WES Development Guidance – Lessons Learnt from Real Sea Deployments

Guidance on Operations and Maintenance

WES_KH03_ER_05

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Project Participants

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Glossary

AIS	Automatic Identification System. An electronic system installed on vessels above a minimum size that sends out and receives information of location, speed and vessel details.
ALARP	As Low As Reasonably Practicable
CAPEX	Capital Expenditure. "One off" costs for the design, procurement and fabrication of an item.
CDM	Construction Design and Management
CoB	Centre of Buoyancy. The central point of buoyancy.
CoG	Centre of Gravity. The centre of mass in air, with no buoyancy considerations.
EIA	Environmental Impact Assessment
EMEC	European Marine Energy Centre
EMP	Environmental Monitoring Programme. The ongoing monitoring proposed and followed during the deployment of device and associated seabed assets.
EPS	European Protected Species
ERCoP	Emergency Response Cooperation Plan. An official plan from the MCA.
ERP	Emergency Response Plan
FAT	Factory Acceptance Test
FMEA	Failure Mode and Effect Analysis
HIRA	Hazard Identification and Risk Assessment
HV	High Voltage. Currents over 1000V AC.
IMS	Integrated Management Systems. Sometimes referred to as a Safety Management System or an Integrated Safety Management System.
LAT	Lowest Astronomical Tide
LCOE	Levelised Cost of Energy. A means of comparing the cost of energy between different sources that includes all capital costs, operational costs, depreciation, costs of borrowing money etc.
MCA	Maritime Coastal Agency
MS-LOT	Marine Scotland Licencing and Operations Team. The government regulatory body that issues marine licences and Section 36 consents.
NRA	Navigation Risk Assessment. A judgement of how much risk the device will pose to other maritime users, both in service and in the case of failure.
O&M	Operations and Maintenance
OPEX	Operational Expenditure

OSC	Orkney Supply Chain
PA	Local Planning Authority. Usually associated with any onshore works and permissions.
PPE	Personal Protective Equipment
PR	Public Relations
Proforma	Pre-prepared form for the capturing and presentation of specific data.
ROV	Remotely Operated Vehicles
SIMOPS	Simultaneous Operations
STCW	The International Convention on Standards of Training, Certification and Watch keeping for Seafarers specifies the minimum standards for training and qualification for those working at sea.
TPV	Third Party Verification
TRL	Technology Readiness Level
USBL	Ultra-Sonic Baseline. A method of underwater position measurement using acoustics.
WEC	Wave Energy Converter
WES	Wave Energy Scotland
WES Stage	A series of defined steps along a technology's TRL progression.

Executive Summary

To inform developers within the programme and to minimise the risk of having to relearn past lessons, Wave Energy Scotland (WES) has commissioned a number of projects to capture industry Know-How. This document is part of the third Know-How project, which aims to produce a set of guidance documents that draw on the lessons learnt from real sea deployments at EMEC. The guidance documents are underpinned by the deployment experience built over the last 12 years within the Orkney Supply Chain (OSC). The input to development of these guidance documents is unprejudiced in drawing together both the positive and negative lessons learnt and cover a depth of expertise captured within each of the participating supply chain companies.

This guidance document highlights the issues to be considered under the WES theme Operations and Maintenance (O&M) and specifically management of marine operations. The discussions around marine operations with the OSC highlighted the importance of effective and timely planning at WES Stage 1. The cost effectiveness of both an Operations and Management plan is emphasised throughout this guidance document and an O&M plan is required for a robust CAPEX/OPEX budget to inform a Levelised Cost of Energy (LCOE) target.

The main sections covered under O&M are:

- Planning
- Inspection and Monitoring
- Safe Operations
- Lines of Responsibility and Personnel
- Management of Operations
- High Risk Operations

There are other industry guidelines covering aspects of marine operations[1], and this report, based on the lessons learnt from the OSC, should complement these other guidelines.

The blue highlighted boxes are there to question the developer team to ensure awareness, planning, engagement and implementation of the critical, high level checklist items. Where appropriate they are referenced back to the checklist proformas.

Following the O&M document are segregated checklist proformas relevant under the O&M theme. It is important to re-emphasise the overlap of other checklists that will fall under the themes for Compliance, Installation, and Handling and have synergies within the O&M theme. Throughout the checklists, it is clear that the OSC advises developers to prepare well in advance; ensuring sufficient plans are in place to facilitate efficient, safe operations.

[1] Including, but not limited to DNV Marine Operations, General, DNV-OS-H101, 2011.

1 Introduction

The potential for job creation and internationalisation in the wave energy sector is considerable. The theoretical wave resource available to the UK alone is estimated to be up to 27 gigawatts (GW) of recoverable energy, with the opportunities for R&D immense. The European Marine Energy Centre (EMEC) in Orkney has hosted the majority of the world's wave and tidal sector prototype testing. However, challenges to the wave development trajectory in terms of device survivability, reliability and performance, including cost effective installation, recovery, operations and decommissioning works have undermined the successful development of the wave energy sector.

With the formation of Wave Energy Scotland (WES) in 2015, the aim has been to bring a measured and phased approach to technology development to address these challenges. The phased approach is now established in the stage-gated WES technology development programme. Novel Wave Energy Converters, PTO developers, material specialists, subsystem and component innovations passing through the WES programme will be thoroughly analysed and tested ensuring the wave sector is prepared and ready prior to large scale prototype deployments in the sea.

This WES commissioned guidance document has been produced to capture the knowledge and lessons learnt by the Orkney Supply Chain (OSC) during the last 12 years. The contributing companies comprised a range of expertise encompassing environmental, electrical, marine operations management, diving and vessel hire companies, and include Aquatera, Bryan J Rendall Electrical, EMEC, Green Marine, Leask Marine, Offshore Subsea Consultancy Services, Orcades Marine, Scotmarine, Sula Marine and the Xodus Group. The guidance documents demonstrate the approach taken in capturing this wealth of knowledge without jeopardising the inherent intellectual property of any individual supply chain company.

Four major themes have been considered as part of this project, and each is explored in detail in its own report delivered as part of this project;

- WES_KH03_ER_02 – Guidance on Compliance
- WES_KH03_ER_03 – Guidance on Handling
- WES_KH03_ER_04 – Guidance on Installation
- WES_KH03_ER_05 – Guidance on Operations and Maintenance

A description is provided separately describing how the project was brought together, how feedback was discussed, and how the priority lessons learnt were captured[2]. Details of participating companies are also given in this overview.

This guidance document focuses on the theme of Operations and Maintenance (O&M), and considers all the onshore and offshore activities that are part of the planned and unplanned test schedule after the initial installation of device and moorings/foundation are complete. This is specific to Stage 3 testing, as previous stages are focused on test tanks where requirements are much lower, and far better defined.

This section of the technology lifecycle can become an iterative testing phase, where lessons are learned and applied in a continuous process. Marine operations become more refined, and areas for improvement are often identified integrated into a feedback loop. Crew members become more practiced at their tasks, and thus the operation can be attempted in wider and wider weather windows, potentially moving away from daylight only operations. As marine operations (and onshore operations to a lesser extent) are such a significant part of the LCOE for a wave energy converter, it's important to take advantage of the opportunity to

[2] EMC_KH03_ER_01 – Approach and Supply Chain

refine and reduce forecasting uncertainties not only for the device, but for the support operations associated with it.

The key to making progress and gaining benefit from this iterative cycle is in the pre-planning and post-analysis of each operation. Planning should be done with experienced contractors/internal resources wherever possible, and should cover all risks, contingencies and potential opportunities. Post operational analysis provides the chance to capture what went well, what needs to be improved and any unforeseen risks that became apparent.

The following sections are not exhaustive in terms of all regulatory, standard or best practices in marine O&M. This document only includes items that were flagged as particularly pertinent issues with the OSC. Where possible, these have been described in detail in terms of the project-based requirements. The document should be used as guidance only. It should be noted that information and guidance provided within this document is appropriate at time of writing but is liable to change with regulations and legislation being updated. Developers should consult with experienced local marine contractors, engineering/environmental consultants and/or the test site management to ensure they fully adhere to safe O&M activities.

Checklist proformas relevant to the O&M theme have been provided in Appendix A: It is important to re-emphasise the overlap and synergies of other checklist proformas that will fall under the WES themes for Compliance, Handling and Installation to this O&M theme.

This suite of guidance documents should be used interactively and as an aid in providing a framework for engagement between developers and the supply chain during the planning and implementing of large-scale testing.

2 Requirements

2.1 Planning

Marine operations shall be properly planned at all stages of a project or operation. Marine operations shall, as far as feasible, be based on the use of well proven principles, techniques, systems and equipment[3].

Considerations for marine operations include:

- Data collection to determine pical local sea and weather conditions;
- Identification and selection of vessels suitable for location and task;
- Vessel audit and marine warranty surveys;
- Identification and selection of suitable ancillary equipment (e.g. towing);
- Determination of the limits for weather and sea states to conduct tasks;
- Development of safe work practices; and
- Training and competence requirements for project team working offshore.

As described in the Guidance for Compliance the following O&M plans should be initiated at WES Stage 1.

- Marine Operations
- Diver Intervention
- Maintenance
- Test Plan (wet testing, dry testing)
- Data Capture
- Integrity Monitoring
- Communications

Other plans such as commissioning, installation, and recovery are associated within the Guidance's on Handling and Installation. The OSC has witnessed developers claim they have designed out the need for diver interactions. However, the experience on site dictates that developers will need to be prepared for diver intervention, thus a plan is necessary. The results are expensive waiting times; halted installation activities, vessels on standby, while developer is waiting for next best diver availability, including time necessary for planning safe diving operations.

The importance of well-prepared marine operations documents covers all phases of the works, from start of preparations for the operation to completed demobilisation, including organisation and communication to familiarise personnel, is vital to long term cost reductions in OPEX. The O&M plan should include the following documentation:

- A description of procedures and acceptance criteria for testing/ commissioning of all equipment to be used for the operations
- Method Statements
- Description of vessels that are to be used
- Detailed procedures for all stages of the operation
- Hold and approval points and criteria for starting each phase of the operation
- Acceptable tolerances, monitoring and reporting details
- Verifications that the operations have been completed in accordance with the design and operational requirements.

[3] EMEC Guidelines for project development in the marine energy industry http://www.emec.org.uk/guidelines-for-project-development-in-the-marine-energy-industry/

Utilising the experience of local expertise and modelling tools will improve operation plans ensuring that each activity through WES Stage 1 to WES Stage 3 has been effectively planned for and executed safely. Holding initial HIRA workshops supported by drafting of the operational activities will inform the method statements as detailed in Guidance for Compliance, the tasks, and timings that should be communicated early through tool-box meetings to the appropriate marine contractors and other support personnel.

2.1.1 Environmental Impact Planning

Influencing every aspect of operations planning is the environment, which not only includes the sea states, weather, marine mammals and fisheries, but other users of the sea. The environmental impact plan and requirements are detailed in the Guidance for Compliance.

However, prior to O&M commencement, environmental statements and requirements will have been submitted, reviewed and approved by the regulator. The environmental duties during this stage are primarily related to complying with the approved plan.

In collaboration with marine contractors an environmental risk assessment and accident action plan in case of spills, etc. should be agreed. It is worth checking these documents and associated equipment are in place as a measure of contractor competence. A third party marine consultant/surveyor can check these items as part of an on-hire survey of a vessel, or as part of a contractor assessment process prior to contracts being put in place.

2.1.2 Operating Environment Considerations

The issues of weather have been discussed in the other guidance documents for Handling and Installation. Several tools are available on the market for planning marine operations. The use of an O&M tool for planning operations will take hindcast and forecast metocean information into account to inform appropriate weather windows for O&M operations. The aim is to improve maintenance scheduling thereby improving OPEX costs.

Robust communications systems are critical when the weather changes. Having clear, redundant communication systems to manage the required change in operations offshore will be vital. There will be a need for back up ship-shore and inter-vessel communications systems and this should be demonstrated in the communications plan.

Other issues with the environment consider the onshore challenges such as transporting the device on the roads. This will entail with most PA's a traffic management plan. This is discussed further in the Guidance on Handling.

Are you aware of the operational methods and tools that would be used during operations? (Stages 1 and 2)

Do you have an operations plan in place covering the system, subsystem and component interfaces? (Stages 1 and 2)

Have you taken into consideration the environmental and operational environment in your plan? (Stages 1 and 2)

2.1.3 Contingency plans

A holistic approach to total quality management needs to be adopted at the start and maintained through the progression of the device development programme. In particular, this should focus on the adoption of suitable CDM and safety management practices within the overarching IMS.

An IMS should contain objectives that underpin the programme and are implemented though a strategic plan that covers all development stages, as well as past, parallel and future activities. This often forms a statement of intent, or a list of goals upon which the business strategy and then the operational plans are formed.

Intense short term activities such as those that characterise the early stages of wet testing a WEC hold numerous risks and tend to involve more one-off type scenarios. These need active and continual management to help ensure all risks are minimised and opportunities are realised. Given the stringent demands on the project team due to the varied one-off scenarios, it is important to recognise where the team is lacking in experience and knowledge. Developing a capabilities matrix is helpful at this stage. In these cases, engaging suitable personnel to produce or review plans can be a very cost effective method.

Past experience from the OSC includes a particular instance where a mooring system proved very difficult to install. Had a suitable review process been followed sufficiently early in the design process, a number of simple changes could have been made to ensure that the components were selected with attention to deployability and maintainability, and the number of vessel days required for the task could have been drastically reduced.

The IMS should contain guidance towards management of change, as there are very few plans that remain unchanged after exposure to weather, daylight, equipment reliability and theoretical rather than practical design specifications. Small changes can, and should be managed on an ad hoc basis during operations by competent staff, with input from all involved parties present. There must however be an awareness that a certain level of change renders a procedure invalid, and operations must be halted to allow for a more detailed review in the calm of a non-operational environment. All changes to procedures however small should be captured for inclusion in later versions of operations.

It is important to try to create contingency plans to provide immediate guidance during an operation for when things deviate from the procedure. While the exact details of a failure may often differ from the contingency scenario, the approach to resolving a similar issue with regards to health safety and project risk management will be of use in the field.

A further aspect of managing change, is agreeing changes with the funding bodies involved with the device test schedule. Regular progress reports and best estimates of timelines and changed plans can give transparency and therefore confidence to investors.

Have you created contingency plans on your marine operations?
Are they reflected in your risk register?
Are they reflected in the operations method statements?
Have they been communicated appropriately to relevant partners? (Stage 1)

2.2 Inspection and Monitoring

Planning is all well and good but equally important is the inspection and monitoring activities to ensure operations do go as planned. There are levels of inspection and monitoring.

- Operational – where you inspect and monitor an activity such as the lifting of the device from shore to quay side,
- System - where you inspect the integrity of the full system, subsystem or component of a device.
- Environment – where you inspect and monitor the external conditions of the site.

Structural, electrical, and environmental (site) inspection and monitoring activities are suggested. It is emphasised by the OSC for developers to undertake a pre-operations survey of equipment or components such as moorings before mobilisation to see if there is any risk of displacement or damage that could significantly affect operations. These inspections are cost saving measures and often overlooked during operations planning. Other inspections required by regulators would be of the seabed prior to deployment and a visual verification of seabed conditions after deployment.

Are you aware of requirements for inspection and monitoring by the regulatory body? (Stages 1 and 2)

Have you engaged with a third party to undertake inspection and monitoring activities? (Stages 1 and 2)

2.3 Safe Operations

It is of prime importance to ensure that the hazards, opportunities and uncertainties associated with all programme activities are identified, understood and managed appropriately and that where necessary, suitable mitigation and insurance has been put in place. The risk register is a singularly important live document that should be updated whenever a new risk, or means of mitigation, is identified.

A complete, well-presented risk register is a first step toward a strong health and safety culture. Furthermore, it may lead to lower insurance premiums as insurers have more confidence in the level of planning being applied.

One considerable addition to the HSE burden on site can be pressure to perform. Where possible, try to disconnect the day to day operations from the financial pressures within the company. The danger of this has been shown in the previous experience of developers where pressure to perform and maintain an unrealistic schedule has resulted in mishap or failure rather than the goal of success leading to revenue. The coupling of energy generation revenues directly to the technology development pathway should be avoided where possible, through guided negotiations with investors or funding bodies.

2.3.1 Construction, Design and Management Regulations 2015

As discussed under the Guidance for Compliance, these regulations concern occupational health, safety and welfare in construction. They place responsibilities in relation to management arrangements and practical measures on a range of construction project participants, including clients, designers and contractors. The CDM regulations[4] will apply to work carried out on EMEC sites.

The Regulations replace and modify existing regulations with the aim of simplifying and clarifying the delivery of improved standards of health, safety and welfare, and related business benefits. Together with the supporting Approved Code of Practice (ACoPs), they maintain the broad level of implementation for H&S. ACoPs provide guidance on compliance with general H&S regulations. The following are regulations.

- The Health and Safety at Work Act (1974)[5]
- The Management of Health and Safety at Work Regulations 1999
- The Reporting of Incidents, Disease and Dangerous Occurrences Regulations 1995
- The Control of Substances Hazardous to Health Regulations (updated in1999)
- The Noise at Work Regulations 1989
- The Provision and Use of Work Equipment Regulations (PUWER)
- The Lifting Operations and Lifting Equipment Regulations (LOLER)

[4] Construction, Design and Management Regulations 2015 http://www.hse.gov.uk/construction/cdm/2015/index.htm

[5] Health and Safety at Work Act 1974 http://www.legislation.gov.uk/ukpga/1974/37/contents

- International Convention for the Prevention of Pollution from Ships (MARPOL)
- The Diving at Work Regulations 1997
- The Electricity at Work Regulations 1989
- Safety of Life at Sea (SOLAS)
- Code of Safe Working Practices for Merchant Seamen
- Confined Spaces Regulations 1997

The ACoP covering The Diving at Work Regulations 1997[6] is the commercial diving projects offshore ACoP. It is prudent to investigate the associated ACoPs for any of the above regulations.

2.3.2 Emergency Response/Reporting

The IMS put in place at the start of a company's development project should include clear sections on emergency response in each point during the test schedule. At early development stages this will likely be very light, and in accordance with emergency procedures at the test tank. However, as the technology moves from Stage 2 to Stage 3 there will be a significant jump in complexity and risk, and the resultant need for increased documentation is evident.

All O&M plans should have operational contingency plans in place for each step in the procedure, and sitting behind these contingencies should be an emergency response plan. This is for use when the situation changes from a means of making project progress, to the safeguarding of personnel and equipment. This ERP should have a detailed process worked out well in advance, and contracts put in place for any additional equipment or vessel hire required. These contracts should cover details like call out rates at various levels of notice, for different times and of different levels of equipment/vessels.

There are responsibilities regarding the reporting of incidents to the authorities, often determined by the impact it has on the persons involved. (see CDM Regulations 2015)

Do you have a complete Health & Safety plan mitigating risks, including covering contingencies and an ERP in place? (Stage 1 and 2)

2.4 Lines of Responsibility and Authority

Establishing a clear line of responsibility and authority is an essential and mandatory (www.hse.gov.uk) H&S requirement for the safe operation of a test plan. In the case of deviation from the procedure, or in an emergency, it is critical that there is no confusion regarding whose instructions to follow and who takes responsibility for any decision.

A chain of command should be established and available for review on each vessel and onshore workplace within any given operation.

Do you have an operations organisational chart?
Do you have supplier organisational charts linked to your organisational chart? (Stage 1 and 2)

2.5 Personnel

Different individuals, companies and agencies bring different qualities and experience to a project. It is important to recognise this, and gain an appreciation of each parties' strengths and weaknesses. Ensure that the right combination of skills, experience and competencies

[6] Diving at Work Regulations 1997 http://www.legislation.gov.uk/uksi/1997/2776/contents/made

are available, both within the lead organisation and within the wider support team, and adjust the requirements at each point in the technology development pathway.

An example of this can be shown in mooring design, specification, procurement and deployment. Moorings require a certified review of the hold capacity versus the anticipated loadings, so the expertise of a certified TPV organisation is essential (required for insurance and marine licencing). This however will only tell you that a particular collection of components is capable of withstanding the design loads, but says nothing about how easy it is to deploy, which vessels can carry out the work, and its ease of maintenance. To determine these often overlooked aspects, dialogue is needed with appropriate supply chain members during the design phase. During the deployment of the moorings there are industry best practices regarding connections such as shackles, and this requires experienced contractors to lead by example. Considering verification and installability at the appropriate stage is an important part of risk management and optimised procedures.

Many of the issues associated with installation and recovery are not specific to each WEC type but more specific to the wave energy sector and the site being worked at. Specific experience of planning and managing WEC related operations at a particular site is invaluable when providing insight and guidance to any installation and recovery team.

Many issues that have arisen to date within WEC O&M were foreseeable, with the OSC providing advice and insight as to how the operations might be tweaked to have a higher success rate. However, this insight was not utilised by developers at the time, leading to some expensive mistakes.

The perception from developers that oil and gas or offshore wind experience would be directly transferable to the uniquely challenging wave environment has also been incorrect. It's worth noting that suppliers outside the sector often operate with this same misperception, so care must be taken when developing requirements for tender, to ensure they capture the unique challenges of a wave energy site.

It is recommended that a safety officer or observer are staffed and involved in monitoring and controlling the O&M activities. The role gives time and direction to the oversight of operations without being directly involved with them, and can highlight safety issues and inefficiencies where they exist. This is especially important at the start of the large scale testing, as the equipment and tasks will be unfamiliar and crew will be learning the intricacies of the devices interactions with the working environment

Have you created and evaluated a capabilities matrix for your O&M activities? (Stage 2)

Have you engaged with relevant marine contractors to support planning of the O&M activities? (Stage 2)

2.5.1 Communications and Reporting

Clear communications are required for many aspects of a test programme, from vital emergency communications, to performance data collection and transmission from a device to shore. These communications can be done in various ways using different technologies, but a mistake often made is to assume that remote test sites enjoy the same benefits that more central areas do in terms of mobile phone reception. Many sites have little to no reception, meaning that mobile coverage is by no means a certainty. Alternative technologies include the use of VHF radios which are more reliable. These do however require a licence to use and their use is restricted on land.

It is well worth asking local supply chain about their experience on the site with communications, or adding phone reception strength and capacity to site survey requirements during the earlier stages of design work for a large-scale device, to be deployed in Stage 3.

Have you visited the site to understand the communications requirements both in terms of equipment and communication routes? (Stages 2 and 3)

Communication on an external level is also worth considering and building into plans. Specifically, PR and stakeholder engagement are important data streams to be aware of. Maintaining control of what information is released can be more complex than anticipated, with pictures of marine operations activities appearing unauthorised on social media. It is important that the need for confidentiality is explained to all the maritime team, including pilot boats etc. This uncontrolled release of data can become an issue when local stakeholders build up an incorrect picture of a situation, especially if things go wrong.

Ensuring that a good communications strategy is in place ahead of operations, which can then be utilised throughout operations, will be helpful for keeping people informed of what has actually happened, rather than what casual observers or contractors may believe. Extended periods with a lack of information will only lead to more speculation about what is taking place.

Do you have a communications plan that covers all aspects of external communication to your stakeholders? (Stage 1)

Do your suppliers realise their responsibilities in terms of PR and social media? (Stage 1)

2.6 Management of Operations

EMEC has an applied IMS for the management of QHSE issues within all areas that constitute EMEC both on sea and on land. The management of these activities includes the activities undertaken by developers using the site (s), to the extent that they may affect the safety of activities conducted on site, the safety of other users of the site, the environment or the integrity of assets of EMEC or the other developers. Following describes some of the key management issues all developers should consider to develop as part of their respective IMS documentation.

2.6.1 Management Systems

Developers shall employ recognised health, safety and environmental management systems.[7] It is a contractual requirement for the Developer to provide EMEC and other relevant stakeholders with access to all relevant health and safety documentation.

It is expected that the choice of marine contractor by the developer will be based on the contractor's experience in the field of similar marine operations such as offshore and other marine renewable energy projects. In all cases the contractor shall have a sound Safety, Environmental, and Quality Management System in place and be compliant with the requirements of the CDM Regulations (2015).

A HAZOP (Hazard Operational Analysis), HAZID (Hazard Identification) and appropriate risk assessments shall be carried out for the proposed marine operations. During this process the key individual skills and experience, regarding the project, of management and operational personnel such as barge masters and tug skippers shall be identified. The developer should ensure that the requisite number of trained and competent supervisors are appointed to effectively manage all hazardous operations and ensure that all risks are adequately mitigated.

2.6.2 Management of Resources

Operational planning, and use of the 'right resources in the right way', is the bedrock of successful and cost effective installation and recovery operations.

An effective, thorough plan will save time and effort at each stage in device development, whether in a laboratory, factory, on land or at sea. It is best to establish the routine/cycle of method statement, risk assessment, risk mitigation, contingency plans and emergency plans from an early stage to ensure best practice is followed. While the operational costs are comparatively low in WES Stage 1 and Stage 2 compared to open water testing with vessels and support personnel, tank testing is still an expensive operation for early TRL developers, and as such, care should be taken to approach tank testing with a solid plan, with contingencies and alternatives put in place, so that the time in the tank is not wasted due to predictable failures and errors.

2.6.2.1 Vessel Selection

All phases of a marine renewables project test schedule in open water will involve vessel based activities requiring the selection of the most suitable type of vessel for each phase.

Vessels will be required that are suitable to deploy/retrieve the device, for cable laying and other offshore installation works. Wave devices and subsystems will be deployed in areas that maximise their potential, which by necessity will include high wave heights, potentially significant tidal flows, and short duration weather windows. Currently there are few, if any, purpose built vessels for these environmental conditions and therefore, early work will be required to identify suitable vessels[8].

Vessel operators should provide in draft how the vessel will support the deployment procedures. This review should be at a sufficiently early stage (WES stage 2) in device design that changes can still be made if needs be. It is important to note that gradual changes in design over time can lead to increases in mass or similar limiting factors that can have step change impacts on the type of vessel required and therefore, the cost of hiring marine services. It is suggested to identify such limits in dialogue with suppliers and be mindful of these when proposing design changes. The full scope of implications can be addressed with this in mind.

Installation costs can be a significant proportion of the device development budget and may escalate due to several factors such as weather down time, multiple deployments due to equipment failure or poorly planned procedures. The approach to installation should therefore be prioritised and included in the design stage in order to minimise costs. There should also be a realistic approach taken to the possible escalation of costs, essentially preparing the budget to include contingency. An appropriate reserve fund specific for any decommissioning should be established. This is covered in more detail within the compliance section.

Have minimum vessel capabilities been defined and matched against those available? (Stage 2)

[8] For additional information, EMEC recommends the RenewableUK Vessel Safety Guide 2015. https://c.ymcdn.com/sites/www.renewableuk.com/resource/collection/AE19ECA8-5B2B-4AB5-96C7-ECF3F0462F75/Vessel_Safety_Guidance.pdf

Have you engaged with local vessel operators to fully understand the vessel capabilities? (Stages 2 and 3)

2.6.3 Management of Deployability

Deployment here is bounded as the temporary installation of a device, or part of a device that is intended to be recovered to shore, or to sheltered waters for maintenance. It does not cover "permanently" installed items such as moorings and foundations, as this is detailed in the installation section.

Scaled tests may not use the same configuration of deployment and recovery as later large-scale and full-scale commercial devices, but it is important to consider handling/lifting activities for each, as design choices can strongly affect ease of deployability, as well as the numbers of vessels, crew and operations required to eventually complete the task.

It can be difficult to imagine and plan for lifting and towing large scale devices while handling small scale devices in a test tank, but this exercise is full of merit and should be carried out as completely as possible prior to the design phase of the WES Stage 3 device. Testing strategies for installation at small scale have been shown to have a positive effect on defining the full scale strategy.

When provisional deployment/recovery plans have been drafted for Stage 3 testing, if you do not have the competency in house for a competent review, consider engaging the expertise of marine consultants or contractors to provide experienced oversight.

2.6.4 Management of Maintenance Operations

Planned preventative maintenance should take place during the summer months when both safety and schedule risks are as low as possible. Any efforts that can be undertaken in the summer fair weather periods should be used to avoid the requirement for work to be completed in the winter months where daylight and fair weather combinations are limited.

2.6.5 Management of Safe Operations

Safety must remain paramount within the industry, and the WES development program will highlight and emphasis this mindset as the baseline of all operations.

A lack of planning, appropriate contingencies and awareness of offshore safety limits and working practices by a developer can lead to an assumption that supply chain companies can bend the rules to meet their requirements. This is not acceptable, and requests of this nature will be refused. Operations must be planned in detail in advance, and discussed with all relevant parties to ensure that no risks to safety have been left unaddressed.

An attitude of "let's see what we do when we get there" within marine operations is intrinsically unsafe, and will not be tolerated within the WES program.

2.6.6 Management of Multiple-contractors

Operations and Maintenance activities often involve multiple resources from multiple suppliers completing multiple activities. To provide continuity, flexibility and adaptability between contractors, a dedicated planning and management role to provide oversight can be very beneficial. Such an approach is also likely to lead to a reduction in insurance premiums if suitably qualified, experienced and proactive management is in place, as has been shown in the offshore oil and gas industry.

The development of procedures shared across multiple resources should be done with contingency in mind. This requires that a Plan B is in place, and that any additional equipment which would be required for Plan B is fabricated and tested to the same level of quality as the rest of the device. For example, suitable accessible lifting/recovery points should be installed on all major structural elements and these should be lift tested so that they can be recovered individually if they become detached from the rest of the device.

2.6.7 Management of Failure

When testing new technologies, it is important to recognise that failure of components or subsystems is inevitable and forms an essential learning aspect of the product development cycle. FMEA is an integral reliability assessment process and should be detailed down to the component level and understood well before marine operations begin.

However, once at the test site, capturing and analysing the details of any failure is an important part of this cycle, and one that can be left aside in the rush to prove full system capability. To illustrate, previously developers have been noted to continually replace a failed bearing with identical components, without appearing to analyse wear patterns and failure modes in order to specify/develop new and improved bearings for inclusion in the device. While it is recognised that this can often be a stop gap to keep a test programme on track, as it is not always possible to redesign/fabricate/procure bespoke items quickly, this should not be the final solution. Including costs for failed component testing/analysis will secure greater knowledge for the developer, including informing and adding greater certainty to the preventative maintenance plan. For earlier Stage 1 designs, using conservative standard, marinised components will mitigate against the high-risk failure mode such as corrosion.

A procedure should be put in place to capture the detail of a failed component, to ensure the comprehensive review of a failure and to outline proposed remedial action. In addition to component or system failure, there is also procedural failure to be considered. This can be recorded through daily reporting logs, incident reports, or through the analysis of video recording of operations. The feedback of where procedures have failed is critically important in the updating of the risk register, and the procedures themselves.

EMEC has a failed component capture, and handling procedure in place to ensure that components are not 'binned'. The challenge is to ensure that a budget is in place for analysis of failures and the data captured in a database like the WMEP[9] wind reliability database or OREDA[10] reliability database for the Oil & Gas sector. A dedicated reliability database for wave and tidal energy would prove beneficial for the ocean energy sector.

Have the potential failures (FMEA) in your system been identified? Has the process for managing, handling, recording, analysis and feedback into your design optimisation stage been demonstrated? (Stages 1 and 2)

Do you have component spares? (Stage 2)

2.7 High Risk Operations

2.7.1 Diving Operations

Diving operations are one of the single most risky operations involved in offshore testing activities. Diving is a heavily regulated industry, with strict limits on many of the core aspects such as working depths, times and weather conditions.

9 Fraunhofer Wind reliability database http://windmonitor.iwes.fraunhofer.de/

10 OREDA Offshore Reliability Database for O&G http://www.oreda.com/

The experience of every developer that has tested in Orkney waters is that even if they had not planned for diver interaction upon their device, failure(s) have meant that the contingency plans put in place have required diver intervention. As such, it is recommended to include design features to make diver intervention a less arduous task. This is particularly the case for initial large-scale deployments, where the test programme is still part of ongoing R&D.

Given the levels of specialisation in commercial diving, it is unwise to assume knowledge of capabilities from a non-diving or even recreational diving point of view. Plans and procedures that involve divers should be written by, or at a minimum quality checked by, divers to ensure that the tasks are practical and achievable, following standards, and are ultimately safe.

Examples of aspects to consider include keeping the maintainable components as shallow as possible, ensuring there is space for manual tools when tightening/loosening bolts, etc., and that there are grab handles or leverage points for divers to work against if they need to apply force to a device.

Have you engaged with commercial offshore diving experts early on? (Stage 2)

Have you considered diving interventions in your deployment, installation, recovery, maintenance and decommissioning plans? (Stage 2)

2.7.2 Crew access to Wave Energy Converters

Putting crew onto or into a WEC while they are deployed is a high-risk activity and should be avoided or minimised, wherever possible. When developing procedures for safe personnel access and egress, consideration should be given (but not limited) to the following:

1. Metocean limits (sea state, wind, temperature, etc.) for safe access, which may require to be lowered during the hours of darkness or in poor visibility;
2. PPE (sea survival suits, lifejackets, footwear, etc.) required during access;
3. Maximum loads including number of personnel accessing devices;
4. The provision of suitable training, for example, confined space working;
5. Emergency plans to remove casualties to a place of safety.

Personnel transfers offshore should always be limited to those deemed strictly necessary, as is the case in other offshore industries. It is imperative that a risk assessment is carried out to develop appropriate control measures including safe systems of work for personnel transfers.

Have procedures and risk mitigations been developed for safe personnel access and transfer activities? (Stage 3)

2.7.3 Confined Space Working

Where a wave device or component is of a size and scale where access to its internals is possible and/or required, then the type of working space categorisation is worthy of consideration. The atmosphere within a wave device may have reduced levels of oxygen, or only one route of entry and therefore, should be considered as a confined space. This is a defined term, in The Confined Spaces Regulations 1997[11], which has implications towards mandatory steps taken before and during access.

It is preferable to prevent the need for a person to enter a confined space. This is particularly relevant offshore where the additional complications of safe access and egress to/from the WEC are likely to hinder an effective response to any incident.

At the design stage, consideration should be given to eliminating the need to enter the device when it's deployed to carry out tasks such as data collection, condition monitoring etc.

Where entry is required then a fully trained, competent person should determine the suitable precautions required. These may include, but are not limited to

- Testing and monitoring for oxygen levels, toxic contaminants, etc.;
- Purging and venting the space to maintain a safe atmosphere;
- Isolation of gases, liquids, mechanical and electrical equipment;
- Provision of suitable equipment, PPE;
- Safe means of access and egress;
- Documented and practised emergency arrangements; and
- Suitable instruction, information, training and supervision.

Will there be a requirement to conduct confined space working for maintenance and inspection crew? (Stages 1 and 2)

Have you planned utilising the ACoP for safe work in confined spaces? (Stages 1 and 2)

2.7.4 Electrical operations

There is considerable overlap between electrical operations and marine operations, with some important safety implications to be accounted for once the device is built. The safety aspects are covered in greater depth in the Guidance for Compliance. The challenges should be planned for early at WES Stage 1. At Pre WES the device concept must balance the power capture and generation characteristics in order to develop a reliable and maintainable device. Forward design planning should include reserving the necessary space for heating and cooling equipment, energy storage, and redundancy in your power electronics and controls. WES Stage 2 activities should investigate a means for isolating the PTO of the device in order to allow for safe working conditions. It is critical to design in structural and mechanical protection for maintenance crew as well.

Past issues at EMEC sites have occurred where cables left on the seabed between deployments have not been left in a testable state. This doesn't allow for condition monitoring/verification, and means that for the cable to be handed over in a verified state a separate vessel deployment is required to lift the cable for testing.

When cable faults are noted onshore after disconnections, the cost to test and, or repair at the offshore cable end is usually not accounted for by developers. They are responsible for returning a cable in the same state they received it (not including incremental wear and tear).

Remote communications during operations are an essential function when operations monitoring and control are to be done remotely from an office. There are cases where

[11] Safe work in confined spaces ACOP; Confined spaces regulations SI 1997 No. 1713 and renewableUK Confined Spaces Circular 2015

computer control/interaction isn't sufficient; the onsite personnel should be adequately trained to handle the onshore electrical equipment to mechanically resolve tripped breakers and the like.

The control of electrical safety, especially when done between a vessel and personnel onshore, is focussed around the use of permits and clear live communication with double checks and confirmations. While electrical contractors are familiar with the use of these permitting procedures, developers and some marine contractors are unfamiliar, and will need training.

Have you produced documentation to cover PTO commissioning, operation and maintenance? (Stages 1 and 2)

Does the maintenance plan include cable connection and disconnection activities to include cable end testing? (Stages 1 and 2)

2.7.5 Simultaneous Operations (SIMOPS)

The control of simultaneous operations[12] between multiple vessels offshore and between on and offshore works is often a weakness in the planning of operations. This can lead to ineffective operations, damage to equipment and a significant increase to risk of harm when dealing with electrical and fibre optical cables. Solutions used to mitigate these issues revolve around improved communication, and familiarity with permitting procedures surrounding safety, such as the use of permits to work and certificate of isolation.

There are solutions that can be integrated into the navigation systems of vessels that allow for precise display of the location of each vessel, including any ROVs in use. This level of information can allow for more informed control of operations. AIS, DGPS and USBL technologies all contribute to a clearer picture of locations of all vessels, ROV's and other underwater assets.

An overall, SIMOPS communications plan should be established for the duration of the SIMOPS based on safety management procedures to ensure that activities are controlled by a single, appropriate authority and that responsibilities for emergency responses are clearly delineated and the actions properly coordinated.
SIMOPS plans include the following;

- Proximity and juxtaposition of vessels, work platforms, devices and associated moorings
- Vessel(s) emergency plans and site egress routes
- Communication plans between EMEC, developers and contractors
- Onshore resources or facilities conflict e.g. electrical testing, energisation or isolation controls
- Radio channel conflict
- Availability of nominated decompression chambers for multiple diving operations
- Local navigational impact – consolidated NTM, need for guard boat etc.
- Local environmental impact – additional noise, light pollution etc.

Have you considered in your O&M plan coverage of SIMOPS? (Stage 3)

Have you included a SIMOPS communication plan to include backup communication systems? (Stage 3)

[12] EMEC Control of Simultaneous Operations SOP

3 Conclusion

The Operations and Maintenance phase of a WES Stage 3 technology programme will be its longest in terms of marine operations. It is a high-risk phase for the project and must be conceptualised early on in design considerations. At Stage 1 and Stage 2 appropriate planning for vessels, divers, and other support personnel will be required. Prior to Stage 3 and entry into real sea testing, a strong proactive management culture will ensure all personnel will be aware and accept ownership of H&S practices. It is highly recommended that a safety officer or observer is reporting and documenting all O&M activities in order to improve device deployment, recovery, operations and maintenance activities. Equally important, as mentioned in the Compliance guidance document, is the incorporation of CDM regulations in all operations and maintenance activities. The above discussions underpin the checklists that are detailed below.

Following are the O&M checklist proformas. It is important to note the checklists are categorised under the respective WES Stage (Pre-WES, Stage 1, Stage 2, Stage 3) based on the following guidelines for relevance. At the appropriate stage the developer should be:

- Pre-WES – Gain an awareness of checklist item. Understanding differences in requirements between sites.
- Stage 1 – Plan for addressing checklist item, taking into consideration statutory timescales/requirements where necessary. Be aware of design modifications that may be required in following stages, mitigate where appropriate.
- Stage 2 – Engage/collaborate/analysis during scale tank testing to mitigate/address checklist item. Begin preparing required plans ready for completion/submission and implementation in Stage 3. Ensure plans are in line with available standards, guidance documents and best practice.
- Stage 3 – Implement checklist item in onshore/offshore activities. Record any lessons learnt and opportunities for future testing, disseminate findings for industry-wide learning.

3.1 Checklist Definitions

The Checklist threads below in Table 1 are the priority checklist items covered in detail with the OSC and prioritised under the O&M guidance. The OSC agreed on specific definitions for each thread for clarity. The proformas should be used interactively and provide a framework for further discussion ahead of future activities.

Table 1 - Checklist definitions

Thread	Definition
Operations planning	Ensuring that each operational stage, whether in a laboratory, factory, on land or at sea, is effectively planned and executed.
Contingency arrangements	Suitable plans and related arrangements are in place to implement if and when things change or don't go as planned.
Site conditions	Ensuring that the specific influences of environmental, social and industrial site conditions on design and operations are understood. This includes taking into account both the laboratory and factory conditions and onsite reality of onshore and at sea conditions.
Electrical Operations	Ensuring that electrical functionality is introduced at a sensible stage in the technology development process and that all electrical interfaces are standardised as far as possible.

Thread	Definition
Inspection and Monitoring	Ensuring that suitable means for inspection and monitoring have been considered and put in place covering integrity, performance, environmental interactions, safety etc.
Device Structure	Ensuring that there is appropriate integrity within the structure of the device for all stages of handling and deployment and that this integrity is monitored during device deployment.
Components	Ensuring that sub components are suited to the conditions and load cycles that they will experience, that the quality and performance of the components has been verified, and that sufficient spares and identified sources for replacements are available.

Appendix A: WES Development Pathway and Checklist Proformas

Throughout the development workshops the documenting of supply chain issues and recommendations was carried out using proformas. The workshops were designed to build the proformas and indicate which specific topic and associated issue were important to address at which WES Stage.

An indication of the topics that should be considered at each Stage of the WES NWEC Programme has been provided below. In addition, a high level overview of the pre-WES requirements is also included. It is understood that each of the WES programmes will have a variation of these typical activities, dependent on the system development programme and the most appropriate stage gated progression. The checklist proformas for each of the prioritised OSC threads relevant to O&M follow this.

Pre WES Concept Creation Feasibility Work	**WES Stage 1** Concept Characterisation & Refinement	**WES Stage 2** Concept Optimisation & Demonstration of Engineering Specification	**WES Stage 3** Small Prototype Development
• Basic technology research • Technology concept formulated • Geometry • Hydrodynamics • Numerical modelling • Natural period • Weight distribution • Small scale tests	• Concept development • Systems engineering • Numerical model and simulation • Power performance estimates • Device efficiency • Shape optimisation • Scale model / component testing	• Concept refinement • Technology optimisation • Control system design • FEED study • Large scale tank testing • Numerical model validation • LCOE calculation • CAPEX estimation • Subsystem testing	• Refined system • Design and fabrication understood • Large open water model developed • Fully operational system • Performance proven for full system • Certification of system

Operations planning	Aim: Ensuring that each operational stage, whether in a laboratory, factory, on land or at sea, is effectively planned and executed.

This involves implementing the WES phased approach to system design. The staged system design plan will fundamentally inform the operational planning phases at WES Stage 1 & 2 based on the system, subsystem and component size, weight, layout, interfacing and handling of the device.

At the early stages, it is essential to begin to understand how the device will be deployed and make the necessary design decisions to ensure that it will be an effective and simple operation. Early engagement with the local supply chain will bring intangible benefits to the design process, particularly from experience of the site conditions and understanding the resources/equipment available. Once the necessary operational plans have been developed for installation, handling, O&M and decommissioning, it is essential to storyboard these with the marine contractor to identify possible risks and issues.

Operational plans remain live documents which are continually updated to reflect current practices and lessons learnt. As the operational plans are updated with more detail, it is necessary to review the strategic programme plans in light of changes and ensure there is a feedback loop. HIRA workshops should be conducted with both marine and onshore contractors present to ensure there is continuity in the planned works, results will inform the operational method statements. Clear and concise method statements including contingency plans should be discussed at the tool-box talks. To accelerate the learning process, utilise local expertise and modelling tools, particularly regarding site conditions and limitations. The practicalities of decommissioning should be considered prior to installation to fully understand the requirements for such an operation.

Pre WES	**WES Stage 1**	**WES Stage 2**	**WES Stage 3**
☐ Gain an awareness of typical operational methods. ☐ Be aware of potential deployment site conditions and impacts to technology programme.	☐ Produce and implement method statement / test plans for any Stage 1 testing. Refer to existing methods and standards where available. ☐ Develop and maintain operational plans for future testing in WES Stage 2 and 3.	☐ Evaluate general site needs and select appropriate sites(s) for further, detailed planning. ☐ Lessons learnt during Stage 1 testing are reviewed and incorporated into appropriate Stage 2 and 3 plans. ☐ Hold an initial HIRA workshop, supported by appropriate planning for installation and handling activities. ☐ Develop prospective O&M schedules with appropriate onshore and marine contractors. ☐ Ensure onshore space requirements (temporary and permanent) and leasing requirements are planned for.	☐ Update, review and refine the HIRA report from Stage 2. Implement HIRA findings within operations. ☐ Finalise storyboard for Installation, Handling, O&M and Decommissioning ☐ Ensure that suitable onshore facilities for testing and welfare are in place. Create safe zones around onshore equipment to prevent accidental interaction with the general public. ☐ Provide full and sufficient documentation and FATs to ensure smooth handover of the device from the fabrication contractors to the test support contractors. ☐ Develop a traffic management plan, mitigation measures and contingencies if large loads are to be transported to and from site. Engage closely with the local planning authority to understand if there is a statutory requirement for a traffic management plan. ☐ Plan for transit to site in operations plan. Have a standalone tow plan if towing is required. ☐ Plan Tool Box meetings before each operation, both onshore and offshore, where

			managers/senior staff explain in detail to all involved the operations, roles, responsibilities and risks. ☐ Use third party peer review as a quality control step of method statements.

Relevant Industry Standards, Guidelines
EMEC Guidelines for manufacturing, assembly and testing of marine energy converter systems http://www.emec.org.uk/guidelines-for-manufacturing-assembly-and-testing-of-marine-energy-conversion-systems/ Carbon Trust guidelines on design and operations of wave energy converters http://www.gl-group.com/pdf/WECguideline_tcm4-270406.pdf DNV Marine Operations, General, DNV-OS-H101, 2011. https://rules.dnvgl.com/docs/pdf/DNV/codes/docs/2011-10/Os-H101.pdf

Contingency arrangements	Aim: Suitable plans and related arrangements are in place to implement if and when things change or don't go as planned.		
Contingency is an important concept due to the remote nature of the test areas, plus the difficulty of accessing a device once deployed. Marine operations are one of the major costs in a test schedule, so implementing engineering contingency/redundancy can offer considerable savings. Delays in procurement, both due to bespoke components and delivery times to remote locations can impact test schedules, so an approach of FMEA followed by strategic spares procurement is advised. Have contracts detailing day rates and contingency method statements in place for all marine activities. If ERP requires use of/ interaction with bespoke equipment, consider providing familiarisation with key contractors. Show consideration of recovery of components that may separate from device during failure event. Put contingency into communication plans. Contingency is also an important consideration in programme planning, and management of any changes to the development programme is another aspect that should be considered.			
Pre WES	**WES Stage 1**	**WES Stage 2**	**WES Stage 3**
	☐ Identify and develop operational contingency plans.	☐ Full develop Plan B operational contingency plans. ☐ Consider how advanced warning of the potential failures might be modelled or measured for components	☐ Ensure contract is in place with marine operations to cover contingency and emergency plans ☐ Hold adequate component spares in Inventory. ☐ Carry out FMEA for Stage 3 device. ☐ Create spares inventory strategy to reduce delays in testing. ☐ Build requirement for Emergency Response Plan (ERP) for Stage 3 open-water testing into budgets, and start contractual negotiations with likely contractors.
Relevant Industry Standards, Guidelines			
Project Management Institute www.pmi.org Standard for Program Management – 3rd Edition.			

<table>
<tr><td>Site conditions</td><td colspan="3">Aim: Ensuring that the specific influences of environmental, social and industrial site conditions on design and operations are understood.</td></tr>
<tr><td colspan="4">This includes taking into account both laboratory and factory conditions and onsite reality of onshore and at sea conditions. In early stages of concept design, consideration of separate component tests in offshore site conditions is less expensive than building a full scale system for survivability, reliability, and performance testing. The feedback and knowledge gained can inform an integrated system and subsystem concept refinement and optimisation. The physical oceanographic and hydrodynamics of the site describe the range of conditions that may be experienced over time and location, this is vital for modelling overall performance. Onshore site conditions are critical to understand, for example seasonal weather variations which impact device handling. Early engagement with local marine contractors with knowledge of the environmental and practical site conditions, can improve device design and deployment planning.</td></tr>
<tr><td>Pre WES</td><td>WES Stage 1</td><td>WES Stage 2</td><td>WES Stage 3</td></tr>
<tr><td>☐ Describe in concept feasibility what types of site conditions your device is targeted at and may be sensitive to.</td><td>☐ Show through preliminary analysis how structural integrity is achieved and maintained.</td><td>☐ Select Stage 3 test site(s) and schedule site assessment visits.
☐ Collate and manage environmental site data, identifying gaps against what is needed within the design parameters.
☐ Evaluate the use of modelling tools for incorporating environmental data and hydrodynamics to describe the range of conditions that may be experienced on site over time and location.
☐ Prepare weather window scenarios incorporating wave/tidal hindcast data.
☐ Establish site data requirements for any onshore sites.
☐ Develop plans for welfare needs and human logistics as part of onshore planning.
☐ Materials considered should be evaluated against corrosion or other mechanical/ structural failure modes of device</td><td>☐ Monitor and analyse data to ensure that site conditions have remained consistent since the surveys undertaken as part of the FEED study.
☐ Plan for remote site maintenance facilities with spares and toolkits.</td></tr>
<tr><td colspan="4">Relevant Industry Standards, Guidelines</td></tr>
<tr><td colspan="4">EMEC Guidance on Assessment of Wave Energy Resource http://www.emec.org.uk/assessment-of-wave-energy-resource/
IHO (International Hydrographic Organisation), 2008 Standards for Hydrographic Surveys http://www.iho.int/iho_pubs/standard/S-44_5E.pdf
IEC TS 62600-101:2015 Marine Energy, Wave, tidal and other water current converters – Part 101: Wave energy resource assessment and characterisation https://webstore.iec.ch/publication/22593</td></tr>
</table>

Electrical operations	Aim: Ensuring that electrical functionality is introduced at a sensible stage in the technology development process and that all electrical interfaces are standardised as far as possible

Electrical isolation in several forms will be essential in consenting and providing safe working access to devices. Some purely structural testing may be advantageous prior to energising the device. Sanity check all plans with test tank operators and contractors supporting open water test sites to confirm availability and strength of power supply. Remote locations have weak grids that cannot handle large fluctuations such as a hydraulic power pack starting up, and may not have generators available to provide power for the onshore commissioning of a device. Consider the requirements of physically making electrical connections during deployment planning.

Pre WES	**WES Stage 1**	**WES Stage 2**	**WES Stage 3**
	☐ Plan ahead for inclusion of electrical and cooling equipment. ☐ Initial device concept design should be carried out balancing the importance of power generation, structural integrity, reliability and a low LCOE in concept development.	☐ Demonstrate that lessons learned from experienced electrical, PTO and WEC contractors have been taken into account in design. ☐ Design must include redundant means of isolating the PTO of the device to allow for safe working conditions. Build a Connection/Disconnection test plan with contingency for failures at each point. Include in section of Marine Operations plan. ☐ Design in structural and mechanical protection of electrical connection system. ☐ Recognise ahead how some tasks may have to be assigned to non-electrical persons i.e. divers. ☐ Consider if onshore electrical test facilities are required before final launch and deployment.	☐ Produce full documentation to cover WEC/PTO/subsystem electrical commissioning, operation and maintenance ☐ Test communications, especially if needed for active control of device ☐ Ensure cables are left in a testable and recoverable state on seabed between deployments and post deployment. ☐ Plan for remotely operated equipment and train key personnel to act as local responders.

Relevant Industry Standards, Guidelines
Electricity at Work Safe Working Practices – HSE 85 http://www.hse.gov.uk/pubns/books/hsg85.htm BS 7671:2001 Requirements for Electrical Installations

Inspection and monitoring	Aim: Ensuring that suitable means for inspection and monitoring have been considered and put in place covering integrity, performance, environmental interactions, safety etc.		
Structural, electrical (ship to shore) and environmental (site) inspection and monitoring plans are suggested and in some places required. It is suggested that there be an initial vetting of contractors, and some degree of ongoing oversight to ensure standards are maintained. Undertake a pre-operations survey of deployed equipment such as moorings before mobilisation to see if there is any risk of displacement or damage that could significantly affect operations. Inspection of seabed prior to deployment, and visual verification of seabed conditions after deployment are required by regulators.			
Pre WES	**WES Stage 1**	**WES Stage 2**	**WES Stage 3**
☐ Be aware of the benefit of, and statutory requirements for, inspection and monitoring of internal components, the whole system, the wave resources and environmental impacts to reduce risk of failure and downtime of the device.	☐ Identify and plan for inspection and monitoring activities.	☐ Develop a FAT for the commissioning of the Stage 3 device. ☐ Inspect site ahead of commencement of installation activities	☐ Carry out required environmental monitoring plan to satisfy regulator. Ensure the tools and procedures are in place to satisfy the compliance plan. ☐ Apply a rigorous approach of photographing the complete installation activities to capture placement of all components, ties etc. ☐ Photograph everything coming out to capture wear patterns, corrosion, fouling etc. ☐ Maintain and monitor a detailed site plan identifying all subsea assets, including those buried. ☐ Conduct a post decommissioning survey immediately after all removal works have been completed.
Relevant Industry Standards, Guidelines			
EMEC Guidelines for manufacturing, assembly, and testing of marine energy conversion systems, 2009. http://www.emec.org.uk/guidelines-for-manufacturing-assembly-and-testing-of-marine-energy-conversion-systems/			

Components	Aim: Ensuring that components are suited to the conditions and load cycles that they will experience, that the quality and performance of the components have been verified through dry and wet testing, that sufficient spares are readily available, and suppliers have been identified and noted for replacements where spares are not pre-purchased.		
The components within a wave energy device may be completely bespoke, or they may be off the shelf from a different industry. However, the same challenges are experienced once they are assembled and combined to form subsystems within the device. These challenges are focused around the application of partially unknown load cases, in remote parts of the country, in expensive to access devices deployed in a highly energetic and corrosive environment. Mechanical failure is common in the industry as peak loads are often higher than expected. Corrosion is also a significant issue, with dissimilar metals providing electrolytic reactions leading to the eventual failure of the component. This is particularly common in electrical connectors, as once a small level of corrosion occurs, electrical leakage follows and the process is accelerated. Avoid dissimilar metal interfaces wherever possible, and be very specific when defining materials, and during assembly to ensure that electrochemical isolation is put in place where designed.			
Pre WES	**WES Stage 1**	**WES Stage 2**	**WES Stage 3**
☐ Identify potential component failures. ☐ Awareness of industry best practice or existing guidelines/standards on components. Including integrity design codes. ☐ Plan to utilise standardised components where possible.	☐ Concept engineering to develop risk register. ☐ Create initial component specification listings.	☐ Create an engineering Bill of Materials (BOM) register to include components. ☐ Evaluate the cost/quality balance when sourcing components. ☐ Design in standard cable connectors. ☐ Optimise design and procurement for wet tested, warranted quality components that are 'saltwater safe'. ☐ Update FMEA analysis; update risk register. ☐ Plan to use mutually compatible materials for the salt environment. Be aware that even small differences in electrochemical properties can result is fast and excessive corrosion.	☐ Monitor & Control component / asset management system (manufacturing Bill of Materials) is in place. ☐ Ensure vulnerable components such as cables are fully protected during commissioning and installation. ☐ Separately test critical components for performance and reliability. ☐ Monitor critical components during operation to identify impending failure where possible ☐ In case of component failure, ensure analysis of failure is fed back into risk register and BOM. ☐ Carry suitable spares for critical components. ☐ Utilise a process for analysing failed components so lessons can be learnt.
Relevant Industry Standards, Guidelines			
OREC Marine energy component analysis, 2016 https://ore.catapult.org.uk/wp-content/uploads/2016/08/PN78-SRT-001-Rev-0-Case-Study.pdf OREC Good Practices for Handling and Investigating Failed Components, 2016 https://ore.catapult.org.uk/wp-content/uploads/2016/08/PN78-SRT-002-Rev-0-Good-Practice.pdf WES Knowledge Capture project Aquamarine Power Limited			