Standardization in Underwater Acoustics – Current status and on-going actions

Christian Audoly[1]

[1]DCNS Research, Technopole de la Mer, 83190 Ollioules, France

ABSTRACT

Contrarily to airborne acoustics where many documents have been made available for different purposes for a long time, no standard was available for underwater acoustics until now. One of the main reasons is that most of the topic was in relationship with military purposes, each Navy using its own procedures while keeping confidentiality. The increasing development of anthropogenic activity at sea combined with the awareness of bio-acousticians regarding environmental impact and protection of marine life changes the context. There is currently a consensus among stakeholders (scientists, industry, government representatives and policy makers) to have at one's disposal some internationally approved standards for underwater acoustics. After a reminder of the role of standardization, not to be confused with regulation, the purpose of this paper is to present the current status and on-going actions, most of them conducted at international level under the auspices of the ISO TC 43-3 committee. The priority topics, corresponding to documents already published or pending are: measurement of radiated noise level from ships in deep waters, terminology for underwater acoustics, and measurement of sound emitted by pile driving. Some other working groups are active or foreseen within a few years.

1. INTRODUCTION

A standard is a document that provides requirements, specifications, guidelines or characteristics that can be used consistently to ensure that materials, products, processes and services are fit for their purpose.

International Standards bring technological, economic and societal benefits. They help to harmonize technical specifications of products and services making industry more efficient and breaking down barriers to international trade. Conformity to International Standards helps reassure consumers that products are safe, efficient and good for the environment.

Standardization should not be confused with regulation. For example, in the domain of aerial acoustics, the requirement that such maximum noise level or indicator is to be fulfilled in a given environment (e.g. workspaces) for a given human activity is a regulation, and the procedure and set-up for the measurement is a standard. A standard may also impose a design requirement on a product. Policy makers will use standards as far as possible to enforce a regulation.

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees composed of experts, generally starting from existing documents or technical reports. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization. Several organizations exist, at different levels as shown on Figure 1 in the case of ISO standards, noting that the same organization would apply with IEC. ISO is organized in TC (Technical Committees), themselves split into subcommittees, where necessary. The role of these committees, which are composed of experts coming from industry, academia, non-governmental organizations, and public bodies, is to propose, discuss and approve standards, in response to needs. Standardization organizations at national level decide whether or not to participate in a given technical group.

The national standardization committees have the possibility to develop their own national standards. However, one of their main tasks is to contribute significantly to the standardization at international level, in particular through drafting and reviewing activities. In that case, they are often called "mirror committees" with regards to the international level. At the European Level, there is also an effort for harmonization at international level, in order to avoid any major deviation between European Member States. In practice, once internationally agreed standards are made available, the national committees tend to adopt them in their corpus without developing specific documents.

This is the case in particular for underwater acoustics, where international standard have not been available until 2016.

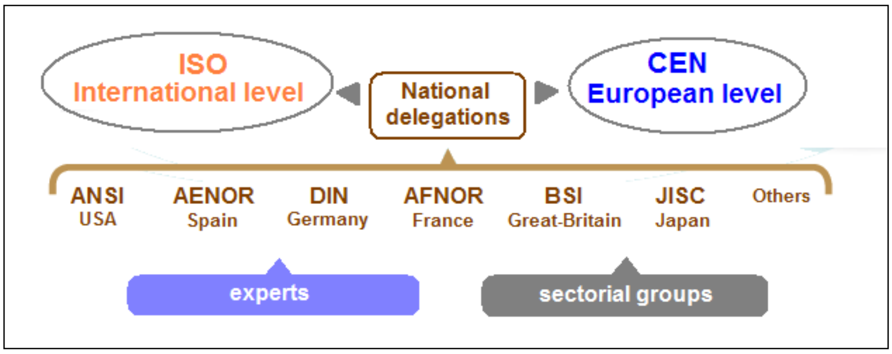

Figure 1: Relation between national and international standardization committees (ISO and CEN)

The scope of ISO TC43 is acoustics. A few years ago, it was decided to establish a new subcommittee ISO/TC 43/SC 3 "Underwater acoustics" with the following scope: *"Standardization in the field of underwater acoustics (including natural, biological, and anthropogenic sound), including methods of measurement and assessment of the generation, propagation and reception of underwater sound and its reflection and scattering in the underwater environment including the seabed, sea surface and biological organisms, and also including all aspects of the effects of underwater sound on the underwater environment, humans and aquatic life."*

Contrarily to airborne acoustics where many documents have been made available for different purposes for a long time, no international, standard was available for underwater acoustics until now, despite the fact that some existing American standards, such as (ANSI. 2009) have been used. One of the main reasons is that most of the topic was primarily in relationship with military purposes, each Navy using its own procedures while keeping confidentiality. The increasing development of anthropogenic activity at sea combined with the awareness of bio-acousticians regarding environmental impact and protection of marine life changes the context. This is consistent with the justification of the creation of that subcommittee is:

"There is increasing concern about noise in the world's oceans and other waterways. Commercial ships, cruise ships, military ships and submarines, air guns used for oceanographic research and minerals exploration, water sports, active sonar, acoustic communications, offshore alternative energy sources (e.g., wind farms, wave turbines), and marine construction projects (e.g., oil rigs, bridges, alternative energy development), along with natural sources (e.g., rain, lightning strikes, earthquakes) and biological sources (e.g., fish choruses, snapping shrimp, marine mammal vocalizations and echolocation) combine to make the seas noisy places. Governments, industry, environmental organizations as well as concerned scientists and engineers are struggling to understand the impacts that this noise may have on marine ecology, marine animals, oceanographic research, underwater biological and anthropogenic acoustic communications, and underwater surveillance of major waterways and ports for protection from potentially catastrophic natural and/or terrorist events. These efforts have revealed that there is a need to standardize the methods of measurement and assessment of underwater noise from various sources, underwater sound propagation and reception of underwater sound by transducers and biological organisms."

In that scope, the purpose of the present paper is to present the current status and on-going actions regarding standardization in underwater acoustics, focusing on the work carried out under the auspices of the ISO TC 43-3 committee.

2. CONTEXT AND NEEDS FOR STANDARDIZATION IN UNDERWATER ACOUSTICS

Electromagnetic waves propagate poorly underwater, contrarily to acoustic waves which can be observed at long distance from the emitter, depending on source level and frequency. The development of the first sonar systems together with submarines about one century ago has initiated an extensive use of underwater sound by navies mainly in relation to underwater warfare.

More recently the increasing worldwide demand of energy and natural resources and the globalization of economy have led to a steady increase of maritime traffic and industrial anthropogenic activity at sea. The increasing concern of the scientific community regarding the impact of underwater sound on marine life incites policy makers and stakeholders of the maritime domain to mitigate their impact through appropriate measures.

2.1 Underwater detection in military applications

Priority topics in military applications are the design and use of efficient sonar systems, whose performance are governed by the sonar equation. The example of the detection of a submarine using a passive sonar system in broadband detection is illustrated on Figure 2. The corresponding sonar equation can be written as follows, "L" meaning the level in dB, and subscripts SL, PL, N, AG, PG, DT relate to "Source Level", "Propagation Loss", "Noise", "Array Gain", "Processing Gain" and "Detection Threshold", respectively.

$$L_{SL} - L_{PL} - L_N + L_{AG} + L_{PG} \geq L_{DT} \quad (1)$$

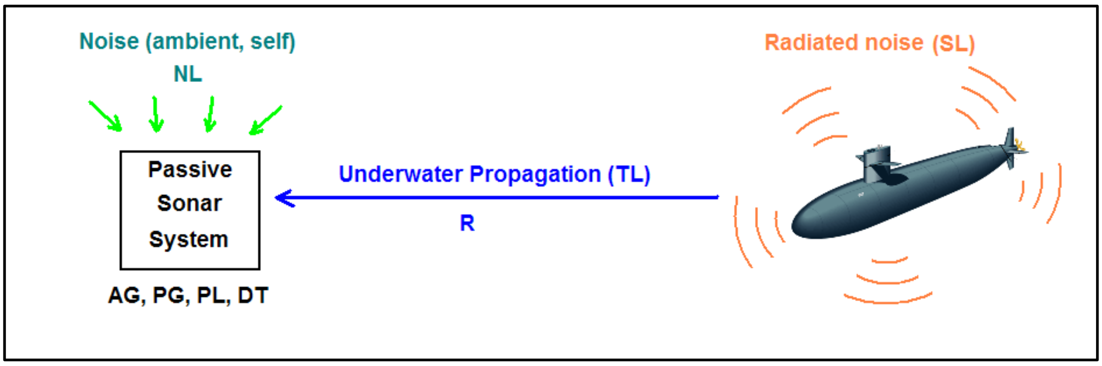

Figure 2: Principle of detection of a submarine by a passive sonar

Another classical method for underwater detection is the use of active sonar, where a powerful transducer is used to generate sound pulses which can be reflected by underwater objects characterized by their target strength, allowing the detection of the echo. An efficient sonar system will allow an increase of detection range R, as L_{PL} generally increases with the distance R between the emitter and the detector. In order to estimate the performance, it is necessary to be able to determine accurately the different quantities in the sonar equation, in particular the source level, the underwater noise level, and the transmission loss which depends strongly on the sound speed profile in the water column and the interaction of propagating waves with sea surface and sea floor. For that reason, the characterization of environment, generally using active systems, is a key issue.

Apart from active or passive sonar, classical applications are underwater weapons (such as torpedoes) and associated countermeasures, underwater communication and mine warfare. More recently, there is an increasing interest for the detection of intruders, such as divers or unmanned vehicles in the vicinity of sensitive facilities, and in the use of unmanned surface or underwater drones, which can be equipped with active or passive acoustic devices.

2.2 Underwater detection in civilian applications

Apart for industrial exploitation of the seas which will be addressed below, underwater acoustic detection systems have also been used for a long time in different civilian applications:

- Echo sounding, determination of sea floor properties,
- Detection of objects on the sea floor, such as wrecks or objects of historical interest,
- Fish detection, in order to locate and optimize catches,
- Sea life monitoring and bioacoustics,
- Acoustic ocean tomography and remote detection of seismic events.

Note that the scientific activity requires the use of suitable research vessels. Two decades ago, a working group established an underwater radiated noise level requirement for fishery research levels (Milton, 1995). Consequently, the new generation of research vessel is much quieter than the older ones, leading adopt an adequate design (generally diesel-electric drive combined with elastic mounts and enclosures for noisy equipment items.

Another aspect regarding bioacoustics is the adverse effect of sound from active sonar on marine fauna, in particular marine mammals. For that reason, some navies are aware of the issue and take operational measures to prevent damage where possible.

2.3 Maritime traffic and the impact on marine life

As maritime traffic has steadily increased in the past decades and is expected to increase further (Figure 1), there is an increasing concern among the scientific community regarding the environmental impact and the consequences on marine life. The sound emitted by shipping can be categorized as continuous noise and covers a wide frequency range, the low and medium frequency component having the capability to propagate at large distances. Despite the fact that the sound levels emitted are lower than sonar systems, large maritime areas can be affected, with the risk of leading in the long term to habitat loss and population reduction.

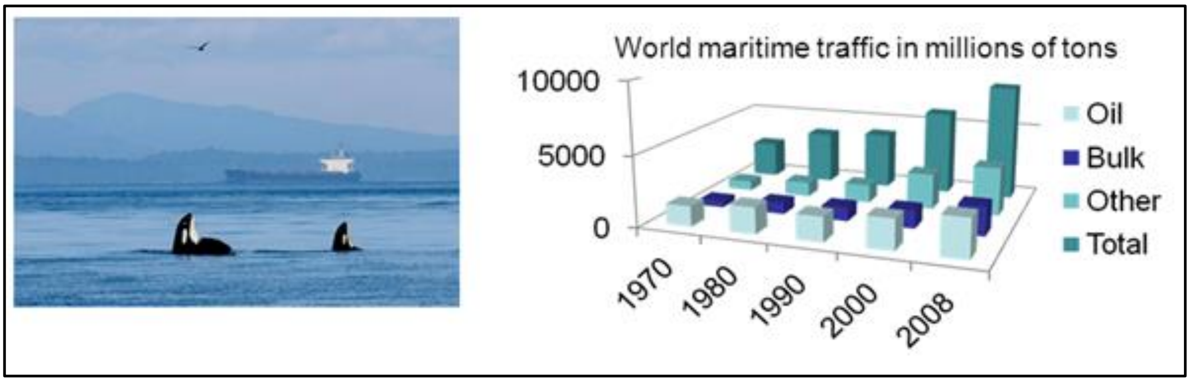

Figure 3: Illustration of the concern with the increase of maritime traffic and the impact on marine life

Some recent work appears in literature regarding, on one hand, the characterization of the commercial ships as underwater noise sources, on the other hand, the bioacoustics impact on marine fauna and the possible mitigation measures.

Noise and vibrations on board ships has been a priority topic for a long time at IMO (International Maritime Organization), because of crew safety or passenger comfort issues, leading to different design guidelines, standards or rule notes (issued by Classification Societies). Recently, the IMO issues non-mandatory guidelines for the design of commercial vessels with the objective the protection of marine life (IMO, 2014).

Besides, the European Union supported two collaborative projects in the scope of the FP7 Research program, with the objective to mitigate underwater noise related to shipping in European maritime areas, including also research on propeller cavitation noise, which is a major noise source on commercial vessels. Synthesis documents of these projects are (AQUO & SONIC, 2015), and (AQUO, 2015) with a summary in (Audoly, 2016) for the latter.

2.4 Exploitation of the seas and protection of environment

Apart from maritime traffic, anthropogenic activity at sea for industrial purposes is developing quickly, raising also concern from the scientific community. The main domains of activity are Oil & Gas industry, Marine Renewable Energy and subsea mining.

2.4.1 Oil and gas survey and exploitation

The search of offshore oil and gas fields in the sediment layers beneath sea bottom is done through seismic surveys requiring the emission of low frequency high intensity impulsive sounds produced by “underwater air guns”. During these surveys, large maritime areas are affected and some operational measures are taken, such as progressive emission levels. Besides, the industry is working on new systems which would allow reducing maximum sound levels.

Another aspect is related to the preparatory phases for exploitation and the operational phases. There, some noisy underwater activity can occur (drilling, pumping, conveying fluids and/or sediments in pipes or risers) as well as the use of ships and acoustic systems on site. Only little information exists on the related underwater sound and its impact on marine life.

2.4.2 Marine renewable energy and marine based construction

There is currently a move to develop renewable energy production, and the seas offer a great potential, using different types of systems: wind turbines mounted on piles or on floating structures, underwater tidal turbines, ocean thermal converters (exploiting the sea water temperature difference between surface and deep waters) and wave energy devices. The most common, suitable for shallow waters areas (down to about 30 m) is the installation of wind turbines on piles, and in particular large offshore wind farms have been installed in the North Sea. The main matter of concern is the pile driving operations, during the installation phase, which produces high intensity impulsive sound, as illustrated on Figure 4. The right-hand side of Figure 4 shows a real pile driving operation while the left-hand side illustrates the propagation phenomena, mainly the acoustic propagation with interactions with sea surface and sea floor, and possibly propagation inside the sediment below sea floor. Note that the issue is also addressing marine based construction, which often involves marine pile driving and other processes producing underwater sound.

Besides, noise emitted by marine renewable energy systems during the production phase, and more generally by underwater equipment for exploitation of sea floor can also be of interest but in that case, the noise emitted is rather continuous and the emergence with regards to natural ambient noise may be not very strong. For example, an IEC working group is addressing the topic for underwater tidal turbines.

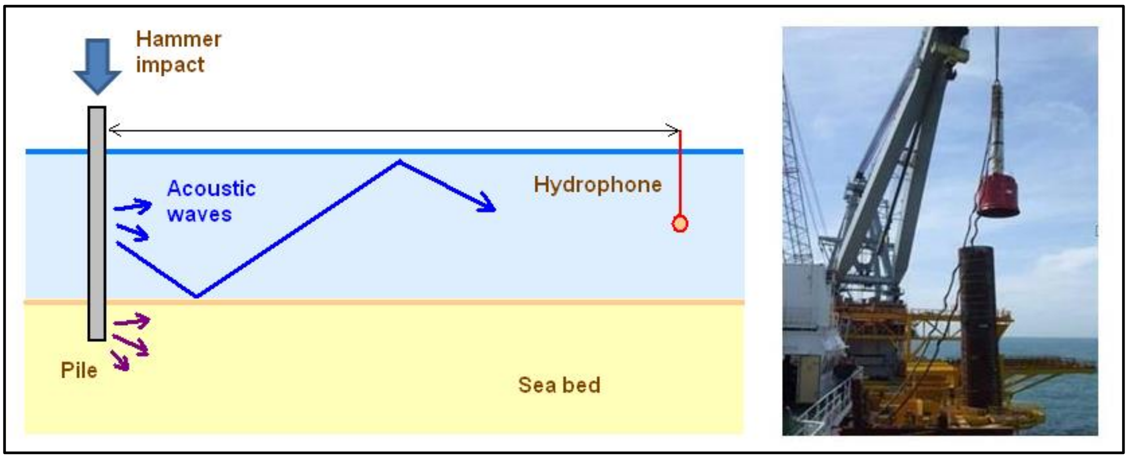

Figure 4: Emission of underwater sound during marine pile driving operations

2.4.3 Exploitation of sea floor

Dredging is a routine operation in some maritime areas which can produce significant underwater noise. Different dedicated workshops are addressing the environmental issues, including noise. Some data is also published in literature.

With the progress of offshore technology and robotics and the demand of minerals for industry, there is an inversing number of projects willing to extract minerals from the sea floor at increasing depths (1000 meters and below). As this induce hazard for marine ecosystems, the environmental impact must be managed properly. Recently, a working group mandated by the European Commissions produced recommendations for that purpose.

2.4.4 Current regulatory framework

Depending on its location, some laws, rules or other local initiatives established for the protection of the marine fauna can be applied (Baudin, 2014).

- United Nations Convention on the Law of the Sea (UNCLOS): The convention defines the rights and responsibilities of nations in their use of the world's oceans. Different jurisdictional marine waters limits are defined in this convention (Territorial Seas, Contiguous Zone, Exclusive Economic Zone, Continental Shelf and High Seas).
- Marine Protected Areas (MPA): Regions in which human activity has been placed under some restrictions in the interest of conserving the natural environment, its surrounding waters and the occupant ecosystems, and any cultural or historical resources that may require preservation or management. Typical restrictions in

MPAs include ones on fisheries, oil and gas mining, and access for tourism. Other restrictions may include the use of ultrasonic devices like sonar, other development and construction.

- European Framework: After adoption of Directive 79/409/EEC on the conservation of wild birds and the Directive 92/43/EEC on the conservation of natural habitats of wild fauna and flora, an important step was made in 2008 with the Directive 2008/56/EC, establishing a framework for community action in the field of marine environmental policy (MSFD, 2008). In Article 10, the Directive drew the basis of establishing a comprehensive set of environmental targets and associated indicators. Two indicators were retained regarding “Underwater noise and other forms of energy”: Low and mid-frequency impulsive sounds and Continuous low frequency sound third octave bands centered at 63 and 125 Hz.

An overview of the status in the year 2013 of regulation regarding underwater noise can be found in (Lucke, 2013). In general, there is not for the moment any regulation regarding underwater noise, except limitation of noise from marine pile driving, which is enforced in Germany and more recently in Netherlands. However, the adoption in 2008 by the European Community of the MSFD is an incitement for stakeholders to address the issue. Besides, most countries require “Environmental Impact Studies” for any project involving industrial activity at sea, and the project may be refused or halted if not properly done. These studies, which cover any form of impact, generally include a chapter for underwater noise.

3. STATUS OF ACTIONS AT ISO LEVEL

For the moment, four working groups (WG) led by conveners are active in the ISO/TC 43/SC 3 are active. Each WG develops one or several projects, leading to the production of standards or other documents:

- Measurement of underwater sound from ships (Convener: Mike Bahtiarian, USA),
- Underwater Acoustics – Terminology (Convener: Michael Ainslie, NL),
- Measurement of radiated noise from marine pile driving (Convener: Stephen Robinson, UK),
- Standard-target method of calibrating active sonars (Convener: Kenneth Foote, USA).

3.1 Measurement of radiated from ships

The current situation is as follows:

- Different navies or stakeholders have developed their own measurement procedure and related instrumentation deployment. Therefore, although it is possible to compare the performance of different ships at a same measurement range or facility, it is more difficult to compare results obtained at different fixed or mobile ranges.
- It is important to distinguish a “radiated noise level RNL”, which is a physical quantity obtained by scaling the measurement at distance R with a simple law (generally the spherical spreading), with the “source level SL”, which is equivalent monopole radiated level the emitter would have in an isotropic and unbounded fluid domain. As a matter of facts, when using simulation for noise mapping in a maritime area, what is needed is the SL of the noise emitters in the area, in particular the ships.

This WG has the objective to fulfill these needs. An important milestone was completed in the beginning of year 2016 with the publication of a first standard, the ISO 17208-1 (ISO, 2016), dealing with the radiated noise measurement of cooperative ships in deep waters for comparison purposes. The procedure and hydrophone deployment configuration adopts the one from the grades A and B of an American standard (ANSI, 2009), using three hydrophones on a vertical line with the following slant angles from the ship: 15°, 30° and 45°. The distance between the ship and the vertical line is the largest of 100 meters and ship length. The outputs from the three hydrophones are corrected to distance using the simple spherical law and averaged in energy. Besides, an average is done on several runs in order to improve accuracy and repeatability.

A well-known phenomenon is the Lloyd mirror effect which is related to the reflection of acoustic waves on sea surface. As shown on Figure 5, the combination of the direct wave path and the surface reflected path leads to interferences introducing strong differences between the source level in an unbounded medium and the affected radiated noise level (back-propagated to 1 meter). When averaged over the three hydrophones using the ISO 17208-

1 configuration (i.e. three hydrophones on a vertical line at distance DM and at depths corresponding to 15°, 30°, and 45° slant angles) and also frequency-averaged over third-octave bandwidths, the variations are smoothed, but there is still a deviation of about 3 dB at high frequencies and a dipole effect at low frequencies, as shown on the dashed blue curve on the right hand side of the figure. In particular, it means that if the level is not corrected for the dipole effect, the low frequency levels in the noise maps for environmental assessment studies would be underestimated. Besides, regarding high frequencies, it is unlikely that the sea surface to be a perfect mirror due to waves related to sea state. Therefore, it is possible to introduce a reflection coefficient depending of frequency and grazing angle, with a reduced surface reflection effect at high frequency (red curve).

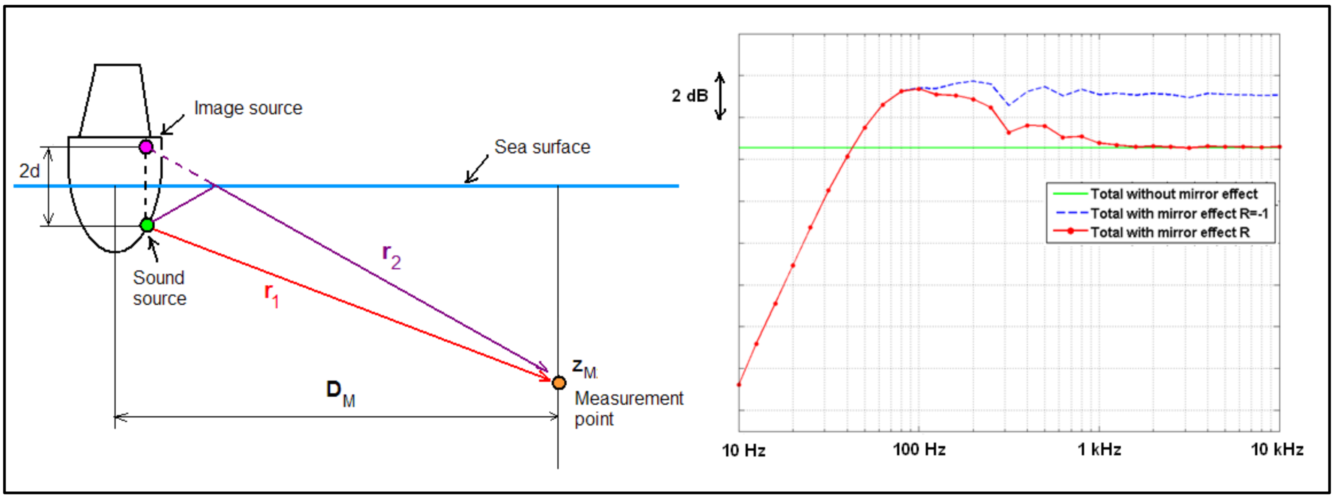

Figure 5: The surface reflection effect and its impact on ship radiated noise measurement (green curve: source level obtained in free field, blue and red curves: radiated noise affected by interference with the reflected wave)

Following the last plenary meeting, the next step in this WG is to produce a Part 2 of ISO 17208 by introducing a correction formula for the surface reflection effect in the deep waters procedure. With d_S defined as the assumed source depth below sea surface, and k being the wavenumber, the correction factor has the following form:

$$SL(f) \approx RNL(f) + \Delta SL(kd_s) \quad (2)$$

Some options are foreseen to take into account an hydrophone arrangement differing from the 17208-1, and also to take into account the non-perfect reflection on sea surface.

In parallel, a longer term objective of the WG is to estimate the source level in an arbitrary environment, including shallow waters. In that case, it is clear that the spherical spreading correction for distance is no longer valid. The correction term should be derived from adequate underwater acoustic propagation models taking into account interaction effects with both sea surface and sea floor, or possibly in-situ measured transfer functions. For that purpose some input can be exploited from recent projects (AQUO & SONIC, 2015) where different studies and experiments in shallow waters were conducted.

A last important issue to consider is that due to operational or cost aspects, most of commercial vessels are not available to spend hours on an acoustic measurement range at sea to perform in a cooperative way a precision measurement procedure. Therefore, the possibility of non-cooperative measurement of ships passing-by a sensor, by inverting the acoustic propagation loss, taking into the actual distance and environment, is also considered for future work item. Note that several authors have already reported results in literature using that type of procedure.

3.2 Terminology for underwater acoustics

Scientists and engineers from distinct disciplines typically work with little inter-disciplinary interaction, and the terminology employed has evolved separately within fields and across applications, to the point that confusion and misunderstandings are common. On the other hand, the already available standards for acoustic terminology and related fields are generally oriented to airborne acoustics and the specific features of underwater acoustics are not sufficiently addressed. For that purpose, the objective is here the adoption a common language, as presented in (Ainslie, 2016).

The ISO 18405 project, which is nearly completed, includes the following sections:

- General terms
- Levels used in underwater acoustics
- Terms for properties of underwater sound sources
- Terms related to propagation and scattering of underwater sound
- Terms for properties of underwater sound signals
- Terms related to sonar equations
- Terms related to underwater bioacoustics

3.3 Measurement of sound radiated from marine pile driving

As said previously, this is a priority topic as some countries have already enforced regulations including noise level limits. Based on existing documents mainly from UK and Germany, the ISO 18406 project, which is expected to be published soon, fills this gap by defining a pragmatic procedure to determine sound levels at relevant distances for the impact on marine life. It is not intended here to derive an equivalent source level. Besides, criteria based on sea floor vibrations are not addressed.

3.4 Standard-target method of calibrating active sonars

The fourth WG is dealing with calibration of active sonars for imaging and measuring scattering, which is of interest for both civilian and military applications. The work in progress, in relation to project ISO 20073, is dealing with a method based on the use of reference calibrated targets, in the form of sphere, preferably made with metallic materials. The size of the target should be adapted to the frequency range of interest.

3.5 Work plan

Other topics are considered for the future in the work plan:

- Approved preliminary work items:
  - Underwater acoustics -- Measurement of ambient sound
  - Underwater acoustics -- Measurement of sound pressure
  - Underwater acoustics -- Measurement of sound from offshore petroleum operations
  - Underwater acoustics – Calibration of autonomous acoustic receiver/recorder systems
- Other topics considered:
  - Effects of underwater sound on divers
  - Measurement of radiated noise from underwater vehicles

4. SUMMARY

Despite the existence of specific procedures within Navies and some national standards or regulating documents, no international standard was available until now in underwater acoustics. As it is of general interest for stakeholders and scientists to adopt common language and procedures, in particular in order to compare measurements one to the others and to be able to carry out good quality environmental impact assessment studies, the standardizations organizations, in particular the ISO/TC 43/SC 3 are working actively to fill the gaps.

A first international standard dealing with the measurement of radiated noise from ships, the ISO 17208-1, is now available. Two other documents, addressing the terminology in underwater acoustics and the measurement of sound radiated by marine pile driving, are nearly completed.

Other topics are considered in the work plan. It should be noted that the production of a standard is a long process, requiring consensus from the experts from the different national committees, sufficient availability from the conveners and project leaders, and expertise from the participants. Also, it is unlikely a standard would be produced successfully if there is not sufficiently technical input available on the topic.

ACKNOWLEDGEMENTS

The author, who is one of the participants in the ISO committee on underwater acoustics, acknowledges the chairman, George Frisk, and the secretary, Neil Stremmel, the permission to report here some of the work carried out in the committee.

REFERENCES

Ainslie, MA et al. 2016, *Standardization of Underwater Acoustical Terminology: Why bother?, Proceedings of the 4th International Conference on The Effects of Noise on Aquatic Life,* Dublin, Ireland, 10-16 June 2016.

ANSI, *Quantities and Procedures for Description and Measurement of Underwater Sound from Ships – Part 1: General Requirements*. ANSI-ASA S12.64/Part1:2009, American National Standard.

AQUO Project, *Synthesis of recommendations, Underwater Noise Footprint of Shipping: The Practical Guide.* AQUO report D5.8 (2015), <http://www.aquo.eu>.

AQUO & SONIC Projects, Guidelines for Regulation on UW noise from commercial shipping, prepared by AQUO and SONIC Projects, 30 November 2015, <http://www.dnvgl.com/sonic>

Audoly, C, Rousset, C, Baudin, E & Folegot, T 2016, "AQUO project - Research on solutions for the mitigation of shipping noise and its impact on marine fauna – Synthesis of guidelines", *Proceedings of the 23rd International Congress on Sound and Vibration,* Athens, Greece, 10-14 July 2016.

Baudin, E, Folegot, T, André, M, Audoly, C, Rizzuto, E, Benedetti, L 2014, "Noise footprint: A proposal within the framework of FP7 AQUO project to define a goal based approach towards the reduction of underwater radiated noise from shipping", *Proceedings of the 33rd International Conference on Ocean, Offshore and Arctic Engineering (OMAE2014),* ASME, 8-13 June 2014, San Francisco, California, USA.

IMO, *Guidelines for the reduction of underwater noise from commercial shipping to address adverse impacts on marine life,* MEPC.1/Circ.833, International Maritime Organization, 7 April 2014.

ISO, *Underwater acoustics — Quantities and procedures for description and measurement of underwater sound from ships — Part 1: Requirements for precision measurements in deep water used for comparison purposes*, ISO 17208-1:2016, International Standardization Organization, Geneva.

Lucke, K, Winter, E, Lam, FP, Snowcoft, G, Hawkins, A, & Popper, AN 2013, "Report of the Workshop on International Harmonisation of Approaches to Define Underwater Noise Exposure Criteria (Budapest, Hungary 17th August 2013)", IMARES Report number C197.13.

MSFD, *Directive 2008/56/EC establishing a framework for community action in the field of the marine environment policy (Marine Framework Strategy Directive)*. European Commission, 17 June 2008.