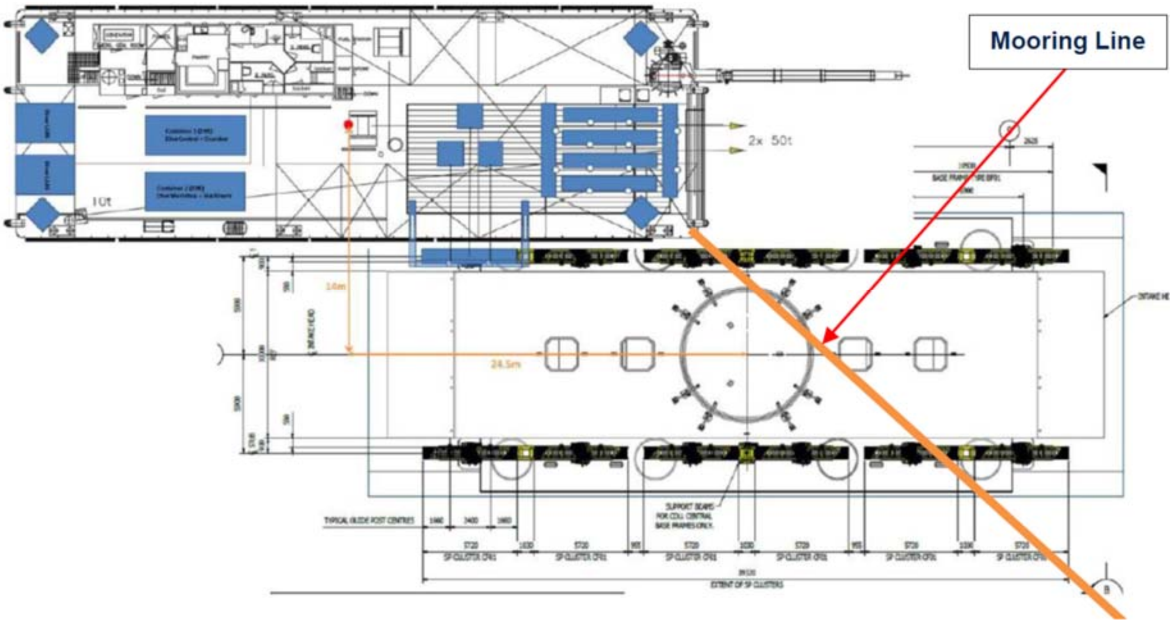
7.4.94 The key issue highlighted by the study is the difficulty of maintaining adequate separation between the mooring lines and the intake head structure, particularly in the low tide shallow water conditions when the vessel is positioned for access to the clusters at the extremities of the intake heads as shown in **Figure 7.18**.

7.4.95 Industry good practice requires clearance of 10 m between the structure and the mooring line(s) to avoid any risk of collision in a situation where the anchor securing the mooring line drags. A minimum clearance of 5 m is recommended in all circumstances. The study showed that the criteria of 5 m clearance will not be achievable at low tide for all tidal conditions.

7.4.96 The main concern with the vessel in the central position along the face of the intake head is the proximity of the vessel hull itself to the intake head (and guideposts if installed), and also the proximity of the mooring lines to the intake head. For the low water case (LAT) the minimum distance between vessel and intake head is around 2.5m.

7.4.97 It will be important to actively manage the paying out / winching in of the mooring line over the intake head to maintain an acceptable clearance. Winching in will increase the tension on the mooring line and straighten the line through the water. It will be important to constantly monitor the tensions in the mooring lines and be aware of how the lines are positioned over the head based on the line tension and length of line. There is a risk that if the weather changes quickly and the lines are not appropriately winched out, the lines could become loaded quickly. To manage this risk, good procedures will need to be in place as well as a positioning system to show location of vessel in relation to the intake head.

Figure 7.18 Vessel at ‘offset’ frame deployment position over intake head



7.4.98 The vessel would need to be offset from the intake heads during spring peak tides to limit the risk of collision and resultant significant impact on the overall program for the maintenance.

7.4.99 Even with the best control procedures, there is the risk of failure of one mooring line (this happened during the UXO survey in summer 2017).

7.4.100 As the intake heads are safety classified structures, any damage to the intake heads from the maintenance vessel anchoring lines will have to be investigated to ensure that the damage does not alter the safety functional requirements of the intake head. Any defect will have to be reported to ONR, and could lead to very difficult repairs.

7.4.101 Considering the frequency of maintenance that will be required and the associated vessel mooring operations around the intake heads, this represents a significant issue for the feasibility of this vessel option and therefore the ability to maintain the SP units.

7.5 Conclusions on AFD maintenance

7.5.1 As part of the option selection and concept design of the AFD system (outlined in Section 5), the maintainability of the AFD system has been one of the key considerations. NNB has investigated multiple solutions to maintain the AFD system within the offshore environment at HPC and at the end of this process has drawn the following conclusions:

- The market available SP technology capable of producing the sound field required to deter the HPC fish assemblage requires very frequent maintenance to ensure reliability. To reduce the maintenance window and ensure the SP units can withstand the environmental conditions at the HPC intake locations long enough to give a maintenance window of 12 to 18 months, considerable development and testing of the market available SP technology will be required before reliability can be confirmed and a viable maintenance window of 18 months proposed.
- The SP maintenance tasks rely on diver, and if possible ROV, intervention. The zero visibility environment results in a high risk of entanglement for diver umbilical or ROV tether with intake structures. Even with the best design, it would not be possible to remove all the risk of entanglement or even diver entrapment on the head itself.
- SP maintenance activities will require diver intervention. The tidal window for diving operations at the HPC intake location is approximately one hour per tidal cycle.
- Diver intervention could be reduced using ROVs; however, existing ROV technology is not suitable for use at HPC. Whilst development of ROV technology is ongoing, there is absolutely no guarantee that the ROV technology required to operate at HPC will be available in the future.
- Working within the limitations of water depth and water velocities, the duration available to perform the SP maintenance activities is limited, both in terms of days available offshore and time allowance per tidal cycle. NNB determined that a minimum of 72 days would be required to undertake the annual SP maintenance. This lengthy annual offshore maintenance campaign does not account for weather or mechanical downtime and the costs of such a campaign are significant.
- The operation of the maintenance vessel in the vicinity of the safety classified intake heads structures raises significant risks. No solution has been found by NNB to mitigate the risk of vessel mooring lines affecting the intake heads.

7.5.2 Considering the significant safety concerns identified during the work summarised in this report, NNB sought to independently verify the NNB assessment of the safety implications. NNB commissioned Bureau Veritas to undertake:

- a review of the NNB process and inclusion of safety in the selection process; and
- a quantitative assessment of the risk of injury and fatality for divers during the proposed operations.

7.5.3 The findings of this assessment are presented in the Bureau Veritas Safety Review Report (Bureau Veritas, 2018).

7.5.4 To put the safety risks into context, it is necessary to understand the regulatory framework in place in the UK to control the risks presented to workers.

7.5.5 Part 1, Paragrah 2 of The Health and Safety at Work etc. Act 1974 specifies the general duty on employers to their employees:

“(1) It shall be the duty of every employer to ensure, so far as is reasonably practicable, the health, safety and welfare at work of all his employees.

(2) Without prejudice to the generality of an employer's duty under the preceding subsection, the matters to which that duty extends include in particular—

> *(a) the provision and maintenance of plant and systems of work that are, so far as is reasonably practicable, safe and without risks to health;*
>
> *(b) arrangements for ensuring, so far as is reasonably practicable, safety and absence of risks to health in connection with the use, handling, storage and transport of articles and substances;*
>
> *(c) the provision of such information, instruction, training and supervision as is necessary to ensure, so far as is reasonably practicable, the health and safety at work of his employees;*
>
> *(d) so far as is reasonably practicable as regards any place of work under the employer's control, the maintenance of it in a condition that is safe and without risks to health and the provision and maintenance of means of access to and egress from it that are safe and without such risks;*
>
> *(e) the provision and maintenance of a working environment for his employees that is, so far as is reasonably practicable, safe, without risks to health, and adequate as regards facilities and arrangements for their welfare at work."*

7.5.6 The general duty described above forms the legal basis for the development of all subsequent health and safety legislation, policies, procedures and methods of working.

7.5.7 These general duties are further reinforced by The Management of Health and Safety at Work Regulations 1999. These regulations require (amongst other things) employers to carry out competent risk assessments and where possible eliminate the risks or reduce them to tolerable levels.

7.5.8 From a design and construction perspective, The Construction (Design and Management) Regulations 2015 aim to ensure health and safety issues are appropriately considered during the development of construction projects. The overall goal is to reduce the risk of harm to those who have to build, use and maintain structures

7.5.9 It is clear even from the basic descriptions of the Statutory Instruments discussed previously that there is a fundamental, legal basis for employers to place high importance in the welfare of their employees and to drive the levels of risk to which they are exposed to levels that are As Low As Reasonably Practicable (ALARP)[11]. Aside from the ethical issues of failing to ensure that risks are ALARP, failure to comply could result in prosecution and if found guilty, a potentially large fine or imprisonment under the Health and Safety at Work etc. Act 1974 and the Management of Health and Safety at Work Regulations 1999.

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[11] "ALARP" is short for "as low as reasonably practicable". At the core is the concept of "reasonably practicable". This involves weighing a risk against the trouble, time and money needed to control it. Thus, ALARP describes the level to which the Health and Safety Executive (HSE) expects to see workplace risks controlled. *(http://www.hse.gov.uk/risk/theory/alarpglance.htm)*

7.5.10 Given the comprehensive process followed by NNB to establish a viable AFD system for the HPC cooling water system, and the conclusions drawn regarding reliability and effectiveness at this location, research and development requirements and difficulties maintaining the system, NNB is of the opinion that the requirement to implement the AFD system at HPC must be reassessed.

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APPENDIX A SAFETY AUDIT REPORT - OH2231-HPC-NNBGEN-XX-000-REP-100000

Report to: NNB Generation Company

Acoustic Fish Deterrent Health and Safety Review

Document Control Sheet

Identification	
Client	NNB Generation Company
Document Title	Acoustic Fish Deterrent Health and Safety Review
Bureau Veritas Contract No.	6468965

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Configuration				
Version	**Date**	**Author**	**Reason for Issue/Summary of Changes**	**Status**
A	27/11/2017	Yann Seral Matthew Baggaley	Early Draft for Client Comment	Issued
B	08/12/2017	Matthew Baggaley	Updated Draft for Client Comment	Issued
C	22/12/2017	Matthew Baggaley	Final Draft for Client Comment	Issued
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	Name	Job Title
Prepared By	Yann Seral Matthew Baggaley	Risk & Safety Engineer Principal Risk & Safety Consultant
Approved By	Mark Rogers	Principal Risk & Safety Consultant

Contents

Abbreviations

ABEX	Abandonment Expenditure
AFD	Acoustic Fish Deterrent
ALARP	As Low As Reasonable Practicable
BOP	Balance Of Plant
BSAC	British Sub Aqua Club
CAPEX	Capital Expenditure
CDM	Construction Design and Management
CDU	Controls Distribution Unit
CMPT	Centre for Marine and Petroleum Technology
CRS	Comments Response Sheet
CW	Cooling Water
DAN	Diving Alert Network
DCO	Development Consent Order
DEA	Danish Energy Agency
DRR	Design Risk Register
EA	Environment Agency
EDF	Électricité De France
FAR	Fatal Accident Rate
HAZID	Hazard Identification [Study]
HID	[HSE] Hazardous Installations Directorate
HPB	Hinckley Point B
HPC	Hinckley Point C
HSE	Health & Safety Executive
HYB	Heysham B
IRF	International Regulators’ Forum
IRPA	Individual Risk Per Annum
ISO	International Organization for Standardization
JIP	Joint Industry Project
MAIB	Marine Accident Investigation Branch
MIR	Major Injury Rate
MOM	Minutes Of Meeting
NCS	Norwegian Continental Shelf

NNB GenCo	Nuclear New Build Generation Company
OPEX	Operational Expenditure
PSA	Petroleum Safety Authority
QRA	Quantitative Risk Assessment
RIDDOR	Reporting of Injuries, Diseases and Dangerous Occurrences Regulations
ROV	Remotely Operated Vehicle
SCUBA	Self-Contained Underwater Breathing Apparatus
SZB	Sizewell B
TIR	Total Injury Rate
TOR	Tolerability Of Risk
UHMS	Undersea and Hyperbaric Medical Society
UKCS	United Kingdom
UKCS	United Kingdom Continental Shelf
UXO	Unexploded Ordnance
WOAD	Worldwide Offshore Accident Database

EXECUTIVE SUMMARY

Bureau Veritas has undertaken an independent review of the Hinkley Point C cooling water intake head Acoustic Fish Deterrent (AFD) optioneering work and associated safety documentation.

The review firstly aimed to provide an independent view as to the relative suitability of the selected design – in terms of safety risks – when compared to the other options under consideration during the optioneering phase.

The second purpose of the review was to quantify the safety risks of the selected design and assess these in comparison with industry standard tolerability thresholds.

The scope of the review included the risks associated with the construction, operation and maintenance of the selected AFD option.

This review has found that the optioneering work and supporting documentation has been produced by suitably qualified and experienced personnel with access to adequate input information and by applying appropriate methodologies. The safety risks of AFD maintenance are considered to be covered appropriately, however the documentation does not always reflect the high level of attention given to safety during the process and NNB GenCo may wish to strengthen the optioneering documentation to more clearly detail how due consideration was given to safety during the optioneering process.

This study has also found that fatality risks associated with the preferred AFD option are tolerable (if As Low As Reasonable Practicable – ALARP) based on HSE thresholds for individual risk of workers, with diving risks only marginally below the unacceptable risk threshold. This is considered to be a realistic estimate of the risk which is, out of necessity given the paucity of activity-specific and location-specific historical accident data, based on some assumptions which are neither unduly cautious nor overly optimistic. It is recommended to carry out further sensitivity analysis and a calculation of the AFD decommissioning risks in order to provide a more complete picture of the plant life risks.

The findings of this review are summarised as:

Reference	Detail
Finding 1	If the AFD system is to be further developed, ROV technologies and capabilities should be continually reviewed to establish if diving activity can feasibly be reduced/eliminated, and the safety risk analyses carried out should consider the most likely viable solution, either diving or ROV (or a combination).
Finding 2	If any future detailed safety analysis is conducted regarding the AFD, it is recommended that a more detailed risk matrix is defined and quantified risk criteria applied to facilitate more accurate evaluations of risk.

Reference	Detail
Finding 3	The safety risks of AFD maintenance are considered to be covered by appropriate safety-based scoring criteria with scoring supported by HAZID analysis. The documentation of this process in the Optioneering Report, however, does not reflect the high level of attention given to safety during the process. NNB GenCo should consider strengthening the optioneering documentation to more clearly detail how due consideration was given to safety during the optioneering process.
Finding 4	If the AFD system is to be further developed, a HAZID action close-out report should be produced to ensure that proper implementation and follow-up of actions has been carried out. Any other future risk assessment workshops should also adhere to this principle.
Finding 5	NNB GenCo should define its own corporate risk tolerability criteria and assess the calculated risk levels in this report against those criteria.
Finding 6	For the preferred AFD option divers are the most at risk worker category and diving risk during AFD installation and maintenance is the major contributor to overall fatality risks in all activities that involve at least some diving.
Finding 7	For the preferred AFD option all offshore workers will be subjected to individual risks of fatality per annum of less than 10^{-3}, with divers subjected to 9.2×10^{-4}.
Finding 8	Over the course of a 70 year plant lifetime it is estimated that NNB GenCo can expect 0.39 fatal injuries associated with AFD installation, maintenance and operation.

1 BACKGROUND

Nuclear New Build Generation Company (NNB GenCo), which is a subsidiary of EDF (Électricité de France), is planning to build two new nuclear power reactors at Hinkley Point in Somerset, collectively known as Hinkley Point C. The new power station will abstract seawater from the Bristol Channel for use as cooling water.

Each reactor is cooled by one cooling water pumping station fed by its own intake tunnel. Each intake tunnel comprises two seabed intake heads located approximately 3.5 km offshore. The intake heads are concrete structures sitting on the seabed and are designed to reduce the seawater intake velocity. The water depth at the intake heads ranges from 6m to 23m dependant on the state of the tide.

To reduce fish impingement, and in application of Environment Agency (EA) guidance, an Acoustic Fish Deterrent (AFD) system has been designed to mitigate fish entry into the cooling water intake. The AFD system deflects fish away from the intake heads by emitting high frequency sound signals which cause the fish to swim into adjacent streamlines and be taken safely past the intake head. Several AFD designs were considered in an optioneering study, concluded at the end of 2016, which resulted in the selection of a preferred design. The installation of the AFD is a condition of the Development Consent Order (DCO).

The environment in the Bristol Channel is particularly challenging for the installation, operation and maintenance of the AFD system owing to the distance from the shore and the environmental conditions; in particular highly turbid water (low-no visibility), very large tidal range and strong currents. Therefore several studies have been commissioned by NNB GenCo since the DCO was granted, alongside the optioneering, in order to assess the health and safety risks associated with installation, operation and maintenance of the AFD system.

The purpose of this report is to review the risk analysis undertaken by/for NNB GenCo to determine whether all safety risks associated with the installation, operation and maintenance of the AFD system have been identified, quantified and are acceptable taking into account the intended operation and environmental conditions. This study will enable NNB GenCo to make informed decisions about the works associated with the AFD system.

2 APPROACH

This report appraises the safety risks associated with the installation, operation and maintenance of the preferred AFD design solution, considering the hazards associated with working in the marine environment of the Bristol Channel.

The work includes an independent review of the hazard identification documentation generated by/for NNB GenCo during the optioneering phase, to provide a view as to the relative suitability of the selected design – in terms of safety risks – when compared to the other options under consideration during the optioneering phase. The work also includes a quantitative assessment of the potential for occupational injuries or fatalities associated with construction, maintenance and operation of the preferred AFD design based on historic accident data for similar activities, and a comparison of the risks with industry standard tolerability thresholds.

The two principal questions addressed by this review are:

1. Was the AFD optioneering study and supporting documentation carried out in a reasonable manner, based on sensible selection criteria and with a defensible conclusion?
2. Are the quantified risks of the preferred AFD design As Low As Reasonable Practicable (ALARP) and reasonable in comparison with tolerable individual risk thresholds?

The following sections outline the main activities undertaken in order to answer the questions above.

2.1 Appraisal of Optioneering Safety Risk Documentation

A number of documents have been provided to Bureau Veritas for review. These documents record the methodology and safety/operability basis underpinning the choice of the preferred AFD design. The safety analyses in these documents have been reviewed to provide an independent judgment on the acceptability of the safety risks associated with the preferred AFD design, in comparison with the other designs considered during the optioneering phase.

The review has focused on the following three key documents:

- HPC-OH2231-U9-HPT-PLN-100003 Rev 2 – Hinkley Point C - Acoustic Fish Deterrent System Optioneering Phase Hazid Output Report [Ref. 1];
- HPC-OH2231-U9-HPT-REP-100007 Rev 4 – Acoustic Fish Deterrent System – Optioneering Report [Ref. 2]; and
- OH2231-HPC-NNBPCP-XX-000-REP-100000 Version 2.0 – Acoustic Fish Deterrent System - Health and Safety Assessment [Ref. 3].

These documents are hereafter referred to, respectively, as the HAZID Study Report, the Optioneering Report and the Health and Safety Assessment Report.

For each of the three key review documents [Ref. 1, 2 and 3], the examination included the following elements:

- Review of the study inputs, methodology and results;
- Review of scoring criteria and weighting used as the basis for the selection criteria applied to the different options (Optioneering Report [Ref. 1]);
- Review of the close-out of actions and recommendations resulting from the report, and a check on the adequacy of action implementation;
- Issue of technical comments and clarifications from Bureau Veritas to NNB GenCo; and
- Issue of findings where necessary (included in Section 3.1).

The document review focused particularly on a qualitative assessment of the weighting and scoring applied to the safety related selection criteria for the different options analysed. Engineering details described in the document (i.e. technical descriptions, construction and operational requirements, discussions of maintenance considerations that could affect the AFD system, CAPEX and OPEX cost summaries) were used as supporting information to carry out the review of weighting and scoring, however, a detailed engineering review was not part of the scope of work.

The document review was carried out as a desktop exercise. The review of each key document resulted in requests for clarifications and comments as deemed necessary. These were recorded in the form of comment response sheets which are included in Appendix A.

2.2 Quantification of Safety Risks for the Preferred AFD Design

The approach to quantifying the risk of the preferred AFD design involved two main activities:

- Gathering information about the construction, maintenance and operation of the AFD in order to identify the likely contributors to safety risks and exposure to occupational hazards; and
- Calculating individual risks for AFD construction, maintenance and operation based on standard risk metrics and historic accident data for similar activities.

The approaches to these activities are outlined in the following sections.

2.2.1 Information Gathering

To commence the information gathering process Bureau Veritas attended and participated in a one day HAZID Review Workshop run by Costain in Manchester on 21 September 2017. The aim of the HAZID was to identify hazards to people and assets that could credibly arise during the installation and maintenance of the AFD. The primary purpose of Bureau Veritas attendance at this workshop was to develop a better understanding of the AFD project prior to undertaking the document review and other activities summarised in this report.

Concurrently with the document review described in Section 2.1, Bureau Veritas facilitated a one day 'AFD Risks/Resources Workshop' at the NNB GenCo office in Bristol on 08 November 2017 with the aims of:

- Quantifying the resources required to support the installation, operation and maintenance activities associated with the AFD system, including risks associated with/from anchoring, depth of water, vessels, divers and ROVs involved in the maintenance operations; and
- Discussing the operations with marine and diving/ROV contractors with actual operating experience within the Bristol Chanel to acknowledge any lessons learnt from marine/ROV/diver operations carried out in the Bristol Channel or similar environments.

The workshop was attended by the participants listed in Table 1. After the workshop the records were reviewed by Bureau Veritas Subsea Engineer Jorge Ramirez Penayo who made some additions based on his experience.

Table 1 AFD Risks/Resources Workshop

Name	Company	Role
Yann Seral	Bureau Veritas	Chair
Matthew Baggaley	Bureau Veritas	Scribe
Olivier Gauvrit	NNB GenCo	Heat Sink/BOP Program Engineering Lead
Ross Pettigrew	NNB GenCo	Environmental Technical Manager
Jonathan Jones	NNB GenCo	CDM Advisor
David McKenna	Costain	Offshore and Marine Rep
Adrian Jones	Costain	Project Manager
Angus Reid	Costain	Engineering Manager

During the workshop, information regarding the installation, operation and maintenance of the preferred AFD design was reviewed to determine the activities required to be conducted offshore during each phase. These activities were cross-referenced with the analysis in the HAZID Report [Ref. 2] to provide context in terms of the hazards, consequences, safeguards and ranked risks. Against each activity, the workshop team discussed the likely duration (based on the limiting environmental conditions such as tides, waves and currents) and frequency of the offshore operations (based on the amount of work involved) and how many crew members would be required. The team also recorded lessons learned from previous diving campaigns carried out at HPC.

The workshop conclusions were documented in a worksheet format and are attached in Appendix B. Discussion of the workshop results is covered in Section 3.2.

2.2.2 Risk Quantification Based on Historic Accident Data

The information regarding the construction, maintenance and operation activities associated with the preferred AFD design – as gathered during the document review and AFD Risks/Resources Workshop – was used to identify the hazardous activities to which crew will be exposed, and the frequency and duration of the exposure. The next step in the quantification of individual risks associated with these activities was to combine these frequencies and durations with the equivalent accident frequencies based on historic reported data.

A literature search of relevant accident and incident databases was conducted to determine the historic frequencies of these occurrences. The intention was to, where possible, select activity-specific, sector-specific and location-specific accident data for the analysis, however, it was found that this level of detail was not available in the literature reviewed for this study. Thus, more generic accident frequencies for categories of offshore operations/workers have been used. Where data were not present in the literature, equivalent data based on correlations have been used.

Bureau Veritas has investigated the following sources of accident data:

- HSE ORION Database;
- HSE Research Reports;
- Petroleum Safety Authority (Norway) Accident Data;
- Petroleum Safety Authority DSYS Database;
- Danish Energy Agency EASY Database;
- International Regulators' Forum Annual Performance Statistics;
- Worldwide Offshore Accident Databank (WOAD);
- Marine Accident Investigation Branch Investigation Reports;
- British Sub Aqua Club Diving Reports;
- Safetec Decommissioning Risk JIP;
- CMPT Offshore QRA Guide; and
- Diving Alert Network Accident Data.

3 ANALYSIS

3.1 Appraisal of Optioneering Safety Risk Documentation

Table 2 presents the list of documents formally reviewed as part of this study, and the corresponding comments response sheet (CRS). The CRSs were issued in order to make clarifications and further information requests based on the reviewed documents. The latest revisions of the comment response sheets are attached in Appendix A.

Table 2 Comment Response Sheets Statuses

Document Title	Document Reference	CRS Reference	CRS Status[1]
AFD System Optioneering Report [Optioneering Report]	HPC-OH2231-U9-HPT-REP-100007 (Rev 4) [Ref. 1]	RRM/17/00219 Rev.0	VI
Acoustic Fish Deterrent System - Optioneering Phase HAZID Output Report [HAZID Study Report]	HPC-OH2231-U9-HPT-PLN-100003 (Rev 2) [Ref. 2]	RRM/17/00217 Rev.0	VI
AFD – Health and Safety Assessment [Health and Safety Assessment Report]	OH2231-HPC-NNBPCP-XX-000-REP-100000 (Version 2.0) [Ref. 3]	RRM/17/00218 Rev.0	VI

Note 1 VI - Report reviewed. No comments pending.

The review of these documents focused on the inputs, methodology and results of each report with the emphasis on safety-related aspects. It also included the verification of the close out of actions and recommendations resulting from the reports. The detailed conclusions of the review are presented below.

3.1.1 Inputs Review

3.1.1.1 HAZID Study Report [HPC-OH2231-U9-HPT-PLN-100003]

In a HAZID study the level of detail of the study is in accordance with the level detail of the input data available. For this HAZID study, the reference documents are judged to be detailed enough to allow identification of the main hazards related to the different AFD options under consideration.

In addition to the input documents, the level of success from the HAZID workshop is largely dependent upon the personnel participating and their knowledge of the subject. Bureau Veritas was not present during the workshop to confirm the active involvement of experienced team members, however, based on the list of participants it appears that the team was composed of specialists in the main areas concerned (design, construction, subsea controls and structure).

3.1.1.2 Optioneering Report [HPC-OH2231-U9-HPT-REP-100007]

The Optioneering Report was reviewed from a safety point of view, and the list of options for each subsystem was found to be exhaustive. The design descriptions for the different solutions were found to be detailed enough to support a thorough analysis.

It must be noted that during the optioneering process a general assumption that Remotely Operated Vehicles (ROVs) would be employed for subsea AFD maintenance activities was applied based on early engagement with an ROV supplier. Subsequent investigation concluded, however, that ROV technology may not be advanced enough at present to make it a viable solution, and that the only established option would involve divers.

Finding 1	If the AFD system is to be further developed, ROV technologies and capabilities should be continually reviewed to establish if diving activity can feasibly be reduced/eliminated, and the safety risk analyses carried out should consider the most likely viable solution, either diving or ROV (or a combination).

3.1.1.3 Health and Safety Assessment Report [OH2231-HPC-NNBPCP-XX-000-REP-100000]

The HAZID Study Report and the Optioneering Report were the main input references used for the Health and Safety Assessment. The level of detail of the input documents is judged to be adequate given that the Health and Safety Assessment Report’s purpose is to summarise the health and safety arguments underpinning the AFD preferred design selection.

This report goes into some detail about the harsh environmental conditions in the Bristol Channel and the impacts these have on operations such as maintenance.

3.1.2 Methodology Review

3.1.2.1 HAZID Study Report [HPC-OH2231-U9-HPT-PLN-100003]

The methodology adopted during the HAZID workshop was in accordance with the good practices usually applied in the industry and was in line with typical standard used for HAZID study such as ISO 17776:2016 ‘Petroleum and natural gas industries - Offshore production installations - Major accident hazard management during the design of new installations’ [Ref. 6].

The list of guidewords used to help the hazard identification process was exhaustive and specific to the facilities studied.

The HAZID study considered consequences of personnel safety, environmental impact and asset damage which is in line with the approach applied in the industry.

The risk matrix applied during the HAZID risk ranking process was simplified (three levels of severity and three level of likelihood) compared to the one proposed in ISO 17776 [Ref. 6]. This simplification inevitably leads to a coarse estimation of risk, however, the choice of risk matrix is justified considering the early stage of the project as well as the qualitative nature of the study.

Finding 2	If any future detailed safety analysis is conducted regarding the AFD, it is recommended that a more detailed risk matrix is defined and quantified risk criteria applied to facilitate more accurate evaluations of risk.

Note that an additional HAZID workshop for the preferred AFD option has subsequently been carried out at the end of concept design focusing on the main safety risks associated with diving operations.

3.1.2.2 Optioneering Report [HPC-OH2231-U9-HPT-REP-100007]

The optioneering process relies on a scoring system based on several criteria, with the values then aggregated into a final score based on criteria weighting. The criteria (drivers), scoring scale and weighting methodology are defined in Appendix 1 of the Optioneering Report. The selected criteria (drivers) cover different considerations of the AFD options ability to:

- Provide a solution minimising the impact on water inlet head (CAPEX / schedule);
- Provide a maintainable solution to minimise OPEX / ABEX;
- Provide a solution which maximises the AFD system availability;
- Provide a solution which maximises the performance of the AFD system to deter fish;
- Provide a solution with minimal impact on the water inlet head hydraulics;
- Provide a solution which minimises CAPEX;
- Provide a solution which maximises expandability / future proofing;
- Provide a solution which has a good track record / minimal risk; and
- Provide a solution with minimal impact to other users / environment.

Consideration of risks associated with the proposed AFD options is covered under two criteria:

- ‘Provide a solution which has a good track record / minimal risk’. This criterion is focused on risks associated with the technology itself and does not explicitly take into account the safety risks associated with the installation, maintenance and operation of the system.
- ‘Provide a maintainable solution to minimise OPEX/ABEX’. This criterion is presented in the ‘Appraisal of Options’ report [Ref. 5] with a ranking of 25%, and is carried forward into the Optioneering Report. On the surface, this criterion appears to be focused on cost, however the associated scoring includes safety impacts with the following scoring:

0: Not acceptable / Intolerable	High likelihood of unsafe activities leading to loss of life
1: Least favourable	High likelihood of unsafe activities leading to loss of life / OPEX costs greater than average +40%
2: Fails to satisfy most requirements	Moderate likelihood of unsafe activities leading to harm of personnel / OPEX Costs Average +10% to +40%
3: Neutral	Low likelihood of harm to personnel / Average OPEX Costs (+/-10%)
4: Satisfies most requirements	Low likelihood of any harm to personnel / OPEX costs -10% to -40% Average
5: Fully satisfies requirements	Low likelihood of any harm to personnel / OPEX costs better than average -40%

The combination of operational and abandonment costs with safety-based criteria is considered appropriate because both costs and safety risks are considered to scale positively with the amount of maintenance and abandonment activity required.

It was mentioned by NNB GenCo that HAZID findings were used as a part of the overall optioneering assessment (Refer to Item #2 of Comment Response Sheet RRM/17/00219 presented in Appendix A). The Optioneering process and Report were supported by the qualitative assessment of options produced by the HAZID workshop held in advance of the Optioneering workshop. Although Bureau Veritas believes this to be the case, the only documented record of how the HAZID findings were factored into the optioneering process is a statement in Section 11.4.2 that diving hazards were identified in the HAZID.

For the consideration of the electrical power hub, a specific criterion called ‘Provide a solution which maximises safety’ was employed with a high weighting of 30%. This driver was introduced because the criteria associated with the AFD and intake head are not relevant for the power hub and safety issues related to subsea transformers were found to be more critical.

Finding 3	The safety risks of AFD maintenance are considered to be covered by appropriate safety-based scoring criteria with scoring supported by HAZID analysis. The documentation of this process in the Optioneering Report, however, does not reflect the high level of attention given to safety during the process. NNB GenCo should consider strengthening the optioneering documentation to more clearly detail how due consideration was given to safety during the optioneering process.

In all other respects, the weighting process and overall scoring methodology was clearly described, practically applied and judged adequate for the purpose of the study. The weighting of existing criteria is judged to be sensible with the more critical criteria weighted with higher importance.

3.1.2.3 Health and Safety Assessment Report [OH2231-HPC-NNBPCP-XX-000-REP-100000]

The Health and Safety Assessment Report presents the main conclusions of the HAZID Report and Optioneering Report. Therefore there is no specific methodology to assess.

3.1.3 Results and Conclusions Review

3.1.3.1 HAZID Study Report [HPC-OH2231-U9-HPT-PLN-100003]

Findings of the HAZID workshop are recorded in HAZID worksheets offering a good level of detail and understanding of the hazards identified. However, as mentioned in Item #4 of the Comment Response Sheet RRM/17/00217 (presented in Appendix A), the follow-up of the actions issued during the workshop could not be verified as no close-out report has been issued.

An additional HAZID workshop for the preferred AFD option has subsequently been carried out at the end of concept design focusing on the main safety risks associated with diving operations. If AFD design development is to be continued, these HAZID studies will need to be revisited and actions will need to be closed out. To assist with this, NNB requested Costain to produce a Design Risk Register (DRR) to cover the different safety risk to mitigate through next phase of the design.

Finding 4	If the AFD system is to be further developed, a HAZID action close-out report should be produced to ensure that proper implementation and follow-up of actions has been carried out. Any other future risk assessment workshops should also adhere to this principle.

In Section 3 of the HAZID Study Report it is stated that non-subsea option 2 (jacket structure with topside electric system) was not assessed during the HAZID workshop because ‘the arrangement was considered to be the most complex, visually challenging and likely to be the most costly option’. However, this option was examined in the Optioneering Report as Option F. This solution was recognised as potentially safer owing to the limited need for underwater operations, but presented some challenges for personnel access to the platform, heavy lifting operations and greater environmental impact. Therefore, the conclusions from the HAZID Study Report and Optioneering Report are consistent in the sense that operational risks, cost and environmental impact appear preclude the non-subsea option, in addition to inferior sound field performance.

3.1.3.2 Optioneering Report [HPC-OH2231-U9-HPT-REP-100007]

Section 3.1.2 of the Optioneering Report refers to a pre-optioneering solutions screening exercise [Ref. 5]. When comparing the two documents it was found that the structure solution numbers and descriptions do not match exactly, which complicates the verification that the findings from the Pre-Optioneering Report were carried over to the Optioneering Report. For example, as can be seen from Table 3, the Pre-Optioneering Report and Optioneering Report AFD structure options numbering (denoted by S1, S2 etc.) are inconsistent with different option titles. Furthermore, the nomenclature then changes (to Option A, Option B etc.). Nonetheless, Table 3 shows that the selected solutions in the Pre-Optioneering Report were all taken forward in various forms for further consideration in the Optioneering Report.

For each option examined, a summary of the advantages and disadvantages was listed. This approach facilitates the process of screening out the options before the scoring process (e.g. Options E discarded based on few advantages and more disadvantages compared to the other solutions). The overall advantage/disadvantage summary for each option was found to be in line with the description of the proposed design and the decision to take forward (or not) to the scoring process was sensible with the highlighted advantage/disadvantage items.

The final decision on the selected solution was in accordance with the stated scoring methodology and results, and the design development work subsequently carried out [Ref. 4] addresses the recommendations for further work made in the Optioneering Report.

Table 3 AFD Structure Options Investigated

Pre-Optioneering Report [Ref. 5 Section 10.1]		Optioneering Report [Ref. 1 Section 3.1.2]	Optioneering Report [Ref. 1 Section 6]	Optioneering Report [Ref. 1 Section 6] and Design Development Review [Ref. 4]
Option Title	**Status**	**Options to Assess**	**Options Assessed**	**Optioneering Outcome**
S1 – Subsea Structures - Diver Intervention	Carry forward to optioneering	S1 – Subsea Structures - Diver Intervention	Option A – Subsea Structures – Gravity Base	Screened out by weighted scoring
			Option B – Subsea Structures – Attached to Water Intake Heads B1 - Mounted on a beam run on posts cast into the base B2 - Discrete structures run onto posts cast into the base B3 - Connected to the lifting points B4 - Connected to the pile caps	Option B2 selected initially in Optioneering Report **Option B5 selected finally in Design Development Review**
			Option C – Subsea Structure – Piled	Screened out by weighted scoring
S2 – Subsea Structures - ROV Intervention	Carry forward to optioneering	S2 – Subsea Structures - ROV Intervention	Option A – Subsea Structures – Gravity Base	Screened out by weighted scoring
			Option B – Subsea Structures – Attached to Water Intake Heads B1 - Mounted on a beam run on posts cast into the base B2 - Discrete structures run onto posts cast into the base B3 - Connected to the lifting points B4 - Connected to the pile caps	Option B2 selected initially in Optioneering Report **Option B5 selected finally in Design Development Review**
			Option C – Subsea Structure – Piled	Screened out by weighted scoring

Pre-Optioneering Report [Ref. 5 Section 10.1]		Optioneering Report [Ref. 1 Section 3.1.2]	Optioneering Report [Ref. 1 Section 6]	Optioneering Report [Ref. 1 Section 6] and Design Development Review [Ref. 4]
Option Title	**Status**	**Options to Assess**	**Options Assessed**	**Optioneering Outcome**
S3 – Equipment Retrievable to a Surface Platform	Carry forward to optioneering	S3 – Speakers retrievable to the surface, electrical components subsea	Option E – Subsea Structure – Piled (Mid Height)	Screened out by weighted scoring
		S4 – Speakers retrievable to surface, electrical components on surface	Option D – Non-Subsea Structure – Piled	Screened out by weighted scoring
			Option F – Non-Subsea Structure – Lattice / Jacket	Screened out by weighted scoring
		S8 – Speakers mounted on rack structure at side of inlet head, recovered to surface platform	Option D – Non-Subsea Structure – Piled	Screened out by weighted scoring
			Option E – Subsea Structure – Piled (Mid Height)	Screened out by weighted scoring
			Option F – Non-Subsea Structure – Lattice / Jacket	Screened out by weighted scoring
S4 – Speakers Mounted on Structure, Recovered to Vessel at Low Tide	Carry forward to optioneering	S9 – Speakers mounted on rack structure of side of inlet head, recovered to vessel at low tide	Option E – Subsea Structure – Piled (Mid Height)	Screened out by weighted scoring
S5 – Speakers suspended from subsea buoy	Screened out	S5 – Speakers suspended from subsea buoy	[NOT INVESTIGATED]	[NOT INVESTIGATED]
S6 – Speakers Suspended from a Floating Buoy	Screened out	S6 – Speakers suspended from a floating buoy	[NOT INVESTIGATED]	[NOT INVESTIGATED]
S7 – Speakers on Articulated Arms	Screened out	S7 – Speakers on articulated arms	[NOT INVESTIGATED]	[NOT INVESTIGATED]

Pre-Optioneering Report [Ref. 5 Section 10.1]		Optioneering Report [Ref. 1 Section 3.1.2]	Optioneering Report [Ref. 1 Section 6]	Optioneering Report [Ref. 1 Section 6] and Design Development Review [Ref. 4]
Option Title	**Status**	**Options to Assess**	**Options Assessed**	**Optioneering Outcome**
S8 – Speakers Mounted on Tie-bars Cast into Inlet Head	Screened out	[NONE]	[NOT INVESTIGATED]	[NOT INVESTIGATED]
S9 – Speakers supported from barge	Screened out	S11 – Speakers supported from barge	[NOT INVESTIGATED]	[NOT INVESTIGATED]
S10 – Modify inlet head nose to incorporate AFD	Screened out	S12 – Modify inlet head nose to incorporate AFD	[NOT INVESTIGATED]	[NOT INVESTIGATED]
S11 – Speakers Mounted on Top of Inlet Head Seal	Screened out	S14 – Speakers Mounted on Top of Inlet Head Seal	[NOT INVESTIGATED]	[NOT INVESTIGATED]
[NONE]	N/A	S13 – Speakers installed on underside of inlet head seal cover	[NOT INVESTIGATED]	[NOT INVESTIGATED]

3.1.3.3 Health and Safety Assessment Report [OH2231-HPC-NNBPCP-XX-000-REP-100000]

The conclusions of the Health and Safety Assessment Report are in line with the HAZID Study Report and Optioneering Report findings.

The Health and Safety Assessment Report made a recommendation to carry out more detailed risk assessment (including quantitative risk assessment) which is in line with Finding 2 of this review. This recommendation has already been actioned by NNB commissioning additional studies with Costain on diving/moorings (not reviewed by Bureau Veritas as this was in development concurrently with this study). In addition, NNB has engaged Bureau Veritas to quantitatively assess the health and safety risks of the preferred AFD option (one of the purposes of this report – see Section 3.2).

If the AFD system is to be further developed, the different health and safety risks listed during the concept design will need to be fully reviewed as part of the detailed design phase.

3.2 Quantification of Safety Risks for the Preferred AFD Design

3.2.1 Exposure to Hazards

The AFD Risks/Resources Workshop produced a list of activities required to be conducted offshore during construction, maintenance and operation of the AFD system. Against each activity, the workshop team recorded the expected duration and frequency of the offshore operations and how many crew members would be required. This enables an estimate to be made as to the frequency and duration of exposure to the offshore hazards.

The workshop records are attached in Appendix B, and the main outcomes in terms of activities and exposures are summarised in Table 4.

Table 4 AFD Offshore Activities

Phase	Task	Notes
Installation	Vessel mobilisation and transit	A dive crew of 10 per shift is required comprising: Up to 5 x divers • Dive supervisor • Dive technician • Offshore superintendent • Rigger • Daughter craft coxswain Therefore, a dive crew of 20 would be required for 24 hour operations. 2 vessels are required, 1 for welfare facilities for workers. 1 week preparation time at the harbour. The sail time is 2.5 hours (from Newport). Several trips are required, or the support vessel might do these trips back to the harbour.
	Installation of Base Frames	2 divers in the water max at any given time. 1 support diver on deck ready for intervention. ~1 hour dive duration. ~1 day per structure (3 structures per side, 2 sides per head) = 6 days of diving time per head (mooring either side of this period) Divers rotate duties (team of 2 swap for another team of 2; the support diver can remain in support) There will be an initial survey dive before installation commences as well. It is thought that each head can be done in one visit from harbour to the work site.
	Installation of Sound Projector Cluster Frames	2 divers in the water max at any given time. 1 support diver on deck ready for intervention. ~1 hour dive duration. ~1 day per cluster (6 clusters per side, 2 sides per head) = 12 days of diving time per head (mooring either side of this period) Divers rotate duties (team of 2 swap for another team of 2; the support diver can remain in support) There will be an initial survey dive before installation commences as well. Each head requires 2 visits in total.

Phase	Task	Notes
	Power / Communication Cable Installation	2 divers in the water max at any given time. 1 support diver on deck ready for intervention. ~1 hour dive duration. For the two CDUs, 2 dives per CDU required. For the EFLs, based on the clipping option of cable fixing, this could be one trip by itself. ~1 day per jumper lead (6 jumpers per side) = 12 days of diving time per head (mooring either side of this period) - this requires 2 visits in total. Divers rotate duties (team of 2 swap for another team of 2; the support diver can remain in support) There will be an initial survey dive before installation commences as well. Total of 3 visits are envisaged per head (but there is a chance this could possibly be done in 2 x 6 day visits).
Commissioning	Commissioning sound survey	The only other considerations during operations are a sound survey to confirm AFD function in comparison to the predictive modelling (carried out by side scanning from a vessel). No other AFD interventions offshore (in addition to those already covered above) are envisaged.
Maintenance	Sound projector replacement	2 divers in the water max at any given time. 1 support diver on deck ready for intervention. ~1 hour dive duration. ~1 day per cluster (6 clusters per side, 2 sides per head) = 12 days of diving time per head (mooring either side of this period) Divers rotate duties (team of 2 swap for another team of 2; the support diver can remain in support) There will be an initial survey dive before installation commences as well. Each head requires 2 visits in total.
	Visits to the power hub for AFD power isolation	Visits to the offshore hub to isolate the power supply to the AFD being maintained. See Power Hub sheet, 'Regular maintenance at the power hub (supply boat)' for details of a single trip, one person.

Phase	Task	Notes
	Electrical cable replacement (and CDU replacement)	Only CDUs and flying leads covered in this analysis. 2 divers in the water max at any given time. 1 support diver on deck ready for intervention. ~1 hour dive duration. For the two CDUs, 4 days per CDU required. Maintenance once/twice in the life of the plant. This can be done in 1 visit per head. For the EFLs, based on the clipping option of cable fixing. ~2 day per jumper lead (6 jumpers per side) = 24 days of diving time per head (mooring either side of this period) - this requires 4 vessel visits in total. Maintenance once/twice in the life of the plant. Divers rotate duties (team of 2 swap for another team of 2; the support diver can remain in support) There will be an initial survey dive before installation commences as well. Total of 5 visits is envisaged once/twice during plant lifetime (per head).
	Visits to the power hub for AFD power isolation	Visits to the offshore hub to isolate the power supply to the AFD being maintained. See Power Hub sheet, 'Regular maintenance at the power hub (supply boat)' for details of a single trip, one person.

The offshore workforce involved in these activities has been split into three categories Divers, Boat Crew/Dive Support Crew and Offshore Maintenance (Power Hub Maintenance) with the following definitions:

- **Divers**: Workers undertaking manned underwater operations (surface-oriented diving) from the moored AFD construction/maintenance vessel;
- **Boat Crew/Dive Support Crew**: Workers undertaking dive support and critical marine functions who remain on the boat at all times; and
- **Offshore Maintenance**: Workers whose primary purpose is to undertake regular maintenance activities on the Power Hub platform, including power isolation/deisolation prior to/after AFD maintenance diving.

To calculate the overall risks experienced by individuals in these work categories there needs to be a quantification of the risks for the activities presented in Table 5. Note that the risk categories in Table 5 refer to ‘injury’; the likelihood of an injury will depend on the severity of the injury. For example, the likelihood of a fatality for a given occupational activity is usually less than the likelihood of a minor injury. Risk metrics are discussed in more detail in Section 3.2.2.

Table 5 Applicable AFD offshore risk metrics for worker categories

Activity	Divers	Boat Crew / Dive Support	Offshore Maintenance
Risk of injury during vessel transit	✓	✓	✓
Risk of injury per fendering operation (to Power Hub)			✓
Injury rate per hour on a moored boat	✓	✓	✓
Injury rate per hour offshore on Power Hub			✓
Injury rate per hour in the water / Risk of injury per dive	✓		

The journey to and from the intake heads by boat provides a source of risk of accidental death for all of the offshore workers. In particular, the ongoing maintenance of the AFD involves a significant numbers of visits, so that transport becomes a significant source of risk in addition to the hazards of the maintenance operation itself, which may be relatively low for those not engaged in the diving operations.

The maintenance workers transferring to the Power Hub for maintenance and/or to isolate/deisolate power supplies to the AFD spend some time on the boat and some time on the Power Hub; they will have a risk profile proportional to the time spent on each stage. They will also have an additional risk contribution from the transfer fendering operation which must be accounted for.

Divers will be undertaking the riskiest activity offshore. This can be quantified either by a ‘risk per dive’ or by a ‘risk per hour diving’ metric. It must be noted that the environment in the Bristol Channel is particularly challenging for diving activities owing to the highly turbid water (causing low/no visibility), very large tidal range and strong currents. These factors compound the risks associated with diving.

3.2.2 Risk Metrics

Occupational accidents for offshore workers include a wide variety of events, such as falls from height, falling overboard, diving accidents, mechanical impacts, burns, electrocution, asphyxiation etc. Accidents to divers and to attendant vessel crew are usually classed as occupational accidents since they usually result in only one or two fatalities at a time (and are therefore not classed as major accidents) and result directly from the offshore work.

Fatality risks from personal accidents are normally expressed in the form of a Fatal Accident Rate (FAR), defined as the number of fatalities per 10^8 exposed hours:

$$FAR = \frac{Fatalities \times 10^8}{Manhours\ Exposed}$$

Exposed hours in this report are taken to be the hours spent offshore undertaking the activities (i.e. time on duty). In some references the hours of exposure are taken to be the entire time workers are offshore (including times not on duty); this approach makes the fundamental assumption that the risk of fatalities in an occupational group is proportional to the number of workers and the amount of time spent offshore. This may be a valid assumption for boat crew and maintenance crew, however, FARs for divers may not be representative because diving risks are high for short periods spent in the water and much lower for the remaining time spent offshore. For this reason, diving risks are better estimated based on measures of diving activity such as FAR per hour in the water (as expressed in the equation above), or FAR per dive.

The risks of major injuries and lost time incidents may be quantified in a similar fashion to FAR; these metrics are designated Major Injury Rate (MIR), Over-3-Day Lost Time Injury Rate (O3DIR) and Total Injury Rate (TIR).

Where one of these metrics is not presented for a dataset in the literature it may be possible to derive it based on other metrics which are given by using pyramid factors. This approach asserts that for every fatality there is a proportional number – a fixed ratio – of major injuries and over-3-day injuries. This means that the number of fatal accidents can be estimated from information about the number of accidents with less severe consequences.

For the purposes of this study the focus is on fatality risks, with lesser severity risks presented only where they provide useful safety insights.

3.2.3 Risk Tolerability Criteria

The HSE has set out its tolerability of risk (TOR) framework for reaching decisions on whether risks from an activity or process are unacceptable, tolerable (if ALARP) or broadly acceptable in its R2P2 publication [Ref. 50]. These three risk categories have the following definitions:

- **Unacceptable:** For practical purposes, a particular risk falling into this region is regarded as unacceptable whatever the level of benefits associated with the activity. Any activity or practice giving rise to such risks would, as a matter of principle, be ruled out unless the activity or practice can be modified to reduce the degree of risk to a level that is outside this region;

- **Broadly acceptable:** Risks falling into this region are generally regarded as insignificant and adequately controlled. The HSE, as a regulator, would not usually require further action to reduce risks at this level unless reasonably practicable measures are available. The levels of risk characterising this region are comparable to those that people regard as insignificant or trivial in their daily lives; and

- **Tolerable if ALARP:** Risk levels between the unacceptable and broadly acceptable thresholds are classed as tolerable if ALARP. Risks in this region are typical of the risks from activities that people are prepared to tolerate in order to secure benefits (e.g. employment). 'Tolerable' does not mean 'acceptable'. It refers instead to a willingness by society as a whole to live with a risk so as to secure certain benefits and in the confidence that the risk is one that is worth taking and that it is being properly controlled.

For workers, the thresholds between these categories are defined for Individual Risk Per Annum of fatality (IRPA) as 1 x 10^{-6} for tolerable/broadly acceptable and 1 x 10^{-3} for tolerable/unacceptable.

An individual risk of death of 1 x 10^{-3} per annum represents the boundary between what could be just tolerable for any substantial category of workers for any large part of a working life, and what is unacceptable for all but fairly exceptional groups.

The HSE TOR framework is based on the method originally applied by the HSE to the control of risk at nuclear power stations, originally published in 1988 as ‘The Tolerability of Risks from Nuclear Power Stations (TOR)’. The TOR framework remains the applicable to workers in all industries today.

In the absence of a NNB GenCo corporate risk tolerability criterion, the HSE’s 1 x 10^{-3} ‘unacceptable’ threshold is therefore used as the principal comparator in this study.

Finding 5	NNB GenCo should define its own corporate risk tolerability criteria and assess the calculated risk levels in this report against those criteria.

3.2.4 Risk Data

Occupational related accidents and incidents offshore are mainly notified to national regulatory authorities based on local legislative requirements, and collated and reported at a national level. The focus is usually given to accidents resulting in fatalities or major/minor injuries, with near misses not always reported. The national regulatory authorities often publish reports on accidents with statistical data and lessons learned, but do not usually allow access to the underlying data. There are also industry bodies and other governmental departments which have particular responsibilities for gathering accident data.

Bureau Veritas has made use of several sources of historic accident data to calculate individual risks when exposed to the AFD activities for the categories in Table 5. These sources and their useful data are summarised in the following sections.

While efforts have been made to identify relevant accident statistics specific to the AFD activities, the industry/sector and the location, it was found that this level of detail was not available in the literature reviewed for this study. Thus, more generic accident frequencies for categories of offshore operations/workers have been used. Where data were not present in the literature, correlations have been used to derive equivalent data given appropriate assumptions which are considered neither unduly cautious nor overly optimistic

The Bristol Channel is particularly challenging for diving activities owing to the high turbidity (causing low/no visibility), very large tidal range and strong currents. Similarly, the proximity to live intake heads (entrainment hazard), mooring lines and other structures (snagging hazards) are likely to make the diving operations more hazardous than most other dives which are represented in the historical accident data. Some of the generic risk statistics are therefore considered likely to be underestimates and safety factors have been used to account for these compounding elements.

HSE ORION Database

The HSE is responsible for regulating health and safety matters offshore in the UK. The HSE works with other regulators under Memorandums of Understanding and agency agreements where there are potential overlaps in responsibilities.

The reporting requirements for UK Continental Shelf (UKCS) offshore operations mean that the main source for accident and incident information for the UKCS offshore industry should be the HSE's ORION database. Access to ORION is not possible for the public, however the HSE publishes reports and safety bulletins each year with statistics based on ORION data [Ref. 9-17]. These Offshore Injury, Ill Health and Incident Statistics reports provide annual statistical summaries of accidents and incidents on UK offshore installations reported under the Reporting of Injuries, Diseases and Dangerous Occurrences Regulations 2013 (RIDDOR).

The RIDDOR data include incidents occurring on:

- Offshore installations;
- Offshore wells and activities in connection with them;
- Offshore pipelines, pipeline works and certain activities in connection with pipeline works;
- Offshore wind farms; and
- Offshore diving operations.

Of particular use for this study are the overall injury rates in Table 6 and the activity-specific statistics in Table 7. Note that the FAR given by the HSE [Ref. 9-17] is per 100,000 employees, whereas FAR is typically based on per 10^8 hours exposed (as presented in Table 6). The conversion between the two metrics is simple because the HSE data are based on an average individual exposure of 2000 hours per year with daily shifts of 12 hours.

Since 2014, these reports have taken a different format and name – Offshore Statistics & Regulatory Activity Report – and the new format doesn't provide the same tabulated data in Table 7. Note also that in 2012 the reporting year was changed to align with the calendar year whereas it was previously aligned with the financial year.

From the data in Table 6 we can derive the summary statistics in Table 8. The general offshore injury rates have improved significantly in recent years versus the 1995-2012 reporting periods, and the pyramid factors have remained similar. The 2012-2016 injury rates and pyramid factors are the most appropriate to use given that these are the most recent figures spanning a reasonable number of years. The average FAR for all offshore workers is calculated as 1.2 (per 10^8 hours).

From the data in Table 7 we can estimate the injury risks per dive based on an assumption of the number of diving operations carried out per year given in [Ref. 7] – these are presented in Table 9. The diving fatality rate is calculated as 6.5×10^{-6} per dive.

Table 6 HSE ORION data – injury rates for offshore workers (derived from [Ref. 8 & 9])

Reporting Year	Injuries and Dangerous Occurrences						Injury Rates (per 10^8 hours exposed)				
	Fatalities	Major injuries	Total fatalities & major injuries	Over-3-day injuries	Total Injuries	Dangerous occurrences	Workforce	Fatal injury rate	Major injury rate	Fatal + major injury rate	Over-3-day injury rate
1995/96	5	42	47	375	422	528	29,003	8.6	72.4	81.0	646.5
1996/97	2	44	46	302	348	569	26,853	3.7	81.9	85.7	562.3
1997/98	3	74	77	291	368	649	23,000	6.5	160.9	167.4	632.6
1998/99	1	74	75	245	320	693	25,500	2.0	145.1	147.1	480.4
1999/00	2	53	55	193	248	647	19,000	5.3	139.5	144.7	507.9
2000/01	3	53	56	177	233	764	23,330	6.4	113.6	120.0	379.3
2001/02	3	47	50	187	237	661	23,206	6.5	101.3	107.7	402.9
2002/03	0	64	64	120	184	635	20,619	0.0	155.2	155.2	291.0
2003/04	3	48	51	103	154	530	18,793	8.0	127.7	135.7	274.0
2004/05	0	48	48	111	159	558	18,940	0.0	126.7	126.7	293.0
2005/06	2	50	52	125	177	491	23,072	4.3	108.4	112.7	270.9
2006/07	2	39	41	164	205	485	28,176	3.5	69.2	72.8	291.0

Reporting Year	**Injuries and Dangerous Occurrences**						**Injury Rates (per 10^8 hours exposed)**				
	Fatalities	**Major injuries**	**Total fatalities & major injuries**	**Over-3-day injuries**	**Total Injuries**	**Dangerous occurrences**	**Workforce**	**Fatal injury rate**	**Major injury rate**	**Fatal + major injury rate**	**Over-3-day injury rate**
2007/08	0	44	44	148	192	509	28,132	0.0	78.2	78.2	263.0
2008/09	0	30	30	140	170	477	28,224	0.0	53.1	53.1	248.0
2009/10	0	50	50	110	160	434	26,598	0.0	94.0	94.0	206.8
2010/11	0	42	42	106	148	430	27,660	0.0	75.9	75.9	191.6
2011/12	2	36	38	95	133	409	29,058	3.4	61.9	65.4	163.5
2012/13	0	47	47	89	136	351	31,798	0.0	73.9	73.9	139.9
Note that the reporting year was changed in 2012 to calendar year rather than financial year.											
2012	1	51	52	94	146	359	31,130	1.6	81.9	83.5	151.0
2013	0	43	43	106	149	425	33,333	0.0	64.5	64.5	159.0
2014	2	28	30	145	175	409	33,589	3.0	41.7	44.7	215.8
2015	0	36	36	77	113	312	32,659	0.0	55.1	55.1	117.9
2016p	1	20	21	78	99	263	30,368	1.6	32.9	34.6	128.4

p = provisional data at the time of issue

Table 7 HSE ORION data – offshore activity-specific injuries (derived from [Ref. 9-17])

Reporting Year	Diving			Deck Operations			Maintenance/Construction			Other		
	Fatal	Major	Over 3 days	Fatal	Major	Over 3 days	Fatal	Major	Over 3 days	Fatal	Major	Over 3 days
2004/05	0	0	2	0	16	26	0	11	36	0	21	47
2005/06	0	3	0	1	20	26	1	15	36	0	12	63
2006/07	0	0	2	0	4	17	2	15	60	0	20	85
2007/08	0	1	2	0	9	29	0	13	59	0	21	58
2008/09	0	0	4	0	7	26	0	9	61	0	14	49
2009/10	0	1	2	0	13	31	0	15	38	0	21	39
2010/11	0	0	1	0	8	24	0	16	39	0	18	42
2011/12	1	0	3	0	7	23	0	11	39	1	18	30
2012/13	0	1	0	0	18	0	0	15	1	0	13	88

Table 8 HSE ORION summary statistics for offshore workers

Statistic	1995 – 2012 (18 years total)	2012 – 2016 (last 5 years total)	2014 – 2016 (last 3 years total)
Fatalities	28	4	3
Major injuries	885	178	84
Over-3-day injuries	3081	500	300
Total Injuries	3994	682	387
Dangerous occurrences	9820	1768	984
Workforce	450962	161080	96616
Fatal injury rate (per 10^8 hours)	3.1	1.2	1.6
Major injury rate (per 10^8 hours)	98.1	55.3	43.5
O3D injury rate (per 10^8 hours)	341.6	155.2	155.3
Total injury rate (per 10^8 hours)	442.8	211.7	200.3
Pyramid factor - MI/F	31.6	44.5	28.0
Pyramid factor - O3D/MI	3.5	2.8	3.6

Table 9 HSE ORION data – diving-specific injuries

Statistic	2004/05 – 2012/13 (9 years)
Fatalities per year	0.1
Major injuries per year	0.7
O3D injuries per year	1.8
All injuries per year	2.6
Assumption of number of dives per year*	17000
Fatalities per dive	6.5×10^{-6}
Major injuries per dive	3.9×10^{-5}
O3D injuries per dive	1.0×10^{-4}
Injuries per dive	1.5×10^{-4}

*Based on number of diving operation estimates from [Ref. 7]

HSE Research Reports

Bureau Veritas has reviewed a number of HSE Research Reports, such as [Ref. 33-38], for relevant accident data for both fixed and floating offshore installations. Review of these references has not yielded any particularly useful data other than those already presented elsewhere in this report.

Petroleum Safety Authority (Norway) Accident Data

All offshore accidents on the Norwegian Continental Shelf (NCS) that result in death or injury should be reported to the Petroleum Safety Authority (PSA). The PSA publishes reports for accidents that have been investigated, and summary accident statistics for fixed and mobile facilities [Ref. 32]. Summarized accident descriptions are also provide on the PSA website.

The accident data are split by main work area and presented as total injuries numbers/rates, including all reportable injuries resulting in any lost work time or more severe. These figures are therefore not directly comparable to HSE accident data which are collated based on the RIDDOR over-3-day or over-7-day absence categories. Data for the last 10 years are presented in Table 10 to Table 12.

The most applicable worker category to consider is ‘construction and maintenance’ which has total injury rates per 10^8 hours exposed of 115.7 and 80.6 for fixed platforms and mobile facilities respectively.

Table 10 Injuries on permanently placed facilities (TIR per 10^8 exposed hours)

Activity		2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Administration and production	Work-hours	9193310	9313287	8920468	8975538	8715265	8997539	9386604	10084881	8869938	7744388
	Injuries	37	47	39	28	22	39	38	25	26	18
	Injury rate	402.5	504.7	437.2	312.0	252.4	433.5	404.8	247.9	293.1	232.4
Drilling and well operations	Work-hours	6556149	6643729	6363025	5893739	5594466	5149376	5553985	5166295	4856239	4499170
	Injuries	67	84	47	47	43	40	41	28	32	31
	Injury rate	1021.9	1264.4	738.6	797.5	768.6	776.8	738.2	542.0	658.9	689.0
Catering	Work-hours	2182479	2213297	2221184	2321410	2402714	2466948	2426849	2347674	2154055	2090811
	Injuries	16	21	28	23	24	14	26	12	23	15
	Injury rate	733.1	948.8	1260.6	990.8	998.9	567.5	1071.3	511.1	1067.8	717.4
Construction and maintenance	Work-hours	11096764	10958779	11079666	11834044	14951055	15408376	15721547	15125636	10636021	9779982
	Injuries	198	171	133	122	154	157	137	178	113	82
	Injury rate	1784.3	1560.4	1200.4	1030.9	1030.0	1018.9	871.4	1176.8	1062.4	838.4
Total	Work-hours	29028702	29129092	28584343	29024731	31663500	32022239	33088985	32724486	26516253	24114351
	Injuries	318	323	247	220	243	250	242	243	194	146
	Injury rate	1095.5	1108.9	864.1	758.0	767.4	780.7	731.4	742.6	731.6	605.4

Table 11 Injuries on mobile facilities (TIR per 10^8 exposed hours)

Activity		2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Administration	Work hours	1438043	1874811	2440528	2161749	2231865	2415107	3485705	3498255	3108503	2467669
	Injuries	0	0	1	0	0	1	2	0	0	0
	Injury rate	0.0	0.0	41.0	0.0	0.0	41.4	57.4	0.0	0.0	0.0
Drilling and well operations	Work hours	3885481	4185411	4956562	4688856	4783584	4825825	6404697	5429854	5758609	3299683
	Injuries	57	53	39	38	45	46	59	43	43	31
	Injury rate	1467.0	1266.3	786.8	810.4	940.7	953.2	921.2	791.9	746.7	939.5
Catering	Work hours	767431	856199	1028146	1086229	1215931	1272508	1424345	1680250	1363538	957758
	Injuries	12	6	9	8	6	9	8	6	2	1
	Injury rate	1563.7	700.8	875.4	736.5	493.4	707.3	561.7	357.1	146.7	104.4
Operation and maintenance	Work hours	2692954	3620034	4415855	4103517	4960119	5151683	5627910	5289588	5066761	3949047
	Injuries	50	35	39	24	42	37	44	38	19	13
	Injury rate	1856.7	966.8	883.2	584.9	846.8	718.2	781.8	718.4	375.0	329.2
Total	Work hours	8783909	10536455	12841091	12040351	13191499	13665123	16942657	15897947	15297411	10674157
	Injuries	119	94	88	70	93	93	113	87	64	45
	Injury rate	1354.7	892.1	685.3	581.4	705.0	680.6	667.0	547.2	418.4	421.6

Table 12 Injuries, work-hours and injury rates by operators and contractors on permanently located installations (TIR per 10^8 exposed hours)

Activity		2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Worker Type
Administration and production	Work-hours	6589519	6496440	6142179	5618034	5555464	5662360	5865308	5591907	5358184	5568357	Operators
		2603791	2816847	2778289	3357504	3159801	3335179	3521296	4492974	3511754	2176031	Contractors
	Injuries	25	36	31	24	16	29	30	15	25	15	Operators
		12	11	8	4	6	10	8	10	1	3	Contractors
	Injury rate	379.4	554.1	504.7	427.2	288.0	512.2	511.5	268.2	466.6	269.4	Operators
		460.9	390.5	287.9	119.1	189.9	299.8	227.2	222.6	28.5	137.9	Contractors
Drilling and well operations	Work-hours			0	0	0	0	0	0	0	0	Operators
		6556149	6643729	6363025	5893739	5594466	5149376	5553985	5166295	4856239	4499170	Contractors
	Injuries	2	1	1	0	0	1	0	1	1	1	Operators
		65	83	46	47	43	39	41	26	31	30	Contractors
	Injury rate											Operators
		991.4	1249.3	722.9	797.5	768.6	757.4	738.2	503.3	638.4	666.8	Contractors
Catering	Work-hours	1196493	1227004	1276188	1358252	1341777	1400887	1401315	1320951	1270449	1176079	Operators
		985986	986293	944996	963158	1060937	1066061	1025534	1026723	883606	914732	Contractors
	Injuries	9	11	10	16	10	9	17	7	16	9	Operators
		7	10	18	7	14	5	9	5	7	6	Contractors
	Injury rate	752.2	896.5	783.6	1178.0	745.3	642.5	1213.1	529.9	1259.4	765.3	Operators
		709.9	1013.9	1904.8	726.8	1319.6	469.0	877.6	487.0	792.2	655.9	Contractors
	Work-hours	2206627	2470555	2749197	3251822	3431786	3759627	4066380	4191901	3921796	3870859	Operators

Activity		2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Worker Type
Construction and maintenance		8890137	8488224	8330469	8582222	11519269	11648749	11655167	10933735	6714225	5909123	Contractors
	Injuries	40	41	23	25	33	20	28	39	29	29	Operators
		158	130	110	97	121	137	109	139	84	53	Contractors
	Injury rate	1812.7	1659.5	836.6	768.8	961.6	532.0	688.6	930.4	739.5	749.2	Operators
		1777.3	1531.5	1320.5	1130.2	1050.4	1176.1	935.2	1271.3	1251.1	896.9	Contractors
Total	Work-hours	9992639	10193999	10167564	10228108	10329027	10822874	11333003	11104759	10550429	10615295	Operators
		19036063	18935093	18416779	18796623	21334473	21199365	21755982	21619727	15965824	13499056	Contractors
	Injuries	76	89	65	65	59	58	75	62	71	54	Operators
		242	234	182	155	184	191	167	180	123	92	Contractors
	Injury rate	760.6	873.1	639.3	635.5	571.2	535.9	661.8	558.3	673.0	508.7	Operators
		1271.3	1235.8	988.2	824.6	862.5	901.0	767.6	832.6	770.4	681.5	Contractors

Petroleum Safety Authority DSYS Database

The Petroleum Safety Authority (PSA) systematically records information on incidents associated with petroleum activities and has established the DSYS database specifically to capture incidents in connection with manned underwater operations (diving). Annual reports from the DSYS diving database with statistics and analysis have been published since 1986. The latest DSYS annual report [Ref. 31] has been reviewed for this study.

The DSYS report differentiates between saturation diving (air dives from a saturation spread consisting of a diving bell and a saturation chamber) and surface-oriented diving (divers entering the water from the surface, carrying out the job at the relevant work depth – usually less than 50 metres – and returning to the surface).

In 2016, 44,569 man-hours of saturation diving and only 219 man-hours of surface-oriented diving were reported on the Norwegian continental shelf. No personal injuries were reported, but there was an increase in hazards related to mooring dumps. Activity levels of surface-oriented diving have been generally low for the last 20 years. This illustrates that the amount of diving undertaken annually is low, and the proportion of that activity which is surface-oriented diving is extremely low (<1%). Note that the type of diving required for AFD maintenance does not require any saturation (owing to the water depth), hence the surface-oriented diving statistics are likely to be more representative.

Figure 1 shows the number of undesirable events (defined to include fatal accidents, personal injuries requiring medical treatment, first aid cases and events resulting in absence within the next 12 hour shift) for surface-oriented diving in the period 1986-2016. A low number of events have been reported for surface-oriented diving, in line with the low level of activity. Figure 2 shows fatal accidents and cases of pressure sickness in surface-oriented diving during the same period. It can be seen that there have not been any fatal accidents during this period.

Figure 1 Undesirable events for surface-oriented diving in the period 1985-2016. (Reproduced from [Ref. 31])

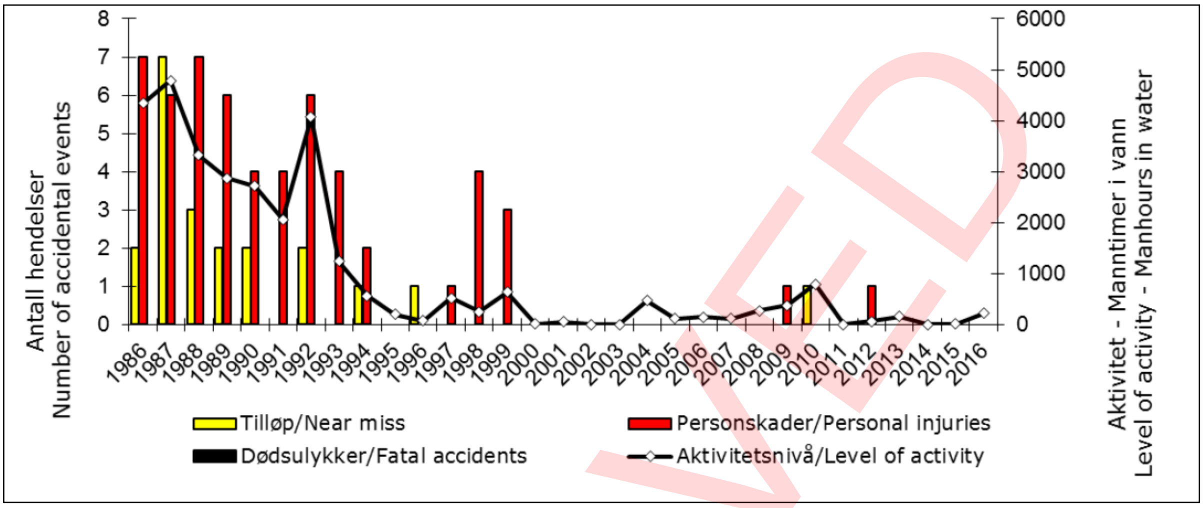
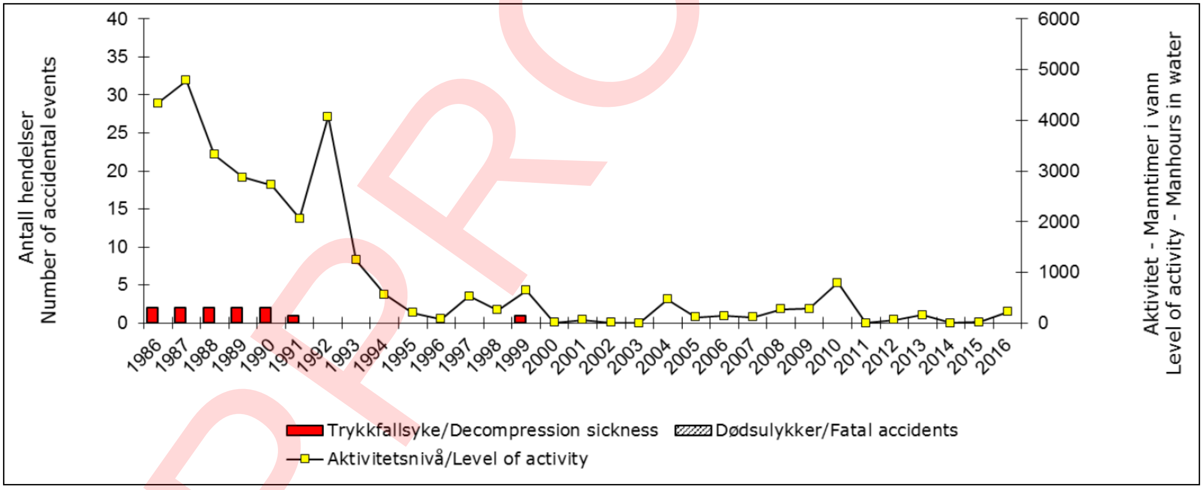


Figure 2 Fatal accidents and decompression sickness in surface-oriented diving in the period 1985-2016. (Reproduced from [Ref. 31])



Danish Energy Agency EASY Database

The Danish Energy Agency (DEA) produces annual reports summarising the offshore oil & gas industry. Until 2012, the overall offshore accident frequency for both fixed and mobile units was included in the report. These data are reported as number of accidents per million working hours. Data for the latest five annual reports [Ref. 18-22] which include these statistics (2008-2012) have been converted and presented in Table 13 and Table 14.

The Danish data suggest total injury rates per 10^8 hours worked of 370.0 and 188.7 for fixed platforms and mobile facilities respectively. These values are similar in magnitude to the average offshore worker TIR of 211.7 presented in Table 8.

Table 13 DEA EASY accident data – TIR for fixed platforms (converted from [Ref. 18-22])

Reporting Year	Hours Worked Offshore	Accidents	TIR (per 10^8 hours)
2008	4,320,000	18	416.7
2009	3,700,000	20	540.5
2010	3,600,000	6	166.7
2011	3,300,000	16	484.8
2012	4,000,000	10	250.0
2008-2012	**18,920,000**	**70**	**370.0**

Table 14 DEA EASY accident data – TIR for mobile units (converted from [Ref. 18-22])

Reporting Year	Hours Worked Offshore	Accidents	TIR (per 10^8 hours)
2008	1,420,000	2	140.8
2009	1,700,000	4	235.3
2010	1,200,000	5	416.7
2011	1,500,000	1	66.7
2012	1,600,000	2	125.0
2008-2012	**7,420,000**	**14**	**188.7**

International Regulators' Forum Annual Performance Statistics

The International Regulators' Forum (IRF) is a group of national regulators of health and safety in the offshore upstream oil and gas industry for 10 countries. Each IRF country has its own methods for measuring the safety performance of offshore activities. In order to be able to compare offshore safety performance among IRF participants a common framework has been established based on a common set of definitions and criteria.

The IRF publishes annual performance statistics [Ref. 39-48], however, these are of varying quality and consistency with a number of gaps in the data. A comparison of UK HSE data with the UK figures provided by IRF has highlighted some discrepancies. Given the concerns with that the IRF data completeness and consistency, and taking into account that risks in other countries (e.g. Mexico and

Brazil) are unlikely to be representative of UK operations, the IRF data have been omitted from the analysis.

Worldwide Offshore Accident Databank (WOAD)

The Worldwide Offshore Accident Databank (WOAD) is a commercial software product [Ref. 23] offering a database of offshore accidents. It comprises a reliable source of failures, incidents and accidents in the offshore oil & gas sector. The database provides a good basis for analysis of previous incidents and lessons learned, however, reporting of incidents is voluntary so it is not a good source of data for statistical analysis. For this reason WOAD has not been used in this analysis.

Marine Accident Investigation Branch Investigation Reports

The Marine Accident Investigation Branch (MAIB) works with the Department of Transport and investigates marine accidents involving UK vessels worldwide and all vessels in UK territorial waters. For offshore floating vessels all accidents and incidents occurring in transit should be reported to MAIB. MAIB publishes investigation reports and safety bulletins covering accidents and incidents ranging from smaller low-consequence events and near misses to major accidents with loss of life. A search of the MAIB website for diving relate accidents resulted in the following two incident reports which may be of interest to NNB GenCo:

- Report on the investigation of a hazardous diving incident involving MV Norma in the Dover Strait on 21 June 2008 [Ref. 24]; and
- Report on the investigation of a fatal accident on Wellservicer 3 miles SE of Aberdeen, Scotland 1 April 2009 [Ref. 25].

The first concerns a diver becoming entangled and being pulled rapidly towards rotating propeller blades, and how the hazardous situation could have been prevented. The second concerns the death of a crew member while working under a suspended load (technically this was maintenance of a diving bell rather than underwater diving).

It is useful to also make reference to several 'Just In Time' briefs produced by EDF relating to diving accidents at other plant:

Diving	BEG/SPEC/OPSV/JIT/0253/HPB Rev 003 [Ref. 26]
Diving Events	BEG/SPEC/OPSV/JIT/0820/SZB Rev 000 [Ref. 27]
Diving Activities	BEG/SPEC/OPSV/JIT/0909/HYB Rev 001 [Ref. 28]

Of particular relevance are the following incidents:

Ref: CR 00338334 Dungeness B 19/07/2006	Whilst diving operations were being carried at Dungeness B out on the isolated B Station Cooling Water intake structure, a diver had to invoke emergency actions. This involved switching from umbilical air to bottled air when the umbilical became entangled with two guide ropes following turbulence from the adjacent Dungeness A Cooling Water live intake structure. The diver cut both guide ropes and was then recovered to the dive vessel. A Significant Adverse Condition Investigation, supported by Safety & Regulation Dept has been instigated. No personnel were injured in the event.
Ref: OE18649 Point Peach Unit 2 May 2004	Endangered Diver Prompts Manual Trip. The diver was part of a five-person dive crew inspecting damage at the intake crib, and entered the intake crib in the vicinity of the operating circulating water intake bell. After about ten minutes in this area, the diver's air/communication line was sucked into the intake bell and snagged on a pipe support for a chlorine injection line. Neither the diver nor the tender on the boat were able to free the line due to the high intake flow. A rescue diver was sent into the area and was also unable to free the line. The snagged diver ended up flattening himself on the ground against the approximate 12" lip of the operating intake bell. Once the pumps were stopped, the rescue diver was able to free the snagged line and both divers left the water under their own power. Neither diver required medical attention.
Brunswick 24/08/2001	On August 24, 2001, with Brunswick Steam Electric Plant Units 1 and 2 operating at full power, a diver's umbilical line (air and communication) became entangled in a service water pump impeller, however the diver was not injured.
Ref: MER ATL 06-270 Brunswick Unit 1 June 2006	Diver Momentarily Pinned on Intake Structure Temporary Trash Rack. On 11th June 2006, an underwater diver became pinned on the cooling water intake pump trash rack, while attempting to remove marine growth. The screen had significant marine growth restricting flow across the screen and creating a high differential pressure. The diver removed sections of debris from the screen which created a local area of high velocity currents. These currents pinned him to the screen. The dive supervisor contacted Operations, who shutdown the pump. On reduction of the flow, the diver was able to release himself from the screen. Communications between the diver and dive supervisor established that the diver could free himself and within 2 minutes of being pinned to the screen, he was able to release himself and return to the boat.
CR 589902 (HYB)	Diver trapped on CW Intake coarse Screen. Heavy fouling of CW coarse screens resulted in unexpected areas of high CW flow on adjacent "in service" CW intake, coupled with inadequate arrangements for maintaining diver orientation caused a

	diver to become temporarily trapped against an in service screen due to differential pressure. Past experience had led the diver to believe that the flow on an in service intake would not cause a diver to be overpowered or trapped due to pressure differential. There have been a number of fatalities worldwide where divers have been trapped in situations where high differential pressures and flows have not been anticipated.

Some of the hazards which were factors in these incidents will exist for AFD construction and maintenance (i.e. entanglement/snagging and entrainment/pinning/trapping). These Just In Time briefs highlight the hazards of diving associated with cooling water systems at power stations and NNB GenCo should make use of the learning points.

British Sub Aqua Club Diving Reports

The British Sub Aqua Club (BSAC) monitors and reports on recreational diving incidents in the interest of promoting diving safety, and publishes an Annual Diving Incident Report containing details of UK diving incidents occurring to recreational divers. The latest report covers the year from 01 October 2016 to 30 September 2017 and documents 205 diving incidents and 11 fatalities [Ref. 29]. These reports do not give any indication of either the frequency or duration of diving therefore it is not possible to derive any accident frequencies. Furthermore, the type of recreational diving (mostly snorkelling and SCUBA – Self-Contained Underwater Breathing Apparatus) and skill of the divers (including novices) are not representative of the type of diving and skill of diver employed for AFD maintenance. In addition, most recreational dives reported to BSAC are likely to have been undertaken in relatively forgiving environments.

Still, the BSAC information underlines how hazardous all types of diving can be, and NNB GenCo may find this a useful source of 'lessons learned'.

Safetec Decommissioning Risk JIP

Research completed in 2005 by a Joint Industry Project (JIP) led by Safetec investigated the occupational risks of offshore decommissioning activities; the findings are reported in [Ref. 30]. The report presents FAR estimates for a set of offshore activities including confidence intervals. As is evident from Figure 3 and Table 15, the risks involved in surface-oriented air diving (per hour in the water) are much higher than for saturation diving (per hour in saturation). Moreover, out of all activities investigated surface-oriented air diving was found to be the riskiest per hour exposed. Note that the type of diving required for AFD maintenance does not require any saturation, hence the surface-oriented air diving statistics are likely to be more representative.

Given the environmental conditions of the Bristol Channel, dive times are limited to around 1 hour. Converting the air diving FAR of 685 per 10^8 hours of diving time into a risk of fatality per dive yields 6.9×10^{-6}. This is very similar to the fatality rate of 6.5×10^{-6} per dive derived in the next section from HSE data. Note that the Safetec report [Ref. 30] defines surface-oriented air diving as including ‘simple work operations related to diving, such as inspection tasks, simple manual operations etc.’ The diving required for AFD maintenance may be more hazardous than represented by this figure; this is discussed in the next section.

The FAR of 7.5 per 10^8 hours for ‘Marine operations – Diving Support’ is another useful figure which can be used in this study.

Figure 3 FAR estimates for offshore decommissioning activities [Ref. 30]

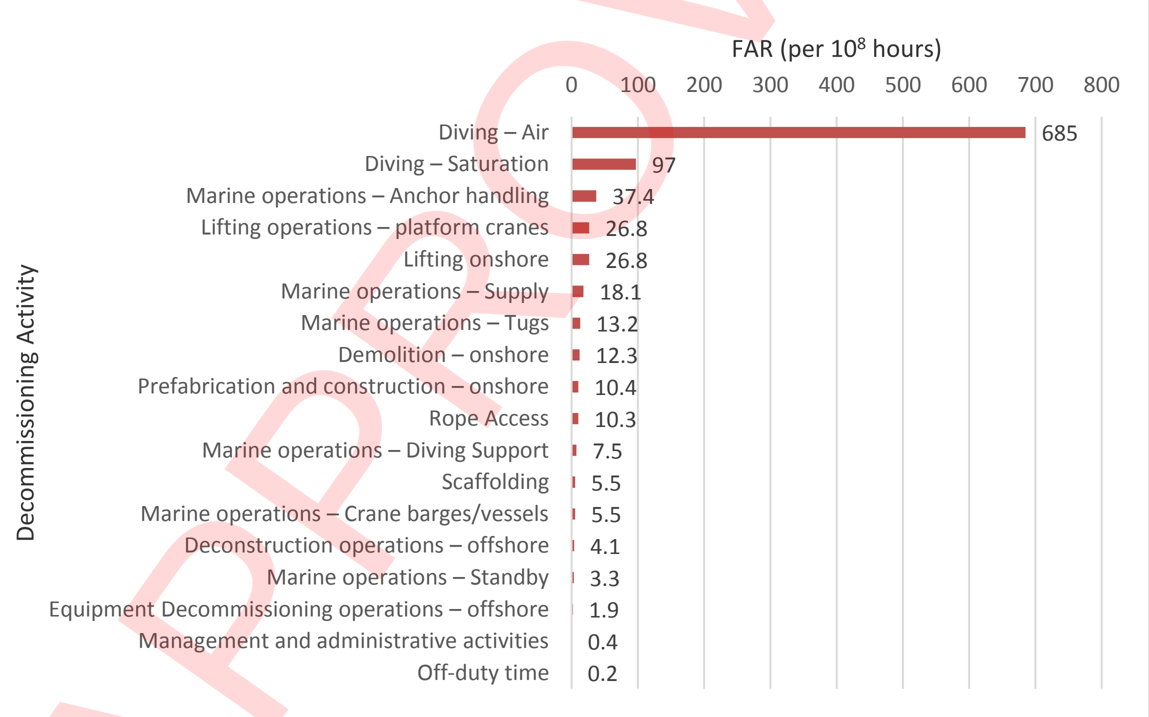


Table 15 FAR estimates for offshore decommissioning activities [Ref. 30]

Number	Activity	FAR
1	Diving – Air	685
2	Diving – Saturation	97
3	Marine operations – Anchor handling	37.4
4	Lifting operations – platform cranes	26.8
5	Lifting onshore	26.8
6	Marine operations – Supply	18.1
7	Marine operations – Tugs	13.2
8	Demolition – onshore	12.3
9	Prefabrication and construction – onshore	10.4
10	Rope Access	10.3
11	Marine operations – Diving Support	7.5
12	Scaffolding	5.5
13	Marine operations – Crane barges/vessels	5.5
14	Deconstruction operations – offshore	4.1
15	Marine operations – Standby	3.3
16	Equipment Decommissioning operations – offshore	1.9
17	Management and administrative activities	0.4
18	Off-duty time	0.2
19	Lifting operations – external cranes*	1.1×10^{-5}
20	Helicopter**	32/97

* Fatal accident rate per lift
** Values for take-off/landing and cruise respectively

CMPT Offshore QRA Guide

Section XIV.2.9 of the Centre for Marine and Petroleum Technology (CMPT) guide for offshore QRA [Ref. 7] attempts to break down FARs based on types of work. These FARs are based on two different analyses of the breakdown of employee occupations, both of which are dated and are unlikely to be representative of current risks. The results are useful in highlighting that diving activity is much riskier than any other offshore activity (between 3.8-206 times the FAR). The differences in the results between the two columns also provides an indication of the uncertainties in the estimates for the different occupations.

Table 16 Comparison of FAR estimates [Ref. 7]

Worker Category	Based on 1979 Survey	Based on 1992 Estimates
Construction	2.1	1.2
Maintenance	1.2	5.5
Boat crew	-	3
Diving	61.9	21
Production	<0.3	0
Operations	-	4.3
Drilling	2.3	3.8
Domestic	0.3	0.3
Overall	3.2	3.2

As mentioned in Section 3.2.2, FARs based on all hours offshore for divers may not be representative because diving risks are high for short periods spent in the water and much lower for the remaining time spent offshore. Section XIV.2.10 of the CMPT guide makes an estimate of 0.3 fatalities per year, and when combined with an estimate of 17,000 diving operations per year determines a fatality rate of 1.8 x 10^{-5} per dive. The overwhelming majority of dives in the North Sea are carried out from a saturation spread consisting of a diving bell and a saturation chamber on a diving support vessel, therefore the fatality rate above may not be representative of the surface-oriented diving required for AFD maintenance.

For the 9 years 2004/05 to 2012/13 in Table 7 the corresponding fatality rate is 6.5 x 10^{-6} per dive, assuming a similar amount of diving activity. It could be argued that the present amount of diving activity is likely to be lower than in the past given the advances in ROV technologies, so this fatality rate per dive may be an underestimation. This assertion, however, is difficult to verify without measured dive activity data.

In the previous section a similar surface-oriented air diving fatality rate of 6.9 x 10^{-6} per dive was derived [Ref. 30]. This takes into account that surface-oriented diving is generally much more risky – around 7 times per hour exposed – than saturation diving. This figure is based on ‘simple work operations related to diving, such as inspection tasks, simple manual operations etc.’ The diving required for AFD maintenance is judged to be more complex than represented by this figure in light of the dive proximity to additional hazards such as:

- Mooring lines;
- Vessels;
- The AFD structure (which presents a snagging/entanglement hazard); and

- Live cooling water intake heads (which present an entrainment/pinning/trapping hazard).

It is therefore proposed to adjust the fatality rate of 6.9 x 10^{-6} per dive upwards by a factor of 2 to account for these additional hazards and a further factor of 2 for the zero visibility conditions in the Bristol Channel which will both increase the likelihood of a diver getting into difficulty and decrease the likelihood that the diver can escape from that difficulty. This results in a risk of 2.7 x 10^{-5} per dive.

Section XIII.7 of the CMPT guide gives an analysis of the risks of crew boat transit (e.g. boat sinking while travelling between locations) and transfer (e.g. a crew member fatally crushed while embarking/disembarking a fixed platform from/to a boat). At the time of writing (1999) there were very few data concerning crew boat accidents, so an estimate was made using a Poisson distribution of frequencies assuming that 0.7 accidents had happened to date (i.e. that the operation was 70% towards having the first accident).

This results in accident rates of:

- 3.1 x 10^{-7} fatalities in transit per passenger hour (90% confidence interval 2.2 x 10^{-8} to 1.3 x 10^{-6}); and
- 2.6 x 10^{-7} fatalities for transfer per passenger transfer stage – including one embarkation plus one disembarkation (90% confidence interval 1.9 x 10^{-8} to 1.1 x 10^{-6}).

The individual risks of a return crew boat journey for personnel undertaking offshore maintenance on the Power Hub can therefore be calculated as:

(2.6 x 10^{-7}) + (3.1 x 10^{-7} x transit durations in hours)

It can be seen that the confidence intervals on these values are very wide.

Note that the 2.6 x 10^{-7} figure for fatalities in transfer per passenger transfer stage accounts for one embarkation plus one disembarkation, so the corresponding risk per one-way transfer is 1.3 x 10^{-7} fatalities per passenger transfer, and this is applicable only to the personnel being transferred (not the boat crew remaining on the boat).

Diving Alert Network Accident Data

The Diving Alert Network (DAN) is primarily concerned with recreational diving, however the DAN accident database provides some insight into the risk factors and contributing causes of diving accidents. For example, an evaluation of 270 accidents in 1987 highlights the following common risk factors [Ref. 49]: Rapid ascent; Fatigue; Current; Buoyancy problem; Exertion on dive; Cold; and Alcohol.

The conditions on the day of the dive play a strong part in the risk factors:

- Current: A strong to moderate current is considered a factor because of the increased exertion;

- Fatigue: Divers reported being physically tired or had missed some sleep the previous night;
- Exertion: Increased muscle activity;
- Cold: The diver said they were cold or uncomfortable.

The same reference goes on to show that environmental factors contributed to 34.8% of the accidents.

3.2.5 Risk Quantification

Table 17 shows the fatal accident rates selected from Section 3.2.4 for the risk quantification based on the worker category and activity from Table 5.

Table 17 AFD Offshore Fatality Rates Used

Activity	Divers	Boat Crew / Dive Support	Offshore Maintenance
Risk of injury during vessel transit	3.1×10^{-7} fatalities per passenger hour [Ref. 7]		
Risk of injury per fendering operation (to Power Hub)	N/A	N/A	1.3×10^{-7} fatalities per passenger transfer [Ref. 7]
Injury rate per hour on a moored boat	7.5 fatalities per 10^{8} hours [Ref. 30]		
Injury rate per hour on the Power Hub	N/A	N/A	1.2 fatalities per 10^{8} hours [Ref. 8]
Injury rate per hour in the water / Risk of injury per dive	2.7×10^{-5} per dive [adjusted from Ref. 30]	N/A	N/A

These values have been combined with the activity duration and exposure information in Table 4 to quantify the individual risks for the three worker categories associated with each operation in the installation, commissioning and maintenance of the AFD system, and the results are presented in Table 18.

The ongoing AFD maintenance ‘campaign’-specific individual risks have then been factored by the frequency of the AFD maintenance (all four intake heads completed every 18 months) to calculate the annualised risks in Table 19. The installation and commissioning activities are carried out only once in the lifetime of the plant therefore the risks associated with these activities are not included in Table 19.

Finally, the number of workers involved in the operations have been factored in to calculate the expected number of fatalities for each activity per campaign, per year and in the 70 year life of the plant in Table 20.

Figure 4 to Figure 10 present the same summary information graphically.

It is clear that divers are the most at risk worker category and diving risk during AFD installation and maintenance is the major contributor to overall fatality risks in all activities that involve at least some diving.

Finding 6	For the preferred AFD option divers are the most at risk worker category and diving risk during AFD installation and maintenance is the major contributor to overall fatality risks in all activities that involve at least some diving.

Electrical cable replacement presents the greatest risk per campaign (Figure 4 and Figure 5), however it is only undertaken twice in the life of the plant and therefore has a smaller overall risk than sound projector replacement, which is undertaken at a rate of one campaign every 18 months.

The estimated IRPAs for ongoing maintenance tasks for the Boat Crew / Dive Support and Offshore Maintenance worker categories are well within the tolerability threshold of 1 x 10^{-3}. Being below this threshold does not mean that the risks are tolerable – this must be established through an ALARP demonstration – it simply means that the level of risk is not unacceptable.

The Diver worker category has a total IRPA for ongoing maintenance tasks of 9.2 x 10^{-4}. This is only just less than the HSE unacceptable threshold of 1 x 10^{-3} but is much higher than a suggested benchmark of 1 x 10^{-4} for modern installations.

Finding 7	For the preferred AFD option all offshore workers will be subjected to individual risks of fatality per annum of less than 10^{-3}, with divers subjected to 9.2 x 10^{-4}.

The expectation value for total number of workers killed through construction, maintenance and operation of the AFD system throughout the life of the plant (assumed to be 70 years) is 0.39. This estimate does not take into account any decommissioning activities which are likely to be of a similar magnitude but lower level to the installation risks. In any case, the expected number of fatalities throughout the life of the plant would still be dominated by diver risks (0.34).

Finding 8	Over the course of a 70 year plant lifetime it is estimated that NNB GenCo can expect 0.39 fatal injuries associated with AFD installation, maintenance and operation.

Figure 4 Expected number of fatalities per campaign by activity

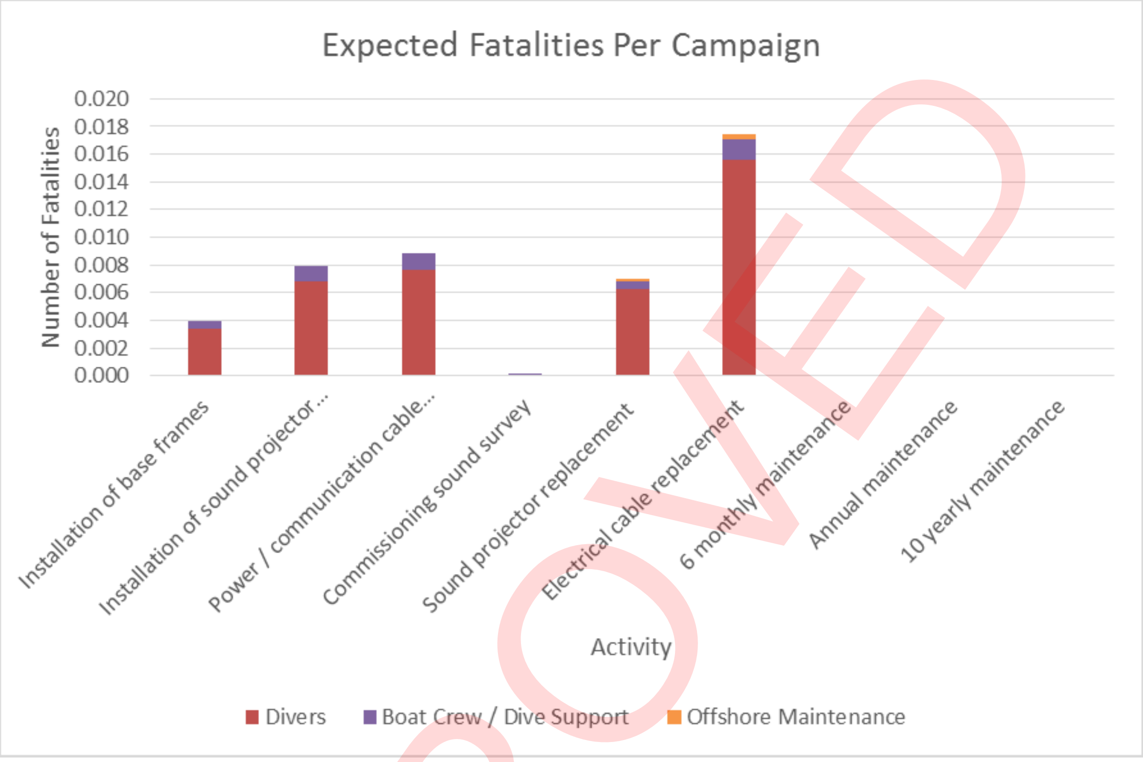


Figure 5 Expected number of fatalities per campaign by worker category

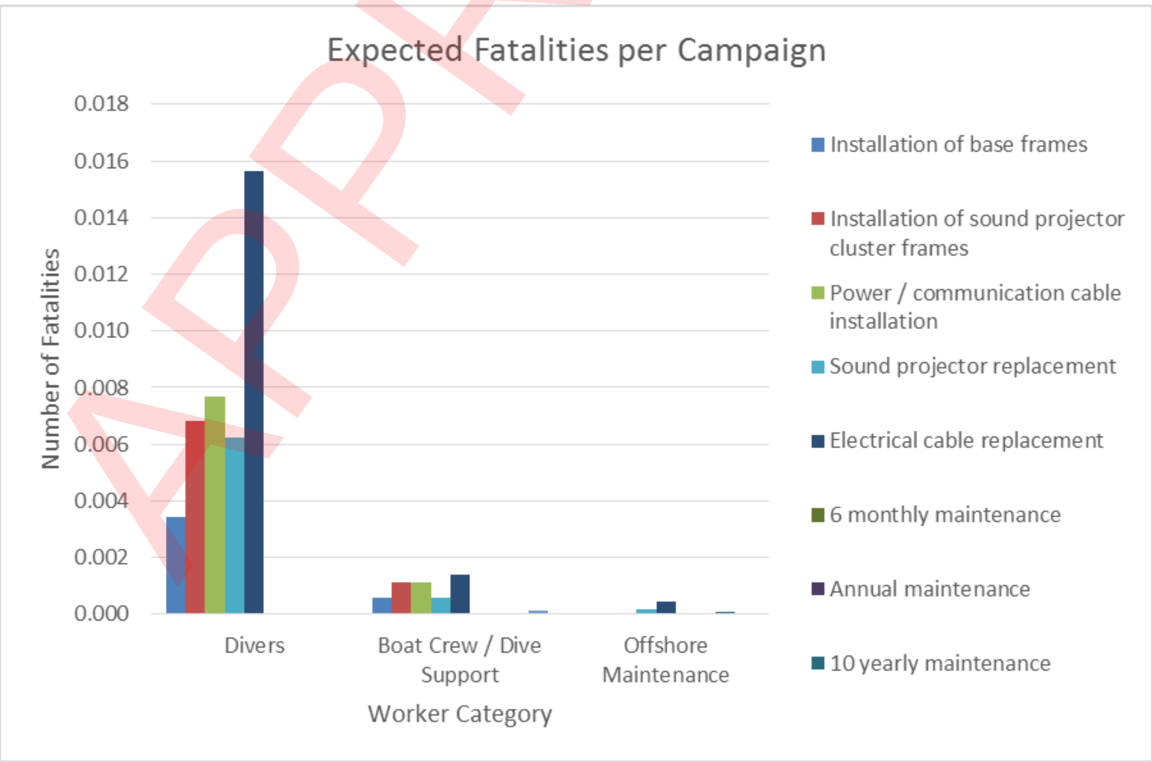


Figure 6 Individual risk of fatality per annum for regular maintenance activities

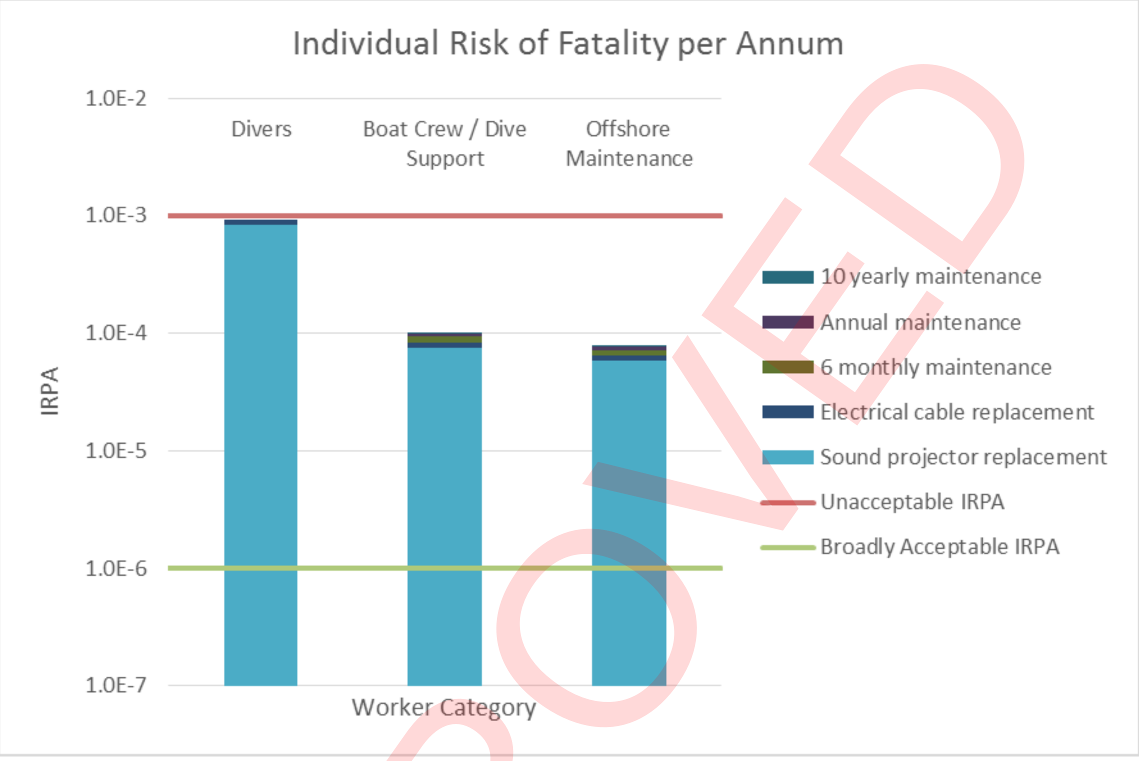


Figure 7 Expected number of fatalities per year for regular maintenance activities

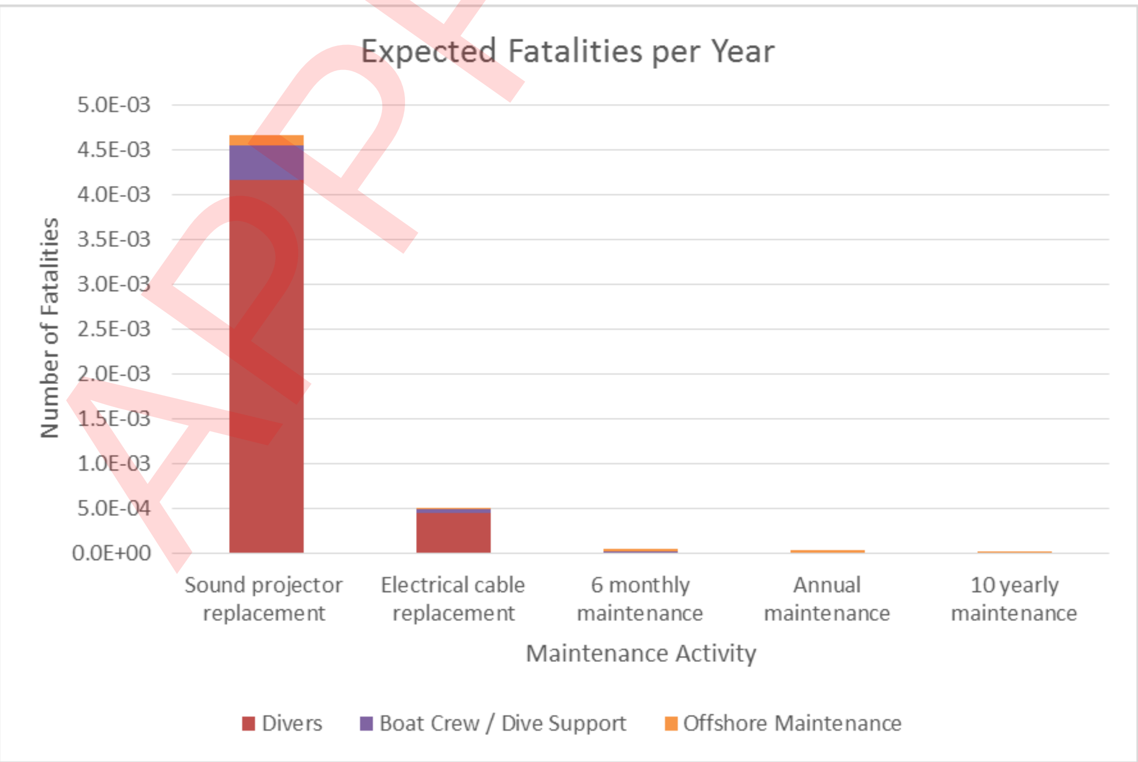


Figure 8 Expected number of fatalities in the lifetime of the plant

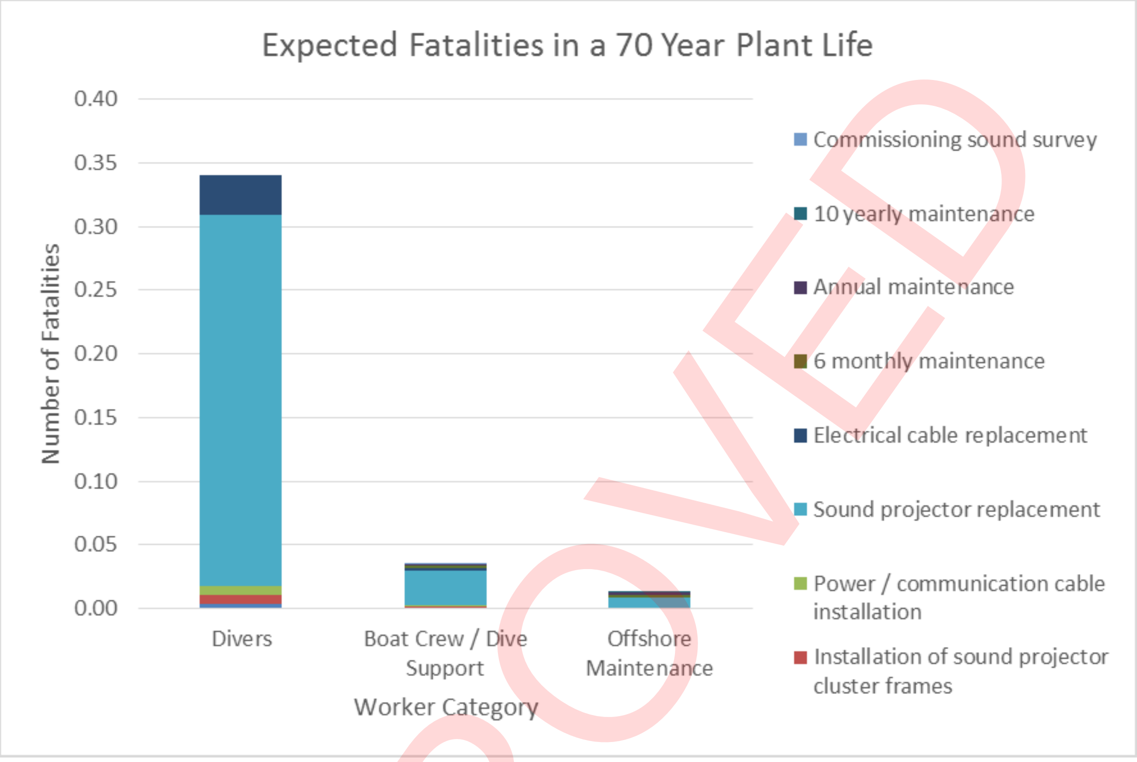


Figure 9 Breakdown of contributors to diver fatality risks for all maintenance activities

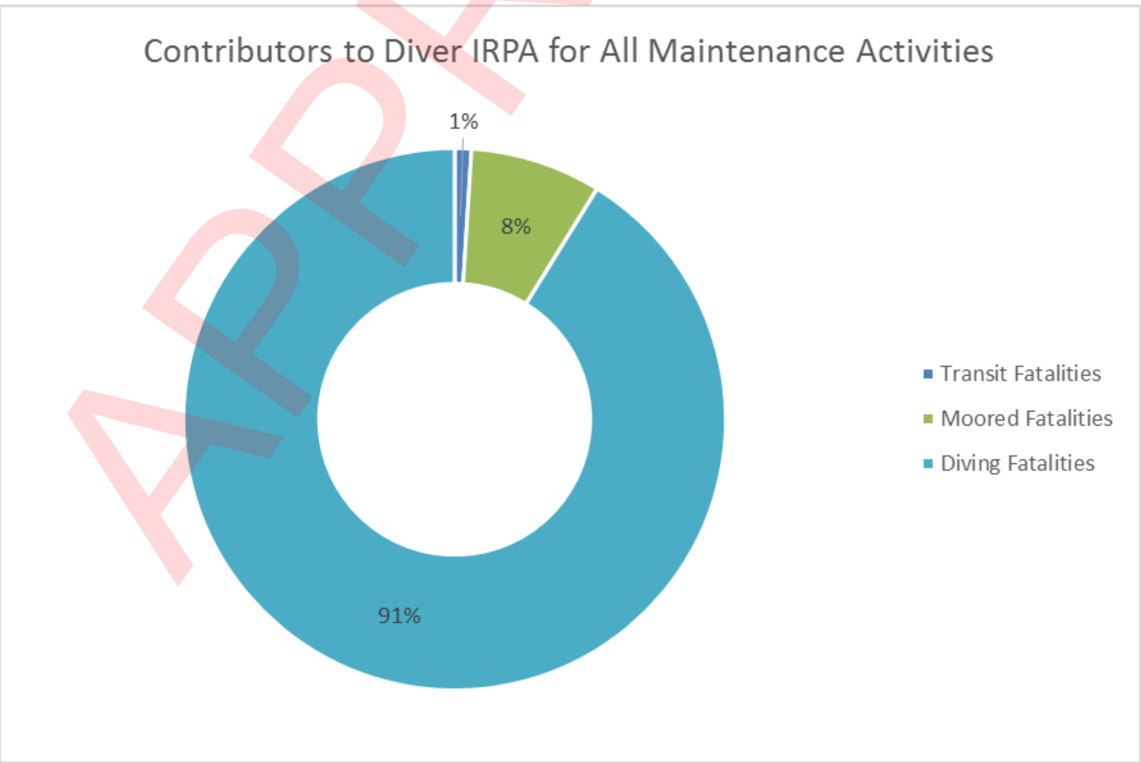


Figure 10 Breakdown of contributors to diver fatality risks over a 70 year plant life

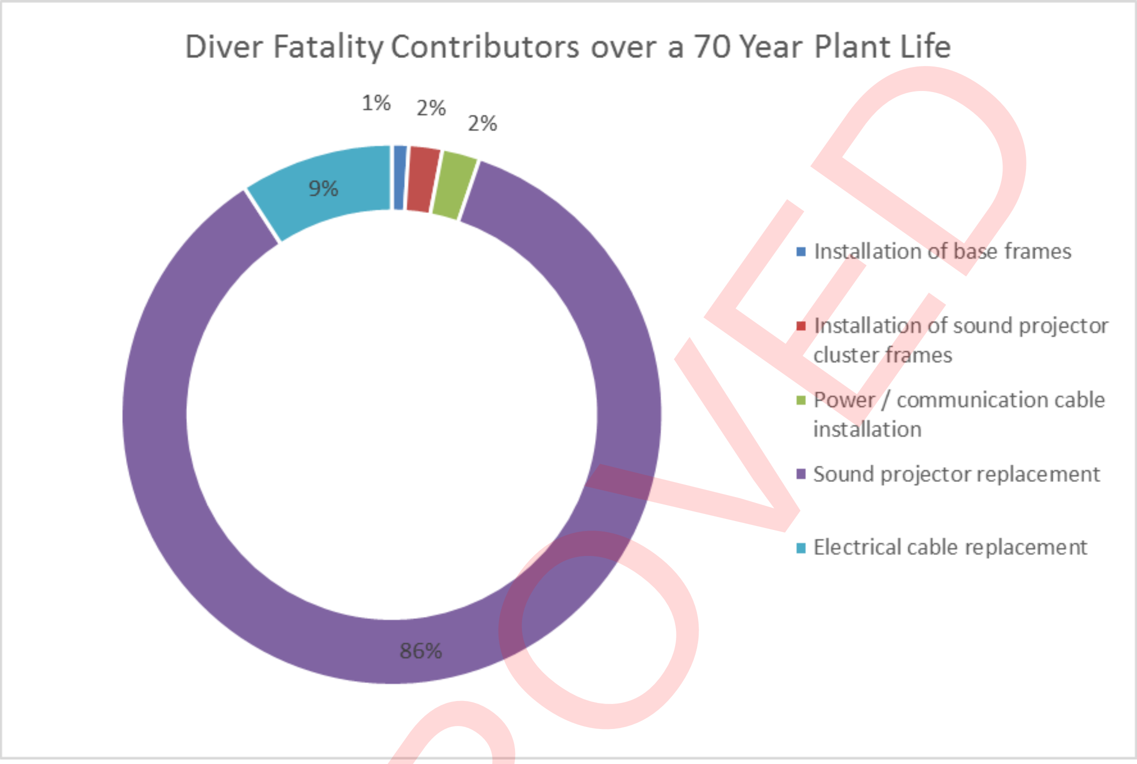


Table 18 Individual risk of fatality for each campaign (set of 4 intake heads completed)

Phase	Activity	Divers				Boat Crew / Dive Support			Offshore Maintenance				
		Transit	Moored	Diving	Sum	Transit	Moored	Sum	Transit	Transfer	Power Hub	Moored	Sum
Installation	Installation of base frames	6.2E-06	5.0E-05	2.8E-04	3.4E-04	6.2E-06	5.0E-05	5.7E-05	-	-	-	-	-
	Installation of sound projector cluster frames	1.2E-05	9.9E-05	5.7E-04	6.8E-04	1.2E-05	1.0E-04	1.1E-04	-	-	-	-	-
	Power / communication cable installation	1.2E-05	9.9E-05	6.6E-04	7.7E-04	1.2E-05	1.0E-04	1.1E-04	-	-	-	-	-
Commissioning	Commissioning sound survey	-	-	-	-	6.2E-06	7.2E-06	1.3E-05	-	-	-	-	-
Maintenance	Sound projector replacement	1.2E-05	9.8E-05	1.1E-03	1.2E-03	1.2E-05	1.0E-04	1.1E-04	1.4E-05	1.5E-05	8.1E-06	5.0E-05	8.7E-05
	Electrical cable replacement	3.1E-05	2.4E-04	2.8E-03	3.1E-03	3.1E-05	2.5E-04	2.8E-04	3.4E-05	3.6E-05	2.0E-05	1.3E-04	2.2E-04
	6 monthly maintenance	-	-	-	-	1.6E-06	3.6E-06	5.2E-06	1.6E-06	5.2E-07	2.9E-07	1.8E-06	4.2E-06
	Annual maintenance	-	-	-	-	1.6E-06	3.6E-06	5.2E-06	1.6E-06	5.2E-07	2.9E-07	1.8E-06	4.2E-06
	10 yearly maintenance	-	-	-	-	1.6E-06	1.3E-05	1.4E-05	1.6E-06	1.8E-06	1.0E-06	6.3E-06	1.1E-05

Table 19 Individual risk of fatality per year (IRPA) for ongoing maintenance activities

Phase	Activity	Divers				Boat Crew / Dive Support			Offshore Maintenance				
		Transit	Moored	Diving	Sum	Transit	Moored	Sum	Transit	Transfer	Power Hub	Moored	Sum
Maintenance	Sound projector replacement	8.3E-06	6.5E-05	7.6E-04	8.3E-04	8.3E-06	6.7E-05	7.5E-05	9.1E-06	9.7E-06	5.4E-06	3.4E-05	5.8E-05
	Electrical cable replacement	8.9E-07	7.0E-06	8.1E-05	8.9E-05	8.9E-07	7.2E-06	8.1E-06	9.7E-07	1.0E-06	5.8E-07	3.6E-06	6.2E-06
	6 monthly maintenance	-	-	-	-	3.1E-06	7.2E-06	1.0E-05	3.1E-06	1.0E-06	5.8E-07	3.6E-06	8.3E-06
	Annual maintenance	-	-	-	-	1.6E-06	3.6E-06	5.2E-06	1.6E-06	5.2E-07	2.9E-07	1.8E-06	4.2E-06
	10 yearly maintenance	-	-	-	-	1.6E-07	1.3E-06	1.4E-06	1.6E-07	1.8E-07	1.0E-07	6.3E-07	1.1E-06

Table 20 Expected number of fatalities

Phase	Activity	Expected Fatalities per Campaign				Expected Fatalities per Year				Expected Fatalities in a 70 Year Plant Life			
		Divers	Boat Crew / Dive Support	Offshore Maintenance	Sum	Divers	Boat Crew / Dive Support	Offshore Maintenance	Sum	Divers	Boat Crew / Dive Support	Offshore Maintenance	Sum
Installation	Installation of base frames	3.4E-03	5.7E-04	N/A	4.0E-03	-	-	-	-	3.4E-03	5.7E-04	-	4.0E-03
	Installation of sound projector cluster frames	6.8E-03	1.1E-03	N/A	7.9E-03	-	-	-	-	6.8E-03	1.1E-03	-	7.9E-03
	Power / communication cable installation	7.7E-03	1.1E-03	N/A	8.8E-03	-	-	-	-	7.7E-03	1.1E-03	-	8.8E-03
Commissioning	Commissioning sound survey	-	1.3E-04	N/A	1.3E-04	-	-	-	-	-	1.3E-04	-	1.3E-04
Maintenance	Sound projector replacement	6.2E-03	5.7E-04	1.7E-04	7.0E-03	4.2E-03	3.8E-04	1.2E-04	1.2E-04	2.9E-01	2.6E-02	8.1E-03	3.3E-01
	Electrical cable replacement	1.6E-02	1.4E-03	4.3E-04	1.7E-02	4.5E-04	4.0E-05	1.2E-05	1.2E-05	3.1E-02	2.8E-03	8.7E-04	3.5E-02
	6 monthly maintenance	-	1.0E-05	1.2E-05	2.3E-05	-	2.1E-05	2.5E-05	4.6E-05	-	1.4E-03	1.7E-03	3.2E-03
	Annual maintenance	-	1.0E-05	2.1E-05	3.1E-05	-	1.0E-05	2.1E-05	3.1E-05	-	7.2E-04	1.5E-03	2.2E-03
	10 yearly maintenance	-	2.8E-05	8.5E-05	1.1E-04	-	2.8E-06	8.5E-06	1.1E-05	-	2.0E-04	6.0E-04	8.0E-04

4 CONCLUSIONS

The two principal questions addressed by this review are:

1. Was the AFD optioneering study and supporting documentation carried out in a reasonable manner, based on sensible selection criteria and with a defensible conclusion?
2. Are the quantified risks of the preferred AFD design ALARP and reasonable in comparison with tolerable individual risk thresholds?

With respect to point 1, this review has found that the majority of the optioneering work and supporting documentation has been produced by suitably qualified and experienced personnel with access to adequate input information and by applying appropriate methodologies. The process for selecting the preferred AFD design, however, did not factor in the safety impacts of ongoing AFD maintenance explicitly. This omission at optioneering stage is not explained in the documentation, and could therefore be used to call into question the final result on safety grounds. It is recommended that NNB GenCo should augment the optioneering study by including a safety-based driver with significant weighting as part of the AFD structure selection. This would provide a more defensible basis for choosing a preferred design (see Finding 3), one which is more robust to challenge.

With respect to point 2, this study has found that fatality risks associated with maintenance of the preferred AFD option lie only marginally below the unacceptable threshold for individual risk of workers. This is considered to be a realistic estimate of the risk which is, out of necessity given the paucity of activity-specific and location-specific historical accident data, based on some assumptions which are neither unduly cautious nor overly optimistic. It is recommended to carry out further sensitivity analysis and a calculation of the decommissioning risks in order to provide a more complete picture of the plant life risks.

The findings of this review are summarised in Table 21.

Table 21 Summary of Findings

Reference	Detail
Finding 1	If the AFD system is to be further developed, ROV technologies and capabilities should be continually reviewed to establish if diving activity can feasibly be reduced/eliminated, and the safety risk analyses carried out should consider the most likely viable solution, either diving or ROV (or a combination).
Finding 2	If any future detailed safety analysis is conducted regarding the AFD, it is recommended that a more detailed risk matrix is defined and quantified risk criteria applied to facilitate more accurate evaluations of risk.

Reference	Detail
Finding 3	The safety risks of AFD maintenance are considered to be covered by appropriate safety-based scoring criteria with scoring supported by HAZID analysis. The documentation of this process in the Optioneering Report, however, does not reflect the high level of attention given to safety during the process. NNB GenCo should consider strengthening the optioneering documentation to more clearly detail how due consideration was given to safety during the optioneering process.
Finding 4	If the AFD system is to be further developed, a HAZID action close-out report should be produced to ensure that proper implementation and follow-up of actions has been carried out. Any other future risk assessment workshops should also adhere to this principle.
Finding 5	NNB GenCo should define its own corporate risk tolerability criteria and assess the calculated risk levels in this report against those criteria.
Finding 6	For the preferred AFD option divers are the most at risk worker category and diving risk during AFD installation and maintenance is the major contributor to overall fatality risks in all activities that involve at least some diving.
Finding 7	For the preferred AFD option all offshore workers will be subjected to individual risks of fatality per annum of less than 10^{-3}, with divers subjected to 9.2×10^{-4}.
Finding 8	Over the course of a 70 year plant lifetime it is estimated that NNB GenCo can expect 0.39 fatal injuries associated with AFD installation, maintenance and operation.

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APPENDICES

Appendix A – Document Review Comment Response Sheets

Appendix B – AFD Workshop Records

Appendix A – Document Review Comment Response Sheets

ITEM	SECTION	BV COMMENT	NNB GenCo COMMENT RESPONSE
1	General comment	Rev.0: Which subsea option from Optioneering phase HAZID (1a, 1b, 1c or 1d) was selected and analysed in the New HAZID Output report?	A variation of option 1a was taken forward and the design development as detailed in HPC-OH2331-U9-HPT-REP-100007
		Rev.1: Closed	
2	General comment	Rev.0: Please clarify how the HAZID analysis results/ risk ranking were used to select the best AFD system option. In other words, which outputs from HAZID were used as basis in the decision making regarding the best AFD system option?	The solutions were ranked and rated as detailed in HPC-OH2231-U9-HPT-REP-10007 Appendix 1.
		Rev.1: Closed	
3	Section 1.5	Rev.0: It is understood that the Power Supply and Distribution, and Control and Communications were not assessed as part of this HAZID as it was considered they would not influence the selection of preferred options for the AFD layout and mounting. Nevertheless, were the risks associated to these structures analysed separately?	Confirmed. The assessment of the power supply and distribution is detailed in HPC-OH2231-U9-HPT-REP-10007 Section 7 onwards
		Rev.1: Closed	
4	Appendix 4	Rev.0: What is the current status of the 21 Actions raised during the Optioneering phase HAZID? Is there a close out report that was prepared in order to follow the implementation of these actions?	Actions have been periodically reviewed, progressed and closed, as appropriate. A close out report is not available.
		Rev.1: Closed	

ITEM	SECTION	BV COMMENT	NNB GenCo COMMENT RESPONSE
1	General comment	Rev.0: Please provide, if available, a document that details the weighting process adopted for each type of structure.	The weighting process is detailed in HPC-OH2231-U9-HPT-REP-100002 and reference should also be made to HPC-OH2231-U9-HPT-REP-100007 Appendix 1 Section 4, Section 13- 14
		Rev.1: Closed	
2	13.2	Rev.0: Did the Optioneering report take into account the Optioneering phase HAZID results for scoring the AFD Speaker Layout Configuration and AFD Speaker Mounting?	Confirmed, these parameter were part of the overall assessment
		Rev.1: Closed	

ITEM	SECTION	BV COMMENT	NNB GenCo COMMENT RESPONSE
1	3.2	Rev.0: Which type of assessment was performed in order to discount the non-subsea structure? Was the decision made based on HAZID results only?	Detailed assessments of the all the subsea and non-subsea solutions were carried out and are detailed in HPC-OH2231-U9-HPT-REP-100007. The selection of the preferred option was based on a number of criteria including the output from the HAZID results as detailed in HPC-OH2231-U9-HPT-REP-10007 Appendix 1
		Rev.1: Closed	
2	3.2	Rev.0: It is mentioned that a subsea structure with sound projectors mounted on the inlet head was the option selected. Does this option correspond to the Option 1a or 1b presented in the optioneering phase HAZID?	Both option 1 and 1b are subsea lightweight structures, these types of structures were progressed in the design and the design developed. Please reference HPC-OH2231-U9-HPT-REP-100007
		Rev.1: Closed	
3	3.4	Rev.0: It is mentioned that “The preferred subsea option presents specific risks linked to underwater activities, however the design concept will minimise these critical tasks and this was considered to present a better option in term of maintainability and operability than other options.” Is there any report that details which characteristics of the design concept of the subsea option chosen were considered better/ safer than other subsea options in terms of safety?	The optioneering report HPC-OH2231-U9-HPT-REP-10007 Appendix 1 details the criteria used for selecting and the report also details why a non-subsea structure was progressed as the preferred design solution
		Rev.1: Closed	

ITEM	SECTION	BV COMMENT	NNB GenCo COMMENT RESPONSE
4	5.3	Rev.0: It is understood that the Substation was not in the optioneering phase HAZID as it was considered it would not influence the selection of preferred options for the AFD layout and mounting. Nevertheless, were the substation hazardous scenarios (i.e.: evacuation of personnel, anchorage, mooring, etc.) analysed in another study?	The requirements and options for the electrical supply to the subsea AFD are fully detailed in HPC-OH2231-U9-HPT-REP-10007. Additional work was commissioned on the preferred electrical hub solution and are detailed in CU-J1967-R-TN-002-Outline Topsides Requirements for the AFD Hub Structure
		Rev.1: Closed	

Appendix B – AFD Workshop Records

Client: **NNB GenCo**

Project: **Acoustic Fish Deterrent Independent Safety Analysis**

Title: **AFD Maintenance Risks/Resources Workshop Records**

Rev	Date	Author	Status
A	17/11/2017	Matthew Baggaley Yann Seral	Draft Report with HOLDs for Attendee Comment

Attendees:

Name		Company	Role	Attendance
Yann	Seral	Bureau Veritas	Chair	Present at workshop
Matthew	Baggaley	Bureau Veritas	Scribe	Present at workshop
Olivier	Gauvrit	NNB GenCo	Heat Sink/BOP Program Engineering Lead	Present at workshop
Ross	Pettigrew	NNB GenCo	Environmental Technical Manager	Present at workshop
Jonathan	Jones	NNB GenCo	CDM Advisor	Present at workshop
David	McKenna	Costain	Offshore and Marine Rep	Present at workshop
Adrian	Jones	Costain	Project Manager	Present at workshop
Angus	Reid	Costain	Engineering Manager	Present at workshop
Jorge	Ramirez Penayo	Bureau Veritas	Subsea Engineer	Post-workshop review of worksheets; comments marked with [**BV Subsea Engineer comment after workshop:**]

AFD Maintenance Worksheet

Phase	Task	Resources required to perform the task	Safety support resources	HAZID Sc. Ref.	Main Hazard identified	Consequence	Safeguard / Mitigation	HAZID recommendation	S	L	R	Lesson learned / Feedback	Workshop recommendation
Installation	Vessel mobilisation and transit – AFD equipment load-out and transport to worksite	A dive crew of 10 per shift is required comprising: Up to 5 x divers • Dive supervisor • Dive technician • Offshore superintendent • Rigger • Daughter craft coxswain Therefore, a dive crew of 20 would be required for 24 hour operations. 2 vessels are required, 1 for welfare facilities for workers. 1 week preparation time at the harbour. The sail time is 2.5 hours (from Newport). Several trips are required, or the support vessel might do these trips back to the harbour.	Anchor handling vessel only.	9	Extreme / Adverse Weather Event	Inability of surface vessels to work in adverse sea conditions Potential for construction / support vessels to lose positional control (Failure of Dynamic Positioning (DP) or mooring lines) with consequential impact with AFD or heads structure leading to damage to heads and AFD, loss of vessel - potential loss of life and or pollution incident.	Vessel operations will only be undertaken at suitable tide heights to ensure a suitable draft is maintained above the AFD and Inlet Heads (Ideally 3-4m above Inlet Heads, absolute minimum 1.5m). Larger clearances would be applied in adverse conditions.	[3] Establish safe operating limits for the vessel. This will include mechanisms for measuring position, cable tension and payout and maximum wind or sea state. This is to be included work method statement.	H	M	3	Notifications to the military site and HPC Harbour Master need to be made before vessel movements. Lock in/out is only possible at high water.	1. [**BV Subsea Engineer comment after workshop:** Consider providing heave compensator system to avoid uncontrolled movement of the load due to waves.]
				35	Dragging of Anchor	Damage to the AFD power cables which may also cause further damage to transformer systems and the acoustic panels via pulling action. Potential for direct impact of anchor with above sea bed AFD systems. Anchor attachment cables may ensnare or strangle the AFD.	Power cables will be buried to a suitable depth in trenches and covered with armoured protection or infill as deemed required. The Burial depth will be considered against the anchor requirements for a 5000 tonne vessel which is the largest routine commercial shipping operation close to the Inlet Heads / AFD (Goes into and out of Bridgewater). Operational vessels associated with the maintenance of the AFD will be managed in terms of maximum size and anchor weight, and movements and anchor positions will be controlled to avoid cables. Area is part of wider restricted area which is controlled by the Bridgwater Bay Harbour Master.	[10] The designers have not confirmed whether drag anchor or weighted anchor systems will be used for mooring cable positioning systems for service vessel. Confirm design basis and number of anchor points to allow a more detailed assessment of risk. [11] Confirm how anchor cable interference with the AFD will be prevented as the service vessel is moved / repositioned.	H	M	3		
				36	Too many Vessels on Station	Impact between service vessels with potential for a vessel to sink and impact the inlet heads or increased risk of impact with the inlet heads or AFD structure. Potential for vessel to sink leading to loss of life and environmental incident.	Control and planning of construction and service related activities.	[12] Confirm which approach is to be adopted for management of vessel position via cable system. Option two requires the vessel to be maintained over the Inlet Heads whilst to maintain one of the two banks of AFD panels.	H	M	3		
				39	Overweighting of crane or unstable lift.	Crane may collapse or slew, or vessel may capsize. May be exacerbated by sea and weather conditions. Damage to inlet heads or AFD structures. Potential for injury or fatality to vessel operatives or divers in water. Refer to Entries 1 and 9	All lifts will be controlled and assessed as per the requirements of the Project Lifting Plan and will take account of the load mass and sea conditions. Structures to be lifted will also be designed so as to limit lifting weight or size to accommodate more manageable lifts. All lifts will comply with the requirements of Lifting Operations Lifting Equipment Regulations (LOLER) – Offshore		H	M	3		
				40	Load or crane cable or vessel impacting with existing structures.	Damage to inlet heads or AFD structures. Potential for injury or fatality to vessel operatives of divers in water. Refer to Entry 1.	Procedural controls to manage movement and operations of boats and crane during construction and on maintenance activities. Specific procedural requirements will be in place for divers to retreat or to be removed from the work area when carrying out maintenance activities if lifting activities are taking place. Divers will also be wearing transponders to identify their position in the water. Transponder beacons on guide posts and on crane hook – to help the lift team to control the load. Vessel positions will be managed through the winch mooring system and navigational / survey system.	[13] Confirm that divers will not need to below the load at any time to assist in locating equipment e.g. AFD panels.	H	M	3		
	Installation of Base Frames: - Deploy guide post extensions on guide wires from construction vessel and attach to AFD stub guide posts - Deploy base frame (running on the guide wires) and land onto stub guide posts - Engage base frame lock-down pins - Disengage guide post extensions from stub interface post and retrieve to vessel ready for installation of next base frame	2 divers in the water max at any given time. 1 support diver on deck ready for intervention. ~1hour dive duration. **[estimated time of construction from the optineering report - but this is still being estimated/defined by the project]** ~1 day per structure (3 structures per side, 2 sides per head) = 6 days of diving time per head (mooring either side of this period) Divers rotate duties (team of 2 swap for another team of 2; the support diver can remain in support) There will be an initial survey dive before installation commences as well. It is thought that each head can be done in one visit from harbour to the work site.	Support diver is always ready for water entry when 1 or 2 other divers are in the water. Backup air supply. Procedures. Trials. Decompression chamber. All divers are medically trained (no specific medic). Support vessel (can do medivac quicker than the barge). Both vessels have watchers for collisions with other vessels. Standard nav aids.	2	Seasonal / Period Changes in Tide levels	Extreme variation in Tidal Range will inhibit diving related to construction and maintenance activities.	Maintenance / construction activities to be planned around known tidal cycles.	[1] Determine if there is a limit to AFD access in relation to min and max tidal height.	M	M	3	There is a 6 day restriction on diving windows. >5m mooring line clearance from structures is desired (derived from a 10m requirement for North Sea operations)	2. Navigation buoys move around due to the tides. There is potential that these will need to be lifted before maintenance to avoid conflicts with the anchor spread. This requires Trinity House involvement. The buoys would need to be replaced following AFD maintenance. This requirement needs to be factored into the work schedule and agreed as acceptable. 3. [**BV Subsea Engineer comment after workshop:** Consider designing base frame with one pole longer that the other to facilitate handling during installation of subsea equipment (secure the longest pole first and then rotate the frame to secure the second pole).] 4. [**BV Subsea Engineer comment after workshop:** Ensure that umbilical length is controlled from the support vessel during diving operation to avoid extra length of umbilical hanging around which could lead to snagging hazard.] 1. [**BV Subsea Engineer comment after workshop**: Consider providing heave compensator system to avoid uncontrolled movement of the load due to waves.]
				5	Strong or Sustained Currents	The Flood and Ebb tide currents will typically be too strong for diving operations, which would have a consequential knock on to construction and maintenance activities. Typically conditions for diving will be limited to 60 minutes around slack water. Potential for tasks not to be completed within the allotted dive window and or an increase in number of dives required to achieve construction or maintenance goals. AFD not available or performance compromised, which could result in enforcement action by the EA.	Design of AFD has been developed to allow simple construction installation and maintenance procedures to be used; including / allowing for working in reduced visibility conditions.	[2] Develop method statements / carry out critical task analysis to determine how construction and maintenance tasks can be suitably carried out within the available dive window, and / or staged to allow longer tasks to be paused between tidal cycles.	H	H	4		
				9	Extreme / Adverse Weather Event	Inability of surface vessels to work in adverse sea conditions Potential for construction / support vessels to lose positional control (Failure of Dynamic Positioning (DP) or mooring lines) with consequential impact with AFD or heads structure leading to damage to heads and AFD, loss of vessel - potential loss of life and or pollution incident.	Vessel operations will only be undertaken at suitable tide heights to ensure a suitable draft is maintained above the AFD and Inlet Heads (Ideally 3-4m above Inlet Heads, absolute minimum 1.5m). Larger clearances would be applied in adverse conditions.	[3] Establish safe operating limits for the vessel. This will include mechanisms for measuring position, cable tension and payout and maximum wind or sea state. This is to be included work method statement.	H	M	3		
				32	Cargo striking the AFD Note: Dropped loads could also come from service vessels e.g. Replacement AFD clusters being transferred from supply ship to maintenance vessel.	Impact with the AFD. Refer to Entry 1.	The AFD speakers are mounted in steel frames which offer some protection against general marine flotsam and debris. Any ship to ship transfers to be performed in a safe area away from the head location. Cargo or items on deck to be sea fastened. Guide wires / posts used to prevent impact on head.	[9] Determine what additional protection can be implemented against impact from large cargo items e.g. sea shipping containers.	H	M	3		
				35	Dragging of Anchor	Damage to the AFD power cables which may also cause further damage to transformer systems and the acoustic panels via pulling action. Potential for direct impact of anchor with above sea bed AFD systems. Anchor attachment cables may ensnare or strangle the AFD.	Power cables will be buried to a suitable depth in trenches and covered with armoured protection or infill as deemed required. The Burial depth will be considered against the anchor requirements for a 5000 tonne vessel which is the largest routine commercial shipping operation close to the Inlet Heads / AFD (Goes into and out of Bridgewater). Operational vessels associated with the maintenance of the AFD will be managed in terms of maximum size and anchor weight, and movements and anchor positions will be controlled to avoid cables. Area is part of wider restricted area which is controlled by the Bridgwater Bay Harbour Master.	[10] The designers have not confirmed whether drag anchor or weighted anchor systems will be used for mooring cable positioning systems for service vessel. Confirm design basis and number of anchor points to allow a more detailed assessment of risk. [11] Confirm how anchor cable interference with the AFD will be prevented as the service vessel is moved / repositioned.	H	M	3		
				39	Overweighting of crane or unstable lift.	Crane may collapse or slew, or vessel may capsize. May be exacerbated by sea and weather conditions. Damage to inlet heads or AFD structures. Potential for injury or fatality to vessel operatives or divers in water. Refer to Entries 1 and 9	All lifts will be controlled and assessed as per the requirements of the Project Lifting Plan and will take account of the load mass and sea conditions. Structures to be lifted will also be designed so as to limit lifting weight or size to accommodate more manageable lifts. All lifts will comply with the requirements of Lifting Operations Lifting Equipment Regulations (LOLER) – Offshore		H	M	3		
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				52	Snagging with AFD structure	Diving during construction and or routine / corrective maintenance; diver becomes trapped - potential injury or fatality.	Dives will only be undertaken with a Standby diver ready enter the water if the working diver becomes entangled. General entanglement issues will most likely impact the diver umbilical hose, which will be subject to hose management good practice.	[15] Develop umbilical management plan. [16] Confirm how a diver would escape if the umbilical could not be freed i.e. could umbilical be released, and a diver return to the diver basket using the mergency breathing gas bottle supply?	H	M	3		

AFD Maintenance Worksheet

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				53	Strong currents / Rough Seas	Diving during construction and or routine / corrective maintenance - potential injury or fatality due to impact with structures or being swept away from the designated dive area.	Divers will only be in water around slack water (Approximately 1 hour window) and in stable and suitably flat sea conditions. A maximum sea state condition will be defined for water entry (typically 1 - 1.5m wave height). Support vessel is available for diver pickup if they have been swept away from the AFD area. However, this should not generally be possible unless too much umbilical has been paid out.		H	M	3		
				56	High Water Turbidity	Inability to see underwater, potential entanglement / disorientation leading to injury or fatality.	Dives will be risk assessed for the task being carried out to determine suitability of working in limited visibility. The installation and maintenance of the AFD system or panels has been designed so as to make it easier for dives to accomplish in low visibility i.e. tool-less engagement systems. Divers will be carry task lighting but this may be of limited use given the very poor visibility for the site. Acoustic imaging cameras are proposed to be carried by the divers. These will relay pictures to the top side support crew which will allow them to direct the diver's movements, to aid in completion of tasks for each operation.		H	H	4		
	Installation of Sound Projector Cluster Frames: - Deploy guide post extensions on guide wires from construction vessel and attach to base frame guide posts - Deploy SP cluster frame (running on the guide wires) and land onto base frame guide posts - Activate SP cluster frame lockdown devices (if applicable) - Disengage guide post extensions from base frame guide posts and retrieve to vessel ready for installation of next SP frame	2 divers in the water max at any given time. 1 support diver on deck ready for intervention. ~1hour dive duration. **[estimated time of maintenance from the optineering report - but this is still being estimated/defined by the project]** ~1 day per cluster (6 clusters per side, 2 sides per head) = 12 days of diving time per head (mooring either side of this period) Divers rotate duties (team of 2 swap for another team of 2; the support diver can remain in support) There will be an initial survey dive before installation commences as well. Each head requires 2 visits in total.	Support diver is always ready for water entry when 1 or 2 other divers are in the water. Backup air supply. Procedures. Trials. Decompression chamber. All divers are medically trained (no specific medic). Support vessel (can do medivac quicker than the barge). Both vessels have watchers for collisions with other vessels. Standard nav aids.	2	Seasonal / Period Changes in Tide levels	Extreme variation in Tidal Range will inhibit diving related to construction and maintenance activities.	Maintenance / construction activities to be planned around known tidal cycles.	[1] Determine if there is a limit to AFD access in relation to min and max tidal height.	M	M	3	Refer above.	Refer above.
				5	Strong or Sustained Currents	The Flood and Ebb tide currents will typically be too strong for diving operations, which would have a consequential knock on to construction and maintenance activities. Typically conditions for diving will be limited to 60 minutes around slack water. Potential for tasks not to be completed within the allotted dive window and or an increase in number of dives required to achieve construction or maintenance goals. AFD not available or performance compromised, which could result in enforcement action by the EA.	Design of AFD has been developed to allow simple construction installation and maintenance procedures to be used; including / allowing for working in reduced visibility conditions.	[2] Develop method statements / carry out critical task analysis to determine how construction and maintenance tasks can be suitably carried out within the available dive window, and / or staged to allow longer tasks to be paused between tidal cycles.	H	H	4		
				9	Extreme / Adverse Weather Event	Inability of surface vessels to work in adverse sea conditions Potential for construction / support vessels to lose positional control (Failure of Dynamic Positioning (DP) or mooring lines) with consequential impact with AFD or heads structure leading to damage to heads and AFD, loss of vessel - potential loss of life and or pollution incident.	Vessel operations will only be undertaken at suitable tide heights to ensure a suitable draft is maintained above the AFD and Inlet Heads (Ideally 3-4m above Inlet Heads, absolute minimum 1.5m). Larger clearances would be applied in adverse conditions.	[3] Establish safe operating limits for the vessel. This will include mechanisms for measuring position, cable tension and payout and maximum wind or sea state. This is to be included work method statement.	H	M	3		
				32	Cargo striking the AFD Note: Dropped loads could also come from service vessels e.g. Replacement AFD clusters being transferred from supply ship to maintenance vessel.	Impact with the AFD. Refer to Entry 1.	The AFD speakers are mounted in steel frames which offer some protection against general marine flotsam and debris. Any ship to ship transfers to be performed in a safe area away from the head location. Cargo or items on deck to be sea fastened. Guide wires / posts used to prevent impact on head.	[9] Determine what additional protection can be implemented against impact from large cargo items e.g. sea shipping containers.	H	M	3		
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				56	High Water Turbidity	Inability to see underwater, potential entanglement / disorientation leading to injury or fatality.	Dives will be risk assessed for the task being carried out to determine suitability of working in limited visibility. The installation and maintenance of the AFD system or panels has been designed so as to make it easier for dives to accomplish in low visibility i.e. tool-less engagement systems. Divers will be carry task lighting but this may be of limited use given the very poor visibility for the site. Acoustic imaging cameras are proposed to be carried by the divers. These will relay pictures to the top side support crew which will allow them to direct the diver's movements, to aid in completion of tasks for each operation.		H	H	4		

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	Power / Communication Cable Installation: - Install Controls Distribution Unit (CDU) by guide wire on to central base frame supports - Install Electrical Flying Leads (EFLs) between CDU and cluster electrical distribution boxes	2 divers in the water max at any given time. 1 support diver on deck ready for intervention. ~1hour dive duration. **[estimated time of maintenance from the optineering report - but this is still being estimated/defined by the project]** For the two CDUs, 2 dives per CDU required. For the EFLs, based on the clipping option of cable fixing, this could be one trip by itself. ~1 day per jumper lead (6 jumpers per side) = 12 days of diving time per head (mooring either side of this period) - this requires 2 visits in total. Divers rotate duties (team of 2 swap for another team of 2; the support diver can remain in support) There will be an initial survey dive before installation commences as well. Total of 3 visits are envisaged per head (but there is a chance this could possibly be done in 2 x 6 day visits).	Support diver is always ready for water entry when 1 or 2 other divers are in the water. Backup air supply. Procedures. Trials. Decompression chamber. All divers are medically trained (no specific medic). Support vessel (can do medivac quicker than the barge). Both vessels have watchers for collisions with other vessels. Standard nav aids.	5	Strong or Sustained Currents	The Flood and Ebb tide currents will typically be too strong for diving operations, which would have a consequential knock on to construction and maintenance activities. Typically conditions for diving will be limited to 60 minutes around slack water. Potential for tasks not to be completed within the allotted dive window and or an increase in number of dives required to achieve construction or maintenance goals. AFD not available or performance compromised, which could result in enforcement action by the EA.	Design of AFD has been developed to allow simple construction installation and maintenance procedures to be used; including / allowing for working in reduced visibility conditions.	[2] Develop method statements / carry out critical task analysis to determine how construction and maintenance tasks can be suitably carried out within the available dive window, and / or staged to allow longer tasks to be paused between tidal cycles.	H	H	4	Air bag lifting is not recommended for use in low visibility conditions, particularly considering the tidal conditions too.	5. The sequencing of the CDU and ubmilical needs to be defined. More information about the size and mass of this equipment is needed to inform the choice of method for installation. 4. [**BV Subsea Engineer comment after workshop:** Ensure that umbilical length is controlled from the support vessel during diving operation to avoid extra length of umbilical hanging around which could lead to snagging hazard.] 1. [**BV Subsea Engineer comment after workshop:** Consider providing heave compensator system to avoid uncontrolled movement of the load due to waves.]
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				32	Cargo striking the AFD Note: Dropped loads could also come from service vessels e.g. Replacement AFD clusters being transferred from supply ship to maintenance vessel.	Impact with the AFD. Refer to Entry 1.	The AFD speakers are mounted in steel frames which offer some protection against general marine flotsam and debris. Any ship to ship transfers to be performed in a safe area away from the head location. Cargo or items on deck to be sea fastened. Guide wires / posts used to prevent impact on head.	[9] Determine what additional protection can be implemented against impact from large cargo items e.g. sea shipping containers.	H	M	3		
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				53	Strong currents / Rough Seas	Diving during construction and or routine / corrective maintenance - potential injury or fatality due to impact with structures or being swept away from the designated dive area.	Divers will only be in water around slack water (Approximately 1 hour window) and in stable and suitably flat sea conditions. A maximum sea state condition will be defined for water entry (typically 1 - 1.5m wave height). Support vessel is available for diver pickup if they have been swept away from the AFD area. However, this should not generally be possible unless too much umbilical has been paid out.		H	M	3		
				56	High Water Turbidity	Inability to see underwater, potential entanglement / disorientation leading to injury or fatality.	Dives will be risk assessed for the task being carried out to determine suitability of working in limited visibility. The installation and maintenance of the AFD system or panels has been designed so as to make it easier for dives to accomplish in low visibility i.e. tool-less engagement systems. Divers will be carry task lighting but this may be of limited use given the very poor visibility for the site. Acoustic imaging cameras are proposed to be carried by the divers. These will relay pictures to the top side support crew which will allow them to direct the diver's movements, to aid in completion of tasks for each operation.		H	H	4		
Maintenance	Sound projector replacement - see Installation	2 divers in the water max at any given time. 1 support diver on deck ready for intervention. ~1hour dive duration. **[estimated time of maintenance from optineering report]** ~1 day per cluster (6 clusters per side, 2 sides per head) = 12 days of diving time per head (mooring either side of this period) Divers rotate duties (team of 2 swap for another team of 2; the support diver can remain in support) There will be an initial survey dive before installation commences as well. Each head requires 2 visits in total.	Support diver is always ready for water entry when 1 or 2 other divers are in the water. Backup air supply. Procedures. Trials. Decompression chamber. All divers are medically trained (no specific medic). Support vessel (can do medivac quicker than the barge). Both vessels have watchers for collisions with other vessels. Standard nav aids.	30	Simultaneous Operations (SIMOPS)	Injury to divers i.e. hearing damage, if in water whilst AFD is operating.	Diver activities will not take place whilst the AFD which is being worked on is active. Electrical systems to be isolated under permit to work system.	[6] Determine whether there is a risk to a diver if one of the Inlet Heads is operating with its associated AFD active / operating, whilst a different / adjacent AFD (Which will be switched off) is being maintained / being worked on.	H	M	3	Mooring lines broke twice during the UXO survey campaign (3 months long). If this happens during operation (maintenance), the intake head will need to be inspected to demonstrate that it has not been damaged (because it is nuclear safety classified).	6. Lifting can only be carried out at high water slack, but diving can still be done at low water (but the vessel may have to be repositioned because of the reduced clearance). This needs to be confirmed following the ongoing analysis, and confirmed as acceptable with the vessel captain. The present analysis has made some assumptions about dive windows which will need to be validated when dive windows are confirmed. 7. The potential to have to notify the nuclear safety authority following intake head impact (because the intake heads are nuclear safety classified) is a project risk with the ultimate consequence of plant shutdown. This should be covered in operational documentation. 4. [**BV Subsea Engineer comment after workshop:** Ensure that umbilical length is controlled from the support vessel during diving operation to avoid extra length of umbilical hanging around which could lead to snagging hazard.]
				32	Cargo striking the AFD Note: Dropped loads could also come from service vessels e.g. Replacement AFD clusters being transferred from supply ship to maintenance vessel.	Impact with the AFD. Refer to Entry 1.	The AFD speakers are mounted in steel frames which offer some protection against general marine flotsam and debris. Any ship to ship transfers to be performed in a safe area away from the head location. Cargo or items on deck to be sea fastened. Guide wires / posts used to prevent impact on head.	[9] Determine what additional protection can be implemented against impact from large cargo items e.g. sea shipping containers.	H	M	3		
				35	Dragging of Anchor	Damage to the AFD power cables which may also cause further damage to transformer systems and the acoustic panels via pulling action. Potential for direct impact of anchor with above sea bed AFD systems. Anchor attachment cables may ensnare or strangle the AFD.	Power cables will be buried to a suitable depth in trenches and covered with armoured protection or infill as deemed required. The Burial depth will be considered against the anchor requirements for a 5000 tonne vessel which is the largest routine commercial shipping operation close to the Inlet Heads / AFD (Goes into and out of Bridgewater). Operational vessels associated with the maintenance of the AFD will be managed in terms of maximum size and anchor weight, and movements and anchor positions will be controlled to avoid cables. Area is part of wider restricted area which is controlled by the Bridgwater Bay Harbour Master.	[10] The designers have not confirmed whether drag anchor or weighted anchor systems will be used for mooring cable positioning systems for service vessel. Confirm design basis and number of anchor points to allow a more detailed assessment of risk. [11] Confirm how anchor cable interference with the AFD will be prevented as the service vessel is moved / repositioned.	H	M	3		

AFD Maintenance Worksheet

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				New (This line was added in the BV workshop)	Mooring line breakage	Potential for the broken mooring line to impact the AFD and intake head. The boat may shift, thereby dragging a remaining line or basket which could impact the intake head. The vessel may become unstable leading to the ultimate consequence of injury to the diver (if in the water) or in the very worst case the boat may sink if it hits the intake head. Any impact to the intake head would require a notification to the nuclear safety authority and follow-up inspections.	The chosen vessel should be able to operate on 3 point mooring. The basket will be raised once diver is in the water.	None made.	H	M	3		1. [**BV Subsea Engineer comment after workshop:** Consider providing heave compensator system to avoid uncontrolled movement of the load due to waves.]
				36	Too many Vessels on Station	Impact between service vessels with potential for a vessel to sink and impact the inlet heads or increased risk of impact with the inlet heads or AFD structure. Potential for vessel to sink leading to loss of life and environmental incident.	Control and planning of construction and service related activities.	[12] Confirm which approach is to be adopted for management of vessel position via cable system. Option two requires the vessel to be maintained over the Inlet Heads whilst to maintain one of the two banks of AFD panels.	H	M	3		
				39	Overweighting of crane or unstable lift.	Crane may collapse or slew, or vessel may capsize. May be exacerbated by sea and weather conditions. Damage to inlet heads or AFD structures. Potential for injury or fatality to vessel operatives or divers in water. Refer to Entries 1 and 9	All lifts will be controlled and assessed as per the requirements of the Project Lifting Plan and will take account of the load mass and sea conditions. Structures to be lifted will also be designed so as to limit lifting weight or size to accommodate more manageable lifts. All lifts will comply with the requirements of Lifting Operations Lifting Equipment Regulations (LOLER) – Offshore		H	M	3		
				40	Load or crane cable or vessel impacting with existing structures.	Damage to inlet heads or AFD structures. Potential for injury or fatality to vessel operatives of divers in water. Refer to Entry 1.	Procedural controls to manage movement and operations of boats and crane during construction and on maintenance activities. Specific procedural requirements will be in place for divers to retreat or to be removed from the work area when carrying out maintenance activities if lifting activities are taking place. Divers will also be wearing transponders to identify their position in the water. Transponder beacons on guide posts and on crane hook – to help the lift team to control the load. Vessel positions will be managed through the winch mooring system and navigational / survey system.	[13] Confirm that divers will not need to below the load at any time to assist in locating equipment e.g. AFD panels.	H	M	3		
				52	Snagging with AFD structure	Diving during construction and or routine / corrective maintenance; diver becomes trapped - potential injury or fatality.	Dives will only be undertaken with a Standby diver ready enter the water if the working diver becomes entangled. General entanglement issues will most likely impact the diver umbilical hose, which will be subject to hose management good practice.	[15] Develop umbilical management plan. [16] Confirm how a diver would escape if the umbilical could not be freed i.e. could umbilical be released, and a diver return to the diver basket using the mergency breathing gas bottle supply?	H	M	3		
				53	Strong currents / Rough Seas	Diving during construction and or routine / corrective maintenance - potential injury or fatality due to impact with structures or being swept away from the designated dive area.	Divers will only be in water around slack water (Approximately 1 hour window) and in stable and suitably flat sea conditions. A maximum sea state condition will be defined for water entry (typically 1 - 1.5m wave height). Support vessel is available for diver pickup if they have been swept away from the AFD area. However, this should not generally be possible unless too much umbilical has been paid out.		H	M	3		
				56	High Water Turbidity	Inability to see underwater, potential entanglement / disorientation leading to injury or fatality.	Dives will be risk assessed for the task being carried out to determine suitability of working in limited visibility. The installation and maintenance of the AFD system or panels has been designed so as to make it easier for dives to accomplish in low visibility i.e. tool-less engagement systems. Divers will be carry task lighting but this may be of limited use given the very poor visibility for the site. Acoustic imaging cameras are proposed to be carried by the divers. These will relay pictures to the top side support crew which will allow them to direct the diver's movements, to aid in completion of tasks for each operation.		H	H	4		
				58	There is a requirement from the site operator to always have some flow through the Inlet Heads i.e. to maintain a least one running inlet pump. This could result in a diver being pinned against water intake grill by differential pressure created by water flow.	Inability to escape from grill, potential injury or fatality. Requirement to send out rescue diver(s) who could also become 'pinned' to the grill.	The maximum design criteria for intake velocity is 0.3 m/s. The generally accepted maximum allowable current for diving in is 0.5 m/s.	[17] Carry out an analysis and risk assessment of diver entrapment against the intake grills of an operating intake head. The risk assessment to be carried out in-line with International Maritime Contractors Association (IMCA) guidelines. (Include discussions with HSE). Note: The IMCA guidelines do not support diving activities around active water intake systems and therefore a deviation would be required if this activity were to take place.	H	H	4		
	Visits to the power hub for AFD power isolation	Visits to the offshore hub to isolate the power supply to the AFD being maintained. See Power Hub sheet, 'Regular maintenance at the power hub (supply boat)' for details of a single trip, one person.	Additional resource is required to visit the power hub to make this isolation/deisolation. The isolation philosophy has not been determined for one/all heads and for the whole duration while the barge is in place/only when a diver is in the water. This affects the number of visits required **[HOLD]**.	None									8. Additional resource is required to visit the power hub to make AFD isolation/deisolation before/after AFD maintenance. The isolation philosophy has not been determined for one/all heads and for the whole duration while the barge is in place/only when a diver is in the water. This affects the number of visits required and needs to be defined.
	Anode replacement (in dry environment) see installation	This activity is done onshore so is not relevant for the present analysis.	N/A	30	Simultaneous Operations (SIMOPS)	Injury to divers i.e. hearing damage, if in water whilst AFD is operating.	Diver activities will not take place whilst the AFD which is being worked on is active. Electrical systems to be isolated under permit to work system.	[6] Determine whether there is a risk to a diver if one of the Inlet Heads is operating with its associated AFD active / operating, whilst a different / adjacent AFD (Which will be switched off) is being maintained / being worked on.	H	M	3		
				32	Cargo striking the AFD Note: Dropped loads could also come from service vessels e.g. Replacement AFD clusters being transferred from supply ship to maintenance vessel.	Impact with the AFD. Refer to Entry 1.	The AFD speakers are mounted in steel frames which offer some protection against general marine flotsam and debris. Any ship to ship transfers to be performed in a safe area away from the head location. Cargo or items on deck to be sea fastened. Guide wires / posts used to prevent impact on head.	[9] Determine what additional protection can be implemented against impact from large cargo items e.g. sea shipping containers.	H	M	3		
				35	Dragging of Anchor	Damage to the AFD power cables which may also cause further damage to transformer systems and the acoustic panels via pulling action. Potential for direct impact of anchor with above sea bed AFD systems. Anchor attachment cables may ensnare or strangle the AFD.	Power cables will be buried to a suitable depth in trenches and covered with armoured protection or infill as deemed required. The Burial depth will be considered against the anchor requirements for a 5000 tonne vessel which is the largest routine commercial shipping operation close to the Inlet Heads / AFD (Goes into and out of Bridgewater). Operational vessels associated with the maintenance of the AFD will be managed in terms of maximum size and anchor weight, and movements and anchor positions will be controlled to avoid cables. Area is part of wider restricted area which is controlled by the Bridgwater Bay Harbour Master.	[10] The designers have not confirmed whether drag anchor or weighted anchor systems will be used for mooring cable positioning systems for service vessel. Confirm design basis and number of anchor points to allow a more detailed assessment of risk. [11] Confirm how anchor cable interference with the AFD will be prevented as the service vessel is moved / repositioned.	H	M	3		
				36	Too many Vessels on Station	Impact between service vessels with potential for a vessel to sink and impact the inlet heads or increased risk of impact with the inlet heads or AFD structure. Potential for vessel to sink leading to loss of life and environmental incident.	Control and planning of construction and service related activities.	[12] Confirm which approach is to be adopted for management of vessel position via cable system. Option two requires the vessel to be maintained over the Inlet Heads whilst to maintain one of the two banks of AFD panels.	H	M	3		

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Phase	Task	Resources required to perform the task	Safety support resources	HAZID Sc. Ref.	Main Hazard identified	Consequence	Safeguard / Mitigation	HAZID recommendation	S	L	R	Lesson learned / Feedback	Workshop recommendation
				39	Overweighting of crane or unstable lift.	Crane may collapse or slew, or vessel may capsize. May be exacerbated by sea and weather conditions. Damage to inlet heads or AFD structures. Potential for injury or fatality to vessel operatives or divers in water. Refer to Entries 1 and 9	All lifts will be controlled and assessed as per the requirements of the Project Lifting Plan and will take account of the load mass and sea conditions. Structures to be lifted will also be designed so as to limit lifting weight or size to accommodate more manageable lifts. All lifts will comply with the requirements of Lifting Operations Lifting Equipment Regulations (LOLER) – Offshore		H	M	3		
				40	Load or crane cable or vessel impacting with existing structures.	Damage to inlet heads or AFD structures. Potential for injury or fatality to vessel operatives of divers in water. Refer to Entry 1.	Procedural controls to manage movement and operations of boats and crane during construction and on maintenance activities. Specific procedural requirements will be in place for divers to retreat or to be removed from the work area when carrying out maintenance activities if lifting activities are taking place. Divers will also be wearing transponders to identify their position in the water. Transponder beacons on guide posts and on crane hook – to help the lift team to control the load. Vessel positions will be managed through the winch mooring system and navigational / survey system.	[13] Confirm that divers will not need to below the load at any time to assist in locating equipment e.g. AFD panels.	H	M	3		
				52	Snagging with AFD structure	Diving during construction and or routine / corrective maintenance; diver becomes trapped - potential injury or fatality.	Dives will only be undertaken with a Standby diver ready enter the water if the working diver becomes entangled. General entanglement issues will most likely impact the diver umbilical hose, which will be subject to hose management good practice.	[15] Develop umbilical management plan. [16] Confirm how a diver would escape if the umbilical could not be freed i.e. could umbilical be released, and a diver return to the diver basket using the mergency breathing gas bottle supply?	H	M	3		
				53	Strong currents / Rough Seas	Diving during construction and or routine / corrective maintenance - potential injury or fatality due to impact with structures or being swept away from the designated dive area.	Divers will only be in water around slack water (Approximately 1 hour window) and in stable and suitably flat sea conditions. A maximum sea state condition will be defined for water entry (typically 1 - 1.5m wave height). Support vessel is available for diver pickup if they have been swept away from the AFD area. However, this should not generally be possible unless too much umbilical has been paid out.		H	M	3		
				56	High Water Turbidity	Inability to see underwater, potential entanglement / disorientation leading to injury or fatality.	Dives will be risk assessed for the task being carried out to determine suitability of working in limited visibility. The installation and maintenance of the AFD system or panels has been designed so as to make it easier for dives to accomplish in low visibility i.e. tool-less engagement systems. Divers will be carry task lighting but this may be of limited use given the very poor visibility for the site. Acoustic imaging cameras are proposed to be carried by the divers. These will relay pictures to the top side support crew which will allow them to direct the diver's movements, to aid in completion of tasks for each operation.		H	H	4		
				58	There is a requirement from the site operator to always have some flow through the Inlet Heads i.e. to maintain a least one running inlet pump. This could result in a diver being pinned against water intake grill by differential pressure created by water flow.	Inability to escape from grill, potential injury or fatality. Requirement to send out rescue diver(s) who could also become 'pinned' to the grill.	The maximum design criteria for intake velocity is 0.3 m/s. The generally accepted maximum allowable current for diving in is 0.5 m/s.	[17] Carry out an analysis and risk assessment of diver entrapment against the intake grills of an operating intake head. The risk assessment to be carried out in-line with International Maritime Contractors Association (IMCA) guidelines. (Include discussions with HSE). Note: The IMCA guidelines do not support diving activities around active water intake systems and therefore a deviation would be required if this activity were to take place.	H	H	4		
	Anode replacement (by divers)	No replacement by the divers is planned. Inspection of anodes is covered under other inspection activities.	N/A	30	Simultaneous Operations (SIMOPS)	Injury to divers i.e. hearing damage, if in water whilst AFD is operating.	Diver activities will not take place whilst the AFD which is being worked on is active. Electrical systems to be isolated under permit to work system.	[6] Determine whether there is a risk to a diver if one of the Inlet Heads is operating with its associated AFD active / operating, whilst a different / adjacent AFD (Which will be switched off) is being maintained / being worked on.	H	M	3		
				32	Cargo striking the AFD Note: Dropped loads could also come from service vessels e.g. Replacement AFD clusters being transferred from supply ship to maintenance vessel.	Impact with the AFD. Refer to Entry 1.	The AFD speakers are mounted in steel frames which offer some protection against general marine flotsam and debris. Any ship to ship transfers to be performed in a safe area away from the head location. Cargo or items on deck to be sea fastened. Guide wires / posts used to prevent impact on head.	[9] Determine what additional protection can be implemented against impact from large cargo items e.g. sea shipping containers.	H	M	3		
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				36	Too many Vessels on Station	Impact between service vessels with potential for a vessel to sink and impact the inlet heads or increased risk of impact with the inlet heads or AFD structure. Potential for vessel to sink leading to loss of life and environmental incident.	Control and planning of construction and service related activities.	[12] Confirm which approach is to be adopted for management of vessel position via cable system. Option two requires the vessel to be maintained over the Inlet Heads whilst to maintain one of the two banks of AFD panels.	H	M	3		
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	Electrical cable replacement (and CDU replacement)	Only CDUs and flying leads covered in this analysis. 2 divers in the water max at any given time. 1 support diver on deck ready for intervention. ~1hour dive duration. **[estimated time of maintenance from optineering report - this is still being estimated/defined by the project. The OPEX estimates give individual swap out frequency for components]** For the two CDUs, 4 days per CDU required. Maintenance once/twice in the life of the plant. This can be done in 1 visit per head. For the EFLs, based on the clipping option of cable fixing. ~2 day per jumper lead (6 jumpers per side) = 24 days of diving time per head (mooring either side of this period) - this requires 4 vessel visits in total. Maintenance once/twice in the life of the plant. Divers rotate duties (team of 2 swap for another team of 2; the support diver can remain in support) There will be an initial survey dive before installation commences as well. Total of 5 visits is envisaged once/twice during plant lifetime (per head).	Support diver is always ready for water entry when 1 or 2 other divers are in the water. Backup air supply. Procedures. Trials. Decompression chamber. All divers are medically trained (no specific medic). Support vessel (can do medivac quicker than the barge). Both vessels have watchers for collisions with other vessels. Standard nav aids.	30	Simultaneous Operations (SIMOPS)	Injury to divers i.e. hearing damage, if in water whilst AFD is operating.	Diver activities will not take place whilst the AFD which is being worked on is active. Electrical systems to be isolated under permit to work system.	[6] Determine whether there is a risk to a diver if one of the Inlet Heads is operating with its associated AFD active / operating, whilst a different / adjacent AFD (Which will be switched off) is being maintained / being worked on.	H	M	3		
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				52	Snagging with AFD structure	Diving during construction and or routine / corrective maintenance; diver becomes trapped - potential injury or fatality.	Dives will only be undertaken with a Standby diver ready enter the water if the working diver becomes entangled. General entanglement issues will most likely impact the diver umbilical hose, which will be subject to hose management good practice.	[15] Develop umbilical management plan. [16] Confirm how a diver would escape if the umbilical could not be freed i.e. could umbilical be released, and a diver return to the diver basket using the mergency breathing gas bottle supply?	H	M	3		
				53	Strong currents / Rough Seas	Diving during construction and or routine / corrective maintenance - potential injury or fatality due to impact with structures or being swept away from the designated dive area.	Divers will only be in water around slack water (Approximately 1 hour window) and in stable and suitably flat sea conditions. A maximum sea state condition will be defined for water entry (typically 1 - 1.5m wave height). Support vessel is available for diver pickup if they have been swept away from the AFD area. However, this should not generally be possible unless too much umbilical has been paid out.		H	M	3		
				56	High Water Turbidity	Inability to see underwater, potential entanglement / disorientation leading to injury or fatality.	Dives will be risk assessed for the task being carried out to determine suitability of working in limited visibility. The installation and maintenance of the AFD system or panels has been designed so as to make it easier for dives to accomplish in low visibility i.e. tool-less engagement systems. Divers will be carry task lighting but this may be of limited use given the very poor visibility for the site. Acoustic imaging cameras are proposed to be carried by the divers. These will relay pictures to the top side support crew which will allow them to direct the diver's movements, to aid in completion of tasks for each operation.		H	H	4		
				58	There is a requirement from the site operator to always have some flow through the Inlet Heads i.e. to maintain a least one running inlet pump. This could result in a diver being pinned against water intake grill by differential pressure created by water flow.	Inability to escape from grill, potential injury or fatality. Requirement to send out rescue diver(s) who could also become 'pinned' to the grill.	The maximum design criteria for intake velocity is 0.3 m/s. The generally accepted maximum allowable current for diving in is 0.5 m/s.	[17] Carry out an analysis and risk assessment of diver entrapment against the intake grills of an operating intake head. The risk assessment to be carried out in-line with International Maritime Contractors Association (IMCA) guidelines. (Include discussions with HSE). Note: The IMCA guidelines do not support diving activities around active water intake systems and therefore a deviation would be required if this activity were to take place.	H	H	4		

AFD Maintenance Worksheet

Phase	Task	Resources required to perform the task	Safety support resources	HAZID Sc. Ref.	Main Hazard identified	Consequence	Safeguard / Mitigation	HAZID recommendation	S	L	R	Lesson learned / Feedback	Workshop recommendation
	Cleaning / Marine growth removal	This is not expected to be a problem, but there is still potential for marine growth. Marine growth on the base frames may present a problem for cluster removal and inspection. Growth on the speakers will be dealt with during refurbishment onshore. The effect of growth is considered only to slow other operations down, rather than requiring specific attention for cleaning. This operation has not been considered separately for the present analysis, but could increase the operation durations for other lines.	N/A	30	Simultaneous Operations (SIMOPS)	Injury to divers i.e. hearing damage, if in water whilst AFD is operating.	Diver activities will not take place whilst the AFD which is being worked on is active. Electrical systems to be isolated under permit to work system.	[6] Determine whether there is a risk to a diver if one of the Inlet Heads is operating with its associated AFD active / operating, whilst a different / adjacent AFD (Which will be switched off) is being maintained / being worked on.	H	M	3	Very little marine growth was observed during the UXO surveys, although there were limited structures to which the growth could adhere. This was attributed to the high current velocity.	
				32	Cargo striking the AFD Note: Dropped loads could also come from service vessels e.g. Replacement AFD clusters being transferred from supply ship to maintenance vessel.	Impact with the AFD. Refer to Entry 1.	The AFD speakers are mounted in steel frames which offer some protection against general marine flotsam and debris. Any ship to ship transfers to be performed in a safe area away from the head location. Cargo or items on deck to be sea fastened. Guide wires / posts used to prevent impact on head.	[9] Determine what additional protection can be implemented against impact from large cargo items e.g. sea shipping containers.	H	M	3		
				35	Dragging of Anchor	Damage to the AFD power cables which may also cause further damage to transformer systems and the acoustic panels via pulling action. Potential for direct impact of anchor with above sea bed AFD systems. Anchor attachment cables may ensnare or strangle the AFD.	Power cables will be buried to a suitable depth in trenches and covered with armoured protection or infill as deemed required. The Burial depth will be considered against the anchor requirements for a 5000 tonne vessel which is the largest routine commercial shipping operation close to the Inlet Heads / AFD (Goes into and out of Bridgewater). Operational vessels associated with the maintenance of the AFD will be managed in terms of maximum size and anchor weight, and movements and anchor positions will be controlled to avoid cables. Area is part of wider restricted area which is controlled by the Bridgwater Bay Harbour Master.	[10] The designers have not confirmed whether drag anchor or weighted anchor systems will be used for mooring cable positioning systems for service vessel. Confirm design basis and number of anchor points to allow a more detailed assessment of risk. [11] Confirm how anchor cable interference with the AFD will be prevented as the service vessel is moved / repositioned.	H	M	3		
				36	Too many Vessels on Station	Impact between service vessels with potential for a vessel to sink and impact the inlet heads or increased risk of impact with the inlet heads or AFD structure. Potential for vessel to sink leading to loss of life and environmental incident.	Control and planning of construction and service related activities.	[12] Confirm which approach is to be adopted for management of vessel position via cable system. Option two requires the vessel to be maintained over the Inlet Heads whilst to maintain one of the two banks of AFD panels.	H	M	3		
				39	Overweighting of crane or unstable lift.	Crane may collapse or slew, or vessel may capsize. May be exacerbated by sea and weather conditions. Damage to inlet heads or AFD structures. Potential for injury or fatality to vessel operatives or divers in water. Refer to Entries 1 and 9	All lifts will be controlled and assessed as per the requirements of the Project Lifting Plan and will take account of the load mass and sea conditions. Structures to be lifted will also be designed so as to limit lifting weight or size to accommodate more manageable lifts. All lifts will comply with the requirements of Lifting Operations Lifting Equipment Regulations (LOLER) – Offshore		H	M	3		
				40	Load or crane cable or vessel impacting with existing structures.	Damage to inlet heads or AFD structures. Potential for injury or fatality to vessel operatives of divers in water. Refer to Entry 1.	Procedural controls to manage movement and operations of boats and crane during construction and on maintenance activities. Specific procedural requirements will be in place for divers to retreat or to be removed from the work area when carrying out maintenance activities if lifting activities are taking place. Divers will also be wearing transponders to identify their position in the water. Transponder beacons on guide posts and on crane hook – to help the lift team to control the load. Vessel positions will be managed through the winch mooring system and navigational / survey system.	[13] Confirm that divers will not need to below the load at any time to assist in locating equipment e.g. AFD panels.	H	M	3		
				52	Snagging with AFD structure	Diving during construction and or routine / corrective maintenance; diver becomes trapped - potential injury or fatality.	Dives will only be undertaken with a Standby diver ready enter the water if the working diver becomes entangled. General entanglement issues will most likely impact the diver umbilical hose, which will be subject to hose management good practice.	[15] Develop umbilical management plan. [16] Confirm how a diver would escape if the umbilical could not be freed i.e. could umbilical be released, and a diver return to the diver basket using the mergency breathing gas bottle supply?	H	M	3		
				53	Strong currents / Rough Seas	Diving during construction and or routine / corrective maintenance - potential injury or fatality due to impact with structures or being swept away from the designated dive area.	Divers will only be in water around slack water (Approximately 1 hour window) and in stable and suitably flat sea conditions. A maximum sea state condition will be defined for water entry (typically 1 - 1.5m wave height). Support vessel is available for diver pickup if they have been swept away from the AFD area. However, this should not generally be possible unless too much umbilical has been paid out.		H	M	3		
				56	High Water Turbidity	Inability to see underwater, potential entanglement / disorientation leading to injury or fatality.	Dives will be risk assessed for the task being carried out to determine suitability of working in limited visibility. The installation and maintenance of the AFD system or panels has been designed so as to make it easier for dives to accomplish in low visibility i.e. tool-less engagement systems. Divers will be carry task lighting but this may be of limited use given the very poor visibility for the site. Acoustic imaging cameras are proposed to be carried by the divers. These will relay pictures to the top side support crew which will allow them to direct the diver's movements, to aid in completion of tasks for each operation.		H	H	4		
				58	There is a requirement from the site operator to always have some flow through the Inlet Heads i.e. to maintain a least one running inlet pump. This could result in a diver being pinned against water intake grill by differential pressure created by water flow.	Inability to escape from grill, potential injury or fatality. Requirement to send out rescue diver(s) who could also become 'pinned' to the grill.	The maximum design criteria for intake velocity is 0.3 m/s. The generally accepted maximum allowable current for diving in is 0.5 m/s.	[17] Carry out an analysis and risk assessment of diver entrapment against the intake grills of an operating intake head. The risk assessment to be carried out in-line with International Maritime Contractors Association (IMCA) guidelines. (Include discussions with HSE). Note: The IMCA guidelines do not support diving activities around active water intake systems and therefore a deviation would be required if this activity were to take place.	H	H	4		
	Silt removal	This is not expected to be a problem, but there is still potential for silt build-up. This may present a problem for cluster removal and inspection. The effect of silt is considered only to slow other operations down, rather than requiring specific attention itself. This operation has not been considered separately for the present analysis, but could increase the operation durations for other lines.	N/A	30	Simultaneous Operations (SIMOPS)	Injury to divers i.e. hearing damage, if in water whilst AFD is operating.	Diver activities will not take place whilst the AFD which is being worked on is active. Electrical systems to be isolated under permit to work system.	[6] Determine whether there is a risk to a diver if one of the Inlet Heads is operating with its associated AFD active / operating, whilst a different / adjacent AFD (Which will be switched off) is being maintained / being worked on.	H	M	3		
				32	Cargo striking the AFD Note: Dropped loads could also come from service vessels e.g. Replacement AFD clusters being transferred from supply ship to maintenance vessel.	Impact with the AFD. Refer to Entry 1.	The AFD speakers are mounted in steel frames which offer some protection against general marine flotsam and debris. Any ship to ship transfers to be performed in a safe area away from the head location. Cargo or items on deck to be sea fastened. Guide wires / posts used to prevent impact on head.	[9] Determine what additional protection can be implemented against impact from large cargo items e.g. sea shipping containers.	H	M	3		
				35	Dragging of Anchor	Damage to the AFD power cables which may also cause further damage to transformer systems and the acoustic panels via pulling action. Potential for direct impact of anchor with above sea bed AFD systems. Anchor attachment cables may ensnare or strangle the AFD.	Power cables will be buried to a suitable depth in trenches and covered with armoured protection or infill as deemed required. The Burial depth will be considered against the anchor requirements for a 5000 tonne vessel which is the largest routine commercial shipping operation close to the Inlet Heads / AFD (Goes into and out of Bridgewater). Operational vessels associated with the maintenance of the AFD will be managed in terms of maximum size and anchor weight, and movements and anchor positions will be controlled to avoid cables. Area is part of wider restricted area which is controlled by the Bridgwater Bay Harbour Master.	[10] The designers have not confirmed whether drag anchor or weighted anchor systems will be used for mooring cable positioning systems for service vessel. Confirm design basis and number of anchor points to allow a more detailed assessment of risk. [11] Confirm how anchor cable interference with the AFD will be prevented as the service vessel is moved / repositioned.	H	M	3		
				36	Too many Vessels on Station	Impact between service vessels with potential for a vessel to sink and impact the inlet heads or increased risk of impact with the inlet heads or AFD structure. Potential for vessel to sink leading to loss of life and environmental incident.	Control and planning of construction and service related activities.	[12] Confirm which approach is to be adopted for management of vessel position via cable system. Option two requires the vessel to be maintained over the Inlet Heads whilst to maintain one of the two banks of AFD panels.	H	M	3		

BUREAU VERITAS

AFD Maintenance Worksheet

Phase	Task	Resources required to perform the task	Safety support resources	HAZID Sc. Ref.	Main Hazard identified	Consequence	Safeguard / Mitigation	HAZID recommendation	S	L	R	Lesson learned / Feedback	Workshop recommendation
				39	Overweighting of crane or unstable lift.	Crane may collapse or slew, or vessel may capsize. May be exacerbated by sea and weather conditions. Damage to inlet heads or AFD structures. Potential for injury or fatality to vessel operatives or divers in water. Refer to Entries 1 and 9	All lifts will be controlled and assessed as per the requirements of the Project Lifting Plan and will take account of the load mass and sea conditions. Structures to be lifted will also be designed so as to limit lifting weight or size to accommodate more manageable lifts. All lifts will comply with the requirements of Lifting Operations Lifting Equipment Regulations (LOLER) – Offshore		H	M	3		
				40	Load or crane cable or vessel impacting with existing structures.	Damage to inlet heads or AFD structures. Potential for injury or fatality to vessel operatives of divers in water. Refer to Entry 1.	Procedural controls to manage movement and operations of boats and crane during construction and on maintenance activities. Specific procedural requirements will be in place for divers to retreat or to be removed from the work area when carrying out maintenance activities if lifting activities are taking place. Divers will also be wearing transponders to identify their position in the water. Transponder beacons on guide posts and on crane hook – to help the lift team to control the load. Vessel positions will be managed through the winch mooring system and navigational / survey system.	[13] Confirm that divers will not need to below the load at any time to assist in locating equipment e.g. AFD panels.	H	M	3		
				52	Snagging with AFD structure	Diving during construction and or routine / corrective maintenance; diver becomes trapped - potential injury or fatality.	Dives will only be undertaken with a Standby diver ready enter the water if the working diver becomes entangled. General entanglement issues will most likely impact the diver umbilical hose, which will be subject to hose management good practice.	[15] Develop umbilical management plan. [16] Confirm how a diver would escape if the umbilical could not be freed i.e. could umbilical be released, and a diver return to the diver basket using the mergency breathing gas bottle supply?	H	M	3		
				53	Strong currents / Rough Seas	Diving during construction and or routine / corrective maintenance - potential injury or fatality due to impact with structures or being swept away from the designated dive area.	Divers will only be in water around slack water (Approximately 1 hour window) and in stable and suitably flat sea conditions. A maximum sea state condition will be defined for water entry (typically 1 - 1.5m wave height). Support vessel is available for diver pickup if they have been swept away from the AFD area. However, this should not generally be possible unless too much umbilical has been paid out.		H	M	3		
				56	High Water Turbidity	Inability to see underwater, potential entanglement / disorientation leading to injury or fatality.	Dives will be risk assessed for the task being carried out to determine suitability of working in limited visibility. The installation and maintenance of the AFD system or panels has been designed so as to make it easier for dives to accomplish in low visibility i.e. tool-less engagement systems. Divers will be carry task lighting but this may be of limited use given the very poor visibility for the site. Acoustic imaging cameras are proposed to be carried by the divers. These will relay pictures to the top side support crew which will allow them to direct the diver's movements, to aid in completion of tasks for each operation.		H	H	4		
				58	There is a requirement from the site operator to always have some flow through the Inlet Heads i.e. to maintain a least one running inlet pump. This could result in a diver being pinned against water intake grill by differential pressure created by water flow.	Inability to escape from grill, potential injury or fatality. Requirement to send out rescue diver(s) who could also become 'pinned' to the grill.	The maximum design criteria for intake velocity is 0.3 m/s. The generally accepted maximum allowable current for diving in is 0.5 m/s.	[17] Carry out an analysis and risk assessment of diver entrapment against the intake grills of an operating intake head. The risk assessment to be carried out in-line with International Maritime Contractors Association (IMCA) guidelines. (Include discussions with HSE). Note: The IMCA guidelines do not support diving activities around active water intake systems and therefore a deviation would be required if this activity were to take place.	H	H	4		
Operation	N/A	The only other considerations during operations are a sound survey to confirm AFD function in comparison to the predictive modelling (carried out by side scanning from a vessel). No other AFD interventions offshore (in addition to those already covered above) are envisaged.	N/A	1	Large Waves Impacting Structure	Damage to the AFD system and or support frames such that they become untethered. Wave or current action could result in impact with the Inlet Head leading to damage or blocking of intake ducts, restriction of coolant water intake flow and shutdown of the associated reactor. Loss of the AFD system will mean fish are no longer diverted from the Inlet Head, which could result in enforcement action by the Environment Agency (EA). The damaged AFD and or support frames will need replacing, which represents a significant outage.	The AFD installation will be designed for 1:10,000 year wave conditions. The inlet heads draw water from two sides limiting the chances of complete flow blockage or significant flow restriction. HPC-CNEPEX-AU-HPT-NOT-201631 report has been produced to examine the potential effects of AFD structural failure upon the inlet head. The report confirms that impact will not affect the ability of the intake heads to operate.		M	L	2		

Power Hub Worksheet

	Task	Ressources required to perform the task	Safety support resources	HAZID Sc. Ref.	Main Hazard identified	Consequence	Safeguard / Mitigation	S	L	R	Lesson learned / Feedback	Workshop recommendation
Installation	Position Jack-up Platform	Activities carried out by a jack-up company have not been analysed here because they are one-off activities (for NNB GenCo) carried out by an external contractor experienced in these activities. The risks of these activities should already have been factored in to the individual risk calculations of the jack-up crew.		The Power Hub HAZID has not yet been carried out.								
	Lower conductor and casings and position pile in pile gate											
	Drill to required socket depth											
	Install pile (200 tonnes approximately) and grout pile/socket annulus											
	Retrieve equipment and repeat with the next pile											
	Pull power/communication cables through J-Tubes via Jack-up Platform and winch arrangement and support at top of piles	This is the only part of the installation operation when a diver is required in the water (and cable protection). This would be a diver from the same dive company carrying out AFD installation and maintenance. There are 9 cables, and 1 dive per cable is required for installation. Cable protection (scour protection) using concrete mattresses is not recommended because of low visibility and diving risks. A rock dump is suggested, without divers in the water.	See AFD analysis for diving safety resources required.								Cable protection (scour protection) using concrete mattresses is not recommended because of low visibility and diving risks. A rock dump is suggested, without divers in the water.	
	Transport power and communication platform / enclosures (60 tonnes each approximately) with suitable installation vessel to location	Activities carried out by a jack-up company have not been analysed here because they are one-off activities (for NNB GenCo) carried out by an external contractor experienced in these activities. The risks of these activities should already have been factored in to the individual risk calculations of the jack-up crew.										
	Install power/communication platform/enclosures on top of piles											
	Transfer personnel to platform											
	Connect power/communication cables											
	Energise power to SPs											
	Transfer Personnel from platform											
Regular maintenance at the power hub (supply boat)	Transfer personnel to platform	Supply boat maintenance at the power hub topsides. Mostly generic systems maintenance (rather than structural). Personnel transfer is by fendering onto a personnel ladder to an internal walkway on the structure. There are typically a couple of people on the supply boat plus the following people on the hub (12 hr/day on the hub, 12 hr/day back on the supply boat): 6 month inspection: Crew of 3 on 2 days 1 year: Crew of 5 on 2 days 10 years: Crew of 8 on 5 days (plus another 2 days per mob/demob) Crew of **[HOLD]** per **[HOLD]** for structural maintenance (e.g. painting)	No additional vessels are required other than the supply boat. See AFD analysis for diving safety resources required.	The Power Hub HAZID has not yet been carried out.								The number of crew, frequency of visits and duration of visits to the Power Hub for structural maintenance (e.g. painting) needs to be confirmed by Costain.
	Carry out maintenance											
	Transfer Personnel from platform											

Power Hub Worksheet

	Task	Ressources required to perform the task	Safety support resources	HAZID Sc. Ref.	Main Hazard identified	Consequence	Safeguard / Mitigation	S	L	R	Lesson learned / Feedback	Workshop recommendation
Dive operation to survey subsea structure and protection	Inspection of the subsea structure using sonar.	Once every 5 years. 2 divers would be required, but this would be better done by small eyeball ROV - total crew of around 15 for 2 days offshore. This would be combined with surveys of the intake heads (which are required to be carried out whatever the AFD/Power Hub solution).	No particular support resources required for ROVinspections. If the ROV is snagged, it may be necessary to send in a dive team to recover it.									
Major plant change out (lift vessel/jack-up)	Lifting of equipment off/onto the hub	The requirement for one major mid-life maintenance campaign was discussed but not considered to be necessary.	N/A	The Power Hub HAZID has not yet been carried out.								
	Transfer personnel to platform											
	Carry out maintenance											
	Transfer Personnel from platform											

Recommendations:

Index	Recommendation	Responsible
1	**[BV Subsea Engineer comment after workshop:** Consider providing heave compensator system to avoid uncontrolled movement of the load due to waves.]	NNB GenCo
2	Navigation buoys move around due to the tides. There is potential that these will need to be lifted before maintenance to avoid conflicts with the anchor spread. This requires Trinity House involvement. The buoys would need to be replaced following AFD maintenance. This requirement needs to be factored into the work schedule and agreed as acceptable.	NNB GenCo
3	**[BV Subsea Engineer comment after workshop:** Consider designing base frame with one pole longer that the other to facilitate handling during installation of subsea equipment (secure the longest pole first and then rotate the frame to secure the second pole).]	Costain
4	**[BV Subsea Engineer comment after workshop:** Ensure that umbilical length is controlled from the support vessel during diving operation to avoid extra length of umbilical hanging around which could lead to snagging hazard.]	NNB GenCo
5	The sequencing of the CDU and ubmilical needs to be defined. More information about the size and mass of this equipment is needed to inform the choice of method for installation.	Costain
6	Lifting can only be carried out at high water slack, but diving can still be done at low water (but the vessel may have to be repositioned because of the reduced clearance). This needs to be confirmed following the ongoing analysis, and confirmed as acceptable with the vessel captain. The present analysis has made some assumptions about dive windows which will need to be validated when dive windows are confirmed.	Costain
7	The potential to have to notify the nuclear safety authority following intake head impact (because the intake heads are nuclear safety classified) is a project risk with the ultimate consequence of plant shutdown. This should be covered in operational documentation.	NNB GenCo
8	Additional resource is required to visit the power hub to make AFD isolation/deisolation before/after AFD maintenance. The isolation philosophy has not been determined for one/all heads and for the whole duration while the barge is in place/only when a diver is in the water. This affects the number of visits required and needs to be defined.	Costain / NNB GenCo
9	The number of crew, frequency of visits and duration of visits to the Power Hub for structural maintenance (e.g. painting) needs to be confirmed by Costain.	Costain

Notes:

Index	Notes
1	HAZID references in the new report (currently being finalised by Costain) have been updated so the references in this worksheet may be out of date.
2	Decommissioning is not covered in the present analysis, but can be considered as a reverse installation with similar risks. The final risk quantification should mention this as a conservative assumption.
3	In reality, decommissioning may not be required for all equipment if a comparitive assessment shows that the environmental damage and safety impacts are not tolerable.

Appendix A - Agenda and Presentation Slides

AFD Risk Workshop

08 November 2017

Bristol, UK

Agenda

- Introductions (All)
- Housekeeping (NNB)
- Safety Moment (MB)
- Workshop Purpose (MB)
- Recap of Optioneering Phase Options Considered (NNB/Costain)
- Selected AFD and Power Hub Options – Task Breakdown (YS)
  - Construction Activities
  - Maintenance Activities
- Environmental Constraints (MB)
- Worksheet – Task Risks (All)
  - Links to HAZID
  - Safety Support Resources
  - Lessons Learnt / Bristol Channel Experience

Safety Moment

Marine Safety Forum – Safety Flash 08-12

“Seaman Injured in Crane Pennant Wire Incident”

Incident:

- Supply Boat working cargo from stern within acceptable weather conditions – 3m significant wave height
- AB1 holding the crane pennant and AB2 disconnecting the hook
- Stern of the ship fell into the trough of a wave, AB1 hoisted into the air 2-3 feet, let go and landed on the deck on his feet.
- He felt a slight twinge to his back but continued working to the end of his shift.
- The following morning, his back had stiffened up such that he was no longer able to work, and when the vessel returned to port he was signed off for two weeks.

Safety Moment

Marine Safety Forum – Safety Flash 08-12

“Seaman Injured in Crane Pennant Wire Incident”

Lessons Learnt:

- Though the ABs had concerns about the movement of the hook and pennant wire, they did not call a safety time out. If in doubt, ‘stop the job’ and review.
- The ABs should not have continued to disconnect the pennant if they felt there was insufficient slack.
- Be aware that the stern of a ship has the greatest vertical movement in a seaway.
- A brief tool box talk must be held before every new or routine task to review the hazards.
- When an incident occurs, it must be reported immediately to prevent a recurrence, and early attention may help to mitigate any injury sustained.

Workshop Purpose

Much good work has already been done to qualify the activities involved in the installation, operation and maintenance of the AFD/structures and their hazards. This workshop's aims are to extend this analysis to include:

- Quantifying the resources required to support the installation, operation and maintenance activities on the AFD system and structures, taking account of any risks associated with/from anchoring, depth of water, vessels, divers and ROVs involved in the maintenance operations; and
- Discussing operations with marine and diving/ROV contractors with actual operating experience within the Bristol Chanel to acknowledge any lessons learnt from Marine/ROV and diver operations carried out at HPC or similar installations.

This will be done by systematically stepping through the installation, operation and maintenance steps and recording the discussions in a worksheet.

The overall purpose is to inform an independent review of the AFD option selection and to quantify the risks of the selected option.

Selected AFD and Power Hub Options – Task Breakdown

- AFD system installation tasks:
  - Vessel mobilisation and transit – AFD equipment load-out and transport to worksite
  - Installation of Base Frames:
    - Deploy guide post extensions on guide wires from construction vessel and attach to AFD stub guide posts
    - Deploy base frame (running on the guide wires) and land onto stub guide posts
    - Engage base frame lock-down pins
    - Disengage guide post extensions from stub interface post and retrieve to vessel ready for installation of next base frame

Selected AFD and Power Hub Options – Task Breakdown

- AFD system installation tasks:
  - Installation of Sound Projector Cluster Frames:
    - Deploy guide post extensions on guide wires from construction vessel and attach to base frame guide posts
    - Deploy SP cluster frame (running on the guide wires) and land onto base frame guide posts
    - Activate SP cluster frame lockdown devices (if applicable)
    - Disengage guide post extensions from base frame guide posts and retrieve to vessel ready for installation of next SP frame
  - Power / Communication Cable Installation:
    - Install Controls Distribution Unit (CDU) by guide wire on to central base frame supports
    - Install Electrical Flying Leads (EFLs) between CDU and cluster electrical distribution boxes

Selected AFD and Power Hub Options – Task Breakdown

- AFD system maintenance tasks:
  - Power / Communication Cable Installation:
    - Install Controls Distribution Unit (CDU) by guide wire on to central base frame supports
    - Install Electrical Flying Leads (EFLs) between CDU and cluster electrical distribution boxes
  - Sound projector replacement see Installation
  - Anode replacement (in dry environment) see installation
  - Anode replacement (by divers)
  - Electrical cable replacement
  - Cleaning / Marine growth removal
  - Silt removal

Selected AFD and Power Hub Options – Task Breakdown

- Power Hub installation tasks:
  - Position Jack-up Platform
  - Lower conductor and casings and position pile in pile gate
  - Drill to required socket depth
  - Install pile (200 tonnes approximately) and grout pile/socket annulus
  - Retrieve equipment and repeat with the next pile
  - Pull power/communication cables through J-Tubes via Jack-up Platform and winch arrangement and support at top of piles
  - Transport power and communication platform / enclosures (60 tonnes each approximately) with suitable installation vessel to location

Selected AFD and Power Hub Options – Task Breakdown

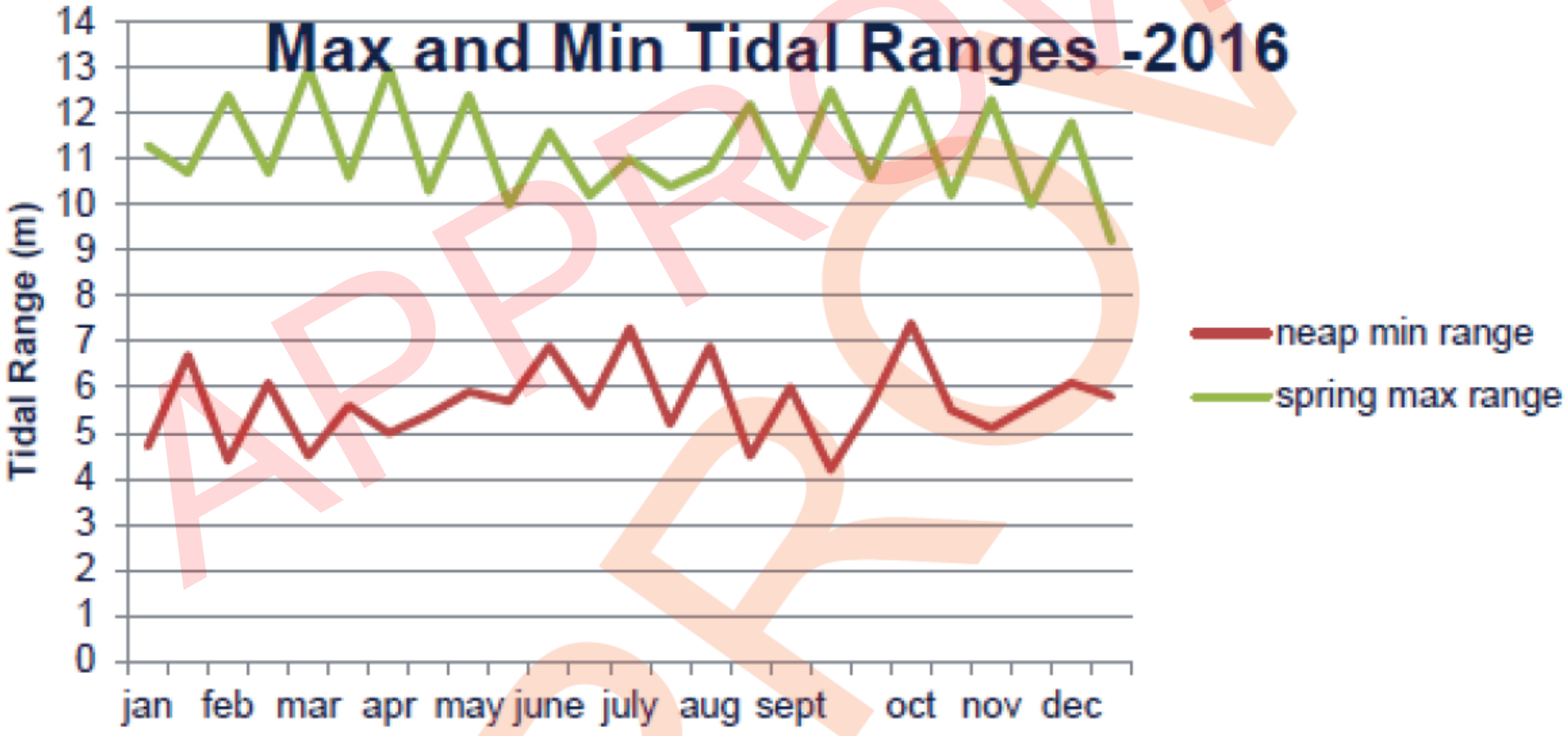
- Power Hub installation tasks:
  - Install power/communication platform/enclosures on top of piles
  - Transfer personnel to platform
  - Connect power/communication cables
  - Energise power to SPs
  - Transfer Personnel from platform

- Power Hub maintenance tasks:
  - Transfer personnel to platform
  - Carry out maintenance
  - Transfer Personnel from platform

Environmental Constraints

Tides

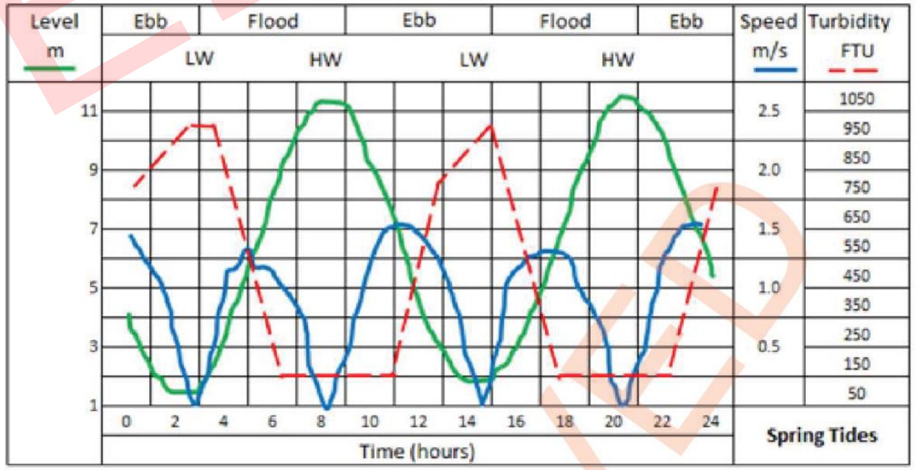
- The Severn has a large tidal range.
- This can affect dive time (compression time) and ROV suitability (insufficient water depth/clearance).



Environmental Constraints

Currents

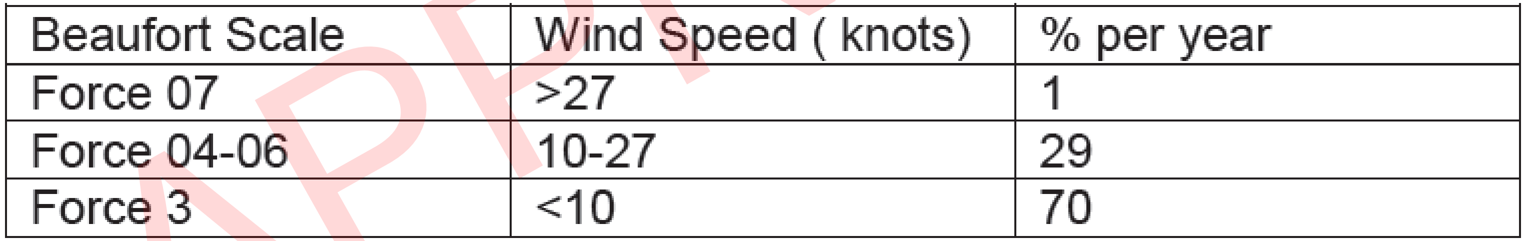
- Diving operations may typically commence with a falling current of 0.5 m/s and be suspended on a rising current of 0.4 m/s (0.8 knots)
- Small work class ROVs can work competently in water speeds of up to 1.3 m/s.
- Working at neap tides is much more preferable to springs as the current will be smaller.
- Assumption of average ~1 hour (lower on spring, higher on neap tides) window for diving.
- Available time in the water is longer at HW slack tide than LW slack tide (and visibility would be best at HW slack tide).
- Due to the current limitation, the replacement of clusters will only be possible for:
  - 1 hour per tide for divers
  - 2 hours for ROVs (technological advancements may extended current limitations in the future).



Environmental Constraints

Wind/Waves

- Maximum wave height for safe diving (safe ingress/egress to/from the water) is 1.5 metre / 20kts (force 3 on Beaufort scale)
- Transfer of personnel from vessels to/from a structure with wave height below 1.5 metres (force 4 on Beaufort scale)
- Combination of waves and wind will limit these operations to less than 70% of the year.

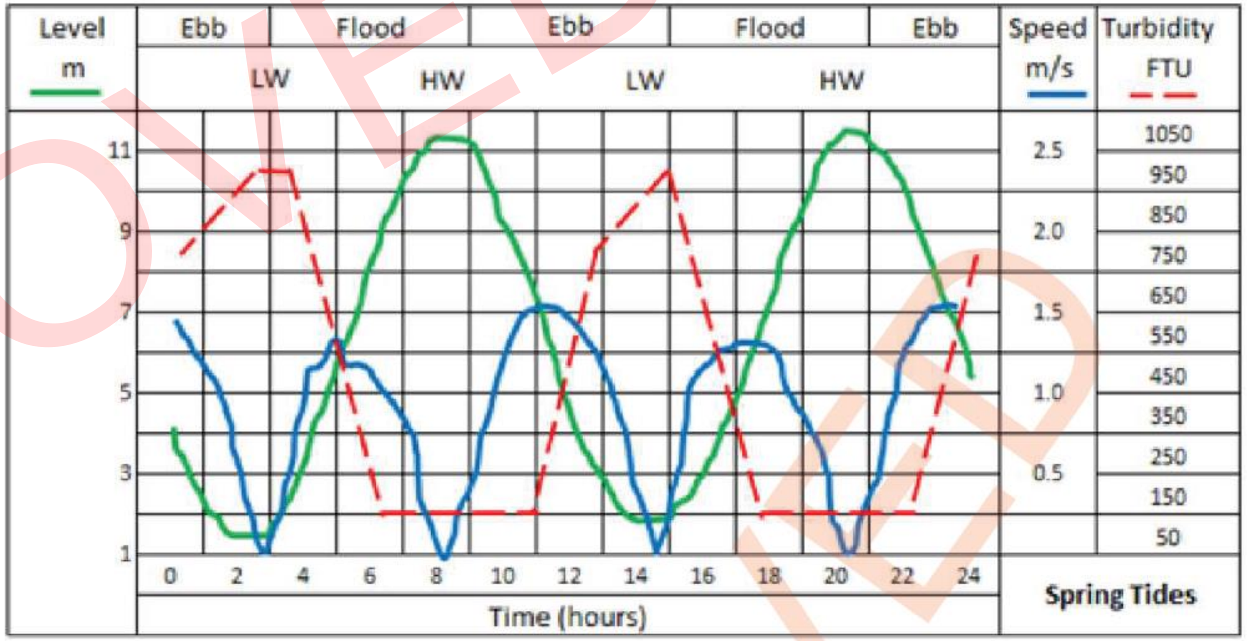


Beaufort Scale	Wind Speed (knots)	% per year
Force 07	>27	1
Force 04-06	10-27	29
Force 3	<10	70

Environmental Constraints

Turbidity

- All but the extreme low ranges of turbidity could be described as ’no visibility’ conditions.
- ROVs will rely on sonar technology. Potential that a second observation ROV will be needed for multiple camera angles on complex tasks.
- Potential for divers to use a sonar camera with audio feedback from diving crew.



Worksheet...