Base Load Power Hub (BLPH)

ALARP Demonstration Report

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Table of contents

1 INTRODUCTION 6
1.1 PROJECT OVERVIEW 6
1.1.1 Project Location 6
1.1.2 Project Concept 7
2 EXECUTIVE SUMMARY 9
3 MAIN REFERENCES 11
4 DEFINITIONS AND ABBREVIATIONS 14
4.1 DEFINITIONS 14
4.2 ABBREVIATIONS 15
5 ALARP REQUIREMENTS 18
5.1 REGULATORY REQUIREMENTS 18
5.2 COMPANY REQUIREMENTS 18
5.3 Project Specific Requirements 19
6 ALARP Methodology 20
6.1 ALARP Principles 20
6.2 Decision Making 20
7 HSE DELIVERABLES SUMMARY 23
7.1 Hazard Identification report (HAZID) 23
7.2 Hazard and Operability Study report (HAZOP) and Layer of Protection Analysis (LOPA) 24
7.2.1 EPCI HAZOP/LOPA 25
7.2.2 Electrolyzer Package HAZOP/LOPA 25
7.2.3 Fuel Cell HAZOP/LOPA 25
7.3 Safety and Operability (SAFOP) study report 25
7.4 Safety actions registers and close-out 25
7.5 Quantitative Risk Assessment report (QRA) 26
7.6 Fire and Explosion Risk Assessment report (FERA) 27
7.7 F&G detection study 27

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7.8 Hazardous area classification 28
7.9 Human Factors Engineering report (HFE) 28
7.10 Evacuation, Escape and Rescue Assessment (EERA) 29
7.11 Safety Critical Task Analysis Workshop Report (SCTA) 30
7.12 Emergency Systems Survivability Assessment Report (ESSA) 31
7.13 Simultaneous Operations Report (SIMOPS) 31
7.14 Vent dispersion study 32
7.15 Safety Critical Elements (SCE) and Performance Standard 34
7.16 Noise study 34
7.17 ALARP Workshop 34
7.18 Philosophies 37
8 Conclusion 38
9 Action plan 39
Attachment 1 – ALARP WORKSHOP STUDY 40
Attachment 2 – ALARP DEMONSTRATION WORKSHEETS 54
Attachment 3 – ALARP DEMONSTRATION RECOMMENDATIONS 67
Attachment 4 – BOW-TIE DIAGRAMS 68

List of Figures

Figure 1 HOLLANDSE KUST NOORD WIND PARK Location Map 6
Figure 2 - Wind Park Details 7
Figure 3 – BLPH Concept 7
Figure 5-1: Hazard Management Hierarchy 18
Figure 6-1: ALARP Triangle 20
Figure 6-2: Decision support framework 21

List of tables

Table 1 - Reference Documents 13
Table 2 - Definitions 15
Table 3 - Abbreviations 17
Table 4: MAH identified during the EPC HAZID 24
Table 5 – Recommendations for the operational phase of the project 36

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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.

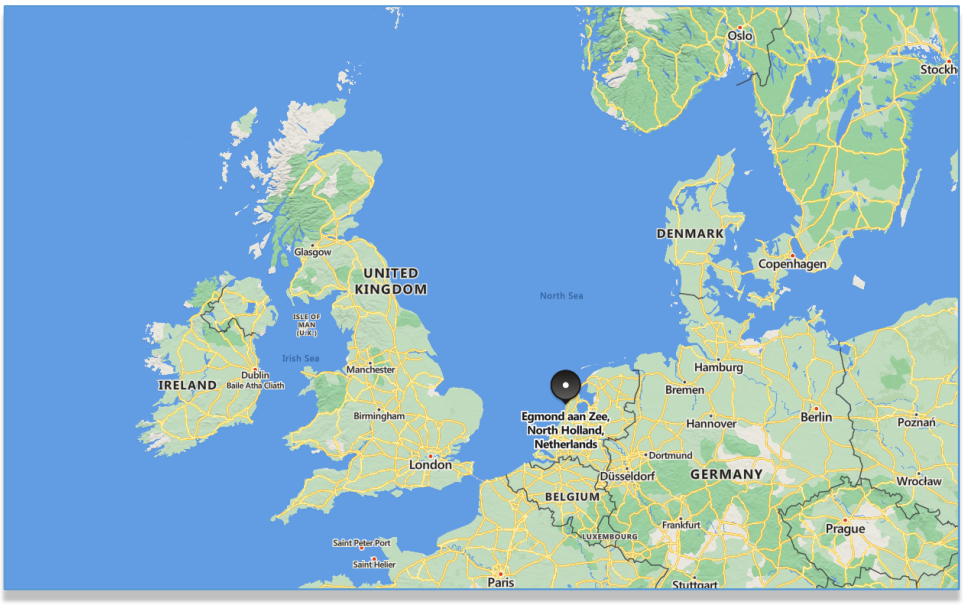


Figure 1 HOLLANDSE KUST NOORD WIND PARK Location Map

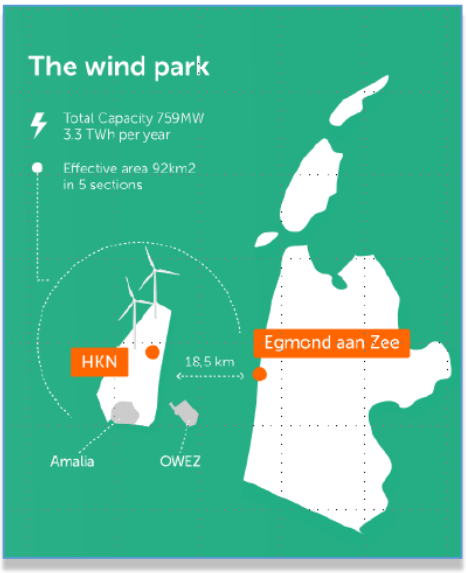


Figure 2 - Wind Park Details

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.

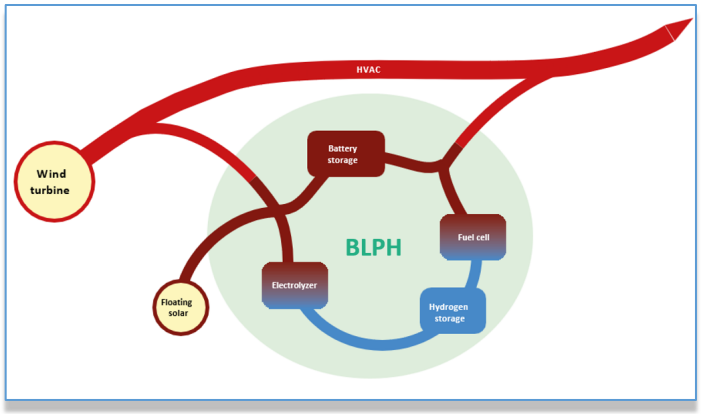


Figure 3 – BLPH Concept

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 EXECUTIVE SUMMARY

DISCLAIMER

The parts of present document, that relates with the CPIs, Company Provided items, was not under Rosetti Marino responsibilities, who does not take any liability for the content of these paragraphs.

The present ALARP report outlines the approach adopted to ensure that Health, Safety, and Environmental risks associated with the project are systematically identified, evaluated, and reduced. The document consolidates findings from key safety studies and workshops conducted throughout the design and development phases, and defines the HSE strategies to be implemented for BLPH. The ALARP demonstration comprises an overview of the studies from the EPC contractor and Company Provided Items (CPIs).

The following key studies and assessments have been considered:

- HAZID (Hazard Identification): Provides an early, high-level identification of hazards during the conceptual and FEED phases.
- HAZOP (Hazard and Operability Study) and LOPA (Layers Of Protection Analysis): Identifies potential process deviations and their consequences on safety and operations.
- SAFOP (Safety and Operability Study): Identifies safety hazards or operability problems inherent in the design and operating philosophies of the electrical systems.
- QRA (Quantitative Risk Assessment): Provides a quantitative evaluation of risks to personnel and assets, supporting risk-based decision-making.
- FERA (Fire and Explosion Risk Assessment): Identifies fire and explosion hazards and recommends preventive and mitigative design features.
- F&G detection study: Evaluates the adequacy and coverage of fire and gas detection systems to ensure timely identification of hazardous events.
- Hazardous area classification: Defines areas where explosive atmospheres may occur and specifies equipment requirements to prevent ignition sources.
- HFE (Human Factors Engineering): Ensures that human capabilities and limitations are integrated into the design to enhance safety and operability.
- EERA (Escape, Evacuation and Rescue Analysis): Evaluates emergency response capabilities and ensures safe evacuation and rescue of personnel.
- SCTA (Safety Critical Task Analysis): Identifies safety-critical tasks and evaluates the potential for human error.
- ESSA (Essential Safety Systems Assessment): Reviews the performance and integrity of safety-critical systems.

- **ALARP Workshop:** to ensure that the risk from ALARP items identified are reduced to a level that is As Low s Reasonably Practicable and no additional measures are required.
- **SIMOPS (Simultaneous Operations):** Assesses potential risks arising from overlapping activities during commissioning, ensuring safe coordination and management.
- **Vent Analysis:** Evaluates the dispersion of gases from vents (including thermal radiation in case of ignition) to verify that emissions/thermal radiation do not pose hazards to personnel or equipment.
- **SCE and Performance Standard :** Identifies critical equipment and systems required for risk control and defines performance standards to ensure they remain effective throughout the lifecycle of the facility.
- **Noise study:** Assesses noise levels generated by equipment and operations to protect personnel hearing and ensure a safe and comfortable working environment.
- **Multiple Philosophies:** Establishes design and operational methodologies to ensure the plant development conforms with applicable national codes, international standards, and good engineering practices, maximizing inherently safe design and effective risk mitigation.

Some of the studies concluded that no further recommendations were necessary, confirming that the current design is already considered acceptable on the basis of analysed risk. Other studies, however, identified specific recommendations for risk management. This report documents the status of each recommendation and provides an update on their implementation or justification for non-implementation.

There are a number of outstanding issues that need to be addressed in the next phase, which are provided in the action plan.

3 MAIN REFERENCES

[1]	ISO 17776 - Petroleum and natural gas industries – Offshore production installations – Major accident hazard management during the design of new installations
[2]	UK HSE - Guidance on ALARP Decisions in COMAH – UK Health and Safety Executive (UK HSE), SPC/Permissioning/37, 2001
[3]	IEC 61511-3:2016 - Functional safety - Safety instrumented systems for the process industry sector - Part 3: Guidance for the determination of the required safety integrity levels
[4]	API RP 521, Guide for Pressure-Relieving and Depressuring Systems. American Petroleum Institute, Washington DC, 1997.
[5]	123A90-DDL-SAF-RE-30011 – ALARP Terms of Reference
[6]	123A90-DDL-SAF-RE-30019 - Quantified Risk Assessment (QRA) Report
[7]	123A90-DDL-SAF-RE-30020 - Fire and Explosion Risk Analysis (FERA) report
[8]	123A90-DDL-SAF-RE-30006 – HAZOP Report
[9]	123A90-DDL-SAF-RE-30009 – HAZID Report
[10]	123A90-DDL-SAF-RE-30021 - Vent Gas Dispersion and Potential Radiation Study
[11]	K559-2254-SE-TEN-001 – Leak Size Analysis
[12]	K559-2254-CWIWP4202201-E99-099 - BLPH BESS Safety description document – Thermal Runaway mitigations and recommendations
[13]	123A90-DDL-SAF-DL-30027 - F&G detectors Layout - lower deck
[14]	123A90-DDL-IN-CE-40002 - Fire & Gas Cause & Effect Matrix
[15]	123A90-DDL-PP-DI-71000 - Isometrics drawing & List
[16]	K559-2254-CWIWP4202202-C99-00 – Megablock Safety Concept
[17]	123A90-DDL-PP-DL-70070 – BLPH – Plot Plan – Lower & Upper Deck
[18]	123A90-DDL-PP-DL-70071 – BLPH – Plot Plan – Below Lower Deck
[19]	123A90-DDL-PP-DL-70072 – BLPH – Plot Plan- Elevation of Looking North & East
[20]	123A90-DDL-SAF-RE-30036 – LOPA Allocation Report

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[21]	123A90-DDL-SAF-RE-30049_02 – Human Factors Engineering Report
[22]	123A90-DDL-SAF-RE-30015 02 - Evacuation, Escape and Rescue Assessment
[23]	123A90-DDL-SAF-RE-30004 - HSSE action tracking register and close-out report
[24]	123A90-DDL-SAF-RE-30040 - Safety Critical Task Analysis workshop report
[25]	CCPS Process Safety Glossary, 2022, Centre of Chemical Process Safety (CCPS),https://www.aiche.org/ccps/resources/glossary
[26]	123A90-DDL-SAF-RE-30046 – HSE Design Philosophy, rev 01
[27]	123A90-DDL-IN-RE-40095 - Process Control Logics Description
[28]	144671-VOOW-TF-ENG-REP-1401 - Boat landing and ladder
[29]	123A90-DDL-SAF-DL-30025 – Escape Route Layout
[30]	123A90-DDL-ST-DD-90122 - Temporary hatch
[31]	1724000448-PR-PID-00013 - Water treatment package P&ID
[32]	123A90-DDL-SAF-RE-30038 - SIMOPS for commissioning activities
[33]	123A90-DDL-SAF-RE-30021 - Vent Gas Dispersion and Potential Radiation Study
[34]	123A90-DDL-PR-RE-80030_01, Relief, Vent and Blowdown Report
[35]	123A90-DDL-SAF-RE-30003 - Safety Critical Elements (SCE) and Performance Standard
[36]	24290I_Vent study_01 - Vent Gas Dispersion and Potential Radiation Study for BLPH platform on Ravenna construction site
[37]	123A90 - Barrier & Access Control Management Plan Rev07
[38]	CRW-01-R-01 - Elogen Electrolyser Package HAZOP/LOPA report
[39]	C63-PUO-001_003 – Elogen HAZOP closeout report
[40]	HAZOP/LOPA Report - CRW-01-R-02 (former SGS-77-R-01), Issue 4.0
[41]	BPSE-INN-BPH-OTH-00021 - Ballard HAZOP Close Out Sheets
[42]	CWHKN-ELE-BPH-RPT-00005 - BLPH BESS SAFOP Report

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[43]	CWHKN-ELE-BPH-RPT-00006 - BLPH Fuel Cell SAFOP Report
[44]	CWHKN-ELE-BPH-RPT-00007 - BLPH Elogen Electrolyser SAFOP Report
[45]	123A90-DDL-EL-RE-20178 - SAFOP Report
[46]	123A90-DDL-SAF-RE-30010 - HAZID close-out
[47]	123A90-DDL-SAF-RE-30007 - HAZOP close-out
[48]	123A90-DDL-EL-RE-20179 - SAFOP close-out
[49]	123A90-DDL-SAF-RE-30051 F&G detection coverage report
[50]	123A90-DDL-SAF-RE-30013 - Hazardous Area Classification schedule
[51]	123A90-DDL-SAF-DL-30024 - Hazardous Area Classification - Elevation looking North and East
[52]	123A90-DDL-SAF-DL-30022 - Hazardous Area Classification - Lower deck & Upper deck
[53]	123A90-DDL-SAF-RE-30001 - Fire Protection Philosophy
[54]	EU DIRECTIVE 2003/10/EC on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (noise) (update with the amendment by Regulation (EU)2019/1243 of 20 June 2019)

.Table 1 - Reference Documents

4 DEFINITIONS AND ABBREVIATIONS

4.1 DEFINITIONS

COMPANY or Client (CPY)	Crosswind
EPC CONTRACTOR (CTR)	ROSETTI MARINO S.p.A.
PROJECT	HOLLANDSE KUST NOORD WIND PARK Project
ALARP	"As Low As Reasonably Practicable" The concept that efforts to reduce risk should be continued until the incremental sacrifice (in terms of cost, time, effort, or other expenditure of resources) is grossly disproportionate to the incremental risk reduction achieved. [25]
CONSEQUENCES	The outcome of an event. For the purpose of this project, the outcome is identified in terms of harm to exposed persons and assets.
EVENT	Occurrence or change of a particular set of circumstances.
FREQUENCY	The estimated number of events per defined unit of time (normally refereed to one-year time).
MAJOR ACCIDENT HAZARD	Any unplanned and uncontrolled event that has the potential to lead to severe or catastrophic consequences to people, assets, the environment and/or business continuity and reputation [26]. A MAHs is defined from at least one of the following categories: • an incident involving an explosion, fire, or release of gas or dangerous substances with a significant potential to cause multiple fatalities; • an incident leading to serious damage to the asset involving, or with a significant potential to cause, multiple fatalities; • any other incident with a potential to lead to greater than 3 fatalities any major environmental incident resulting from incidents referred to in points above.
OPTION	Any additional risk reduction measure beyond those already in place.
RECOMMENDATION	Improvements /actions required to reduce the identified risk.

RISK	Combination of frequency and consequence of scenarios. For the purpose of the present project, the risk is evaluated on exposed persons and on project equipment, due to the effects of events caused by LOC of hazardous substances.
SAFEGUARD	Measure, system, or action designed to prevent hazardous events, control risks, or mitigate the consequences of an incident

Table 2 - Definitions

4.2 ABBREVIATIONS

ALARP	As Low As Reasonably Practicable
API	American Petroleum Institute
ATEX	Atmosphères Explosibles
BDV	Blowdown Valve
BESS	Battery Energy Storage System
BLPH	Base Load Power Hub
CAPEX	Capital Expenditure
CBA	Cost Benefit Analysis
C&E	Cause and Effect
COMAH	Control of Major Accident Hazards
CPI	Company Provided Item
EPC	Engineering, Procurement and Construction
EERA	Evacuation, Escape and Rescue Assessment
F&G	Fire and Gas
FEED	Front-End Engineering Design
FERA	Fire and Explosion Risk Assessment
FT	Full Time
HAZID	Hazard Identification
HAZOP	Hazard and Operability

HFE	Human Factors Engineering
HKN	Hollandse Kust Noord
HMI	Human Machine Interphase
HSSE	Health, Safety, Security and Environment
HT	Half Time
I&C	Instrumentation and Control
IEC	International Electrotechnical Commission
IRPA	Individual Risk per Annum
LFL	Lower Flammability Limit
LOC	Loss of Containment
LSIR	Location Specific Individual Risk
MAH	Major Accident Hazard
MOC	Management of Change
MOPO	Matrix of Permitted Operations
NUI	Normally Unmanned Installation
Occ.	Occurrence
OPEX	Operational Expenditure
PEM	Proton Exchange Membrane
PFP	Passive Fire Protection
PPE	Personal Protective Equipment
PM	Project Manager
PS	Performance Standard
PSV	Pressure Safety Valve

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PV	Photovoltaic
QRA	Quantitative Risk Assessment
RAM	Risk Assessment Matrix
SCE	Safety Critical Element
SCTA	Safety Critical Task Analysis
SIMOPS	Simultaneous Operations
VCE	Vapour Cloud Explosion
VooW	Van Oord Offshore Wind

Table 3 - Abbreviations

5 ALARP REQUIREMENTS

5.1 REGULATORY REQUIREMENTS

The current BLPH project understanding of the laws and regulations of The Netherlands and the Joint Venture permits have not yielded any specific requirements to demonstrate ALARP.

5.2 COMPANY REQUIREMENTS

The Shell HSSE & SP Control Framework requires that projects provide a documented demonstration of ALARP for the project HSSE risks. The demonstration of ALARP requires systematic application of HEMP. Throughout the project it shall:

- Identify HSSE hazards and document their effects on people, assets, environment and reputation in a Hazards and Effects Register;
- Assess the risk of identified hazards for worst-case credible scenarios using the Risk Assessment Matrix (RAM);
- Apply the hierarchy of controls for managing risk, see Figure 5-1;
- Where reasonably practicable eliminate hazards or substitute hazards with ones having lower risk;
- Identify and implement control and recovery measures to reduce risks to ALARP;
- Actively seek out and where reasonably practicable select the lowest risk options; and
- Integrate HSSE & SP into project decisions.

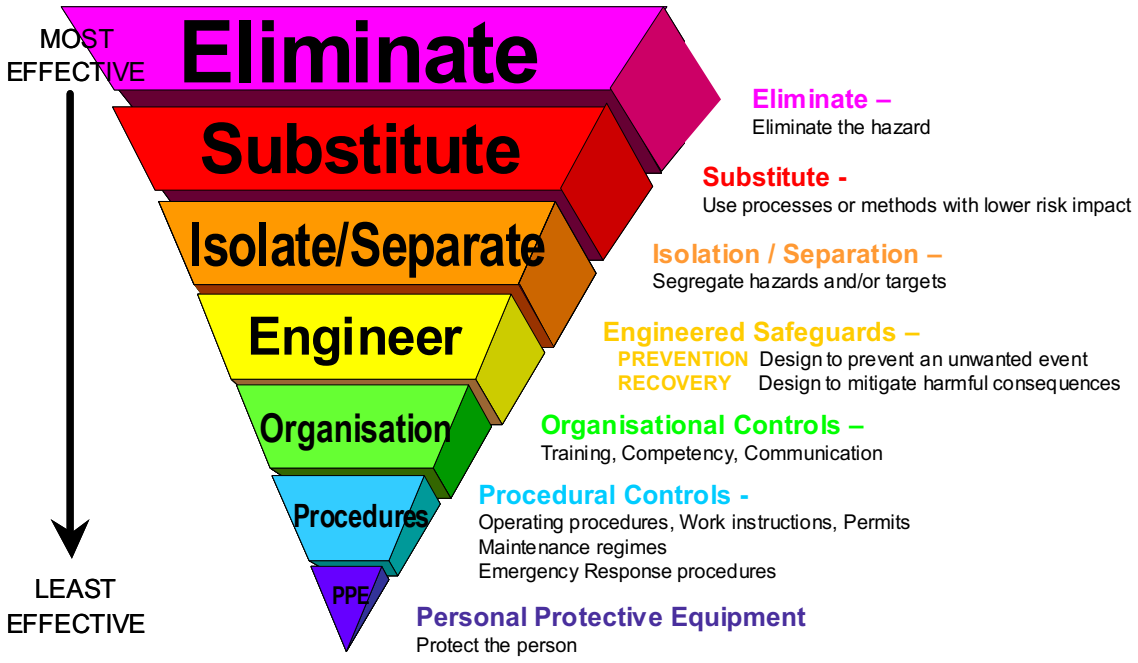


Figure 5-1: Hazard Management Hierarchy

5.3 Project Specific Requirements

For the purpose of this ALARP Demonstration, it is assumed that BLPH will be Shell-operated. Specific project requirements shall be implemented for alignment of emergency systems/response between onshore, Crosswind and BLPH operations due to different engineering standards and health, safety and environment (HSE) Management Systems being applied.

6 ALARP METHODOLOGY

6.1 ALARP Principles

The principle of ALARP is that HSSE risks shall be demonstrated to be both tolerable (within all legislative and other company and project requirements), and also further reduced as far as reasonably practicable. To reduce a risk to a level which is ALARP involves balancing reduction in risk against the time, trouble, difficulty and cost of achieving it. This level presents the point, objectively assessed, at which the time, trouble, difficulty and cost of further reduction measures become grossly disproportionate to the additional risk reduction achieved.

In the ALARP region risk reduction measures (design options, additional or better barriers) should be sought until the cost and effort to implement these measures is grossly disproportionate to the risk reduction. When that point is reached the risks have been reduced to ALARP. The risks should then be managed for continuous improvement.

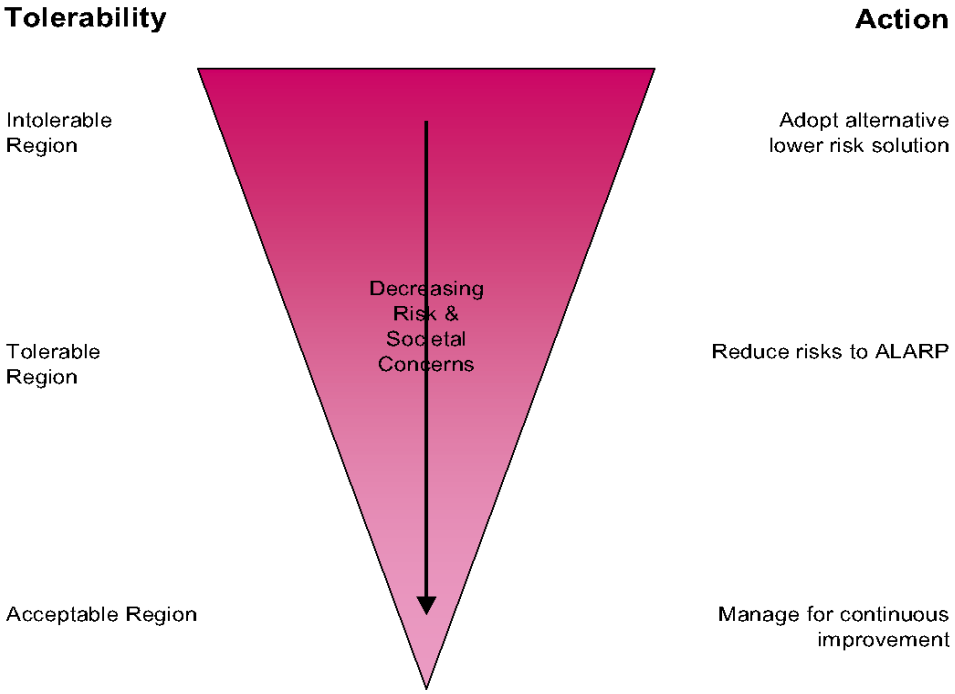


Figure 6-1: ALARP Triangle

6.2 Decision Making

A generic framework developed for the UK Offshore Operators Association (UKOOA) (UKOOA – Industry Guidelines on "A Framework for Risk Related Decision Support") by an industry workgroup including Shell Exploration and Production, has been adopted globally by Shell in the Process Safety ALARP Guidance.

This framework assists in guiding and supporting the decision-making process for the implementation of safety recommendations or issues.

Figure 6-2 shows the UKOOA model; the framework represents a gradual progression of change in the decision type from top to bottom. The figure shows that the basis of decision-making changes with the nature of the problem and its environment. The drivers on the right-hand side of the figure have been characterized into 3 decision types.

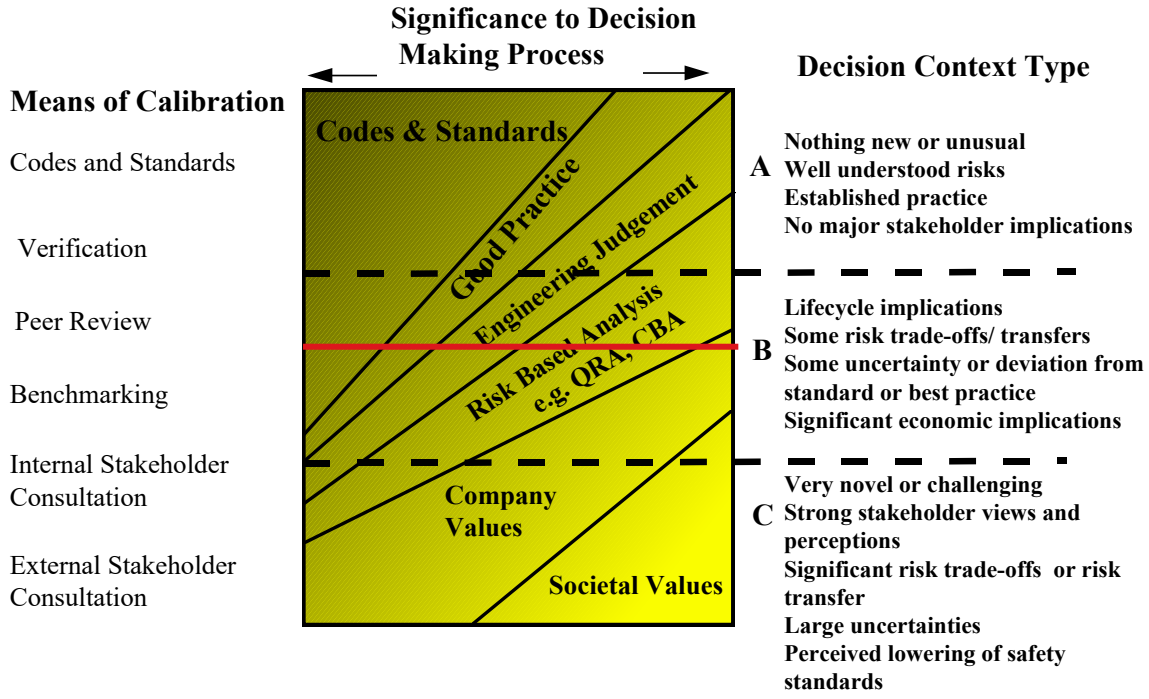


Figure 6-2: Decision support framework

The following is an overview of the three decision context types:

a) These types of scenarios are nothing new or unusual. The risks are well understood and have no major stakeholder implications. The hazards are managed using well established practices and Industry and Company Codes and Standards. Demonstration of ALARP for these types of scenario is by verifying the "appropriate" use of established codes, standards and practices in the design.
b) These scenarios have some risk uncertainty to them or involve some risk trade-offs (e.g. lifecycle implications). There might be no body of well-established practices that applies, and application of codes and standards requires some extension through engineering judgment. Options will likely require risk based analysis to support the decision. Demonstration of ALARP for these types of hazards requires a higher level of review. The verification of proper hazard mitigation requires the use of peer reviews and/or benchmarking of best practices.
c) These types of hazard are novel and/or very challenging. By definition, there is a large uncertainty in risk. They may also include strong stakeholder views and perceptions. Proper hazard mitigation of these requires internal and external stakeholder consultation to demonstrate ALARP. Most of these issues occur early in the Project development where completely novel development concepts and/ or equipment are selected.

In practice the level of the decision will be estimated by reference to the decision types on the right hand side of the framework. A horizontal band across the framework at that level then shows which methods or approaches such as use of codes and standards, good practice, engineering judgment, risk based analysis, the need to consider company or society values are likely to be relevant. The means of calibration down the left hand side of the framework give some indication of how the actual basis of the decision can be identified and checked. The calibration sources can also be used as an input to determine the decision context. The framework helps address both risk assessment and judging the tolerability of the risks.

The predominant decision context type for the BLPH development is considered to be Type B. The principal reason for this is:

- An electrolyser, H2 storage, BESS and fuel cell is proven technology, however doing this offshore on a Normally Unattended Installation (NUI) brings some uncertainty or deviation from standard or best practise.

7 HSE DELIVERABLES SUMMARY

The present document has been prepared incorporating the results of the risk studies elaborated during the project. The development of this document ensures that all hazards have been addressed, that control measures are in place and that risk levels have been reduced to a level that is As Low As Reasonably Practicable (ALARP).

This report serves as a structured demonstration that the project has systematically identified assessed and managed health, safety, security and environmental risks in accordance with industry standards and regulatory requirements.

7.1 Hazard Identification report (HAZID)

A HAZID study [9] was conducted for the Engineering Procurement and Construction (EPC) Phase of the project with the following objectives:

- Identify (major) hazard scenarios, which result from the operation under consideration, using the Risk Assessment Matrix (RAM) of Company and threats that relate to potential major hazard accidents.
- Identify the essential controls required to ensure risks are tolerable and ALARP.
- Make recommendations/action items that will be implemented in the design. Subsequent completion of these actions to eliminate, reduce and control risks will become a key part of the formal demonstration of ALARP.
- Identify and assign the action owner for each recommendation made.
- Gain a common understanding of the relevant Health, Safety, Security and Environment (HSSE) risks.
- Provide input to update the Hazards & Effects Risk Register.
- Provide input to bow tie assessments or equivalent methodology for the major HSE hazards and information to identify Safety Critical Elements (SCE) in support of the ALARP Demonstration.

The identified Major Accidental Risks identified in the workshop are reported below for reference in Table 4 and are related to hydrogen leaks in the electrolyser, hydrogen leaks in the process system and thermal runaway reactions in BESS.

Node	Item	Hazard	Threat	Consequence
Node 1	H-03.05a	Hydrogen	Leakage of Hydrogen from (Proton Exchange Membrane) PEM.	Potential of Explosion. Jet fire & impingement to adjacent equipment. Escalation. Invisible flames. Potential for personal injuries if people are on the platform Asset damage
Node 1	H-03.05d	Oxygen & Hydrogen	Hydrogen leaking into oxygen system leading to fire in the PEM	Potential for internal explosion
Node 1	H-11.02c	Temperatures greater than 150°C	Thermal runaway within BESS during maintenance activities	Potential explosive atmosphere. Potential fatalities.
Node 2	H-03.05a	Hydrogen	"Leakage from Hydrogen system.	Potential of Explosion. Jet fire & impingement to adjacent vessel. Escalation. Invisible flames.
Node 2	H-03.05d	Oxygen & Hydrogen	Hydrogen leaking into oxygen system	Potential of formation of explosive mixture leading to internal explosion

Table 4: MAH identified during the EPC HAZID

Recommendations raised in the HAZID workshop are included in Attachment 4 of the HAZID report [9]. These recommendations have been closed-out and tracked in the HAZID close-out report and in the HSSE action registers, refer to paragraph 7.4 for details. Each action-sheet states the recommendation, the party responsible for closing the action, and the full close-out description.

7.2 Hazard and Operability Study report (HAZOP) and Layer of Protection Analysis (LOPA)

Three HAZOP workshops were conducted for the EPC phase. Following the conclusion of the HAZOP workshops, a LOPA was conducted. The following HAZOP/LOPA sessions were held during the EPC phase:

1. EPC HAZOP/LOPA.
2. HAZOP/LOPA Elogen Electrolyser Package; and
3. HAZOP/LOPA Ballard Fuel Cell Package;

Note that any future changes made in design or operation including those initiated by this HAZOP & LOPA, shall be re-assessed as part of the management of change (MOC) procedure.

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7.2.1 EPCI HAZOP/LOPA

The EPCI HAZOP/LOPA was carried out in the Rosetti offices. The study team was made up of representatives of Crosswind and Rosetti, the study chairman was independent of all participants. A total of 56 HAZOP/LOPA recommendations were raised during the workshop. All recommendations made during the HAZOP/LOPA were successfully closed out in EPC phase.

7.2.2 Electrolyzer Package HAZOP/LOPA

The Electrolyzer package HAZOP/LOPA was carried out in the Elogen offices. The study team was made up of representatives of Crosswind and Elogen, the study chairman was independent of all participants. A total of 106 HAZOP/LOPA recommendations raised during the workshop. All recommendations made during the HAZOP/LOPA were successfully closed out in EPC phase.

7.2.3 Fuel Cell HAZOP/LOPA

The Fuel Cell package HAZOP/LOPA was carried out in the Ballard offices. The study team was made up of representatives of Crosswind and Ballard, the study chairman was independent of all participants. A total of 9 HAZOP/LOPA recommendations raised during the workshop. All recommendations made during the HAZOP/LOPA were successfully closed out in EPC phase.

7.3 Safety and Operability (SAFOP) study report

Four SAFOP workshops were conducted for the EPC phase. The following SAFOP sessions were held during the EPC phase:

1. EPC SAFOP [45];
2. SAFOP Elogen Electrolyser Package [44];
3. SAFOP Ballard Fuel Cell Package [43]; and
4. SAFOP BESS Package [42];

All recommendations made during these SAFOPs were successfully closed out in EPC phase.

7.4 Safety actions registers and close-out

The objective of the registers and close out reports is to provide a track and a formal close out record for each action that have been raised during the design phase. This includes both FEED Deferred Actions (i.e., all the actions that wasn't closed out in the past Project Phase) and all EPC Actions.

The Close Out Reports have been implemented on the project to ensure that all key HSE actions raised from formal workshops and from any safety related study are managed and tracked.

During the EPC phase of the project, three documents were prepared, to capture from different safety studies and reviews all recommendations:

1. HAZID close-out, doc. N. 123A90-DDL-SAF-RE-30010 [46][9];
2. HAZOP close-out, doc. N. 123A90-DDL-SAF-RE-30007 [47];
3. SAFOP close-out, doc. N. 123A90-DDL-EL-RE-20179 [48].

4. HSSE action tracking register and close-out report, doc. N. 123A90-DDL-SAF-RE-30004 [23]

A total of 237 actions have been raised and they have been all properly closed, so, assuming that operators will follow the design indications, all identified risks have been managed to ALARP.

During the ALARP workshop, three recommendations were identified, all related to the operational phase. These are included in the Action Plan presented in Chapter 9. The complete ALARP workshop documentation is provided in the attachments to this report, specifically, the ALARP Workshop Report in Attachment 1, the ALARP Workshop Worksheet in Attachment 2, and the ALARP Workshop Recommendations in Attachment 3.

All actions from the HAZID and HAZOP close-out are also included in the HSSE action tracking.

7.5 Quantitative Risk Assessment report (QRA)

A Quantitative Risk Assessment (QRA) [6] was performed to evaluate the potential risks associated with LOCs on the BLPH platform. The study aims to quantify individual risk levels to personnel and to verify compliance with applicable risk acceptance criteria. The objectives of the study include the following:

- Identification of potential fire and explosion scenarios involving equipment within the scope of work, including CPI's.
- Calculation of damage distances for fire, explosion, and flammable release events to assess the potential impact on personnel health and safety.
- Providing recommendations for appropriate risk reduction measures where necessary.

The methodology was based on the identification of hazardous events followed by frequency estimation and consequence analysis using validated tools and data sources. Event trees were developed to model accident scenarios. Consequences such as fire and explosion are evaluated using dedicated simulation software. Risk results were presented through risk contour maps. The main findings of the QRA study are reported below.

- Based of LSIR contours on the lower and upper deck, it is possible to conclude that the risk on the lower deck is lower than on the upper deck. The maximum calculated value of the LSIR on the lower deck is equal to 3.0E-05 occ/year.

  The main contribution to the risk in the lower deck is coming from a potential VCE of H_2 from a thermal runaway of the BESS system with a frequency of occurrence of 1.0E-05 occ/year.
- The upper deck shows a higher risk than the lower deck. This is due the presence of the H_2 storage system, confirming that the risk from storage section is the highest process risk of the platform. The maximum calculated value of the LSIR is equal to 6.3 E-05 occ/year.

  In particular, jet fire shows significant contribution, involving all the platform area with frequency about 1.0E-05 occ/year. For the upper deck, the explosion contribution, even if still in the order of 1-0E-05 occ/year, is lower than the contribution of jet fire scenarios, which covers the entire platform area.
- The IRPA of a platform operator is 2.1E-06 /year. The risk is classified inside the "acceptable" region based on acceptability criteria and no additional barrier is deemed necessary. The highest

contribution is the risk associated with non-process hazards (96%), while the risk associated with process hazard contributes only for 4% to the total IRPA.

The calculated IRPA for the BLPH platform was found to be in the acceptable tolerability region, demonstrating ALARP operation.

7.6 Fire and Explosion Risk Assessment report (FERA)

The Fire and Explosion Risk Assessment (FERA) [7] was performed to evaluate the potential risks associated with LOCs on the BLPH platform. The study aims to quantify the risk levels to the asset and to verify compliance with the applicable risk acceptance criteria. The objectives of the study include the following:

- Identification of potential fire and explosion scenarios originating from equipment within the defined scope of work, including CPI's.
- Calculation of damage distances for fire, explosion, and flammable release scenarios to assess the potential for escalation.
- Detailed evaluation of fire escalation scenarios and identification of appropriate risk reduction measures.

The methodology was based on the identification of hazardous events followed by frequency estimation and consequence analysis using validated tools and data sources. Event trees were developed to model accident scenarios. Consequences such as fire and explosion are evaluated using dedicated simulation software. Risk results was presented through risk contour maps. The main findings of the FERA study are reported below.

Jet Fires

there are no areas in the platform in which the thermal radiation threshold contours of 37.5 kW/m^2 from jet fire is equal to or above 1.0E-04 per year. The impact of jet fire scenarios on equipment is lower than target frequency and can be classified as acceptable .

Explosions (VCEs)

there are no areas in the platform in which the explosion threshold contours of 0.35, 0.27, 0.15 and 0.07 bar are equal to or above 1.0E-04 per year, thus the risk from VCE is considered acceptable .

Recommendations has been made in the FERA, which were tracked with the HSE action tracker and close-out. With all recommendations closed, the risk is deemed acceptable and the risks involving escalation potential are regarded as ALARP.

7.7 F&G detection study

A coverage study of the fire and gas detection has been done to ensure effective coverage of all platform areas and response to an unplanned process release, of which detailed information can be found in the F&G Detectors Coverage Report [49].

7.8 Hazardous area classification

A classification of hazardous areas has been performed for the project, highlighting the location of classified areas where only suitable certified material can be used [51].

7.9 Human Factors Engineering report (HFE)

A Human Factors Engineering (HFE) [21] Workshop was conducted to identify, assess, and mitigate human factor-related risks across the design and operational phases of the facility. The primary aim of the study is to ensure that the design enables safe, efficient, and error-tolerant human performance, in alignment with applicable industry standards and best practices. The objectives of the study include the following:

- Verification that the design complies with established HFE principles.
- Execution of a model walk-through to identify potential design issues or opportunities for improvement.
- Identification of specific mitigation measures and actionable recommendations to be incorporated

The study has been developed according to the following steps:

- Identification of main activities performed by the operators in the platform.
- Application of the HFE Check list in order to verify that the layout and workplaces comply with the technical standards requirements of applicable regulations and to identify the potential human factors issues associated with workplaces and equipment on the basis of operators main activities.
- The HFE Check list has been prepared specifically for the Base Load Power Hub (BLPH), based on the principles and requirements reported in international standards (e.g. NORSOK, ISO)
- Identification of possible actions, including mitigations and design modifications, to ensure that the identified risks are reduced.

Some actions emerged from the workshop based on the application of the HFE checklist. For each action, an action sheet was prepared and shared between RM and CW. All identified actions have been considered closed, as their resolution was reviewed and validated by all involved parties. The table below provides a summary of the shared evidence confirming the closure of the recommendations.

n.	Platform area	Recommendation	Follow -up
1	General requirement (where applicable considering the presence of rungs)	Consider providing non-slip surface to the rungs of vertical ladders	As per doc "Boat landing and ladder", non slip surfaces are provided at all ladders [28].
2	BLPH Interface level	Verify the type and position of the stairs for transition piece entrance in order to avoid possible interference with primary muster point	As per escape route layout, no interference is present with the primary muster area moved to the north side of the deck [29].

n.	Platform area	Recommendation	Follow -up
3	BLPH Lower deck workplaces: equipment inspection activities	Ensure adequate space for maintenance activities of water pumps in the final position	As per the 3D model, adequate space for maintenance has been provided
4	BLPH Lower deck workplaces: equipment inspection activities	Ensure adequate space for maintenance activities for flanges/ valves near the WTP	As per the 3D model, adequate space for maintenance for flanges/ valves are present.
5	BLPH Lower deck workplaces and equipment inspection activities	Ensure that the access will be equipped with vertical ladder to reach equipment on top of TP.	Access to the top of the TP is through a removable cover on the lower deck. Access to the top of the TP is only foreseen in exceptional cases due to the overhead height of 600mm. Therefore, no access ladder is provided, but a temporary aluminium ladder will be fitted if deemed necessary [30].
6	BLPH Lower deck workplaces and equipment inspection activities	Rosetti to investigate if sample collection is needed to check biocide concentration	As per water treatment package no sample collection point is included on tank biocide. Sample points are at intermediate system to ensure performance of the water treatment package [31].
7	BLPH Lower deck Technical rooms	Rosetti to provide portable step ladders in case of operation in the top of cabinets	Height of the steps will be adjustable in order to adapt to each container door. The ladders weight will not exceed a normal weight to be lifted from/to inside containers.

With all recommendations implemented, the risk is deemed acceptable and the risks involving human factors are regarded as ALARP.

7.10 Evacuation, Escape and Rescue Assessment (EERA)

The Evacuation, Escape and Rescue Assessment (EERA) [22] was aimed at evaluating the effectiveness and reliability of emergency response measures in terms of escape/evacuation in the event of accidental scenarios occurring on the BLPH platform. The main objectives of this assessment were to:

- Identify and assess potential hazardous scenarios, such as fire, explosion, or gas release, that may impact the ability of personnel to safely escape or evacuate;
- Evaluate escape routes and muster points, ensuring they remain available and functional under emergency conditions;

- Calculate the total time required for evacuation or escape, taking into account all phases from the initial alarm to the final abandonment of the facility;
- Verify the adequacy of safety equipment and emergency procedures, including escape devices, life-saving appliances, and alarm systems.

The assessment follows applicable international standards and guidelines and integrates data and outcomes from the Quantitative Risk Assessment (QRA), Fire and Explosion Risk Analysis (FERA), and other relevant industry practices. The overall goal was to ensure that personnel have safe and timely access to a place of safety during any foreseeable emergency scenario, and that muster points are located in positions deemed safe based on the specific hazards present on the platform.

Based on the scenarios analysed, the calculated evacuation and escape times fall within acceptable industry thresholds. The study confirms that the evacuation and rescue systems currently in place are adequate and aligned with the platform's structural resistance and the nature of the identified risks.

No additional measures are required based on the results of the EERA study and the risks regarding emergency events have been managed to ALARP.

7.11 Safety Critical Task Analysis Workshop Report (SCTA)

The Safety Critical Task Analysis (SCTA) [24] was aimed at analyse tasks that are critical to maintaining the safety of personnel, the environment, and the facility. A Safety Critical Task is a task where human factors could cause, or contribute to, a major accident or fail to reduce the effect of one, including during:

- operational tasks;
- prevention and detection;
- control and mitigation, and
- emergency response.

The main objectives of this assessment are to:

1. Identify maintenance tasks performed by operators.
2. Identify possible human failures.
3. Identify the consequences of human failures.
4. Determine safety measures to control risk of human failures.
5. Identify recommendations, if agreed by the team.

The analysis was based on industry standards and best practices, including the Energy Institute's guidance on human factors in safety critical task analysis. Given that BLPH is a Normally Unmanned Installation, the study considered limited maintenance scenarios, with operator presence expected only four times over the platform's two-year life cycle.

The workshop concluded that ten tasks qualify as Safety Critical Tasks. For each task, a specific SCTA checklist was applied to verify whether incorrect performance could cause a Major Accident Hazard, identify possible human errors, evaluate the related consequences, and review existing safety measures.

The existing safety measures were considered appropriate, and no additional recommendations arose during the workshop, meaning the current design is acceptable.

7.12 Emergency Systems Survivability Assessment Report (ESSA)

The Emergency Systems Survivability Analysis (ESSA) study was carried out to analyse the survivability of emergency equipment from specific Major Accident hazard and its consequences based on the equipment vulnerability, failure mode and redundancy/diversity. Emergency systems are the last line of defence to protect people and assets from the MAH such as fire, explosion. Survivability of these equipment from the effects of MAH is one of the mandatory requirements to ensure the emergency systems are able to perform their intended function during and/or after the MAH. The main process steps within an ESSA study are:

- Identification of the "criticality": based on MAH, it is required to identify the elements which are required in function in order to mitigate the consequences;
- Identification of the "vulnerability": for each critical element, it is required to identify if the elements is vulnerable to MAHs;
- Identification of the "Fail status": if the selected element is vulnerable to MAHs, it is required to verify if the system fails safe and if it able to perform the safety action for the required duration;
- Identification of the "Redundancy/diversity": if the selected element has not a fail safe status, it is required to verify if the element is provided with redundancy or alternative system which are not vulnerable to MAHs.

Assessment of critical equipment and scenarios resulted in the following findings:

- Fire and gas system meets ESSA requirements;
- Emergency shutdown systems (ESDs), emergency shutdown valves (ESDVs) and blowdown valves (BDVs) meet ESSA requirements;
- Emergency response systems (emergency/escape lighting, communication systems and power system) meet ESSA requirements; and
- Personal survival equipment (evacuation system) meets ESSA requirements.

As all systems meet the ESSA requirements, no further recommendations were raised and risks involving emergency systems are regarded as ALARP.

7.13Simultaneous Operations Report (SIMOPS)

The Simultaneous Operations (SIMOPS) study [32] was carried out to analyse the risks associated with the initial commissioning of the platform at the onshore yard of Rosetti Marino, before it is transported to the North Sea. Given that a detailed SIMOPS assessments will be performed daily during onshore and offshore activities, this study focuses on the general overview of the main activities and the identification of potential interference of risks between them. The following objectives are included in the scope of the study:

- Apply SIMOPS analysis for main commission activities to be carried out in the on-shore construction yard.
- Apply MOPO and SIMOPS analysis for commission activities to be carried out in the off-shore platform.
- Verify eventual constraints for the planned maintenance activities on the off-shore platform.

Two recommendations were issued during the analysis of commissioning activities for on-shore activities.
The first recommendation related to the use of hydrogen feed by means of a road trailer and flexible hose during commissioning. It required the implementation of adequate protective measures, including the definition of a safety exclusion zone to prevent potential incidents during hydrogen handling, and limiting personnel presence to only those strictly necessary for the test. However, since the field tests were carried out without the use of an external hydrogen source, this recommendation is considered not applicable.
The second recommendation focused in the definition of impact of hydrogen venting during hydrogen circuit commissioning. It required the definition of a restricted area, both on the platform and for surrounding activities in the yard, based on potential consequences in the vicinity of the vent stack, to account for hydrogen releases from vent during commissioning. Specifically, a study was conducted to assess the consequences of a hydrogen release from the vent under the commissioning test conditions [36]. Based on these results, a further study [37] titled "Barrier & Access Control Management Plan," detailed, for each operational scenario, the access areas and identified the specific personnel required, as well as the need to suspend any other ongoing work activities in potentially hazardous zones. Thus, this recommendation is considered completed and fully addressed.
In conclusion, from the SIMOPS study related to the commissioning activities of the onshore platform, no further open recommendations remain, and therefore no residual risks requiring mitigation have been identified.

For offshore commissioning, based on the available schedule and assumptions, the team developed a MOPO matrix in which all activities was classified as "allowable." This confirms that the commissioning schedule was, in general, appropriately organized.
No additional measures are required based on the results of the SIMOPS study offshore commissioning, meaning the current design is acceptable. However, it is clearly stated that this study does not replace the need for daily detailed SIMOPS assessments during field activities. These daily reviews are essential to address real-time progress and potential conflicts based on the actual work schedule.

7.14Vent dispersion study

The Vent Gas Dispersion and Potential Radiation Study [33] was performed to verify that the vent system ensures safe depressurization of hydrogen-containing equipment, without posing risks to nearby equipment or operators during maintenance activities.

The methodology involved identifying the worst-case scenario, as defined in the project documentation Relief, Vent and Blowdown Report [34], which is the simultaneous discharge of all seven blowdown valves on the platform (this scenario includes the simultaneous discharge of all H_2 storage vessel). Several receptor points were analysed, including those located at valves on the platform above the storage vessels (the equipment closest to the stack) and at operator working positions across the platform.

FLARESIM and PHAST were used to model thermal radiation and gas dispersion respectively. FLARESIM was applied to confirm that thermal radiation does not exceed critical thermal radiation for asset and for operators in accessible areas. PHAST was used to simulate the spread of hydrogen gas, ensuring that dangerous concentrations remain above platform level where no ignition source are present.

Results showed that thermal radiation values at equipment locations remain within acceptable limits, confirming the suitability of the vent design for asset protection. However, in two specific areas the thermal radiation exceeds the acceptable limit for personnel exposure:

- The second level of the platform above storage vessel on upper deck (elevation +38.6 m.);
- The roof of electrolyser package on upper deck (elevation +36.8 m.)

Even if these areas are generally unmanned, they could still pose a risk to personnel in the unlikely event of an emergency coinciding with maintenance operations. To mitigate these risks, the study recommends classifying these areas as restricted access zones, and limiting the access only during maintenance activities:

- In these zones, ensure that the access will be limited to the maintenance activity (e.g. BDV/PSV valves) after total depressurization of storage vessels, in order to avoid excessive thermal radiation on operator in case of accidental ignition of gas released during an emergency depressurization.

  (note that this recommendation is included in the Action Plan reported in Chapter 9).

Regarding flammable gas dispersion, simulation results for all meteorological conditions and wind directions confirmed that flammable hydrogen concentrations remain above the platform level and do not affect platform equipment or structures. As hydrogen is lighter than air and the vent is the highest point on the platform, gas disperses vertically and does not accumulate near potential ignition sources or critical infrastructure.

In conclusion, the study confirms that the current vent design is safe for both equipment and people, as long as access is restricted in the two areas where thermal radiation is above the safety limit.

Additionally, during the ALARP workshop (see Chapter 6), the team verify the possibility to remove the need for restricted zones by considering alternative solutions such as increasing the height of the vent stack, lowering the storage pressure, or changing the depressurization logic. However, based on the workshop results, the current vent stack design is considered to fall within the ALARP region, and the recommendation to limit access remains applicable.

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7.15Safety Critical Elements (SCE) and Performance Standard

The study [35] was performed to identify the Safety Critical Elements (SCE) and relevant Performance Standards (PS) for equipment in the scope of BLPH project. SCE are defined as the elements which can be subjected to failure and substantially cause, contribute, prevent or help recover from a major accident hazard or event on the platform, and the purpose of Performance Standard is to determine maintenance testing activities necessary to maintain SCE in suitable working conditions.

The methodology used in the study includes a systematic analysis of Major Accident Hazards identified during earlier project phases such as HAZID, HAZOP, QRA, and other safety and risk assessments. Based on this analysis, SCEs were categorized according to eight hardware barrier groups: Structural Integrity, Process Containment, Ignition Control, Detection Systems, Protection Systems, Shutdown Systems, Emergency Response, and Life Saving Equipment.

Each SCE is listed in a dedicated register, including technical details such as tag number, function, group classification and maintenance notes. The Performance Standards for each SCE group have been formalized through PS card, which include specific criteria to assess functionality, reliability, survivability, and performance, as well as inspection and testing requirements. These cards also specify the operational boundaries and interdependencies with other systems, ensuring that each element can perform its safety role effectively under both normal and emergency conditions.

Following the identification of the Safety Critical Elements (SCEs) and the definition of their associated Performance Standards, these elements have been used as a reference throughout the design and development of the BLPH. In particular, they have been considered during the selection of materials, procurement processes, validation activities, and the definition of maintenance strategies for systems critical to safety. This approach ensures that the BLPH is equipped with appropriate measures to prevent or mitigate major accident hazards and to support safe and reliable operation throughout its lifecycle.

7.16Noise study

A noise study was conducted to confirm whether noise levels generated by the BLPH platform are within 85 decibel as per Noise Levels Regulation and international standard [54]. Two scenarios were investigated; normal operation and maintenance/emergency. During normal operation, noise pressure values will not exceed the work area noise limit of 85 dB(A), however, three areas will require signage indicating the presence of noise hazards (>80 dB(A)). In the case of an emergency, noise levels are not expected to exceed the absolute work area noise limit of 115 dB(A).

7.17ALARP Workshop

An ALARP workshop was conducted to document specific design selections in ALARP worksheets. The complete ALARP workshop documentation is provided in the attachments to this report, specifically, the ALARP Workshop Report in Attachment 1, the ALARP Workshop Worksheet in Attachment 2, and the ALARP Workshop Recommendations in Attachment 3. The following goals were set for the workshop:

- Evaluate the adequacy of in place controls, safeguards, mitigation and recovery measures;

- Identify all possible risk reduction strategies, in addition to those already in place, to bring the risk posed by each item to ALARP;
- Discuss the practicality of the identified additional options, by qualitatively weighing their cost and benefits; and
- Issue possible recommendations for further work, design or engineering change to improve the next phases of the project.

The following items were assessed in ALARP worksheets:

1. Hydrogen release from single hydrogen storage vessel – during maintenance;
2. Hydrogen release from single hydrogen storage vessel leading to escalation;
3. BESS thermal runaway - venting;
4. Location of hydrogen piping on the lower deck;
5. Vent height – operator injuries;
6. Tag numbering of the hydrogen storage vessels.

The risks of the selected items were generally found to be managed to ALARP level for the EPC phase. Recommendations and requirements were raised to be closed during the Operational phase, listed in Table 5.

ALARP item no.	Recommendation	By
1	AL1: Ensure that specific risk assessment is performed before any maintenance activity as per control of work procedures to determine the safest configuration of the hydrogen circuit (e.g., establish whether to depressurize or not)	Operators
9	AL2: Apply controls to restrict access to the impacted area to prevent potential exposure of operators or maintenance personnel to radiation from the hydrogen vent. Ensure the restricted area is properly indicated on drawings, layouts and the 3D model.	Operators
11	AL4: Ensure as built documentation, plant signage and HMI reflect the actual status of vessels V-25001C and D location. NOTE REGARDING AL4 (June 2024) [23]: *Point superseded, vessels are in alphabetic order as per original design. In fact, as per actions taken after the issuance of NCR 2025-Q-123A90-0003: Each tank have its correct Tag number painted on the manways and side panels in accordance with the P&ID references. This identification is clear, permanent, and aligned with project documentation to avoid any confusion. In addition a plate*	EPC Contractor CLOSED

	with the correct Tag is placed close to the PED and ASME plates. A statement issued by Rosetti will be included in the final dossier, confirming full traceability and ensuring that the identification of each tank is correctly referenced in all project documentation. In conclusion, the AL4 can be considered not applicable.	
ALARP item no.	Requirement for Operations HSSE Plan	By
9	AL3: Ensure that the access to the second level of the platform above storage vessel on upper deck (elevation +38.6 m) will be limited to the maintenance activity (e.g., BDV/PSV valves) after total depressurization of storage vessels, in order to avoid excessive thermal radiation on maintenance crew in case of accidental ignition of gas released during an emergency depressurization. Ensure signs are located towards the restricted area.	Operators

Table 5 – Recommendations for the operational phase of the project

7.18Philosophies

In addition to the detailed studies, various design and operational philosophies were constructed to ensure that the design of the platform conforms with national codes, practices and regulations. In doing so, this maximised inherently safe design where possible and ensured effective risk mitigation. The following philosophies are available:

- Health Safety and Environment (HSE) Design Philosophy, rev. [26], in which several high-level Fire & Gas shutdowns are described; and
- Fire Protection Philosophy, rev. [53], to provide a basis for the selection of fire protection measures for the BLPH project.

8 CONCLUSION

An assessment has been conducted to demonstrate that the risks associated with the EPC phase of the BLPH are being managed to ALARP levels.

Any changes made in design or operation including those initiated due to the workshops/studies referenced in this report, shall be re-assessed as part of the MOC procedure.

Pending that the recommendations made in this document for the Operational phase are followed up and closed-out, it can be concluded that the risks associated with the BLPH is demonstrated ALARP.

9 ACTION PLAN

There are a number of outstanding issues that need to be addressed in the next phase. For clarity they are listed in the below table.

No	Issue	Action
1	Operators	Ensure that specific risk assessment is performed before any maintenance activity as per control of work procedures to determine the safest configuration of the hydrogen circuit (e.g., establish whether to depressurize or not)
9	Operators	Apply controls to restrict access to the impacted area to prevent potential exposure of operators or maintenance personnel to radiation from the hydrogen vent. Ensure the restricted area is properly indicated on drawings, layouts and the 3D model.
3	Operators	Ensure that the access to the second level of the platform above storage vessel on upper deck (elevation +38.6 m) will be limited to the maintenance activity (e.g., BDV/PSV valves) after total depressurization of storage vessels, in order to avoid excessive thermal radiation on maintenance crew in case of accidental ignition of gas released during an emergency depressurization. Ensure signs are located towards the restricted area.

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ATTACHMENT 1 – ALARP WORKSHOP STUDY

1 SCOPE AND OBJECTIVES

During the workshop all elements in the scope of work of the BLPH platform were considered. The following items were excluded:

- Construction/Commissioning activities, that shall be analyzed during a Constructability workshop/ SIMOPS workshop.
- Decommissioning.

The objectives of the workshop were to:

- Review the list of previously selected ALARP items.
- Evaluate the adequacy of in place controls, safeguards, mitigation and recovery measures.
- Identify all possible risk reduction strategies, in addition to those already in place, to bring the risk associated with each item to ALARP.
- Discuss the practicality of the identified additional options, by qualitatively weighing their cost and benefits.
- Issue possible recommendations for further work, design or engineering change to improve the next phases of the project.

2 PROJECT ASSUMPTIONS

The following assumptions were applied during the ALARP demonstration workshop:

- CPIs were included in the discussion based on Company information only.
- The analysis was based on the results of the safety studies present at the moment of the review.
- The assessment of ALARP items was limited to events occurring within the project's defined Scope of Work. Hazards from external sources or those considered not reasonably foreseeable or credible were not addressed during the workshop.

3 LIST OF ALARP ITEMS

Throughout the workshop, the following ALARP items were assessed.

No.	ALARP ITEMS
1	Hydrogen release from single hydrogen storage vessel
2	Escalation event of hydrogen from all storage area
3	BESS thermal runaway
4	Hydrogen release inside electrolyser container
5	Potential for explosion inside electrolyser due to membrane failure

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No.	ALARP ITEMS
6	Hydrogen release inside fuel cell container
7	Location of hydrogen piping on the lower deck
8	Fire in technical rooms
9	Vent height – operator injuries
10	Possible damage to the platform – transformer location
11	Sequence of hydrogen storage vessels

Table 6 – List of ALARP items

4 WORKSHOP EXECUTION

4.1 ALARP Team Members

The ALARP session was conducted by a third-party Facilitator, who ensured the correct application of the ALARP methodology.

The ALARP team included all functions involved in the platform design and it was composed, indicatively, by the following figures:

- Facilitator - Consultant for ALARP session
- Scribe - Consultant for ALARP session
- PM representative from Company and Contractor side
- Safety Representatives from Company and Contractor side
- Process and I&C Representatives from Company and Contractor side
- Others on call

4.2 Schedule and Venue

The ALARP workshop was held on December 4th, 2024, at Rosetti Marino's premises in Milan, with a number of technicians remotely connected via Microsoft Teams.

4.3 Recording and Reporting

The output of the various review sessions was recorded by the Scribe under the management of the Facilitator To provide concise documentation of ALARP issues, a worksheet style was adopted which focuses on the key points of verifying that decision making adheres to the ALARP principles set out in the previous section. The worksheet structure is illustrated in the below table.

IDENTIFY	Problem Definition
	HSSE Issues and Potential Risk
	HSSE Standard and Tolerability Criteria
ASSESS	Options Considered
	Basis for Selection & Uncertainties
	Option Discussion:
	Justification for Rejected Options (e.g. Options not incorporated as considered beyond ALARP)
CONTROL & EVALUATION	Residual HSSE Risk
	Recommendations for Next Project Phase
	Requirements for the Operations HSSE-Plan

Table 8 – Template of the worksheets employed in the workshop

This worksheet is broken down into three areas, firstly identifying the ALARP issue, and associated hazards, then assessing options, with reference where appropriate to other risk assessments, codes and standards etc. before justifying the selected option and detailing as part of control and evaluation the residual risks and any considerations for the next phase of the project. The worksheets and the recording process were projected onto a screen during the session, so that the workshop team could view, comment and amend as necessary the generated content as it was produced. The following information was recorded for each item:

- Scenario number
- Expected risk
- Description of scenario
- Qualitative risk assessment
- Safeguards, controls, mitigating and recovery measures
- Proposed additional risk reduction options
- Justification for chosen and rejected options
- Recommendations (if necessary) for the operational phase of the project and responsibility
- Requirements for the Operations HSSE Plan and responsibility

The recorded worksheets are reported in Attachment 2.

5 RESULTS

During the workshop, a total of 6 out of 11 previously identified ALARP items were analyzed, and for each of them a discussion was held to identify possible additional risk mitigation measures, if any.

In most cases, the risks associated with the analyzed events were found to be already ALARP, as all investigated alternative solutions involved effort, time or cost grossly disproportionate to the benefit gained. Otherwise, no additional options were identified at all.

Only one item was deemed not ALARP, and effective options were determined to reduce its risk in a practicable manner.

Regarding the items associated with the electrolyser package, no specific design choice has been made, and no additional risk reduction options were identified. Therefore, no ALARP worksheet has been developed.

A summary of the discussion about the items evaluated throughout the workshop is reported below.

1. Hydrogen release from single hydrogen storage vessel – during maintenance: this event involves a hydrogen release from a single storage vessel with potential consequences like fire or explosion, which can in turn lead to fatalities as maintenance activities are carried out. Three options were evaluated for this scenario, and the team members eventually considered the current condition ALARP. In particular, the following options were discussed:

   a) As per current design (i.e., purge the electrolyser and not operate the fuel cell, keep the H_2 storage vessels pressurized).

   b) Always purge complete hydrogen inventory with nitrogen prior to personnel boarding and start maintenance activities.

   c) Always minimize hydrogen inventory to 3 barg (minimal operational pressure of the fuel cell, so that no hydrogen is vented) prior to personnel boarding and start maintenance activities.

   Option B was considered grossly disproportionate because it would result in the loss of a considerable amount of hydrogen via the vent and the use of nitrogen to purge the vessels, the cost of both outweighs the potential benefit gained. In addition, completely emptying the storage vessels might lead to other hazards, e.g. air ingress and internal explosion Furthermore, purging the vessels with nitrogen would require a significant amount of time to be completed and to reach the required hydrogen purity for the fuel cell after the restart, given the presence of nitrogen within the vessels.

   Option C was also excluded since it involves converting hydrogen into energy when it is not efficient, thus eliminating the purpose of the BLPH and causing an economic loss. This option will only be applied when personnel are required on the elevated deck, otherwise it is considered grossly disproportionate as it will not reduce the frequency of a leak.

   Therefore, maintaining the current design solution (i.e., not venting and purging the H_2 vessels while doing maintenance, as offshore storage vessels are typically not depressurized for NUIs during maintenance activities) was considered the most practical option.

A residual risk remains in connection with the presence of hydrogen under pressure in the hydrogen storage vessels, but they are designed to ALARP as per Bow-Tie in Attachment 4.

A recommendation arose during the workshop to ensure that specific risk assessment is performed before any maintenance activity as per control of work procedures to determine the safest configuration of the hydrogen circuit (e.g., establish whether to depressurize or not)

2. Hydrogen release from single hydrogen storage vessel leading to escalation: this event involves a hydrogen release from a single storage vessel with potential escalation to the adjacent hydrogen storage vessels or to other packages (i.e., fuel cell, electrolyser). A potential scenario for escalation is a flange leak in one of the H_2 storage vessels, leading to a jet fire flame impingement at an adjacent structure. Three options were evaluated for this event:

   a) As per current design.

   b) Additional spacing between hydrogen storage vessels.

   c) Passive fire protection (PFP) on structural elements around the hydrogen storage vessels.

   Option B would entail rethink the design of the whole BLPH, which was considered grossly disproportionate, given the current construction work progress. In short, in all phases of the project, the potential escalation between:

   - hydrogen storage vessels
   - other units

   has been analysed [6], [7], [11] and deemed ALARP with the current layout.

   Option C was ruled out as well, since the cost to implement passive fireproofing measures was deemed disproportionate to the benefit gained, as detailed in Attachment 2.

   A residual risk remains in connection with the presence of hydrogen under pressure in the hydrogen storage vessels, but they are designed to ALARP as per Bow-Tie in Attachment 4.

3. BESS thermal runaway: for the BESS thermal runaway itself, as agreed by the team members, no additional risk reduction options were identified. Regarding the existing safety measures in place, refer to the bow-tie diagram in Attachment 4 and BLPH BESS Safety description document – Thermal Runaway mitigations and recommendations [12].

   However, additional options were evaluated to reduce the risk posed by the venting of the BESS thermal runaway gases below the upper deck, which might lead to the accumulation of flammable substances, the most critical of which is hydrogen, within a congested area, potentially resulting in a fire or explosion. In particular, the following options were discussed:

   a) As per current design.

   b) Route the BESS emergency exhaust ventilation conduit outside the deck to a safe area.

c) Route the BESS emergency exhaust ventilation conduit through a vent line to the main emergency vent (Q-43004).

As options B and C were considered grossly disproportionate due to the cost and time needed to implement the new piping given the construction work progress, the team agreed that maintaining the current design was the most practical option. A number of reasons are in support of this:

- The amount of exhaust gases produced by a thermal runaway is very limited, and such gases are vented to the atmosphere with sufficient dilution to ensure no flammable mixture occurs within the BESS.
- The composition of the gaseous mixture coming out from the exhaust ventilation conduit is below hydrogen LFL. Moreover, from a molecular point of view, hydrogen would stay evenly distributed throughout the mixture and could not spontaneously build up to a hazardous concentration.
- The area is naturally ventilated. If the ventilation inside the BESS is not working sufficiently there may be a flammable mixture inside the BESS and subsequently outside the BESS, but this will not be prevented by the installation of ventilation conduit.
- A network of gas detectors is foreseen above the BESS container in the potential hydrogen accumulation area, as indicated in the F&G detectors layout (rev. 02 sh. 1) [13] and F&G C&E Matrix [14].

Therefore, for this specific scenario, even though a residual risk remains in connection with the presence of thermal runaway gases at the top of the BESS below the plated top deck, the team members considered the current condition ALARP.

4. Hydrogen release inside electrolyser container: for this event no specific design choice has been made, and no additional risk reduction options were identified. Therefore, no ALARP worksheet has been developed. Regarding the potential escalation from the electrolyser to the storage vessels, refer to the bow-tie diagram in Attachment 4, and to the FERA [7] and QRA [6] results.
5. Potential for explosion inside electrolyser due to membrane failure: for this event no specific design choice has been made, and no additional risk reduction options were identified. Therefore, no ALARP worksheet has been developed. Regarding the potential escalation from the electrolyser to the storage vessels, refer to the bow-tie diagram in Attachment 4 and to the LOPA [20].
6. Hydrogen release inside fuel cell container: for this event no specific design choice has been made, and no additional risk reduction options were identified. Therefore, no ALARP worksheet has been developed, since the risk associated with this event is deemed already ALARP, as per HAZOP [8] and Megablock safety concept [16]. Regarding the potential escalation from the fuel cell to the storage vessels, refer to the FERA [7] and QRA [6] results.
7. Location of hydrogen piping on the lower deck: this event involves a potential hydrogen release under the plated floor of the upper deck, which might lead to the accumulation of hydrogen within a congested area, potentially resulting in a fire or explosion. It is worth specifying that the piping

investigated during the workshop is the one going from the storage vessels to the fuel cell, as the one going from the electrolyser to the storage vessels has been already relocated on the upper deck. The two following options were discussed for this scenario:

a) As per current design.

b) Relocate the piping from the storage vessels to the fuel cell above the upper deck floor.

Option B was excluded, since the only available location of the piping would be above the existing emergency escape route. The relocation of the piping would require a dedicated support structure, which was considered impractical at this stage of the project, due to its high cost and added complexity. Indeed, not only would it increment the total weight of the platform, but it would also be subject to vibrations, increasing the risk of dropped objects in an area that must be free from any obstruction.

Consequently, the team agreed that maintaining the current design solution is the most practical option, since the frequency of occurrence of a release is estimated to be very low, given that the portion of piping running below the upper deck is entirely welded and no release sources, such as flanges or fittings, are foreseen. The only opening in the section under examination is a removable cap employed only during the commissioning phase for the hydrotest, after which it is seal welded (isometric drawing no. 16, line no. 2"-HY-023-01HSS-N [15]). Also, no corrosion is expected, since the purity of hydrogen inside the piping is 99.999%. The deck above the piping is plated, so the risk of dropped objects is prevented as well. In addition, the outlet to the fuel cell from the H2 storage vessel is from the top (not from the bottom), so there will be no liquid going to the low point in the piping system. Finally, there is no hazardous area classification around the piping, hence the full lower deck stays a "no hazardous area".

For further information, refer to FERA [7] and QRA [6].

Therefore, the risk posed by a hydrogen release below the plated floor of the upper deck was considered ALARP. Nevertheless, a residual risk still exists, which can be effectively managed through the existing F&G network.

8. Fire in technical rooms: for this event no specific design choice has been made, and no additional risk reduction options were identified. Therefore, no ALARP worksheet has been developed.
9. Vent height – operator injuries: this event involves, in case of a simultaneous discharge of all blowdown valves on the storage vessels, a hydrogen release from the vent. This might lead to a jet fire, in case of immediate ignition, or to a flammable gas dispersion, eventually resulting in a flash fire, in case of late ignition. If a jet fire occurs, as stated in the Vent Gas Dispersion and Potential Radiation Study [10], a thermal radiation threshold of 6.31 kW/m^2 can reach areas of the platform where operators might be during maintenance activities. This is because the vent stack is not sufficiently high. As a result, the aforementioned study recommends that the second level of the platform above the storage vessels be prohibited for operators unless total depressurization of the vessels is carried out, which is planned to be done only before maintenance activities on the upper deck (i.e., once a year for a total duration of 8 hours). It is also worth noting that in the FEED phase

of the project the boarding of personnel without prior total depressurization of the storage vessels was excluded. This possibility was introduced in the EPC phase and communicated to the Contractor after the vent was already ordered.

In light of these aspects, the following options were evaluated for this scenario:

a) As per current design, having a sterile area on the top of the BLPH.

b) Increase vent height so that the minimum height of 6.31 kW/m^2 is above the top of the BLPH.

c) Staggered depressurization of the storage vessels.

d) Reduce hydrogen storage vessels pressure so that the radiation from the vent is below 6.31 kW/m^2 for the top of the BLPH.

Option B was considered grossly disproportionate at this stage of the project, due to the time and cost of ordering a new vent and re-considering its support structure.

Option C was considered not feasible due to the time constraint of the emergency depressurization, according to API 521 [4].

Option D was ruled out as well, since the pressure that would be required to remove the restriction from the second level of the platform above the storage vessels is as low as 4.5 barg. This, being above the minimum operation pressure of the fuel cell, would cause a significant loss of hydrogen via the vent.

In conclusion, the team agreed that the risk associated with the current vent configuration is ALARP. Even so, there is still the residual risk of operator exposure to a maximum heat radiation of 8.5 kW/m^2 [10], in case of ignition of the hydrogen vented during an emergency scenario. Hence, a recommendation was issued for the operational phase of the project, to ensure that the relevant controls are applied to restrict access to the impacted area and also to ensure the restricted area is properly indicated on drawings, layouts and the 3D model. Moreover, it is required to specify in the Operations HSSE Plan to ensure that the access to the second level of the platform above storage vessel on upper deck (elevation +38.6 m) will be limited to the maintenance activity (e.g., BDV/PSV valves) after total depressurization of storage vessels, in order to avoid excessive thermal radiation on maintenance crew in case of accidental ignition of gas released during an emergency depressurization. Additionally, ensure signs are located towards the restricted area.

10. Possible damage to the platform – transformer location: this event involves the transformer acting as an ignition source for hydrogen, potentially released by the nearby piping. Indeed, although the transformer is turned off during maintenance activities, it is still energized. However, given that, similarly to item no. 7, the portion of hydrogen piping running close to the transformer is entirely welded, no specific design choice has been made and no additional risk reduction options were identified for this event. Therefore, no ALARP worksheet has been developed.

11. Sequence of storage vessels: this event is related to an error in labelling the hydrogen storage vessels, swapping vessel C and D. As a consequence, the vessels are not arranged in alphabetical order but are labelled ABD-CEF instead. This might lead to miscommunication issues (e.g., operator has to perform a maintenance task on vessel C and goes to vessel D instead), potentially resulting in

process or maintenance upsets or even in fatalities when the incorrect vessel has been depressurized. For this event, two additional options were identified and discussed:

a) Consider decommissioning vessel D and commissioning vessel C to change the order to ABC-DEF.

b) Update the project documentation and labelling on the platform to highlight the position of vessels C and D.

Option A was considered grossly disproportionate at this stage of the project due to the cost and time needed for the re-certification (back to vendor fabrication) of the vessels. Therefore, the team members agreed to adopt option B to reduce the risk to an ALARP level.

In this regard, a recommendation was made to ensure as built documentation, plant signage and HMI reflect the actual status of the location of the vessels V-25001C and D.

NOTE ; Point (11) superseded, vessels are in alphabetic order as per original design. In fact, as per actions taken after the issuance of NCR 2025-Q-123A90-0003: Each tank have its correct Tag number painted on the manways and side panels in accordance with the P&ID references. This identification is clear, permanent, and aligned with project documentation to avoid any confusion. In addition a plate with the correct Tag is placed close to the PED and ASME plates. A statement issued by Rosetti will be included in the final dossier, confirming full traceability and ensuring that the identification of each tank is correctly referenced in all project documentation.

All the considerations above are summarized in the worksheets employed during the ALARP workshop, which are reported in Attachment 2.

6 RECOMMENDATION

The outcomes of the ALARP demonstration workshop highlight that for most of the ALARP items analysed the current conditions already demonstrate an ALARP level of risk. This is because all potential additional risk-reduction measures have been deemed grossly disproportionate to the benefits achieved. This outcome is also influenced by the fact that the construction work for the BLPH is already underway, and some of the proposed solutions would require modifications to structures currently being fabricated or already installed (e.g., increasing the height of the vent, or building new support structures to allow a different piping routing), or changes to the arrangement of elements already assembled (e.g., increasing the space between the hydrogen storage vessels). Therefore, such options are impractical at this stage of the project.

Overall, the outcomes of the ALARP workshop are summarised in the following table.

ALARP item no.	ALARP item description	Chosen option
1	Hydrogen release from single hydrogen storage vessel – during maintenance	The team agreed that the risk associated with the current design solution is ALARP.
2	Hydrogen release from single hydrogen storage vessel leading to escalation	The team agreed that the risk associated with the current design solution is ALARP.
3	BESS thermal runaway	The team agreed that the risk associated with the current design solution is ALARP.
4	Hydrogen release inside electrolyser container	No specific design choice made, and no additional risk reduction options identified.
5	Potential for explosion inside electrolyser due to membrane failure	No specific design choice made, and no additional risk reduction options identified.
6	Hydrogen release inside fuel cell container	No specific design choice made, and no additional risk reduction options identified.
7	Location of hydrogen piping on the lower deck	The team agreed that the risk associated with the current design solution is ALARP.
8	Fire in technical rooms	No specific design choice made, and no additional risk reduction options identified.
9	Vent height – operator injuries	The team agreed that the risk associated with the current design solution is ALARP.
10	Possible damage to the platform – transformer location	No specific design choice made, and no additional risk reduction options identified.
11	Sequence of hydrogen storage vessels	The team agreed that the risk can be brought to ALARP by updating the documentation and labelling related to hydrogen storage vessels V-25001C and D.

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In conclusion, the workshop, along with the numerous control and mitigation measures that are currently in place, highlighted the following recommendations. In particular, the worksheet reports three recommendations and one requirement, as described in the following tables.

ALARP item no.	Recommendation	By
1	AL1: Ensure that specific risk assessment is performed before any maintenance activity as per control of work procedures to determine the safest configuration of the hydrogen circuit (e.g., establish whether to depressurize or not)	Operators
9	AL2: Apply controls to restrict access to the impacted area to prevent potential exposure of operators or maintenance personnel to radiation from the hydrogen vent. Ensure the restricted area is properly indicated on drawings, layouts and the 3D model.	Operators
11	AL4: Ensure as built documentation, plant signage and HMI reflect the actual status of vessels V-25001C and D location. NOTE REGARDING AL4 (June 2024) **Errore. L'origine riferimento non è stata trovata.**: ***Point superseded, vessels are in alphabetic order as per original design. In fact, as per actions taken after the issuance of NCR 2025-Q-123A90-0003: Each tank have its correct Tag number painted on the manways and side panels in accordance with the P&ID references. This identification is clear, permanent, and aligned with project documentation to avoid any confusion. In addition a plate with the correct Tag is placed close to the PED and ASME plates. A statement issued by Rosetti will be included in the final dossier, confirming full traceability and ensuring that the identification of each tank is correctly referenced in all project documentation.*** In conclusion, the AL4 can be considered not applicable.	EPC Contractor CLOSED

ALARP item no.	Requirement for Operations HSSE Plan	By
9	AL3: Ensure that the access to the second level of the platform above storage vessel on upper deck (elevation +38.6 m) will be limited to the maintenance activity (e.g., BDV/PSV valves) after total depressurization of storage vessels, in order to avoid excessive thermal radiation on maintenance crew in case of accidental ignition of gas released during an emergency depressurization. Ensure signs are located towards the restricted area.	Operators

These recommendations/requirement are included in the HSSE Register and will be considered in the following phases of project development, especially those pertaining to the operational phase of the platform, which will be under the responsibility of the owner.

7 RESULTS

Based on the evaluation of the recommendations developed throughout the main HSE studies, including QRA, FERA, HAZID, HAZOP, HFE, and others, it can be concluded that all recommendations have been addressed during the engineering phase of the project (or have been recorded in the HSSE Register for those related to the operational phase of the platform, which will be under the responsibility of the owner).

Each recommendation has been reviewed with respect to its feasibility, relevance, and alignment with the current project design and schedule. Where applicable, risk reduction measures have been integrated into the design. In cases where implementation was not practicable, appropriate justifications have been documented in accordance with the ALARP principle.

Three recommendations from the ALARP workshop remain open, all of which relate to the operational phase of the platform. These items are the responsibility of the owner and will need to be further developed and implemented during future operational planning.

This structured approach confirms that HSE risks have been proactively identified and managed, and that the overall project design is consistent with industry best practices and complies with applicable regulatory requirements.

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ALARP DEMONSTRATION ATTENDANCE LIST

Name	Company	Role	Attendance
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Alberto Baldassarri	ICARO	Scribe	FT presence
Claudia Giunchi	ROSETTI MARINO	Project Engineer	FT presence
Edoardo Carminati	ROSETTI MARINO	Technical Safety Engineer	FT presence
Carolina Caracciolo	ROSETTI MARINO	Safety Leader	FT presence
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Nicolas Le Brun	CROSSWIND	HSE Leader	FT online
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ATTACHMENT 2 – ALARP DEMONSTRATION WORKSHEETS

1 Hydrogen release from single hydrogen storage vessel – during maintenance

IDENTIFY

Problem Definition

Hydrogen release from single H_2 storage vessel

HSSE Issues and Potential Risk

Loss of Containment of H_2 from the H_2 storage vessels has been identified as an MAH and subjected to Bowtie analysis with following consequences:

- Explosion leading to more than 3 fatalities
- Jet Fire leading to less than 3 fatalities
- Escalation to other packages (fuel cell/electrolyser) – additional asset damage

In case of any maintenance on the H_2 storage vessels themselves requiring containment breaking, a full H_2 removal will be required as per risk assessment.

HSSE Standard and Tolerability Criteria

The risk is managed to tolerable by meeting standard design requirements and the tolerability criteria in the project's HSE design philosophy (Document Number: 123A90-DDL-SAF-RE-30046).

Note that the BLPH does not fall under the "mijnbouwwet" and the EU directive https://wetten.overheid.nl/BWBR0014168/2022-01-01

https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:32013L0030

as these rules apply for storage below 100 m underground and pipelines.

Note that the BLPH does not fall under the "Besluit risico's zware ongevallen 2015 - https://wetten.overheid.nl/BWBR0036791/2015-07-08", as there will be less than 5 tonne of H_2 (see part 2 of https://eur-lex.europa.eu/legal-content/NL/TXT/?uri=CELEX:32012L0018).

ASSESS

Options Considered

3 different options have been proposed:

a) As per current design – purge the electrolyser and not operate the fuel cell, keep the H_2 storage vessels pressurized
b) Always purge complete hydrogen inventory with nitrogen prior to personnel boarding and start maintenance activities
c) Always minimize hydrogen inventory to the minimal operational pressure of the fuel cell (3 barg)

Basis for Selection & Uncertainties

UKOOA Decision Framework decision Context Type B selected. These scenarios have some risk uncertainty to them or involve some risk trade-offs. Application of codes and standards requires some extension through engineering judgment. Options will likely require risk based analysis to support the decision.

Expert judgement	Decision was taken by the project team.
Risk Based Analysis	Qualitative and Quantitative risk based analysis was part of the decision making.

	Option Discussion: the team agrees that the risk associated with the current design solution is ALARP.	
	Justification for Chosen Option	
	As the BLPH is normally unmanned the risk to people has been considered ALARP based on the QRA (doc. no. 123A90-DDL-SAF-RE-30019). In combination with process hazard studies (HAZOP/LOPA) [8] and the Bow-Tie in Attachment 4 option A is chosen as the risk of the current design is considered ALARP by the ALARP workshop team. The current philosophy is that the H_2 storage vessels will not be emptied and purged while doing maintenance in the vicinity of the H_2 storage vessels. Offshore storage vessels are typically not depressurized for NUIs during maintenance activities.	
	Justification for Rejected Options (e.g. Options not incorporated as considered beyond ALARP)	
	During the SELECT phase, the ALARP demonstration note considered similar options. The conclusion during the SELECT phase was to purge the whole inventory, as per **option B**, with a recommendation to better analyze this in the next phase. Hence during the DEFINE phase this was done. The conclusion in DEFINE is that it is more hazardous to purge the complete system, specifically the fuel cell system. For the hydrogen inside the storage vessels, completely emptying the storage vessels might lead to other hazards, e.g. air ingress and internal explosion. Also a key issue identified is to get the H_2 back on spec for the fuel cell. It will take many cycles to reach the purity required and hence lots of H_2 need to be sent to the atmosphere prior to restarting the fuel cell. This is a significant cost of the lost hydrogen and cost/time for purging with H_2. **In Option C,** no hydrogen is vented prior to personnel boarding and start of maintenance activities. However, the hydrogen is converted into energy when it is not efficient, hence eliminating the purpose of the hydrogen on the BLPH. So there is a potential for a significant loss of hydrogen which is expensive. Option C will be applied when personnel is required on the elevated deck. When no personnel is required on the elevated deck this option is considered grossly disproportionate as it will not reduce the frequency of a leak.	
CONTROL & EVALUATION	Residual HSSE Risk	
	Residual risks remain in connection to the presence of H_2 under pressure in the H_2 storage vessel but are designed to ALARP as per BowTie in Attachment 4.	
	Recommendations for Next Project Phase	By
	AL1: Ensure that specific risk assessment is performed before any maintenance activity as per control of work procedures to determine the safest configuration of the hydrogen circuit (e.g., establish whether to depressurize or not)	Operators
	Requirements for the Operations HSSE-Plan	

	None

2 Hydrogen release from single hydrogen storage vessel leading to escalation

IDENTIFY	**Problem Definition**
	Hydrogen release from single H_2 storage vessel with potential escalation to the other H_2 storage vessels
	HSSE Issues and Potential Risk
	Ignited release of H_2 at one H_2 storage vessel leading to escalation to one of the other H2 storage vessels. A potential scenario for escalation is a flange leak in one of the H_2 storage vessels, leading to a jet fire flame impingement at an adjacent structure. The risk associated with escalation has been ranked as 3B using the Crosswind Risk assessment matrix (one storage vessel is around €1M, escalation towards 2 storage vessels has been assumed) and is not a major accident.
	HSSE Standard and Tolerability Criteria
	The risk is managed to tolerable by meeting standard design requirements and the tolerability criteria in the project's HSE design philosophy (Document Number: 123A90-DDL-SAF-RE-30046). Note that the BLPH does not fall under the "mijnbouwwet" and the EU directive https://wetten.overheid.nl/BWBR0014168/2022-01-01 https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:32013L0030 as these rules apply for storage below 100m underground and pipelines. Note that the BLPH does not fall under the "Besluit risico's zware ongevallen 2015 - https://wetten.overheid.nl/BWBR0036791/2015-07-08", as there will be less than 5 tonne of H_2 (see part 2 of https://eur-lex.europa.eu/legal-content/NL/TXT/?uri=CELEX:32012L0018).
ASSESS	**Options Considered**
	3 different options have been proposed: a) As per current design b) Additional spacing between H2 storage vessels c) Passive fire protection (PFP) on structural elements around the H_2 storage vessels
	Basis for Selection & Uncertainties
	UKOOA Decision Framework decision Context Type B selected. These scenarios have some risk uncertainty to them or involve some risk trade-offs. Application of codes and standards requires some extension through engineering judgment. Options will likely require risk based analysis to support the decision.

Expert judgement	Decision was taken by the project team.
Risk Based Analysis	Qualitative and Quantitative risk based analysis was part of the decision making.

Option Discussion: the team agrees that the risk associated with the current design solution is ALARP.

Justification for Chosen Option

During the SELECT phase, this concern was initially raised, and a MEMO (416041-40751/MEMO-001) has been created with determined that the distance between the H2 storage vessels was sufficient. In the SELECT ALARP report a recommendation was given: "During the next phase, the basis for the leak size and the related distances between the hydrogen vessels shall be evaluated in more detail."

During the DEFINE phase, this recommendation has been closed with the "leak size analysis report" (doc. no. K559-2254-SE-TEN-001) and a FERA (Document No: K559-2254-SE-REP-007). The distance between the H2 storage vessels have been considered ALARP.
A key point to note is that the guidance for estimating hydrogen separation distances is geared towards land based hydrogen filling stations and is focused on distances from the entire hydrogen system to an external receptor.

During the Execute phase, the FERA (doc. no. 123A90-DDL-SAF-RE-30020) has been updated to the latest design and the risk associated with fire and explosions from the hydrogen storage system is tolerable and ALARP for a 2 year test facility.

In combination with process hazard studies (HAZOP/LOPA) [8]and the Bow-Tie in Attachment 4 option A is chosen as the risk of the current design is considered ALARP by the ALARP workshop team.

Justification for Rejected Options (e.g. Options not incorporated as considered beyond ALARP)

Option B, additional spacing between H2 storage vessels
This option requires a larger platform with massive increased CAPEX, which is grossly disproportionate considering the risk for escalation is assesses as tolerable according to FERA (doc. no. 123A90-DDL-SAF-RE-30020), QRA (doc. no. 123A90-DDL-SAF-RE-30019) and leak size analysis (doc. no. K559-2254-SE-TEN-001).

Option C – PFP on structural elements around the H2 storage vessels
PFP requires an investment of around €80 000 and reduces the fire escalation risk. The potential risk for fire escalation is already below 10^{-4}/yr according to FERA (doc. no. 123A90-DDL-SAF-RE-30020) and leak size analysis (doc. no. K559-2254-SE-TEN-001). The specific directionally has not been taken into account and would reduce the frequency of escalation even further.

Normally a Cost Benefit Analysis (CBA) is only performed for MAH. However, for this escalation event, a CBA is performed for PFP.

BenefitRR = The statistic value generated in reducing the risk over the period under consideration.

	BenefitRR [€/year] = (ΔCA + ΔCP + ΔCE) + (ΔCF x FGD)
	• ΔCA = The cost of asset damage avoided over the period under consideration
	  • Assuming PFP would eliminate the fire escalation would lead to a frequency of $<10^{-4}$/yr
	  • Assuming loss of 2 additional storage vessels" with a value of €1M each (€2M total)
	  • ΔCA = €2M * 10^{-4}/yr = €200/yr
	• ΔCP = The cost of production loss avoided over the period under consideration = N/A
	• ΔCE = The cost of environmental damage avoided over the period under consideration = N/A
	• ΔCF = The cost of averting the total fatalities over the period under consideration = N/A
	• FGD = The factor of gross disproportionality in case of fatality = N/A
	CostRR = CAPEX / life time of the project + yearly OPEX = €80 000/2 + 0 = €40 000/yr
	
	CostRR > BenefitRR hence the proposed mitigation is not ALARP and can be discarded.
	
	A key point to note is that the guidance for estimating hydrogen separation distances is geared towards land based hydrogen filling stations and is focused on distances from the entire hydrogen system to an external receptor. The FERA has assumed that the inventory of the 6 H_2 storage vessels are a single unit.
	
	Therefore, adding PFP to structural elements around the H_2 storage vessels is considered grossly disproportionate.

CONTROL & EVALUATION	Residual HSSE Risk
	Residual risks remain in connection to the presence of H_2 under pressure in the H_2 storage vessels but are designed to ALARP as per the BowTie in Attachment 4.
	Recommendations for Next Project Phase — By
	None
	Requirements for the Operations HSSE-Plan
	None

3 BESS thermal runaway – venting

For the BESS thermal runaway itself, as agreed by the team members, no additional risk reduction options were identified. Regarding the existing safety measures in place, refer to the bow-tie in Attachment 4 and BLPH BESS Safety description document – Thermal Runaway mitigations and recommendations (doc. no. K559-2254-CWIWP4202201-E99-099). However, additional options were evaluated to reduce the risk associated with the venting of the BESS thermal runaway gases below the upper deck, which might lead to the accumulation of flammable substances within a congested area.

<table>
<tr><td>IDENTIFY</td><td>Problem Definition</td></tr>
<tr><td></td><td>BESS Thermal Runaway</td></tr>
<tr><td></td><td>HSSE Issues and Potential Risk</td></tr>
<tr><td></td><td>The outlet of the BESS thermal runaway gases from BESS emergency response is on top of the BESS container below the bottom of steel of the upper deck flooring and the primary steel of the upper deck.
Potential accumulation of BESS thermal runaway gases (including hydrogen) below the plated deck.</td></tr>
<tr><td></td><td>HSSE Standard and Tolerability Criteria</td></tr>
<tr><td></td><td>The risk is managed to tolerable by meeting standard design requirements and the tolerability criteria in the project's HSE design philosophy (Document Number: 123A90-DDL-SAF-RE-30046).</td></tr>
<tr><td>ASSESS</td><td>Options Considered</td></tr>
<tr><td></td><td>a) As per design, with the presence of gas detectors above the BESS container in the potential hydrogen accumulation area, as indicated in the F&G detectors layout (doc. no. 123A90-DDL-SAF-DL-30027 Rev.02 SH1) and F&G C&E Matrix (doc. no. 123A90-DDL-IN-CE-40002)
b) Route the BESS emergency exhaust ventilation conduit outside the deck to a safe area
c) Route the BESS emergency exhaust ventilation conduit through a vent line to the main emergency vent (Q-43004)</td></tr>
<tr><td></td><td>Basis for Selection & Uncertainties</td></tr>
<tr><td></td><td>UKOOA Decision Framework decision Context Type B selected. These scenarios have some risk uncertainty to them or involve some risk trade-offs. Application of codes and standards requires some extension through engineering judgment. Options will likely require risk based analysis to support the decision.</td></tr>
<tr><td></td><td><table><tr><td>Expert judgement</td><td>Decision was taken by the project team.</td></tr><tr><td>Risk Based Analysis</td><td>Qualitative and Quantitative risk based analysis was part of the decision making.</td></tr></table>
Option Discussion: the team agrees that the risk associated with the current design solution is ALARP.</td></tr>
<tr><td></td><td>Justification for Chosen Option</td></tr>
<tr><td></td><td>The BESS thermal runaway scenario is assessed in a Bow-Tie [4]. Any additional barriers from Thermal Runaway mitigations and recommendations (doc. no. K559-2254-CWIWP4202201-E99-099) have been assessed and implemented in the BESS design.</td></tr>
</table>

	The amount of produced gasses by a thermal runaway is limited (doc. no. K559-2254-CWIWP4202201-E99-099) and a limited amount of batteries are affected. Any produced runaway gases from BESS are vented to atmosphere with sufficient dilution to ensure no flammable mixture occurs within the BESS. Once the diluted gasses are exiting the BESS, these gasses cannot de-mix and no flammable mixture can occur outside the BESS. Outside the BESS there is natural ventilation. If the ventilation inside the BESS is not working sufficiently there may be a flammable mixture inside the BESS and subsequently outside the BESS, but this will not be prevented by the installation of ventilation conduit. To be able to detect any elevated hydrogen concentration outside the container, hydrogen detectors are installed under the top deck above the BESS vents. Therefore, option A is chosen as the risk of the current design is considered ALARP by the ALARP workshop team.	
	Justification for Rejected Options (e.g. Options not incorporated as considered beyond ALARP)	
	Both Options B & C require significant engineering changes and cost for implementing new piping. The exhaust ventilation conduit routes the thermal runaway gasses to a safe area, but does not prevent the risk for buildup gasses inside the container if the ventilation is not available. Therefore this is considered grossly disproportionate.	
CONTROL & EVALUATION	Residual HSSE Risk	
	The residual risk remains in the presence of thermal runaway gasses at the top of the BESS below the plated top deck.	
	Recommendations for Next Project Phase	By
	None	
	Requirements for the Operations HSSE-Plan	
	None	

4 Location of hydrogen piping on the lower deck

IDENTIFY	**Problem Definition**
	Location of hydrogen piping on the lower deck from the H_2 storage vessels to the fuel cell (the piping from the electrolyser to the H_2 storage vessels has been relocated above the plated floor of the upper deck)
	HSSE Issues and Potential Risk
	A leak from this piping can lead to an explosion or jet fire on the lower deck, which is rated as a non-ATEX zone.
	HSSE Standard and Tolerability Criteria
	The risk is managed to tolerable by meeting standard design requirements and the tolerability criteria in the project's HSE design philosophy (Document Number: 123A90-DDL-SAF-RE-30046).
ASSESS	**Options Considered**
	a) As per design b) Relocate the piping from the H_2 storage vessels to the fuel cell above the upper deck floor
	Basis for Selection & Uncertainties
	UKOOA Decision Framework decision Context Type A selected. These types of scenarios are nothing new or unusual. The risks are well understood and have no major stakeholder implications. The hazards are managed using well established practices and Industry and Company Codes and Standards.
	<table><tr><td>Expert judgement</td><td>Decision was taken by the project team.</td></tr><tr><td>Risk Based Analysis</td><td>Qualitative and Quantitative risk based analysis was part of the decision making.</td></tr></table> Option Discussion: the team agrees that the risk associated with the current design solution is ALARP
	Justification for Chosen Option
	- The piping from the H_2 storage vessels to the fuel cell will have no flanges or fittings - There is no hazardous area classification around the piping, hence the full lower deck stays a "no hazardous area". - The purity of the H_2 inside this piping is 99.999% hence no corrosion expected. - The outlet to the fuel cell from the H_2 storage vessel is from the top (not from the bottom), so there will be no liquid going to the low point in the piping system - There is a cap installed in the line for the hydrotest, which will be seal welded after commissioning (refer to isometric drawing no. 16, line no. 2"-HY-023-01HSS-N [15]). - The deck above is plated hence no risk of dropped objects Based on the FERA (doc. no. 123A90-DDL-SAF-RE-30020) and QRA (doc. no. 123A90-DDL-SAF-RE-30019) results the risk associated with this piping is small. Additionally, F&G detection is located on the lower deck around the hydrogen piping. Therefore, the risk of the current design (Option A) is considered ALARP by the ALARP workshop team.

	Justification for Rejected Options (e.g. Options not incorporated as considered beyond ALARP)
	Option B requires re-routing of the hydrogen piping above the emergency escape route on the upper deck. This would increase the complexity of the piping and require dedicated structural support, making the option costly and requires re-engineering.
CONTROL & EVALUATION	Residual HSSE Risk
	Potential hydrogen leak source in the lower deck, which is mitigated by the absence of flanges or fittings, and by the presence of F&G network
	Recommendations for Next Project Phase
	None
	Requirements for the Operations HSSE-Plan
	None

5 Vent height – operator injuries

IDENTIFY	**Problem Definition**
	Initially the project philosophy was to depressurize the H_2 storage vessels prior to boarding the BLPH. There was a change in the project philosophy, to keep the H_2 storage vessels pressurized when accessing the BLPH platform. The hydrogen vent was already ordered based on the original non pressurized philosophy. The vent study concluded that the top area of the BLPH exceeds the 6.31 kW/m^2 during an ignited release from the simultaneous discharge of all 7 blowdown valves.
	HSSE Issues and Potential Risk
	Possibility of operator exposure to a maximum heat radiation of 8.5 kW/m^2 in case of ignition of hydrogen vented during emergency scenario.
	HSSE Standard and Tolerability Criteria
	The risk is managed to tolerable by meeting standard design requirements and the tolerability criteria in the project's HSE design philosophy (Document Number: 123A90-DDL-SAF-RE-30046). API 521 is used as standard for the vent design. The radiation of 6.31 kW/m^2 (including solar radiation) shall not be reached in location where people presence can be possible. 6.31 kW/m^2 is "the maximum radiant heat intensity in areas where emergency action lasting up to 30 s can be required by personnel without shielding but with appropriate clothing".
ASSESS	**Options Considered**
	a) As per vent study recommendation to have a sterile area on the top of the BLPH b) Increase vent height so that the minimum height of the 6.31 kW/m^2 is above the top of the BLPH c) Staggered depressurization of the storage vessels d) Reduce the pressure to 4.5 barg of the hydrogen storage vessels so that the radiation from the vent is below 6.31 kW/m^2 for the top of the BLPH.
	Basis for Selection & Uncertainties0
	UKOOA Decision Framework decision Context Type A selected. These types of scenarios are nothing new or unusual. The risks are well understood and have no major stakeholder implications. The hazards are managed using well established practices and Industry and Company Codes and Standards.
	<table><tr><td>Expert judgement</td><td>Decision was taken by the project team.</td></tr><tr><td>Risk Based Analysis</td><td>Qualitative risk based analysis was part of the decision making.</td></tr></table> Option Discussion: the team agrees that the risk associated with the current design solution is ALARP when the sterile area is implemented.
	Justification for Chosen Option
	Personnel is only required to enter the top of the BLPH for maintenance on the hydrogen storage vessels and related equipment (e.g., valves, instruments, etc.). This is expected to occur once during the 2 years of operation. When the sterile area is implemented, option A is considered ALARP by the ALARP workshop team, because the other options are grossly disproportionate.

	Justification for Rejected Options (e.g. Options not incorporated as considered beyond ALARP)	
	- Option B requires a costly design change for building the support structure of the new higher vent and the additional cost of a new vent. Therefore, this is considered grossly disproportionate. - Option C reduces the vent load and subsequently the radiation. However this is not feasible due to the time constraint of the emergency depressurization, according to API 521. Option D The minimum operation pressure of the fuel cell at which the power output is above 600kW is 4 barg. The actual minimum pressure which initiates a shutdown is 3 barg. The pressure of the hydrogen storage vessels so that the radiation from the vent is below 6.31 kW/m^2 for the top of the BLPH is 4.5 barg. As the minimum operation pressure is lower it is required to vent hydrogen for option D, which is considered grossly disproportionate.	
CONTROL & EVALUATION	Residual HSSE Risk	
	The sterile area includes the top area of the BLPH, hence no maintenance can take place when the H2 storage vessels are pressurized. Within the hazard hierarchy, procedures & PPE are least effective. Hence if personnel does not comply to the restriction, there is the possibility of operator exposure to a maximum heat radiation of 8.5 kW/m^2 in case of ignition of hydrogen vented during emergency scenario.	
	Recommendations for Next Project Phase (operational phase)	By
	AL2: Apply controls to restrict access to the impacted area to prevent potential exposure of operators or maintenance personnel to radiation from the hydrogen vent. Ensure the restricted area is properly indicated on drawings, layouts and the 3D model.	Operators
	Requirements for the Operations HSSE-Plan (operational phase)	By
	AL3: Ensure that the access to the second level of the platform above storage vessel on upper deck (elevation +38.6 m) will be limited to the maintenance activity (e.g., BDV/PSV valves) after total depressurization of storage vessels, in order to avoid excessive thermal radiation on maintenance crew in case of accidental ignition of gas released during an emergency depressurization. Ensure signs are located towards the restricted area.	Operators

6 Tag numbering of H2 storage vessels

<table>
<tr><td rowspan="8">IDENTIFY</td><td colspan="2">Problem Definition</td></tr>
<tr><td colspan="2">Installed sequence of vessels is not as per alphabetic order. The H_2 storage vessel layout is numbered "ABD" for the lower 3 vessels and "CEF" for the top vessels.</td></tr>
<tr><td colspan="2">HSSE Issues and Potential Risk</td></tr>
<tr><td colspan="2">Human factor error due to miscommunication (e.g., operator has to go to vessel C and goes to vessel D instead), leading to maintenance on the wrong vessel and potential fatalities when incorrect vessel has been depressurized.</td></tr>
<tr><td colspan="2">HSSE Standard and Tolerability Criteria</td></tr>
<tr><td colspan="2">The risk is managed to tolerable by meeting standard design requirements and the tolerability criteria in the project's HSE design philosophy (Document Number: 123A90-DDL-SAF-RE-30046).</td></tr>
<tr><td colspan="3"></td></tr>
<tr><td colspan="3"></td></tr>
<tr><td rowspan="11">ASSESS</td><td colspan="2">Options Considered</td></tr>
<tr><td colspan="2">a) Consider decommissioning vessel D and commissioning vessel C to change the order to ABC-DEF
b) Update the project documentation and labelling on the platform to highlight the position of vessels C and D</td></tr>
<tr><td colspan="2">Basis for Selection & Uncertainties</td></tr>
<tr><td colspan="2">UKOOA Decision Framework decision Context Type A selected. These types of scenarios are nothing new or unusual. The risks are well understood and have no major stakeholder implications. The hazards are managed using well established practices and Industry and Company Codes and Standards. Demonstration of ALARP for these types of scenario is by verifying the "appropriate" use of established codes, standards and practices in the design</td></tr>
<tr><td colspan="2"><table><tr><td>Expert judgement</td><td>Decision was taken by the project team.</td></tr><tr><td>Risk Based Analysis</td><td>Qualitative risk based analysis was part of the decision making.</td></tr></table>
Option Discussion: the team agrees to select option B.</td></tr>
<tr><td colspan="2">Justification for Chosen Option</td></tr>
<tr><td colspan="2">Option B is chosen as the benefit gained outweighs the effort, time and cost to implement it.</td></tr>
<tr><td colspan="2">Justification for Rejected Options (e.g. Options not incorporated as considered beyond ALARP)</td></tr>
<tr><td colspan="2">Option A would need to re-certificate (back to vendor fabrication) the H_2 storage vessels C & D, which is considered grossly disproportionate.</td></tr>
<tr><td colspan="3"></td></tr>
<tr><td rowspan="6">CONTROL & EVALUATION</td><td colspan="2">Residual HSSE Risk</td></tr>
<tr><td colspan="2">As per HSSE Issues and Potential Risk</td></tr>
<tr><td colspan="2">Recommendations for Next Project Phase</td></tr>
<tr><td>AL4: Ensure as built documentation, plant signage and HMI reflect the actual status of vessels V-25001C and D location.</td><td>EPC contractor</td></tr>
<tr><td colspan="2">Requirements for the Operations HSSE-Plan</td></tr>
<tr><td colspan="2">None</td></tr>
</table>

ATTACHMENT 3 – ALARP DEMONSTRATION RECOMMENDATIONS

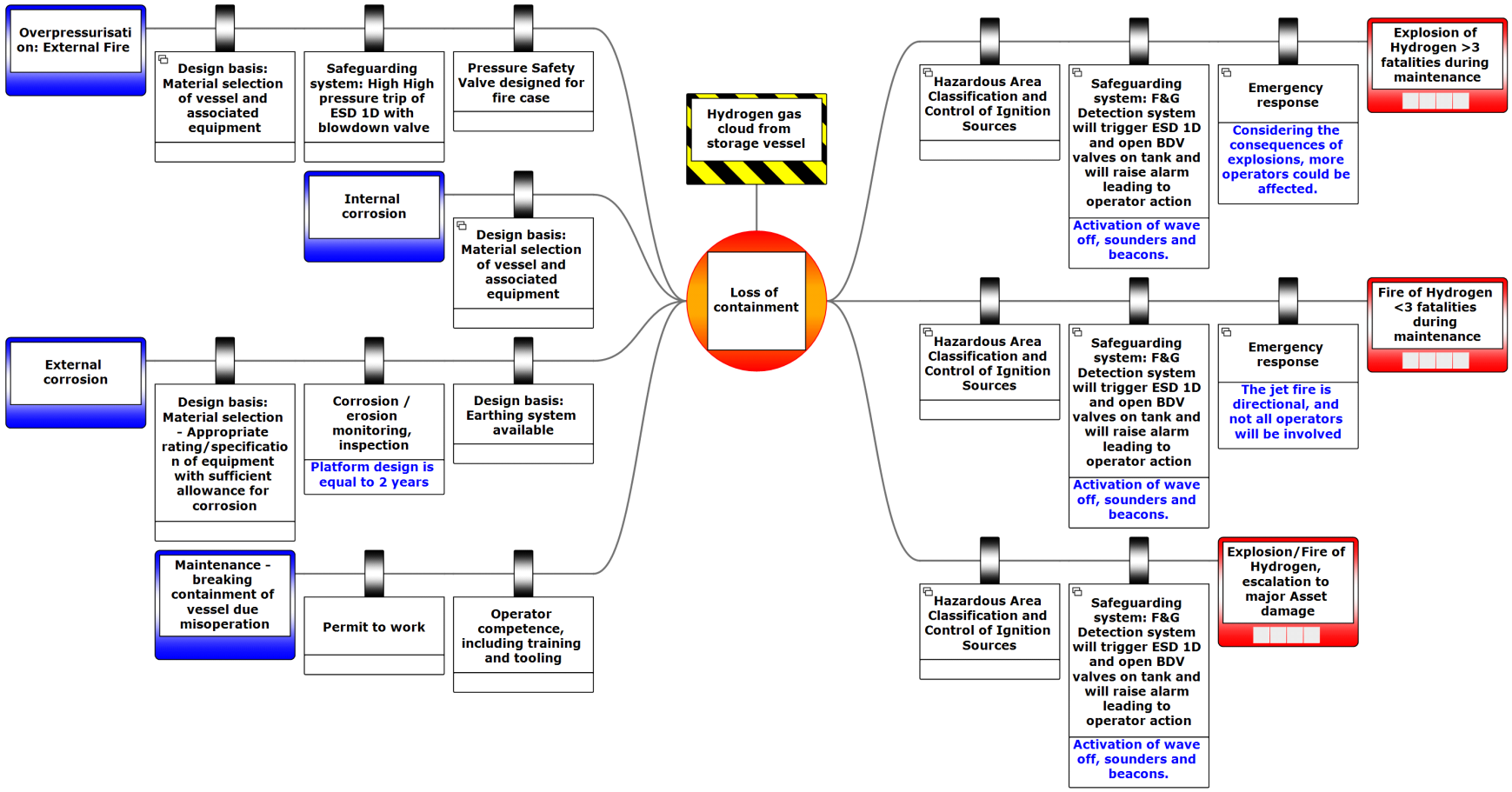
ALARP item no.	Recommendation	By
1	AL1: Ensure that specific risk assessment is performed before any maintenance activity as per control of work procedures to determine the safest configuration of the hydrogen circuit (e.g., establish whether to depressurize or not)	Operators
9	AL2: Apply controls to restrict access to the impacted area to prevent potential exposure of operators or maintenance personnel to radiation from the hydrogen vent. Ensure the restricted area is properly indicated on drawings, layouts and the 3D model.	Operators
11	AL4: Ensure as built documentation, plant signage and HMI reflect the actual status of vessels V-25001C and D location. NOTE REGARDING AL4 (June 2024) [23]: *Point superseded, vessels are in alphabetic order as per original design. In fact, as per actions taken after the issuance of NCR 2025-Q-123A90-0003: Each tank have its correct Tag number painted on the manways and side panels in accordance with the P&ID references. This identification is clear, permanent, and aligned with project documentation to avoid any confusion. In addition a plate with the correct Tag is placed close to the PED and ASME plates. A statement issued by Rosetti will be included in the final dossier, confirming full traceability and ensuring that the identification of each tank is correctly referenced in all project documentation.* In conclusion, the AL4 can be considered not applicable.	EPC Contractor CLOSED

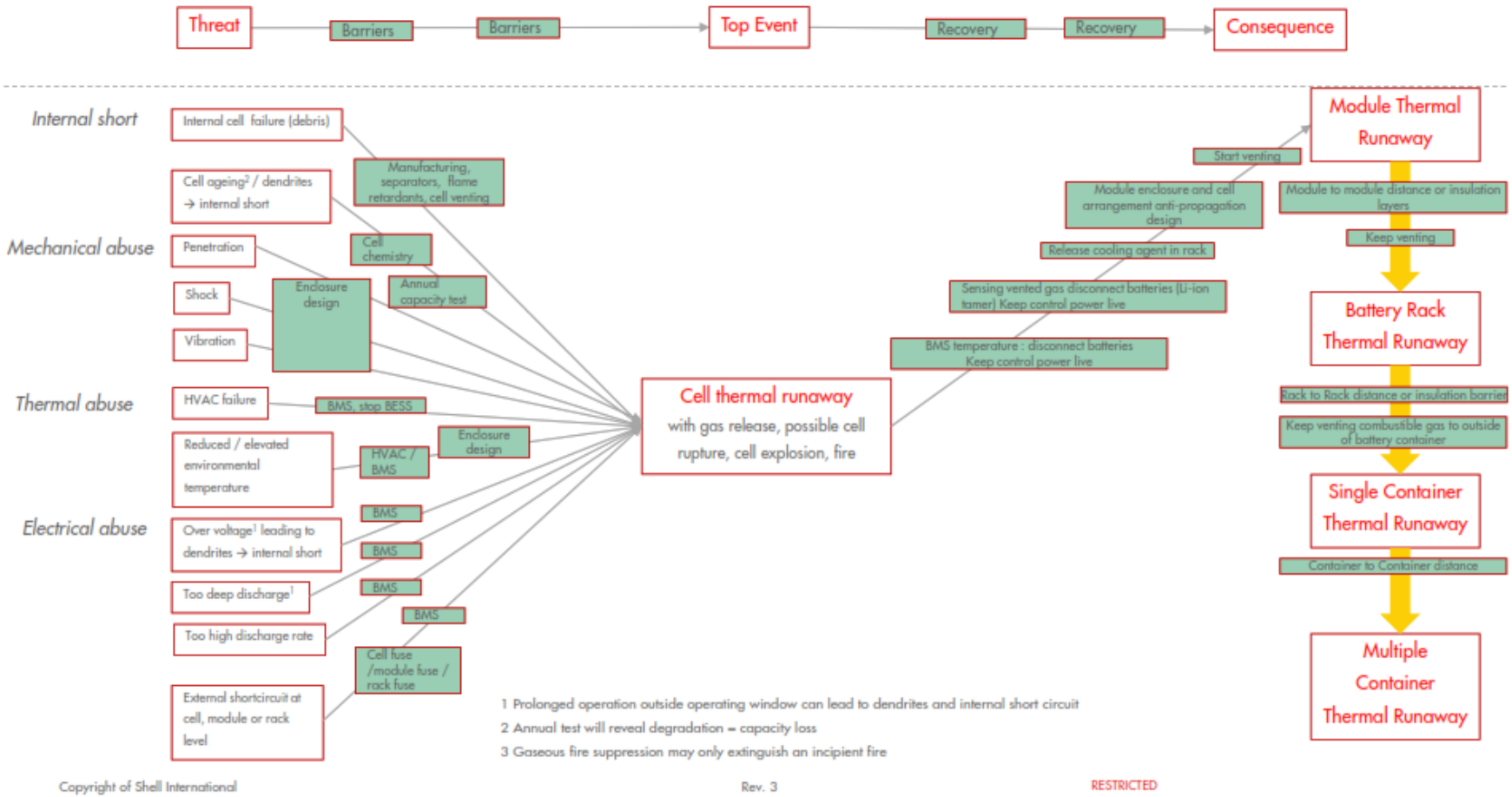
ALARP item no.	Requirement for Operations HSSE Plan	By
9	AL3: Ensure that the access to the second level of the platform above storage vessel on upper deck (elevation +38.6 m) will be limited to the maintenance activity (e.g., BDV/PSV valves) after total depressurization of storage vessels, in order to avoid excessive thermal radiation on maintenance crew in case of accidental ignition of gas released during an emergency depressurization. Ensure signs are located towards the restricted area.	Operators

In addition to the actions above, it is required that the following recommendation from the Vent Gas Dispersion and Potential Radiation Study (ref [10]) be included in the Operations HSSE Plan.

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ATTACHMENT 4 – BOW-TIE DIAGRAMS


Overpressurisation: External Fire
Design basis: Material selection of vessel and associated equipment
Safeguarding system: High High pressure trip of ESD 1D with blowdown valve
Pressure Safety Valve designed for fire case
Internal corrosion
Design basis: Material selection of vessel and associated equipment
External corrosion
Design basis: Material selection - Appropriate rating/specification of equipment with sufficient allowance for corrosion
Corrosion / erosion monitoring, inspection
Platform design is equal to 2 years
Design basis: Earthing system available
Maintenance - breaking containment of vessel due misoperation
Permit to work
Operator competence, including training and tooling
Hydrogen gas cloud from storage vessel
Loss of containment
Hazardous Area Classification and Control of Ignition Sources
Safeguarding system: F&G Detection system will trigger ESD 1D and open BDV valves on tank and will raise alarm leading to operator action
Activation of wave off, sounders and beacons.
Emergency response
Considering the consequences of explosions, more operators could be affected.
Explosion of Hydrogen >3 fatalities during maintenance
Hazardous Area Classification and Control of Ignition Sources
Safeguarding system: F&G Detection system will trigger ESD 1D and open BDV valves on tank and will raise alarm leading to operator action
Activation of wave off, sounders and beacons.
Emergency response
The jet fire is directional, and not all operators will be involved
Fire of Hydrogen <3 fatalities during maintenance
Hazardous Area Classification and Control of Ignition Sources
Safeguarding system: F&G Detection system will trigger ESD 1D and open BDV valves on tank and will raise alarm leading to operator action
Activation of wave off, sounders and beacons.
Explosion/Fire of Hydrogen, escalation to major Asset damage


Threat
Barriers
Barriers
Top Event
Recovery
Recovery
Consequence
Internal short
Internal cell failure (debris)
Manufacturing, separators, flame retardants, cell venting
Cell ageing[2] / dendrites → internal short
Mechanical abuse
Penetration
Cell chemistry
Shock
Enclosure design
Annual capacity test
Vibration
Thermal abuse
HVAC failure
BMS, stop BESS
Reduced / elevated environmental temperature
HVAC / BMS
Enclosure design
Electrical abuse
Over voltage[1] leading to dendrites → internal short
BMS
Too deep discharge[1]
Too high discharge rate
Cell fuse /module fuse / rack fuse
External shortcircuit at cell, module or rack level
Cell thermal runaway
with gas release, possible cell rupture, cell explosion, fire
BMS temperature : disconnect batteries Keep control power live
Sensing vented gas disconnect batteries (Li-ion tamer) Keep control power live
Release cooling agent in rack
Module enclosure and cell arrangement anti-propagation design
Start venting
Module Thermal Runaway
Module to module distance or insulation layers
Keep venting
Battery Rack Thermal Runaway
Rack to Rack distance or insulation barrier
Keep venting combustible gas to outside of battery container
Single Container Thermal Runaway
Container to Container distance
Multiple Container Thermal Runaway
1 Prolonged operation outside operating window can lead to dendrites and internal short circuit
2 Annual test will reveal degradation = capacity loss
3 Gaseous fire suppression may only extinguish an incipient fire
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