NREL

Managing Marine Energy Risks for Project Success

David Snowberg
National Renewable Energy Laboratory

August 12–14, 2025

This presentation was produced when the laboratory operated as the National Renewable Energy Laboratory (NREL). The laboratory is now the National Laboratory of the Rockies (NLR).

Note: referenced IEC standards reproduced with IEC permission and are available for purchase at https://webstore.iec.ch/

Photo from iStock-627281636

Marine Energy Risk Management Workshop

Marine Energy Risk Management Workshop

Marine Energy Risk Management

Presentation based on NREL's Marine Energy Risk Framework published in 2024, which replaced 2015 version (referenced as **NREL Marine Energy Risk Framework, 2024**):

- https://www.nrel.gov/docs/fy24osti/90212.pdf
- Or Google, "***NREL Marine Energy Risk Framework***"
- Link on cover page to risk register template and FMECA

This risk management framework shall be used on all DOE Water Power Technologies Office (WPTO) projects that require system testing in the open water.


NREL

Marine Energy Technology Development Risk Management Framework

David Snowberg, Ritu Treisa Philip, and Jochem Weber

National Renewable Energy Laboratory

Link to download Risk Register template
Link to download FMECA template

David Snowberg's Background (Engineering, Marine Expeditions, and Risk)

- 30-year professional career:
  - 15 years at NREL
  - Wind energy engineer for original equipment manufacturers before NREL
  - Renewable energy focus throughout career
- Education and credentials:
  - B.S. Mechanical Engineering, University of Colorado (CU) Boulder (1995)
  - M.E. Engineering Management, CU Boulder (2015)
  - P.E. (Mechanical, Arizona registration: 47205)
  - PMP (Certification: 1655274)

Photo by Dennis Schroeder, NREL

David Snowberg's Background (Engineering, Marine Expeditions, and Risk)

- Past experiences planning and completing several multi-month sea kayak expeditions:
  - 87 days paddling solo from Puerto Montt to Puerto Natales, Chile (2003–2004)
  - 132 days paddling from Seattle to Bering Sea (2004)
  - 51 days solo paddling from Homer to Valdez, Alaska (2006)
  - 37 days solo paddling from Fort McPherson, Canadian Northwest Territories, to Prudhoe Bay, Alaska in Arctic Ocean (2006)
- ***Managing risks in a marine environment was critical to success (and survival).***

Photo from Armada de Chile (Puerto Montt)

Photo by David Snowberg, NREL

Photo by David Snowberg, NREL

Photo by David Snowberg, NREL

David Snowberg's Background (Engineering, Marine Expeditions, and Risk)

Risk management is the process to manage uncertainty in *any* situation.

Questions	Process Step
What is uncertain that could harm me?	Risk Identification
What might cause this to happen?	Risk Identification
What might be the effect of this happening?	Risk Identification
How likely is this risk to happen?	Risk Analysis
What is the impact of this happening?	Risk Analysis
What is the priority of this risk?	Risk Analysis
What will I do about it?—and when?	Risk Response
What do I expect to result from the response?—is the expected result sufficient?	Risk Response
What do I expect to result *because* of my response? (secondary risks)	Risk Response
What is my backup plan? (contingency plan)	Risk Response
What has changed since I last considered this risk?	Risk Monitoring/Controlling
Have any triggers occurred to indicate this risk may occur?—or should response be implemented?	Risk Monitoring/Controlling

Photo by David Snowberg, NREL

Marine Energy Risk Management Workshop

Why Marine Energy Risk Management?

"Risk is an uncertain event or condition that, if it occurs, has a positive or negative effect on one or more objectives. Positive risks are opportunities, while negative risks are threats."

—**Project Management Institute, *The Standard for Risk Management in Portfolios, Programs, and Projects*, 2019**

Why Marine Energy Risk Management?

Failed Ramsey Sound tidal energy scheme 'faulty for months'

12 December 2016

A failed £18m tidal energy project in Pembrokeshire stopped generating electricity after just three months because of a fault, its operators have admitted.

https://www.bbc.com/news/uk-wales-politics-38236014

ENGINEERING NEWS

Wave energy pioneer Pelamis calls in administrators

21 Nov 2014
PE

Lack of cash puts future of the company in jeopardy

Wave energy specialist Pelamis Wave Power is calling in administrators after failing to secure new funding.

The company, which was founded in 1998, designs, manufactures and operates the Pelamis wave energy converter.

It is widely regarded as one of the world's most advanced wave energy technology companies.

https://www.imeche.org/news/news-article/wave-energy-pioneer-pelamis-calls-in-administrators#:~:text=Wave%20energy%20specialist%20Pelamis%20Wave,advanced%20wave%20energy%20technology%20companies

Problems for Wello's Penguin Wave Energy Device

BY THEORKNEYNEWS ON MARCH 26, 2019 • (1 COMMENT)

The European Marine Energy Centre (EMEC) in Orkney reports that the Wello Penguin device is no longer visible at the Billia Croo test site.

EMEC state:

"As part of the ongoing operational monitoring an issue was identified on Monday and following inspection it was confirmed that the device was taking on water. The device has been closely monitored over the last few days, and remains attached to its moorings at Berth 5 however is no longer visible."

https://theorkneynews.scot/2019/03/26/problems-for-wellos-penguin-wave-energy-device/

Wave goodbye: Aquamarine Power folds due to lack of private sector support

News Analysis | 1 min read

Scottish wave energy pioneer Aquamarine Power has folded, making it the latest casualty in the marine energy sector since Pelamis fell into administration in December 2014.

https://www.theengineer.co.uk/content/news-analysis/wave-goodbye-aquamarine-power-folds-due-to-lack-of-private-sector-support

Why Marine Energy Risk Management?

2010

HYDROELECTRIC

Massive Offshore Waves Sink Australia's Oceanlinx Wavepower Pilot

By Susan Kraemer Published May 22, 2010 9 Comments

Oceanlinx; named one of the world's Top Ten Renewable Energy Investments by the UN, needs to go back to the drawing board to iron out some kinks in the design of its 2.5 MW wave energy power station.

A massive swell at the Port Kembla site, 150 meters off the coast of Australia was able to sink the continent's first wave power device to feed power to the Australian grid. The $5 million pre-commercial pilot project had just begun supplying power to the shore in February 2010.

https://cleantechnica.com/2010/05/22/massive-offshore-waves-sink-australias-oceanlinx-wavepower-pilot/

2014

The first creditors' meeting to consider the future of the wave energy company Oceanlinx will be held today.

The company was placed into administration last week.

Its $7 million wave energy unit is currently stuck off Carrickalinga after being damaged while in transit to Port MacDonnell last month.

The company has suffered financially since the incident as some of its funding depended it on meeting installation deadlines.

The Mayor of the District Council of Grant, Richard Sage, says the council did not invest in the project but it requested conditions to guarantee the machine would be salvaged if it failed.

https://www.abc.net.au/news/2014-04-02/support-aired-for-oceanlinx-project-as-creditors/5361898

2014

THE AUSTRALIAN

HOME NATION WORLD BUSINESS HEALTH COMMENTARY SPORT ARTS VIDEO

BUSINESS > BUSINESS SPECTATOR

Oceanlinx goes bankrupt owing $10m

By STAFF REPORTER

https://www.theaustralian.com.au/business/business-spectator/news-story/oceanlinx-goes-bankrupt-owing-10m/aad66275ffb93a4d33be1ece0d994a97

2021

"wave generator wreckage's partial removal to finally begin"

(3,000-tonne structure)

https://www.abc.net.au/news/2021-03-11/works-finally-begin-to-partially-remove-carrickalinga-oceanlinx/13237328

Why Marine Energy Risk Management?

Washington State Department of Commerce

Divisions | Programs | Funding | News | Abou

Commerce rescinds funding for tidal energy project after tribal objections

April 4, 2025

Share

Decision to rescind funding respects sovereignty of tribal nations

OLYMPIA, WA – The **Washington State Department of Commerce** has withdrawn funding for a proposed tidal energy research project in response to concerns from multiple tribal nations whose treaty-protected waterways would be affected by the installation and project work.

https://www.commerce.wa.gov/commerce-rescinds-funding-for-tidal-energy-project-after-tribal-objections/

ENVIRONMENT

Oregon wave energy stalls off the coast of Reedsport

Updated: Aug. 30, 2013, 3:01 p.m. | Published: Aug. 30, 2013, 2:01 p.m.

, regulatory and technical difficulties have all but halted the project. Federal regulators notified the company earlier this year it had violated

the license

after failing to file a variety of plans and assessments.

All that remains in the water are pieces of a single anchoring system on the ocean floor. State officials have told the New Jersey company to remove them by month's end.

Leading a new industry has been rough sailing for OPT, as state and federal agencies scramble to write policies for marine energy, and coastal communities worry about fishing grounds and environmental protection. Powerful enough wave technology that can elbow a niche in the energy industry remains a work in progress.

https://www.oregonlive.com/environment/2013/08/oregon_wave_energy_stalls_off.html

A Once-Promising Green Energy Technology Hits a Roadblock

Tidal power turbines operating on the Bay of Fundy in Nova Scotia were suspended after the company running them was unable to get a permit to continue testing.

Share full article

By Ian Austen

April 29, 2023

https://www.nytimes.com/2023/04/29/world/canada/sustainable-marine-tidal-energy-suspended.html

Marine Energy Risk Management Workshop

Marine Energy Technology Development Flowchart

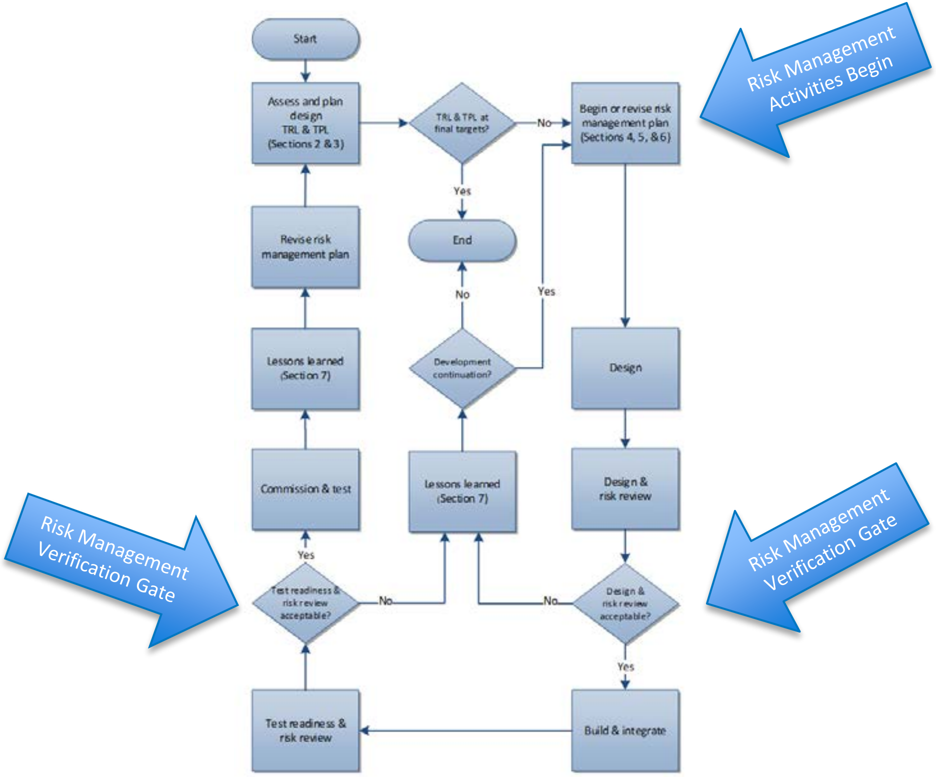


Figure 1 from NREL Marine Energy Risk Framework (2024)

- Technology development flowchart is foundation of risk framework:
  - Design
  - Build
  - Test
  - Lessons learned
- Risks managed through development processes and specific activities
- Technology development cycle based on technology readiness level (TRL) and technology performance level (TPL)
- Cycle applies to components and overall system
- Review gates:
  - Design and risk
  - Pre-test and risk
- Improve process through lessons learned
- **Other technology development processes can be used with the marine energy risk framework**

Marine Energy Risk Management Activities

Activity Required at TRL Level									Risk Management Activity	IEC References	Section
1	2	3	4	5	6	7	8	9			
x	x	x	x	x	x	x	x	x	Risk management plan		4.1
x	x	x	x	x	x	x	x	x	Project plan		4.2
		x	x	x	x	x	x	x	Technology qualification	IEC TS 62600-4	4.3
x	x	x	x	x	x	x	x	x	Risk register		4.4
			x	x	x	x	x	x	Failure mode effects and criticality analysis (FMECA)	IEC TS 62600-4 IEC 60812	4.5
x	x	x	x	x	x	x	x	x	Design basis	IEC TS 62600-2	4.6
x	x	x	x	x	x	x	x	x	Design basis – requirements	IEC TS 62600-2	4.6.1
			x	x	x	x	x	x	Design basis – loads	IEC TS 62600-2 IEC TS 62600-3	4.6.2
			x	x	x	x	x	x	Design basis – design description		4.6.3
			x	x	x	x	x	x	Design basis – design analysis	IEC TS 62600-2	4.6.4
			x	x	x	x	x	x	Design basis – define survivability, reliability, and maintainability targets and strategies	IEC TS 62600-2 (Section 6 & 12.9)	4.6.5
x	x	x	x	x	x	x	x	x	Design basis – environmental, health, and safety		4.6.6
x	x	x	x	x	x	x	x	x	Lessons learned		4.7

- Reference: Table 3 from NREL Marine Energy Risk Framework (2024)
- Section references are to sections in the framework document
- Risk management activity requirements are based on target TRL for current development cycle

Marine Energy Risk Management Activities

Activity Required at TRL Level									Risk Management Activity	IEC References	Section
1	2	3	4	5	6	7	8	9			
x	x	x	x	x	x	x	x	x	Risk management plan		4.1
x	x	x	x	x	x	x	x	x	Project plan		4.2
		x	x	x	x	x	x	x	Technology qualification	IEC TS 62600-4	4.3
x	x	x	x	x	x	x	x	x	Risk register		4.4
			x	x	x	x	x	x	Failure mode effects and criticality analysis (FMECA)	IEC TS 62600-4 IEC 60812	4.5
x	x	x	x	x	x	x	x	x	Design basis	IEC TS 62600-2	4.6
x	x	x	x	x	x	x	x	x	Design basis – requirements	IEC TS 62600-2	4.6.1
			x	x	x	x	x	x	Design basis – loads	IEC TS 62600-2 IEC TS 62600-3	4.6.2
			x	x	x	x	x	x	Design basis – design description		4.6.3
			x	x	x	x	x	x	Design basis – design analysis	IEC TS 62600-2	4.6.4
			x	x	x	x	x	x	Design basis – define survivability, reliability, and maintainability targets and strategies	IEC TS 62600-2 (Section 6 & 12.9)	4.6.5
x	x	x	x	x	x	x	x	x	Design basis – environmental, health, and safety		4.6.6
x	x	x	x	x	x	x	x	x	Lessons learned		4.7

- How risks are managed throughout development cycle
- NREL Marine Energy Risk Framework (2024) document provides foundation
- Improve risk management plan after each development cycle

Marine Energy Risk Management Activities

Activity Required at TRL Level									Risk Management Activity	IEC References	Section
1	2	3	4	5	6	7	8	9			
x	x	x	x	x	x	x	x	x	Risk management plan		4.1
x	x	x	x	x	x	x	x	x	Project plan		4.2
		x	x	x	x	x	x	x	Technology qualification	IEC TS 62600-4	4.3
x	x	x	x	x	x	x	x	x	Risk register		4.4
			x	x	x	x	x	x	Failure mode effects and criticality analysis (FMECA)	IEC TS 62600-4 IEC 60812	4.5
x	x	x	x	x	x	x	x	x	Design basis	IEC TS 62600-2	4.6
x	x	x	x	x	x	x	x	x	Design basis – requirements	IEC TS 62600-2	4.6.1
			x	x	x	x	x	x	Design basis – loads	IEC TS 62600-2 IEC TS 62600-3	4.6.2
			x	x	x	x	x	x	Design basis – design description		4.6.3
			x	x	x	x	x	x	Design basis – design analysis	IEC TS 62600-2	4.6.4
			x	x	x	x	x	x	Design basis – define survivability, reliability, and maintainability targets and strategies	IEC TS 62600-2 (Section 6 & 12.9)	4.6.5
x	x	x	x	x	x	x	x	x	Design basis – environmental, health, and safety		4.6.6
x	x	x	x	x	x	x	x	x	Lessons learned		4.7

- Project plan is how project is managed throughout development cycle
- Manage project dynamics that may influence risk
- Consider Project Management Institute's (PMI's) *A Guide to the Project Management Body of Knowledge* (PMBOK, 2021, 7th Ed.) for project management guidance

Marine Energy Risk Management Activities

Activity Required at TRL Level									Risk Management Activity	IEC References	Section
1	2	3	4	5	6	7	8	9			
x	x	x	x	x	x	x	x	x	Risk management plan		4.1
x	x	x	x	x	x	x	x	x	Project plan		4.2
		x	x	x	x	x	x	x	Technology qualification	IEC TS 62600-4	4.3
x	x	x	x	x	x	x	x	x	Risk register		4.4
			x	x	x	x	x	x	Failure mode effects and criticality analysis (FMECA)	IEC TS 62600-4 IEC 60812	4.5
x	x	x	x	x	x	x	x	x	Design basis	IEC TS 62600-2	4.6
x	x	x	x	x	x	x	x	x	Design basis – requirements	IEC TS 62600-2	4.6.1
			x	x	x	x	x	x	Design basis – loads	IEC TS 62600-2 IEC TS 62600-3	4.6.2
			x	x	x	x	x	x	Design basis – design description		4.6.3
			x	x	x	x	x	x	Design basis – design analysis	IEC TS 62600-2	4.6.4
			x	x	x	x	x	x	Design basis – define survivability, reliability, and maintainability targets and strategies	IEC TS 62600-2 (Section 6 & 12.9)	4.6.5
x	x	x	x	x	x	x	x	x	Design basis – environmental, health, and safety		4.6.6
x	x	x	x	x	x	x	x	x	Lessons learned		4.7

- Comply with IEC 62600 Part-4 (Technology Qualification [TQ])
- Plan for verifying when and how technology meets design requirements and targets
- Graded approach to TQ planning details with TRL
- Test plan a subset of TQ plan

Marine Energy Risk Management Activities

Activity Required at TRL Level									Risk Management Activity	IEC References	Section
1	2	3	4	5	6	7	8	9			
x	x	x	x	x	x	x	x	x	Risk management plan		4.1
x	x	x	x	x	x	x	x	x	Project plan		4.2
		x	x	x	x	x	x	x	Technology qualification	IEC TS 62600-4	4.3
x	x	x	x	x	x	x	x	x	Risk register		4.4
			x	x	x	x	x	x	Failure mode effects and criticality analysis (FMECA)	IEC TS 62600-4 IEC 60812	4.5
x	x	x	x	x	x	x	x	x	Design basis	IEC TS 62600-2	4.6
x	x	x	x	x	x	x	x	x	Design basis – requirements	IEC TS 62600-2	4.6.1
			x	x	x	x	x	x	Design basis – loads	IEC TS 62600-2 IEC TS 62600-3	4.6.2
			x	x	x	x	x	x	Design basis – design description		4.6.3
			x	x	x	x	x	x	Design basis – design analysis	IEC TS 62600-2	4.6.4
			x	x	x	x	x	x	Design basis – define survivability, reliability, and maintainability targets and strategies	IEC TS 62600-2 (Section 6 & 12.9)	4.6.5
x	x	x	x	x	x	x	x	x	Design basis – environmental, health, and safety		4.6.6
x	x	x	x	x	x	x	x	x	Lessons learned		4.7

- List of uncertain events with positive or negative impact on technology development
- Risk register template available on cover page of NREL Marine Energy Risk Framework, 2024
- Risk register will be described in more detail later in workshop

Marine Energy Risk Management Activities

Activity Required at TRL Level									Risk Management Activity	IEC References	Section
1	2	3	4	5	6	7	8	9			
x	x	x	x	x	x	x	x	x	Risk management plan		4.1
x	x	x	x	x	x	x	x	x	Project plan		4.2
		x	x	x	x	x	x	x	Technology qualification	IEC TS 62600-4	4.3
x	x	x	x	x	x	x	x	x	Risk register		4.4
			x	x	x	x	x	x	Failure mode effects and criticality analysis (FMECA)	IEC TS 62600-4 IEC 60812	4.5
x	x	x	x	x	x	x	x	x	Design basis	IEC TS 62600-2	4.6
x	x	x	x	x	x	x	x	x	Design basis – requirements	IEC TS 62600-2	4.6.1
			x	x	x	x	x	x	Design basis – loads	IEC TS 62600-2 IEC TS 62600-3	4.6.2
			x	x	x	x	x	x	Design basis – design description		4.6.3
			x	x	x	x	x	x	Design basis – design analysis	IEC TS 62600-2	4.6.4
			x	x	x	x	x	x	Design basis – define survivability, reliability, and maintainability targets and strategies	IEC TS 62600-2 (Section 6 & 12.9)	4.6.5
x	x	x	x	x	x	x	x	x	Design basis – environmental, health, and safety		4.6.6
x	x	x	x	x	x	x	x	x	Lessons learned		4.7

- Identify and prioritize possible system problems from component failures
- Analyze failure modes, effects, and potential causes
- FMECA template available on cover page of NREL Marine Energy Risk Framework, 2024
- More on this later in the workshop

Marine Energy Risk Management Activities

Activity Required at TRL Level									Risk Management Activity	IEC References	Section
1	2	3	4	5	6	7	8	9			
x	x	x	x	x	x	x	x	x	Risk management plan		4.1
x	x	x	x	x	x	x	x	x	Project plan		4.2
		x	x	x	x	x	x	x	Technology qualification	IEC TS 62600-4	4.3
x	x	x	x	x	x	x	x	x	Risk register		4.4
			x	x	x	x	x	x	Failure mode effects and criticality analysis (FMECA)	IEC TS 62600-4 IEC 60812	4.5
x	x	x	x	x	x	x	x	x	Design basis	IEC TS 62600-2	4.6
x	x	x	x	x	x	x	x	x	Design basis – requirements	IEC TS 62600-2	4.6.1
			x	x	x	x	x	x	Design basis – loads	IEC TS 62600-2 IEC TS 62600-3	4.6.2
			x	x	x	x	x	x	Design basis – design description		4.6.3
			x	x	x	x	x	x	Design basis – design analysis	IEC TS 62600-2	4.6.4
			x	x	x	x	x	x	Design basis – define survivability, reliability, and maintainability targets and strategies	IEC TS 62600-2 (Section 6 & 12.9)	4.6.5
x	x	x	x	x	x	x	x	x	Design basis – environmental, health, and safety		4.6.6
x	x	x	x	x	x	x	x	x	Lessons learned		4.7

Marine Energy Risk Management Activities

Activity Required at TRL Level									Risk Management Activity	IEC References	Section
1	2	3	4	5	6	7	8	9			
x	x	x	x	x	x	x	x	x	Risk management plan		4.1
x	x	x	x	x	x	x	x	x	Project plan		4.2
		x	x	x	x	x	x	x	Technology qualification	IEC TS 62600-4	4.3
x	x	x	x	x	x	x	x	x	Risk register		4.4
			x	x	x	x	x	x	Failure mode effects and criticality analysis (FMECA)	IEC TS 62600-4 IEC 60812	4.5
x	x	x	x	x	x	x	x	x	Design basis	IEC TS 62600-2	4.6
x	x	x	x	x	x	x	x	x	Design basis – requirements	IEC TS 62600-2	4.6.1
			x	x	x	x	x	x	Design basis – loads	IEC TS 62600-2 IEC TS 62600-3	4.6.2
			x	x	x	x	x	x	Design basis – design description		4.6.3
			x	x	x	x	x	x	Design basis – design analysis	IEC TS 62600-2	4.6.4
			x	x	x	x	x	x	Design basis – define survivability, reliability, and maintainability targets and strategies	IEC TS 62600-2 (Section 6 & 12.9)	4.6.5
x	x	x	x	x	x	x	x	x	Design basis – environmental, health, and safety		4.6.6
x	x	x	x	x	x	x	x	x	Lessons learned		4.7

- Requirements to be met by technology (e.g., environmental conditions, design standards, controllability, etc.)
- Comply with IEC 62600—Part 2 (Design Requirements)

Marine Energy Risk Management Activities

Activity Required at TRL Level									Risk Management Activity	IEC References	Section
1	2	3	4	5	6	7	8	9			
x	x	x	x	x	x	x	x	x	Risk management plan		4.1
x	x	x	x	x	x	x	x	x	Project plan		4.2
		x	x	x	x	x	x	x	Technology qualification	IEC TS 62600-4	4.3
x	x	x	x	x	x	x	x	x	Risk register		4.4
			x	x	x	x	x	x	Failure mode effects and criticality analysis (FMECA)	IEC TS 62600-4 IEC 60812	4.5
x	x	x	x	x	x	x	x	x	Design basis	IEC TS 62600-2	4.6
x	x	x	x	x	x	x	x	x	Design basis – requirements	IEC TS 62600-2	4.6.1
			x	x	x	x	x	x	Design basis – loads	IEC TS 62600-2 IEC TS 62600-3	4.6.2
			x	x	x	x	x	x	Design basis – design description		4.6.3
			x	x	x	x	x	x	Design basis – design analysis	IEC TS 62600-2	4.6.4
			x	x	x	x	x	x	Design basis – define survivability, reliability, and maintainability targets and strategies	IEC TS 62600-2 (Section 6 & 12.9)	4.6.5
x	x	x	x	x	x	x	x	x	Design basis – environmental, health, and safety		4.6.6
x	x	x	x	x	x	x	x	x	Lessons learned		4.7

- All load conditions that guide design development
- Comply with IEC 62600—Part 2 (Design Requirements)

Marine Energy Risk Management Activities

Activity Required at TRL Level									Risk Management Activity	IEC References	Section
1	2	3	4	5	6	7	8	9			
x	x	x	x	x	x	x	x	x	Risk management plan		4.1
x	x	x	x	x	x	x	x	x	Project plan		4.2
		x	x	x	x	x	x	x	Technology qualification	IEC TS 62600-4	4.3
x	x	x	x	x	x	x	x	x	Risk register		4.4
			x	x	x	x	x	x	Failure mode effects and criticality analysis (FMECA)	IEC TS 62600-4 IEC 60812	4.5
x	x	x	x	x	x	x	x	x	Design basis	IEC TS 62600-2	4.6
x	x	x	x	x	x	x	x	x	Design basis – requirements	IEC TS 62600-2	4.6.1
			x	x	x	x	x	x	Design basis – loads	IEC TS 62600-2 IEC TS 62600-3	4.6.2
			x	x	x	x	x	x	Design basis – design description		4.6.3
			x	x	x	x	x	x	Design basis – design analysis	IEC TS 62600-2	4.6.4
			x	x	x	x	x	x	Design basis – define survivability, reliability, and maintainability targets and strategies	IEC TS 62600-2 (Section 6 & 12.9)	4.6.5
x	x	x	x	x	x	x	x	x	Design basis – environmental, health, and safety		4.6.6
x	x	x	x	x	x	x	x	x	Lessons learned		4.7

- Describes design at current TRL and TPL levels
- Description detail is adequate to build and integrate system and/or component(s)
- May include model code, descriptive text, schematics, build prints, assembly design in form of solid or CAD models

Marine Energy Risk Management Activities

Activity Required at TRL Level									Risk Management Activity	IEC References	Section
1	2	3	4	5	6	7	8	9			
x	x	x	x	x	x	x	x	x	Risk management plan		4.1
x	x	x	x	x	x	x	x	x	Project plan		4.2
		x	x	x	x	x	x	x	Technology qualification	IEC TS 62600-4	4.3
x	x	x	x	x	x	x	x	x	Risk register		4.4
			x	x	x	x	x	x	Failure mode effects and criticality analysis (FMECA)	IEC TS 62600-4 IEC 60812	4.5
x	x	x	x	x	x	x	x	x	Design basis	IEC TS 62600-2	4.6
x	x	x	x	x	x	x	x	x	Design basis – requirements	IEC TS 62600-2	4.6.1
			x	x	x	x	x	x	Design basis – loads	IEC TS 62600-2 IEC TS 62600-3	4.6.2
			x	x	x	x	x	x	Design basis – design description		4.6.3
			x	x	x	x	x	x	Design basis – design analysis	IEC TS 62600-2	4.6.4
			x	x	x	x	x	x	Design basis – define survivability, reliability, and maintainability targets and strategies	IEC TS 62600-2 (Section 6 & 12.9)	4.6.5
x	x	x	x	x	x	x	x	x	Design basis – environmental, health, and safety		4.6.6
x	x	x	x	x	x	x	x	x	Lessons learned		4.7

- Analyze design at current TRL and TPL levels
- Limit state analysis from IEC 62600-2 (Design Requirements)
- Based on requirements and loads from design basis document
- Analysis fidelity commensurate with failure risk

Marine Energy Risk Management Activities

Activity Required at TRL Level									Risk Management Activity	IEC References	Section
1	2	3	4	5	6	7	8	9			
x	x	x	x	x	x	x	x	x	Risk management plan		4.1
x	x	x	x	x	x	x	x	x	Project plan		4.2
		x	x	x	x	x	x	x	Technology qualification	IEC TS 62600-4	4.3
x	x	x	x	x	x	x	x	x	Risk register		4.4
			x	x	x	x	x	x	Failure mode effects and criticality analysis (FMECA)	IEC TS 62600-4 IEC 60812	4.5
x	x	x	x	x	x	x	x	x	Design basis	IEC TS 62600-2	4.6
x	x	x	x	x	x	x	x	x	Design basis – requirements	IEC TS 62600-2	4.6.1
			x	x	x	x	x	x	Design basis – loads	IEC TS 62600-2 IEC TS 62600-3	4.6.2
			x	x	x	x	x	x	Design basis – design description		4.6.3
			x	x	x	x	x	x	Design basis – design analysis	IEC TS 62600-2	4.6.4
			x	x	x	x	x	x	Design basis – define survivability, reliability, and maintainability targets and strategies	IEC TS 62600-2 (Section 6 & 12.9)	4.6.5
x	x	x	x	x	x	x	x	x	Design basis – environmental, health, and safety		4.6.6
x	x	x	x	x	x	x	x	x	Lessons learned		4.7

- Targets are conditions technology is expected to survive, and strategy is a plan to achieve targets
- Reliability targets may be mean time between failures (MTBF) or mean time to repair (MTTR)
- Maintainability targets may be maintenance free operating period (MFOP)
- Comply with IEC 62600—Part 2 (Design Requirements)

Marine Energy Risk Management Activities

Activity Required at TRL Level									Risk Management Activity	IEC References	Section
1	2	3	4	5	6	7	8	9			
x	x	x	x	x	x	x	x	x	Risk management plan		4.1
x	x	x	x	x	x	x	x	x	Project plan		4.2
		x	x	x	x	x	x	x	Technology qualification	IEC TS 62600-4	4.3
x	x	x	x	x	x	x	x	x	Risk register		4.4
			x	x	x	x	x	x	Failure mode effects and criticality analysis (FMECA)	IEC TS 62600-4 IEC 60812	4.5
x	x	x	x	x	x	x	x	x	Design basis	IEC TS 62600-2	4.6
x	x	x	x	x	x	x	x	x	Design basis – requirements	IEC TS 62600-2	4.6.1
			x	x	x	x	x	x	Design basis – loads	IEC TS 62600-2 IEC TS 62600-3	4.6.2
			x	x	x	x	x	x	Design basis – design description		4.6.3
			x	x	x	x	x	x	Design basis – design analysis	IEC TS 62600-2	4.6.4
			x	x	x	x	x	x	Design basis – define survivability, reliability, and maintainability targets and strategies	IEC TS 62600-2 (Section 6 & 12.9)	4.6.5
x	x	x	x	x	x	x	x	x	Design basis – environmental, health, and safety		4.6.6
x	x	x	x	x	x	x	x	x	Lessons learned		4.7

- Hazards identified and appropriately managed.
- Safety integrated into design
- Environmental, health, and safety considerations occur early, often, and throughout any development process

Marine Energy Risk Management Activities

Activity Required at TRL Level									Risk Management Activity	IEC References	Section
1	2	3	4	5	6	7	8	9			
x	x	x	x	x	x	x	x	x	Risk management plan		4.1
x	x	x	x	x	x	x	x	x	Project plan		4.2
		x	x	x	x	x	x	x	Technology qualification	IEC TS 62600-4	4.3
x	x	x	x	x	x	x	x	x	Risk register		4.4
			x	x	x	x	x	x	Failure mode effects and criticality analysis (FMECA)	IEC TS 62600-4 IEC 60812	4.5
x	x	x	x	x	x	x	x	x	Design basis	IEC TS 62600-2	4.6
x	x	x	x	x	x	x	x	x	Design basis – requirements	IEC TS 62600-2	4.6.1
			x	x	x	x	x	x	Design basis – loads	IEC TS 62600-2 IEC TS 62600-3	4.6.2
			x	x	x	x	x	x	Design basis – design description		4.6.3
			x	x	x	x	x	x	Design basis – design analysis	IEC TS 62600-2	4.6.4
			x	x	x	x	x	x	Design basis – define survivability, reliability, and maintainability targets and strategies	IEC TS 62600-2 (Section 6 & 12.9)	4.6.5
x	x	x	x	x	x	x	x	x	Design basis – environmental, health, and safety		4.6.6
x	x	x	x	x	x	x	x	x	Lessons learned		4.7

- Lessons learned captured when they occur and at debriefing
- Formalize institutional learning and avoid repeating mistakes
- Used to improve risk management plan
- More detail will be provided later in workshop

Marine Energy Risk Management Workshop

Marine Energy Risk Register

Activity Required at TRL Level									Risk Management Activity	IEC References	Section
1	2	3	4	5	6	7	8	9			
x	x	x	x	x	x	x	x	x	Risk management plan		4.1
x	x	x	x	x	x	x	x	x	Project plan		4.2
		x	x	x	x	x	x	x	Technology qualification	IEC TS 62600-4	4.3
x	x	x	x	x	x	x	x	x	Risk register		4.4
			x	x	x	x	x	x	Failure mode effects and criticality analysis (FMECA)	IEC TS 62600-4 IEC 60812	4.5
x	x	x	x	x	x	x	x	x	Design basis	IEC TS 62600-2	4.6
x	x	x	x	x	x	x	x	x	Design basis – requirements	IEC TS 62600-2	4.6.1
			x	x	x	x	x	x	Design basis – loads	IEC TS 62600-2 IEC TS 62600-3	4.6.2
			x	x	x	x	x	x	Design basis – design description		4.6.3
			x	x	x	x	x	x	Design basis – design analysis	IEC TS 62600-2	4.6.4
			x	x	x	x	x	x	Design basis – define survivability, reliability, and maintainability targets and strategies	IEC TS 62600-2 (Section 6 & 12.9)	4.6.5
x	x	x	x	x	x	x	x	x	Design basis – environmental, health, and safety		4.6.6
x	x	x	x	x	x	x	x	x	Lessons learned		4.7

- More details on a risk register

Marine Energy Risk Register (Overview)

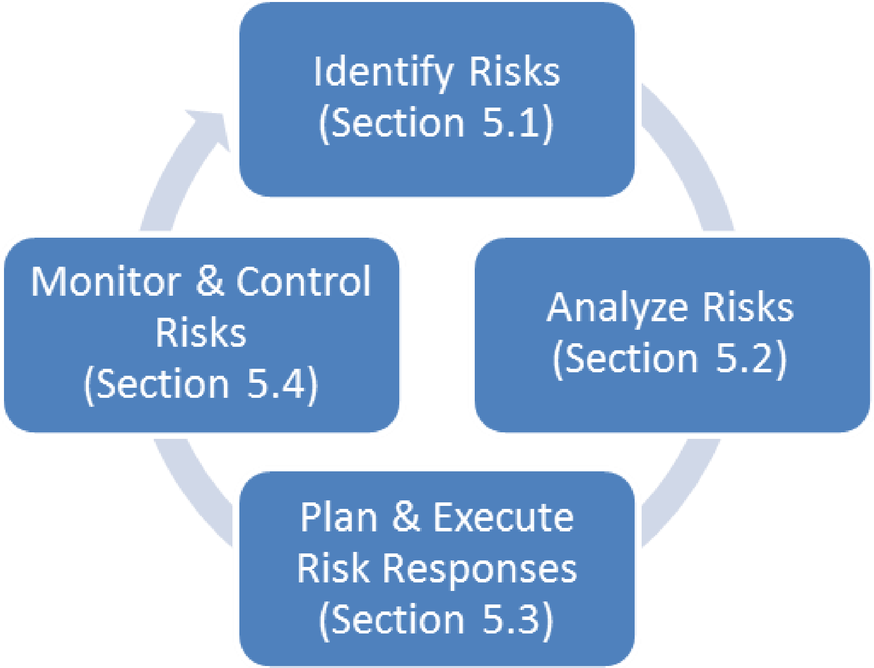


Figure 2 from NREL Marine Energy Risk Framework (2024). Section numbers refer to sections in the framework document.

- Comprehensive list of positive and negative uncertainties
- Analysis enables prioritization
- Planned responses
- Monitor and control risks throughout technology development cycle(s)

Marine Energy Risk Register (Identify Risks)

RBS Level 0	RBS Level 1	RBS Level 2
All sources of project risk	1. Safety Risk	1.1 All personnel
		1.2 Internal personnel
		1.3 External personnel
	2. Technical Risk	2.1 Scope definition
		2.2 Requirements definition
		2.3 Estimates, assumptions, constraints
		2.4 Technical processes
		2.5 Technology
		2.6 Technical interfaces
		2.7 System reliability
		2.8 Performance
		2.9 Security
		2.10 TBD
	3. Management Risk	3.1 Project management
		3.2 Program/Portfolio management
		3.3 Operations management
		3.4 Organization
		3.5 Human resourcing
		3.6 Funding
		3.7 Communication
		3.8 Information
		3.9 Quality
		3.10 Reputation
		3.11 TBD
	4. Commercial Risk	4.1 Contractual terms and conditions
		4.2 Internal procurement
		4.3 Suppliers and vendors
		4.4 Subcontracts
		4.5 Client/customer stability
		4.6 Partnerships and joint ventures
		4.7 Levelized cost of energy (LCOE)
		4.8 TBD
	5. External Risk	5.1 Legislation
		5.2 Exchange rates
		5.3 Site/facilities
		5.4 Environmental/weather
		5.5 Competition
		5.6 Regulatory
		5.7 Political
		5.8 Force majeure
		5.9 External stakeholder
		5.10 TBD

Table 4 from NREL Marine Energy Risk Framework (2024)

- Identify uncertainties
- Risk breakdown structure (RBS)
- Technology life phases
- Risk owner
- Per TRL and TPL
- International standards
- Previous experience

Marine Energy Risk Register (Analyze Risks—Severity or Consequence)

Consequence with impact to persons, project, environment, and regulatory compliance								
Impact (IMPCT)	Impact Level	Risk Classifications (CLASS)						
		Safety (S)	Cost (C)	Time (T)	Scope (P)	Quality (Q)	Environment (E)	Regulation (R)
0	None	No injury	$0K	No delay	No scope impact	No quality impact	No pollution	Full compliance
1	Insignificant	Negligible injury, effect on health	$1.5K	Less than 1-week delay	Insignificant scope impact	Insignificant quality impact	Negligible pollution or no effect on environment	Insignificant regulatory infraction with no consequences
2	Marginal	Minor injuries, health effects	$15K	1-week to 1-month delay	Moderate scope impact	Moderate quality impact	Minor pollution/slight effect on environment (minimum disruption on marine life)	Moderate regulatory infraction with inconvenient but reversible consequences
3	Critical	Moderate injuries and/or health effects	$350K	1-month to 6-months delay	Major scope impact (rescoping required to some of the project)	Critical quality impact (possibly irreversible)	Limited levels of pollution, manageable/ moderate effect on environment	Major regulatory infraction causing system shutdown until compliance is reassured
4	Catastrophic	Significant injuries	$2.5M	6-months to 1-year delay	Serious scope impact (rescope most of project)	Catastrophic quality impact (likely irreversible)	Moderate pollution, with some cleanup costs/serious effect on environment	Serious regulatory infraction likely causing irreversible system shutdown and substantial fines
5	Lethal	A fatality	$13M	1-year or more delay	Complete scope impact (rescope entire project)	Devastating and irreversible quality impact	Major pollution event, with significant cleanup costs/ disastrous effects on the environment	Very serious regulatory infraction causing project shutdown, major fines and/or bankruptcy, lengthy legal proceedings

Baseline Definitions

Table 5 from NREL Marine Energy Risk Framework (2024), based on IEC TS 62600-4, *Specification for establishing qualification of new technology* (2020)

Marine Energy Risk Register (Analyze Risks—Severity or Consequence)

Consequence with impact to persons, project, environment, and regulatory compliance								
Impact (IMPCT)	Impact Level	Risk Classifications (CLASS)						
		Safety (S)	Cost (C)	Time (T)	Scope (P)	Quality (Q)	Environment (E)	Regulation (R)
0	None	No injury	$0K	No delay	No scope impact	No quality impact	No pollution	Full compliance
1	Insignificant	Negligible injury, effect on health	$1.5K	Less than 1-week delay	Insignificant scope impact	Insignificant quality impact	Negligible pollution or no effect on environment	Insignificant regulatory infraction with no consequences
2	Marginal	Minor injuries, health effects	$15K	1-week to 1-month delay	Moderate scope impact	Moderate quality impact	Minor pollution/slight effect on environment (minimum disruption on marine life)	Moderate regulatory infraction with inconvenient but reversible consequences
3	Critical	Moderate injuries and/or health effects	$350K	1-month to 6-months delay	Major scope impact (rescoping required to some of the project)	Critical quality impact (possibly irreversible)	Limited levels of pollution, manageable/ moderate effect on environment	Major regulatory infraction causing system shutdown until compliance is reassured
4	Catastrophic	Significant injuries	$2.5M	6-months to 1-year delay	Serious scope impact (rescope most of project)	Catastrophic quality impact (likely irreversible)	Moderate pollution, with some cleanup costs/serious effect on environment	Serious regulatory infraction likely causing irreversible system shutdown and substantial fines
5	Lethal	A fatality	$13M	1-year or more delay	Complete scope impact (rescope entire project)	Devastating and irreversible quality impact	Major pollution event, with significant cleanup costs/ disastrous effects on the environment	Very serious regulatory infraction causing project shutdown, major fines and/or bankruptcy, lengthy legal proceedings

Table 5 from NREL Marine Energy Risk Framework (2024), based on IEC TS 62600-4, *Specification for establishing qualification of new technology* (2020)

Baseline Definitions

What to do for smaller-scale projects?

Marine Energy Risk Register (Analyze Risks—Severity or Consequence)

Consequence with impact to persons, project, environment, and regulatory compliance									
Impact (IMPCT)	Impact Level	Risk Classifications (CLASS)							
		Safety (S)	Cost (C)	Time (T)	Scope (P)	Quality (Q)	Environment (E)	Regulation (R)
0	None	No injury	$0K	No delay	No scope impact	No quality impact	No pollution	Full compliance
1	Insignificant	Negligible injury, effect on health	$1.5K	Less than 1-week delay	Insignificant scope impact	Insignificant quality impact	Negligible pollution or no effect on environment	Insignificant regulatory infraction with no consequences
2	Marginal	Minor injuries, health effects	$15K	1-week to 1-month delay	Moderate scope impact	Moderate quality impact	Minor pollution/slight effect on environment (minimum disruption on marine life)	Moderate regulatory infraction with inconvenient but reversible consequences
3	Critical	Moderate injuries and/or health effects	$350K	1-month to 6-months delay	Major scope impact (rescoping required to some of the project)	Critical quality impact (possibly irreversible)	Limited levels of pollution, manageable/ moderate effect on environment	Major regulatory infraction causing system shutdown until compliance is reassured
4	Catastrophic	Significant injuries	$2.5M	6-months to 1-year delay	Serious scope impact (rescope most of project)	Catastrophic quality impact (likely irreversible)	Moderate pollution, with some cleanup costs/serious effect on environment	Serious regulatory infraction likely causing irreversible system shutdown and substantial fines
5	Lethal	A fatality	$13M	1-year or more delay	Complete scope impact (rescope entire project)	Devastating and irreversible quality impact	Major pollution event, with significant cleanup costs/ disastrous effects on the environment	Very serious regulatory infraction causing project shutdown, major fines and/or bankruptcy, lengthy legal proceedings

Table 5 from NREL Marine Energy Risk Framework (2024), based on IEC TS 62600-4, *Specification for establishing qualification of new technology* (2020)

__Example__ definition tailoring for project scale (e.g., cost *0.1 and time shift)

Tailor definitions to a project *before* it starts

Some definitions such as safety may not be appropriate to tailor

Tailored Definitions

Impact (IMPCT)	Cost (C)	Time (T)
0	$0K	No delay
1	$150	1-day delay
2	$1.5K	Less than 1-week delay
3	$35K	1-week to 1-month delay
4	$250K	1-month to 6-months delay
5	$1.3M	6-months to 1-year delay

Marine Energy Risk Register (Analyze Risks—Probability of Occurrence

Probability	Probability Description	AFR in % per year (up to)	AFR (up to)	Frequency of Occurrence (up to)
0	Not Possible	0%	0	0
1	Very Low	0.01%	1E-04	once every 10,000 years
2	Low	0.1%	1E-03	once every 1,000 years
3	Medium	1%	1E-02	once every 100 years
4	High	10%	1E-01	once every 10 years
5	Very High	100%	1E-00	once a year

Table 6 from NREL Marine Energy Risk Framework (2024)

AFR = F/(U × T) ×100, where:

- **AFR** is the annual failure (event) rate (%)
- **F** is the number of failures (or events)
- **U** is the number of units tested
- **T** is the time period over which the units were tested (years).

Baseline probability definitions from IEC TS 62600-4, *Specification for establishing qualification of new technology* (2020), which presumes mature technology being qualified.

Marine Energy Risk Register (Analyze Risks—Probability of Occurrence

Probability	Probability Description	AFR in % per year (up to)	AFR (up to)	Frequency of Occurrence (up to)
0	Not Possible	0%	0	0
1	Very Low	0.01%	1E-04	once every 10,000 years
2	Low	0.1%	1E-03	once every 1,000 years
3	Medium	1%	1E-02	once every 100 years
4	High	10%	1E-01	once every 10 years
5	Very High	100%	1E-00	once a year

Table 6 from NREL Marine Energy Risk Framework (2024)

AFR = F/(U × T) ×100, where:

- **AFR** is the annual failure (event) rate (%)
- **F** is the number of failures (or events)
- **U** is the number of units tested
- **T** is the time period over which the units were tested (years).

Baseline probability definitions from IEC TS 62600-4, *Specification for establishing qualification of new technology* (2020), which presumes mature technology being qualified.

What to do for short-duration testing?

Marine Energy Risk Register (Analyze Risks—Probability of Occurrence

Baseline Definitions

Probability	Baseline **annual** failure rates (up to), from IEC TS 62600-4
1	1E-04 (once every 10,000 years)
2	1E-03 (once every 1,000 years)
3	1E-02 (once every 100 years)
4	1E-01 (once every 10 years)
5	1E-00 (once a year)

Table 6 from NREL Marine Energy Risk Framework (2024)

Example definition tailoring for project scale (e.g., 100x baseline)

Tailored Definitions

Example tailored **annual** failure rates (up to) **(100x the baseline)**
1E-02 (once every 100 years)
1E-01 (once every 10 years)
1E-00 (once a year)
1E+01(10 times per year, or once per 36.5 days)
1E+02 (100 times per year, or once per 3.65 days)

Considerations for tailoring definitions:

1) Tailor definitions to a project before it starts
2) Project duration
3) Enable a range of usable resolution (tailoring could be 0.1x, 10x, 100x, etc.)

Marine Energy Risk Register (Analyze Risks—Risk Priority)

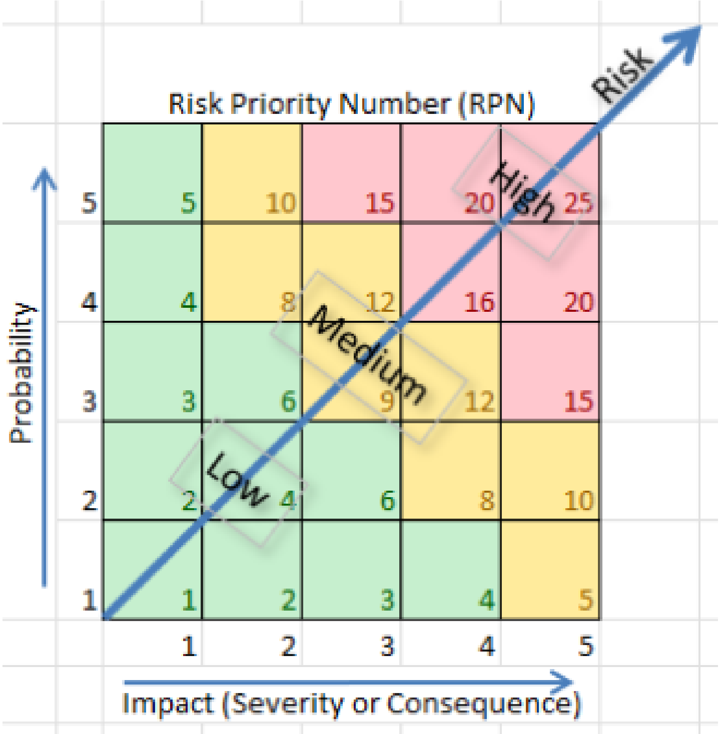


Figure 3 from NREL Marine Energy Risk Framework (2024)

Marine Energy Risk Register (Analyze Risks—Risk Priority)

Tailoring of probability and/or impact values is acceptable when risk thresholds align with risk appetite.

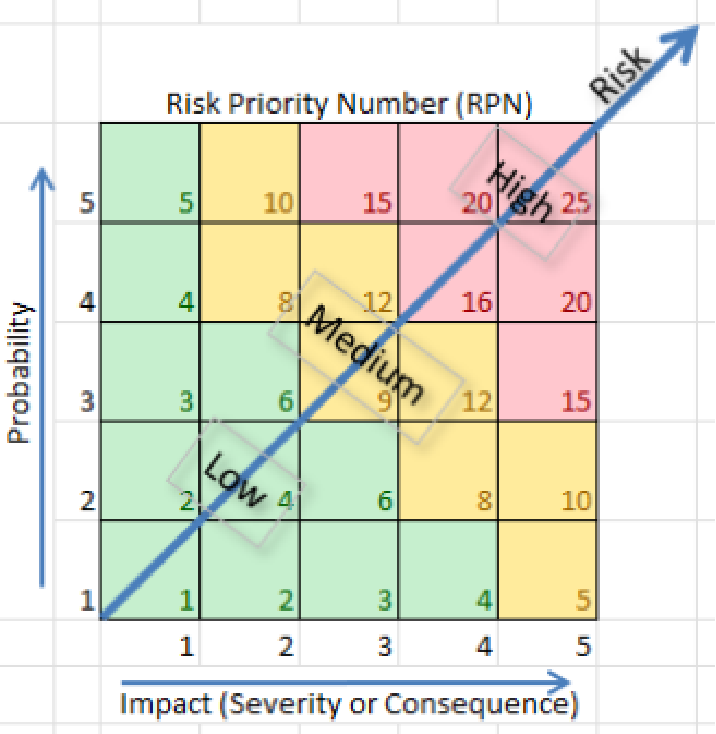


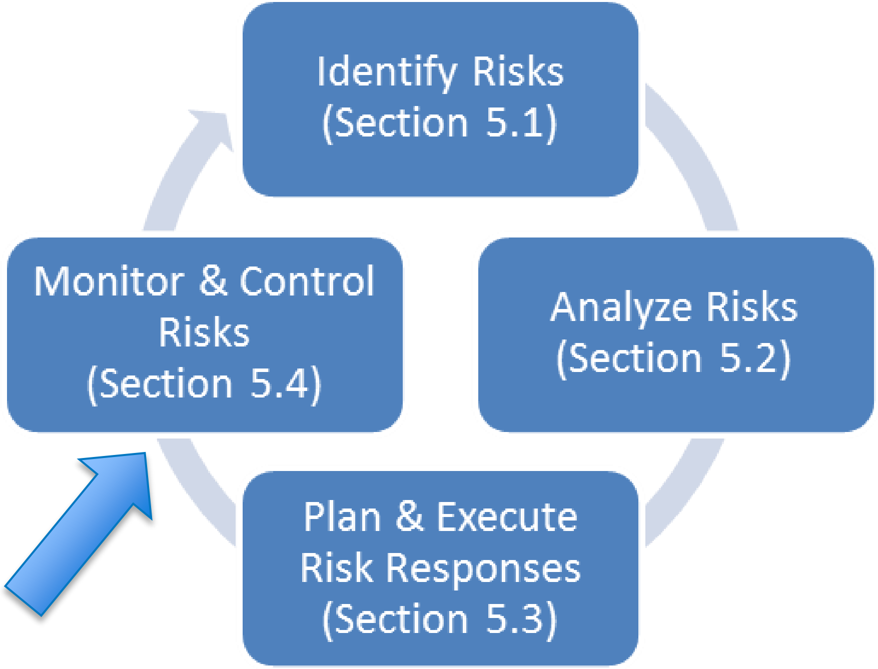
Figure 3 from NREL Marine Energy Risk Framework (2024)

Marine Energy Risk Register (Planned Response)

Negative Risk (Threats) Responses		Positive Risk (Opportunity) Responses	
Strategy Type	**Strategy Description**	**Strategy Type**	**Strategy Description**
Avoid	Ensuring the risk cannot occur or will have no impact on the project (e.g., removing high-risk equipment from the system)	Exploit	Ensuring the opportunity will occur and the project will benefit from it
Transfer	Transferring the risk to a third party (e.g., insurance company)	Share	Sharing the opportunity with another party
Mitigate	Reducing the probability and/or consequence of a risk	Enhance	Increasing the probability and/or consequence of an opportunity
Accept	Accepting the risk without pursuing any of the other strategies—contingency plans may be developed if the risk occurs	Accept	Accepting the opportunity without pursuing any of the other strategies
Escalate	Escalating the risk response to the level within the organization that can provide an appropriate response.	Escalate	Escalating the risk response to the level within the organization that can provide an appropriate response.

- Table 7 from NREL Marine Energy Risk Framework (2024)
- Plan risk response timing
- Residual risk quantifies expected outcome
- Consider secondary risks resulting from risk response
- Contingency plan describes action to take if risk event occurs

Marine Energy Risk Register (Monitor and Control)



- Detect differences between current and previous risk register information
- Execute risk responses based on plans
- Identify new risks
- Cycle occurs continuously throughout development

Marine Energy Risk Register (Excel Template)

Identification — Analysis — Response — Monitor and Control

IDENTIFY RISKS PROCESS

Risk ID	Revision Date	RBS: RBS Level 1	RBS: RBS Level 2	RBS: Risk Name	RBS: TRL	RBS: TPL	RBS: Technology Life Phase	Risk Owner
2	23-May-24	External	5.9 External stakeholder	Community acceptance	7	5	Multiple (or all) life phases	Mary (CEO)
3	23-May-24	Safety	1.2 Internal personnel	Personnel falling while transferring from vessel to MEC	7	5	Assembly and commissioning	Patricia (COO)

ANALYZE RISKS PROCESS — Baseline Risk (before response)

Risk ID	+-	CLASS	IMPCT	PROB	RPN	Baseline Risk Description (Consequence)
2	-	P	5	4	20	If the local community is not an advocate (or neutral) for the project, then community resistance could stop the deployment project from obtaining objectives.
3	-	S	4	3	12	Personnel may be injured if they slip, trip, or fall when transferring between the support vessel and the MEC during commissioning.

RISK RESPONSE PROCESS--STRATEGY, TIMING, & RESIDUAL RISK

Risk ID	Risk Response: Strategy	Risk Response: Risk Response Description	Risk Response: Risk Response Timing	Residual Risk (after response): IMPCT	Residual Risk: PROB	Residual Risk: RPN	Residual Risk: Residual Risk Description	Residual Risk: Secondary Risks Resulting From Risk Response
2	mitigate	Develop a comprehensive stakeholder management plan that includes: 1) identified stakeholders, 2) stakeholder interests related to this project, 3) custom management plan for each stakeholder.	June	3	3	9	Stakeholder identification process may miss important stakeholders. Or, engagement plan may not be successful with some key stakeholders.	none
3	mitigate	1) Consider design and deployment plan that does NOT require personnel to transfer onto MEC. 2) If transfer to MEC is deemed essential, then develop engineered controls on MEC for safe transfer (e.g., railings, anti-slip surfaces) and then develop safe operating procedures for this task.	before design finalized	4	2	8	1) Although personnel not required to transfer onto MEC, they may do it anyway. 2) Accidents may still happen, even with the engineered controls.	1) MEC commissioning may be more complex without having direct contact with it. 2) Engineered controls for personnel transfer could impact MEC performance.

MONITOR & CONTROL RISK PROCESS

Risk ID	Risk Triggers	Contingency Plan (if the risk event has occurred)	Risk Status (as of date in Column B)	Recommendations & Action Items
2	Observed actions by external stakeholders that are a threat to project objectives.	Rescope project for a different location with a different community.	PRIORITY monitoring (risk may be imminent)	Continue with response plan and attempt to meet with the mayor, who recently proclaimed this project will never start while she is in office.
3	Vessel with personnel near MEC.	Implement emergency plan for man overboard (MOB) if personnel is in water.	Active monitoring (pending risk response)	Complete risk response & monitor for triggers

Link to marine energy risk register template on framework cover page:
https://www.nrel.gov/docs/fy24osti/90212.pdf

Marine Energy Risk Register (Excel Template)

Who Why What When

	E	I	J	O	Q	R
1	IDENTIFY RISKS		ANALYZE RISKS PROCESS		RISK RESPONSE PROCESS--STRATEGY,	
2	RBS		Baseline Risk (before response)		Risk Response	
3	Risk Name	Risk Owner	+ -	Baseline Risk Description (Consequence)	Risk Response Description	Risk Response Timing
4						
6	Community acceptance	Mary (CEO)	-	If the local community is not an advocate (or neutral) for the project, then community resistance could stop the deployment project from obtaining objectives.	Develop a comprehensive stakeholder management plan that includes: 1) identified stakeholders, 2) stakeholder interests related to this project, 3) custom management plan for each stakeholder.	June, 2025
7	Personnel falling while transferring from vessel to MEC	Patricia (COO)	-	Personnel may be injured if they slip, trip, or fall when transferring between the support vessel and the MEC during commissioning.	1) Consider design and deployment plan that does NOT require personnel to transfer onto MEC. 2) If transfer to MEC is deemed essential, then develop engineered controls on MEC for safe transfer (e.g., railings, anti-slip surfaces) and then develop safe operating procedures for this task.	before design finalized

Template can be simplified to get started by hiding columns

Marine Energy Risk Management Workshop

1 Background

2 Why Marine Energy Risk Management?

3 Marine Energy Risk Management Activities

4 Risk Register

5 Failure Modes Effects and Criticality Analysis (FMECA)

6 Collecting and Using Lessons Learned

7 Current Work in Marine Energy Risk Management

Marine Energy Risk FMEA/FMECA

Activity Required at TRL Level									Risk Management Activity	IEC References	Section
1	2	3	4	5	6	7	8	9			
x	x	x	x	x	x	x	x	x	Risk management plan		4.1
x	x	x	x	x	x	x	x	x	Project plan		4.2
		x	x	x	x	x	x	x	Technology qualification	IEC TS 62600-4	4.3
x	x	x	x	x	x	x	x	x	Risk register		4.4
			x	x	x	x	x	x	Failure mode effects and criticality analysis (FMECA)	IEC TS 62600-4 IEC 60812	4.5
x	x	x	x	x	x	x	x	x	Design basis	IEC TS 62600-2	4.6
x	x	x	x	x	x	x	x	x	Design basis – requirements	IEC TS 62600-2	4.6.1
			x	x	x	x	x	x	Design basis – loads	IEC TS 62600-2 IEC TS 62600-3	4.6.2
			x	x	x	x	x	x	Design basis – design description		4.6.3
			x	x	x	x	x	x	Design basis – design analysis	IEC TS 62600-2	4.6.4
			x	x	x	x	x	x	Design basis – define survivability, reliability, and maintainability targets and strategies	IEC TS 62600-2 (Section 6 & 12.9)	4.6.5
x	x	x	x	x	x	x	x	x	Design basis – environmental, health, and safety		4.6.6
x	x	x	x	x	x	x	x	x	Lessons learned		4.7

- More details on a FMECA

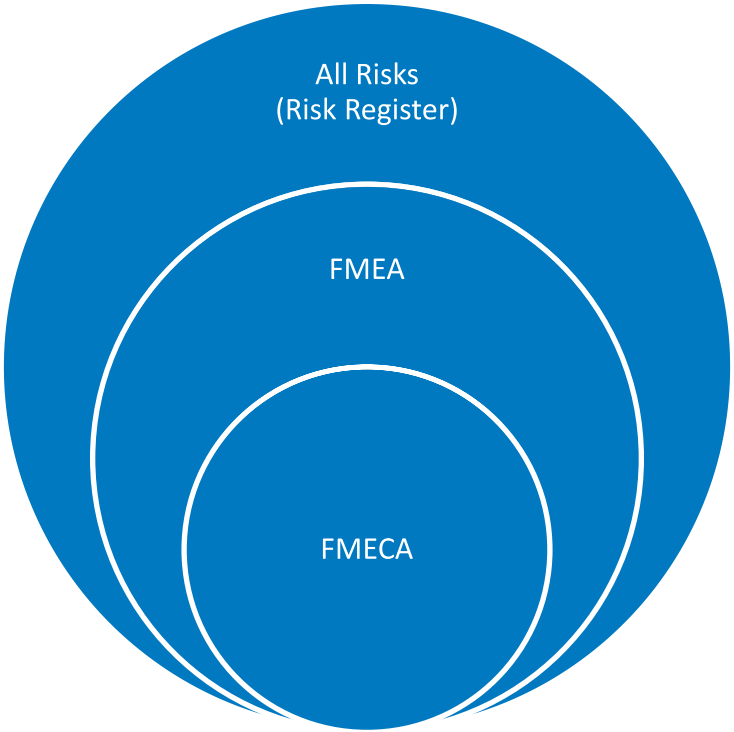
Marine Energy Risk FMEA/FMECA

- Why complete a failure modes effects and criticality analysis (FMECA)?
  - Early identification of failure modes, effects, and causes
  - Improve system reliability
  - Lower cost
- **IEC 60812**, Edition 3.0, 2018-08; Failure modes and effects analysis (FMEA and FMECA)
- **IEC TS 62600-4**, Edition 1.0 2020-09; Marine energy – wave, tidal and other water current converters – Part 4: Specification for establishing qualification of new technology

Marine Energy Risk FMEA/FMECA

- **FMEA** = failure modes effects analysis
- **FMECA** = failure modes effects and criticality analysis
- ***Criticality*** provides way to prioritize the failure risk (typically multiplying severity and likelihood estimates)
- Sometimes a FMECA analysis is informally called an FMEA

	Risk Register	FMECA
An analysis tool to manage technical risks	X	X
Addresses programmatic risks such as schedule, supply chain, and environmental hazards	X	
A detailed sub-system analysis that identifies potential causes and impacts of a failure.		X



Marine Energy Risk FMEA/FMECA

Table A.1 – Probability of occurrence

Class	Name	Description	Indicative annual failure rate (up to)
1	Very low	Negligible event frequency	1,0E-04
2	Low	Event unlikely to occur	1,0E-03
3	Medium	Event rarely expected to occur	1,0E-02
4	High	One or several events expected to occur during the lifetime	1,0E-01
5	Very high	One or several events expected to occur each year	1,0E+00

Table A.2 – Classification of consequence

Class	Description of consequences (impact on)				
	Safety	Environment	Operation	Assets	Cost (USD)
1	Negligible injury, effect on health	Negligible pollution or no effect on environment	Negligible effect on production (hours)	Negligible	1,5 k
2	Minor injuries, health effects	Minor pollution/slight effect on environment (minimum disruption on marine life)	Partial loss of performance (retrieval not required outside maintenance interval)	Repairable within maintenance interval	15
3	Moderate injuries and/or health effects	Limited levels of pollution, manageable/moderate effect on environment	Loss of performance requiring retrieval outside maintenance interval	Repairable outside maintenance interval	350 k
4	Significant injuries	Moderate pollution, with some clean-up costs/Serious effect on environment	Total loss of production up to 2,5 m (USD)	Significant but repairable outside maintenance interval	2,5 m
5	A fatality	Major pollution event, with significant clean-up costs/disastrous effects on the environment	Total loss of production greater than 2,5 m (USD)	Loss of device, major repair needed by removal of device and exchange of major components	13 m

Table A.3 – Categories of risk

	Consequence				
Probability	1	2	3	4	5
5	Low	Med	High	High	High
4	Low	Med	Med	High	High
3	Low	Low	Med	Med	High
2	Low	Low	Low	Med	Med
1	Low	Low	Low	Low	Med

Low	Tolerable, no action required
Medium	Mitigation and improvement required to reduce risk to low
High	Not acceptable: mitigation and improvement required to reduce risk to low (ALARP)

Note: same concept of tailoring definitions for risk register could be applied to FMECA

Reference: IEC TS 62600-4:2020

Marine Energy Risk FMECA—Process

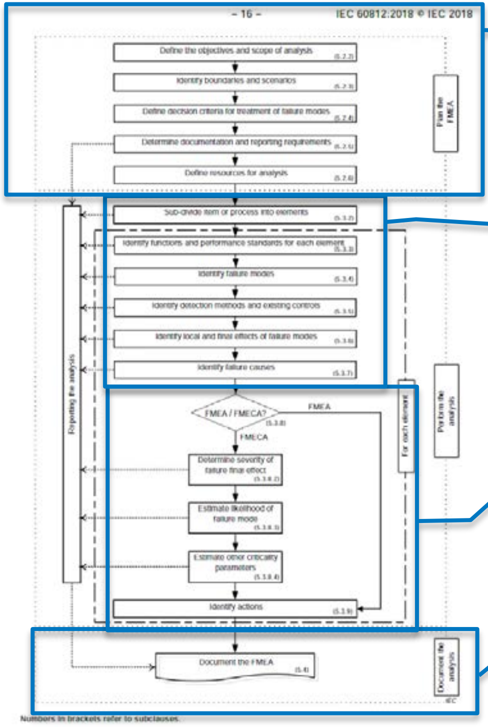


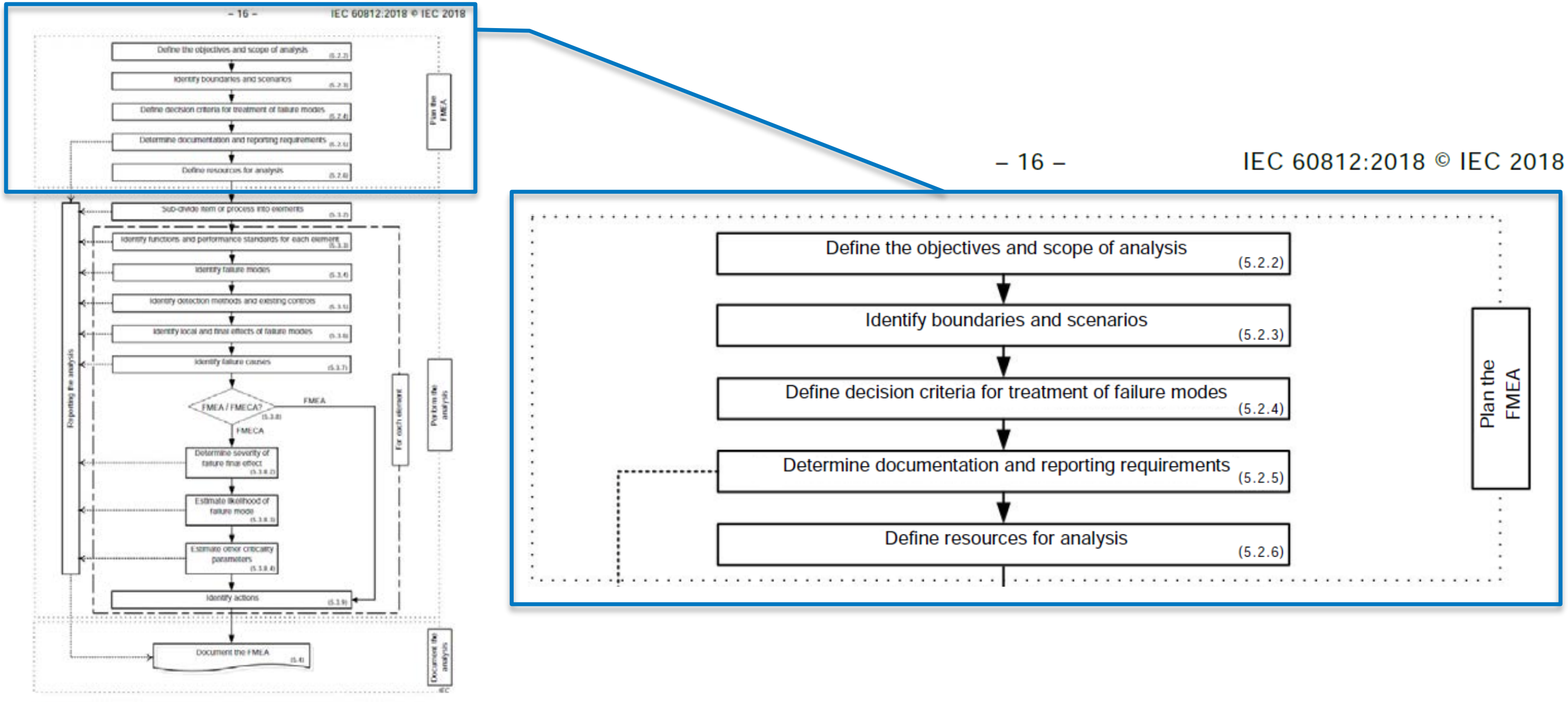
Figure 1 – Overview of FMEA methodology before tailoring

<u>FMECA process:</u>

1) Plan the FMEA/FMECA
2) Perform the analysis
3) Document the analysis

Reference: IEC 60812:2018

Marine Energy Risk FMECA—Planning

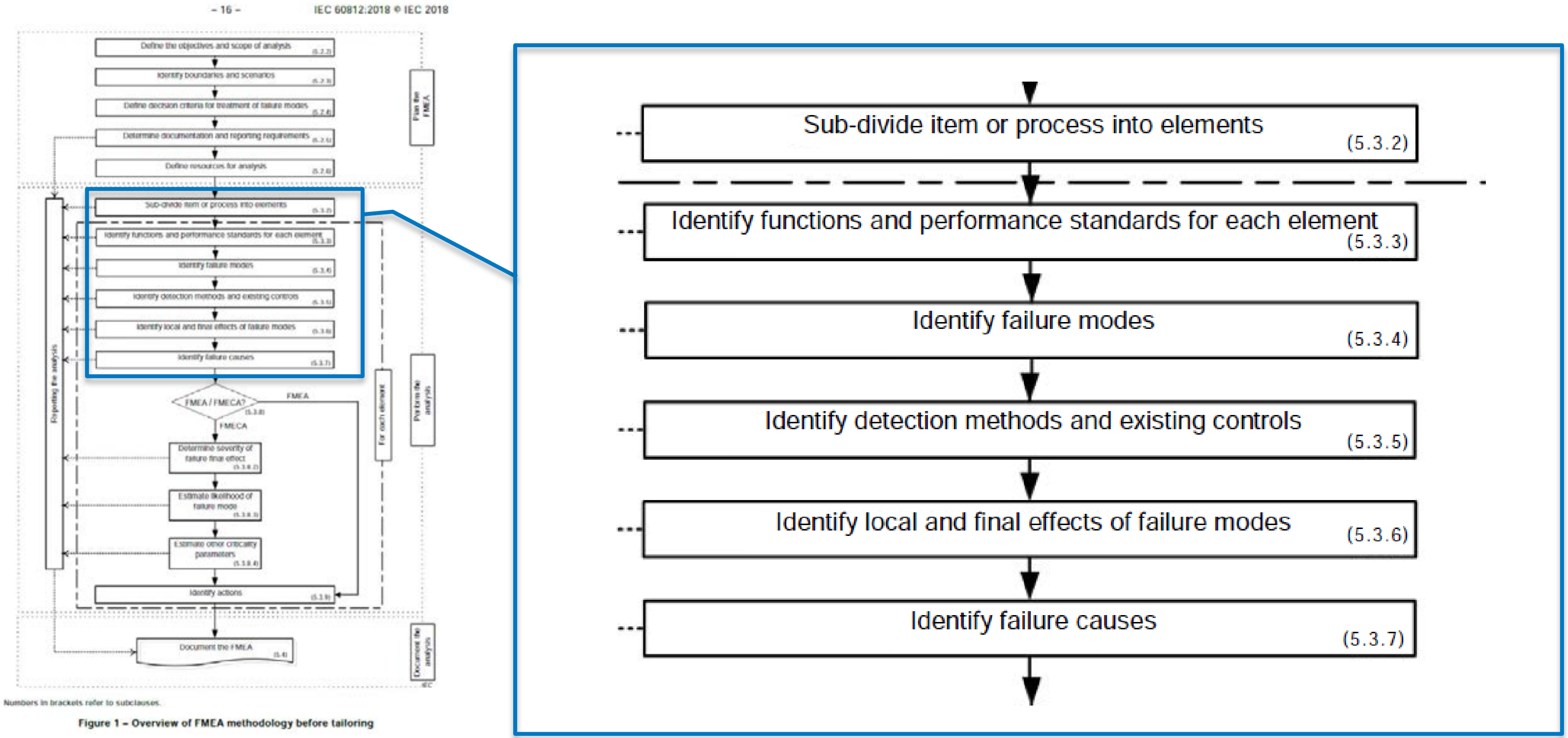


Numbers in brackets refer to subclauses.

Figure 1 – Overview of FMEA methodology before tailoring

Reference: IEC 60812:2018

Marine Energy Risk FMECA—Analyzing



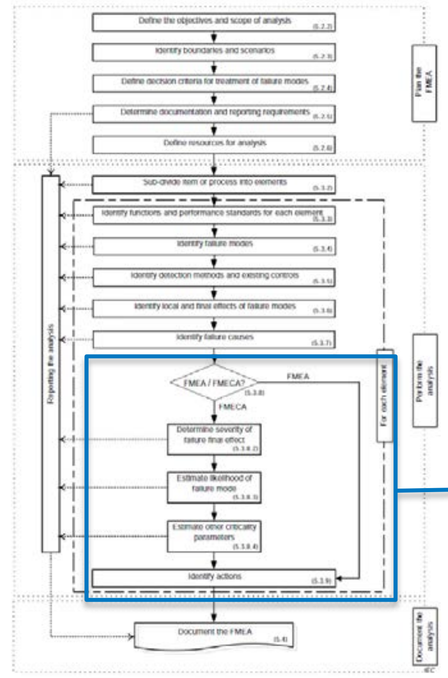
Numbers in brackets refer to subclauses.

Figure 1 – Overview of FMEA methodology before tailoring

Reference: IEC 60812:2018

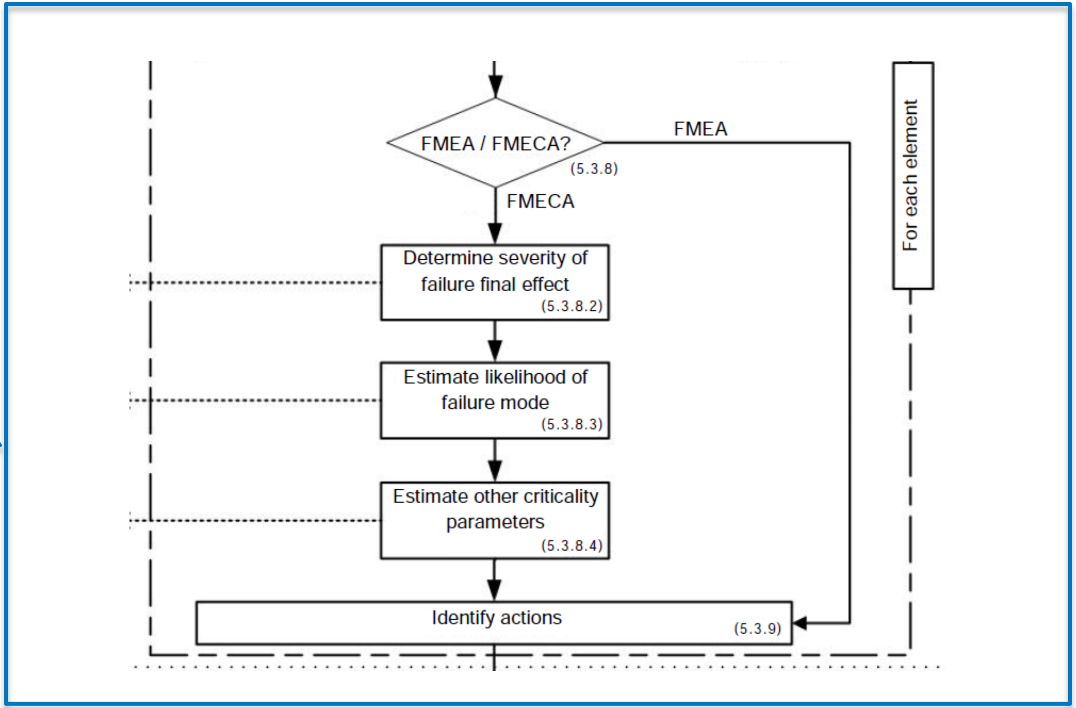
Marine Energy Risk FMECA—Analyzing

– 16 – IEC 60812:2018 © IEC 2018



Numbers in brackets refer to subclauses.

Figure 1 – Overview of FMEA methodology before tailoring



Reference: IEC 60812:2018

Marine Energy Risk FMECA—Documenting

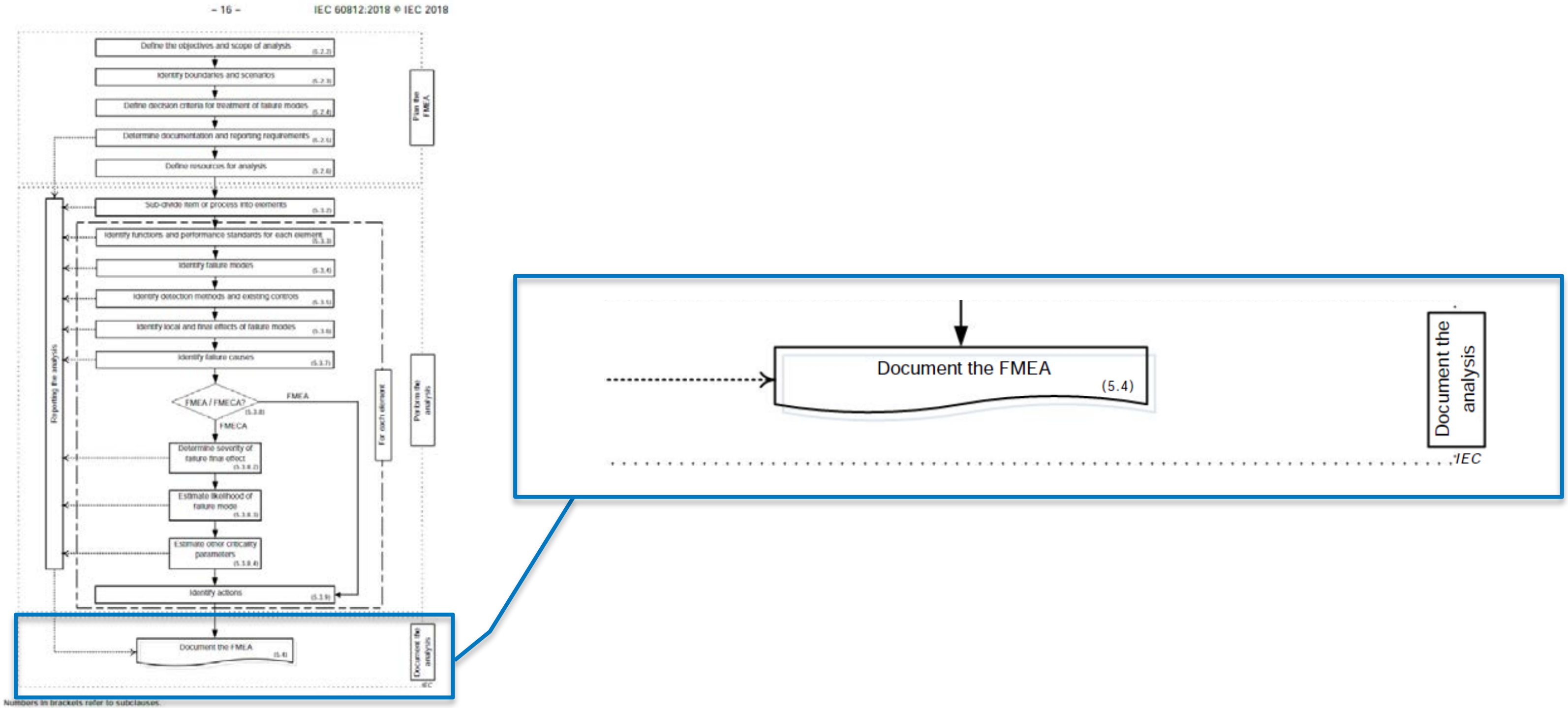
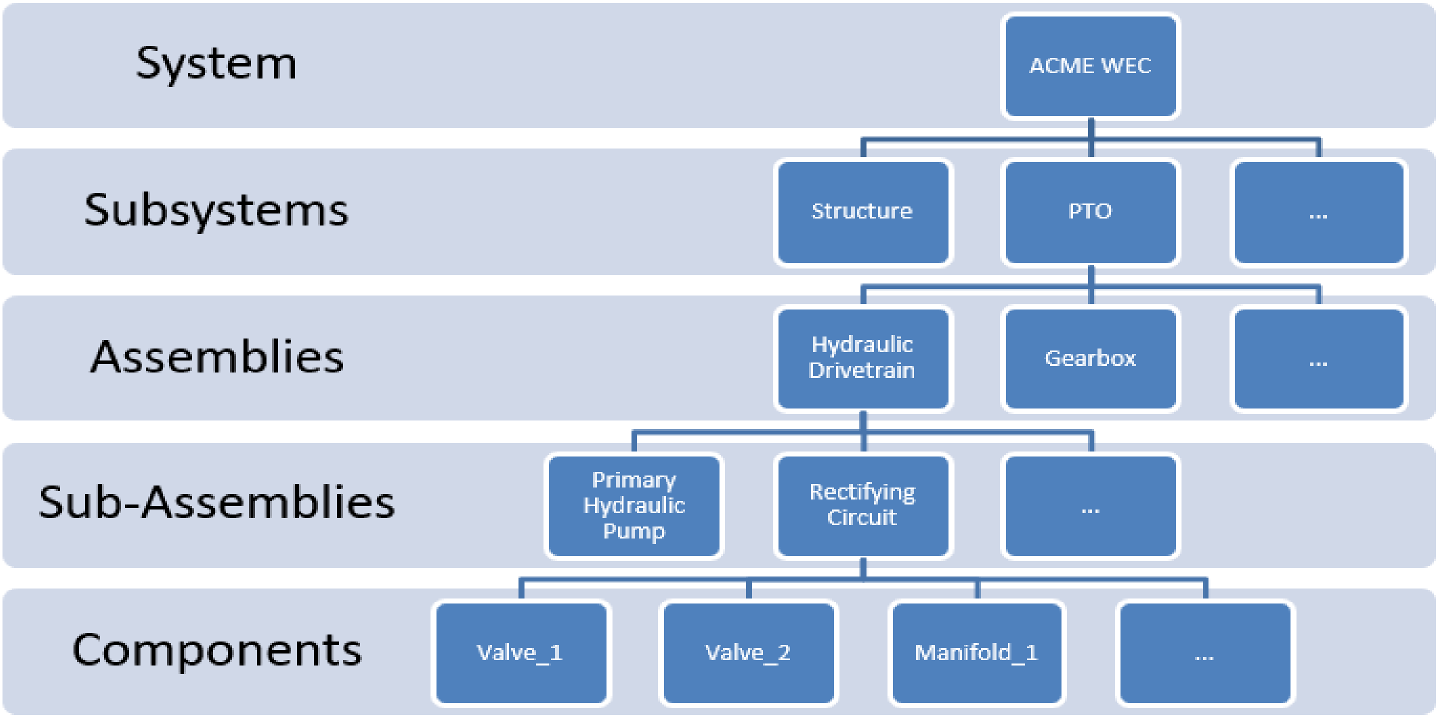


Figure 1 – Overview of FMEA methodology before tailoring

Reference: IEC 60812:2018

Marine Energy Risk FMECA System Decomposition Example



Marine Energy Risk FMECA—Template

System Decomposition | Failure Modes | Cause | Priority | Actions | Contingency

ITEM/FUNCTION						POTENTIAL FAILURE MODES						POTENTIAL CAUSES				RECOMMENDED ACTION(S)						
	System Decomposition Into Elements							Potential Effect(s) of Failure									Action Results				Contingency Plan	
ID	Subsystem	Assembly	Subassembly	Component	Function & Performance Standard	Potential Failure Mode	Detection Methods	Local Effect	Final Effect	CLASS	SEV	Potential Failure Cause	Prevention Controls	PROB	RPN	Recommended Action(s)	Actions Taken	SEV	PROB	RPN	(planned actions to take if failure occurs)	Notes:
1	Structure	prime mover	primary structural sub-assembly		overall structure holding MEC together; withstand loads from IEC TS 62600-2	steel yields	lower (or loss of) power production	structural misalignment at pivot for oscillating surge flap	oscillating surge flap seizes; no power production from PTO	O	4	actual loads to deployed device exceeded design loads	design MEC to IEC TS 62600-2 standard	2	8	engage certifying body to ensure design approach complies with IEC TS 62600-2 standard before deployment		4	1	4	implement device decommissioning plan	
2	Structure	prime mover	primary structural sub-assembly		overall structure holding MEC together; withstand loads from IEC TS 62600-2	steel fails catastrophically	no power production	oscillating surge flap separates from steel structure	oscillating surge flap sinks	A	5	actual loads to deployed device exceeded design loads	design MEC to IEC TS 62600-2 standard	2	10	engage certifying body to ensure design approach complies with IEC TS 62600-2 standard before deployment		5	1	5	implement device recovery plan	
3	Structure	prime mover	buoyancy chambers		maintain buoyancy of structure during all operating conditions	loss of buoyancy in (1) chamber	water sensor inside buoyancy chamber	MEC operates lower in water than design intent	reduced power production	O	3	leaky seal from design defect	pressure test chambers before deployment	3	9	develop buoyancy chamber seal design with considerations for pressures, aging effects, redundancies, and inspection methods		3	2	6	follow O&M procedure for seal replacement	

Link to marine energy FMECA template on framework cover page:
https://www.nrel.gov/docs/fy24osti/90212.pdf

Marine Energy Risk FMEA—Template

System Decomposition | Failure Modes | Cause | Actions

ITEM/FUNCTION						POTENTIAL FAILURE MODES				POTENTIAL CAUSES		RECOMMENDED ACTION(S)
	System Decomposition Into Elements							Potential Effect(s) of Failure				
ID	Subsystem	Assembly	Subassembly	Component	Function & Performance Standard	Potential Failure Mode	Detection Methods	Local Effect	Final Effect	Potential Failure Cause	Prevention Controls	Recommended Action(s)
1	Structure	prime mover	primary structural sub-assembly		overall structure holding MEC together; withstand loads from IEC TS 62600-2	steel yields	lower (or loss of) power production	structural misalignment at pivot for oscillating surge flap	oscillating surge flap seizes; no power production from PTO	actual loads to deployed device exceeded design loads	design MEC to IEC TS 62600-2 standard	engage certifying body to ensure design approach complies with IEC TS 62600-2 standard before deployment
2	Structure	prime mover	primary structural sub-assembly		overall structure holding MEC together; withstand loads from IEC TS 62600-2	steel fails catastrophically	no power production	oscillating surge flap separates from steel structure	oscillating surge flap sinks	actual loads to deployed device exceeded design loads	design MEC to IEC TS 62600-2 standard	engage certifying body to ensure design approach complies with IEC TS 62600-2 standard before deployment
3	Structure	prime mover	buoyancy chambers		maintain buoyancy of structure during all operating conditions	loss of buoyancy in (1) chamber	water sensor inside buoyancy chamber	MEC operates lower in water than design intent	reduced power production	leaky seal from design defect	pressure test chambers before deployment	develop buoyancy chamber seal design with considerations for pressures, aging effects, redundancies, and inspection methods

Hide columns to make into FMEA:

- Easier start
- No prioritization

Link to marine energy FMECA template on framework cover page:
https://www.nrel.gov/docs/fy24osti/90212.pdf

FMECA Data Sources

FMECA often based on estimates,
but sometimes data are available…

FMECA Data Sources

Challenges with Mooring System Design for Floating Offshore Installations

Krish Thiagarajan Sharman, *UMass Amherst*

Abstract

Moorings are one of the more vulnerable components of an offshore energy production system. Many mooring failures go unreported, and those that have a consequence and need to be reported give an impression of high levels of unknown risk. For example, an annual probability of failure of 0.3% was estimated for mooring systems for floating production systems in the Gulf of Mexico based on reported failures between 2001 – 2011. Given the translation of recommended practices from the oil and gas industry to the offshore renewable industry, some risks and challenges posed by mooring systems need to be understood in this context.

https://scholars.unh.edu/ccom_seminars/299/

bp

Underlying Causes of Mooring Lines Failures Across the Industry

Guy Drori
24th March 2015

https://mcedd.com/wp-content/uploads/2014/04/00_Guy-Drori-BP.pdf

SEVEN MECHANISMS THAT CONTRIBUTE TO MOORING LINE FAILURE

10/01/2022

Permanent mooring systems can have a life span of 20 to 30 years and Floating Production System (FPS) operators often face mooring system integrity issues including mooring line failure

Maritime history shows that mooring systems fail in a wide range of water depths, regions and environmental conditions (mild to severe sea states). Consequences of mooring failure can be very serious from asset damage and production interruption to environmental issues and even personnel loss. When it comes to mooring line failure, several elements can be responsible, from basic wear-and-tear and corrosion to integral production defects. These include, but are not limited to:

1 – Wear: This can occur when the mooring line rubs on adjacent line components at connecting links, fairleaders, bending shoes, etc.

2 – Fatigue damage: This can be due to crack initiation and propagation from repetitive axial and bending stress.

3 – Abrasion: When chain gets in contact with the seabed, sediments can be abrasive and friction can erode the chain.

4 – Corrosion: Rust and corrosion can result from chemical reactions between the material and the surrounding environment. The growth of marine life (algae, barnacles…) can further contribute to the need to replace the mooring line to avoid failure.

5 – Damage: Chain, wire rope or polyester rope can get damaged during installation operations or inspection operations, as well as from dropped objects, and other external events.

6 – Flawed materials: Impurities in the materials, improper heat treatment, improper or non-compliant assembly, or poor coating or lubrication are all reasons that can lead to a weaker material, and consequently to failure.

7 – Excessive tension: Mooring lines should be inspected after exposure to severe environmental conditions (storms, hurricanes…) or extreme loads.

https://acteon.com/blog/seven-mechanisms-that-contribute-to-mooring-line-failure/#:~:text=When%20it%20comes%20to%20mooring,fairleaders%2C%20bending%20shoes%2C%20etc

Marine Energy Risk Management Workshop

1 Background

2 Why Marine Energy Risk Management?

3 Marine Energy Risk Management Activities

4 Risk Register

5 Failure Modes Effects and Criticality Analysis (FMECA)

6 Collecting and Using Lessons Learned

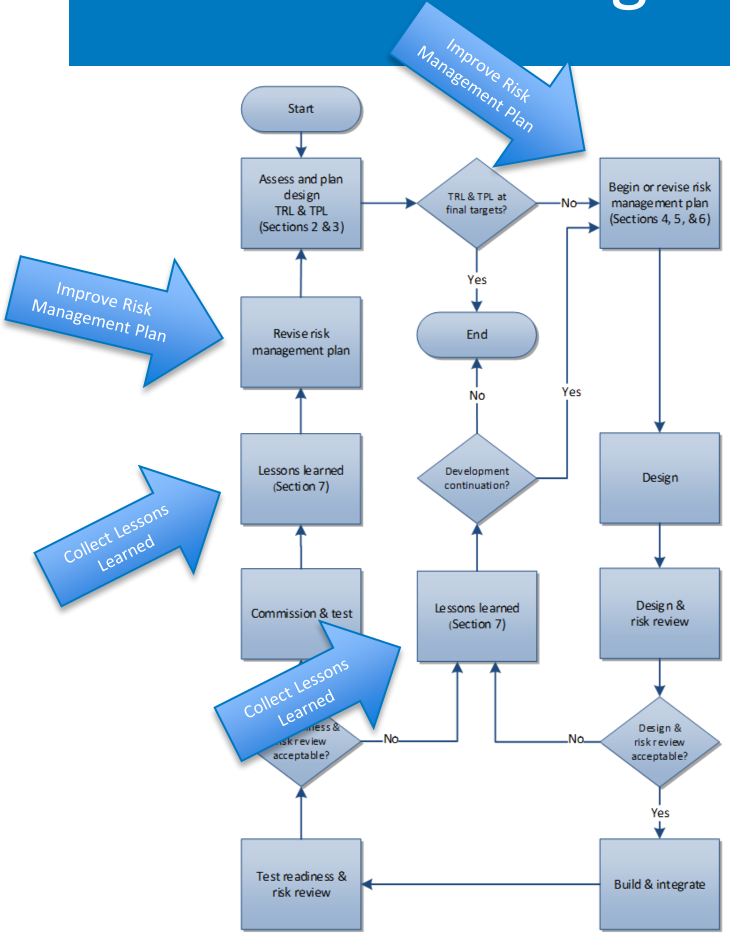
7 Current Work in Marine Energy Risk Management

Collecting and Using Lessons Learned

Activity Required at TRL Level									Risk Management Activity	IEC References	Section
1	2	3	4	5	6	7	8	9			
x	x	x	x	x	x	x	x	x	Risk management plan		4.1
x	x	x	x	x	x	x	x	x	Project plan		4.2
		x	x	x	x	x	x	x	Technology qualification	IEC TS 62600-4	4.3
x	x	x	x	x	x	x	x	x	Risk register		4.4
			x	x	x	x	x	x	Failure mode effects and criticality analysis (FMECA)	IEC TS 62600-4 IEC 60812	4.5
x	x	x	x	x	x	x	x	x	Design basis	IEC TS 62600-2	4.6
x	x	x	x	x	x	x	x	x	Design basis – requirements	IEC TS 62600-2	4.6.1
			x	x	x	x	x	x	Design basis – loads	IEC TS 62600-2 IEC TS 62600-3	4.6.2
			x	x	x	x	x	x	Design basis – design description		4.6.3
			x	x	x	x	x	x	Design basis – design analysis	IEC TS 62600-2	4.6.4
			x	x	x	x	x	x	Design basis – define survivability, reliability, and maintainability targets and strategies	IEC TS 62600-2 (Section 6 & 12.9)	4.6.5
x	x	x	x	x	x	x	x	x	Design basis – environmental, health, and safety		4.6.6
x	x	x	x	x	x	x	x	x	Lessons learned		4.7

- More details on collecting and using lessons learned

Collecting and Using Lessons Learned



- Section 7 from NREL Marine Energy Risk Framework (2024)
- Promote organizational learning
- Tailor and improve processes for ***your*** organization
- Reduce severity or probability of future problems (Table 12)
- Build on successes (Table 13)
- Captured when they occur and debrief meeting
- Debrief meeting allows team to stop and examine previous development cycle:
  - What worked well?—or didn't work well?
  - What needs to be done differently?
  - What project circumstances were not anticipated?
  - How can we improve our technology development process?

Date	Project Cycle	Issue category	Issue name	Issue description (possible cause)	Impact	Recommendation for improvement (action items)	Action item initials	Follow-up actions completed
140712	TRL 5, TPL 7	Scope	Bolt torque	It was uncertain if bolts on generator were torqued according to the specification	Potential damage to generator if operated without proper torque; required potentially unnecessary retorque operation	Develop a checklist for technician to initial when torque operation completed	MD	Checklist developed for next test phase
140712	TRL 5, TPL 7	Quality	Missing test records	During testing, notes were not regularly taken by test personnel	Unable to reconstruct the actual test events	Develop a dedicated logbook for each test campaign; develop process for capturing test events in logbook	SB	Logbooks available for each test; procedure developed for logbook usage
140712	TRL 5, TPL 7	Human resource	Staff availability	Staff availability was unknown in advance of absence	Testing was delayed due to key staff being unavailable	Develop a staff calendar indicating upcoming staff vacations and other out of office events	DS	TBD

Table 12 from NREL Marine Energy Risk Framework (2024)

Marine Energy Risk Management Workshop

1 Background

2 Why Marine Energy Risk Management?

3 Marine Energy Risk Management Activities

4 Risk Register

5 Failure Modes Effects and Criticality Analysis (FMECA)

6 Collecting and Using Lessons Learned

7 Current Work in Marine Energy Risk Management

Current FY25 Work in Marine Energy Risk Management

- Gathering input and compiling a queue of updates for a future risk framework revision (send input to david.snowberg@nrel.gov)
- Supporting risk management activities for various projects
- Developing new tools and templates for marine energy risk management, e.g.:
  – Marine energy risk identification tools (checklists, prompt lists, stakeholder analysis, assumption analysis, etc.)
  – Marine energy failure mode list with potential causes
  – What would help you? (send suggestions to david.snowberg@nrel.gov)

Risk Management Summary

Risk management is the process to manage uncertainty in *any* situation.

Questions	Process Step
What is uncertain that could harm me?	Risk Identification
What might cause this to happen?	Risk Identification
What might be the effect of this happening?	Risk Identification
How likely is this risk to happen?	Risk Analysis
What is impact of this happening?	Risk Analysis
What is the priority of this risk?	Risk Analysis
What will I do about it?—and when?	Risk Response
What do I expect to result from the response?—is the expected result sufficient?	Risk Response
What do I expect to result *because* of my response? (secondary risks)	Risk Response
What is my backup plan? (contingency plan)	Risk Response
What has changed since I last considered this risk?	Risk Monitoring/Controlling
Have any triggers occurred to indicate this risk may occur?—or should response be implemented?	Risk Monitoring/Controlling

Photo from John McCord, Coastal Studies Institute (NREL image 74188)

Photo by David Snowberg, NREL

Risk Management Summary and Takeaways

- NREL's marine energy risk framework can help anyone manage risks for project success. https://docs.nrel.gov/docs/fy24osti/90212.pdf
- Risk framework can and should be tailored to each project and organization.
- While risks will always be inevitable, taking calculated risks is the smart approach.
  - Know the risks you are taking.
  - Have a plan, then follow and improve it.
- Effective risk management will help you reach your objectives.
- Risk management processes become increasingly important as systems and communications become more complex.
- Reach out to David Snowberg with any questions or requests: david.snowberg@nrel.gov


NREL

Marine Energy Technology Development Risk Management Framework

David Snowberg, Ritu Treisa Philip, and Jochem Weber

National Renewable Energy Laboratory

Link to download Risk Register template
Link to download FMECA template

Q&A

NLR/PR-5000-95769

www.nrel.gov

david.snowberg@nrel.gov

This work was authored by NREL for the U.S. Department of Energy (DOE), operated under Contract No. DE-AC36-08GO28308. Funding provided by U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Water Power Technologies Office. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.

Photo from iStock-627281636

NREL