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AENEAS

innovAtive ENErgy storage systems onboArd vesselS

Deliverable D1.3: Checklists for operational safety for the selected broad range of vessel types

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Project Abstract

AENEAS aims to advance climate-neutral and environmentally friendly water transport through the development of three innovative clean energy storage solutions. These next-generation solutions, namely Solid-State Battery (SSB), SuperCapacitor (SC), and a Hybrid system combining SSB and SC, go beyond the traditional battery systems.

Their primary goal is to enable (partial or full) electric shipping, accommodating various ship types and challenging conditions, including adverse weather and in-land waterways. Eventual impact is an increase of the global competitiveness of the EU waterborne transport sector by European technology leadership for energy storage solutions for diverse waterborne applications.

AENEAS will evaluate these solutions for a range of applications in short-sea shipping and in-land waterways, enhancing their global competitiveness. Simultaneously, AENEAS will define the pathway for Energy Storage Solutions (ESSs) in different ship types, ensuring a comprehensive understanding of their applicability and potential impact on diverse waterborne transport.

Public Summary

This document is part of **Work Package 1**, **Operational scenario Specification and Requirements**, whose main objective is to draw and define the main vessels characteristics that are currently electrified by using batteries and those one that will be electrified in the near future and that are suitable for the application of new ESS systems.

The scope of this document is to define the checklist for operational safety for the selected broad range of vessel types. The checklist will pave the way for the task 6.1 in which there will be a safety assessement based on the cagetories defined within this deliverable (for further details, please refer to section 2.2).

This deliverable provides a detailed description of how the checklist has been developed. In particular, the bulding process of the checklist started from the safety requirements included within the AENEAS D1.1. Then, the safety experts defined the “steps” for the development of the checklist. Finally, after the definition of categories addressing the safety requirements, the checklist has been developed.

1 Introduction

1.1 Rational of this deliverable

The objective of this deliverable is to draw a checklist for operational safety for the selected broad range of vessel types.

An operational safety checklist is a tool used to ensure the safe and efficient operation of equipment, machinery, or systems. It typically includes a set of guidelines or procedures that should be followed before, during, and after operation. These checklists can help identify potential hazards, ensure proper maintenance, and prevent accidents or injuries.

This deliverable is part of Work Package 1 (WP1), which focuses on defining checklist for operational safety for the selected broad range of vessel types. The document is structured as follows:

- Section 1: Introduction
- Section 2: Checklist methodology
- Section 3: Safety requirements
- Section 4: Operational Safety Checklist
- Section 5: Conclusions

Contributions to this deliverable come from beneficiaries and other sources, including insights from previous deliverables such as T1.1 (which provides safety requirements and operational profiles of the selected broad range of ships). Collaborative input is sought from GRI operators representing the ship operator perspective and FV and SOERMAR, who offer insights from the ports point of view.

The primary outcomes of this deliverable is the definition of the operational safety checklist for the implementation of the ESSs on board the ships. This work will then be of fundamental importance in the execution of thel Task 6.1 Life cycle, cost, environmental and safety impact analysis in which a safety assessment will be performed based on the checklist for operational safety developed here.

2 Checklist methodology

During the definition/design of a novel technology/system, it is fundamental to take into consideration all the possible variables that a designer could face during the whole definition process. This is particularly true when the topic is based on safety critical environment (such as the maritime domain) in which there are health and economical aspects that cannot be neglected.

However, as already mentioned, the AENEAS project main goal is to investigate the development of Energy Storage Systems (ESSs). Indeed, hybrid and full electric ships with ESSs will contribute to reducing the emissions and fuel consumption. Implementation of ESSs will also result in reduced maintenance, better operational performances and will improve the safety of the ship [1]. The ESSs implementation represent a very important and critical topic. Indeed, the battery market is growing and growing year per year due to innovations, market request, rules, policy makers, etc. hence there are several types and sizes of batteries and systems. Safety has to be investigated assessed during the implementation phase of the ESSs on board the ships. According to the [2] concerns seem to increase when batteries are stored in one location. Faulty batteries and short circuits may cause fire that can turn into serious danger. As already mentioned in AENEAS D1.1 [3] battery safety concerns are several and can include Internal Short Circuit (ISC), External Short Circuit (ESC), overcharge, discharge and thermal runway [4].

In this perspective, detecting battery safety issues is essential to ensure safe and reliable operations. Hence, it is necessary to establish an assessment tool that has a double role: (i) advanced organizer and (ii) reminder of a key aspects to be considered. This document is intended to define an ad-hoc operational safety checklist taking into consideration the broad range of vessel types considered in AENEAS deliverable 1.1 and including several safety aspects (i.e. Components and alarms; Emergency; Module designs with safety features; System safety solutions; Crew training; Conditions for implementation; End of implementation; Maintenance;). For the development of a checklist, it is imperative to accurately describe the scope of the checklist to effectively comprehend the components to be implemented and to identify the risks that the safety checklist aims to mitigate. This ensures that the checklist is comprehensive, precise, and comprehensible to end-users. There are no operational safety checklists based on the implementation of the ESSs. In this prospective, this document will pave the baseline in this field.

Following an initial documentation phase, which in the AENEAS project is detailed in D1.1 where the ESSs and Safety requirements were described, the following steps should be taken for the development of a checklist. The definition of the operational safety checklist has to follow predetermined steps during the building phase [5] [6]:

1. Identification of the categories to be included in the checklist;
2. Organizing the structure of the checklist;
3. Listing the individual checklist items;
4. Reviewing by the experts;
5. Testing the checklist to validate its effectiveness and identify any necessary improvements;
6. Continuous updating to ensure the checklist remains current and relevant.

By following this process, a checklist can be developed that is thorough, accurate, and tailored to the needs of its users, ultimately contributing to the mitigation of identified risks and the enhancement of safety.

2.1 Checklist steps description

2.1.1 Category identification

Category identification is intended to describe the safety aspects that the checklist should cover. In this document, the categories that will be covered are:

- Choices of materials;
- Components and alarms;
- Emergency;
- Module designs with safety features;
- System safety solutions;
- Crew training;
- Conditions for implementation;
- End of implementation;
- Maintenance;

2.1.2 Checklist structure

Once the relevant categories for the items have been selected, it is necessary to organize the structure of the checklist by dividing it into categories, thus considering separately each specific aspect of the process to be analysed in order to make it more intuitive and user-friendly to read, create, and search through, allowing anyone who refers to it to quickly find the information they need.

2.1.3 Individual checklist items

Once prepared the structure of the table and are clear about the risks associated with the scope of the checklist, its compilation can be undertaken by taking into account several key characteristics that the points must meet in order to create an effective checklist. In particular, each item on the checklist should be accompanied by clear and concise instructions to facilitate the understanding of the task to be performed.

To achieve this, it will be used action verbs that explicitly indicate what needs to be done for each task. Additionally, specificity can be ensured in the instructions, providing additional details, images, or specifications when necessary. Clear and concise instructions leave no room for ambiguity or misinterpretation, ensuring that tasks are completed accurately and in a timely manner. Before finalizing a checklist, it is essential to review and refine it taking the right time to go through each item and ensure its accuracy and relevance.

2.1.4 Expert review and test

To define an operational safety checklist, an iterative process involving experts, end users and stakeholders is necessary. Hence, it is crucial gather feedback from the people involved within the assessment who might have valuable insights or suggestions for improvement as to identify any missing tasks or confusing instructions. Once the checklist has been refined based on feedback, it is important to validate and test it. The validation phase can be carried out through a simulated assessment with the intended users of the checklist to ensure alignment with their needs and expectations. To this end, a dedicated team comprised of safety experts,

shipowners, and ESS specialists will evaluate the checklist to ensure its strict adherence to the requirements and expectations established for the designated use cases.

2.1.5 Periodic review

To ensure the effective utilization of the checklist, it is essential to guarantee that all pertinent actors involved are informed of the checklist existence and are knowledgeable about its access and usage. Proper training should be provided to end-users to ensure proficient usage. A periodic review strategy, which considers new risks and feedback with the objective of continuous safety improvement, can ensure the accuracy and dissemination of the checklist. This approach enables the identification and mitigation of potential hazards, thereby enhancing the overall safety and efficiency of the process.

2.2 Categories definition

This Checklist lays down functional requirements for design, construction, installation, operation, including maintenance, of ESSs on board ships as source of power, ensuring the safety of the crew, passengers and the ship.

The structure used for the development of the checklist provides for the division of the checklist into different categories to ensure greater clarity of use. Each category concentrates on a singular, well-defined aspect that must be given due consideration. These categories are designed to be followed in a specific, linear order to ensure a comprehensive and sequential evaluation. The identification of these crucial aspects was driven by the paramount need to satisfy all necessary safety requirements. By adhering to this structured approach, the checklist aims to facilitate a safe and efficient implementation process. Here below are provided details for each category identified:

2.2.1 Choices of materials

The **Choices of materials** category outline the characteristics that the materials used for the ESS must meet to enable the safe implementation of the system under the high energy and power requirements, while also considering the environment in which this implementation takes place. The purpose of this category is to verify that the materials used in the implementation of the ESS are suitable for prolonged use in a marine environment.

2.2.2 Components and Alarms

The **Components and Alarms** category outlines the set of sensors and alarms required to verify the proper operation of the ESS and to signal any malfunction, abnormal operation, or safety hazard. The purpose of this category is to verify the presence of the necessary instrumentation to identify hazardous situations and the functionality of alarms capable of alerting the crew and signaling the issue to ensure an effective incident response1.

2.2.3 Emergency

The **Emergency** category outlines the emergency procedures that the ESS must be capable of autonomously adopting for managing abnormal cell operation or anomalous conditions within the ESS compartment. The purpose of this category is to verify the ESS's capability to autonomously respond to anomalous situations in order to prevent hazardous events.

[1] The operational environment should be carefully considered. As a consequence, the employed alarms have to adhere to the specifications outlined in International Maritime Organization (IMO) Resolution A.830. This resolution establishes the mandatory audible alarm sound pressure levels and frequencies. [8]

2.2.4 Module designs with safety features

The **Module designs with safety features** category details the specific safety features implemented in the module to mitigate the identified hazards. These safety features encompass protective devices, module insulation, and fail-safe mechanisms. The purpose of this category is to verify that:

- Access for safety inspections and maintenance procedures is considered during the design phase.
- Adequate redundancy of modules is implemented to ensure continued operation even in the event of module failures.
- Fail-safe mechanisms are incorporated to guarantee that the module remains in a safe state even in case of component failures or unexpected events.

2.2.5 System safety solutions

The **System safety solutions** category outlines all the solutions adopted for safety incident prevention, mitigation, and fire suppression, indicating also the relationship between the ESS and the ESS compartment. The purpose of this category is to verify that the designated ESS area meets specific safety requirements.

2.2.6 Crew Training

The **Crew Training** category outlines the training aspects required for the safe installation of the ESS and the management of both normal and abnormal conditions when working with ESS. The purpose of this category is to ensure that the procedures for the implementation, operation, and maintenance of the ESS are clearly defined onboard and that all crew members have received the necessary training.

2.2.7 Conditions for implementation

The **Conditions for implementation** category outline the working conditions and the presence of the necessary authorizations. The purposes of this category are:

- Verify the existence of ergonomic and safe working conditions to minimize potential hazards and ensure the well-being of personnel during the operation.
- Confirm the presence of the necessary crew members with the requisite skills and experience to safely execute the operation.
- Ensure that all relevant members of the chain of command are adequately informed about the procedures to be followed and the safety protocols in place.

2.2.8 End of Implementation

The **End of Implementation** category outlines the procedures to be followed for safe completion of the activities. The purpose of this category is to verify the proper functioning of the ESS, to ensure its safe operation and to confirm the resumption of normal shipboard operations.

2.2.9 Maintenance

The **Maintenance** category outlines the procedures required to conduct routine maintenance in a safe manner. The purpose of this category is therefore to verify the existence of ergonomic and safe working conditions, confirm the presence of the necessary crew to carry out the operation safely, ensure that all relevant chain of command is adequately informed about the operations, check for any damages, wear and tear, or compromises to the previously listed characteristics, and confirm the correct resumption of normal onboard activities.

3 Safety Requirements

To develop a comprehensive checklist, it is imperative to consider the risks that need to be mitigated. In this context, the efforts outlined in D1.1, involving the creation of a Preliminary Risk Assessment (PRA), hold significant importance as they have resulted in the identification of various safety requirements. The identified risks and established requirements should be carefully considered when selecting the components to be incorporated into the checklist. This selection process should encompass choices related to materials, components, inherent safety attributes of cells, module designs featuring safety elements, and system solutions aimed at preventing safety incidents, mitigating risks, and implementing fire suppression measures. In this perspective, here below (Table 1) shown the safety requirements for the ESSs integration on board the ships defined within the D1.1 and based on the study conducted by European Maritime Safety Agency [7].

Table 1 - Safety requirements for the ESS integration

Requirement ID	Requirement text
REQ-AENEAS-D11-001	The ESS shall be installed in a well designed module well separated from other modules and easily accessible for the human
REQ-AENEAS-D11-002	The ESS shall be installed in a proper module well separated from external heat sources
REQ-AENEAS-D11-003	The ESS shall be able to be automatically shutted down in case of thermal ruanaway and/or any other contigency situation that requires an emergency shutdown
REQ-AENEAS-D11-004	The ESS shall contain IoT sensors for temperature monitoring in case of thermal runaway
REQ-AENEAS-D11-005	The ESS module shall contain an alarm in case of high temperature coming from inside/outside the ESS module
REQ-AENEAS-D11-006	The ESS alarm shall be understable with different sound and clearly visible to the crew
REQ-AENEAS-D11-007	The ESS module shall contain a cooling system in case of high temperature coming from inside/outside the ESS module
REQ-AENEAS-D11-008	The ESS module shall contain a fire extinguishing system in order to prevent a cascade effect in case of fire
REQ-AENEAS-D11-009	The ESS shall contain IoT sensors for gas detection in case of gas development
REQ-AENEAS-D11-010	The ESS shall be installed in a compartment in which the ventilation system is installed for heat/gas dissipation in case of fire/gas development
REQ-AENEAS-D11-011	The ESS shall be able to be automatically shutted down in case of battery overcharge
REQ-AENEAS-D11-012	The ESS shall have a redundand battery system in case the batteries are undercharged
REQ-AENEAS-D11-013	The ESS shall be able to automatically exclude the defective cell

REQ-AENEAS-D11-014	The ESS shall be able to automatically reduce the voltage in case of defective cell
REQ-AENEAS-D11-015	An alarm shall be activated in case of defective cell
REQ-AENEAS-D11-016	The ESS shall be able to be automatically shutted down in case of water coming from other compartment
REQ-AENEAS-D11-017	An alarm shall be installed within the ESS module for the entrance of water within the batteries compartment
REQ-AENEAS-D11-018	The ESS system shall be installed with a reduntant battery system in case of cell failure
REQ-AENEAS-D11-019	The ESS system shall be installed in areas where collision probability is low
REQ-AENEAS-D11-020	All the crew shall be well trained about ESS system
REQ-AENEAS-D11-021	All the crew shall be well trained about the procedure to follow for the integration of ESS system
REQ-AENEAS-D11-022	A safety check list shall be available for the installation of ESS on board ships
REQ-AENEAS-D11-023	All the crew shall know the procedure to be followed in both normal and abnormal conditions when working with ESS systems

4 Operational Safety Checklist

In this section, an operational safety checklist for the implementation of ESSs on board ships considered within the AENEAS project will be outlined. The checklists will be drawn up in accordance with what is indicated in section 2 and will be subject to periodic review to ensure its effectiveness.

4.1 ESS Operational Safety Checklist

Table 2 - ESS Operational Safety Checklist

ESS Operational Safety Checklist			
Procedure start date:		**Starting time:**	
Procedure end date:		**Ending time:**	
Ship's Name:			
Operator/Agent:			
Master:			
Engineer on watch:			
Category	**ID**	**Description**	**Check**
Choices of materials	1.1	The ESS is build taking into consideration fireproof materials	☐
	1.2	The materials are resistant to high temperature	☐
	1.3	The materials used take in consideration the humidity of the marine environment	☐
	1.4	The materials used have good resistance to corrosion caused by marine environment	☐
	1.5	Materials are chemically stable and not pose any fire or explosion hazards during operations	☐
	1.6	The materials have reliable charging and discharging ability without yelding large temperature differences	☐
	1.7	The materials are phisically stable under forces	☐
	1.8	The materials has high fraccture toughness and high compressive strenght	☐
Components and alarms	2.1	The ESS and the ESS compartment contain IoT sensors for temperature monitoring in case of thermal runaway	☐
	2.2	The ESS and the ESS compartment contain IoT sensors for gas detection in case of gas development	☐
	2.3	The ESS alarm is in place and understable with different sound and clearly visible to the crew	☐

	2.4	An alarm is working in case of defective cell	☐
	2.5	The ESS module contains an alarm in case of high temperature coming from outside the ESS module	☐
	2.6	The alarm is working in case of thermal runaway	☐
	2.7	The defective module can be identified by a control panel	☐
	2.8	The ESS alarms are visible on the bridge	☐
	2.9	The alarm is in place within the ESS module for the entrance of water within the batteries compartment	☐
Emergency	3.1	The ESS is able to be automatically shutted down in case of thermal ruanaway	☐
	3.2	The ESS is able to be automatically shutted down in case of battery overcharge	☐
	3.3	The ESS is able to be automatically shutted down in case of battery overdischarge	☐
	3.4	The ESS is able to automatically exclude the defective cell	☐
	3.5	The ESS is able to automatically reduce the voltage in case of defective cell	☐
	3.6	The ESS is able to be automatically shutted down in case of water coming from other compartment	☐
	3.7	The ESS is able to be automatically shutted down in case of gas detection	☐
	3.8	The ESS is able to be automatically shutted down in case of contigency situation	☐
	3.9	The ESS is able to be automatically shutted down in case of Converter, Power Management System (PMS), Battery Management System (BMS) or Energy Management System (EMS) failure	☐
Module designs with safety features	4.1	The ESS module is well separated from other modules and easily accessible	☐
	4.2	The ESS module contains a fire extinguishing system in order to prevent a cascade effect in case of fire	☐
	4.3	The ESS has a redundand battery system in case the batteries are undercharged	☐
	4.4	The ESS is installed with a reduntant battery system in case of cell failure	☐

	4.5	The ESS module is mechanically secured to the ship's structure to withstand seagoing conditions	☐
System safety solutions	5.1	The ESS is installed in a proper module well separated from external heat sources	☐
	5.2	The ESS module contains a cooling system	☐
	5.3	The ESS is in a compartment in which the ventilation system is installed for heat/gas dissipation in case of fire/gas development	☐
	5.4	The ESS is in an areas where collision probability is low	☐
	5.5	The ESS compartment is properly illuminated	☐
	5.6	The ESS compartment has sufficient clearance for maintenance	☐
	5.7	The ESS compartment has A60/A0 insulation to adjacent rooms	☐
	5.8	ESSs are located in spaces where they pose minimum risk of harm to crew and passengers in case of battery gassing, fire and/or explosion.	☐
	5.9	Portable fire extinguishers is located outside the room or space(s) at or near the entrance(s).	☐
Crew Training	6.1	The procedures to follow for the implementation are contained in the Safety Management System	☐
	6.2	The procedures to follow in case of emergency are contained in the Safety Management System	☐
	6.3	All the crew received an ah-doc trainining about ESS system	☐
	6.4	All the crew is aware of the procedures to be followed in both normal and abnormal conditions when working with ESS systems	☐
Conditions for implementation	7.1	The captain is aware of and has approved the implementation	☐
	7.2	The engineer on watch is present and ready	☐
	7.3	All the necessary crew is present following the summons issued by the engineer on watch	☐
	7.4	The ESS is disconnected from vessel's EMS	☐
	7.5	The work area is properly illuminated and ventilated	☐
	7.6	Personal protective equiptments are in place	☐
End of implementation	8.1	Tests on the system do not detect any anomalies	☐

	8.2	The ESS is properly isolated from any corrosive or cell-damaging agents	☐
	8.3	Functional tests on fire detector, fire extinction and ventilations are conducted	☐
	8.4	Tests of battery (charge/discharge) and electric power convertor are conducted	☐
	8.5	Tests of the proper functioning of the Interface between ESS and EMS and the interface between PMS and EMS are conducted	☐
	8.6	Test on emergency shutdown device is conducted	☐
	8.7	Test on Overcharge and overvoltage protection devices is conducted	☐
	8.8	A verification of the proper functioning of the fire prevention systems is conducted	☐
	8.9	The engineer officer deems it appropriate for the crew to return to their on-board activities	☐
	8.10	The ESS is reconnected to vessel's Energy Management System	☐
	8.11	The captain is informed of the end of the end of integration operations	☐
Maintenance	9.1	The captain is informed of maintenance	☐
	9.2	The engineer on watch is present and ready	☐
	9.3	The ESS is disconnected from vessel's Energy Management System	☐
	9.4	A visual inspection of the ESS is conducted	☐
	9.5	A visual inspection of ESS compartment and its openings is conducted	☐
	9.6	Functional tests on fire detector, fire extinction and ventilations are conducted	☐
	9.7	Tests of battery (charge/discharge) and electric power convertor are conducted	☐
	9.8	Tests of the proper functioning of the Interface between ESS and EMS and the interface between PMS and EMS are conducted	☐
	9.9	Test on emergency shutdown device is conducted	☐
	9.10	Test on Overcharge and overvoltage protection devices is conducted	☐
	9.11	A verification of the proper functioning of the fire prevention systems is conducted	☐
	9.12	A battery capacity and wear test is conducted	☐

	9.13	The tests results are reported to Chief Engineer	☐
	9.14	The ESS is connected back to the ship's energy management system	☐

5 Conclusions

The deliverable has defined a checklist for operational safety for the selected broad range of vessel types for the design, construction, installation, and operation of Energy Storage Systems (ESS) on board ships as a power source, ensuring the safety of the crew, passengers, and the ship.

The checklist has been divided into nine categories focusing on different aspects to be considered and has been compiled to be followed sequentially during on-board operations.

The checklist has therefore met the safety requirements indicated in D1.1 by addressing threats of fire, corrosion, wear, gas, and impact, defining the procedures and skills necessary to carry out operations safely.

This deliverable has provided an easy-to-use operational safety checklist for onboard operators in the implementation of the ESS identified by the project. It will subsequently be employed in Task 6.1, Life Cycle, Cost, Environmental and Safety Impact Analysis, where a safety assessment will be conducted based on the aforementioned operational safety checklist.

6 References

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3	ABEE	AVESTA BATTERY & ENERGY ENGINEERING
4	SIE	SIEMENS INDUSTRY SOFTWARE SAS
5	UVA	VAASAN YLIOPISTO
6	I2M	I2M UNTERNEHMENSENTWICKLUNG GMBH
7	GRIM	GRIMALDI EUROMED SPA
8	INLS	INLAND SHIPPING SRL
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Abbreviations and Definitions

Term	Definition
BMS	Battery Management System
EMS	Energy Management System
EMSA	European Maritime Safety Agency
ESC	External Short Circuit
ESS	Energy Storage System
IoT	Internet of Things
ISC	Internal Short Circuit
PMS	Power Management System
PRA	Preliminary Risk Assessment
SC	Supercapacitor
SSB	Solid-State Battery

List of Tables