



POWER STORAGE IN D OCEAN

D6.3. RISK ASSESSMENT

Document Information	
Deliverable	6.3 Risk Assessment
Lead Beneficiary	TPH
Type:	R -
Work Package	WP6 Risk assessment and safety studies
Date	30th June 2026



Funded by the
European Union

This project is funded by European Climate, Infrastructure and Environment Executive Agency (CINEA), under the powers delegated by the European Commission under grant agreement Project: 101096457 – POSEIDON - HORIZON-CL5-2022-D5-01.

Dissemination level

Dissemination Level	
PU: Public	X
SEN: Sensitive, limited under the conditions of the Grant Agreement	

History

Version	Date	Reason	Revised by
1	22/04/2026	First draft	Mª Dolores Fernández
2	27/06/2026	Final Version	Mª Dolores Fernández
3	30/06/2026	Peer reviewed	Alejandro Luna
4	30/06/2026	Final version submitted	Alejandro Luna

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1. GLOSSARY OF TERMS

AC: Alternating Current

CSS: Cryogenic Supply System

DC: Direct Current

DNV: Det Norske Veritas

EESS: Electrical Energy Storage System

EMC: Electromagnetic Compatibility

ESD: Emergency Shutdown

ESS: Energy Storage System

FAT: Factory Acceptance Test

FMEA: Failure Modes and Effects Analysis

FRESS: Fire and Explosion Risk Engineering Safety System

HAZID: Hazard Identification

HLC: High Level Control

HTS: High Temperature Superconductor

HV: High Voltage

IAMS: Integrated Asset Management System

IEC: International Electrotechnical Commission

ILO: International Labour Organization

IP: Ingress Protection

KESS: Kinetic Energy Storage System

ODH: Oxygen Deficiency Hazard

PCS: Power Conversion System

PLC: Programmable Logic Controller

PPE: Personal Protective Equipment

PV: Photovoltaic

PWM: Pulse Width Modulation

SAT: Site Acceptance Test

SMES: Superconducting Magnetic Energy Storage

SOLAS: Safety of Life at Sea

THD: Total Harmonic Distortion

UPS: Uninterruptible Power Supply

2. INTRODUCTION

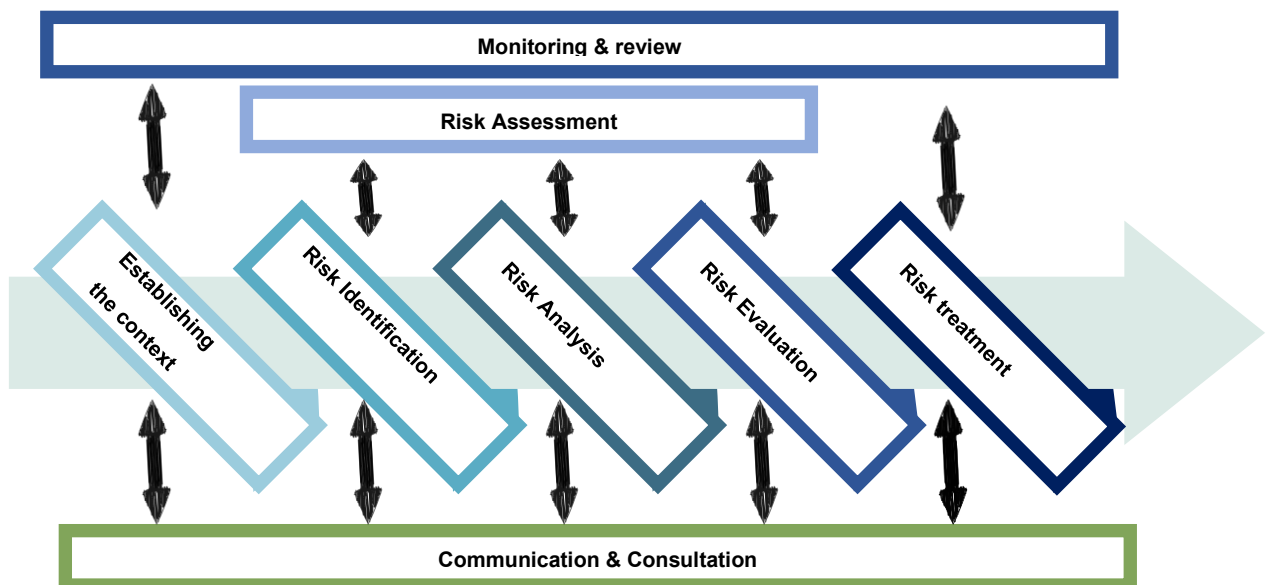
The POSEIDON project aims to demonstrate the applicability of three innovative fast-response energy storage systems (ESS) for waterborne transport: supercapacitors, flywheels, and magnetic energy storage systems. The project focuses on their integration onboard ships to improve safety, energy efficiency, and cost competitiveness in maritime operations.

A risk assessment is essential to ensure the safety and regulatory compliance of these innovative ESS. It enables early identification of potential hazards, supporting timely mitigation measures and effective risk management throughout the project lifecycle. This is particularly important given the safety, regulatory, and long-term operational implications of deploying advanced energy storage technologies in maritime environments.

The risk assessment workshop will build on the consortium's previous HAZID study. Risks related to the storage solution will be evaluated and ranked based on severity and likelihood. The analysis will focus on a container installed on the garage deck of a ferry operating as a 200-hour prototype, while the final solution will consist of a containerized system integrated onboard for full-service operation.

To support the HAZID workshop, relevant documentation will be shared with participants, including key design decisions, outputs from the previous HAZID study, and operational information on the ESS. Additional details regarding the vessel and container specifications will also be provided to ensure a common understanding of the system and associated risks.

The risk management process follows a structured framework comprising context definition, risk identification, analysis, evaluation, and treatment. Communication, consultation, monitoring, and review are integral throughout all stages to ensure continuous improvement. This approach supports informed decision-making, reduces uncertainty, and enhances overall safety and operational performance.



3. ESTABLISH THE CONTEXT

In this section of the deliverable, we will concentrate on the Risk Assessment, particularly the necessary documents, scope, approach, key participants, and expected outcomes upon completion of the Risk Assessment. Additionally, it will summarize the Risk Assessment procedure and the results of the workshop, since it has been conducted with the relevant stakeholders.

3.1. OBJECTIVES

The objectives of this risk assessment are the following:

Risk Assessment: Conducting a thorough HAZID (Hazard Identification) to identify and mitigate potential risks associated with the integration and operation of ESS.

Stakeholder Engagement: Involving various stakeholders, including maritime operators, regulatory bodies, and technology providers, to gather insights and feedback.

Knowledge Sharing: Facilitating discussions on best practices, challenges, and solutions related to the deployment of advanced ESS in the maritime sector.

3.2. PARTICIPANTS

- **CTN** --> Project coordinator. CTN will organize the meetings and ensure its good functioning.
- **TPH** --> Work Package leader & expertise in naval engineering projects. TPH will contribute to the workshop by sharing its expertise at naval engineering projects.
- **ABS** --> HAZID facilitator. ABS will collaborate by sharing its expertise with safety regulation and assisting during the procedure of the HAZID.
- **OCEM** --> EESS designer and manufacturer of the adaptations. OCEM will provide a deep knowledge about the functioning of the EESS.
- **Balearia** --> Shipowner of the "Cap de Barbaria". Balearia will inform about the container installation specifications and the operation of the ship where it will be installed.
- **Cyclomed** --> SMES designer. Cyclomed will provide a deep knowledge about the functioning of the SMES.
- **ANTEC** --> SMES and KESS manufacturer. ANTEC will participate in the workshop providing a more effective view of the functioning of the KESS & SMES and the necessary equipment connected for its good functioning.
- **DAMEN** --> Shipbuilder. DAMEN will collaborate in the HAZID by offering its experience on the necessary adaptations to the system to adapt to the maritized environment in which it will be installed.
- **EFESTO** --> grid side electric supplier and HLC collaborator. EFESTO will give information about the necessary grid connection for a safe energy distribution through the container and about the high-level controller.
- **CIEMAT** --> KESS designer. CIEMAT will provide a deep knowledge about the functioning of the KESS.

- **Cause:** The underlying reason why a hazard or unwanted event occurs.
- **Consequence:** The resulting damage, harm or impact of an undesired event.
- **Example:** An example that show a practical scenario for identifying and analysing risk.
- **COMMENT:** is used to clarify justify or add context to information in a risk assessment.
- **SAFEGARDS – RECOMMENDATIONS:** are proposed measures to reduce or eliminate a risk.
- **SAFEGARDS – ACTIONS:** are the actual steps taken or planes to implement to reduce or eliminate a risk.

3.4.0. RISK ANALYSIS

The risk analysis section of the worksheet contains the following columns:

- **PEOPLE:** related to safety and health of people.
- **ENVIROMENT:** related to environmental damage or impact.
- **ASSETS:** related to damage or loss of equipment, materials or property.

These three categories of risk are assessed according to their likelihood and severity in support the overall risk evaluation.

3.4.0.1. FREQUENCY OF OCCURRENCE

The frequency of occurrence for the three risk categories is defined as follows:

- **Rare:** Highly unlikely to occur during the lifetime of an operation.
- **Unlikely:** May occur during the lifetime of an operation.
- **Likely:** Expected to occur occasionally (less than once per year).
- **Very Likely:** Recurring event during the lifetime of the operation (more than once per year)

3.4.0.2. POTENTIAL SEVERITY

The potential severity rating for each of three risk categories is defined below:

- **Safety**
 - **Minor:** Minimal injury only first aid.
 - **Moderate:** Injury requiring medical treatment, restricted duty or lost time; reversible health effects, or hearing loss.
 - **Significant:** One or more fatalities, permanent disabilities, or isolated cases of cancer or terminal/serious disease.
 - **Catastrophic:** Multiple fatalities resulting from events such as slope failure, transport accidents, chemical releases or clusters of cancer or terminal disease.
- **Environmental:**
 - **Minor:** Minimal, measurable, temporary on-site impact.
 - **Moderate:** Short term on-site impacts that are correctable or repairable.
 - **Significant:** Notable environmental degradation, including on-site impacts or localize off-site impacts that are reversible.
 - **Catastrophic:** Major on-site degradation or irreparable off-site environmental damage.
- **Assets:**
 - **Minor:** Minimal disruption to operations, negligible financial loss and no legal, compliance or reputational impact.

- **Moderate:** Noticeable operational impact, moderate financial loss and potential minor legal or compliance issues.
- **Significant:** Major disruption to operations, significant financial losses and legal consequences or regulatory breaches.
- **Catastrophic:** Extremely severe impact where operations cannot continue, with substantial financial losses, multiple legal or regulatory penalties and significant reputational damage.

3.4.0.3. RISK CRITERIA

The level of risk is determined by a combination of frequency of occurrence and the potential severity.

The risk criteria are the following:

- **Negligible:**
 - **Meaning:** Almost no risk.
 - **Impact:** No real consequences or extremely minor.
 - **Action:** No actions required; just document if needed.
- **Very Low:**
 - **Meaning:** Very unlikely and minimal impact.
 - **Impact:** Insignificant effects.
 - **Action:** Acceptable; occasional monitoring.
- **Low:**
 - **Meaning:** Small but existing risk.
 - **Impact:** Minor consequences
 - **Action:** Basic controls or standard procedures
- **Moderate**
 - **Meaning:** Medium risk.
 - **Impact:** Noticeable impact on operations or results.
 - **Action:** Implement control measures and monitor
- **High**
 - **Meaning:** Significant risk.
 - **Impact:** Serious consequences.
 - **Action:** Priority action required to reduce risk.
- **Extreme**
 - **Meaning:** Very high probability and/or very severe impact.
 - **Impact:** Major damage or disruption.
 - **Action:** Not acceptable – immediate action required or stop activity.
- **Critical**
 - **Meaning:** Highest level of risk.
 - **Impact:** Catastrophic consequences
 - **Action:** Completely unacceptable – stop immediately and apply urgent controls.

3.5. RISK ASSESSMENT WORKSHOP AGENDA

The Risk Assessment workshop would take place during week 11 of 2026. A doodle will be shared to all the participants 13th of march.

3.6. DOCUMENTATION SHARED WITH ASSISTANTS TO THE RISK ASSESSMENT WORKSHOP

To prepare the Risk Assessment workshop for each technology the following information will be shared between the participants:

- HAZID workshop result excels for SMES, KESS and EESS.
- Previous documentation needed for the HAZID workshop already shared between partners.

4. RISK IDENTIFICATION

The second part of the risk assessment is risk identification. This stage was developed in Deliverable D6.2 through a comprehensive HAZID (Hazard Identification) study, where potential hazards associated with the system and its operation were systematically identified. In addition, several examples of identified hazards and related scenarios were included in specific cases to support the assessment process and illustrate potential risk situations.

5. RISK ANALYSIS

The third part of the risk assessment is risk analysis. Once the hazards have been identified, the potential causes and consequences associated with these hazards are systematically analyzed. At the same time, existing safeguards and mitigation measures are recognized and evaluated, including recommendations, preventive actions, and operational controls aimed at reducing the likelihood and impact of the identified risks.

6. RISK EVALUATION

Risk evaluation is the process of identifying potential problems, estimating their likelihood of occurrence, and assessing the severity of their potential consequences. The consortium uses this process to support better decision-making, reduce uncertainty, and protect people, assets, and the environment. The defined safeguards presented in the table are taken into account to determine both the frequency and severity of each risk.

This risk evaluation is divided into three parts, with one section dedicated to each EESS technology.

6.1. RISK EVALUATION OF KESS

HAZARD (CATEGORY)	CAUSE	CONSEQUENCES	EXAMPLE	COMMENT	SAFEGARD		PEOPLE			ENVIRONMENT			ASSETS		
					RECOMENDATIONS	ACTIONS	FREQUENCY	SEVERITY	RISK LEVEL	FREQUENCY	SEVERITY	RISK LEVEL	FREQUENCY	SEVERITY	RISK LEVEL
Global node	Vessel operation (acute inclination)	Equipment failure	The inclination of the ship affects the functioning of all the equipment.	It was studied the lifetime of the bearing due to the force of the spinning flywheel suffering some gyroscopes forces (at maximum inclination the lifecycle would be about 10 hours)	· Check the inclination of its functioning system at 21.5 °. · Check if the inclination for trim is 10°. · Do not operate KESS if vessel inclination exceeds 21.5°	· Make a graph to correlate the maximum inclination and maximum lifetime for the bearings - Deliverable D5.5 (Section 5.1.5). · Deliverable D5.3 (Section 5.1) – Equipment design according to service environmental conditions.	Rare	Minor	Negligible	Rare	Minor	Negligible	Likely	Significant	High
Global node	Acceleration/moving of the vessel vibrations	Affect the container installation		The track that contains the container is going to be leased and studied as a track.	· The vibration issue has to be analysed by the company.	· Deliverable D5.3 (Section 5.1) – Equipment design according to service environmental conditions. · IEC 60068-2-6, vibration sensors, anti-vibration mounts.	Rare	Moderate	Very Low	Rare	Minor	Negligible	Likely	Significant	High
Global node	Cargo powder	Dust entering the containerized solution and affecting the electronics	Some powder from transporting tracks enters the container and affect the system.	Some open roof trucks can transport scrap or construction materials in bulk. It has a vacuum chamber, so the mechanical part is isolated.		· The Ventilation system does not exchange air with the outside of the garage.	Rare	Minor	Negligible	Rare	Minor	Negligible	Rare	Minor	Negligible
Global node	Fumes or ventilation rate calculation		Failure in fumes or ventilation dissipation system could produce risk of overpressure or suffocation.		· Installation of fumes detector · Installation of an extinction equipment with some overpressure equipment.	· Deliverable D5.5 (Section 3.1) – Ventilation design in accordance with thermal simulation results.	Unlikely	Minor	Very Low	Unlikely	Minor	Very Low	Unlikely	Minor	Very Low
Global node	Drop object	A small drop or a collision with a vehicle during embarkation or disembarkation could damage the equipment	During parking manoeuvring a car hits the container track.		· The safety zone for the containerized solution should be indicated.		Likely	Minor	Low	Likely	Minor	Low	Likely	Minor	Low
Global node	Small collision	Collision between components of the system	Sensitive electronic equipment can be suffering damages.				Rare	Minor	Negligible	Rare	Minor	Negligible	Rare	Significant	Low
Global node	Flooding	Some water enters the container and affects the electronics	Some water reaches the deck where the container is located.		· The electronic components are affected first rather than the mechanical ones; therefore, containment measures should primarily target the electronic systems.	· The electrical part of the KESS is not flood resistant, but the casing should be studied. · Recommended to add a containment to protect the coils from the possible flooding.	Rare	Minor	Negligible	Rare	Minor	Negligible	Rare	Moderate	Very Low
Global node	Lightning	Being hit by a lightning	During stormy weather, a lightning strikes the container.		· It is possible to have a lighting protection, study how this protection would be working with the ship grid.		Rare	Minor	Negligible	Rare	Minor	Negligible	Rare	Moderate	Very Low
Technology node	Materials	The materials should be tolerant for a salinity ambient			· Study the salinity tolerance of the system.	· Study if the cooling system can prevent salinity inside the container for the 2-month operation.	Rare	Minor	Negligible	Rare	Minor	Negligible	Rare	Moderate	Very Low
Technology node	Power quality	Problems on the grid side connection of the ship	The energy supplied by the system has adjustment problems to the grid side.	It is stated that there won't be any problem with power quality due to the grid.			Rare	Minor	Negligible	Rare	Minor	Negligible	Rare	Minor	Negligible

HAZARD (CATEGORY)	CAUSE	CONSEQUENCES	EXAMPLE	COMMENT	SAFEGARD		PEOPLE			ENVIRONMENT			ASSETS		
					RECOMENDATIONS	ACTIONS	FREQUENCY	SEVERITY	RISK LEVEL	FREQUENCY	SEVERITY	RISK LEVEL	FREQUENCY	SEVERITY	RISK LEVEL
Technology node	Heat in the wires of the electrical part (coils)	Heat from the bearings can affect other components		If the coils are affected by the heat, the system have to be stopped.	· These coils are air forced cooled, but the heat transferred should be considered. · Monitor temperature by sensors in the sensitive parts.	· Deliverable D5.5 (Section 3.1) - Development of a thermal model for the container prototype. · Temperature alarms + automatic speed reduction.	Likely	Minor	Low	Likely	Minor	Low	Likely	Moderate	Moderate
Technology node	Collision of the flywheel	As the flywheel spins at high rpm, any failure can produce high damage			· Make sure that, in case of flywheel collision, there is a safety zone so anybody could get hurt.	· Study the containment of the flywheel inside the device. · The flywheel RPM are limited when operating in safety mode. · Examine the flywheel enclosure in accordance with a reference standard (e.g., IEC or DNV). · Monitor bearing temperature to avoid failure & wear. Also possible by vibration monitoring. Proper design against fatigue.	Rare	Significant	Low	Rare	Minor	Negligible	Rare	Catastrophic	Moderate
Technology node	Startup/ Shut down operation	The starting/ stopping process has to be controlled to know when there is risk due to the operating of the system		· The vessel operator should know when to start/stop the system. · For this project, for the safety of the load resistant, there is installed an UPS (actuate for all the systems in the container).	· Ensure the system have enough quantity of energy before powering on. · The system have to be able to stop without the electronics (only with the safety valve). · Operating automatically using only the safety valve, without relying on electronic components in the event that they are unavailable.	· Formal ESD procedure, interlocks, crew training.	Very likely	Minor	Moderate	Very likely	Minor	Moderate	Very likely	Minor	Moderate
Technology node	Cooling	Emergency discharge of flywheel produces a lot of heat inside the container		· The heat transfer method inside the container is natural convection.	· Study to be conducted on the heat transfer of the container. · Time and temperatures reached are values of interest.	· Deliverable D5.5 (Section 3.1) - Development of a thermal model for the container prototype. · Emergency thermal threshold + thermal trip protection.	Likely	Minor	Low	Likely	Minor	Low	Likely	Moderate	Moderate
Technology node	Redundancy	Redundancy may not be necessary for the demonstration, but if the technology is installed on a vessel and becomes unavailable, it's important to assess whether continued operation without it is acceptable		No redundancy system because this is working with some other energy power system.	· Determine the consequences if the system stop working.		Unlikely	Minor	Very Low	Unlikely	Minor	Very Low	Unlikely	Minor	Very Low
Technology node	Effect of the container (noise)	The noise level inside the container can affect the surrounding environment		When the electrical machine is operating, the noise is high. The main noise generator could be the fan for the cooling system.	· Necessary PPE inside the container if the electrical machine is working.	· Soundproofing of the container and limits in accordance with SOLAS/ILO regulations. · It has to be measured and monitored the noise level on deck when the machine is operating.	Very likely	Minor	Moderate	Very likely	Moderate	High	Very likely	Minor	Moderate

HAZARD (CATEGORY)	CAUSE	CONSEQUENCES	EXAMPLE	COMMENT	SAFEGARD		PEOPLE			ENVIRONMENT			ASSETS		
					RECOMENDATIONS	ACTIONS	FREQUENCY	SEVERITY	RISK LEVEL	FREQUENCY	SEVERITY	RISK LEVEL	FREQUENCY	SEVERITY	RISK LEVEL
Technology node	Control/Monitoring/alarm system	In case of danger it should be detected and notified so the security actions should be carried out		· There are security valves (that eliminate the vacuum of the chamber) in case there are any hazards detected.	· Recommended to add an emergency bottom outside of the container (wait 10 minutes so it is stopped). · Sensor at the entrance so nobody enters the container during its functioning (for this application) · There should be an alarm to provide information about the fire alarm to the ship. (Visual and acoustic alarm).	· Test the time to discharge the system until it goes to 0 rpm. · Connection to the vessel's IAMS + multisensory shutdown.	Unlikely	Minor	Very Low	Unlikely	Minor	Very Low	Unlikely	Significant	Moderate
Technology node	Revolution drops under 400 rpm	The energy consumed by the system is higher than the energy that is supplied		400rpm would be an estimated threshold.	· Evaluate the speed value is not worth having the system rotating.		Unlikely	Minor	Very Low	Unlikely	Minor	Very Low	Unlikely	Minor	Very Low
System	Indecency of the system	Prevent the lack of generated energy			· There should be installed an UPS .		Rare	Minor	Negligible	Rare	Minor	Negligible	Rare	Minor	Negligible
System	Interference with the existing electrical connections	The members of the consortium will act in accordance with the connection points, safety measures, and potential interferences with the existing vessel.		Balearia and the system integration team for the container have to agree on a common connection point.	· The modification needed will be checked with a Classification society (Current and Voltage THD will be within the regulation limits (5%)).	· Deliverable POSEIDON - Bureau Veritas Rev.0.	Rare	Minor	Negligible	Rare	Minor	Negligible	Rare	Minor	Negligible
System	Feasibility with other renewable sources of energy	The question is raised about how the connection would differ on a vessel designed to also integrate renewable energy sources. The inquiry focuses on the feasibility of installing supercapacitor technology on such a vessel, considering the intermittent nature of renewable energy sources.	Lagging phenomena on photovoltaic sources	· There is no issue when combined with intermittent renewable sources because the power converter can ensure the power quality. · Energy cycle characteristics to/from flywheel will not create a problem in the operation if connected to an intermittent (or renewable) power source.			Rare	Minor	Negligible	Rare	Minor	Negligible	Rare	Minor	Negligible
System	Fire fighting	The container is equipped with fire-fighting systems and alarm systems, which are to be connected to the vessel's systems.		· There is a system that can handle both flywheel and supercapacitors. CO2 is suggested solution.	· There will be installed some sensors for fumes/ fire at the container that will operate a firefighting system.	· Deliverable POSEIDON - Bureau Veritas Rev.0 - Verify the feasibility of using CO2 as firefighting solution for both flywheel and super caps.	Rare	Moderate	Very Low	Rare	Minor	Negligible	Rare	Significant	Low
System	Fire in the garage	A fire event on the vessel's open deck could have implications for multiple areas of the vessel, including the container.		· Outside of the container, the firefighting system would be water. · The fire in the garage has a high likelihood in the ferries vessels.		· Deliverable POSEIDON - Bureau Veritas Rev.0 - The boundary of container has insulation A-60.	Unlikely	Minor	Very Low	Unlikely	Minor	Very Low	Unlikely	Moderate	Low
System	Bilge system	In case there are some waste that is necessary to collect so we prevent dangers		No toxic materials for the POSEIDON project.	· To be studied the materials used for the KESS system in case they could be toxic.	· Study the installation of a manually operated normally closed drainage valve.	Rare	Minor	Negligible	Rare	Significant	Low	Rare	Minor	Negligible
System	Emergency and escape routes	The evacuation routes shouldn't be affected by any danger produced because of the operation of this system			· Not obstructing any evacuation route.		Rare	Minor	Negligible	Rare	Minor	Negligible	Rare	Minor	Negligible

HAZARD (CATEGORY)	CAUSE	CONSEQUENCES	EXAMPLE	COMMENT	SAFEGARD		PEOPLE			ENVIRONMENT			ASSETS		
					RECOMENDATIONS	ACTIONS	FREQUENCY	SEVERITY	RISK LEVEL	FREQUENCY	SEVERITY	RISK LEVEL	FREQUENCY	SEVERITY	RISK LEVEL
System	Maintenance	To prevent problems due to fatigue there should be planned some maintenance activities to monitor the status of the critical components		Specific emphasis to be given on the bearing degradation	· Maintenance plan should be prepared for this container/ system, this will be reflected on a manual.		Unlikely	Moderate	Low	Unlikely	Minor	Very Low	Unlikely	Significant	Moderate
System	Bearings	As critical components is important to control the bearings to prevent dangers		In the POSEIDON project the heat is dissipated by convection and radiation.	· Monitor the temperature and once it reaches the limit temperature (90º) establish a speed reduction so the bearings can be cooled.	· Alarm/trip setpoints (90ºC) + continuous temperature monitoring.	Likely	Minor	Low	Likely	Minor	Low	Likely	Moderate	Moderate
System	Excessive dissipation of heat inside the container from the flywheel (casing)	The heat produced on the bearings could accumulate and create a risk due to the high temperatures			· It will be necessary to calculate the heat dissipated over the range of operating conditions. · It will be necessary a ventilation analysis of the container.	· Deliverable D5.5 (Section 3.1) - Development of a thermal model for the container prototype.	Unlikely	Minor	Very Low	Unlikely	Minor	Very Low	Unlikely	Moderate	Low

6.2. RISK EVALUATION OF EESS

HAZARD (CATEGORY)	CAUSE	CONSEQUENCES	EXAMPLE	COMMENT	SAFEGARD		PEOPLE			ENVIROMENT			ASSETS		
					RECOMENDATIONS	ACTIONS	FREQUENCY	SEVERITY	RISK LEVEL	FREQUENCY	SEVERITY	RISK LEVEL	FREQUENCY	SEVERITY	RISK LEVEL
Global node	Vessel operation (acute inclination)	Equipment failure	The inclination of the ship affects the functioning of all the equipment.		· Check the inclination of its functioning system at 21.5 °. · Check if the inclination for trim is 10°	· Deliverable D5.3 (Section 5.1) – Equipment design according to service environmental conditions.	Unlikely	Minor	Very Low	Rare	Minor	Negligible	Rare	Moderate	Very Low
Global node	Acceleration/moving of the vessel vibrations	Affect the electronic components of the EESS	The movement may affect the electronics of the EESS	How the vibration may affect during the lifetime the functioning of its electronic components. The vibration issue has to be analysed by the company	· Study the effect of the vibrations on the technology. · The vibration issue has to be analysed by the company	· Deliverable D5.3 (Section 5.1) – Equipment design according to service environmental conditions.	Unlikely	Minor	Very Low	Rare	Minor	Negligible	Rare	Moderate	Very Low
Global node	Cargo powder	Dust entering the containerized solution and affecting the electronics parts.	Some powder from transporting tracks enters the container and affect the system	Some open roof trucks can transport scrap or construction materials in bulk. It has a vacuum chamber, so the mechanical part is isolated		The Ventilation system does not exchange air with the outside of the garage.	Rare	Minor	Negligible	Rare	Minor	Negligible	Rare	Minor	Negligible
Global node	Fumes or ventilation rate calculation		Failure in fumes or ventilation dissipation system could produce risk of overpressure or suffocation		· Installation of fumes detector · Installation of an extinction equipment with some overpressure equipment.	· Deliverable D5.5 (Section 3.1) – Ventilation design in accordance with thermal simulation results	Unlikely	Minor	Very Low	Unlikely	Minor	Very Low	Unlikely	Minor	Very Low
Global node	Drop object	A small drop or a collision with a vehicle during embarkation or disembarkation could damage the equipment	During parking manoeuvring a car hits the container track		The safety zone for the containerized solution should be indicated		Likely	Minor	Low	Likely	Minor	Low	Likely	Moderate	Moderate
Global node	Small collision	Collision between components of the system	Sensitive electronic equipment can be suffering damages				Rare	Minor	Negligible	Rare	Minor	Negligible	Rare	Significant	Low
Global node	Flooding	Some water enters the container and affects the electronics	Some water reaches the deck where the container is located		It will affect first the electronical parts rather than the mechanical, so the contention measures should focus on the electronic part		Rare	Minor	Negligible	Rare	Minor	Negligible	Rare	Significant	Low
Global node	Lightning	Being hit by a lightning	During stormy weather, a lightning strikes the container		It is possible to have a lighting protection, study how this protection would be working with the ship grid		Rare	Minor	Negligible	Rare	Minor	Negligible	Rare	Significant	Low
Technology node	Materials	The materials should be tolerant for a salinity ambient			Study the salinity tolerance of the system	Study if the cooling system can prevent salinity inside the container for the 2-month operation.	Unlikely	Minor	Very Low	Unlikely	Minor	Very Low	Unlikely	Moderate	Low
Technology node	Power quality	Problems on the grid side connection of the ship	The energy supplied by the system has adjustment problems to the grid side	It is stated that there won't be any problem with power quality due to the grid			Rare	Minor	Negligible	Rare	Minor	Negligible	Rare	Minor	Negligible
Technology node	Startup/ Shut down operation	The starting/ stopping process has to be controlled to know when there is risk due to the operating of the system		Ensure the system have enough quantity of energy before powering on. The vessel operator should know when to start/stop the system	· Ensure the system have enough quantity of energy before powering on. · The system has to be able to stop without the electronics (only with the safety valve).	· Formal ESD procedure, interlocks, crew training	Very likely	Minor	Moderate	Very likely	Minor	Moderate	Very likely	Minor	Moderate

HAZARD (CATEGORY)	CAUSE	CONSEQUENCES	EXAMPLE	COMMENT	SAFEGARD		PEOPLE			ENVIROMENT			ASSETS		
					RECOMENDATIONS	ACTIONS	FREQUENCY	SEVERITY	RISK LEVEL	FREQUENCY	SEVERITY	RISK LEVEL	FREQUENCY	SEVERITY	RISK LEVEL
					· Operating automatically using only the safety valve, without relying on electronic components in the event that they are unavailable.										
Technology node	Cooling	Emergency discharge of supercaps and flywheel will produce a lot of heat inside the container		Study to be conducted on the heat transfer of the container. Time and temperatures reached are values of interest (in the container is natural convection)		Deliverable D5.5 (Section 3.1) - Development of a thermal model for the container prototype. Deliverable D5.5 (Section 4.2) - Development of a thermal model for the supercapacitors	Likely	Minor	Low	Likely	Minor	Low	Likely	Minor	Low
Technology node	Redundancy	Redundancy may not be necessary for the demonstration, but if the technology is installed on a vessel and becomes unavailable, it's important to assess whether continued operation without it is acceptable		What would be the consequences if the system stops working?	This FRESS are used only to enhance grid stability, they are not designed for large energy storage or emergency functions.		Likely	Minor	Low	Likely	Minor	Low	Likely	Minor	Low
Technology node	Effect of the container (noise)	The noise level inside the container can affect the surrounding environment.		Study the noise produced by the cabinet of the supercaps. The main noise generator could be the fan for the cooling system			Unlikely	Minor	Very Low	Unlikely	Minor	Very Low	Unlikely	Minor	Very Low
Technology node	Control/Monitoring/alarm system	In case of danger, it should be detected and notified so the security actions should be carried out			Use a HLC		Rare	Minor	Negligible	Rare	Minor	Negligible	Rare	Minor	Negligible
Technology node	Voltage drops under 40%			Check if the voltage drop could affect the functioning of the Supercapacitors.			Likely	Minor	Low	Likely	Minor	Low	Likely	Minor	Low
System	Independency of the system	Prevent the lack of generated energy		There should be installed an UPS		Check by OCEM pag.4 D4.1	Rare	Minor	Negligible	Rare	Minor	Negligible	Rare	Minor	Negligible
System	Interference with the existing electrical connections	The members of the consortium will act in accordance with the connection points, safety measures, and potential interferences with the existing vessel.		Balearia And the system integration team for the container have to agree on a common connection point. The modification needed will be checked with a Classification society (Current and Voltage THD will be within the regulation limits (5%))		Deliverable POSEIDON - Bureau Veritas Rev.0 Deliverable D5.2 (Section 5 & 6) - Establish the battery limits and its connection to the ship.	Unlikely	Minor	Very Low	Rare	Minor	Negligible	Rare	Minor	Negligible
System	Feasibility with other renewable sources of energy	The question is raised about how the connection would differ on a vessel designed to also integrate renewable energy sources. The inquiry focuses on the feasibility of installing supercapacitor technology on such a vessel, considering the intermittent nature of renewable energy sources.		Lagging phenomena on photovoltaic sources			Rare	Minor	Negligible	Rare	Minor	Negligible	Rare	Minor	Negligible

HAZARD (CATEGORY)	CAUSE	CONSEQUENCES	EXAMPLE	COMMENT	SAFEGARD		PEOPLE			ENVIROMENT			ASSETS		
					RECOMENDATIONS	ACTIONS	FREQUENCY	SEVERITY	RISK LEVEL	FREQUENCY	SEVERITY	RISK LEVEL	FREQUENCY	SEVERITY	RISK LEVEL
System	Fire fighting	A fire inside the container could spread throughout the ship's garage.		There will be installed some sensors for fumes/ fire at the container that will operate a firefighting system. There should be an alarm to provide information about the fire alarm to the ship. (Light and noise alarm)	There will be installed some sensors for fumes/ fire at the container that will operate a firefighting system.	· Deliverable POSEIDON - Bureau Veritas Rev.0 - Verify the feasibility of using CO2 as firefighting solution for both flywheel and supercapacitors.	Unlikely	Moderate	Low	Unlikely	Moderate	Low	Unlikely	Significant	Moderate
System	Fire in the garage	It may damage the equipment inside the container.		Outside of the container, the firefighting system would be water	Switching off the container electric feeding from the ship, the container shall de-energize and stop	· Deliverable POSEIDON - Bureau Veritas Rev.0 - The boundary of container has insulation A-60	Unlikely	Minor	Very Low	Unlikely	Moderate	Low	Unlikely	Significant	Moderate
System	Bilge system	Toxic material inside. When firefighting with water, contaminated water can lead to the bilge producing ship damage or danger		Not for our system but should be considered for a future application (Something to be studied)	Drain in another container minimized the hazards		Rare	Minor	Negligible	Rare	Significant	Low	Rare	Minor	Negligible
System	Emergency and escape routes	The evacuation routes shouldn't be affected by any danger produced because of the operation of this system		Not obstructing any evacuation route	The placement does not interfere with any escape route or emergency device		Rare	Minor	Negligible	Rare	Minor	Negligible	Rare	Minor	Negligible
System	Maintenance	To prevent problems should be planned some maintenance activities to monitor the status of the critical components		Maintenance plan should be prepared for this container/ system, this will be reflected on a manual.			Rare	Moderate	Very Low	Rare	Minor	Negligible	Rare	Moderate	Very Low

6.3. RISK EVALUATION OF SMES

					SAFEGUARD		PEOPLE			ENVIROMENT			ASSETS		
HAZARD (CATEGORY)	CAUSE	CONSEQUENCES	EXAMPLE	COMMENT	RECOMMENDATIONS	ACTIONS	FREQUENCY	SEVERITY	RISK LEVEL	FREQUENCY	SEVERITY	RISK LEVEL	FREQUENCY	SEVERITY	RISK LEVEL
Global node	Static / dynamic inclination of vessel	Cryostat, magnet supports or auxiliary equipment operate outside allowable heel/trim envelope.	Worst-case heel/trim changes cryogenic fluid distribution, support loads and clearances.	Cryostat, current leads, cold head and support alignment must be verified against ship heel/trim cases.	· Define allowable heel/trim for operation and transport. · Verify cryostat/cold-head/support design for 21.5° heel and 10° trim or project limits. · Include automatic ramp-down/interlock if inclination exceeds limits.	· Confirm design load cases with vessel integrator/class society. · Add inclination sensor threshold to alarm/interlock logic.	Unlikely	Moderate	Low	Unlikely	Minor	Very Low	Unlikely	Moderate	Low
Global node	Ship acceleration, shock and vibration	Mechanical fatigue or displacement of cryostat, cold mass, HTS pancakes, current leads, piping or PCS cabinets.	Vibration during navigation or cargo handling damages cryogenic components or degrades HTS tape/joints.	Previous safeguards based on generic vibration pads are insufficient for SMES. Verify cold-mass supports, flexible helium lines, current leads and container lashings.	· Perform vibration/shock qualification against marine/container load cases. · Use anti-vibration mounts only after verifying cryogenic alignment and fatigue. · Provide positive locking/lashing and flexible connections where required.	· Request supplier vibration limits/certificates for cryocooler/CSS. · Add inspection criteria after transport and sea trials.	Unlikely	Moderate	Low	Rare	Minor	Negligible	Unlikely	Significant	Moderate
Global node	Vibration of cryogenic supply system (CSS)	Reduced cooling capacity, pipe fatigue, loss of thermal contact or premature quench.	Cryocooler or helium loop is affected by vessel vibration, causing temperature rise and trip.	D3.1 selects a flow refrigeration CSS; cooling reliability is a key SMES-specific dependency, not a generic electronics issue.	· Validate CSS under expected vibration/acceleration and inclination. · Monitor helium flow, pressure, cold-head temperature and magnet temperature. · Define safe ramp-down / dump sequence on loss of cooling.	· Add CSS FMEA and vibration test to open actions. · Define alarm thresholds for flow, pressure and temperature.	Unlikely	Moderate	Low	Rare	Minor	Negligible	Likely	Significant	High
Global node	Dust / cargo powder ingress	Contamination of PCS, filters, fans, sensors or insulation surfaces; possible tracking or overheating.	Cargo dust enters during ventilation or maintenance and deposits on HV/PCS cabinets.	Magnet is vacuum-contained, but PCS, controls, ventilation filters and cabinet insulation remain exposed to container air.	· Keep container normally closed and filtered. · Specify IP rating, filtered ventilation and periodic filter replacement. · Avoid taking air directly from dusty cargo spaces.	· Define cabinet IP rating and filter maintenance interval. · Add housekeeping / contamination inspection to maintenance plan.	Unlikely	Minor	Very Low	Unlikely	Minor	Very Low	Unlikely	Moderate	Low
Global node	Helium release / inadequate ventilation	Oxygen deficiency, asphyxiation risk, overpressure in container and loss of cooling.	Pipe rupture, relief valve lift or quench releases helium into a closed container.	For SMES, inert helium release and ODH are the primary hazards.	· Size ventilation and relief paths for maximum credible helium release. · Install oxygen deficiency monitoring with audible/visual alarm. · Route relief vents to safe location away from personnel/intakes.	· Calculate helium inventory, expansion volume and ODH classification. · Define entry procedure, purge/ventilation time and rescue response.	Unlikely	Catastrophic	High	Unlikely	Minor	Very Low	Unlikely	Significant	Moderate

HAZARD (CATEGORY)	CAUSE	CONSEQUENCES	EXAMPLE	COMMENT	SAFEGUARD		PEOPLE			ENVIROMENT			ASSETS		
					RECOMMENDATIONS	ACTIONS	FREQUENCY	SEVERITY	RISK LEVEL	FREQUENCY	SEVERITY	RISK LEVEL	FREQUENCY	SEVERITY	RISK LEVEL
Global node	Dropped object / external impact during handling	Damage to cryostat, vacuum vessel, relief piping, PCS cabinets or container structure.	Forklift, truck or handling equipment strikes the container during embarkation/disembarkation.	Impact can damage the cryogenic envelope even if the system is off; consequences are mainly asset damage plus possible helium release.	· Define exclusion zone and handling procedure. · Protect exposed cryogenic connections and cabinet penetrations. · Transport with magnet de-energized and pressure state controlled.	· Add mechanical guarding around cryogenic lines and relief devices. · Verify lifting/lashing points and handling checklist.	Unlikely	Moderate	Low	Rare	Minor	Negligible	Likely	Significant	High
Global node	Internal collision / inadequate component restraint	Relative movement between magnet, cryostat, CSS, dump resistor or cabinets causing mechanical/electrical damage.	Internal equipment shifts during ship motion or collision and damages cooling lines or HV connections.	This is credible for a containerized prototype with cryogenic and HV equipment.	· Use structural supports designed for ship accelerations and emergency loads. · Separate or restrain components to prevent contact. · Inspect after shock events.	· Complete container internal layout review with minimum clearances. · Include fastener locking and post-voyage inspection.	Unlikely	Moderate	Low	Rare	Minor	Negligible	Unlikely	Significant	Moderate
Global node	Flooding / green water / water ingress	Short circuit, corrosion, loss of insulation, trip of PCS/control system and possible unsafe shutdown.	Water reaches the deck or enters the container through ventilation/openings.	Water ingress is primarily an electrical and control-system risk; cryostat vacuum space is not the first failure point.	· Specify weathertight container and protected ventilation openings. · Install water ingress detection and drain strategy. · Define automatic isolation and safe discharge on water alarm.	· Verify IP rating / weathertightness and sill height. · Add flooding response to operating manual.	Unlikely	Significant	Moderate	Unlikely	Moderate	Low	Unlikely	Significant	Moderate
Global node	Lightning / surge	Damage to PCS, controls, sensors, insulation or magnet protection system; possible fire or trip.	Lightning strike or switching surge couples into container or grid connection.	SMES PCS and controls are sensitive to surges; lightning protection must be coordinated with ship earthing.	· Provide lightning/surge protection, bonding and earthing design. · Coordinate SPD with isolation transformer/converter and ship grid. · Verify EMC and insulation coordination.	· Define bonding/earthing concept and SPD locations. · Review with vessel electrical integrator/class society.	Rare	Significant	Low	Rare	Minor	Negligible	Rare	Significant	Low
Technology node	Humidity / salinity / condensation	Corrosion and insulation degradation of PCS, cabinets, sensors, current leads and connectors.	Door opening or HVAC shutdown allows humid salty air to condense on cold or energized parts.	Stainless cryostat helps, but electrical cabinets and connectors remain vulnerable.	· Maintain HVAC/dehumidification and humidity alarm. · Use marine-grade/corrosion-resistant cabinets and coated PCBs where needed. · Define warm-up/door-opening procedure to avoid condensation.	· Specify humidity/salinity acceptance criteria. · Add periodic corrosion/insulation resistance checks.	Likely	Minor	Low	Likely	Minor	Low	Likely	Moderate	Moderate
Technology node	Power quality / PCS harmonics / PWM pulse voltage	Grid instability, nuisance trips, insulation stress, partial discharge or accelerated magnet insulation ageing.	High-frequency PWM pulse voltage from PCS propagates to magnet terminals and causes overvoltage.	The Applied Energy paper shows PCS-magnet interaction and PWM overvoltage are key SMES design issues; this was understated in the sheet.	· Include DC-side filter and cable length limitation. · Verify switching frequency avoids magnet resonance. · Demonstrate THD, EMC and insulation coordination within class limits.	· Add PCS-magnet interaction study: cable length, RLC filter, switching frequency, peak voltage. · Record acceptance criteria in FAT/SAT.	Unlikely	Significant	Moderate	Rare	Minor	Negligible	Unlikely	Significant	Moderate
Technology node	Start-up / shutdown / standby procedure	Unexpected warm-up, low SOC/current, failed ramp, magnet quench or inability to deliver requested power.	Operator starts SMES before cryogenic temperature, vacuum, current or protection status is ready.	The previous text referred generically to having enough energy; for SMES, permissives must include cryogenic readiness and magnet protection status.	· Define start/stop permissives: vacuum, temperature, helium flow/pressure, PCS readiness, dump circuit available. · Provide operator checklist and automatic sequencing.	· Draft operating modes and interlock matrix. · Train vessel/operator team before sea trial.	Likely	Moderate	Moderate	Unlikely	Minor	Very Low	Likely	Moderate	Moderate
Technology node	Cryogenic contact / cold surface exposure	Cryogenic burns, brittle fracture of adjacent materials and oxygen condensation risk near very cold surfaces.	Technician contacts cold pipe/cold head or leak creates frost/cold plume during maintenance.	Credible mainly during maintenance or abnormal release; PPE alone is insufficient without access control and insulation.	· Insulate/guard cold surfaces and restrict access during operation. · Provide cryogenic PPE and maintenance procedure. · Use suitable materials for low-temperature exposure.	· Identify accessible cold surfaces and label/guard them. · Add cryogenic safety training and permit-to-work.	Unlikely	Significant	Moderate	Rare	Minor	Negligible	Rare	Moderate	Very Low

HAZARD (CATEGORY)	CAUSE	CONSEQUENCES	EXAMPLE	COMMENT	SAFEGUARD		PEOPLE			ENVIROMENT			ASSETS		
					RECOMMENDATIONS	ACTIONS	FREQUENCY	SEVERITY	RISK LEVEL	FREQUENCY	SEVERITY	RISK LEVEL	FREQUENCY	SEVERITY	RISK LEVEL
Technology node	Loss of cooling / quench / hot spot	Rapid magnet temperature rise, loss of superconductivity, pressure increase, coil degradation and forced discharge.	CSS failure, excessive AC losses, blocked flow, current lead heat leak or control failure causes quench.	This is a core SMES hazard. D3.1 notes HTS quench propagation is slow and requires active detection/protection.	- Implement quench detection, fast energy dump and validated dump resistor path. - Monitor temperatures, voltages and helium flow/pressure. - Define maximum current/ramp limits and thermal margins.	- Complete quench protection study and test plan. - Verify relief sizing for credible quench/helium expansion.	Unlikely	Catastrophic	High	Rare	Minor	Negligible	Likely	Catastrophic	Extreme
Technology node	Loss of operational redundancy / unavailable SMES support	Power-quality support unavailable; ship remains dependent on main generators/other ESS.	SMES trips or is isolated during grid disturbance or peak load event.	If SMES is not a safety-critical/emergency power source, people severity is limited, but asset/mission impact remains.	- Confirm SMES is not credited as emergency power. - Define degraded operating mode if SMES unavailable. - Provide UPS for controls and safe shutdown.	- Document system safety function allocation with vessel integrator. - Add UPS autonomy requirement for controls/interlocks.	Unlikely	Minor	Very Low	Rare	Minor	Negligible	Likely	Moderate	Moderate
Technology node	Noise from cryocoolers, pumps, fans or ventilation	Personnel discomfort, communication issues or exceedance of occupational noise limits near container.	Cryocooler compressor, pump or container fan operates continuously during port/maintenance.	Noise is credible but usually manageable by enclosure/acoustic treatment and operating restrictions.	- Measure noise during FAT/SAT and compare with vessel occupational limits. - Add acoustic insulation or access restrictions if needed.	- Add noise test to commissioning checklist. - Define insulation protection requirement if thresholds exceeded.	Likely	Minor	Low	Rare	Minor	Negligible	Likely	Minor	Low
Technology node	Control / monitoring / alarm failure	Delayed response to quench, helium leak, fire, water ingress, high temperature or PCS fault.	Loss of sensor, PLC/HLC, alarm communication or ship interface masks a developing fault.	SMES depends on active monitoring and interlocks; this deserves higher people/asset severity than currently shown.	- Define safety-critical alarms and independent hardwired trips where needed. - Monitor ODH, smoke/fire, humidity, water ingress, temperature, voltage, current, pressure and flow. - Provide fail-safe de-energize logic.	- Produce alarm/interlock cause-and-effect matrix. - Test alarms during FAT/SAT and integrate with ship alarm system.	Unlikely	Catastrophic	High	Unlikely	Minor	Very Low	Unlikely	Catastrophic	High
System	Auxiliary power / UPS loss	Loss of controls, valves, monitoring, ventilation or safe shutdown capability.	Ship power loss occurs while SMES is energized and controls/ventilation lose supply.	SMES may not be main generator, but auxiliary power is required to detect faults and execute safe discharge/ventilation.	- Provide UPS-backed controls, monitoring, valves and communication long enough for safe shutdown. - Define behaviour on blackout and restart.	- Size UPS autonomy and loads. - Test blackout sequence and automatic safe state.	Unlikely	Moderate	Low	Rare	Minor	Negligible	Unlikely	Significant	Moderate
System	Ship grid connection / grounding / isolation mismatch	Unsafe electrical interface, earth fault, circulating currents, THD exceedance or failed connection to vessel grid.	Container PCS cannot connect to agreed ship bus or protection settings conflict with vessel system.	Classification society review and a defined point of common coupling are essential.	- Agree point of common coupling, earthing, protection and isolation. - Validate voltage range, short-circuit contribution, THD/EMC and emergency isolation.	- Hold electrical interface review with Balearia/integrator/class. - Produce single-line diagram and protection settings.	Unlikely	Significant	Moderate	Rare	Minor	Negligible	Unlikely	Significant	Moderate
System	Renewable/hybrid ESS integration assumptions	Incorrect control coordination causes cycling, unmet response or unstable power sharing.	Future PV/battery integration changes duty cycle and increases SMES ramp frequency/AC losses.	Relevant for future integration, not necessarily the current demonstrator; should be treated as an interface/control risk.	- Define SMES duty cycle envelope and ramp limits. - Validate controller coordination with any battery/PV/ship grid EMS.	- Keep as open interface item for future renewable integration. - Update risk assessment if duty cycle changes.	Rare	Minor	Negligible	Rare	Minor	Negligible	Unlikely	Moderate	Low
System	Internal fire in SMES container	Fire damages PCS, controls, cables, insulation or cryogenic systems; smoke release and possible loss of safe discharge.	Electrical cabinet fault, overheated dump resistor, fan failure or external heat source ignites material.	SMES has no flammable electrolyte, but PCS/dump resistor/cables and container contents still present credible fire hazards.	- Install smoke/heat detection and suitable extinguishing system for electrical/cryogenic equipment. - Ensure emergency stop and discharge are coordinated with fire system. - Keep fire load low.	- Select extinguishing medium compatible with energized HV and cryogenic equipment. - Add fire alarm to ship interface.	Unlikely	Catastrophic	High	Unlikely	Moderate	Low	Unlikely	Catastrophic	High

					SAFEGUARD		PEOPLE			ENVIROMENT			ASSETS		
HAZARD (CATEGORY)	CAUSE	CONSEQUENCES	EXAMPLE	COMMENT	RECOMMENDATIONS	ACTIONS	FREQUENCY	SEVERITY	RISK LEVEL	FREQUENCY	SEVERITY	RISK LEVEL	FREQUENCY	SEVERITY	RISK LEVEL
System	External garage fire / A-60 boundary exposure	External fire heats container, causes loss of cooling, pressure rise, insulation damage or forced shutdown.	Vehicle/cargo fire in garage exposes SMES container to heat and firefighting water.	A-60 boundary and safe isolation/discharge procedure remain open and important.	· Confirm fire rating / A-60 boundary requirement with class. · Define external fire response: isolate, discharge, stop PCS, maintain/vent pressure safely.	· Confirm container fire insulation rating. · Add emergency response procedure for garage fire.	Rare	Catastrophic	Moderate	Unlikely	Moderate	Low	Unlikely	Catastrophic	High
System	Bilge / contaminated runoff / leaked fluids	Water used for firefighting carries contaminants or cryogenic-system residues to bilge; slip/corrosion/environmental impact.	Firefighting water enters the container and drains to ship bilge.	SMES toxic inventory is limited versus batteries, but glycol/oils, cleaning residues or contaminated firewater should be listed.	· Inventory all liquids and materials that can reach bilge. · Provide containment/drain routing and SDS information. · Avoid uncontrolled discharge to bilge where practicable.	· Prepare chemical/liquid inventory and SDS pack. · Confirm drainage/containment with ship owner.	Rare	Minor	Negligible	Rare	Moderate	Very Low	Rare	Minor	Negligible
System	Emergency access / escape route obstruction	Container placement blocks evacuation, emergency equipment or firefighting access.	Container, cable routing or ventilation ducts interfere with ship escape routes.	Primarily a layout/class approval issue; severity may be high if escape routes are affected.	· Place container and cables outside escape routes and emergency equipment zones. · Mark access/exclusion zones clearly.	· Verify layout against vessel escape/fire plan. · Include in class/ship-owner review.	Rare	Significant	Low	Rare	Minor	Negligible	Rare	Minor	Negligible
System	Maintenance / inspection not performed	Degradation of vacuum, cryogenic seals, relief devices, insulation resistance, filters or sensors leading to failure.	Prototype runs without planned checks after transport/sea trial.	Maintenance should cover cryogenic, HV, control, ODH, fire and mechanical restraint systems.	· Prepare preventive maintenance plan and spares list. · Include vacuum/pressure relief, helium leak, insulation resistance, sensor calibration and filter checks.	· Add maintenance manual action with intervals and responsible owner. · Track open safety-critical maintenance items.	Unlikely	Moderate	Low	Rare	Minor	Negligible	Unlikely	Significant	Moderate
System	Pressure relief / venting failure	Container or cryostat overpressure from helium expansion or quench discharge; projectile or structural damage.	Relief path blocked or undersized during quench, fire exposure or loss of vacuum/cooling.	Existing row correctly identifies helium expansion but severity was too low for people/assets.	· Size relief valves/rupture discs and vent routing for worst credible helium release/quench/fire case. · Keep vent outlets clear and away from personnel/intakes. · Add pressure monitoring and inspection.	· Complete relief sizing calculation and vent dispersion check. · Add periodic relief device inspection to maintenance plan.	Rare	Catastrophic	Moderate	Rare	Minor	Negligible	Rare	Catastrophic	Moderate

7. RISK TREATMENT

Once the risk has been assessed, those with a high and a medium risk level will be analysed in detail as follows. The purpose of risk treatment is to select and implement options to address risk. Risk treatment involves an iterative process of:

- Formulating and selecting risk treatment options.
- Planning and implementing risk treatment options
- Evaluating the effectiveness of that treatment
- Deciding whether the residual risk is acceptable
- If it is not acceptable, undertaking further treatment

The risk treatment is divided into three parts, one for each Energy Storage System studied. In all cases, the risks are not eliminated or minimized; however, they must be identified, assessed, and appropriately managed for a fixed onboard installation.

7.1. RISK TREATMENT OF KESS

Risk treatment is the process of selecting and implementing measures to reduce, control, transfer or eliminate identified risk. After risk have been evaluate take into account the safeguards established, appropriate actions are defined to minimize their likelihood and/or mitigate their potential consequences. The objective of risk treatment is to endure that risk is maintained at an acceptable level while supporting the safe and reliable operation of the system or technology.

7.1.0. CAUSE: VESSEL OPERATION (ACUTE INCLINATION)

ACTUAL RISK TREATMENT

Hazard Category: Global node

Consequences: Equipment failure.

Actual safeguards.

- Recommendations:
 - Check the inclination of its functioning system at 21.5 °.
 - Check if the inclination for trim is 10°.
 - Do not operate KESS if vessel inclination exceeds 21.5°
- Actions
 - Make a graph to correlate the maximum inclination and maximum lifetime for the bearings - Deliverable D5.5 (Section 5.1.5).
 - Deliverable D5.3 (Section 5.1) – Equipment design according to service environmental conditions.

Risk Evaluation: High in assets.

Conclusion

The risk associated with the prototype is not reduced in this case, as it is intended for short-duration operation (approximately 200 hours). However, several control measures have been identified and implemented to support the future integration of this technology onboard and to inform subsequent risk-reduction activities.

SELECT CONTROL MEASURES

The following control measures could be implemented:

- Define allowable vibration thresholds and integrate real-time alarm logic in the monitoring system. Design or upgrade the bearing systems to increase tolerance to angular misalignment

COMPLETION RECOMENDATIONS

- Ensure continuous monitoring of vessel inclination and trim using calibrated sensors to maintain operation within safe limits.
- Validate bearing lifetime and performance under realistic operational profiles, including worst-case environmental conditions.
- Conduct regular inspection and condition monitoring of bearings to detect early signs of misalignment or fatigue.
- Update operational manuals and checklists to clearly reflect environmental and inclination constraints.
- Use simulation and testing results to refine acceptable operating envelopes and improve design margins.

7.1.1. CAUSE: ACCELERATION/MOVING OF THE VESSEL VIBRATIONS

ACTUAL RISK TREATMENT

Hazard Category: Global node

Consequences: Affect the container installation and the electronic components of the KESS

Actual safeguards.

- Recommendations:
 - The vibration issue has to be analysed by the company
- Actions
 - Deliverable D5.3 (Section 5.1) – Equipment design according to service environmental conditions.
 - IEC 60068-2-6, vibration sensors, anti-vibration mounts.

Risk Evaluation: High in assets.

Conclusion

In this case, the risk associated with the prototype is not reduced, as the system is limited to a short operational duration of 200 hours. However, several control measures have been defined to be considered during the future onboard implementation of this technology.

SELECT CONTROL MEASURES

The following control measures could be implemented:

- Implement vibration isolation platforms specifically designed for marine environments (e.g., elastomeric or spring-damper systems).

- Define allowable vibration thresholds and integrate real-time alarm logic in the monitoring system.
- Optimize equipment layout onboard to minimize transmission of vibration from propulsion or machinery sources.

COMPLETION RECOMENDATIONS

- Establish operational guidelines limiting vessel speed or machinery operation when excessive vibration levels are detected.
- Avoid installation of sensitive components near known high-vibration zones.
- Perform periodic vibration trend analysis to detect degradation or changes in dynamic behaviour over time.

7.1.2. CAUSE: HEAT IN THE WIRES OF THE ELECTRICAL PART (COILS)

ACTUAL RISK TREATMENT

Hazard Category: Technology node

Consequences: Heat from the bearings can affect other components.

Actual safeguards.

- Recommendations:
 - These coils are air forced cooled, but the heat transferred should be considered.
 - Monitor temperature by sensors in the sensitive parts
- Actions
 - Deliverable D5.5 (Section 3.1) -Development of a thermal model for the container prototype.
 - Temperature alarms + automatic speed reduction

Risk Evaluation: Moderate in assets.

Conclusion

The risk associated with the prototype is not reduced in this case, as it is a short-duration prototype (200 hours of operation). However, several control measures are introduced to be considered during the implementation of this technology onboard.

SELECT CONTROL MEASURES

The following control measures could be implemented:

- Introduce redundancy in cooling systems
- Improve airflow management within the enclosure to enhance heat dissipation and avoid localized hotspots.
- Install thermal insulation barriers between heat-generating components and temperature-sensitive equipment.
- Integrate predictive thermal monitoring to anticipate overheating trends before critical thresholds are reached.

COMPLETION RECOMMENDATIONS

- Establish preventive maintenance procedures focused on cleaning and verifying cooling system performance.
- Ensure adequate separation between heat sources.
- Validate thermal performance under long-duration operation to reflect real mission profiles.

7.1.3. CAUSE: COLLISION OF THE FLYWHEEL

ACTUAL RISK TREATMENT

Hazard Category: Technology node

Consequences: As the flywheel spins at high rpm, any failure can produce high damage.

Actual safeguards.

- Recommendations:
 - Make sure that, in case of flywheel collision, there is a safety zone so anybody could get hurt.
- Actions
 - Study the containment of the flywheel inside the device. (Deliverable 5.5)
 - The flywheel RPM will be limited when operating in safety mode.
 - Examine the flywheel enclosure in accordance with a reference standard (e.g., IEC or DNV).
 - Monitor bearing temperature to avoid failure & wear. Also possible by vibration monitoring. Proper design against fatigue.

Risk Evaluation: Moderate in assets.

Conclusion

In this case, the risk associated with the prototype is not reduced, as the system is limited to a short operational duration of 200 hours. However, several control measures have been defined to be considered during the future onboard implementation of this technology.

SELECT CONTROL MEASURES

The following control measures could be implemented:

- Design a fully rated containment system capable of safely retaining fragments in the event of catastrophic flywheel failure.
- Introduce overspeed protection mechanisms to automatically limit or shut down the system if critical RPM thresholds are exceeded.
- Conduct burst testing or equivalent validation to confirm containment integrity under worst-case scenarios.

COMPLETION RECOMMENDATIONS

- Define strict operational limits for flywheel speed under all operating modes, including emergency conditions.

- Establish clear maintenance and inspection intervals focused on rotor integrity and bearing condition.
- Ensure that all personnel procedures include emergency response actions for high-energy mechanical failure scenarios.
- Validate enclosure design against recognised safety standards for rotating machinery.
- Incorporate simulation-based safety validation into the design lifecycle to reduce uncertainty before commissioning.

7.1.4. CAUSE: START-UP/SHUT DOWN OPERATION

ACTUAL RISK TREATMENT

Hazard Category: Technology node

Consequences: The starting/ stopping process has to be controlled to know when there is risk due to the operating of the system.

Actual safeguards.

- Recommendations:
 - Ensure the system have enough quantity of energy before powering on.
 - The system has to be able to stop without the electronics (only with the safety valve).
 - Operating automatically using only the safety valve, without relying on electronic components in the event that they are unavailable.
- Actions
 - Formal ESD procedure, interlocks, crew training

Risk Evaluation: Moderate in people, environment and assets

Conclusion

The risk associated with the prototype is not reduced in this case, as it is a short-duration prototype (200 hours of operation). However, several control measures are introduced to be considered during the implementation of this technology onboard.

SELECT CONTROL MEASURES

The following control measures could be implemented:

- Implement a sequenced start-up/shut-down logic with built-in safety interlocks to prevent unsafe transitions.
- Introduce automatic state monitoring to verify safe conditions before allowing system activation.
- Add redundant safety actuation paths to ensure shutdown capability under all failure modes.
- Define pre-start checklists including energy availability, system status, and environmental conditions.
- Incorporate automatic inhibition of start-up if critical safety conditions are not met.
- Implement alarm systems to alert operators of unsafe start or stop conditions.

COMPLETION RECOMENDATIONS

- Establish clearly defined operating envelopes for start-up and shut-down conditions, including environmental and system constraints.
- Ensure continuous training and certification of crew members responsible for system operation.
- Perform periodic drills simulating emergency start-up and shut-down scenarios.
- Validate start-up/shut-down sequences through simulation and onboard testing prior to commissioning.
- Maintain detailed operational logs to support traceability and post-event analysis.

7.1.5. CAUSE: COOLING

ACTUAL RISK TREATMENT

Hazard Category: Technology node

Consequences: Emergency discharge of flywheel will produce a lot of heat inside the container.

Actual safeguards.

- Recommendations:
 - Study to be conducted on the heat transfer of the container.
 - Time and temperatures reached are values of interest.
- Actions
 - Deliverable D5.5 (Section 3.1) -Development of a thermal model for the container prototype.
 - Emergency thermal threshold + thermal trip protection.

Risk Evaluation: Moderate in assets.

Conclusion

In this case, the risk associated with the prototype is not reduced, as the system is limited to a short operational duration of 200 hours. However, several control measures have been defined to be considered during the future onboard implementation of this technology.

SELECT CONTROL MEASURES

The following control measures could be implemented:

- Improve internal airflow management to ensure uniform heat distribution and prevent local overheating.
- Incorporate thermal shielding between the flywheel containment area and sensitive equipment.
- Implement redundant temperature monitoring at critical points inside the container.

COMPLETION RECOMMENDATIONS

- Ensure continuous thermal monitoring with real-time alarm and response capability.
- Validate cooling performance under both normal and emergency operating conditions.
- Include thermal event scenarios in safety analysis and operational risk assessments.

7.1.6. CAUSE: EFFECT OF THE CONTAINER (NOISE)

ACTUAL RISK TREATMENT

Hazard Category: Technology node

Consequences: The noise level inside the container can affect the surrounding environment.

Actual safeguards.

- Recommendations:
 - Necessary Personal Protective Equipment (PPE) inside the container if the electrical machine is working.
- Actions
 - Soundproofing of the container and limits in accordance with SOLAS/ILO regulations
 - It has to be measured and monitored the noise level on deck when the machine is operating.

Risk Evaluation: Moderate in people and assets and High in environment.

Conclusion

The risk associated with the prototype is not reduced in this case, as it is a short-duration prototype (200 hours of operation). However, several control measures are introduced to be considered during the implementation of this technology onboard.

SELECT CONTROL MEASURES

The following control measures could be implemented:

- Install advanced acoustic insulation materials within the container structure to reduce noise transmission.
- Implement vibration-to-noise mitigation strategies (e.g., dampers and anti-vibration mounts for rotating equipment).
- Design acoustic barriers or enclosures around high-noise sources.
- Introduce real-time noise monitoring systems with alarm thresholds for personnel and environmental limits.
- Optimize equipment layout to minimize noise propagation paths.
- Apply low-noise design principles in electrical machines and auxiliary systems where feasible.
- Conduct noise mapping studies to identify critical emission points and validate mitigation effectiveness.

COMPLETION RECOMMENDATIONS

- Define maximum allowable noise exposure limits for both personnel and environmental compliance.
- Ensure mandatory use of PPE in all high-noise operating conditions and enforce compliance through procedures.
- Perform periodic noise measurements under all operational modes to ensure regulatory compliance.
- Include noise impact assessment in operational risk reviews and safety case documentation.
- Provide crew training on noise hazards and safe working practices in high-noise environments.
- Validate acoustic performance of the container design under worst-case operational conditions before commissioning.

7.1.7. CAUSE: CONTROL/MONITORING/ALARM SYSTEM

ACTUAL RISK TREATMENT

Hazard Category: Technology node

Consequences: In case of danger, it should be detected and notified so the security actions should be carried out.

Actual safeguards.

- Recommendations:
 - Recommended to add an emergency bottom outside of the container (wait 10 minutes so it is stopped).
 - Sensor at the entrance so nobody enters the container during its functioning (for this application)
 - There should be an alarm to provide information about the fire alarm to the ship. (Visual and acoustic alarm)
- Action:
 - Test the time to discharge the system until it goes to 0 rpm.
 - Connection to the vessel's IAMS + multisensory shutdown.

Risk Evaluation: Moderate in assets.

Conclusion

In this case, the risk associated with the prototype is not reduced, as the system is limited to a short operational duration of 200 hours. However, several control measures have been defined to be considered during the future onboard implementation of this technology.

SELECT CONTROL MEASURES

The following control measures could be implemented:

- Implement automatic emergency shutdown activation in case of fire, intrusion, or abnormal operating conditions.
- Install redundant detection systems for fire, smoke, temperature, and unauthorized access.
- Introduce access interlocks preventing container door opening while the flywheel is rotating above safe RPM limits.

- Provide emergency lighting and clearly marked evacuation/signage systems around the container area.
- Integrate remote monitoring and alarm transmission to the vessel control room.
- Establish fail-safe communication between the prototype and the vessel safety systems.

COMPLETION RECOMMENDATIONS

- Ensure that all emergency alarms are continuously monitored and periodically tested.
- Define and validate safe waiting times before container access following emergency shutdown.
- Establish clear emergency response procedures for operators and crew members.
- Conduct regular drills simulating emergency scenarios such as fire, system failure, or unauthorized access.
- Verify compatibility and integration of the prototype safety systems with the vessel safety architecture.
- Ensure all sensors and alarms remain operational under marine environmental conditions.

7.1.8. CAUSE: MAINTENANCE

Hazard Category: System

Consequences: To prevent problems due to fatigue there should be planned some maintenance activities to monitor the status of the critical components.

Actual safeguards.

- Recommendations:
 - Maintenance plan should be prepared for this container/ system, this will be reflected on a manual.

Risk Evaluation: Moderate in assets.

Conclusion

The risk associated with the prototype is not reduced in this case, as it is a short-duration prototype (200 hours of operation). However, several control measures are introduced to be considered during the implementation of this technology onboard.

SELECT CONTROL MEASURES

The following control measures could be implemented:

- Implement condition-based maintenance using vibration, temperature, and performance monitoring of critical components.
- Define periodic inspection intervals for structural components, bearings, electrical connections, and rotating equipment.
- Introduce fatigue monitoring procedures for components exposed to cyclic loading conditions.
- Maintain detailed maintenance and operational records to support traceability and trend analysis.
- Establish preventive replacement schedules for components with limited-service life.
- Integrate diagnostic tools capable of detecting early signs of wear, imbalance, or degradation.

COMPLETION RECOMMENDATIONS

- Ensure that maintenance procedures are aligned with the expected operational profile and environmental conditions onboard.
- Periodically review and update the maintenance plan based on operational experience and inspection results.
- Provide crew training on inspection routines and early detection of abnormal conditions.
- Include emergency maintenance procedures within the system manual.
- Validate maintenance intervals through operational testing and reliability analysis.

7.1.9. CAUSE: BEARINGS

ACTUAL RISK TREATMENT

Hazard Category: System

Consequences: As critical components are important to control the bearings to prevent dangers.

Actual safeguards.

- Recommendations:
 - Monitor the temperature and once it reaches the limit temperature (90°) establish a speed reduction so the bearings can be cooled.
- Action:
 - Alarm/trip setpoints (90°C) + continuous temperature monitoring

Risk Evaluation: Moderate in assets.

Conclusion

In this case, the risk associated with the prototype is not reduced, as the system is limited to a short operational duration of 200 hours. However, several control measures have been defined to be considered during the future onboard implementation of this technology.

SELECT CONTROL MEASURES

The following control measures could be implemented:

- Install redundant temperature sensors on critical bearings to improve reliability of thermal monitoring.
- Implement automatic shutdown logic if temperature continues increasing after speed reduction.

- Introduce predictive maintenance techniques based on thermal trend analysis.
- Integrate vibration monitoring to detect early signs of bearing wear or misalignment.
- Ensure adequate lubrication systems and monitoring of lubricant condition.
- Improve cooling airflow around the bearing assembly to enhance heat dissipation

COMPLETION RECOMMENDATIONS

- Define maximum allowable operating temperatures and emergency shutdown thresholds for all critical bearings.
- Perform periodic calibration and verification of temperature monitoring sensors.
- Establish preventive maintenance intervals based on operational hours and thermal loading conditions.
- Validate bearing thermal behaviour under worst-case operating scenarios.
- Include bearing overheating scenarios in operational procedures and emergency response plans.
- Maintain inspection records and trend analysis to support reliability assessment and lifetime prediction.

7.2. RISK TREATMENT OF EESS

Risk treatment is the process of selecting and implementing measures to reduce, control, transfer or eliminate identified risk. After risk have been evaluate take into account the safeguards established, appropriate actions are defined to minimize their likelihood and/or mitigate their potential consequences. The objective of risk treatment is to endure that risk is maintained at an acceptable level while supporting the safe and reliable operation of the system or technology.

7.2.0. CAUSE: DROP OBJECT

ACTUAL RISK TREATMENT

Hazard Category: Global node

Consequences: A small drop or a collision with a vehicle during embarkation or disembarkation could damage the equipment.

Actual safeguards.

- Recommendations:
 - The safety zone for the containerized solution should be indicated

Risk Evaluation: Moderate in assets.

Conclusion

The risk associated with the prototype is not reduced in this case, as it is a short-duration prototype (200 hours of operation). However, several control measures are introduced to be considered during the implementation of this technology onboard.

SELECT CONTROL MEASURES

The following control measures could be implemented:

- Install physical protective barriers or impact protection structures around vulnerable equipment areas.
- Define controlled handling and transport procedures for embarkation and disembarkation activities.
- Implement collision warning markings and high-visibility signage around the container.

COMPLETION RECOMMENDATIONS

- Ensure that all embarkation and disembarkation operations are supervised by trained personnel.
- Establish minimum clearance distances between vehicles and the containerized system during operations.
- Perform risk assessments for loading, unloading, and transport scenarios under representative operational conditions.
- Verify structural resistance of the container and support systems against accidental impacts.
- Include handling and transport procedures within the operational manual and crew training activities.
- Conduct periodic inspections after transport operations to identify possible structural or equipment damage.

7.2.1. CAUSE: STARTUP/SHUT DOWN OPERATION

ACTUAL RISK TREATMENT

Hazard Category: Technology node

Consequences: The starting/ stopping process has to be controlled to know when there is risk due to the operating of the system

Actual safeguards.

- Recommendations:
 - Ensure the system have enough quantity of energy before powering on.
 - The system has to be able to stop without the electronics (only with the safety valve).
 - Operating automatically using only the safety valve, without relying on electronic components in the event that they are unavailable.
- Actions
 - Formal ESD procedure, interlocks, crew training

Risk Evaluation: Moderate for people, environment and assets

Conclusion

In this case, the risk associated with the prototype is not reduced, as the system is limited to a short operational duration of 200 hours. However, several control measures have been defined to be considered during the future onboard implementation of this technology.

SELECT CONTROL MEASURES

The following control measures could be implemented:

- Implement automatic verification of minimum energy availability before system start-up.
- Introduce permissive logic preventing system activation if critical safety conditions are not met.
- Integrate redundant shutdown paths to guarantee safe stop capability under fault conditions.
- Install status indication systems providing operators with clear information on operational readiness and shutdown conditions.
- Implement automatic alarms for abnormal start-up, low-energy conditions, or shutdown failures.
- Define controlled start-up and shut-down sequences within the control system software.

COMPLETION RECOMMENDATIONS

- Establish clear operational procedures defining safe start-up and shut-down conditions.
- Validate all emergencies stop and shutdown functions through testing prior to commissioning.
- Ensure periodic inspection and testing of safety valves, interlocks, and shutdown systems.
- Conduct operational drills for abnormal and emergency scenarios involving loss of electronic control.
- Maintain updated operating manuals and crew guidance documentation onboard.

7.2.2. CAUSE: FIRE FIGHTING

ACTUAL RISK TREATMENT

Hazard Category: System

Consequences: A fire inside the container could spread throughout the ship's garage.

Actual safeguards.

- Recommendations:
 - There will be installed some sensors for fumes/ fire at the container that will operate a firefighting system.
- Actions
 - Deliverable POSEIDON - Bureau Veritas Rev.0 - Verify the feasibility of using CO2 as firefighting solution for both flywheel and supercapacitors.

Risk Evaluation: Medium in assets.

Conclusion

The risk associated with the prototype is not reduced in this case, as it is a short-duration prototype (200 hours of operation). However, several control measures are introduced to be considered during the implementation of this technology onboard.

SELECT CONTROL MEASURES

The following control measures could be implemented:

- Implement an automatic fire detection and suppression system with redundant sensing capability.
- Integrate the container fire alarm system with the vessel's central alarm and monitoring system.
- Install fire-resistant insulation and compartmentalization barriers to limit fire propagation.
- Introduce emergency ventilation shutdown to prevent smoke and heat spread during fire events.
- Ensure safe emergency isolation of electrical power during fire conditions.
- Provide portable fire extinguishing equipment suitable for electrical and energy storage system fires.
- Implement continuous thermal monitoring of critical components to detect early overheating conditions.

COMPLETION RECOMMENDATIONS

- Validate the effectiveness of the selected fire-fighting agent for all onboard operating scenarios.
- Conduct fire scenario simulations and emergency response testing before commissioning.
- Ensure compliance with applicable marine fire safety regulations and classification society requirements.
- Establish regular inspection and maintenance procedures for all fire detection and suppression equipment.
- Provide crew training on emergency fire response procedures related to the containerized system.
- Verify that fire detection and suppression systems remain operational under marine environmental conditions.

7.2.3. CAUSE: FIRE IN THE GARAGE

ACTUAL RISK TREATMENT

Hazard Category: System

Consequences: It may damage the equipment inside the container.

Actual safeguards.

- Recommendations:
 - Switching off the container electric feeding from the ship, the container shall de-energize and stop.
- Actions
 - Deliverable POSEIDON - Bureau Veritas Rev.0 - The boundary of container has insulation A-60

Risk Evaluation: Moderate in assets.

Conclusion

In this case, the risk associated with the prototype is not reduced, as the system is limited to a short operational duration of 200 hours. However, several control measures have been defined to be considered during the future onboard implementation of this technology.

SELECT CONTROL MEASURES

The following control measures could be implemented:

- Implement automatic power isolation of the container in case of fire detection in adjacent vessel spaces.
- Integrate the container emergency shutdown system with the vessel fire detection and alarm system.
- Install thermal and smoke monitoring at the container boundaries to detect external fire exposure.
- Ensure emergency ventilation shutdown to limit heat and smoke ingress into the container.
- Provide protected cable routing and fire-resistant penetrations for electrical and communication interfaces.
- Introduce emergency operational procedures for safe isolation of the prototype during vessel fire events.

COMPLETION RECOMMENDATIONS

- Validate the thermal resistance and integrity of the A-60 insulation under representative fire scenarios.
- Ensure compatibility between the prototype shutdown logic and the vessel emergency systems.
- Conduct fire emergency drills involving both vessel crew and prototype operators.
- Periodically inspect the condition of fire insulation, cable penetrations, and emergency isolation systems.
- Assess the impact of external fire exposure on critical components and define acceptable operational recovery procedures.
- Verify that all alarms and shutdown signals are properly transmitted to the vessel control room.

7.3. RISK TREATMENT OF SMES

The SMES is not considered a prototype within the POSEIDON project; therefore, risk management will be addressed in future phases when a higher TRL is reached. However, laboratory tests of the system have been carried out, which have provided a first assessment of its behaviour and associated risks.

In addition, the risk analysis performed, using the same boundary conditions as for the supercapacitors and the KESS, shows high, moderate, and very high-risk levels in several aspects, which will need to be taken into account in future onboard integrations.

7.3.0. CAUSE: SHIP ACCELERATION, SHOCK AND VIBRATION

ACTUAL RISK TREATMENT

Hazard Category: Global node

Consequences: Mechanical fatigue or displacement of cryostat, cold mass, HTS pancakes, current leads, piping or PCS cabinets.

Actual safeguards.

- Recommendations:
 - Perform vibration/shock qualification against marine/container load cases.
 - Use anti-vibration mounts only after verifying cryogenic alignment and fatigue.
 - Provide positive locking/lashing and flexible connections where required.
- Actions
 - Request supplier vibration limits/certificates for cryocooler/CSS.
 - Add inspection criteria after transport and sea trials.

Risk Evaluation: Moderate in assets.

Conclusion

The identified risks are mainly associated with mechanical fatigue and displacement caused by vibration and shock loads during onboard operation. Although the overall risk level is considered moderate, additional qualification testing, supplier validation, and inspection procedures are recommended to ensure the integrity and reliability of the SMES system in future marine applications.

SELECT CONTROL MEASURES

The following control measures could be implemented:

- Perform vibration and shock qualification testing under representative marine and transport load cases.
- Implement secure locking/lashing systems and flexible mechanical connections to minimize displacement and mechanical stress.
- Verify cryogenic alignment and fatigue behaviour before installing anti-vibration mounts.
- Define inspection and maintenance procedures after transport, installation, and sea trials.
- Request and validate supplier certifications and vibration limits for critical equipment such as the cryocooler and CSS.

COMPLETION RECOMMENDATIONS

- Complete mechanical qualification testing prior to onboard integration.
- Establish acceptance criteria for vibration, fatigue, and alignment performance.
- Include periodic inspection plans within the maintenance strategy for future deployments.

- Ensure that all transport and installation procedures are documented and validated.
- Reassess the risk level once operational and sea-trial data become available in higher TRL stages.

7.3.1. CAUSE: VIBRATION OF CRYOGENIC SUPPLY SYSTEM (CSS)

ACTUAL RISK TREATMENT

Hazard Category: Global node

Consequences: Reduced cooling capacity, pipe fatigue, loss of thermal contact or premature quench.

Actual safeguards.

- Recommendations:
 - Validate CSS under expected vibration/acceleration and inclination.
 - Monitor helium flow, pressure, cold-head temperature and magnet temperature.
 - Define safe ramp-down / dump sequence on loss of cooling.
- Actions
 - Add CSS FMEA and vibration test to open actions.
 - Define alarm thresholds for flow, pressure and temperature.

Risk Evaluation: High risk in assets.

Conclusion

The main risks identified are associated with reduced cooling capacity, pipe fatigue, loss of thermal contact, and potential premature quench events under marine operating conditions. Due to the critical dependence of the SMES system on stable cryogenic performance, the overall risk level for assets is considered high. The implementation of monitoring systems, qualification testing, alarm management, and validated emergency procedures will be essential to improve system reliability and support future onboard integration at higher TRL levels.

SELECT CONTROL MEASURES

The following control measures could be implemented:

- Validate the CSS under expected marine vibration, acceleration, and inclination conditions.
- Implement continuous monitoring of helium flow, pressure, cold-head temperature, and magnet temperature.
- Define and automate safe ramp-down and energy dump sequences in case of cooling loss.
- Establish alarm thresholds and interlock mechanisms for abnormal flow, pressure, and temperature conditions.
- Perform vibration qualification and functional testing of the cooling system before onboard integration.

COMPLETION RECOMMENDATIONS

- Complete the CSS FMEA to identify critical failure modes and mitigation actions.
- Finalize vibration and operational qualification tests under representative marine conditions.
- Verify the effectiveness of monitoring and alarm systems during laboratory and integration tests.
- Develop operational procedures for emergency cooling-loss scenarios and quench management.
- Reassess the residual risk level after testing and validation activities at higher TRL stages.

7.3.2. CAUSE: HELIUM RELEASE / INADEQUATE VENTILATION

ACTUAL RISK TREATMENT

Hazard Category: Global node

Consequences: Oxygen deficiency, asphyxiation risk, overpressure in container and loss of cooling.

Actual safeguards.

- Recommendations:
 - Size ventilation and relief paths for maximum credible helium release.
 - Install oxygen deficiency monitoring with audible/visual alarm.
 - Route relief vents to safe location away from personnel/intakes.
- Actions
 - Calculate helium inventory, expansion volume and ODH classification.
 - Define entry procedure, purge/ventilation time and rescue response.

Risk Evaluation: High risk in people and moderate risk in assets.

Conclusion

The identified risks are mainly related to the degradation or loss of cooling performance, which could lead to pipe fatigue, thermal instability, or premature quench events. Given the importance of maintaining stable cryogenic conditions, the risk level for assets is considered high. The implementation of qualification testing, continuous monitoring, alarm management, and validated emergency procedures will be essential to ensure system integrity and reliability in future onboard applications.

SELECT CONTROL MEASURES

- Validate the CSS under representative vibration, acceleration, and inclination conditions expected during marine operation.
- Implement continuous monitoring of helium flow, pressure, cold-head temperature, and magnet temperature.
- Define and validate safe ramp-down and energy dump procedures in the event of cooling loss.
- Establish alarm thresholds and protection logic for abnormal flow, pressure, and temperature values.
- Perform vibration and functional qualification testing prior to onboard deployment.

COMPLETION RECOMMENDATIONS

- Complete the CSS FMEA and include the identified mitigation measures in the system design.
- Carry out vibration testing under representative transport and operational marine conditions.
- Verify the effectiveness and response time of monitoring and alarm systems during testing activities.
- Develop detailed operational and emergency procedures for cooling-loss and quench scenarios.
- Review and update the residual risk assessment after validation at higher TRL stages.

7.3.3. CAUSE: DROPPED OBJECT / EXTERNAL IMPACT DURING HANDLING

ACTUAL RISK TREATMENT

Hazard Category: Global node

Consequences: Damage to cryostat, vacuum vessel, relief piping, PCS cabinets or container structure.

Actual safeguards.

- Recommendations:
 - Define exclusion zone and handling procedure.
 - Protect exposed cryogenic connections and cabinet penetrations.
 - Transport with magnet de-energized and pressure state controlled.
- Actions
 - Add mechanical guarding around cryogenic lines and relief devices.
 - Verify lifting/lashing points and handling checklist.

Risk Evaluation: High risk in assets.

Conclusion

The assessment identified a significant risk of damage to critical equipment and infrastructure due to dropped objects or external impacts during handling activities. Components such as the cryostat, vacuum vessel, relief piping, PCS cabinets, and container structure are particularly vulnerable. Given the potential for substantial asset damage and operational disruption, the risk is classified as High and requires the implementation of appropriate engineering and administrative controls prior to handling and transportation operations.

SELECT CONTROL MEASURES

- Establish and enforce an exclusion zone during all lifting, handling, and transportation activities.
- Develop and implement detailed handling procedures, including roles, responsibilities, and communication requirements.
- Install mechanical guards and protective covers around exposed cryogenic lines, relief devices, and cabinet penetrations.
- Verify all lifting and lashing points before movement and use approved lifting equipment.
- Implement a handling checklist to confirm readiness before transport or lifting operations.
- Ensure the magnet is fully de-energized and the pressure condition is maintained within specified limits during transport.
- Conduct pre-job briefings and personnel training on handling hazards and emergency response actions

COMPLETION RECOMMENDATIONS

The identified high asset risk can be reduced to an acceptable level provided that the following measures are fully implemented and verified before handling or transportation activities commence:

- Establish and clearly demarcate an exclusion zone around the handling area.
- Develop, approve, and communicate a detailed handling procedure to all personnel involved.
- Install mechanical guarding to protect exposed cryogenic lines and relief devices from accidental impact.
- Protect exposed cryogenic connections, cabinet penetrations, and other vulnerable equipment interfaces.
- Verify the integrity and suitability of all lifting and lashing points prior to use.
- Complete and sign off the handling checklist before each lifting or transportation operation.
- Confirm that the magnet is fully de-energized before transport.
- Verify that the pressure state is controlled and maintained within the specified limits during handling and transportation.
- Conduct a pre-move inspection to ensure all protective measures are in place and no outstanding defects exist.
- Ensure personnel involved in the operation are trained and briefed on handling hazards, exclusion zone requirements, and emergency response procedures.

7.3.4. CAUSE: INTERNAL COLLISION / INADEQUATE COMPONENT RESTRAINT

ACTUAL RISK TREATMENT

Hazard Category: Global node

Consequences: Relative movement between magnet, cryostat, CSS, dump resistor or cabinets causing mechanical/electrical damage.

Actual safeguards.

- Recommendations:
 - Use structural supports designed for ship accelerations and emergency loads.
 - Separate or restrain components to prevent contact.
 - Inspect after shock events.
- Actions

- Complete container internal layout review with minimum clearances.
- Include fastener locking and post-voyage inspection

Risk Evaluation: Moderate risk in assets.

Conclusion

The assessment identified a risk of internal collision and inadequate component restraint during transportation, which could result in relative movement between the magnet, cryostat, CSS, dump resistor, and PCS cabinets. Such movement may cause mechanical damage, electrical faults, loss of alignment, or degradation of system integrity. The risk is particularly relevant during vessel motions, shock events, emergency manoeuvres, and other dynamic loading conditions. Appropriate structural restraint, separation distances, and inspection requirements are therefore necessary to maintain equipment integrity throughout transport. The identified hazard presents a high risk to assets, as relative movement between the magnet, cryostat, CSS, dump resistor, and cabinets during transport could result in significant mechanical and electrical damage. To mitigate this risk, robust structural supports capable of withstanding ship accelerations and emergency loads should be implemented, along with adequate restraints and separation between components. A thorough review of the container's internal layout, verification of minimum clearances, use of locking fasteners, and post-voyage inspections are necessary actions to reduce the likelihood and impact of damage and ensure the integrity of the equipment throughout transportation.

SELECT CONTROL MEASURES

- Install transport-rated structural supports designed to withstand ship accelerations, vibration, and emergency loads.
- Secure and restrain the magnet, cryostat, CSS, dump resistor, and cabinets to prevent relative movement during transport.
- Maintain adequate minimum separation clearances between components to avoid contact and impact.
- Use locking fasteners and anti-vibration securing methods to prevent loosening during shipment.
- Establish inspection procedures following any significant shock or abnormal transport event.

COMPLETION RECOMMENDATIONS

- Complete and document the container internal layout review, verifying clearances and load paths.
- Verify that all supports, restraints, and fastening systems are installed according to the approved transport design before shipment.
- Conduct a pre-shipment inspection to confirm compliance with transport securing requirements.
- Perform a post-voyage inspection to check for movement, damage, loose fasteners, or degradation of equipment.
- Update transport and maintenance procedures to include shock-event inspections and acceptance criteria before commissioning the equipment.

7.3.5. CAUSE: FLOODING / GREEN WATER / WATER INGRESS

ACTUAL RISK TREATMENT

Hazard Category: Global node

Consequences: Short circuit, corrosion, loss of insulation, trip of PCS/control system and possible unsafe shutdown.

Actual safeguards.

- Recommendations:
 - Specify weathertight container and protected ventilation openings.
 - Install water ingress detection and drain strategy.
 - Define automatic isolation and safe discharge on water alarm.
- Actions
 - Verify IP rating / weathertightness and sill height.
 - Add flooding response to operating manual.

Risk Evaluation: People and assets as a moderate risk level

Conclusion

Water ingress into the container presents a moderate risk to both people and assets due to the potential for short circuits, corrosion, insulation degradation, PCS/control system trips, and unsafe shutdown conditions. Ensuring adequate protection against water intrusion, early detection of flooding, and defined response procedures is essential to maintain personnel safety, equipment reliability, and operational continuity.

SELECT CONTROL MEASURES

- Specify and use a weathertight container suitable for the environmental conditions expected during transport and operation.
- Protect all ventilation openings against water ingress while maintaining required airflow.
- Install water ingress or flooding detection systems with appropriate alarm functionality.
- Provide a drainage strategy to prevent water accumulation within the container.
- Implement automatic electrical isolation and safe energy discharge functions upon detection of water ingress.
- Verify that equipment enclosures and electrical systems meet the required IP protection ratings.

COMPLETION RECOMMENDATIONS

- Verify and document the container's weathertightness, IP ratings, and sill height requirements.
- Confirm that water ingress detection and drainage systems are installed and functioning as designed.
- Validate the automatic isolation and safe discharge sequence through testing and commissioning activities.
- Incorporate flooding response procedures, alarms, and emergency actions into the operating manual.
- Conduct periodic inspections and maintenance of seals, drainage paths, and detection systems to ensure continued effectiveness.

7.3.6. CAUSE: HUMIDITY / SALINITY / CONDENSATION

ACTUAL RISK TREATMENT

Hazard Category: Technology node

Consequences: Corrosion and insulation degradation of PCS, cabinets, sensors, current leads and connectors.

Actual safeguards.

- Recommendations:
 - Maintain HVAC/dehumidification and humidity alarm.
 - Use marine-grade/corrosion-resistant cabinets and coated PCBs where needed.
 - Define warm-up/door-opening procedure to avoid condensation.
- Actions
 - Specify humidity/salinity acceptance criteria.
 - Add periodic corrosion/insulation resistance checks.

Risk Evaluation: Moderate risk in assets.

Conclusion

Exposure to high humidity and saline environments presents a moderate risk to assets, particularly affecting PCS equipment, cabinets, sensors, current leads, and connectors through corrosion and insulation degradation. Appropriate environmental control, corrosion protection, and inspection measures are required to maintain equipment reliability and prevent premature failure.

SELECT CONTROL MEASURES

- Maintain HVAC and dehumidification systems to control humidity levels within the container.
- Install humidity monitoring with alarm functionality to provide early warning of adverse conditions.
- Use marine-grade or corrosion-resistant cabinets, materials, and hardware where appropriate.
- Apply protective coatings to PCBs and sensitive electronic components exposed to humid or saline environments.
- Implement controlled warm-up and door-opening procedures to minimize condensation formation.

COMPLETION RECOMMENDATIONS

- Define and document acceptable humidity and salinity limits for equipment operation and storage.
- Verify that HVAC, dehumidification, and humidity alarm systems meet design requirements and are properly commissioned.
- Specify corrosion-resistant materials and protective coatings in procurement and design documentation.
- Include periodic inspections for corrosion, moisture ingress, and equipment condition in maintenance plans.
- Perform regular insulation resistance testing to identify degradation before equipment reliability is affected.

7.3.7. CAUSE: POWER QUALITY / PCS HARMONICS / PWM PULSE VOLTAGE

ACTUAL RISK TREATMENT

Hazard Category: Technology node

Consequences: Grid instability, nuisance trips, insulation stress, partial discharge or accelerated magnet insulation ageing.

Actual safeguards.

- Recommendations:
 - Include DC-side filter and cable length limitation.
 - Verify switching frequency avoids magnet resonance.
 - Demonstrate THD, EMC and insulation coordination within class limits.
- Actions
 - Add PCS-magnet interaction study: cable length, RLC filter, switching frequency, peak voltage.
 - Record acceptance criteria in FAT/SAT.

Risk Evaluation: Moderate risk in people and assets.

Conclusion

Electrical interactions between the PCS and magnet system present a moderate risk to both people and assets. Potential consequences include grid instability, nuisance trips, insulation stress, partial discharge, and accelerated ageing of magnet insulation, which can affect system reliability, availability, and long-term equipment integrity. Proper design verification, filtering, and testing are necessary to ensure safe and reliable operation.

SELECT CONTROL MEASURES

- Install appropriate DC-side filtering to reduce electrical disturbances and voltage stress.
- Limit cable lengths between the PCS and magnet to minimize adverse electrical effects.
- Verify that PCS switching frequencies do not coincide with magnet or system resonance frequencies.
- Demonstrate compliance with Total Harmonic Distortion (THD), Electromagnetic Compatibility (EMC), and insulation coordination requirements.
- Establish voltage and transient control measures to protect insulation systems from excessive electrical stress.

COMPLETION RECOMMENDATIONS

- Perform a detailed PCS-magnet interaction study covering cable lengths, RLC filter requirements, switching frequencies, resonance effects, and peak voltage levels.
- Define and document acceptable limits for THD, EMC performance, insulation coordination, and voltage transients.

- Validate the design through simulation, testing, and engineering review before commissioning.
- Include acceptance criteria and verification results in Factory Acceptance Tests (FAT) and Site Acceptance Tests (SAT).
- Maintain records of compliance and testing results as part of the project quality and commissioning documentation.

7.3.8. CAUSE: START-UP / SHUTDOWN / STANDBY PROCEDURE

ACTUAL RISK TREATMENT

Hazard Category: Technology node

Consequences: Unexpected warm-up, low SOC/current, failed ramp, magnet quench or inability to deliver requested power.

Actual safeguards.

- Recommendations:
 - Define start/stop permissive: vacuum, temperature, helium flow/pressure, PCS readiness, dump circuit available.
 - Provide operator checklist and automatic sequencing.
- Actions
 - Draft operating modes and interlock matrix.
 - Train vessel/operator team before sea trial.

Risk Evaluation: Moderate risk in people and assets.

Conclusion

Inadequate operational readiness or incorrect sequencing of system startup and shutdown can present a moderate risk to both people and assets. Potential consequences include unexpected magnet warm-up, insufficient state of charge (SOC) or current, failed ramping operations, magnet quench events, and an inability to deliver the required power. Clearly defined operating conditions, interlocks, and automated sequencing are necessary to ensure safe and reliable system operation.

SELECT CONTROL MEASURES

- Define start-up and shutdown permissives based on critical system parameters, including vacuum level, temperature, helium flow and pressure, PCS readiness, and dump circuit availability.
- Implement automatic startup and shutdown sequencing to minimize operator error and ensure correct operating order.
- Establish interlocks that prevent operation when critical conditions are not met.
- Provide comprehensive operator checklists for normal operation, startup, shutdown, and abnormal conditions.
- Monitor key operating parameters continuously and generate alarms for out-of-limit conditions.

COMPLETION RECOMMENDATIONS

- Develop and document operating modes, startup/shutdown procedures, and system permissives.
- Prepare a detailed interlock matrix defining all operational dependencies and trip conditions.
- Verify sequencing logic and interlock functionality during commissioning and testing activities.
- Include operating limits, permissives, and acceptance criteria in FAT and SAT documentation.
- Train vessel personnel and operators on system operation, emergency response, and abnormal condition management before sea trials and operational deployment.

7.3.9. CAUSE: CRYOGENIC CONTACT / COLD SURFACE EXPOSURE

ACTUAL RISK TREATMENT

Hazard Category: Technology node

Consequences: Cryogenic burns, brittle fracture of adjacent materials and oxygen condensation risk near very cold surfaces.

Actual safeguards.

- Recommendations:
 - Insulate/guard cold surfaces and restrict access during operation.
 - Provide cryogenic PPE and maintenance procedure.
 - Use suitable materials for low-temperature exposure.
- Actions
 - Identify accessible cold surfaces and label/guard them.
 - Add cryogenic safety training and permit-to-work.

Risk Evaluation: People as a moderate risk level

Conclusion

Exposure to cryogenic contact and cold surfaces presents a moderate risk to people, with potential consequences including cryogenic burns, brittle fracture of nearby materials, and oxygen condensation leading to local oxygen enrichment hazards. Effective physical protection, procedural controls, and training are required to prevent accidental contact and ensure safe handling during operation and maintenance.

SELECT CONTROL MEASURES

- Insulate and/or guard all accessible cryogenic and cold surfaces to prevent direct contact during normal operation and maintenance.
- Restrict access to areas containing exposed cold surfaces while the system is in operation.
- Provide appropriate cryogenic personal protective equipment (PPE) for maintenance activities.

- Use materials that are suitable for low-temperature exposure and resistant to brittle fracture.
- Ensure ventilation and monitoring to mitigate risks associated with oxygen condensation and enrichment near cold surfaces.

COMPLETION RECOMMENDATIONS

- Identify all accessible cold surfaces within the system and ensure they are clearly labeled and physically guarded where necessary.
- Implement cryogenic safety training for all personnel involved in operation and maintenance activities.
- Establish and enforce a permit-to-work system for activities involving exposure to cryogenic components.
- Verify that insulation and guarding measures are installed and effective through inspection and commissioning checks.

7.3.10. CAUSE: LOSS OF COOLING / QUENCH / HOT SPOT

ACTUAL RISK TREATMENT

Hazard Category: Technology node

Consequences: Rapid magnet temperature rise, loss of superconductivity, pressure increase, coil degradation and forced discharge.

Actual safeguards.

- Recommendations:
 - Implement quench detection, fast energy dump and validated dump resistor path.
 - Monitor temperatures, voltages and helium flow/pressure.
 - Define maximum current/ramp limits and thermal margins.
- Actions
 - Complete quench protection study and test plan.
 - Verify relief sizing for credible quench/helium expansion.

Risk Evaluation: High risk level in people and Extreme risk level in assets.

Conclusion

A loss of cooling, quench, or hot spot event presents a moderate risk to people, primarily due to rapid magnet temperature rise, loss of superconductivity, and resulting pressure increase within the system. Such conditions can lead to coil degradation and forced energy discharge, potentially creating hazardous operating conditions. Robust detection, protection, and pressure relief systems are essential to ensure safe energy dissipation and prevent escalation.

SELECT CONTROL MEASURES

- Implement reliable quench detection systems with fast-response capability.
- Ensure a validated fast energy dump path through appropriately rated dump resistors.
- Continuously monitor critical parameters including temperature, voltage, and helium flow/pressure.
- Define and enforce maximum current and ramp rate limits to maintain safe thermal margins.
- Incorporate protection logic to initiate controlled shutdown during abnormal thermal or electrical conditions.

COMPLETION RECOMMENDATIONS

- Complete a detailed quench protection study, including modelling of worst-case scenarios and system response.
- Develop and execute a comprehensive test plan to validate quench detection and energy discharge performance.
- Verify that pressure relief systems are correctly sized for credible quench and helium expansion cases.
- Confirm integration and functionality of all protection systems during commissioning and acceptance testing.
- Document operational limits, protection logic, and emergency response procedures in system safety documentation.

7.3.11. CAUSE: LOSS OF OPERATIONAL REDUNDANCY / UNAVAILABLE SMES SUPPORT

ACTUAL RISK TREATMENT

Hazard Category: Technology node

Consequences: Power-quality support unavailable; ship remains dependent on main generators/other ESS.

Actual safeguards.

- Recommendations:
 - Confirm SMES is not credited as emergency power.
 - Define degraded operating mode if SMES unavailable.
 - Provide UPS for controls and safe shutdown.
- Actions
 - Document system safety function allocation with vessel integrator.
 - Add UPS autonomy requirement for controls/interlocks.

Risk Evaluation: Assets as a moderate risk level

Conclusion

Loss of operational redundancy or unavailability of SMES support presents a moderate risk to assets, as it results in reduced power-quality support and increased reliance on main generators or alternative energy storage systems. While not immediately hazardous, this condition may impact system performance, stability, and operational flexibility. Clear definition of system roles, degraded operating modes, and backup power for critical controls is essential to maintain safe and controlled operation.

SELECT CONTROL MEASURES

- Confirm that SMES is not credited or relied upon as an emergency power source.

- Define a degraded operating mode for safe operation when SMES is unavailable.
- Provide uninterruptible power supply (UPS) protection for control systems and safe shutdown functions.
- Ensure critical interlocks and safety functions remain operational under all redundancy loss scenarios.
- Maintain system capability to safely transition to alternative power sources without disruption.

COMPLETION RECOMMENDATIONS

- Document full system safety function allocation in coordination with the vessel integrator.
- Define and verify UPS autonomy requirements for all critical controls and interlock systems.
- Validate degraded mode functionality through testing and operational scenarios.
- Ensure operational procedures clearly describe actions during SMES unavailability.
- Include redundancy loss cases and mitigation measures in commissioning and safety assurance documentation.

7.3.12. CAUSE: CONTROL / MONITORING / ALARM FAILURE

ACTUAL RISK TREATMENT

Hazard Category: Technology node

Consequences: Delayed response to quench, helium leak, fire, water ingress, high temperature or PCS fault.

Actual safeguards.

- Recommendations:
 - Define safety-critical alarms and independent hardwired trips where needed.
 - Monitor ODH, smoke/fire, humidity, water ingress, temperature, voltage, current, pressure and flow.
 - Provide fail-safe de-energize logic.
- Actions
 - Produce alarm/interlock cause-and-effect matrix.
 - Test alarms during FAT/SAT and integrate with ship alarm system.

Risk Evaluation: People and Assets as a high-risk level

Conclusion

A delayed or insufficient response to critical system faults such as quench events, helium leaks, fire, water ingress, overheating, or PCS faults represents a high risk to both people and assets. Such delays can escalate hazardous conditions, increasing the likelihood of equipment damage, unsafe operating states, and potential harm to personnel. Reliable detection, prioritization of safety-critical alarms, and fail-safe shutdown capability are essential to ensure rapid and appropriate system response.

SELECT CONTROL MEASURES

- Define and implement safety-critical alarms with clearly prioritized response levels.
- Use independent hardwired trip functions where necessary to ensure reliable activation during control system failure.
- Continuously monitor key safety parameters, including ODH, smoke/fire detection, humidity, water ingress, temperature, voltage, current, pressure, and flow.
- Implement fail-safe de-energization logic to ensure safe system shutdown under fault conditions.
- Integrate alarm and protection systems with vessel-wide alarm and safety systems for coordinated response.

COMPLETION RECOMMENDATIONS

- Develop a comprehensive alarm and interlock cause-and-effect matrix covering all credible fault conditions.
- Validate alarm functionality, response timing, and interlock performance during Factory Acceptance Testing (FAT) and Site Acceptance Testing (SAT).
- Ensure full integration of safety alarms with the ship's overall alarm and monitoring system.
- Confirm that all critical alarms and trips operate correctly under simulated failure conditions.
- Document alarm hierarchy, response actions, and safety logic in operational and safety assurance documentation.

7.3.13. CAUSE: AUXILIARY POWER / UPS LOSS

ACTUAL RISK TREATMENT

Hazard Category: System

Consequences: Loss of controls, valves, monitoring, ventilation or safe shutdown capability.

Actual safeguards.

- Recommendations:
 - Provide UPS-backed controls, monitoring, valves and communication long enough for safe shutdown.
 - Define behaviour on blackout and restart.
- Actions
 - Size UPS autonomy and loads.
 - Test blackout sequence and automatic safe state.

Risk Evaluation: Assets as a moderate level

Conclusion

A loss of electrical power or control system functionality presents a moderate risk to assets, as it may result in loss of control over valves, monitoring systems, ventilation, and safe shutdown capability. Although immediate danger may be limited, prolonged or poorly managed outages can compromise system safety, equipment integrity, and recovery capability. Ensuring reliable backup power and defined blackout behaviour is essential for maintaining a controlled and safe system state.

SELECT CONTROL MEASURES

- Provide UPS-backed power supply for critical controls, monitoring systems, valves, and communication equipment to support safe shutdown operations.
- Ensure UPS autonomy is sufficient to maintain all essential functions until the system reaches a safe state.
- Define and implement clear system behaviour during blackout conditions and subsequent restart.
- Ensure automatic transition to a predefined safe state in the event of total power loss.
- Protect critical shutdown and safety functions from loss of power under all credible scenarios.

COMPLETION RECOMMENDATIONS

- Size UPS capacity and autonomy based on full critical load analysis, including control, monitoring, and shutdown systems.
- Identify and document all critical loads requiring uninterrupted power supply.
- Test blackout response sequences, including automatic safe-state activation and recovery procedures.
- Validate system restarts behaviour to ensure controlled and safe re-energization.
- Include blackout scenarios, UPS performance requirements, and recovery procedures in operational and commissioning documentation.

7.3.14. CAUSE: SHIP GRID CONNECTION / GROUNDING / ISOLATION MISMATCH

ACTUAL RISK TREATMENT

Hazard Category: System

Consequences: Unsafe electrical interface, earth fault, circulating currents, THD exceedance or failed connection to vessel grid.

Actual safeguards.

- Recommendations:
 - Agree point of common coupling, earthing, protection and isolation.
 - Validate voltage range, short-circuit contribution, THD/EMC and emergency isolation.
- Actions
 - Hold electrical interface review with integrator/class.
 - Produce single-line diagram and protection settings.

Risk Evaluation: People and assets as a moderate level

Conclusion

An unsafe or poorly defined electrical interface with the vessel grid presents a moderate risk to both people and assets, potentially leading to earth faults, circulating currents, excessive harmonic distortion (THD), failed grid connection, and unsafe operating conditions. Without proper coordination of protection, earthing, and power quality requirements, the system may experience instability and equipment stress. Clear interface definition and verified protection coordination are essential for safe integration.

SELECT CONTROL MEASURES

- Define and agree the Point of Common Coupling (PCC), including earthing strategy, protection coordination, and isolation philosophy.
- Validate system compatibility with vessel electrical conditions, including voltage range, short-circuit contribution, THD limits, and EMC requirements.
- Implement coordinated protection settings to ensure selective fault clearance and system stability.
- Ensure emergency isolation capability is defined and functionally verified.
- Conduct power quality assessment to confirm compliance with vessel and class requirements.

COMPLETION RECOMMENDATIONS

- Hold a formal electrical interface review with the system integrator and classification authority.
- Develop and approve a complete single-line diagram including all protection devices and interface boundaries.
- Define, document, and validate all protection settings prior to commissioning.
- Perform verification tests for grid connection, fault response, and power quality compliance.
- Include interface agreements, protection coordination studies, and test results in final system documentation.

7.3.15. CAUSE: INTERNAL FIRE IN SMES CONTAINER

ACTUAL RISK TREATMENT

Hazard Category: System

Consequences: Fire damages PCS, controls, cables, insulation or cryogenic systems; smoke release and possible loss of safe discharge.

Actual safeguards.

- Recommendations:
 - Install smoke/heat detection and suitable extinguishing system for electrical/cryogenic equipment.
 - Ensure emergency stop and discharge are coordinated with fire system.
 - Keep fire load low.
- Actions
 - Select extinguishing medium compatible with energized HV and cryogenic equipment.
 - Add fire alarm to ship interface.

Risk Evaluation: People and Assets as a high-risk level

Conclusion

A fire affecting PCS, control systems, cables, insulation, or cryogenic equipment represents a high risk to both people and assets, with potential consequences including equipment destruction, smoke release, and loss of safe discharge capability. Due to the combined electrical and cryogenic nature of the system, rapid detection and coordinated suppression and shutdown actions are essential to prevent escalation and ensure personnel safety.

SELECT CONTROL MEASURES

- Install appropriate smoke and heat detection systems covering electrical and cryogenic equipment areas.
- Provide a suitable fire suppression system compatible with energized high-voltage equipment and cryogenic installations.
- Ensure coordinated operation between emergency stop functions, energy discharge systems, and fire detection systems.
- Minimize fire load through careful material selection and cable management.
- Maintain clear segregation of critical systems to limit fire propagation.

COMPLETION RECOMMENDATIONS

- Select and validate a fire suppression medium suitable for HV electrical and cryogenic environments.
- Integrate fire detection and alarm signals with the ship's safety and alarm system.
- Verify coordinated response between fire detection, emergency shutdown, and energy discharge during system testing.
- Conduct fire safety review and approval with relevant stakeholders and classification authorities.
- Document fire protection strategy, system interfaces, and response procedures in operational safety documentation.

7.3.16. CAUSE: EXTERNAL GARAGE FIRE / A-60 BOUNDARY EXPOSURE

ACTUAL RISK TREATMENT

Hazard Category: System

Consequences: External fire heats container causes loss of cooling, pressure rise, insulation damage or forced shutdown.

Actual safeguards.

- Recommendations:
 - Confirm fire rating / A-60 boundary requirement with class.
 - Define external fire response: isolate, discharge, stop PCS, maintain/vent pressure safely.
- Actions
 - Confirm container fire insulation rating.
 - Add emergency response procedure for garage fire.

Risk Evaluation: Moderate risk level in people and high risk level in assets

Conclusion

An external garage fire exposing the container boundary presents a high risk to both people and assets, as thermal loading may lead to loss of cooling, internal pressure rise, insulation damage, and forced system shutdown. If not properly contained, such an event can escalate into equipment failure and compromise safety systems. Ensuring adequate fire-rated separation and a coordinated emergency response strategy is essential to maintain containment and controlled shutdown.

SELECT CONTROL MEASURES

- Confirm that the container boundary meets the required fire rating (e.g., A-60) in accordance with classification requirements.
- Ensure the structure provides sufficient thermal protection to prevent heat transfer into critical systems.
- Define a clear external fire response strategy, including system isolation, controlled energy discharge, PCS shutdown, and safe pressure management.
- Ensure pressure relief and ventilation paths remain functional under fire exposure conditions.
- Coordinate system responses with shipboard fire detection and suppression systems.

COMPLETION RECOMMENDATIONS

- Verify and document the container fire resistance rating and compliance with class requirements.
- Confirm structural fire protection performance through design validation and certification evidence.
- Develop and implement an emergency response procedure specifically for external garage fire scenarios.
- Integrate fire scenario response actions (isolation, shutdown, discharge) into operational safety procedures.

7.3.17. CAUSE: MAINTENANCE / INSPECTION NOT PERFORMED

ACTUAL RISK TREATMENT

Hazard Category: System

Consequences: Degradation of vacuum, cryogenic seals, relief devices, insulation resistance, filters or sensors leading to failure.

Actual safeguards.

- Recommendations:
 - Prepare preventive maintenance plan and spares list.
 - Include vacuum/pressure relief, helium leak, insulation resistance, sensor calibration and filter checks.
- Actions
 - Add maintenance manual action with intervals and responsible owner.
 - Track open safety-critical maintenance items.

Risk Evaluation: Assets as a moderate level

Conclusion

Failure to perform scheduled maintenance and inspections presents a moderate risk to assets, as it can lead to gradual degradation of critical systems such as vacuum integrity, cryogenic seals, pressure relief devices, insulation resistance, sensors, and filters. Over time, this degradation may result in equipment malfunction or failure, reducing system reliability and increasing the likelihood of operational interruptions. A structured preventive maintenance regime is essential to preserve system integrity and ensure long-term safe operation.

SELECT CONTROL MEASURES

- Establish a preventive maintenance plan covering all critical systems, including vacuum, cryogenic, electrical, and instrumentation components.
- Maintain an approved spares list to ensure timely replacement of critical components.
- Include routine checks for vacuum integrity, pressure relief devices, helium leaks, insulation resistance, sensor calibration, and filter condition.
- Assign clear ownership for maintenance tasks and ensure accountability for completion.
- Track and manage all safety-critical maintenance items to ensure timely closure.

COMPLETION RECOMMENDATIONS

- Integrate maintenance actions, inspection intervals, and responsibilities into the system maintenance manual.
- Implement a formal tracking system for open and overdue safety-critical maintenance tasks.
- Define inspection and servicing intervals based on manufacturer recommendations and operational experience.
- Ensure preventive maintenance procedures are validated and approved prior to commissioning.
- Conduct periodic audits to verify compliance with maintenance schedules and system condition requirements.

7.3.18. CAUSE: PRESSURE RELIEF / VENTING FAILURE

ACTUAL RISK TREATMENT

Hazard Category: System

Consequences: Container or cryostat overpressure from helium expansion or quench discharge; projectile or structural damage.

Actual safeguards.

- Recommendations:
 - Size relief valves/rupture discs and vent routing for worst credible helium release/quench/fire case.
 - Keep vent outlets clear and away from personnel/intakes.
 - Add pressure monitoring and inspection.
- Actions
 - Complete relief sizing calculation and vent dispersion check.
 - Add periodic relief device inspection to maintenance plan.

Risk Evaluation: People and Assets as a moderate level

Conclusion

Failure or inadequacy of pressure relief and venting systems presents a moderate risk to both people and assets, primarily due to the potential for container or cryostat overpressure caused by helium expansion, quench events, or fire scenarios. Such conditions can lead to structural damage, projectile hazards, and loss of containment integrity. Properly designed, sized, and maintained pressure relief systems are essential to ensure controlled release and prevent hazardous overpressure conditions.

SELECT CONTROL MEASURES

- Size pressure relief valves and rupture discs based on worst credible scenarios, including helium release, quench, and fire cases.
- Design and verify vent routing to ensure safe discharge away from personnel areas, air intakes, and sensitive equipment.
- Maintain vent outlets free from obstruction at all times.
- Implement continuous or periodic pressure monitoring of critical system volumes.
- Include pressure relief devices within routine inspection and maintenance programs.

COMPLETION RECOMMENDATIONS

- Complete detailed relief sizing calculations and validate vent capacity for all credible operating and fault scenarios.
- Perform vent dispersion and exhaust path analysis to confirm safe release locations and conditions.

- Incorporate pressure relief devices into the preventive maintenance schedule, including inspection and replacement intervals.
- Verify installation and accessibility of relief systems during commissioning and system audits.
- Document venting philosophy, design basis, and inspection requirements in system safety and operational manuals.