Base Load Power Hub (BLPH)

LOPA Terms of Reference

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1 INTRODUCTION

1.1 PROJECT OVERVIEW

Crosswind, a Shell and Eneco joint venture, was awarded the tender to develop the offshore Hollandse Kust Noord (HKN) wind farm, located 18.5km off the coast of Netherlands near the town of Egmond aan Zee. The consortium plans to have HKN operational in 2023 with an installed capacity of 759MW generating at least 3.3TWh per year. This is sufficient renewable power to supply more than 1 million Dutch households with green electricity.

Offshore wind farms produce intermittent electricity and balancing these dips and peaks and integrating this electricity into the national energy system requires new technologies. For this reason, the offshore wind farm will include several new technologies that could be implemented at full-scale in the future. The new technologies being explored include a floating solar park, a short-duration battery storage as well as long-term storage via green hydrogen produced by water electrolysis and subsequently consumed in a fuel cell. The combination of these individual measures, herein referred to as the Base Load Power Hub (BLPH) will ensure a continuous power supply regardless of the wind situation.

1.1.1 Project Location

The Hollandse Kust Noord (HKN) wind farm is located 18.5km off the coast of the Netherlands near the town of Egmond aan Zee.

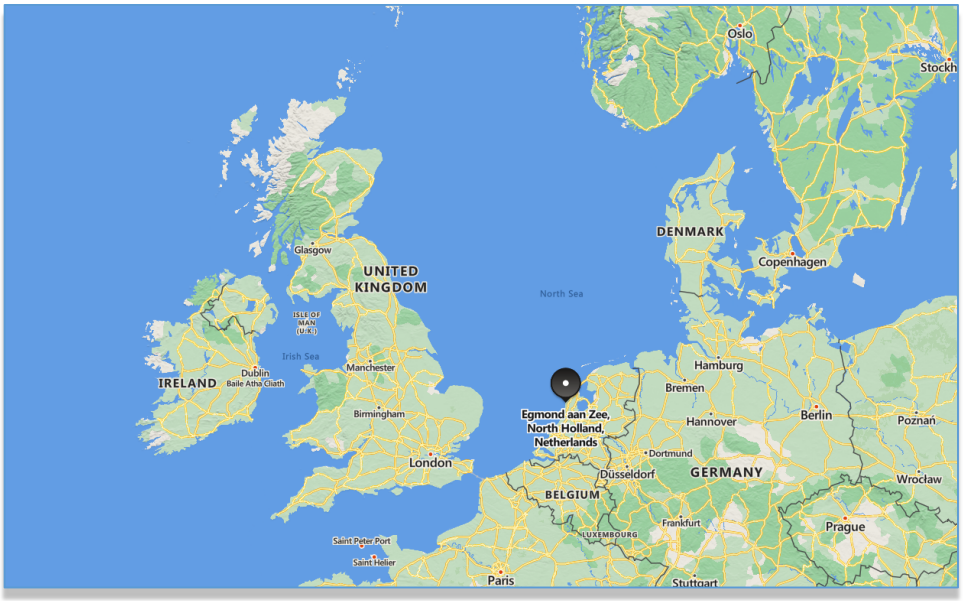


Figure 1 - HOLLANDSE KUST NOORD WIND PARK Location Map

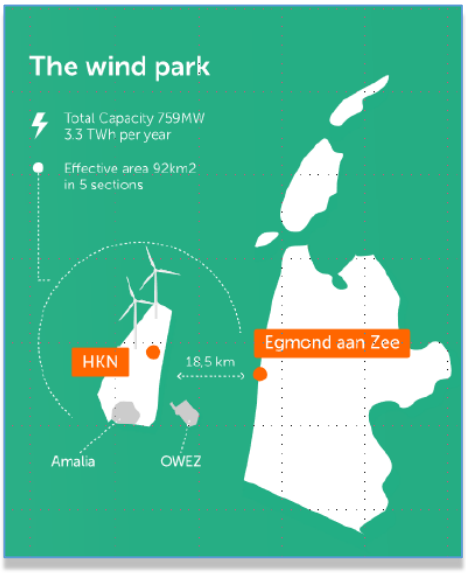


Figure 2 - Wind Park Details

The wind farm will consist of No. 69 x 11.5MW wind turbine generators each to be installed on a dedicated monopile structure. A 70th monopile located on coordinates E 590719.1, N 5841602.3 is reserved for installing the platform accommodating the BLPH. The monopile structure was designed and installed by Van Oord Offshore Wind (VooW) and therefore not part of the BLPH scope.

1.1.2 Project Concept

All components included in the BLPH will be integrated onshore on a topsides and installed in an offshore location within the boundaries of the HKN wind farm. At its simplest, the BLPH will store energy during periods of high electricity generation from renewable sources (a wind turbine generator and the floating solar PV farm) and release it during periods of low generation. In practice. It is expected that the energy stored will supplement generation from renewable sources to ensure that at least 1.0MW of power is exported to the electrical grid regardless of wind/solar availability.

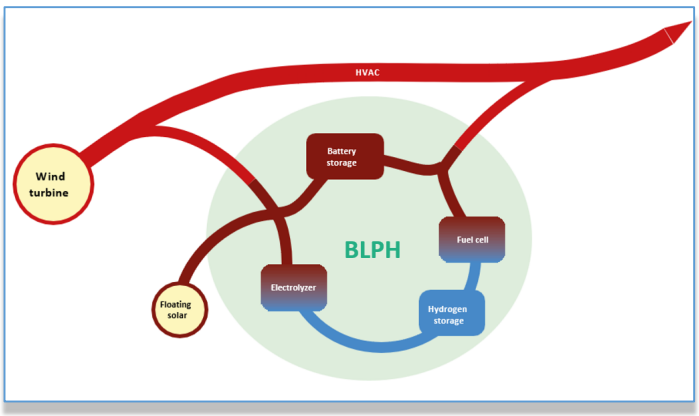


Figure 3 – BLPH Concept

Electricity in the BLPH will be stored in the form of electrons in a battery energy storage system (BESS) as well as converted into green hydrogen via water electrolysis. When the power output from the connecting wind turbine drops to below 1 MWe, the BLPH will return its stored energy to supplement the remaining power output. This will be by discharging the BESS, while stored hydrogen will be converted back into electricity using a fuel cell to extend the discharge duration.

The purpose of the BLPH s to function as a testbed for the integration of energy storage technologies with renewable generation. It is expected that equipment installed on the BLPH will operate as Normally Unmanned Installation for at least two (2) years with no or minimal maintenance and it will have its own independent control room with the ability to communicate with Crosswind's control room.

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2 DOCUMENT SCOPE

This document is the specific Layer of Protection Analysis (LOPA) Terms of Reference (ToR) for the Integration Package Scope. The LOPA is integrated with the Hazard and Operability (HAZOP) study. A separate ToR covering the requirements of the HAZOP study has also been issued.

2.1 TOR OBJECTIVES

The objectives of this Terms of Reference are to:

- Define the boundaries of the study;
- Present the workshop details and essential pre-read for the workshop attendees;
- Identify the appropriate disciplines and competencies required for the workshop team; and
- Collate the main documents to be used during the LOPA workshop.

2.2 REFERENCES

Doc. No.	Description
DEP 01.00.02.13	Layers of Protection Analysis (LOPA)
DEP 01.00.02.13	Overpressure and Underpressure – Prevention and Protection

Table 1 - Reference Documents

2.3 DEFINITIONS AND ABBREVIATIONS

COMPANY or Client (CPY)	Crosswind
CONTRACTOR (CTR)	ROSETTI MARINO S.p.A.
PROJECT:	HOLLANDSE KUST NOORD WIND PARK Project
ALARP	As Low As Reasonable Practicable
BLPH	Base Load Power Hub
BPCS	Basic Process Control System
CBL	Consequential Business Loss
DCS	Distributed Control System
DEP	Design and Engineering Practice
DSM	Downstream Manufacturing
HAZOP	Hazard and Operability
HER	Hazard and Effects Register
HKN	Hollandse Kust Noord

HSE	Health, Safety and Environment
IEF	Initiating Event Frequency
IPL	Independent Protection Layer
LOPA	Layer of Protection Analysis
LOPC	Loss of Primary Containment
MEF	Mitigated Event Frequency
PEFS	Process Engineering Flow Sheets
PFD	Process Flow Diagram
RAM	Risk Assessment Matrix
SIF	Safety Instrumented Function
SIL	Safety Integrity Level
TOR	Terms of Reference
WTG	Wind Turbine Generator

Table 2 - Definitions and Abbreviations

3 OBJECTIVES

The objectives of the integrated LOPA study are to:

- Establish the required SIL for each SIF identified as safeguard.

3.1 MANAGING RISK TO ALARP

Identified hazards will be ranked in the HAZOP in accordance with the Project Hazards and Effects Register (HER) which is supplied by Shell. The project HER sets the expectation as to how HSE risks are to be managed to ALARP.

Key steps in managing risks to ALARP are:

- Eliminate or reduce the hazard by an inherently safer design;

Manage the risk by:

- Meeting laws and regulations and stakeholder expectations;
- Applying codes, Shell or industry standards, and best practices if the risk is well understood; and
- Performing hazard analysis (e.g. LOPA) if the risk is not well understood.
- Assess the risk and demonstrate that the barriers incorporated in design reduce the risk to a tolerable level as a minimum with additional barriers considered and applied to demonstrate ALARP.

The tolerability criteria for residual risk are as stated below:

- The tolerability criteria (i.e., occurrences per year) shall be equal to the values shown in Table 1 [DEP 01.00.02.13, Table 1] below.

Consequence Severity	People	Community	Environment	Tolerability Criteria (Occurrences per year)
RAM 5	**10 or more fatalities.**[2]			1E-05
	>Than 3 fatalities <10 Fatalities Multiple illnesses with irreversible health effects.	**Massive Effect:** • Persistent, severe impact on livelihood, social and cultural assets, community security, health, vulnerable or Indigenous Peoples and/or human rights infringements. • International public concern.	**Massive Effect** Persistent severe environmental damage that will lead to loss of natural resources over a wide area.	1E-04
RAM 4	**Permanent total disability or up to 3 Fatalities.** Illnesses with irreversible health			1E-04
		Major Effect: • Persistent effects on livelihood and/or social and cultural assets, community health. • National public concern. • National government and/or NGO involvement	**Major Effect** Severe environmental damage that will require extensive measures to restore beneficial uses of the environment.	1E-03

Table 3 - Risk Tolerability Criteria

- Project steer is to assume >10 fatalities for potential RAM5-People hazards leading to explosion and to request consequence/dispersion modelling if the required safeguarding is out of proportion;
- In case of jet fire, it is very unlikely to have >10 people inside the line of fire, hence the tolerability criterion for this type of release is 1E-4 per year for RAM 5 hazards;
- Where public injuries or fatalities are potentially involved, the Table 3 tolerability criteria shall be reduced by a factor of 10 (e.g., 1E-4 per year becomes 1E-5 per year);

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- For events with a People consequence severity 3, the tolerability criteria shall be 1E-3 per year;
- For events with "asset" consequence severity RAM 4 or RAM 5, a tolerability criteria of 1E-3 per year may be applied;
- "Asset" consequence includes only direct damage to assets, and does not include consequential business loss (CBL) (e.g., lost production, quality costs, clean-up costs);
- For events with "community" or "environment" consequence severity RAM 3, a tolerability criteria of 1E-2 per year may be applied.

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4 WORKSHOP

4.1 WORKSHOP SCHEDULE

The LOPA workshop is scheduled for the 1st December 2023.

The workshop will be carried out face-to-face at the Rosetti Marino office in Milan, Italy. It is understood that a number of personnel will also be joining the workshops virtually using Microsoft Teams. As the workshops will utilise two displays concurrently, two Teams meetings should be arranged to allow virtual participation. Details on how to enter the meetings are provided in Attachment 3.

4.2 DAILY AGENDA

The following agenda is proposed. This will be adjusted on the basis of progress made at the discretion of the workshop team.

Time	Activity
09.00 – 09.15	Presentation, introduction to project
09.15 – 11.00	Start LOPA
11.00 – 11.15	Break
11.15 – 13.00	Continue LOPA
13.00 – 14.00	Lunch Break
14.00 – 16.30	Continue LOPA
16.30 – 16.45	Break
16.45 – 17.45	Continue LOPA
17.45 – 18.00	Wrap-up / Conclusion

Table 4 – Workshop Daily Agenda

4.3 WORKSHOP ATTENDEES

The team members required for the Integration Package HAZOP/LOPA Workshop should as a minimum consist of the following members:

- Chairperson;
- Recorder (HAZOP Scribe);
- Process Engineer;
- Operations Representative;
- Technical Safety Engineer; and
- Process, Automation, Control and Optimisation (PACO)/Instrumentation Engineer.

For the Integration Package HAZOP/LOPA a specialist regarding package should be present.

4.4 DOCUMENTS REQUIRED

The documents presented in Table 5 are required for the LOPA, and should be made available to the LOPA team prior to the workshops.

Doc. No.	Description
123A90-DDL-IN-CE-40000	Process Safety Cause & Effect Matrix
123A90-DDL-IN-LIS-40027	Master Alarm Database
123A90-DDL-PR-RE-80040	Process Design Philosophy
123A90-DDL-SAF-RE-30046	HSE Design Philosophy

Table 5 - DEFINE LOPA Documents

5 LOPA METHODOLOGY

5.1 INTRODUCTION

The LOPA will be carried out immediately following completion of the HAZOP.

The LOPA shall be carried out in full accordance with the Shell LOPA DEP.

LOPA shall be applied to risk assessment scenarios for the following situations:

a. To establish the Probability of Failure on Demand (PFD) target for each SIF listed as a barrier, when it has not been specified elsewhere (e.g., a DSM model bowtie or specified in a DEP);

   Note that the SIF must have the design intent to protect against the consequence being considered to trigger a LOPA for this consequence.

   An example of a DEP specified PFD is the requirement for a SIL 2 rated backflow protection in case backflow can lead to overpressure.

b. When a HAZOP or other risk assessment team considers that there might not be sufficient barriers;

c. If required per local regulatory or by the business to support ALARP demonstration.

If the risks are well understood, if there is a standard and good practice (industry standards, DEPs) to follow, (e.g. simple relief valve without a SIF), and if the scenario is not covered by the situations mentioned above, then the following apply:

a. LOPA should not be done;

b. If LOPA is performed, then any additional SIF shall be subject to approval by the TA1 in Technical Safety of the Principal or the Business.

We do not do LOPA if there is no SIF as safeguard, risk is well understood and safeguarded as per DEP/ industrial standards/ good practices (e.g. what is indicated in the process guide, what is commonly applied in similar units). An example of this approach is an overpressure scenario safeguarded with a valid barrier and an adequately sized relief valve).

- All scenarios are to be safeguarded as per Shell /industry standards and good practices to demonstrate ALARP. Please note, DEP may cover part of the safeguarding, additional safeguards may be addressed in another DEP. A good example is double seals requirement for a pump in hazardous service. As double seals can fail, additional safeguards such as fire detection by polyflow activating the sprinkler may be needed, which is addressed in another DEP.
- ALARP demonstration text is always required in HAZOP/LOPA worksheets for yellow and red risks.
- When LOPA is done, perform ALARP assessment after achieving tolerable risk in LOPA worksheet and write down ALARP considerations (or alternatively specify actions for tolerable / ALARP).
- When LOPA is not done, write in ALARP column in HAZOP worksheet how ALARP was demonstrated (incl. reference to shell/industry standard claimed) and (if applicable) which actions are required to meet ALARP.

5.2 GROUND RULES & ASSUMPTIONS

5.2.1 Safeguards/Barriers

The following definitions will be applied when identifying barriers in the HAZOP:

- Barriers are engineered systems or administrative controls designed to prevent the causes or mitigate the consequences of deviations (e.g., process alarms, process controls, interlocks, SIFs); and
- Barriers shall only be taken into account if they are part of the design (e.g., already part of the design hardware, documentation or operating procedures).

The barriers identified have to satisfy the following criteria to be considered valid:

- Effective;
- Independent;
- Auditable; and.
- Dependable (applicable for Safety Instrumented Functions (SIFs) only - being designed, implemented, maintained, inspected and tested in accordance with IEC 61511.

In the HAZOP all safeguards (barriers) will be listed, both valid and non-valid. Barrier validity will be recorded in the HAZOP for yellow and red risks. Where a safeguard is identified as non-valid then the reason why shall be recorded. When the barrier is identified as valid, the checks made to ascertain validity will be recorded, e.g., nature of operator response (e.g. tag of the valve that the operator will close), which operator (field or control room) will act (when the initiating event is a human error), sufficient time for operator response, direction of failure of the valve for a control loop barrier, sensors and final elements for SIFs, clean service, etc.

Control actions for those BPCS loops (in or outside the unit being considered) that detect the deviation caused by the initiating event and react to it to restore normal conditions/resolve the upset will be recorded as barriers in the HAZOP. Example: a level control loop in a vessel of which the inlet control valve fails open. Barrier validity must be assessed.

Control actions for those BPCS loops (in or outside the unit being considered) that do not detect the deviation caused by the initiating event and (therefore) do not react to it to restore normal conditions/resolve the upset are considered independent from the initiating event (of course only if they also have independent sensors and final elements). Example: a steam system pressure control loop is independent from the reflux control loop in the column the steam is used as reboiler medium.

The challenge of whether the BPCS can be claimed as an Independent Protection Layer (IPL), in accordance with the Shell LOPA DEP will be carried out in the HAZOP.

The challenge of whether the alarm can be claimed as an IPL, in accordance with the Shell LOPA DEP, will be carried out in the HAZOP.

5.2.2 SIFs

Only the final elements for each respective SIF which prevent the consequence shall be recorded, i.e. if the C&Es identifies several executive actions, only the primary actions which prevent the consequence shall be recorded against the SIF.

If a SIF is considered for a particular consequence (e.g. overpressure) but the SIF design intent does not include the consequence being discussed (e.g. prevent sending liquid to furnace), the SIF may be recorded in the HAZOP but the threat to consequence line will not take part in the LOPA to determine the SIL of the SIF. The SIF design intent should be recorded. If the final element that would be effective for the consequence being considered (e.g. valve in inlet) is not a primary final element (in SIFPro), the SIF will not be considered valid for this particular consequence.

5.2.3 Relief Valves

The following information shall be recorded for relief valves:

- Set points; and
- Correctly sized for the over-pressure event, with documentary evidence.

Passing relief valves shall not be taken as a "cause" unless the relief valve discharges to atmosphere.

5.2.4 Over-Pressure Consequences

In accordance with the Shell LOPA DEP, the LOPA Team shall record over-pressure consequences as follows:

1. Consequence of rupture – this will have the highest severity
2. Consequence of flange leak – possibly a lower severity

Recording the consequences this way will allow the probability of rupture to be identified in the LOPA in accordance with the data in Table 6 and the leak hole size in accordance with the data in Table 7.

The consequence shall be written to clearly indicate the design pressure and the maximum pressure generated from the upset case so that over-pressure ratio can be clearly seen.

A suitably sized relief valve is the default minimum safeguarding solution for overpressure cases. Only if implementing an adequate relief system is not practicable, an alternative design approach may be adopted. See Shell Overpressure DEP Section 2.10.3 for definition of what is not practicable and for an alternative safeguarding approach. It is not the purpose of a HAZOP or LOPA to design safeguarding systems. However, if the team identifies an overpressure case without suitable relief system and no documented justification of the non-practicability of the relief system, a recommendation to review the design and comply with DEP requirements should be raised in the HAZOP.

Vessel Design Code	Safety Factor	Probability of equipment rupture (Note 1)		
		Prob = 0.01	Prob = 0.1	Prob = 1.0
ASME Section VIII Pre-2000	4:1	2.8≤PR<3.2	3.2≤PR<3.6	3.6≤PR
ASME Section VIII 2000 and newer	3.5:1	2.5≤PR<2.8	2.8≤PR<3.2	3.2≤PR
ASME Section VIII Div 2, Stoomwezen, or CODAP	3:1	2.2≤PR<2.4	2.4≤PR<2.7	2.7≤PR
EN-13445	2.4:1	1.8≤PR<2.0	2.0≤PR<2.2	2.2≤PR
AS-1210 or PD5500	2.35:1	1.8≤PR<2.0	2.0≤PR<2.2	2.2≤PR

Table 6 - Probability of Rupture

Vessel Design Code	Safety Factor	Pressure/MAWP ratio or design pressure (PR) that results in hole of given diameter (probability = 1) (Note 1)		
		7 mm (0.28 in) (Note 2)	25mm (1 in.)	100mm (4 in.) (Note 3)
ASME Section VIII Pre-2000	4:1	cHTP≤PR<1.9	1.9≤PR<3	3≤PR<3.6
ASME Section VIII 2000 and newer	3.5:1	cHTP ≤PR<1.9	1.9≤PR<2.7	2.7≤PR<3.2
ASME Section VIII Div 2, Stoomwezen, or CODAP	3:1	cHTP ≤PR<1.9	1.9≤PR<2.5	2.5≤PR<2.7
EN-13445	2.4:1	cHTP ≤PR<1.9	1.9≤PR<2.1	2.1≤PR<2.2
AS-1210 or PD5500	2.35:1	cHTP ≤PR<1.9	1.9 ≤PR<2.1	2.1 ≤PR<2.2

NOTES:

1. PR = Pressure ratio, this being the ratio of [vessel over-pressure] to [MAWP or design pressure].
2. cHTP = corrected Hydrotest Pressure= actual hydrotest pressure corrected for relief scenario or design temperature.
3. beyond the value of PR given in the 100mm (4 in) diameter hole size column, there is no need to assess a leak case as the probability for equipment rupture is considered to be 1 (i.e., leak case will not be determining).

Table 7 - Flange Hole Size

5.2.5 Locked Manual Valves

If inadvertent closure of a Locked Open (LO) valve causes "immediate" overpressure, verify compliance with ASME VIII Appendix M (North America) or corresponding (outside North America) Shell interpretation (single valve with or without lock is normally not accepted as an open system if closure of that valve can create an immediate overpressure case greater than 110% of the design pressure).

For locked valves, 2 human errors could occur:

1. The operator has intentionally operated the locked valve (e.g. for shutdown/start-up) and forgot to re-instate it in its normal, locked position. In this case, the lock is not a barrier since the valve was intentionally operated. Operating a locked valve should follow a procedure and therefore initiating event frequencies can be calculated based on LOPA DEP Table 5 and the expected frequency of operation of the locked valve. For this, it is important to understand why the valve was implemented and why it needs to be operated. It is quite different to have a valve that was put for construction purposes only and will never be operated versus a valve that will be used for some special modes of operation.
2. Inadvertent operation of the wrong valve. Operator should close valve B but closes valve A instead. In this case, the lock is a barrier with PFD=0.1 as per LOPA DEP Table 2 Row 25 (Keyed Bypass /Interlock). In this case, the frequency of operation of the "other/right" valve (in this example valve B) should be considered. This could be a valve physically nearby or a valve on a parallel string/train.

In cases where the human error related to the locked valve is another reason for e.g. a path to be closed, it may not be significant mathematically (in a LOPA/SIF classification). However, it may be quite important to look at if the locked valve is not the only cause for the scenario to develop.

5.3 FOLLOW-UP

5.3.1 Reporting

A report of all content created by the workshop, including any required supporting material will be produced after the workshop for comment.

The report will contain the assumptions made and the main output of the workshop, as a detailed worksheet and the action-sheets for each recommendation raised during the sessions.

5.3.2 Actions

Recommendations raised will be collected with the close-out and tracked into a HSSE Action Tracking Register and recorded in the HAZOP Close out report, doc. No. 123A90-DDL-SAF-RE-30007 by Rosetti Marina. Each action-sheet will indicate the recommendation, with the responsible of closing the action, the answer showing how the recommendation is properly closed.

ATTACHMENT 1 – LOPA WORKSHEET

Deviation	Cause	Consequence	Hazard Register	IPF Summation - Threat	RAM Score				LOPA?	Barriers				IE Type	IE Frequency	EFs		CMs			Total EF	Barrier Total PFD	MEF (/yr)	RRF	Tolerable?				Recommendations						RRF After Recs	ALARP
					Rec	S	L	RR		Barrier Description	Validity	Protective Layer Description	PFD			EF Description	EF Prob.	CM Description	CM Probability	Total CM PFD					Freq (/yr)	Y/N	Gap (PFD)	Gap	Recommendation	Resp.	Type	Protective Layer Description	IPL PFD improvement	Total PFD		

ATTACHMENT 2 – RECCOMENDATION CLOSE-OUT SHEET

BLPH SHEAMS SIGNATURE FORM

Action Title: **Ref. Doc.**	
Item No.	
Cause:	
Consequence:	
Safeguards:	
Actions:	
Assigned Respondent (By)	
RESPONSE	
Attachments:	
Issue Date (dd/mm/yy)	

Approvals / Endorsements	
EPC Discipline Lead	**Sign**
EPC HSE Lead	**Sign**
EPC Project Manager	**Sign**
Client	**Sign**

ATTACHMENT 3 – VIRTUAL MEETING INSTRUCTIONS

Two meeting invitations will be sent out containing Microsoft Teams links to allow personnel attending virtually to view both the HAZOP/LOPA minutes and other documents such as the PEFS simultaneously. Please accept both meeting invitations.

Personnel attending the meeting face-to-face do not need to join the virtual meetings as a room microphone and audio will be available via the office facilities.

For those joining virtually:

- Open Teams meeting [1] in the Teams Application and select 'use computer audio''.
- Meeting [1] will be used for audio and for display of the workshop minutes.
- Open Teams meeting [2] in a web browser – either use the:
    - 'Join on the web' link along with the Meeting ID and passcode;

      or
    - 'Copy & Paste' the 'Click here to join the meeting' link into a web browser;
- Cancel the 'Open in Microsoft Teams?' pop-up, then select 'Continue on this browser';
- Select 'Don't use Audio' and join the meeting;
- Please leave you microphone on mute unless you wish to say something to minimise background noise;
- Following breaks, please 'raise your hand' to indicate that you have re-joined;

We will have a round of introductions at the start of the first meeting when we will have video cameras active. Following these introductions video cameras should be switched off to minimise bandwidth.

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