ENVRI^plus DERIVERABLE

D3.2
New set of standards for the qualification of instruments towards extreme conditions

WORK PACKAGE 3 - Improving measurement networks: common technology solutions

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Author(s):	Beneficiary/Institution
Vito Vitale	Consiglio Nazionale delle ricerche (CNR)
Mauro Mazzola	Consiglio Nazionale delle ricerche (CNR)
Federico Zardi	Consiglio Nazionale delle ricerche (CNR)
Jean Francois Rolin	IFREMER
Laurent Delanuey	IFREMER

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ABSTRACT

The present report aims to address the topic of robustness of instruments and equipment to extreme environmental conditions issue. We are interest to define standard test methods suitable to the specific activities of ENVRI RIs. In this sense, attention need to be devoted not only to commercial instruments, but also to technical solutions often adopted to adapt commercial and/or custom instruments to the extreme environmental conditions in which they will be deployed and will operate. In this report, for our scopes, the concept of extreme environment/conditions is always intended in a very broad sense.

First two chapters are mainly devoted to provide a brief but exhaustive introduction about the concept of standards and actual landscape of international as well as national organizations, normative panorama and ongoing tendency arising from rapid technological transformation and global economy. We focus on technical standards, from definitions until description of the whole tailoring process needed to be implemented to carry on in a correct way standard test methods for ruggedness. About this process, Chapter 3 is devoted to describe the typical life cycle of instrumentation operated by RIs of different domains.

Based on an analysis of technical standards available for robustness (chapter 4), four standards have been identified to provide necessary information and standard procedures for scope of ENVRI RIs. They are MIL-STD-810G, NF-X 10-812, IEC 60068 and IEC 60259 (IP code).

These standards, briefly described in Chapter 4, are considering different environmental parameters and induced effects, providing for all of part of them standard test methods. They group test methods into categories, and, when necessary, include guidelines and suggestions on how to fix or control other environmental parameters affecting the results. For the scope of this Report, categories provided by selected standards have been revisited considering usual environmental conditions in which ENVRI RIs operate, determining a comprehensive list of 24 categories (environmental condition in which we are interested) spanning from cold to low pressure/altitude, from icing/freezing rain to immersion/temperature shock, from corrosion to sand and dust. Categories provided by single standards have been, sometimes merged into a broader category, when necessary retaining only some of proposed test methods. New categories and groups of test methods have been created with the scope to be more compact and suitable for ENVRI RIs and serve more than one environmental domain (Chapter 5).

In addition to that, we provide recommendations, as well as illustrate an alternative approach for the most classical and expected harsh environment, polar regions (Chapter 7), and we also illustrate (Chapter 6) how resources and facilities for testing robustness and qualify instruments/systems are not only provided by the private sector, but also inside the ENVRI RIs community, sometimes also supported by EU.

Finally, in chapter 8, the issue of implementing a dedicated service is addressed through a sustainable approach based on several steps.

Project internal reviewer(s):

Project internal reviewer(s):	**Beneficiary/Institution**
Helle Pedersen	ISTerre: Institut des Sciences de la Terre (CNRS)
Philipp Kozin	CEA, Laboratoire des Sciences du Climat et de l'Environnement

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Amendments, comments and suggestions should be sent to lead Authors Vito Vitale, v.vitale@isac.cnr.it and Mauro Mazzola, m.mazzola@isac.cnr.it

TERMINOLOGY

A complete project terminology is included as an Appendix

PROJECT SUMMARY

ENVRIplus is a Horizon 2020 project bringing together Environmental and Earth System Research Infrastructures, projects and networks together with technical specialist partners to create a coherent, interdisciplinary and interoperable cluster of Environmental Research Infrastructures across Europe. It is driven by three overarching goals: 1) promoting cross-fertilization between RIs, 2) implementing innovative concepts and devices across RIs, and 3) facilitating research and innovation in the field of environmental understanding and decision-making for an increasing number of users outside the RIs.

ENVRIplus aligns its activities to a core strategic plan where sharing multi-disciplinary expertise will be most effective. The project aims to improve Earth observation monitoring systems and strategies, including actions to improve harmonization and innovation, and generate common solutions to many shared information technology and data related challenges. It also seeks to harmonize policies for access and provide strategies for knowledge transfer amongst RIs.

ENVRIplus develops guidelines to enhance trans-disciplinary use of data and data-products supported by applied use-cases involving RIs from different domains. The project coordinates actions to improve communication and cooperation, addressing Environmental RIs at all levels, from management to end-users, implementing RI-staff exchange programs, generating material for RI personnel, and proposing common strategic developments and actions for enhancing services to users and evaluating the socio-economic impacts. ENVRIplus is expected to facilitate structuration and improve quality of services offered both within single RIs and at the inter-RI (European and Global) level. It promotes efficient and multidisciplinary research offering new opportunities to users, new tools to RI managers and new communication strategies for environmental RI communities. The resulting solutions, services and other project outcomes are made available to all environmental RI initiatives, thus contributing to the development of a coherent European RI ecosystem.

TABLE OF CONTENTS

1. Introduction

Climate Change challenges require observations of the climate components/domains with high spatial and temporal coverage and capability to measure many parameters at the simultaneously and in real time. New technologies offer more possibilities to answer fully or partly these needs, building a sustainable observing system based on autonomous and continuous measurements and a robust interconnection and remote communication.

Increase both coverage and measured parameters in a single site is strictly connected with our capability to qualify single instruments as well as complex observing platforms to operate for long durations in all natural environments on Earth with reliable accuracy. This capability being based on the existence of standards to test capacity of an instrument/systems to resist to extreme environments and environmental stresses, generating confidence in environmental worthiness and its overall robustness and durability.

In the last 50 years, many public and private organizations have worked on this issue, producing a huge amount of possible standard test methods/schemes for research, development, test, and evaluation (RDTE) of systems, instruments and materials used throughout their life cycles. The most popular and exhaustive is the MIL standard developed by U.S. Army. However, all of them were built for different scopes with respect to environmental operations of equipment for various markets, and most importantly considering engineering and budgetary conditions far above those available to standard operation of environmental research and Environmental Research Infrastructures (RIs). So that, even if we consider a single specific domain, none of these standards can be directly applied to ENVRI RIs operations. Indeed, qualification to operate in standard as well as harsh environments/conditions is a *tailoring process that results in realistic materiel designs and test methods based on materiel system performance requirements* **(1)**.

In the last 10-15 years several RIs, mainly in the marine domain, have faced the problem of instrument qualification with respect to several environmental (temperature, humidity, water pressure, etc.) and operational (vibration, mechanical and electromagnetic shocks, etc.) harsh conditions, acquiring a lot of experience and developing specific testing procedures and/or facilities.

The overall aim of this document is (i) to revisit the environmental design/test tailoring process of instruments and observing platforms from the point of view of Environmental RIs in different domains, (ii) select suitable test-methods and best practices/procedures for a large amount of environmental and operational parameters/conditions, when necessary adapting them to typical life cycles and RIs operations,(iii) start to address the issue of qualification of complex autonomous observing platforms. Test-methods, procedures, best practices will provide than building blocks helping RIs engineers to address systematically the qualification problem (tailoring process) and develop for specific case a robust comprehensive procedure (engineering plan). The possibility to develop on these basis a qualification service for ENVRI RIs will also be addressed and main elements necessary to implement such a service, mainly in relation to man-power, determined.

2. Standardization processes, qualification standards, landscape and scope of this work

In a broad sense, standardization is the process of articulating and implementing technical knowledge **(2)**, with the aim of providing an answer to a fundamental question: what's the best way of doing this? The use of standards helps in the creation of products and services that are safe, reliable and of good quality. Their definition also helps businesses to increase productivity while minimizing errors and waste. The standards also serve to safeguard consumers and the end-users of products and services, ensuring that certified products conform to the minimum standards, in terms of reliability, accuracy, quality and performances, set internationally.

The specific meaning of the term "standard" varies depending on context and end-users community. In the context of natural science, in which Environmental Research Infrastructures (RIs) operate, we are interested in technical standards, or in other words in established norm or requirement for the technical systems, in particular measuring instruments. It is usually a formal document that establishes uniform engineering or technical criteria, methods, processes and practices. A technical standard (cfr. below) can also be an artefact/system/method used for calibration. In a metrology system, primary standards represent the reference base of the traceability chain, while secondary, tertiary, working/check standard and standard material can be used for reference.

We can classify technical standards in the following six categories **(3)**:

- *A **standard specification** is an explicit set of requirements of an item, material, component, system or service. It is often used to formalize the technical aspects of a procurement agreement or contract.*
- *A **standard test method** describes a definitive procedure that produces a test result. It may involve making a careful personal observations conducting a highly technical measurement. For example, a physical property of a material is often affected by the precise method of testing: any reference to the property should therefore reference to the test method used.*
- *A **standard practice or procedure** gives a set of instructions for performing operations or functions. For example, there are detailed standard operating procedures for operation of a nuclear power plant.*
- *A **standard guide** is general information or options which do not require a specific course of action*
- *A **standard definition** is formally established terminology*
- ***Standard units**, in physics and applied mathematics, are commonly accepted measurements of physical quantity*

Considering multidisciplinary characteristics of standardization process, is not surprising to see how not unique, discontinuous and contradictory was in the past, and in some extent continue to be, standardization process, even limiting to technical standards. In fact, politics, business & economics, science & technology, labour, and culture & ideas are inextricably linked through standardization, and it is not infrequent that answers to the fundamental question stated beginning of section could be different at national as well as regional level. These distinct realms, each bringing different awareness, are responsible of a process based substantially on a private and unilateral base. They also lead to a landscape populated by thousands of industry or sector-based organizations whose primary activities are developing, coordinating, promulgating, revising, amending, reissuing, interpreting, technical standards. We talk usually of standard organizations or standard development organizations (SDOs). The landscape is so complicated that web pages/portals have been open to help engineering and end-users to find information on SDOs at national (https://www.standardsportal.org/usa_en/resources/sdo.aspx) as well as international levels (https://www.engineeringtoolbox.com/standards-organizations-t_48.html).

SDOs landscape is nowadays dominated by International Organization for Standardization (ISO) and its members (one per country), that are National Standard Body (NSB). In general, NSB are private organizations legally recognized by their government as national ruler and privileged representative on national and international forum/organizations, but being private, they have not an exclusive role in producing, testing and promoting standards. A clear example of this ambiguity is provided below in relation to EU regulation and list of NSB. We will come back more extensively on ISO, its story, organization and actual role in the system in Section 4, when we will discuss and select standards of interest for the scope of this deliverable.
Complexity of SDOs landscape adds to the challenge to rule and provide standards for global end-user communities (scientist not excluded) and hundreds of sectors and thousand of specific areas. Such necessity leads a single large organization to develop and host a large amount of technical standards. As an example, ISO has developed/hosts now more than 22.000 technical standards **(4).** The great amount of SDOs and sometime their competition increase challenges, contributing to weaken the system at least at international level.
Most standards are offered for adoption without the request of mandatory use. Therefore success and use of a standard depend strongly on reputation of SDO developing and promulgating it and general/formal consensus of technical experts. In addition to that, nowadays governments play an important role in using their authority to enforce the use of standards.

With attention to technical standards and specific interests of Environmental RIs, historically metrology, through the need to create rational measurement systems on a geographical level suitable to sustain the development of modern nations and commerce, was the first area where governments have presided over the creation of standards **(1, 5)**. The meter is the first and most important example. In late eighteenth-century in France, revolution promoted/forced the change from a confounding diversity of up to 250,000 different units of weights and measures across the provinces and towns, to the creation of a more rational system, touted as a way to erase the arbitrary nature of local rule. Since then the role of governments has grown, despite difficulties to bring together and accommodate interests and vision of SDOs with those of companies (interested in developing internal standardization). Development of ISO and its reputation is a key example of this evolution.

At European Union level, the relevant legal framework is based on UE Regulation 1025/2012 **(6)**. Scope of this Regulation is to establish **(6, Article 1)**

> *"....rules with regard to the cooperation between European standardisation organisations, national standardisation bodies, Member States and the Commission, the establishment of European standards and European standardisation deliverables for products and for services in support of Union legislation and policies, the identification of ICT technical specifications eligible for referencing, the financing of European standardisation and stakeholder participation in European standardisation"*

European standardisation organisations, namely CEN (European Committee for Standardisation), CENELEC (European Committee for Electrotechnical Standardisation) and ETSI (European Telecommunications Standards Institute) have the rights to label their standard as European standards. The two Committees being organized on a national representation base.

Despite this label, this doesn't include an obligation for member states to adopt same standards, so dialogue/cooperation is the way to promote harmonization and avoid conflicting standards and technical impediments with respect to market and services. More than this, regulation 1025/2012 does not impose to identify a unique NSB. This is because the situation in different member states is different and needs to be taken into account. For Example Italy has two NSB, UNI covering all sectors with the exception of the electrical, and CEI devoted to cover this residual but very relevant sector.

With respect to metrology, a legal framework is provided by EU Regulation 765/2008 **(7)**. In this case, each member state is obliged to identify and designate a unique accrediting organization. Such organization or Consortium if not including National Metrological Institutes (NMIs) signed with them cooperation agreement in order to acquire the necessary metrological competencies. NMIs are organized in the EURAMET Consortium at European level, which hence represents the natural counterpart of Environmental RIs.

Above brief excursus on actual status of Standardization process and landscape at International and European level is not irrelevant for ENVRIPLUS. This considering the great interest of partner RIs to work in cooperation with industry to develop new technologies for measurements and help SMEs to enlarge their market. Considering interest of RIs to develop reference standards and reference materials for parameters for which we have not well established metrology and traceability. However, these issues are more connected with activities developed in WP1 and WP2.

There is a need to help and orient Environmental RIs in this complex and not clearly defined landscape. This is relevant even if we limit our target to only one category of standard test methods and to the specific scope to test capability of an instrument/systems to extreme environments, with the general aims to (i) generate confidence in environmental worthiness and overall robustness and durability of equipment, and (ii) help RIs to increase reliability of measurements and mainly increase sustainability of activities reducing maintenance costs.

Deep analysis of existing standard operations and procedures, and typical life cycle (and connected stress) of instruments and systems employed by Environmental RIs in different domains will enable us to select, among those developed in the past by different SDOs, most suitable standard test methods. The selection is made considering not only the authoritative level of the Standard Organization developing it but mainly usefulness of standard test method in the context of Environmental observations/activities. Attention will be paid to a large range of parameters covering needs of all domains. For each parameter and selected method we will define on the basis of the life profile severity with which to test equipment for different operational and environmental conditions. In this way, we will provide a "new" set of Standard methods, procedures and best practices to test robustness and durability of equipment in harsh as well as not extreme conditions. We will additionally create the backbone for implementing in the near future a services for Environmental RIs. When achieved/implemented, this service will complement and integrate those elaborated in the marine domain by previous European projects ESONET and FixO3. **(8, 9)**.

3. Typical ENVRI RIs operations and extreme conditions

A fundamental step of the whole environmental design/test tailoring process is represented by definition of the environmental conditions that instruments, materials, observing systems will experience during their operational life (life cycle profile), including storage and delivery by the manufacturer.

In making this analysis for instruments and other systems employed by Environmental RIs, we need to take into account some peculiarities arising from the typical scenario in which they operate:

1 - only one or very few manufactures for instruments and equipment, and small number of instruments/equipment to be purchased. In this case it is key to base the choice on objective tests which can be presented to the manufacturer as reference conditions and can be pledged in case of damage in delivery/transportation phase.

2 - instruments and material may be modified by RIs after acquisition and/or integrated in more complex observing platforms. So, the consistency of the tests performed on the initial equipment and on the modified equipment must be ensured. Alternatively, post integration/modification tests should be implemented.

3 - integrity of instruments and materials are usually tested when received by RIs. In the life cycle, after a storage (typically back from a yearly mission) or an upgrade, some of the initial integrity tests might be needed.

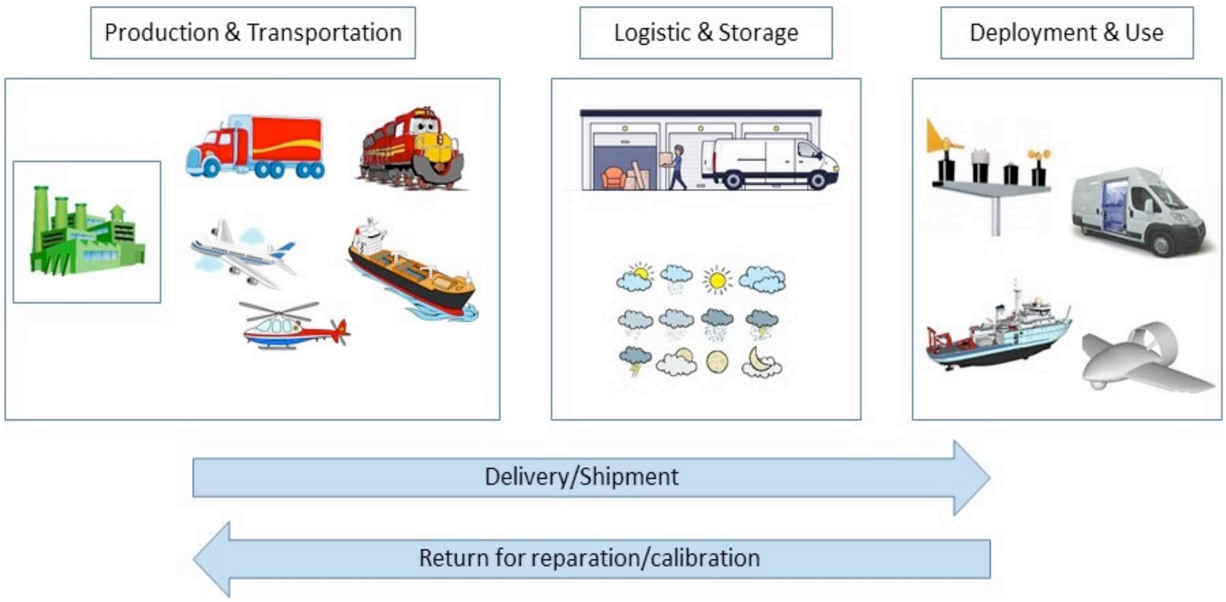

Figure 1 Generalized life cycle histories for instruments/equipment/systems used by RIs for Environmental Monitoring and Observation

Shipping/transportation needs to be included in a standard dedicated to ENVRI RIs. Typically, instruments and materials are received by the laboratory and only subsequently shipped to observing sites. Moreover, during their operational life, instruments may rotate between sites or be sent back to lab or manufacturer for repairs, or at the end shipped on a routine basis to calibration facilities. However, in all these cases, shipment is under the control of RIs, so that results of tests assessing response to transportation natural and induced stresses can become useful to guide RIs to identify and use more safe procedures. Of course, after some time of use, every equipment will end his life cycle due to not convenience or possibility in repairing them.

A general guide for developing a Life Cycle Environmental profile (LCEP) for a specific case is presented in Figure 1 and Tables 1-3. Figure and tables have been developed starting from figure

1.4 of MIL standard **(1)**, considering both the above discussed life concept for ENVRI RIs and standard operation for environmental measurements in all domains. As MIL standard, we also group events occurring in the life of equipment in three phases: shipping/transportation, Storage, and Use/Operation. Categorizations of events for each phase is mainly based on platforms used to perform the action. For each group and each category, both Induced and Natural Environmental Stress Generation Mechanisms are listed in Tables 1-3.

As stated in MIL standard documentation **(1)**

> *Tailor LCEPs to specific programs, treating each line in the body of Figure 1 as a survey or a questionnaire item to see if it applies to the specific programs for which the LCEP is being developed.......*

and

> *It is important to note that the LCEP does not specify design or test requirements. Rather it serves as a tailored guide for deriving materials and instruments designs and test parameters ....based on performance requirements.*

Table 1 Shipment/Transportation Stress Generation Mechanisms

	Handling & Road Transportation	**Handling & Air Transportation**	**Handling & Rail Transportation**	**Handling & Ship Transportation**
Induced Environmental Stress Generation Mechanisms	Road Shock (Large Bumps/Potholes) Road Vibration (Random) Handling Shock (Dropping/Overturning)	Rail Shock (Humping) Rail Vibration Handling Shock (Dropping/Overturning)	In-Flight Vibration (Engine/Turbine Induced) Landing Shock Handling Shock (Dropping/Overturning)	Wave-Induced Vibration (Sinusoidal) Wave Sine Shock Mine/Blast Shock Handling Shock (Dropping/Overturning)
Natural Environmental Stress Generation Mechanisms	High Temperature (Dry/Humid) Low Temperature Rain/Hail Sand/Dust	High Temperature (Dry/Humid) Low Temperature Rain/Hail Sand/Dust	Reduced Pressure Thermal Shock (Air Drop Only) Rapid decompression	High Temperature (Humid) Low Temperature Rain Temporary Immersion Salt Fog

Table 2 Logistic and Storage Stress Generation Mechanisms

	Handling & Logistic Transport Worst Route	Storage, Sheltered	Storage, Open
Induced Environmental Stress Generation Mechanisms	Road Shock (Large Bumps/Holes) Road Vibration (Random) Handling Shock (Dropping/Overturning) Thermal Shock (Air Drop)	None	None
Natural Environmental Stress Generation Mechanisms	High Temperature (Dry/Humid) Low Temperature/ Freezing Rain/Hail Sand/Dust Salt Fog Solar Radiation Reduced Pressure	High Temperature (Dry/Humid) Low Temperature/ Freezing Salt Fog Fungus Growth	High Temperature (Dry/Humid) Low Temperature/Freezing Rain/Hail Sand/Dust Salt Fog Solar Radiation Fungus Growth

Table 3 Deployment and Use Stress Generation Mechanisms

	Deployment & Use at the Ground	Deployment & Use Aboard Ships	Deployment & Use on Aircraft	Deployment & Use On Sea/Underwater
Induced Environmental Stress Generation Mechanisms	Handling Shock (Dropping/Slamming/ Overturning) Acoustic Noise Explosive Atmosphere Electromagnetic Interference	Wave Induced Vibration (Sinusoidal) Engine-Induced Vibration Acoustic Noise Wave-Slam Shock Electromagnetic Interference	Runway-Induced Vibration Aerodynamic Turbulence (Random Vibration) Maneuver Buffet Vibration Engine-Induced Vibration Acoustic Noise Take-Off/Landing/Maneuver Acceleration Air Blast Shock Handling Shock Aerodynamic Heating Explosive Atmosphere Electromagnetic Interference	Launch Acceleration Handling/Launch Shock Engine-Induced Vibration Acoustic Noise Explosive Atmosphere Electromagnetic Interference Increased Pressure (Submarine)

Natural Environmental Stress Generation Mechanisms	High Temperature (Dry/Humid) Low Temperature/Freezing Thermal Shock (Storage to Use) Rain/Hail Sand/Dust/Mud Salt Fog Solar Radiation Fungus Growth Chemical Attack	High Temperature (Dry/Humid) Low Temperature/Freezing Thermal Shock (Storage to Use) Rain Salt Fog Solar Radiation Fungus Growth Chemical Attack	High Temperature (Dry/Humid) Low Temperature/Freezing Thermal Shock (Storage to Use) Rain Salt Fog Solar Radiation Rain Intrusion Sand/Dust Intrusion Fungus Growth Chemical Attack	Immersion Thermal Shock

Acquisition of data and ranges of environmental conditions/stresses (natural, induced) characterizing the specific problem/case is very important to build a realistic and accurate Life Cycle Environmental Profile (LCEP). They in fact will be fundamental to identify parameters for which to perform environmental tests and fix appropriate criterion levels to apply test methods. Such data and ranges can derive from direct/indirect measurements as well as, if necessary/convenient, from modelling.

On the basis of above remarks, below for each domain are developed general considerations about typical life cycles of employed instruments, materials and observing systems.

3.1. Typical life profiles for instruments/systems used in the atmospheric domain:

Instrumentation for atmospheric measurements can be subdivided in two categories:

1 -<u>Family of equipment usually functioning indoors</u>
Several atmospheric devices are manufactured for operating in building rooms or in dedicated shelter/box, probing the atmosphere through inlets or optical aperture. Typically, rooms/shelters/boxes are exposed to ambient conditions and, when necessary, equipped to maintain temperature above 0°C. More rarely equipment operate in air-conditioned rooms/Shelters/boxes. Instruments for aerosol/gas sampling (e.g. chemical sampler, particle counters, aethalometer, nephelometer, etc.), and several instruments for remote sensing (LIDAR, FTIR, microwave radiometers), in particular those that include very complex and delicate optical parts fall within this category. More than to temperature, optics are very sensitive to humidity stresses that can significantly alter characteristics and functioning. The need to protect these type of instruments is higher in remote installation where constant human presence impossible and, apart consideration on repair costs and lab maintenance, less necessary at stations/sites where personnel work regularly, often 24 hours or on daily basis.

2 - <u>Family of equipment functioning outdoors</u>
Most of equipment for atmospheric measurements need to stay (completely or in part) outside, being for them necessary a direct contact with the measured medium in order to carry out accurate/realistic measurements of observed parameters. Meteorological and radiation instrumentation represent a clear example of this category. They are exposed to hot and cold temperatures, condensation and humid heat, freeze and defreeze, mechanical stress (e.g. vibrations due to wind, ice growth, accumulation of snow,...), solar radiation, corrosion, lightning strikes, etc. Usually, technical measures (like shields preventing heating from solar radiation or

cooling by wind) need to be adopted in order to reduce the influence of variable environmental conditions on observations.

Concerning operational conditions, we need to consider if instruments/systems are installed at the surface (fix stations or surface mobile vehicles) or at air platforms (manned, unmanned) for which height (and than environmental ambient conditions) can change rapidly.

Is also important to note that indoors and outdoors broad categories described above are strongly overlapping, mainly as a consequence of the evolution of technologies (electronics in particular). The need to reduce source of errors in measurements and the need to install instrumentation in remote areas to increase spatial coverage, promotes the deployment of all equipment outdoors, increasing influence of extreme ambient conditions on the devices. In such a case, the communication or transmission capabilities of the equipment are of great importance for controlling and checking the functioning of the apparatus itself and so, a particular attention on testing of these features should be paid.

Storage

Usually the equipment is stored, protected from adverse weather at ambient temperatures. This storage can last from several weeks to several months.

Typical storage temperature is comprised between -20°C and +50°C and the relative humidity can reach up to 90% at 50°C.

If storage is at the Institute/Laboratory and not in the field, if necessary equipment are located in heated storehouse, so avoiding below zero temperature. At the contrary, if storage is at measurement site, weather protection can be really very week, so that temperature of -50°C or + 60°C can be encountered by equipment intended for use in polar and tropical regions, respectively.

In this case, procedures to reduce the thermal shock before to use the instrument need to be adopted even if environmental testing have been successfully passed.

In remote measurement sites where equipment are frequently stored ready to replace broken ones, large temperature variations can occur.

Mobilisation and transport to service

Before being transported to the measurement site, equipment can by handled/used to perform tests and calibration, can be pre-assembled or disassembled, can be modified to be adapted to specific operational constraints and conditions, packed into a case (dedicated or not), etc.

The associated handling operations vary with the type of transport: This transport can be:

— by road: normal road transport,

— by airplane: in pressurised or un-pressurised, but heated and ventilated holds. In un-pressurised holds, a negative pressure difference of approximately 0.8 bar can be encountered,

— by helicopter: in this case the level of vibration experienced by the equipment must be taken into account,

— by ship: in this case, the equipment is usually located inside containers placed on the ship deck or, more rarely, on the hold.

Transportation by ship can imply:

— Before embarkation, the equipment can be temporarily stored in port. In this case, the equipment can be exposed to adverse weather conditions.

— vibrations such as those encountered on the deck of a ship in heavy seas,

— pitch and roll that can reach an amplitude of ± 30° and a frequency of 10 s,

— damp, saline atmosphere that can lead to condensation and corrosion,
— temperatures that can reach up to +70°C for items stored inside commercial containers crossing tropical/equatorial regions or down to -40°C if the ship route touches the polar latitudes,
— solar radiation and heat,
Transportation by airplane in addition to pressure shock before indicated can also imply:
— Before embarkation, the equipment can be temporarily stored in ambient conditions at the airport storehouse or at open air near the runway. In this case, the equipment can be exposed to adverse weather as well as to:
— damp heat conditions in low latitudes areas,
— temperatures that can reach +60°C in tropical/equatorial regions or -40°C in polar regions,
— solar radiation and heat,

Deployment, installation and use
Together with the above indicated two broad categories, observing platform on which equipment is installed and used largely determine life cycle and environmental aggressions/stresses to which it could be undergone.
If installed/used in a fix measurement station pertain to ENVRI RIs, equipment/instrument/system can be submitted to:
- temperature typically ranging between - 10°C and + 40 °C for station located at sea level in the Mediterranean area. This range need to be extended up to -30°in the Mountain regions (Alps, Pyrenee) and moving to higher latitudes. On the other limit of the scale, range need to be extended to +60°C when the station is located south of Italy or along south coast of Mediterranean sea during summer months.
- humidity that during rain of snowfall can reach 100%
- damp heat conditions at low latitude during summer, with humidity can reach 90% at 50°C.
- mainly on mountain regions and Arctic latitudes, icing and de-icing processes. In humid conditions these episode could became very severe and affect non only optical coats and cables but also the mechanical integrity of the instrument.
- mechanical stress arising by vibrations by caused by the wind,
- solar radiation,
- lightning strikes and electromagnetic disturbances arising fro the station and/or other instruments

Maintenance, repair at service facilities
Environment is identical to that for storage, for operations conducted at service facilities at disposal both at the Institute/Laboratory or on the measurement site. The same differences between the two situations identify for storage, apply.
If maintenance-repair operations are conducted on measurement site, outdoors the service facilities, the aggressions are identical to those encountered during transit and may involve internal parts.

3.2. Typical life profiles for instruments/systems used in the marine domain:

Oceanographic instrumentation, was subdivided in 4 categories by the AFNOR XP-X 10-800 (**10**) simplifying previous Navy standards. Devices considered are instruments or equipment which may be mounted on marine exploration platforms (ship, submersible, buoy, moorings, pontoons). The platforms themselves used to be outside the scope of the above indicated standard. However, since autonomous platforms are becoming smaller, it appeared useful in the recent years to use classification and methodology provided by XP-X 10-800 also for them. In particular, for our analysis we will consider also small platforms such as profilers and gliders.

E1: Family of marine equipment functioning, in the atmosphere.

Equipment used on:

- ship deck or masts,
- buoys,
- shore at the vicinity of the coast.

They are submitted to salty water spray, cold, humid heat, frost and defrost, vibrations, manipulation shocks, and many other environmental and operational stress factors.

E2: Family of equipment functioning in seawater.

Equipment used underwater, immersed:

- on a platform such as ship, submarine, ROV, gliders, profilers.
- on the seafloor,
- towed by a surface ship,
- along a mooring line.

When stored or in transit to the deployment site, these instruments are submitted to the same aggressive conditions as the E1 family equipment in addition to specific aggressive conditions such as hydrostatic pressure.

I1: Family of equipment functioning in air conditioned rooms

Due to the evolution of technologies such as electronics during the following decades, the I1 case was assumed not relevant in 2011 AFNOR Committee review (**11**). No marine specific robustness limitation had been reported nor have been reported since.

I2: Family of equipment functioning in other than conditioned rooms (ambient conditions)

These rooms are usually technical shops on board of ships or onshore (lighthouses, pontoons, etc.)

The E2 family is the most prone to environment testing. The 2013 AFNOR NFX 10 812 (**12**) is more dedicated to that family and analysed the life cycle as follows:

Storage

The equipment is stored, protected from adverse weather at ambient temperatures. This storage can last from several weeks to several months.

The storage temperature varied between -20°C and +50°C and the relative humidity can reach 93% at 50°C.

A temperature of -40°C can be encountered by equipment intended for use in very cold climates (arctic regions for example).

Mobilisation and outgoing transport

Before being transported to the site of use (immersion) or to the site of embarkation, this equipment can undergo, in the testing laboratory, pre-assembly, testing, disassembly, packing into a crate, etc.

The associated handling operations vary with the type of transport: This transport can be:

— by road: normal road transport,

— by airplane: in pressurised or unpressurised, but heated and ventilated holds. In unpressurised holds, a negative pressure difference of approximately 0.8 bar can be encountered,

— by helicopter: in this case the level of vibration experienced by the equipment must be taken into account,

— by ship: in this case, the equipment is placed on the ship deck in premises that are air-conditioned or at ambient temperature.

Installation on board a vessel, on a lighthouse or on land (near the coast)
Before embarkation, the equipment can be temporarily stored in port. In this case, the equipment can be exposed to adverse weather.
Handling and installation of the equipment on board a vessel or on its final marine structure requires the use of cranes or specialised lifting equipment.

Transit to service site (or use as soon as installed)
During this part of transit, the equipment may be in operation or stored in one of the following conditions:
— outside, under the hull of the ship,
— outside, in a crate on the deck,
— inside, in air-conditioned premises,
— inside, in an equipment room.
During transit, set-up, verifications, connections and testing may be carried out on the deck in a saline environment.
During transit, the following hostile conditions can be encountered:
— vibrations such as those encountered on the deck of a ship in heavy seas,
— salt spray,
— damp, saline atmosphere that can lead to condensation and corrosion,
— temperatures varying between -20°C and +50°C
(+70°C for items in direct contact with the metal deck),
(-40°C for equipment intended for use in very cold climates, in arctic regions for example):
— solar radiation and heat,
— movement of the deck due to
- swells,
- heaves (ship),
- pitch and roll that can reach an amplitude of ± 30° and a frequency of 10 s,
— electromagnetic disturbance caused by transmissions made from the ship,
— contamination from hydrocarbons spilled on deck,
— jets of water,
— heavy seas,
— hail,
— freeze/thaw cycles,
— frost,
— etc.

On-site dives
Dives have various phases and levels of aggression:
Preparation: Equipment is operational in all its functions on the deck of the ship (maximum force 4-5 seas)
During this operation, the equipment can undergo an impact due to a fall.
Deployment in water: equipment undergoes impacts and wave action at the air/water interface with rapid, repeated immersions
For example:
— shocks and stress due to heaves, surges and pitches of the equipment and the ship,
— Swinging and banging against the hull of the ship or shocks with various objects on the surface,
— thermal shock upon immersion (differences of temperatures within the range of -40°C or +20°C can be observed),

— contamination by hydrocarbons present on the surface of the water,
— corrosion.

Dives: during immersion, the equipment is subjected to

— pitch and roll that can reach an amplitude of ±10°,
— vibrations of the mooring line to which it is attached, mechanical stress exerted on the cable,
— shocks encountered when landing on the seafloor (but generally less violent than landing on the deck),
— corrosion,
— hydrostatic pressure.

Recovery: During recovery, the aggressions undergone by the equipment are identical to those during deployment. In addition, the equipment can suffer from an impact upon landing on the deck.

Return transit

The aggressions are identical to those for outgoing transit.

Lay up

The aggressions to take into account are identical to those encountered during installation on board.

Return transport and demobilisation

The aggression are identical to those for outgoing transit and mobilisation.

Maintenance at service facilities — Repair — Storage

Environment is identical to that for storage, for operations conducted at service facilities.

If maintenance-repair operations are conducted on site, outside of the service facilities, the aggressions are identical to those encountered during transit and may involve internal parts.

3.3. Typical life profiles for instruments/systems used in the Ecosystem and Earth Science domains

Families of instrument before identified for atmospheric and marine domain also apply to these other two domains, covering all possibilities. Instruments to monitor and investigate ecosystems are typically located outdoors and frequently near or inside water sources (river, lakes etc.). On the other hand, instruments used in Earth science domain are mainly classified in connection with location (indoors, outdoors) or with the type of environment, that respects acceptable disturbance during operations. For example, seismometers are installed in locations with a low seismic noise level for earthquake detection, but are installed onsite in for example volcano monitoring.

Being categories similar to those described and analysed yet in sections 3.1 and 3.2, means that the same life cycle apply for instruments used in these domains with respect those used in atmospheric and marine domain. In any case, there are some peculiarities we need to take into account when we consider ecosystem and Earth Science domains:

1 - both domains are interfaced, observe different matrices: atmosphere, soil, water. So, for specific applications, possible stress arising from different Earth components need to be carefully considered in order to prepare and perform standard tests on robustness to extreme conditions.

2 - in both domains instruments can be subject to unusual mechanical stress arising either from wildlife (in the case of ecosystems) or from natural events such as dust and small rocks (in the case of earth sciences).

3 - both domains can have large stress arising from specific parameter(s) due the location where instruments are located: for ecosystem humid environments are often privileged areas for observation of ecosystems, while for Earth Science temperature conditions can be extreme.

These peculiarities need to be very well take into account in determine the life profile of the equipment and can lead to very different Life Cycle Environmental profile (LCEP) even for an identical instrument. This can of course occur also for atmospheric and marine domains (e.g. if the same instrument is used at ground or on airplane) but in the case of ecosystem and Earth Science, such differences can be much more significant.

The Table 4 below summarizes the generalized life cycle histories for instruments/ materials/systems in each domain.

Table 4 Life cycles histories for instruments/materials/systems and different domains.

	shipping/transportation				storage		deployment/use			
	truck	train	ship	Air	close space	in air	ground	mobile	ship	airborne
atmosphere	Yes	Yes	Yes (less relevant)	Yes, no helicopter		Yes (depending on application)	Yes (depending on application)	Yes (depending on application)	Less frequent	Yes (depending on application)
marine	Yes	Yes	Yes	Yes, no helicopter	Yes	Yes	Yes	Yes	Yes (3 families E1, E2, I2)	Exceptional
ecosystem	Yes	Yes	Yes	Yes	Yes	Yes (depending on application)	Yes (depending on application)	Yes (depending on application)	Yes	Yes (depending on application)
Earth	Yes	Yes	Yes	Yes	Yes	Yes (depending on application)	Yes (depending on application)	Yes (depending on application)	Yes	Yes (depending on application)

4. Existing standards for qualifying instruments to extreme conditions and environmental stresses

In section 2, we have briefly illustrated the status and landscape of standardization process with respect to technical topics that include the category of standard test methods. We have there outlined how there are a large amount of standards developed in the years by hundred private organizations. In order to make a selection, focusing on the most important for the scope of ENVRI RIs, it is necessary to give a more in-depth look into existing standards. In addition, is important also to give a deep look to development occurring in the landscape as a consequence of a stronger public engagement and challenges/requirements of a global market. The second issue, relevant in respect to better address, providing the correct market perspectives, ENVRI RIs developing specific procedures and/or implementing facilities.

With respect to existing technical standards and their scope in addition to categories reported in section 2 we can group them in two classes: the first devoted to define common characteristics and make objects interoperable for different applications and between different countries, and the second devoted to on the definition of characteristics that can ensure safety and resistance to environmental stresses and to solicitations that can occur during transport/operations. Also limiting to the second class that is the area in which we are interested in this document, there are standards developed for very specific industrial sectors, like for example those provided by NORSOK for the extraction industry (**13**), or SAE for the automotive, as well as standards for generic scope (MIL, ISO, NF-X, EN, etc. - see below in this section for references). In most cases, the official documents are not publicly available and need to be purchased.

Among standards we have analysed and considered for this report, the ones that take more into account environmental factors are the MIL and NF-X, the latter being specific for marine environment. The IP standard (see below for reference) can be very useful for the specific problem of dust and water intrusion. In particular, part 3 of the MIL-STD-810 documentation describes environmental parameters that can be encountered in different regions of the world. Incidentally, probably the extreme polar environment (Antarctica) is not contemplated, as it is excluded from the possibility of conflicts thanks to Antarctic Treaty.
Both MIL-810G and NF-X accurately describe test procedures for evaluating the resistance of devices to environmental solicitations (both natural and induced) such as temperature, vibration, pressure, humidity, fog, precipitation, clouds, blowing dust and sand, icing, wind conditions, high sea state, etc. Both do not have test methods with respect to electromagnetic field and noise. These procedures define test levels, ranges, rates and durations that should be fulfilled by each of the parameters to be checked. Some tests may be conducted in laboratory, but it is always recommended to integrate these tests with on-field verifications, as not always is possible to reproduce the real conditions in laboratory. For example, in the natural environment, different phenomena may occur simultaneously, giving different effects compared to the situation where they act separately. An advantage of the laboratory tests is the possibility of conducting accelerated tests, where the same phenomena are repeated much faster than they would be in natural conditions. This can help to obtain results in a shorter time, but again attention should be paid when extrapolating the results from the laboratory to real-life environmental conditions. When performing tests, both in the laboratory or in the field, it is sometimes possible to use alternatives to the actual device, or part of it, using similarity criteria with already tested items.

With respect to organizations/bodies developing standard and public efforts to regulate the process, no doubt that reputation acquired by ISO (International Organization for Standardization) and assurance of a strict connection with government efforts to regulate standardization process through membership allowed to only one National Standard Organization (NSB) for each country, have produced in few tens of years a huge change in the panorama, and started an irreversible process.

The organization today known as ISO began in 1926 as the International Federation of the National Standardizing Associations (ISA). Even if born with a broader remit to enhance international cooperation for all technical standards and specifications, before war this organization focused heavily on mechanical engineering. The body was suspended in 1942 during World War II, and after the war reorganized under the current name ISO, in 1946, thanks to an agreement with

United Nations Standards Coordinating Committee (UNSCC). First meeting in London, was attended by delegates of 25 countries. In 50 year of history, the organization is grown to include 161 countries (**14**). As stated on the cited web page

> *ISO is an independent, non-governmental international organization.....Through its members, it brings together experts to share knowledge and develop voluntary, consensus-based, market relevant International Standards that support innovation and provide solutions to global challenges.*

The bulk of the work of ISO is done by the778 technical committees and subcommittees (**14**) and working groups. Each committee and subcommittee is headed by a Secretariat from one of the member organizations. A nice compendium of the very complex and long process to create a ISO standard were made by the students taking a course on Information Technology Standards and Standardization in the Department of Information Science and Telecommunications at the University of Pittsburgh (**15**)

> *Each standard goes through a six-stage process before being published as an ISO standard. The first stage is the proposal stage in which a need for a standard is determined and members are identified who are willing to work on it. The standards then enters the preparatory stage where a working draft of the standard is developed. When the working draft is completed, it enters the committee stage and is sent out for comments until a consensus is reached. The output of this stage is the Draft International Standard (DIS). The DIS then enters the enquiry stage where it is circulated among all member bodies and then voted upon. If a DIS does not receive 75% of the vote, it returns to lower stages and work on it continues. If it passes the enquiry stage, it becomes a Final Draft International Standard and enters the approval stage. During this stage, it will again circulate through all member bodies for a final vote and again it must pass this stage with 75% of the vote. If the standard passes this stage, it enters the publication stage and is sent to the ISO Central Secretariat for publication. Because certain technologies are changing so rapidly, ISO has instituted a Fast Track procedure that allows a standard which has been proven in the market to enter the approval process at the enquiry stage.*

Similar information can be extracted by a simple introductive publication released by ISO in 2015 (**16**). Despite large participation and reputation, ISO needs to interact and dialogue with many other international, regional and national SDOs, so a main activity of the Secretariat in Geneve is to develop communication tools that could raise attention of business owners, politicians and consumers about standardization process, standards and their usefulness. To help single company and/or organizations to evaluate economic benefit of used standards, ISO has developed a *Methodology toolbox* (**17**), including publications to help in using this toolbox in an appropriate way. A repository of performed studies made also using this toolbox have also been created (**18**) Posing attention on ENVRI RIs interests, on the ISO web site we can found two interesting publications: the first devoted to show how ISO standards can help to address climate change issues (**19**), the second devoted to present the way in which standards affect consumers (**20**). Also interesting for ENVRI RIs a publication related to good practice for teaching standards (**21**) I particular the former is contains rich information that is relevant to environmental RIs and generally unknown to RI researchers and managers. A specific section on climate change (now protecting our planet) has been created on an ISO web page (**22**), where a link is provided to related technical committees.

Despite the enormous amount of standards established by ISO, few are truly useful for ENVRI RIs, the most important being for sure ISO/IEC 17025, providing general requirements for the competence of testing and calibration laboratories. This is the international reference for laboratory quality systems, needed to be used by testing and calibration laboratories wanting to demonstrate their capacity to deliver reliable results. Compliance with this standard provides a globally accepted basis for laboratory accreditation. The standard specifies the management and technical requirements to be met by testing and calibration laboratories in both their organisation and their management of quality. A new version of the standard was published by ISO and the International Electrotechnical Commission (IEC) in 2017 to update its content and better serve the laboratories that use it. The new version cover the large changes in market conditions and technology occurred since previous release in 2005. The new version covers technical changes, vocabulary and developments in IT techniques. It also takes into consideration the latest version of ISO 9001 (**23**).

ISO organization does not provide a tool or a standard specifically dedicated to standard test methods to qualify instruments and equipment for extreme conditions. One reason could reside in the fact that, historically, robustness against external and in particular environmental stresses was an issue for military and defence industry, and only more recently is became an issue for computer and electronic technology industry and in some extent for manufactures of scientific equipment. It is not a causality that much more attention on these questions have been devoted by IEC (cfr. below). Manufacturers of rugged computers and electronics just use ISO 9001 to certify quality of productive process, and reliability of characteristics they declare for products. The same occur for scientific instruments manufactures.

ISO organization covered market field and potential applications are limited by the presence of other two international well-established Standard Organization covering the specific sector of electricity and telecommunications. Electric area is covered by the International Electrotechnical Commission (IEC), while telecommunications sector is covered by the International Telecommunication Union. (ITU). For the scope of this report, we are interested to analyse only IEC with the aim to identify standards useful to ENVRI RIs, including test methods for electronic and electromagnetic shocks that instruments they use could suffer during operations. For this analysis, we limit to land/ship operations. Airborne operations from this point of view are strictly regulated and any equipment operating onboard an aircraft need to pass severe tests performed by specialized lab and companies, usually connected to civil aviation and air forces, and need to perform final tests in flight conditions to receive final certification from national aviation authorities.

IEC history is longer compared to ISO. This organization were, in fact, constituted in 1906 with Lord Kelvin as first President. At the first meeting representatives from 14 countries was present. Nowadays with the enormous development of electronics and hundred millions of devices that contain electronics, and use or produce electricity, role of this organization, world's leading in preparing and publish International Standards for all electrical, electronic and related technologies, is fundamental to assure all these equipment perform, fit and work safely together. Despite the relevance in relation to economy, society and our individual life is increasing exponentially, the specific field of operation-limited expansion of the organization. In comparison to ISO, from the 14 initial countries currently full members are 62 and associated member 22 that means half of countries sitting in ISO (**24**). In addition, much less of ISO are technical and sub-technical committees: total 204 in IEC with respect 778 in ISO.

IEC standards have identification numbers in the range 60000–89999. IEC 60417 standard (**25** - Graphical symbols for use on equipment), provide for each of them a graphical symbol and a name in English and French, together with a graphical representation in GIF or PNG and in vectorised PDF. Following the Dresden Agreement with CENELEC the numbers of older IEC standards were converted in 1997 by adding 60000, for example IEC 27 became IEC 60027. Standards of the 60000 series are also found preceded by EN to indicate that the IEC standard is also adopted by CENELEC as a European standard, for example, IEC 60034 is also available as EN 60034.

Considering how information are presented on the IEC web page, it is not an easy task to identify the most useful standard for our scope. From this web page, is even difficult to understand how many standards are currently released by IEC. In any case, since IEC (as ISO) publish more than 100 new standards each month, a similar information should be of not great usefulness. In fact, such a huge rate leads to conclusions that each new release just produce little changes with respect to old standards and attention/questions need to be raised by users with respect the real usefulness of new standard. Large number of standards are devoted to very specific electronic equipment categories or electronic components (power supply, transformers, cables, integrated circuits) and than are no useful for ENVRI RIs. However, from a deep analysis we can identify at list three standards relevant for environment

1 - the first, IEC 60068 is devoted to environmental testing,
2 - the second, IEC 60721 is devoted to Classification of environmental conditions,
3 - the third, IEC 60529, also known as IP standard, is devoted to classify degrees of protection provided by enclosures and establish related tests methods.

First two standards where developed by IEC Technical Committee 104. They were devoted to address issues related to environmental conditions and to develop classification and methods of test (**26**). In addition to these two standards, the Technical Committee 104 also released technical reports IEC TR 62131 devoted to provide guidelines and information on Vibration and shock of electrotechnical equipment during transportation on vehicles and rail and/or installation on aircraft wing etc. IEC 60721 refers to storage and transportation, providing for both phases of the life cycle of an equipment/instruments groups classification of interesting parameters and their severities (with respect to electronic part). It can be very useful to develop the whole LCEP plan for tests and address the issue of severity level for a specific environmental condition. However, it not provide any standard test methods.

The third standard was developed by IEC Technical Committee 70 (TC70) and established for the purpose of developing methods and releasing standards in relation to the degrees of protection provided by enclosures for electrical equipment (**27**). TC70 work is limited to equipment with a voltage not exceeding 72.5 kV. In defining standard test methods this standard, refer largely to IEC 60068.

IEC 60068 and IEC 60529, provide the necessary information and standard procedures for electronics, complementing for our scope MIL and NF-X.

Below, for each of the selected standards, a brief but exhaustive description.

MIL-STD-810

Environmental Engineering Considerations and Laboratory Tests (last version being MIL-STD-810G) (**1**), is a United States Military Standard which overarching scope is to tailor an equipment's environmental design and to test its limits in the conditions that it will experience throughout its service life. For this, it establishes "...*laboratory test methods that replicate the effects of the environment ... rather than trying to reproduce the environments themselves*" (**1- foreword**). Although prepared for military applications, this standard is generally accepted standard of ruggedisation testing and compliance for mobile computers, cables, connectors and any application where ruggedness is required or expected. Nowadays, MIL-STD-810 test methods are largely used to generate confidence in the environmental worthiness and overall durability of equipment design. First Edition of MIL-STD-810 was released in 1962, while the last revision MIL-STD-810G, was released 31 October 2008. As stated by cited publication

> *Guidance and test methods included in this standard are intended to: (1) define environmental stress sequences, durations, and levels of equipment life cycles and evaluate their consequent performances, (2) be used to develop analysis and test criteria suitable for specific equipment and its environmental life cycle, (3) identify deficiencies, shortcomings, and defects in equipment design, materials, manufacturing processes, packaging techniques, and maintenance methods, and (4) demonstrate compliance with contractual requirements.*

MIL-STD-810G is composed by three parts (**1 part-one, pp. 2-3**).

Part 1 contains general program guidelines for the management, engineering, and tailoring design and test criteria to the specific environmental conditions an equipment will encounter during its service life.
Part 2 describes the environmental laboratory test methods to be applied using the test tailoring guidelines described in the first part. Each test method supports the test engineer by describing preferred laboratory test facilities and methodologies.
Part 3 contains a compendium of climatic data and guidance assembled from several sources, including AR 70-38, Research, Development, Test and Evaluation of Materials for Extreme Climatic Conditions (1979). It also provides planning guidance for realistic consideration of climatic conditions in various regions throughout the world.

MIL-STD-810 deals with the whole environmental design and tailoring process, identifying engineering and technical figures and their roles in developing a suitable test plan including specific documentation and procedures (specific tests and levels) appropriate to the environment in which equipment is expected to be used. Than, actual tests are carried out according to pre-defined test plan and criteria. The tests can be laboratory or natural environment field tests or a combination, whichever applies. The test procedure is dependent on the environment tested. The procedure(s) and its execution provide the basis for collecting the necessary information. After completion of each environmental test, the post-test data is examined and recorded/documented in accordance with guidelines reported in the standard. In particular, a final test report is created for each test, which include an analysis of test results. With respect to laboratory test methods, they are broken down in 28 categories.

As stated above, part 3 of the MIL-STD-810 standard describes the different environmental conditions that can be found in different zones of the world. There conditions are of three types: (a) climatic (temperature, humidity, solar radiation, rain, snow, wind, blowing sand, dust and snow, icing phenomena, ozone, freeze-thaw occurrences, fog, cloud ceiling heights, and visibility), (b) weather-related atmospheric obscurants (rain, snow, fog, cloud cover), and (c) induced climatic conditions (storage and transit). Different climatic types are defined: hot, average, cold, and severe cold. Some of them are further subdivided based on the values of other parameters, such as humidity in the case of the hot type (dry and humid) or on their variability (e.g. constant or cyclic humidity). Maps of the world indicating the different climatic zones are provided. As anticipated, they don't include Antarctica and even the ice continent can for sure be included into the severe cold type, the conditions are probably worse than all others in the world. Maps of minimum and maximum temperatures are also reported. Besides the specific parameter extreme values, also the frequency of occurrence over long-term periods is indicated. For each of the climatic types a table summarizing the minimum and maximum temperature, relative humidity and solar radiation at environmental conditions is provided. For temperature and relative humidity extreme are provided also for storage and transport (induced conditions). Another important information is the daily cycle of these parameters, they are provided for each climatic type for long-term records, also including wind speed, in some cases for both environmental and induced conditions. In case of high humidity types, statistics also for dew point temperature are provided. On the other hand, for cold types, solar radiation and humidity are not considered.

IEC 60068

As reported on the web page of IEC Technical Committee 104, scope of this Technical Committee is:

> *1. Standardization of environmental condition classes which represent the conditions to which products are most likely to be subjected whilst being:- transported, - stored, - installed and - used. The classification shall use validated environmental parameters and provide guidance in the selection and use of those classes intended for the preparation of relevant specifications.*
> *2. Standardization of environmental test methods intended for the preparation of relevant specifications and to provide guidance in the selection and use of those methods.*
> *3. The correlation and transformation of environmental condition classes to environmental tests.*

Out of the scopes of TC 104 are Electromagnetic Compatibility and Fire Hazard, two issues that could be of some relevance for ENVRI RIs. They are in charge of other two IEC Technical Committees, TC 77 and TC 89, respectively. Since 1976, TC104 has released 135 publications (**28**), the most important for this report being

IEC 60068-1 - Environmental testing - Part 1: General and guidance released in 2013 (**29**) and
IEC 60068-2 - Environmental testing - Part 2: Tests - ALL PARTS just released beginning 2018 (**30**)
IEC 60068 includes a series of uniform and reproducible environmental, climatic, dynamic and combined tests for environmental testing along with their appropriate severities, and prescribes (in part 1) various atmospheric conditions for measurements and tests design. These test methods are based upon available international engineering experience and judgement and are primarily designed to provide information on the following properties of specimens:
a) the ability to operate within specified limits of temperature, pressure, humidity, mechanical stress or other environmental conditions and combinations of these conditions,
b) the ability to withstand conditions of transportation, storage and installation.
Although primarily intended for electrotechnical products, this standard is not restricted to them and may be used in other fields where desired. In the last release of part 1 (2013), the framework of environmental test tailoring process is given (Appendix C) in order to assist the production of test specifications with appropriate tests and test severities.

The IEC 60068 series consists of three parts:

a) IEC 60068-1 – General and guidance, which deals with generalities,
b) IEC 60068-2 – Tests – which publishes particular tests separately for different applications,
c) IEC 60068-3 – Supporting documentation and guidance, which deals with background information on a family of tests.

In the second Part, 19 categories of tests are identified. Classification scheme is in any case developed in order to accept improvements without ambiguity and allow developing integrated test approach. This is very important in a field developing so fast and where new relevant specifications for specific product categories (electrical, electromechanical or electronic devices, their subassemblies components and constituent parts) can rapidly be introduced by advancement of technology.

IEC 60529 (IP code)

As reported on the web page of IEC Technical Committee 70, scope of this Technical Committee is:

> *To prepare international standards including appropriate test methods for degrees of protection provided by enclosures against ingress of solid foreign objects and water and against access to dangerous parts.*
> *Such degrees should be expressed by the IP Code.*

IEC 60529 (**31**) applies to the classification of degrees of protection provided by enclosures for electrical equipment with a rated voltage not exceeding 72,5 kV. The object of this standard is to give:

a) Definitions for degrees of protection provided by enclosures of electrical equipment as regards:
   1) protection of persons against access to hazardous parts inside the enclosure,
   2) protection of the equipment inside the enclosure against ingress of solid foreign objects,
   3) protection of the equipment inside the enclosure against harmful effects due to the ingress of water.

b) Designations for these degrees of protection.

c) Requirements for each designation.

d) Tests to be performed to verify that the enclosure meets the requirements of this standard.

This standard is also applicable to empty enclosures provided that the general test requirements are met and that the selected degree of protection is suitable for the type of equipment to be protected.

External influences or conditions considered by IEC 60259, against which is necessary to determine protection degree for both the enclosure and the equipment inside the enclosure, include: mechanical impacts, corrosion, corrosive solvents (for example, cutting liquids), fungus, vermin, solar radiation, icing, moisture (for example, produced by condensation), explosive atmospheres, and the protection against contact with hazardous moving parts external to the enclosure (such as fans). As indicated yet, in elaborating standard test methods IEC 60259 largely refers and make use of procedures and methods elaborated in IEC 60068.

A core part of this standard is the system for classifying the degrees of protection provided by the enclosures of electrical equipment, the IP Code (or International Protection Rating, sometimes also interpreted as Ingress Protection Rating - explanation of letters IP is given by IEC 60529 Ed. 2.1 clause 4.1) (**32**). Aim of IP Code is to provide users, in a simple and intuitive way, with a more detailed information than vague marketing terms such as waterproof. It consists of the letters IP followed by two digits and an optional letter. The digits (characteristic numerals) indicate conformity with specific conditions.

- The first digit indicates the level of protection that the enclosure provides against access to hazardous parts (e.g., electrical conductors, moving parts) and the ingress of solid foreign objects. This number ranges from 1 to 6 (with 6 being the best). The digit 0 is used where no protection is provided.
- The second digit indicates the level of protection that the enclosure provides against harmful ingress of water. Ratings range from 1 to 7 (with 7 corresponding to the highest protection). A few devices have a liquid ingress rating of 8 or 9, but these standards are set by the individual manufacturer themselves, so they can't be reliably compared with each other. Again, the digit 0 is used where no protection is provided.
- Further letters can be appended to provide additional information related to the protection of the device (f - oil resistant, H - high voltage device, M - device moving during water test, - S - device standing still during water tests, W - weather conditions). The letter K sometimes found is specified in DIN 40050-9, and not in IEC 60529.

Some IP codes contain an "X" instead of a number. This designation should not be misconstrued as a lack of protection. An X signifies that the manufacturer considers that rating is irrelevant. For example, if a radio is designed to be used in a wet setting, the rating for solid particle ingress is largely irrelevant. In this case, manufacturer can decide not performing specific tests to collect data necessary to specify, following the standard, a protection rating against this specific external influence.

NF-X 10-812 "Milieu marin - matériels immergés - Essais en environement et recommandations"
This AFNOR standard has been issued in June 2013, the official translation into English was issued in November 2016 (**12**). It replaces the experimental standard XP-X 10-812 of November 1995. It corresponds to the immersed equipment (type E2 of the experimental standard XP-X 10 800 - see Life cycle definition in the present document and reference **10**).
NF-X 10-812 sets out the operating conditions for underwater oceanographic equipment and instruments and defines the corresponding aggressive conditions to be taken into account to ensure that the equipment is capable of withstanding the marine environment. For this type of equipment, the document lays down the standard reference life cycle, the corresponding type and level of aggression, the tests to be performed and the recommendations to be taken into account. It was prepared by the French national organization for standardization (Association Française de Normalisation, AFNOR).
The equipment and instruments covered include those that can be operated immersed in seawater and, by extension, in freshwater lakes, ponds, reservoirs, watercourses. This equipment and these instruments can be installed on marine vehicles (ships, buoys, towed bodies, submersibles, mooring lines, etc.).
This NF-X 10-812 and former standards XP-X 10-8xx are referenced to the French Navy standards GAM EG 13 *General environmental testing of equipment.*

5. Extreme conditions and critical parameters in different domains

Standards listed and briefly described in previous section, are considering different environmental parameters and induced effects, providing for all or part of them standard test methods. As written above, test methods are grouped in categories referring to different environmental condition. For each environmental condition, usually defined/represented through one or two parameters, standards provide rules and recommendations to collect information about induced effect. When necessary test methods include guidelines and suggestions on how to fix or control other environmental parameters affecting the results. MIL-STD-810 presents the set of 28 categories, , and a very detailed list of test methods, rules, guidelines addressing all tailoring process phases (from preparation to report of results) for all of them at about 700 pages (**1 - part two**). Even if several categories and environmental condition of interest are similar between MIL, NF-X, and IEC 60068 standards, approach in most of the case is different considering the specific scope of each standard. More than this, both NF-X and IEC 60068 introduce specific environmental conditions, for example, IEC 60068 is particularly interested to provide test methods for exposure to corrosive agents. For the scope of this report, categories provided by selected standards have been revised considering usual environmental conditions in which ENVRI RIs operate, in order to determine a comprehensive list of environmental parameters and induced effects of interest for them, selecting test methods and grouping them in categories appropriate/suitable for their work. This means that sometimes categories provided by single standards are being merged in a broader category, when necessary, retaining only some of proposed test methods. New categories and group of test methods have been created in order to be more compact and suitable for ENVRI RIs and serve more than one environmental domain. Results of this work lead to the following list:

Number	Category
1	**cold**
2	**heat**
3	**damp heat/humidity**
4	**low pressure/altitude**
5	**rain**
6	**icing/freezing rain**
7	**salt spray/fog**
8	**solar radiation**
9	vibrations/mechanical shock
10	motion
11	earth continuity
12	mains supply disturbance
13	electromagnetic compatibility
14	**immersion/temperature shock**
15	hydrostatic pressure

16	condensation
17	marine fouling/fungus
18	lightning strike
19	shock from swinging/vibrations
20	contamination by fluids
21	corrosion
22	gas leakage
23	volcanic ashes
24	**, sand and dust**

Follow, for some (in **bold**) of the listed parameters, are reported recommendations and best practices ENVRI RIs can use in developing the Life Cycle Environmental planning (LCEP) and identify suitable test methods and severity levels. Work to establish procedures and test methods for other categories will continue along the time of the project and if necessary also later, to achieve the scope to provide a new standard for ENVRI RIs about qualification of instruments to extreme conditions

5.1. COLD

General remarks

Exposure at very low temperatures could alter the physical properties of materials temporary or permanently. In particular, it can lead to hardening and embrittlement of materials, binding of parts from differential contraction of dissimilar materials and the different rates of expansion, loss of lubrication due to decreased viscosity, changes in electronic components (resistors, capacitors, etc.), transformers and electromechanical components, effects due to condensation and freezing of water in or on the materiel, etc.

Although the natural low temperature environment is normally cyclic, the effect of solar loading is minimal, if not absent, so in most instances it is acceptable to use a constant low temperature test.

Table 502.5-I of the MIL-STD-810G standard reports lowest extremes of air temperature, in terms of hourly averages for: (i) Basic Cold (Most of Europe,, Northern contiguous US,, Coastal Canada,, High-latitude coasts (e.g., southern coast of Alaska),, High elevations in lower latitudes), (ii) Cold (Canada, Alaska (excluding the interior),, Greenland (excluding the “cold pole”),, Northern Scandinavia,, Northern Asia (some areas), High Elevations (Northern and Southern Hemispheres),, Alps,, Himalayas,, Andes) and (iii) Severe Cold (Interior of Alaska,, Yukon (Canada),, Interior of Northern Islands,, Greenland ice cap,, Northern Asia) that are -30, -46, and -51 °C, respectively. For

storage/transit situations the first one can be as low as -33 °C. The MIL standard don't consider Antarctica, but there the temperature can be easily lower than -75 °C.
Here the effect of the blowing wind should be considered as its chill effect (http://en.wikipedia.org/wiki/Wind_chill), i.e. the apparent temperature should be used instead of the real temperature.
All the domains (atmosphere, ecosystem, Earth, and marine) can be affected by these conditions.

Suitable existing test methods and recommendations on their application
The MIL standard, for all cold conditions indicates a test duration between 4 and 72 h, depending on the type of item, with no need to perform tests where temperature change following a specific cycle.
The NF X indicates no cycle. This is related to the very low influence of solar irradiation usually encountered in these environments.

Severity levels
To better fit needs of ENVRI RIs, harder tests are suggested in terms of temperature values with respect to NF X. Table 5 report the temperature and durations for the Low Temperature test. For interior of Antarctica, a further test at -70 °C is recommended for specific cases.

Table 5 Values of the parameters suggested for the Low Temperature test.

		Class A		Class B		Class C	
		Transp./Storage	Operation	Transp./Storage	Operation	Transp./Storage	Operation
Temperature	T (°C)	-50	-50	-30	-20	-20	-10
Duration	D (h)	72	16	72	16	72	16

5.2. HEAT

General remarks
High temperature exposure could alter, temporary or permanently, the physical properties of materials. In particular it can bring to: disconnection of parts due to different thermal expansion,, lubricants can become more viscous and lose their properties bringing to breaks, changes in object physical dimensions, packing, gaskets, bearings and shafts become distorted, bind, and fail, resistances, electronic circuits and relays modify their behaviour while transformers heat up. Other effects could be decolouring of surfaces and development of high pressure on sealed boxes. In general, there is a shortening of the life of the object.
High temperatures can be encountered in the deserted zones of the planet, such as near the equator, or in particular cases near natural heat sources such as volcanos. In the first case air

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temperature can easily reach values around 50 °C, while the ground can have a temperature higher than 30 °C (see for example Table C-I of the MIL-STD-810G document).
The domains luckily affected by these conditions are the atmospheric, the ecosystem and the Earth ones, the latter two potentially influenced by both the two cited factors. The marine domain is most probably not affected by high temperature problems, oceans acting as natural cooling agents. For this reason, the NF X standard only considers the case of damp heat.

Suitable existing test methods and recommendations on their application
Both the MIL-STD-810G and NF X 10-812 provide indications for the storage/transport and for the operational situations.
The **MIL-STD-810G** standard suggests to test ruggedness of devices with respect heat in two different ways: against constant high temperature conditions, and against an environmental conditions characterized by a high temperature cycle. In the first case, the temperature should be maintained for 2 hours after the stabilization at the test value. In the second case, the temperature cycle for the specific climatic category should be repeated for a number of times, different for transport/storage and for operation. Each cycle lasts for 24 hours. See Tables 501.5-II and 501.5-III for the Basic Hot and Hot Dry climatic type cycles.
The **NF X 10-812** suggests to perform a similar high temperature test (Damp Heat (A.2)), even if in some way simplified. It consist of two varying temperature periods and two constant temperature periods. The two extreme temperatures and the periods lengths vary for the different severity classes and for storage and operation conditions. In this standard, also relative humidity is specified.

Severity levels
On the basis of existing standards, the authors of the present report propose a similar approach to the NF X 10-812 one, with a schematic test cycle (see Figure 2). In order to consider also dry environments, we suggest repeating the tests also for low RH (~50%, see *Table 1*). Furthermore, for extremely hot environments an additional test at 70 °C for 8 h is considered appropriate.

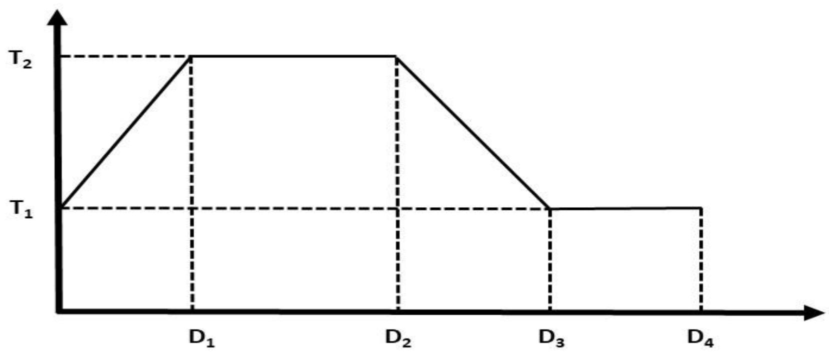

Figure 2 Test cycle for the High Temperature case.

Table 6 Values of the parameters suggested for the High Temperature cyclic test. Regardless of the operating state of the equipment, a fixed relative humidity value is applied during the constant temperature phases D2 and D4.

		Class A	Class B	Class C

		Transp./Storage	Operation	Transp./Storage	Operation	Transp./Storage	Operation
Temperature	T1 (°C)	20	20	20	20	20	20
	T2 (°C)	50	50	50	50	40	40
Duration	D1 (h)	2	2	2	2	2	2
	D2 (h)	96	6	96	6	96	6
	D3 (h)	2	8	2	8	2	8
	D4 (h)	-	8	-	8	-	8
Humidity	RH (%)	50 and 90	50 and 90	50 and 90	50 and 90	50 and 90	50 and 90
N. of cycles	-	1	5	1	5	1	5

5.3. DAMP HEAT/HUMIDITY

General remarks
Common failures may include surface effects, such as oxidation and/or galvanic corrosion of metals, chemical reactions, with external agents deposited on the surfaces, changes in friction coefficients, resulting in binding or sticking, changes in material properties, such as electrical and thermal insulating characteristics, de-lamination of composite materials, degradation of hygroscopic materials, degradation of optical element image transmission quality, degradation of lubricants.
Warm and humid conditions usually occur year-round in tropical areas, but they can be observed seasonally in mid-latitude areas, or as result of the combination of changes in pressure, temperature, and relative humidity. The natural environment is so complex that in general many temperature/humidity conditions are difficult to reproduce in laboratory. Nevertheless, this test can be useful to depict the main problems that can arise.

Suitable existing test methods and recommendations on their application
The **MIL-STD-810G** suggests to perform different tests for the climatic conditions characterized by three humidity levels (constant and cyclic temperature with high humidity, and hot humid) for both operation and storage/transit, besides one extreme test to evaluate long-term effects. They consist of 24 h cycles, with temperature and relative humidity indicated hourly.

Severity levels
Figure 3 and Figure 4 and Table 7 report the severity levels for temperature and relative humidity for the Damp Heat/Humidity test. Complete cycles are of 24 hours.

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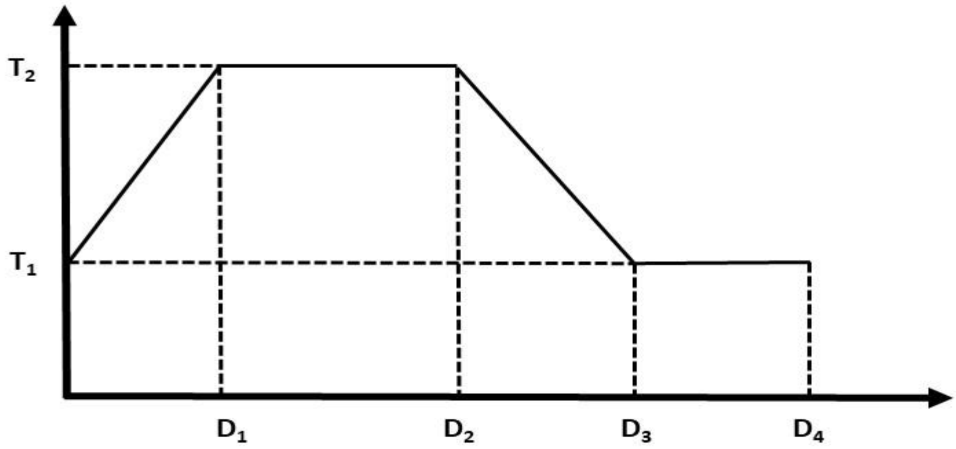

Figure 3 Temperature test cycle for the Damp Heat/Humidity case.

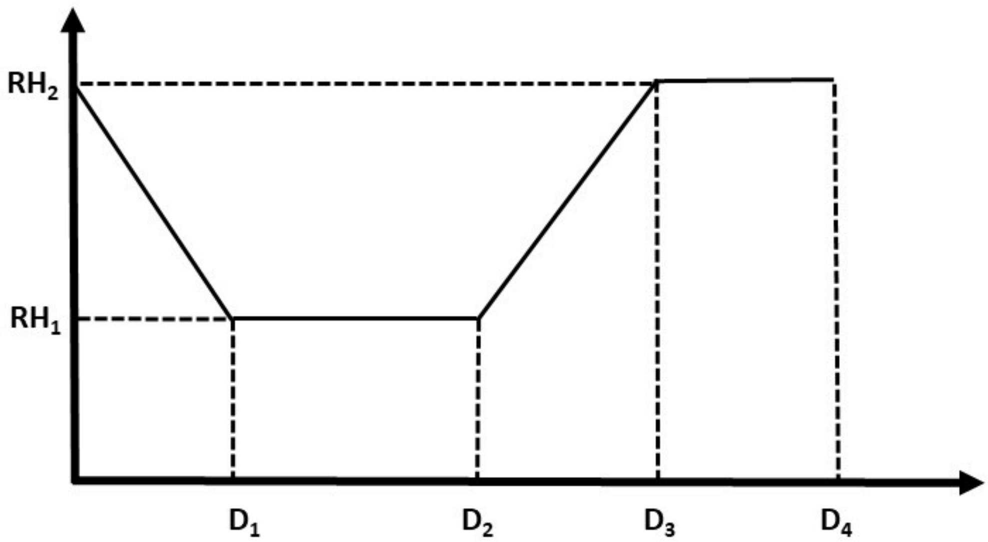

Figure 4 Relative Humidity test cycle for the Damp Heat/Humidity case.

Table 7 Values of the parameters suggested for the Damp Heat/Humidity cyclic test.

		Class A		Class B		Class C	
		Transp./Storage	Operation	Transp./Storage	Operation	Transp./Storage	Operation
Temperature	T1 (°C)	30	30	30	25	25	30
	T2 (°C)	70	40	60	35	25	30
Relative Humidity	RH1 (%)	20	60	20	75	95	95

	RH2 (%)	80	90	75	100	100	100
Duration	D1 (h)	6	7	6	7	3	3
	D2 (h)	6	3	6	3	9	9
	D3 (h)	6	7	6	7	3	3
	D4 (h)	6	7	6	7	9	9
N. of cycles	-	15	15	90	45	90	45

A further test with fixed RH above 95% and variable temperature (with D periods equally distributed) between 30 and 60 °C is recommended for evaluation of the effects of long-term exposure of the item.

5.4. SALT SPRAY/FOG

General remarks

This test is useful to verify the efficacy of protective coatings on materials and possible effects of salt deposits on the physical and electrical properties of devices. Even if not representative of the natural environment this test could provide indications of potential problems associated with the marine environment. This test cannot substitute other compounds corrosion test or the effects of humidity and fungus.

Sea salt is found everywhere (oceans, atmosphere, and ground) but the most evident effects occur at coastal regions.

Possible corrosion mechanisms include corrosion arising by acidic/alkaline solutions formed following salt ionization in water and further ion hydrolysis, because of electrochemical reactions. Electrical effects are mainly represented by creation of conductive coatings and corrosion of insulating materials. Physical effects could be represented by the blistering or corrosion of paints because of electrolysis.

This test is obviously suitable mainly for the marine domain, but can became relevant also for any other domains if/when they are operating on the coast in areas near to the sea, mainly if characterized by strong wind regime and than high salt spray concentration in the air.

Suitable existing test methods and recommendations on their applications

The **MIL-STD-810G** suggests to expose the item to an irrigation with a 5% salt solution at a fallout rate equal to 1-3 ml/80cm^2/h for 48 h, followed by a drying period of 48 h. The temperature in both periods should be 35 °C. If possible 2 cycles of 24h+24h (same total time) is preferred. **NF X 10-812** suggests similar criteria.

Severity levels

Figure 5 and Table 8 indicate the severity levels for the parameters of the Salt Spray test. The test should be performed with the device out of operation in order to avoid possible damages. Its functionality will be verified after the completion of the wet-dry cycles.

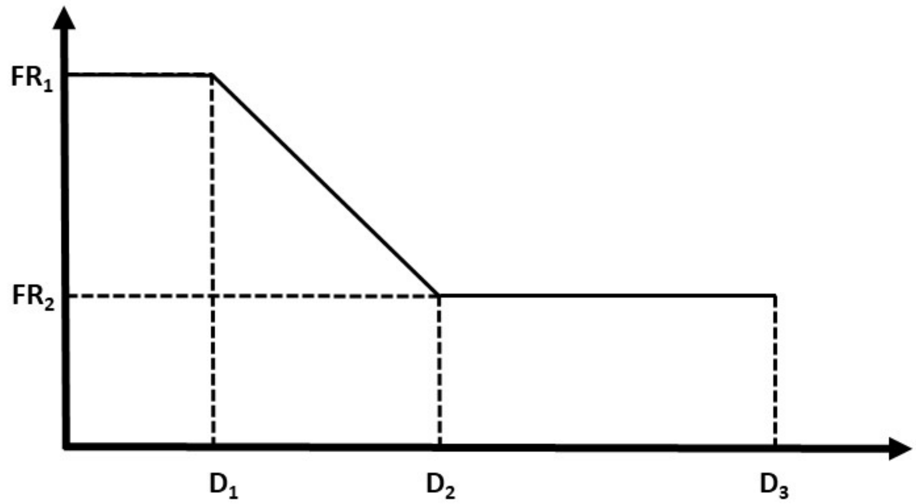

Figure 5 Test cycle for the Salt Spray test.

*Table 8*Values of the parameters suggested for the Salt Spray cyclic test.

		Transp./Storage
Temperature	T (°C)	35
Salinity	S (%)	5
Fallout Rate	FR ($ml/m^2/h$)	250
Duration (*)	D1 (h)	24
	D2 (h)	-
	D3 (h)	24
N. of cycles (Class A/B/C)	-	10/5/2

(*) D1 is the duration of the salt solution irrigation and D3 is the duration of the drying phase. D2 is instantaneous in this case.

5.5. SOLAR RADIATION

General remarks

The heating effects of solar radiation differ from those caused by high air temperature alone as solar radiation could generate directional heating and thermal gradients due to differently exposed surfaces. In the solar radiation test, the amount of heat absorbed or reflected depends primarily on the absorptive or reflective surface properties (e.g., roughness, colour, etc.) on which the radiation is incident. In addition to those problems identified for the heat case, other specific problems can occur, such as weakening of solder joints and glued parts, changes in strength and elasticity, loss of seal integrity, changes in characteristics of elastomers and polymers, blistering, peeling, and de-lamination of paints,, composites, and surface laminates applied with adhesives such as radar absorbent material (RAM), difficulty in handling the device if necessary. In addition to heating, solar energy in specific portions of the spectrum, particularly the ultraviolet, could cause other effects such as fading of fabric and plastic colours, fading of paints, deterioration of natural and synthetic elastomers and polymers through photochemical reactions initiated by shorter wavelength radiation.

The MIL standard considers two different situations to investigate effects on devices/materiels that are exposed outdoors to direct sun light in realistically hot climate conditions. The first is represented by the most severe locations characterized by very high temperatures accompanied by high levels of solar radiation, such as hot and dry deserts, while the second is for locations that experience less severe conditions, with high temperatures accompanied by high levels of solar radiation, winds, and moderately low humidity. Photochemical reactions usually do not occur until materiel surfaces receive large amounts of sunlight.

All the domains (atmosphere, ecosystem, Earth, and marine) can be potentially affected by these conditions.

Suitable existing test methods and recommendations on their application

The **MIL-STD-810G** standard suggests radiation and temperature test cycles for both considered severity cases, with radiation values that peak at 1120 W/m^2 while temperatures set at 49 °C and 43 °C, respectively. Evaluating actinic affects using cyclic tests could take months and therefore the use of an accelerated test is suggested. It consists of quasi-continuous exposure to high radiation values, with short brakes in order to avoid permanent damages to the equipment.

The **NF X 10-812** suggests cyclic tests, identical for transport/storage and operation, but does not provide a test for evaluation of actinic effects.

Severity levels

Suggested cyclic tests are illustrated in Figure 6 and Table 9. The three severity levels differ only by the number or repetitions per test.

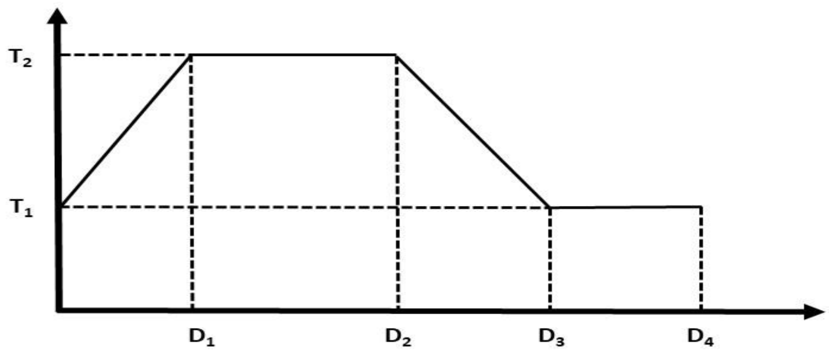

Figure 6 Test cycle for the Solar Radiation case.

Table 9 Values of the parameters suggested for the Solar Radiation cyclic test.

		Transp./Storage	Operation
Maximum Solar Radiation	I (W/m^2)	1120	1120
Temperature	T1 (°C)	10	10
	T2 (°C)	55	55
Duration	D1 (h)	4	4
	D2 (h)	10	10
	D3 (h)	4	4
	D4 (h)	6	6
N. of cycles (Class A/B/C)	-	10/3/3	10/3/3

For the evaluation of the actinic effects, constant values of solar radiation and temperature equal to the maximum values of Table X need to be applied. Short breaks of 3-4 hours are possible in order to avoid permanent damages.

5.6. IMMERSION/THERMAL SHOCK

General remarks

This test is suitable to determine if the device can continue to operate correctly during or after immersion. In some cases, this test may be used to verify water tightness in places of the test pertaining rain, but it should be noted that the water pressure itself during immersion might contribute to prevention of water penetration in the device. Possible problems arising during or after immersion include: fouling of lubricants, internal electrical shortcuts,, corrosion.
This test is useful mainly for the marine domain activities.

Suitable existing test methods and recommendations on their application

Usually immersion under 1 m of water is sufficient to detect possible problems. If a harder test is needed, it is possible to raise water pressure taking into account the formula $P = 9.8d$ (fresh water), where P is water pressure and d is the immersion depth.
During immersion, the formation of bubbles could indicate the presence of leaks. The addition of colouring substances to the water could help to detect intrusions into the device.

Severity levels

Figure 7 and Table 10 report the severity levels for the parameters of the immersion test.

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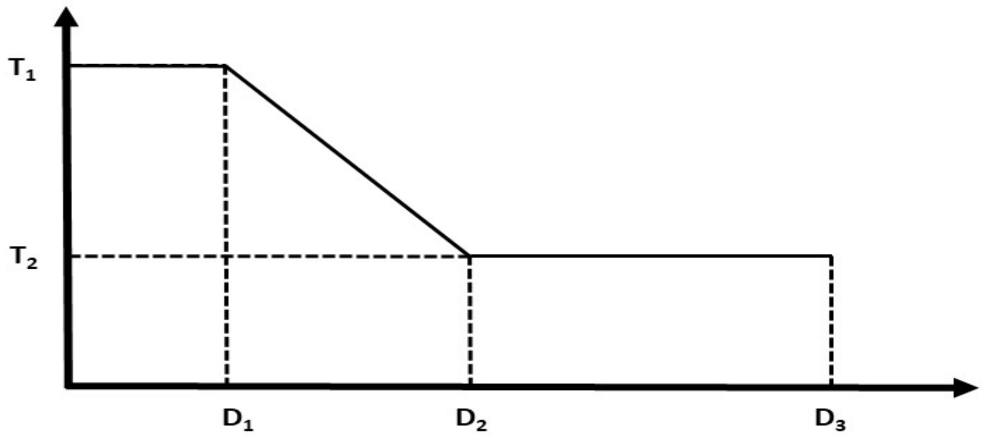

Figure 7 Test cycle for the Immersion case.

Table 10 Values of the parameters suggested for the Immersion test.

		Class A	Class B	Class C
Temperature	T1 (°C)	50	23	23
	T2 (°C) (*)	10	10	18
Duration	D1 (h)	2	2	2
	D2 (sec)	ASAP (**)	ASAP (**)	10
	D3 (h)	2	2	0.5
Depth	d (m)	1	1	0.2

(*) T2 is the water temperature.
(**) As short as possible.

5.7. ICING/FREEZING RAIN

General remarks

Icing on operational devices can bring to the following malfunctions: binding of moving parts, adding weight to moving or fixed parts, interfering with clearances between moving parts, inducing structural failures, reducing airflow efficiency as in cooling systems or filters, reducing visibility through windshields and optical devices, affecting transmission of electromagnetic radiation, providing a source of potential damage from the employment of ice removal measures.

Ice formation could occur due to rain, drizzle, or fog falling on materiel with the temperatures at or below freezing point, from sublimation, from freezing rain or freezing drizzle falling on materiel at or near freezing, from sea spray and splash that coats materiel when the materiel temperature is below freezing point. Ice density can vary in the range 0.2-0.5 g/cm^3 for rime ice (soft to hard) to the range 0.6-0.9 g/cm^3 for glaze ice. Ice thickness is usually between 6 and 75 mm.

All the domains (atmosphere, ecosystem, Earth, and marine) could be affected by these conditions if operations are performed at places where water can exist in liquid and solid form, such as coastal areas with very cold climate or at elevated mountains.

Suitable existing test methods and recommendations on their applications

The **MIL-STD-810G** recommends the irrigation of the device under test by water spray with a temperature between 0 and 5 °C for 1 h at a rate of about 25 mm/h. The device should be initially at a temperature slightly above zero, to ensure water can penetrate into small openings. at the temperature of the device shall be lowered to -10 °C and irrigation shall be continued until the desired ice thickness is obtained. One shall wait for 4 h to ensure ice hardening.

Severity levels

Figure 8 and Table 11 illustrate the test procedure and parameter values for the icing test. In the first phase, water spray is directed towards the device, also using wind or side spray in order to assure complete coverage of the device. Then the test chamber is cooled under the water freezing point and irrigation continues until the desired ice thickness is obtained. Finally, stable conditions are maintained to ensure ice hardening. The severity levels differ through variation of the amount of ice (thickness) accumulated on the device.
Formation of ice during transportation or storage should not damage the equipment, as usually they are protected by hard cases.

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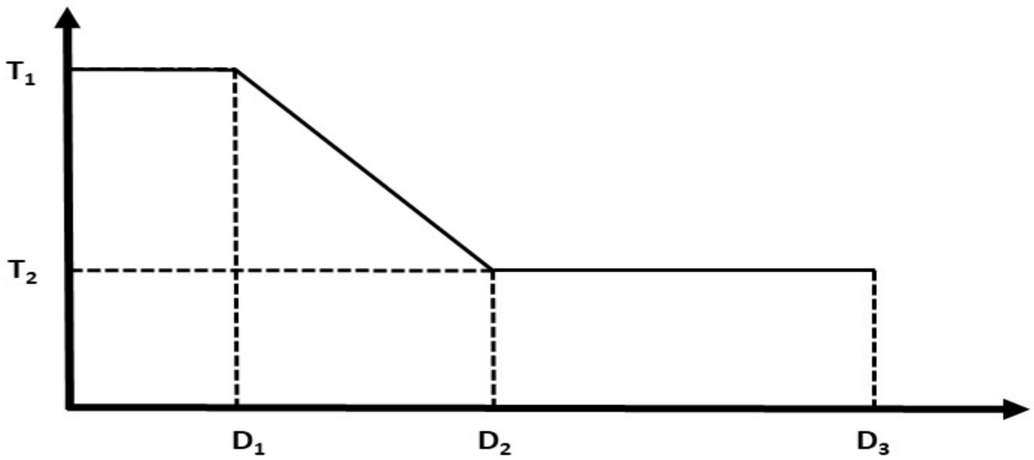

Figure 8 Test cycle for the Icing case.

Table 11 Values of the parameters suggested for the Icing test. Regardless of the operating state of the equipment.

		Operation
Temperature	T1 (°C)	0
	T2 (°C)	-10
Duration	D1 (h)	1
	D2 (h)	(*)
	D3 (h)	4
Water delivery rate	WR (mm/h)	25
Ice thickness (Class A/B/C)	IT (mm)	75/50/10

(*) Continue irrigation until the required ice thickness is obtained.

5.8. LOW PRESSURE/ALTITUDE

General remarks

This test is suitable for devices that are likely to be stored and/or operated at high elevation sites, transported or operated in pressurized or unpressurized aircraft, exposed to a rapid decompression, or carried externally on aircraft. Possible undesired effects include leakage of gases or fluids from gasket-sealed enclosures, deformation, rupture or explosion of sealed containers, overheating due to reduced heat transfer, electronic malfunctions due to breakage of electrolytic capacitors.

For ground operations, temperature and pressure data should be used or, if not available, precompiled atlas could be used. Most pressurization systems simply let cargo compartment at external atmospheric pressure up to a particular altitude, and then set and maintain with sufficient accuracy (few mbars) a specific pressure above that altitude, the so-called "cabin altitude". The temperature associated with the various low-pressure conditions depends on the capabilities of the environmental control system of the aircraft.

In the **MIL-STD-810G** the highest elevation currently contemplated for ground military operations is 4572 m (15000 ft), with an equivalent air pressure of 57.2 kPa. Mount Everest summit has average pressure equal to 33.7 kPa (8800 m). For aircraft operations, the maximum height taken into account is around 21000 m (70000 ft).

This test is suitable for devices involved in the atmospheric domain studies, such as airborne or balloonborne measurements.

Suitable existing test methods and recommendations on their applications

For ground operations **MIL-STD-810G** recommends, unless otherwise identified, to use 4572 m (15000 ft) for the cabin altitude and test the item for at least 1 hour. For the altitude change test the rate of 10 m/s is indicated, as this is the maximum value reachable by military transport aircrafts at takeoff.

Severity levels

Figure 9 and Table 12 report the parameters for the Low Pressure test, in terms of cabin altitude. For fixed height operations there are three severity classes corresponding to three different altitudes, the higher being at the limit of the troposphere. For decompression test, three different altitude change rates are indicated, the intermediate test period being the one of interest.

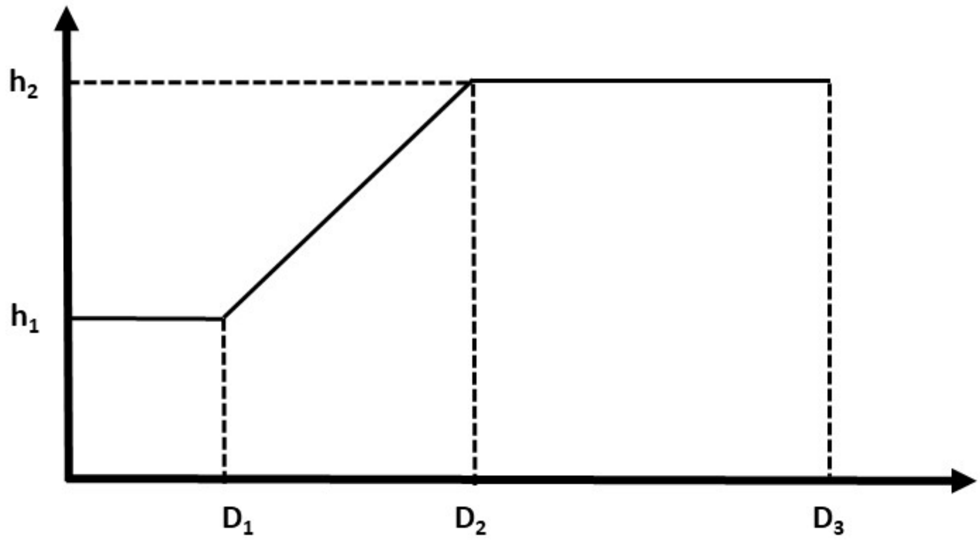

Figure 9 Test cycle for the Low Pressure case.

Table 12 Values of the parameters suggested for the Low Pressure test.

		Fixed Height	Decompression
Cabin Height (Class A/B/C)	h1 (m)	2000/4000/10000	0
	h2 (m)	-	1000
Duration	D1 (h)	1	-
	D2 (min)	-	9/4/2 (*)
	D3 (h)	-	-
Height Change (Class A/B/C)	hc (m/s)	-	2/5/10

(*) The duration of the decompression is approximate.

5.9. DUST AND SAND

General remarks

Here we consider dust as consisting of particles with the diameter smaller than 150 µm, while sand is composed of particles with the diameter greater than 150 and smaller than 850 µm. While dust could mainly obstruct openings, penetrate into cracks, crevices, bearings, and joints, sand could bring to abrasion/erosion or clogging effects. Other effects include degradation of electrical circuits, interference of moving parts, reduction of thermal conductivity, interference with optical characteristics, overheating and fire hazard due to restricted ventilation or cooling, increased chaffing and wear between non-mating contacting surfaces. The blowing sand and dust environment is usually associated with hot and dry regions, but they can be found seasonally in most other regions.

Suitable existing test methods and recommendations on their application

Climatic conditions during the test should include temperatures as high as reachable during operations and low humidity (<30%), in order to avoid coagulation of the particles. The blowing particles should hit the most vulnerable surfaces, and rotation of the item could be necessary. Different tests could be necessary depending on the operation conditions of the item, i.e. protected or unprotected. The **MIL-STD-810G** suggests dust an air velocities range between 1.5 m/s and 10 m/s, typical for desert winds, while mass concentration for the blowing dust test around 10 g/m^3,. 6-hours long tests are suggested. For sand, velocities between 20 and 30 m/s and concentrations around 0.2 g/m^3 should be used. In this case, 90 minutes of exposure are suggested.

Severity levels

Figure 10 and Table 13 report the severity levels parameters for the Sand and Dust test.

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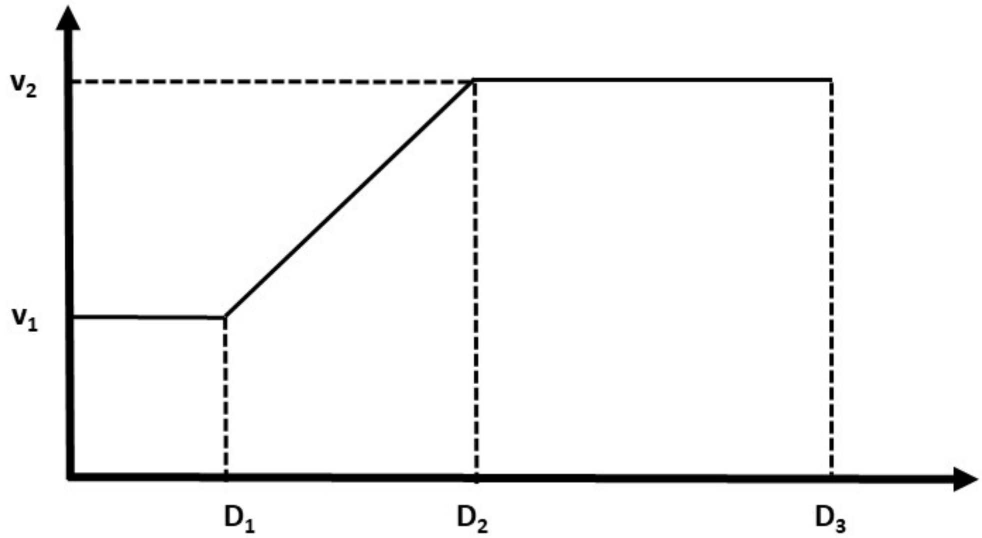

Figure 10 Test cycle for the Dust and Sand case.

Table 13 Values of the parameters suggested for the Dust and Sand test.

		Dust	Sand
Air blow velocity	v1 (m/s)	1.5	20
	v2 (m/s)	10	30
Duration (Class A/B/C)	D1 (h)	5/10/20	1/2/5
	D2 (h)	-	-
	D3 (h)	5/10/20	1/2/5

Mass concentration	c (g/m^3)	10	0.2

(*) RH should be < 30%. The test shall be repeated at ambient temperature and at maximum operating temperature.

5.10. RAIN

General remarks

This test is useful to determine if rain, water spray, or dripping water can cause penetration of water into the device despite the use of covers, cases, and seals in preventing the penetration of water into the materiel. Moreover, it should be used to determine effects on performances of devices during and after exposure to water. Finally, is useful to determine physical deterioration rate of the materiel at long water exposure, and the effectiveness of water removal systems.
This test is usually not necessary if the device has passed the immersion test.
Rain can have different effects, not only via impact or as deposited water, such as: interference with radio communication and radar effectiveness, inhibited visibility through optical devices, erosion of surfaces, degraded strength of materials also due to corrosion, increased weight, malfunction of electrical materiel, freezing inside devices and producing cracks into the devices themselves or in part of them.
This test is suitable for all the domains, when devices and instruments are operating (stored) outdoors.

Suitable existing test methods and recommendations on their application

The MIL-STD-810G proposes three different test procedures: Rain and Blowing Rain, Exaggerated (for large size devices), and, Drip (for devices that can be exposed to falling water from condensation or leakage). Important parameters for the test are rainfall rate, wind velocity, test item exposure surfaces, and water pressure. Experience has shown that a temperature difference between the test item and the rainwater can affect the results of a rain test. When specified for nominally sealed items, increasing the test item temperature to about 10°C higher than the rain temperature at the beginning of each exposure period to subsequently producing a negative pressure inside the test item will provide a more reliable verification of its water tightness.

Severity levels

Table 14 reports the severity levels for three different situations related to rain and dripping water.
All surfaces onto which the rain could fall or be driven should be subjected to the test conditions. This could be obtained by rotating the item as required to expose all vulnerable surfaces.
A water-soluble dye such as fluorescein may be added to the rainwater to help with detection and analysis of water leaks.

Table 14 Values of the parameters suggested for the Rain test.

		Rain (*)	Exaggerated (**)	Drip (*)

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Rain Rate	RR (mm/h)	120	-	-
Drops Velocity	DV (m/s)	-	18	-
Drip Rate	DR ($l/m^2/h$)	-	-	250
Drops Diameter	DD (μm)	0.5 - 4.5	0.5 - 4.5	-
Water Temperature (below the item temperature)	Tw (°C)	> 10	> 10	> 10
Duration (Class A/B/C)	D (h)	0.5	0.75	0.25

(*) For steady state rain the drops should approach the terminal velocity of about 9 m/s, that means falling from a height of no less than 1 meter.
(**) The system should be reheated after changing the exposed face and before restart irrigation.

6. Facilities, testing lab, and services at disposal to qualify instruments to extreme conditions

Numerous infrastructures (testing labs, sea-bottom, cold rooms, etc.) are provided by both research institutions, including inside ENVRI RIs, and the private market for instrument qualification to extreme conditions and quantification of their degree of ruggedness to environmental conditions. Some of them are organized as a network, as in the case of Hydralab+ (http://hydralab.eu/) that includes some capacities to test hydrodynamic behaviour, ice or wind effects. European Commission can provide support to these networks through the Integrated Infrastructure Initiative (I3) funding instrument. European Commission also supported in the past access to a specific infrastructure through a dedicated Trans-national Access Programme (TNA). This is the case of METRI project (http://www.ifremer.fr/metri/pages_metri/metri.htm). Thanks to EU support, until 2010, public and private subjects, engaged in scientific and technological research activities, had possibility to have free of charge access to IFREMER Marine Environment Tests and Research Infrastructure (METRI). In this section, without the claim of being exhaustive, we provide a short description of some of these infrastructures. Aim of this section is to provide to ENVRI RIs, and, inside them, to competencies interested/devoted to the topic of devices ruggedness, piece of information useful to address the issue of what "market" is offering.
Is important to repeat that we are interested to evaluate effects of environmental as well as operational stresses (extreme environment) on the instrument integrity and capability to perform correctly, more than to estimate effects on the output of instrument (measured parameter value). This analysis is normally addressed in metrology through identification of "variables of influence", quantification of errors and correction factors/functions/curves. Determine robustness or weakness of devices being a step necessary to require to manufacturers, or directly implement, modification to reduce (ideally eliminate) unwanted effects.

6.1. Inside ENVRI Consortium and or public organizations

INSEAN has two towing tanks. Tank no. 1 is one of the largest worldwide. It is 470 m long, 13.5 m wide and has a depth of 6.5 m. It is equipped with a towing carriage that can achieve a maximum speed of 15 m/s. Tank no. 2 is of smaller size (220 m 9 m 3.8 m) and maximum carriage speed of

10 m/s. It is equipped with a single-flap wave generator, which provides regular as well as irregular waves for the investigation of seakeeping characteristics and ride comfort.
http://www.insean.cnr.it/it/node/331

PLOCAN offers land-based and sea-based novel facilities to promote long-term observation and sustainability of the ocean, providing a cost-effective combination of services. PLOCAN is able to provide access and multidisciplinary logistic support through its onshore facility and two marine test sites (Taliarte harbor and offshore). The facility and test sites are located in the North-East coast of Gran Canaria Island, and the platform is integrated in the offshore test site.
http://www.plocan.eu/index.php/en/facilities

ARGONNE National Laboratory offers High Temperature Corrosion Test Facilities and High Pressure Test Facilities for Metal Dusting. About corrosion, six corrosion test facilities and two thermos-gravimetric systems are at disposal of users and stakeholders for conducting corrosion tests in complex mixed gas environments, in steam and in the presence of deposits. In relation to degradation effects caused by dusting, five different facilities are instead at disposal.
https://www.ne.anl.gov/facilities/eda/metaldusting.html

CNR-ISAC Wind Tunnel
The cold vertical closed circuit wind tunnel is 7.9 m height and 3.2 wide; cross section is 0.4 m times 0.4 m that can be reduced in the working leg. The air velocity, inside the tunnel, can be set between 2 and 30 m/s, and the lowest working temperature is about -25°C. There is an inlet of droplets, generated by an outside droplets sprayer on the bottom of the tunnel. The injected droplets, in a short time, come to thermal equilibrium with the tunnel air temperature and are therefore super cooled. The working leg (80 cm height) is located in the upper part of the tunnel. In the working leg, several experiments can be designed such as: ice accretion experiments on a rotating pivot, ice growth on plane wings, etc. It is therefore possible to perform tests on graupels from icing of super cooled droplets simulating the processes of hail formation inside clouds. By changing the operating parameters (air temperature and velocity, water liquid content, etc) it is possible to obtain ice accretion with different properties and morphologies. In the same way, tests on wings can be performed simulating airplanes flying through clouds containing super cooled droplets and ice crystals.
http://www.isac.cnr.it/en/content/wind-tunnel

Flowing Seawater Test Facility
The seawater immersion system is utilized for the evaluation of protective coatings, metal alloys, reinforced concrete composites and other materials in an ocean environment. This system is composed of two immersion tanks with a continuous once-through, filtered supply of seawater, and has the ability to expose a variety of specimens, including test coupons, component hardware or full-scale test articles.
This seawater is pumped directly from the Atlantic Ocean and is representative of surface oceanic conditions. (Natural seawater has been documented as more corrosive than artificial seawater or simple salt solutions.) Specialized tests can be designed to study impingement-corrosion, erosion-corrosion, cavitation and other velocity effects. Both 110-volt power and data acquisition connections are available at the facility to power test articles and record onboard data instrumentation outputs. The water in the tanks is continuously monitored for salinity, temperature, dissolved oxygen, and pH.

The inlet to our site is on the open ocean providing:

- a continuously refreshed source of clean, natural seawater.
- seasonal water temperatures varying from 20o to 28oC.

The site has the capability of exposing samples in a wide variety of racks and sample configurations. The flowing seawater tanks are especially useful for replicating exposures in industrial facilities using seawater-piping systems.
https://corrosion.ksc.nasa.gov/seawater.htm

University of Dayton Research Institute
Particle Erosion Test Facility (Sand and Dust)
UDRI maintains and operates the US Air Force's Particle Erosion Test Facility at Wright-Patterson AFB. This facility is part of the Air Force Research Laboratory's Materials Degradation Test Facility. A Cooperative Research & Development Agreement (CRADA) with the Air Force allows us to provide easy access for commercial customers.
The "dust rig" was designed and developed in 1983 to simulate erosion effects on aircraft surfaces subjected in flight to dust-laden environments. It has been recently upgraded to test the larger mass loading seen by helicopter rotors. Typically, crushed silica in sizes ranging from 38 to 250 microns is used as the test media. Specimens are translated in front of an oscillating nozzle. The 6-inch square test area is uniformly covered with a pre-determined mass of particles of a known size at a measured speed. Impact angles from normal to 20 degrees (70 degrees angle of incidence) can be tested, and many specimen configurations are possible. A calibrated screw feed in a plenum tank and an electronic pressure controller ensure correct mass delivery and stability, and a laser Doppler anemometry system is used to determine a delivery pressure for the required velocity.
Test parameters and results are treated in a proprietary manner and our database is accessed only under a strict USAF need basis. A User's Guide (PDF) further describes the facility and testing parameters. Specimens may be shipped for testing, and visitors are welcome. Please contact Cheryl Castro or Andrew Phelps (information at right) to learn more about the particle erosion facility or scheduling time for your projects.
https://www.udri.udayton.edu/NONSTRUCTURALMATERIALS/COATINGS/Pages/ParticleErosionTestFacility.aspx

6.1.1. Facilities for qualification at IFREMER

Hyperbaric chambers
Three chambers are at disposal, and may be alternatively used depending on the availability at the time of sending by the partner. Common characteristics are:
1000 bar maximum pressure (2400 bar - more than twice the maximum abyssal depth - available for high safety factors).
Height: 1.65 m – Usable diameter 0.3 m.
Pressure variation controlled from 1 to 100 bar/mn –Automated cycling in pressure,
Temperature setting and controlled from 2°C to 55 °C.
More information at the web page
http://www.ifremer.fr/metri/pages_metri/infrastructure/hyperbaric.htm

Figure 11 - One of the hyperbaric chambers used for tests at Ifremer

Figure 12 – Pressure test corresponding to a NF X 10 812 qualification

Climatic Chamber
Volume 2.5m^3
Temperature controlled from -65°C to +150°C
Relative moisture controlled between 20% to 98% in the temperature range of +10°C and 90°C

Figure 13 - Climatic simulation chamber used for tests at Ifremer

Vibration and shock generator
Hydraulic QUIRI, Horizontal monobase BAUGN ENGINEERING. Control by DATA PHYSICS software. Maximum charge is 50kg for sinusoidal vibration (Frequency from 1 Hz, Amplitude 1mm, Maximum acceleration 10m.s^{-2}) and half-sinus shocks (Acceleration 15 g, Duration 20ms).

Figure 14 – Instrument on a vibration test bench

Other information can be collected at the Ifremer web page https://wwz.ifremer.fr/en/Research-Technology/Research-Infrastructures/Testing-infrastructure/Testing-facilities

6.2. Facilities provided by private market

ILK Dresden
Development of innovative cryogenic test chambers

As part of a cooperation project with an industry partner a high-performance material test chamber was developed and built, which operates in a temperature range from -180 °C to +200 °C (-292 °F to 392 °F). Different methods and components were investigated, to achieve an optimal adaptation of test chambers for the intended use. As a result of the project, the advantages and disadvantages of different materials and installation systems were identified and evaluated to ensure the most efficient operation and, above all, corresponding with all technical requirements. These requirements relate to:

- the spatial and temporal distribution and stability of temperature within a range of less than ± 1 K,
- a safe supply and disposal of all media (refrigerant, heat, electricity, gas) and
- a flexible design of the sample geometry as possible, with at the same time possibly less influence on the performance of the chamber system at cooling rates from 0 to 30 K/min.

The applications of such chambers are located mainly in the field of aviation and space technology, but also in highly sensitive electronic applications that are exposed to high thermal stresses.
http://www.ilkdresden.de/en/project/low-temperature-test-facilities/

Rheinmetall Defence

Testing of systems, assemblies and components under extreme climates according to all national and international standards (MIL/STANAG/IEC/DIN/EN) is possible at this private facility. During testing, it is possible to obtain highly qualified technical support from experienced collaborators. In particular, is possible to have support of required occupational-medical health examinations e.g. for working in the cold and working in the heath (G21/G30). Facilities offer possibility, for smaller systems and for components, to perform tests for various temperature regulation and cooling appliances. Test can be performed with temperature ranging between –70°C up to +180°C and relative atmospheric humidity ranging between <10% up to >95%. More than to Cold and heat, other tests possible to be carried out include:

- Height testing, e.g. altitude, rapid decompression
- Sand- and dust testing
- Testing of water tightness
- Testing under rain
- Icing
- Corrosion testing (Salt spray mist)
- Simulation of sun
- Contamination testing “Contamination by fluids”
- Temperature shock testing

https://www.rheinmetall-defence.com/en/rheinmetall_defence/systems_and_products/test_centres/ezu_rheinmetall_test_centre_unterluess/klima/index.php

Christian Michelsen Research

Three temperature chambers are available at CMR for equipment testing over a wide range of temperatures. These temperature chambers are suitable for soak testing, cycling, environmental stress screening etc.

Temperature Test Chambers

The temperature in the actual chamber is programmed from a control PC that allows easy repetition of temperature cycles. The same PC also logs the temperature in the chamber, storing

them for future reference. Access ports are provided for the connection of cables. A calibrated precision Pt-100 thermometer (±0.015 °C) is also available for crosschecking the temperature in the chamber.
The temperature chambers are of different size and have different temperature ranges.
https://www.cmr.no/facilities/cmr-temperature-test-chambers/
Pressure Test Facilities
Several facilities can be used, depending from application. For large volumes, up to 5Mpa, a bench feeding fresh water, with only manual logging, is at disposal. Instead of this, for small volumes, up to 100Mpa, a bench feeding hydraulic oil, with automatic logging of pressure and two temperatures can be used. Gas pressurizing is accomplished by means of a gas cylinder depot.
https://cmr.no/facilities/pressure-test-facilities/

METLABS
MET can be used to test Environmental stress, Physical stress, Extreme climatic conditions, and Chemical exposure testing simultaneously.
Testing Capabilities:

- Seismic/Shock/Vibration Testing
- Airborne Contamination Testing
- Flame Testing
- Fungus Testing
- Enclosure Testing
- HALT/HASS
- Green Testing Services
- Energy Efficiency Testing
- Dust & Water Testing

http://www.metlabs.com/services/environmental-simulation-testing/

Smithers Pira
This company is interesting mainly in relation to material testing. The UK laboratories are temperature and humidity controlled, and are ISO 17025 accredited for a wide range of paper and plastic testing services. In addition, they can provide tests to evaluate resistance of labelling to marine conditions, following British Standard BS 5609.
This is a specification for printed pressure-sensitive, adhesive-coated labels for marine use, including requirements for label base material. It sets out various durability criteria including adhesive performance, print permanence and abrasion resistance, stipulating minimum standards for labels to be used in "Marine Environments".
BS 5609 testing is a requirement for self-adhesive drum labels needing International Maritime Dangerous Goods (IMDG) certification. Testing includes a 3-month exposure of labelled test plates in salt water at mid-tide.
https://www.smitherspira.com/services/materials-testing/adhesives-and-labels/subsea-adhesion

Sonardyne
Hydrostatic testing is the most reliable and cost-effective way to validate the integrity of subsea equipment before it is deployed in the field. Sonardyne's state-of-the-art pressure chamber was installed and commissioned in 2015. It uses the latest technology to simulate ultra-deep water operating environments.

These excellent facilities include a 6,300 m (20,670 feet, 630 bar) hydrostatic pressure test chamber which is used to simulate the immense pressure of ultra-deep operating environments and its effect on product integrity.
https://www.sonardyne.com/product/hydrostatic-pressure-testing-facility/

ESPEC

ESPEC's test equipment is designed to handle many different quality and reliability evaluation applications. From standard temperature chambers to altitude test chambers and other specialized equipment, our equipment can handle testing ranging from semiconductor and aircraft equipment evaluations to secondary battery safety tests. We can also plan and provide testing tailored to client needs. Our equipment is upgraded continuously to meet increasingly diverse client needs.
http://www.espec.co.jp/english/products/trustee/test/

7. Best practices and recommendations for qualifying instruments to extreme conditions

❖ In some cases, it is necessary to perform the tests while the equipment is functioning. It is up to the designer to ask for such tests as they may lead to complex setting for the tests. In any case, it is important to check the functionalities before and after the environmental test. This is an acceptance criterion together with visual inspection.

❖ Most standards are suggesting, for the same type of test, to use various levels of severity classes according to the required level of robustness. For instance in the marine domain, NF X 10-812 suggests 3 classes:

— Class A for high robustness requirements,

— Class B for medium robustness requirements,

— Class C for low robustness requirements.

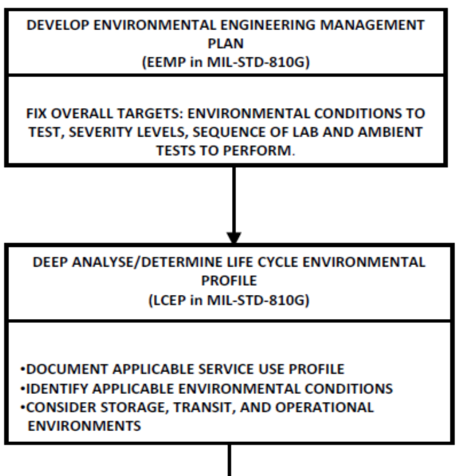
For a given simulated environment, the testing levels will vary according to equipment class.

The different classes can also correspond to

— extreme, real, known environments in which the equipment will be used (very cold regions, for example),

— requirements deliberately chosen according to the confidence that the author of the specifications has with regard to the capacities of the manufacturer to make equipment with the same degree of quality.

The author of specifications can, for a given item of equipment, choose different classes according to the environment (for example, Class A to withstand cold conditions, Class B to withstand mechanical shocks, Class C to withstand vibrations, etc.).



Actually, the analyses of the use cases of Marine Environmental RIs often lead to the use of the Class B (medium robustness requirement). The markets targeted involving human occupancy vehicles or high cost systems, are the cases of use of Class A (liable to occur in EMSO ERIC). Class C is more common when the loss of the equipment in operation is not worth a risk of damage during severe test. Class C is also used when the manufacturing follows precise reproduction scheme and the user is confident that the severity of tests is covering all operating conditions because of the handling by trained and skilled personnel for instance (could be the case for EUROARGO ERIC).

❖ Always consider very well the complete environmental tailoring process necessary to qualify instruments for operation in extreme conditions. The scheme of engineering program that necessarily need to be carefully implemented is illustrated in the side diagram, developed on the basis of MIL standard applying a simplified approach suitable to scope and capability of ENVRI RIs with respect an army or defence organization/industry. In particular, always consider the decisive role of a correct definition of the instrument life cycle, together with a clear definition of environmental conditions in which the equipment usually will work.

7.1. Offshore operations in polar environments

As stated at beginning of Section 5, approach of standards usually consider a specific environmental condition (category - in general represented through one or two parameters) and a single instrument or system. Complexity or dimension of the instrument/system do not affect the validity of the provided standard test methods from a conceptual point of view. However, both dimensions and complexity can rapidly introduce limitations in practical application of the standard test method or a huge increase in costs to perform it. A way to operate in presence of great of very complex systems, can lead to perform tests on single element of the system, and add functioning tests to the whole system/device in real operational conditions when developing the Environmental Engineering Management Plan (EEMP). As obvious, a similar approach can be very demanding in time and resources. In any case provide not a satisfactory answer to the need to have clear indications and guidelines during the design phase of the instrument/system itself.
On the other hand, if induced effects of considered environmental conditions are limited in number and well defined, the alternative approach to develop a specific standard can be considered and pursuit. This has been in effect the case for operations of mobile and offshore installation in cold climate areas. Because of the great economic interest and very high value economic activities in the area, the DET NORSK VERITAS AS (DNV now DNV-GL, see https://www.dnvgl.com/about/in-brief/our-history.html) started a process for developing such a standard in the early 2000s. First simple rules were released January 2006 (**33**), while a first tentative standard started to be released tentatively in October 2013. This process completed two

years later with final release of DNV-OS-A201 standard (**34**). Document is publicly available through DNV-GL web site, but is also possible to find it elsewhere (**35**).

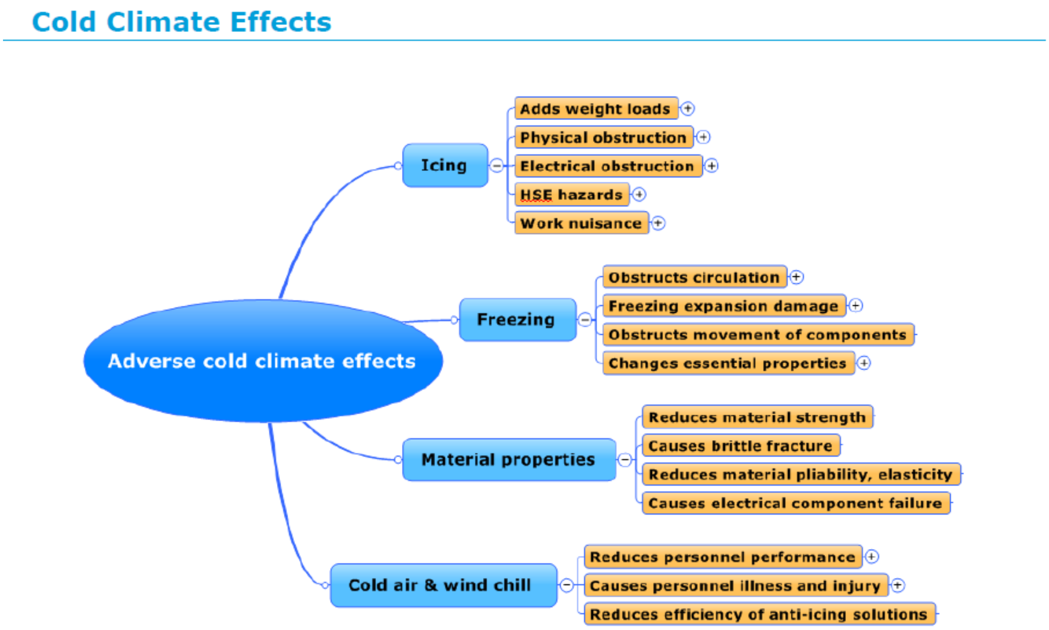


Figure 15 – Adverse effects for operations induced by cold climate conditions

Undesirable effects can arise from cold climate conditions, which are well summarized at Figure 15. A challenge in developing a standard is mainly due to the need to consider winterization for crew well-being (fatigue, frostbite, hypothermia, etc), and winterization for safety (critical equipment and systems), together with the more typical question such as winterization for operability (maintain the functionality of desired operations).
To respond to these challenges, DNVGL-OS-A201 identify a winterization level, *Basic*, *Cold* or *Polar*, depending on temperature conditions to which the mobile or offshore platforms will operate (Table 15)

Forma
Delet

Table 15 Temperature conditions corresponding to the different winterization levels defined by DNVGL-OS-A201.

Winterization Level	*"Indicative" Winterization Temperature (t_w)*	*Sea water temperature*	*Typical Application*
Basic (t_w)	−15°C	+4°C without ice class −2°C with ice class	Operation occasionally in cold-climate conditions for short periods
Cold (t_w)	−30°C	+2°C without ice class −2°C with ice class	Operation in cold-climate conditions regularly or for an extended period of time.
Polar (t_w)	−45°C	−2°C	Operation in extreme cold-climate conditions of the polar regions year-round, typically in ice-infested waters.

where t_w => "extreme low" air temperature for intended operating location.
In addition, the standard applies a three-tired approach (**34, pag. 6**)

> *First, winterization requirements are based upon fulfilling the stated **functional requirements**, which provide the fundamental rationale and intent behind a particular*

winterization issue.

*Second, some functional requirements are further supported by one or more **performance requirements**. These explain in greater detail the type of performance a winterization measure should achieve in order to fulfil the intent of the functional requirement, either in part or in whole.*

*Third, functional and performance requirements are supported by **prescriptive rules and guidance notes**. These provide a set of generally acceptable solutions to meet the functional and performance requirements, either in part or in whole.*

Functional requirements can address issues related to “Function as Normal” (activities important for safety, structure, stability, ballast, power, propulsion, position keeping, etc.), or impose “Restrictions” on operational limits (industrial activities, e.g. crane operations, drilling activities, cargo handling, etc), minimise potential disruption (“Do No Harm”, e.g. basic habitability, anti-freezing protection for other piping systems, etc.), and be devoted to address “Special Studies” (wind chill, dropped object hazards, emergency contingency planning, JTA of critical de-icing, etc.).

Attention of the standard focused on the adverse effects and control of snow, freezing, sea spray and atmospheric icing. To this scope, Anti-icing, anti-freezing and de-icing measures/solutions are deeply analysed at the beginning of the chapter providing Technical Provisions for Winterized (**34, chapter 2, section 1, pp. 12-14**). Strong attention is than devoted to assure selection of materials with appropriate properties for cold climate conditions to which systems will operate. Last, but not list, the standard devote attention to adverse effects of cold and wind chill both on equipment and personnel, providing requirements and rules/notes to implement procedures for safe operation and personnel welfare.

The standard do not prescribe any specific test methods, but thanks to the articulate set of requirements and rules/notes "*provide an internationally acceptable standard for managing the potential deterioration in functionality as a result of cold climate operations*" (**34, pag. 6**), ensuring that a vessel or offshore installation as a whole is capable of and suitable prepared for operations in cold climate.

A similar approach, quite different with respect to that adopted by MIL or NF-X (cfr. i.e. Section 4 pag. 18) can represent in many case for RIs an useful alternative based much more on the technical experience and knowledge. Great advantage can arise from possibility to consider a set of equipment and systems as a whole, and from the possibility to address adverse effects for personnel too.
Is important in any case to state that at the base of this approach are always:

a - a complete rigorous knowledge of material properties and effectiveness of adopted technical solutions. That means, in general, that we are using results of tests performed on the base of prescriptions defined in MIL or other standards addressing robustness issue.

b - a clear complete knowledge of adverse effects and relative importance of different environmental constraints.

8. Towards a ENVRI service

In the previous sections, we have defined a new set of standards suitable for RIs operating in the Environmental area/domain (Chapter 5). To achieve the result we have carried out a careful analysis of standards landscape, focusing on those developed to address the question to verify/certify robustness of equipment to extreme environmental conditions. In addition to the new set of standard test methods foe extreme conditions, we have provide recommendations, as well as illustrate an alternative approach for the most classical and expected harsh environment: Polar Regions (chapter 7). We need always consider that for our scope, the concept of extreme environment/conditions is seen in a very broad sense. We have also illustrated (Chapter 6) how resources and facilities for testing of robustness and qualify instruments/systems are not only provided by the private sector, but also by the ENVRI RIs community and sometimes also supported by EU (chapter 6 pag. 41).

Based on above remarks, we would like to briefly analyse, in this last section, possibility to establish certain services that could serve for the whole ENVRI community. As illustrated in this report, previous projects like ESONET and FiXO3 allocated time and resources to develop a possible "label" service for the Environmental marine community (8, 9). The target to create a "label" service, is probably too ambitious to achieve in only one step, as figured out previously by cited projects, while can be more sustainable if pursued through several intermediate steps. Have in mind the final goal to achieve, is in any case very important in defining this one by one step process. Also important is to avoid defining any roadmap for this process, leaving to opportunities, disposability of resources and RIs interest, to fix the time necessary to move from one step to the another.

In part-one of its documentation (**1**), MIL-STD-810G deeply analyse the whole tailoring process and human resources necessary to manage this process, identifying the need of "*three different group of personnel*": program managers, environmental engineering specialists and design/test engineers & facility operators. Obviously, we cannot image for ENVRIplus service a large amount of people similar those envisaged by MIL developers. In any case, also considering the simplified engineering program for RIs reported in section 7 (pag. 46), we can for sure to maintain the same structure of MIL standard base on three well identified roles. Figure 16, reports in graphic form the role of personnel, that should participate to the tailoring process for ENVRI RIs and the connection with the engineering programme defined in Section 1 Chapter 7.

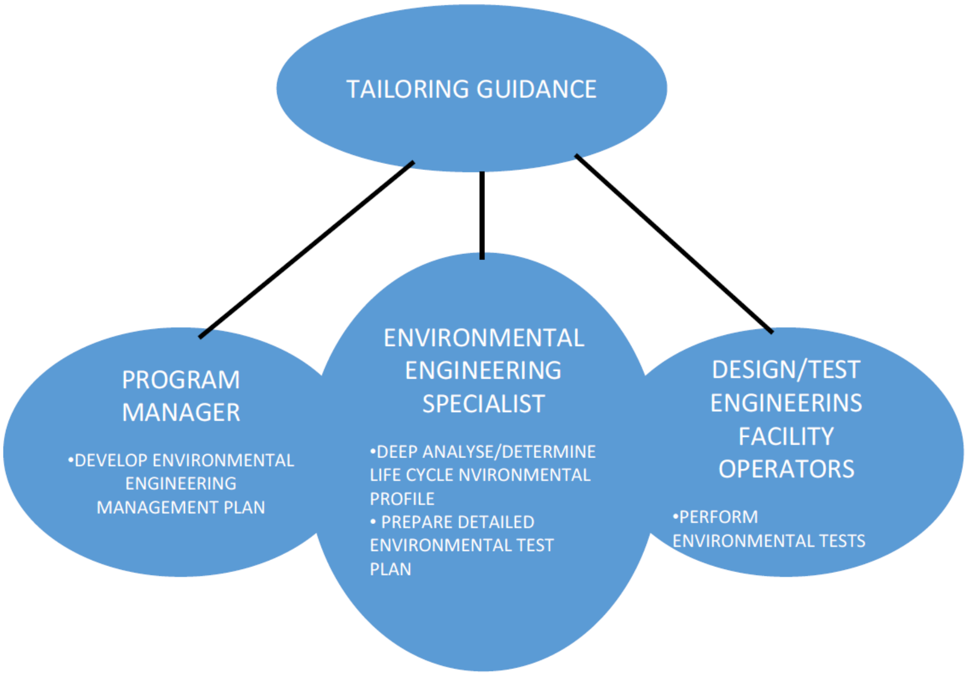


Figure 16 – Roles of acquisition personnel in a design/test tailoring process for ENVRI RIs

In fully implementing a possible dedicated ENVRI community service devoted to test/certify robustness to extreme environmental conditions, we can image a process based on four steps. Steps of this process can be suitable for qualification of commercial instruments, as well as, more important, to evaluate appropriateness of technical solutions adopted to adapt commercial and/or custom instruments to environmental conditions in which they need to operate. Each step can be seen as an advancement along the road to fully implement the service, but also as a way to provide a partial concrete sustain to RIS on this topic. In such a perspective, all three steps before the full implementation can be considered individually as a service, differentiating between each other in the amount of support only:

1 - As first step, ENVRIplus should work to organize an Expert Team on Robustness. This level can be organized on a voluntary basis, exploiting the large potentiality and competencies existing inside ENVRI Community. As a target, we can consider an Expert Team (ET) based on 4-5 people. Ideally, this group should include expertise connected to different domains, but at least in the beginning we can sacrifice multi-domain competencies in favour of time and enthusiasm of engaged people. IT instruments, like a forum, that can be developed thanks the support of Theme 2 could not only represent the way through which Expert Team mainly provide assistance, but also improve multidisciplinarity of the ET. The ET, also to share knowledge, could provide support in identifying public or private structures where RIs requiring assistance can find appropriate assistance and solutions.

2 - As second step, ENVRIplus and/or if the project will end, ENVRI community, could consider the possibility to add to the ET, a dedicated Environmental Engineering specialist. If we consider the simplified engineering programme and the typical level of problems Environmental RIs need to solve in respect robustness, this figure is for sure crucial much more of the program manager. This full time engaged expert will help RIs to analyse correctly life cycle and environmental conditions and to prepare an adequate test plan. More than this, he will be able to monitor potentiality at public and private level and than provide to ET useful information. ET will remain the main

element of the system, but a dedicated human resource will largely increase the level of assistance and will secure time for answers.

3 - As third step, a dedicated Project Manager could be added to the Environmental Engineering Specialist. In this phase, attempt should be done to establish light agreements with some facility inside ENVRI RIs community, to assure concrete support in performing tests and lab evaluations/qualifications.

4 - As forth and final step, a service to fully qualify ("label") instruments and devices managing the whole tailoring engineering process should be provided. A third figure of employ should be engaged, while agreements with ENVRI and eventually private structures shall be better formalized and secured. We do not expect that ENVRIplus establish a common facility, but vice versa try to optimize as much as possible resources and expertise at disposal. However to have a facility operator (cfr. Figure 16) in addition to the previous two figures will allow to take in charge the whole tailoring process, assuring that tests are performed at reduced costs, with the necessary competencies, eventually in cooperation with the personnel operating routinely at the facility.

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14 - ISO web page - https://www.iso.org/about-us.html

15 - www.sis.pitt.edu/mbsclass/standards/

16 - https://www.iso.org/files/live/sites/isoorg/files/archive/pdf/en/isoinbrief_2015.pdf

17 - https://www.iso.org/benefits-of-standards-the-iso-materials.html

18 - https://www.iso.org/sites/materials/benefits-of-standards/benefits_repository.html

19 - https://www.iso.org/publication/PUB100067.html

20 - https://www.iso.org/publication/PUB100058.html

21 - https://www.iso.org/publication/PUB100354.html

22 - https://www.iso.org/protecting-our-planet.html

23 - www.iso.org/casco

24 - IEC web page - list of members - http://www.iec.ch/dyn/www/f?p=103:5:0

25 - IEC 60417 standard: Graphical Symbols for Use on Equipment https://webstore.iec.ch/preview/info_iec60417_DB.pdf

26 - TC 104 - web page - http://www.iec.ch/dyn/www/f?p=103:7:0::::FSP_ORG_ID:1308

27 - TC 70 web page - http://www.iec.ch/dyn/www/f?p=103:7:0::::FSP_ORG_ID:1256

28 - TC 104 - publication list http://www.iec.ch/dyn/www/f?p=103:22:13369421718839::::FSP_ORG_ID,FSP_LANG_ID:1308,25

29 - IEC 60068-1 Environmental testing - Part 1 - General and guidance https://webstore.iec.ch/publication/501

30 - IEC 60068-2 - Environmetal testing - Part 2 - ALL TESTS - https://webstore.iec.ch/publication/62437

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35 - https://standards.globalspec.com/std/9980713/dnvgl-dnv-os-a201

APPENDIX 1

ENVRI Project Glossary

The most updated list of the ENVRI Terminology and Glossary can be found here:
https://confluence.egi.eu/pages/viewpage.action?pageId=14452608

ENVRI Reference Model Glossary

Full ENVRI RM terminology and glossary can be found here:
https://confluence.egi.eu/display/EC/Appendix+B+Terminology+and+Glossary

Project acronyms

AC: Active Collab (ENVRIplus Project Management System)

BEERi: Board of European Environmental Research Infrastructures - is an internal advisory board representing the needs of environmental Research Infrastructures

CA: Consortium Agreement - Legal contract between the ENVRIplus beneficiaries

DL: Deliverable / Deadline

DoW: Description of Work

DoA: Description of Action

GA:

1) Grant Agreement - Contract between Coordinator and Commission

2) General Assembly - GA is the ultimate decision-making body of the consortium

EB: Executive Board - supervisory body for the execution of the Project

EC: European Commission - is the executive body of the European Union responsible for proposing legislation, implementing decisions, upholding the EU treaties and managing the day-to-day business of the EU

ENV SWG ESFRI: the European Strategy Forum on Research Infrastructures - Strategic Working Group on Environment

ESFRI: the European Strategy Forum on Research Infrastructures

PM: Person Month

RI: Research Infrastructure

WP: Work Package

Organisational Acronyms

ACTRIS: Aerosols, Clouds, and Trace gases Research InfraStructure network

AQUACOSM : EU network of mesocosms facilities for research on marine and freshwater ecosystems open for

global collaboration

BEERI: Board of European Environmental Infrastructures

CEA: Commissariat a l Energie Atomique et aux Energies Alternatives

CINECA: Consorzio Interuniversitario CNR: Consiglio Nazionale Delle Richerche

CNRS: Centre National de la Recherche Scientifique

CODATA: Committee on data for Science and Technology

ConnectinGEO: Coordinating an Observation Network of Networks EnCompassing saTellite and IN-situ to fill the Gaps in European Observations

COOPEUS: Strengthening the cooperation between the US and the EU in the field of environmental research infrastructures

COPERNICUS: previously known as GMES (Global Monitoring for Environment and Security), is the European Programme for the establishment of a European capacity for Earth Observation

CSC: CSC - IT Center for Science

CU: Cardiff University

D4Science: is an organisation offering a Hybrid Data Infrastructure service and a number of Virtual Research Environments

DANUBIUS: The international center for Adavanced studies on river-sea systems

DASSH: Data archive for seabed species (a UK marine biology resource centre)

DIRAC : Distributed Infrastructure with Remote Agent Control

DiSSCo: Distributed Systems of Scientific Collections

DKRZ: Deutsches Klimarechenzentrum GmBH

EAA : Umweltbundesamt GmbH - Environment Agency Austria

EduGAIN: is an international interfederation service interconnecting research and education identity federations

EEA: European Environment Agency

EGI : European Grid Infrastructure

EGLEU:

EINFRA-1-2014:H2020 Call for e-infrastructures (Managing, preserving and computing with big research data)

EISCAT: EISCAT Scientific Association

EMBL: European Molecular Biology Laboratory

EMBRC: European Marine Biological Resource Centre a consortium of research organisations interested in marine biology

EMODNET: The European Marine Observation and Data Network

EMRP: European Metrology Research Programme

EMSC: Euro-Mediterranean Seismological Centre

EMSO: European Multidisciplinary Seafloor and Water Column Observatory

ENVRI : FP7 project on Implementation of common solutions for a cluster of ESFRI infrastructures in the field of environmental Sciences

EPOS: The European Plate Observing System

EUDAT : H2020 project on Research Data Services, Expertise & Technology Solutions (previously funded by FP7)

EUFAR : European Facility for Airborne Research

EUROCHAMP2020 : European atmospheric simulation chambers

EURO-ARGO: European ARGO programme (ARGO are a type of marine survey device)

EUROFLEETS:New operational steps towards an alliance of European research fleets

EUROGOOS: European Global Ocean Survey System

EuroSITES: European Ocean Observatory Network

ERIS: Environmental Research Infrastructure Strategy 2030

ESONET Vi: European Seafloor Observatory NETwork

ETHZ: Eidgenoessische Technische Hochschule Zurich

ESFRI: European Strategy Forum on Research Infrastructures

FIM4R: Federated Identity Management for Research collaborations

FMI: Ilmatieteen Laitos (Finnish Meteorological Institute)

FZJ: Forschungszentrum Juelich GmbH

FixO3: Fix point open ocean observatories (survey programme)

GBIF: Global Biodiversity Information Facility

gCube: is an open-source software toolkit used for building and operating Hybrid Data Infrastructures enabling the dynamic deployment of Virtual Research Environments by favouring the realisation of reuse oriented policies

GEO : The Group on Earth Observations coordinates international efforts to build a Global Earth Observation System of Systems (GEOSS)

GEOMAR: Helmholtz Zentrum Für Ozeanforschung Kiel

GEOSS : Global Earth Observation System of Systems coordinated by GEO (The Group on Earth Observations)

GROOM: Gliders for research ocean observation and management

H2020: Horizon 2020, European level research funding scheme

HELIX Nebula: partnership between big science and big business in Europe that is charting the course towards the sustainable provision of cloud computing - the Science Cloud

IAGOS - In-service Aircraft for a Global Observing System

ICOS : Integrated Carbon Observation System

ICSU: The International Council for Science

INFREMER : Institute Francais de Recherche Pour l'Exploitation de la Mer

INGV: Instituto Nazionale di Geofisica e Vulcanologia

INSPIRE : Integrated Sustainable Pan-European Infrastructure for Researchers in Europe

INRA: Institut National de la Recherche Agronomique

IS-ENES: RI for the European Network for Earth System Modelling

INTERACT: International Network for Terrestrial Research and Monitoring in the Arctic

IPBES: Intergovernmental Platform on Biodiversity & Ecosystem Services

I3: Integrated Infrastructures Initiative (I3) combines several activities essential to reinforce research infrastructures and to provide an integrated service at the European level

JERICO: Towards a joint European research infrastructure network for coastal observatories

LifeWatch:European e-Science infrastructure for biodiversity and ecosystem research

LU: Lund University

LTER: The Long-term Ecological Research Network

LTER-EUROPE : European Long-term Ecosystem Research network of 21 national LTER networks

MBA: Marine Biological Association of the United Kingdom

NERC: Natural Environment Research Council

NILU: Norsk Institutt for Luftforskning (Norwegian Institute of Air Research)

NMI: National Metrological Institutes

PANGAEA: Data Publisher for Earth & Environmental Science (Open Access library aimed at archiving, publishing and distributing georeferenced data from earth system research)

PLOCAN : Consorcio Para el Diseno, Construccion, Equipamiento y Explotacion de la Plataforma Oceanica de Canarias

RCN: Norges Forskningsrad (Research Council of Norway)

RDA: Research Data Alliance

RI: Research Infrastructures – facilities, resources and related services used by the scientific community to conduct top-level research in their respective fields, ranging from social sciences to astronomy, genomics to nanotechnologies.

SCAPE: SCAlable Preservation Environments (FP7 project)

SeaDataNet: Pan-European infrastructure for ocean & marine data management

SIOS: Svalbard Integrated Arctic Earth Observing System

SME: small and medium-sized enterprises

UCPH: Kobenhavns Universitet (Copenhagen University)

UEDIN: University of Edinburgh

UGOT: Goeteborgs Universitet (University of Gothenburg)

UHEL: Helsingin Yliopisto (University of Helsinki)

UiT: Universitetet i Tromsoe (University of Tromso)

UniHB: Universitaet Bremen (University of Bremen)

UNILE: Universita del Salento (University of Salento)

UNITUS: Universita Degli Studi della Tuscia

USTAN : The University Court of the University of St. Andrews (University of St Andrews)

UvA : Universiteit van Amsterdam (University of Amsterdam)

Important Technical Terms/Acronyms

API: Application Program Interface, is a set of routines, protocols, and tools for building software applications

Biodiversity: is the variety of different types of life found on earth

Biodiversity metrics: measurements of the number of species and how they are distributed

CERIF: Common European Research Information Format

CIARD RING: A global directory of information services and datasets in agriculture

Data stream: is a sequence of digitally encoded coherent signals used to transmit or receive information that is in the process of being transmitted

Data pipeline: In computing, a pipeline is a set of data processing elements connected in series, where the output of one element is the input of the next one.

DCAT: is a resource description format vocabulary designed to facilitate interoperability between data catalogues

DOI: Digital Object Identifier

E-infrastructure: can be defined as networked tools, data and resources that support a community of researchers, broadly including all those who participate in and benefit from research

HPC: High Performance Computing

HTC: High Throughput Computing

IoT: The Internet of Things - is a scenario in which objects, animals or people are provided with unique identifiers and the ability to transfer data over a network without requiring human-to-human or human-to-computer interaction.

ICT: Information and Communications technology

INFRADEV-4: Subcall of H2020 INFRADEV call for Implementation and operation of cross-cutting services and solutions for clusters of ESFRI and other relevant research infrastructure initiatives

IPR: Intellectual Property Rights

KOS: Knowledge Organization Systems - is a generic term used in Knowledge organization about authority lists, classification systems, thesauri, topic maps, ontologies etc.

LOD: Linked open data is linked data that is open content

LOV: Linked Open Vocabularies

Metadata : is data that describes other data. Metadata summarizes basic information about data, which can make finding and working with particular instances of data easier

NGI: National Grid Initiative

NREN: National Research and Education Network

NRT: Near Real Time - refers to the time delay introduced, by automated data processing or network transmission, between the occurrence of an event and the use of the processed data (For example, a near-real-time display depicts an event or situation as it existed at the current time minus the processing time, as nearly the time of the live event)

OASIS: Advancing Open Standards for the Information Society (non-profit consortium)

ODP: Open Distributed Processing

OIL-E: The Open Information Linking model for Environmental science - is a semantic linking framework

Ontology: (In computer science and information science) an ontology is a formal naming and definition of the types, properties, and interrelationships of the entities that really or fundamentally exist for a particular domain of discourse

QoE: Quality of user experience

over dispersion : a statistical characteristic of data such that the data have more clusters than compared to what might be expected if the data were distributed randomly in proportion to the time/space available.

NetCDF: a file format.

OceanSITES: s a worldwide system of long-term, open-ocean reference stations measuring dozens of variables and monitoring the full depth of the ocean from air-sea interactions down to the seafloor

OOI: Ocean Observatories Initiative

RDA: Resource Description and Access, a standard for descriptive cataloguing

RM: Reference Model - is an abstract framework or domain-specific ontology consisting of an interlinked set of clearly defined concepts produced by an expert or body of experts in order to encourage clear communication

SensorML - The primary focus of the Sensor Model Language is to provide a robust and semantically-tied means of defining processes and processing components associated with the measurement and post-measurement transformation of observations

Semantics : is the study of meaning

Syntax: In computer science, the syntax of a computer language is the set of rules that defines the combinations of symbols that are considered to be a correctly structured document or fragment in that language

SLA: Service Level Agreement

UV: unmanned vehicles

VCP: (ENVRI) Virtual Community Platform

VL: Virtual Laboratory

VLDATA: this was the name of the failed project proposal so I think it can be deleted

VRE: Virtual Research Environments, web based package tailored to a specific community