Guidelines on

Underwater Radiated Noise and Measurements

July 2023

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Guidelines

Underwater Radiated Noise and Measurements

July 2023

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Section 1

General

1.1 Scope

1.1.1 Ship generated underwater noise is a topic of considerable interest due to recognition of its possible environmental implications and the potential of issuance of regulatory measures. The topic is also complex due to the broad range of vessel types, operating conditions and the oceanic environments that need to be addressed. Ship types can range from relatively small vessels to very large complex vessels, with speeds ranging from relatively slow near-shore and congested sea-lanes to full speeds in open seas. Further, the oceanic environment can vary from shallow waters, where the seabed can play an important role to deep waters, where the seabed plays no role.

1.1.2 Underwater noise is not desirable from an environmental point of view for marine organisms. Also, some vessels, (by nature of their operations) use hydro-acoustic transducers which need to operate in a certain acceptable background noise regime. Also, certain vessels need to control their underwater noise for operational reasons (e.g. naval vessels). These Guidelines are applicable to vessels that have opted for additional class notations pertaining to Underwater Radiated Noise (URN). These additional class notations aim at managing and mitigating impact of underwater noise in environmentally sensitive areas, as also to enable certain vessels to minimize their URN from operational point of view.

1.1.3 These Guidelines provide guidance on the methodology and criteria for assessment of URN from vessels and are to be applied in addition to the other relevant requirements of the applicable IRS Rule sets (*Rules and Regulations for the Construction and Classification of Steel Ships; Rules and Regulations for the Construction and Classification of Indian Naval Ships*) (hereinafter referred to as the Rules).

1.1.4 In addition to the requirements in these Guidelines, any additional requirements of flag Administrations, Statutory/ National authorities are to be complied with.

1.1.5 The URN class notations will be assigned to vessels on successful completion of the underwater radiated noise measurement tests and trials, as relevant and applicable.

1.1.6 Underwater radiated noise measurements are to be carried out by IRS approved service suppliers.

1.2 Definitions

For the purpose of these Guidelines, definitions provided in ISO 18405, ISO 17208-1 and those given below apply.

1.2.1 *Acoustic Center*: The position on the vessel where it is assumed that all the noise sources are co-located as a single point source. It is assumed to be located:

> In the longitudinal direction, halfway between the center of the engine room and the propeller for all test conditions.
> In the vertical direction, at 0.7 of the vessel draught from waterline.

1.2.2 *Background Noise Level* (L_{BN})*:* Noise from all sources (biotic and abiotic) other than the ship being measured, including self-noise/ instrument noise, expressed in dB re 1μPa.

1.2.3 *Cavitation Inception Speed*: Vessel speed at which a propeller starts to cavitate.

1.2.4 *Closest point of approach (CPA):* Point where the horizontal distance (during a test run) from the reference acoustic center of the vessel under test to the hydrophone(s) is the smallest.

1.2.5 *Cutoff Frequency*: Cut off frequency is the frequency below which the noise measurements would not be reliable for a given water depth.

1.2.6 *Decibel (dB):* A relative unit for the intensity of a sound wave to a reference intensity. For underwater sound, it is expressed using the logarithmic decibel scale referenced to 1 micro-Pascal, as dB re 1 μPa. Here, 1 μPa is the reference sound pressure and 1m is the reference distance.

1.2.7 *Decidecade:* one tenth of a decade i.e. $0.1\log_2(10)$. This is analogous to $1/3^{rd}$ Octave band.

1.2.8 *Effective Sound Pressure:* The root mean square of the sound pressure of the source over a given interval of time or space.

1.2.9 *Far Field:* A region in free space, away from the sound source. In this region, the sound pressure is in phase with the sound particle velocity. In the far field, the direct field radiated by most machinery sources will decrease at the rate of 6 dB each time the distance from the source is doubled.

1.2.10 *Free Field:* A sound field region where sound may propagate freely without any form of obstruction. In practice, a free field can be said to exist if the direct sound is 6 dB, or preferably 10 dB, greater than the reverberant or reflected sound.

1.2.11 *Hydrophone:* A transducer that produces electric signals in response to water borne acoustic signals. For the purpose of these Guidelines, “hydrophone” could also refer to the underwater microphone or electro-acoustic transducer.

1.2.12 *Lloyd’s Mirror Effect*: alteration of radiated noise levels caused by the presence of a free (pressure release) surface. At moderate distances from the source of sound an underwater receiver would detect two signals—an acoustic pressure fluctuation due to the direct arrival of sound from the source and a second signal from its reflected mirror image. If the arrivals combine constructively (in-phase) a loud sound is observed and likewise when the arrivals combine destructively (out-of-phase) a fade is observed. Successive regions of loudness and fading are referred to as an image interference effect. The combination of a source near an out-of-phase reflecting surface is referred to as Lloyd’s Mirror.

1.2.13 *Narrow Band:* The entire frequency range is divided into subsections with equal bandwidth. The bandwidth is usually 1 Hz.

1.2.14 *Near Field:* A part in the sound field region which is close to a source where the sound pressure is not in phase with the sound particle velocity. In this region, the sound field does not decrease by 6 dB each time the distance from the source is increased (as it does in the far field). The near field is limited to a distance from the source equal to about a wavelength of sound or equal to three times the largest dimension of the sound source (whichever is larger).

1.2.15 *One-third Octave Band:* The logarithmic frequency band whose upper limit is $2^{1/3}$ (1.26) times the lower limit, and the center frequency is the geometric mean of the upper and lower frequency limits. In underwater sound applications, the sound source spectrums are usually represented in the one-third octave bands. The standard one-third octave band center frequencies are defined as: 10, 12.5, 16, 20, 25, 31.5, 40, 50, 63, 80 Hz, and factors of 10 times and 100 times of this list of frequencies, and so on.

1.2.16 *Propagation Loss (PL):* A transfer function defined as the difference between Source Level and Sound Pressure Level. It should include the related water column and for shallow waters, seabed characteristics.

1.2.17 *Quiet Operation Condition:* A low-speed operation condition for a vessel operating in environmentally sensitive areas. The quiet operating condition should be performed at a reduced power relative to the normal operating condition.

1.2.18 *Radiated Noise*: A vessel's radiated noise is the acoustic energy radiated into the sea by sources originating at or within the vessel, from machinery transmitted to the hull-water interface, machinery and flow noise through sea-connected piping systems, and hydrodynamic noise caused by the interaction of the vessel hull.

1.2.19 *Radiated Noise Level (L_{RN}):* Level of the product of the distance from a ship reference point of a sound source, d, and the far field root-mean-square sound pressure, p_{rms}(d), at that distance for a specified reference value.

$$L_{RN} = 20\log(\frac{prms}{po}) + 20\log\frac{d}{d1}$$

Where, 'd', is the slant range from the ship's reference point to each hydrophone. The above formula is based on spherical spreading of sound energy.

'd_1' is the reference value for distance 1 m.

1.2.20 *Source Level (Ls):* is the monopole radiated noise level at 1 m distance, corrected for water surface reflections (Lloyd's mirror effect).

$$L_s = L_{RN} + PL \quad \text{(dB)}$$

Where, PL is the propagation loss in dB, accounting for reflections from the sea surface and seabed.

1.2.21 *Sound Pressure Level or Sound Level (Lp):* A logarithm measure of the effective sound pressure of a sound relative a reference value. It is measured in decibels (dB) above a standard reference level where p_{rms} is the root-mean-square sound pressure measured and p_o is the reference sound pressure. In water, a reference level of 1 µPa is used.

$$Lp = 20\,log\frac{prms}{po}$$

Section 2

Plans and Documentation

2.1 Plans and Documentation for Information

2.1.1 The following plans and documentation are to be submitted to IRS, for information:

- GA drawings with vessel main particulars such as overall length, draft, etc.
- Machinery information (main and auxiliary machinery including pumps, a.c. plants ref plants, etc.) including manufacturer, model, power, RPM, etc.
- Propeller information: manufacturer, model, propeller diameter, propeller pitch, number of blades, speed, power, etc.
- Main and auxiliary machinery foundation plans
- Ventilation plans

2.2 Plans and Documentation for Approval

2.2.1 The URN measurement protocol is to be submitted to IRS for approval prior to the measurement of underwater radiated noise of ship. The URN measurement protocol is to include, at least the following:

- Details of vessel and participants involved;
- URN measurement equipment, such as acoustic measurement equipment, distance measurement equipment, speed measurement equipment, etc.
- URN measurement conditions, including the details of sea area where trials are being conducted, water depth, conditions of the seabed, and sea conditions (such as wind, waves, etc.)
- Operational particulars such as speed, pitch and power of propeller or side thrust; main engine power and speed; ship speed; loading condition of the ship;
- URN measurement procedure, such as hydrophone arrangement, ship's sailing path, etc.

2.3 Measurement Report

2.3.1 After the URN measurement is completed, the measurement report is to be submitted to IRS for approval. The report is to include at least the following:

- URN measurement equipment and data recording system used, including their calibration records;
- URN measurement conditions, the operation status of the ship and list of running equipment;
- Deviations from the approved URN measurement protocol (if any), such as trial conditions, vessel operation status, measurement procedure, etc.
- One-third octave band measurement results for each hydrophone and each test run;
- Background noise spectrum, background noise correction method;

- Methods for evaluating the measurement uncertainty;
- Post processing report including aspects such as data quality assessment, sensitivity adjustment, distance normalization, verification of measurement results against criteria, etc.

Section 3

Underwater Radiated Noise Notations

3.1 URN Notations

3.1.1 Vessels complying with the requirements contained in these Guidelines may be assigned additional class notations as follows:

(a) **URN (NO)** – (.i.e. normal operations)
(b) **URN (Q) -** (i.e. quiet operations)
(c) **URN (R)** - (i.e. research vessels (oceanography, arctic, etc.))
(d) **URN (FR)** - (i.e. Fishery research vessels)
(e) **URN (NR)** - (i.e. naval research vessels, new generation research vessels)

Note: 1. Research vessels, in general can be for any given purpose (bathymetry, oceanography, arctic research related). These can be noisier vessels compared to naval research, new generation research vessels or fishery research vessels (where the intention is to collect data of mammals, fish etc. or operate around mammals). Fish are sensitive to vessel noise and tend to go away from the vessel when vessel starts approaching it. Typical distance of fish response could be within 100m from vessel which makes it difficult for the vessels to collect desired data.

2. Notwithstanding **URN (NR)** notation, URN levels for naval vessels would be subject to agreement with the Naval Authority and Shipyard, in each case.

3.2 URN Levels and Criteria

3.2.1 Few aspects to be noted whilst measuring and deciding the URN levels are as follows:

.1 The frequency range to be evaluated is between 10 Hz to 50,000 Hz for commercial vessels and between 10 Hz to 100,000 Hz for research vessels (as per ICES guidelines).

.2 Allowable limits are expressed in one-third octave bands. The unit of the sound pressure level limit is 1 μPa @ 1 m. It means that the sound pressure level is to be evaluated at 1 m from the acoustic center of the vessel and the reference sound pressure is 1 μPa.

.3 A maximum 3 dB more than the criteria curve at a single one-third octave band is considered acceptable if the overall measured noise level of the vessel can meet the criteria specified in these Guidelines.

.4 Deviations from the requirements may be accepted upon assessment by IRS, provided that such deviations are adequately justified (for e.g., if the narrow band analysis shows that deviations at low frequencies are not related to the underwater noise source, but from disturbance of the measuring device due to sea surface effect or from interference of another object, such as a buoy).

.5 Compliance with the requirements in these Guidelines is to be verified through actual underwater noise measurements.

3.2.2 URN noise limits that need to be complied with for various types of vessels and their operating conditions are as follows:

.1 The maximum allowable noise limits for different vessel types depending upon their operations etc. are given as various criteria curves (along with their equations), as shown in Fig. 3.2.2. These limits apply to the operating condition with the vessel sailing straight ahead at a constant speed.

.2 *Normal Operations*: The 'normal operations' criteria apply for commercial vessels (container ships, tankers, bulk carriers, car carriers, anchor handling vessels, tugs, passenger ships, cruise ships, ferries, etc.), typically at 85 percent of the maximum continuous rating (MCR).

.3 *Quiet Operations*: The 'quiet operations' criteria are intended for cruise ships and other commercial vessels operating, e.g. in environmentally sensitive areas, typically with a maximum speed of 10 knots. The 'quiet operations' criteria are also applicable to fishing vessels sailing at typical cruising speeds (no trawling load).

.4 *Research Vessels*: The 'research' criteria apply to research vessels. Typically, the default test condition is for such vessels sailing straight ahead at 11 knots. Only the necessary equipment needed for achieving the test speed is to be in operation during the test, e.g. power generation and propulsion systems. A separate test can also be performed with an agreed towing load, as relevant and applicable. In general, the fishery research vessels are to comply with noise levels per ICES Guidelines.

.5 *Seismic Vessels*: The 'normal operations' criteria are also applicable for seismic vessels. In general, the default test condition for such vessels is 5 knots, with the designed normal towing load. A separate test can also be performed for a free sailing condition (no towing load). The operating conditions are to to be agreed with the Owner for each vessel.

.6 *Thruster noise*: The 'normal operations' criteria also apply to under water noise from transverse thrusters or dynamic positioning (DP) operations, beyond 1000 Hz. The test condition for vessels in DP mode or with thrusters operating should be 40 per cent of the nominal load. No other parts of the propulsion system, e.g. fixed propellers, are to be operated during test of thrusters and systems. For research vessels, thruster operation will be specially considered.

.7 *Naval Vessels*: The operating conditions and noise limits are to be agreed with the Naval Authority and Shipyard for each vessel/ Class of Ships.

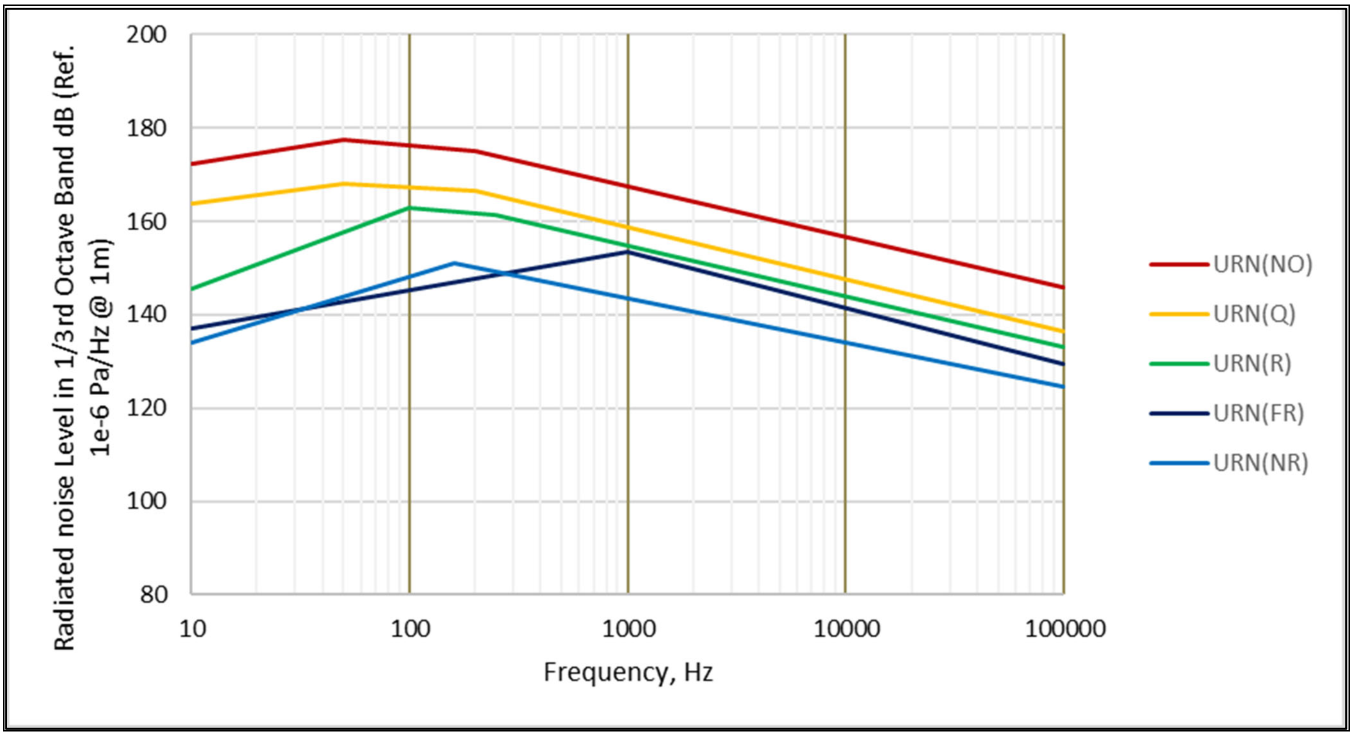

Fig. 3.2.2: URN Notations

URN Limit Curves

(a) Normal Operations (NO)

165 + 7.3*log(f)	10≤f≤50
195 – 8.7* log(f)	50<f≤200
198 – 10.4* log(f)	200<f≤100000

(b) Quiet Operations (Q)

158 + 5.8 log(f)	10≤f≤50
175 – 3.7* log(f)	50<f≤200
194 – 11.5* log(f)	200<f≤100000

(c) Research Operation (R)

128 + 17.5* log(f)	10≤f≤100
170 – 3.6* log(f)	100<f≤250
188 – 11* log(f)	250<f≤100000

(d) Fishery Research (FR)

128.7 + 8.3* log(f)	10≤ f≤1000
189.6 – 12* log(f)	1000< f≤100000

(e) Naval Research (NR)

120 + 14* log(f)	10≤f≤160
172 – 9.5* log(f)	160<f≤100000

3.3 URN Prediction

3.3.1 Underwater noise computational models may be useful for understanding what reductions might be achievable for certain changes in design or operational behaviour. Such models may be used to analyze the noise sources on the ship, the noise transmission paths through the ship and estimate the total predicted noise levels. This analysis can help shipowners, shipbuilders and designers, to identify noise control measures that could be considered for specific applications, taking into account expected operational conditions. Such measures may include amongst others: vibration isolation mounts (i.e., resilient mounts) for machinery and other equipment, dynamic balancing, structural damping, acoustical absorption and insulation, hull appendages and propeller design for noise reduction.

3.3.2 The different types of computational models that may assist in reducing underwater noise include:

.1 Computational Fluid Dynamics (CFD) can be used to predict and visualize flow characteristics around the hull and appendages, generating the wake field in which the propeller operates;

.2 Propeller analysis methods such as lifting surface methods or CFD can be used for predicting cavitation;

.3 Statistical Energy Analysis (SEA) can be used to estimate high-frequency transmitted noise and vibration levels from machinery; and

.4 Finite Element Analysis (FEA) and Boundary Element Method (BEM) may contribute to estimate low-frequency noise and vibration levels from the structure of the ship excited by the fluctuating pressure of propeller and machinery excitation.

3.4 Design Considerations

3.4.1 General

.1 The maximum opportunities for reduction of underwater noise will be during the initial design of the ship. The hull form has influence on the inflow of water to the propeller. For effective reduction of underwater noise, hull and propeller design should be adapted to each other.

3.4.2 Hull Design

.1 Uneven or non-homogeneous wake fields are known to increase cavitation. Therefore, the ship hull form with its appendages should be designed such that the wake field is as homogeneous as possible. This will reduce cavitation as the propeller operates in the wake field generated by the ship hull.

.2 Consideration can be given to the investigation of structural optimization to reduce the excitation response and the transmission of structure-borne noise to the hull.

3.4.3 Propellers

.1 Propellers should be designed and selected to reduce cavitation. Cavitation will be the dominant radiated noise source and may increase underwater noise significantly. Cavitation can be reduced under normal operating conditions through good design, such as optimizing propeller load, ensuring as uniform water flow as possible into propellers (which can be influenced by hull design), and careful selection of the propeller characteristics such as: diameter, blade number, pitch, skew and sections.

.2 Ships with a controllable pitch propeller could have some variability on shaft speed to reduce operation at pitch settings too far away from the optimum design pitch which may lead to unfavourable cavitation behaviour (some designs may be able to operate down to a shaft speed of two thirds of full).

.3 The ship and its propeller could be model tested in a cavitation test facility such as a cavitation tunnel for optimizing the propeller design with respect to cavitation induced pressure pulses and radiated noise.

.4 If the predicted peak fluctuating pressure at the hull above the propeller, in design draft is below 3 kPa (1st harmonic of blade rate) and 2 kPa (2nd harmonic) for ships with a block coefficient below 0.65 and 5 kPa (1st harmonic) and 3 kPa (2nd harmonic) for ships with a block coefficient above 0.65, this could indicate a potentially lower noise propeller. Comparable values are likely to be 1 kPa higher in ballast condition.

.5 Noise-reducing propeller design options are available for many applications and should be considered. However, it is acknowledged that the optimal propeller with regard to underwater noise reduction cannot always be employed due to technical or geometrical constraints (e.g. ice-strengthening of the propeller). It is also acknowledged that design principles for cavitation reduction (i.e. reduce pitch at the blade tips) can cause decrease of efficiency.

3.4.4 Machinery

.1 Consideration should be given to the selection of onboard machinery along with appropriate vibration control measures, proper location of equipment in the hull, and optimization of foundation structures that may contribute to reducing underwater radiated and onboard noise affecting passengers and crew.

.2 Manufacturers should supply information on the airborne sound levels and vibration produced by their machinery to allow analysis by methods indicated in Section 3.3.2 and recommend methods of installation that may help reduce underwater noise.

.3 Diesel-electric propulsion is an effective propulsion-train configuration option for reducing underwater noise. In some cases, the adoption of a diesel-electric system should be considered as it may facilitate effective vibration isolation of the diesel generators which is not usually possible with large direct drive configurations. The use of high-quality electric motors may also help to reduce vibration being induced into the hull.

.4 The large two-stroke engines used for most ships' main propulsion are not suitable for consideration of resilient mounting. However, for suitable four-stroke engines, flexible couplings and resilient mountings should be considered, and where appropriate, may significantly reduce underwater noise levels. Four-stroke engines are often used in combination with a gear box and controllable pitch propeller. For effective noise reduction, consideration should be given to mounting engines on resilient mounts, possibly with some form of elastic coupling between the engine and the gear box. Vibration isolators are more readily used for mounting of diesel generators to foundations.

.5 Consideration should be given for the appropriate use of vibration isolation mounts as well as improved dynamic balancing for reciprocating machinery such as refrigeration plants, air compressors, and pumps. Vibration isolation of other items and equipment such as hydraulics, electrical pumps, piping, large fans, ventilation trunks and AC ducting may be beneficial for some applications, particularly as a mitigating measure where more direct techniques are not appropriate for the specific application under consideration.

3.5 Operational and Maintenance Considerations

3.5.1 Although the main components of underwater noise are generated from the ship design (i.e. hull form, propeller, the interaction of the hull and propeller, and machinery configuration), operational modifications and maintenance measures should be considered as ways of reducing noise for all ships. These would include, among others:

- Propeller cleaning
- Maintaining smooth underwater hull surface
- Reducing speed (especially for fixed pitch propellers)

Note: IRS *Guidelines on Biofouling Management* may also be referred.

3.6 Modifications

3.6.1 For vessels assigned with URN notations, IRS is to be specifically informed, in advance, of any modifications being made to the vessel, such as changes to the hull form, the main machinery (including propulsion and large auxiliary equipment) and propellers, which contribute to the underwater radiated noise.

Section 4

Instrumentation and Data Acquisition

4.1 General

4.1.1 This Section provides instrumentation and data acquisition requirements for measurement of URN. It is recommended that ISO 17208 series of standards may be referred for further details.

4.1.2 In general, the instrumentation used for the measurement of underwater noise include equipment for:

- acoustic measurements
- distance measurement
- speed measurement

4.2 Acoustic Measurement

4.2.1 The acoustic measurement system at least consists of three omni-directional hydrophones and data recording equipment (a measuring amplifier may be fitted if necessary).

4.2.2 The sampling frequency of data recording equipment is at least to be 2 times the maximum analysis frequency.

4.2.3 The hydrophone is to be fitted with a preamplifier. The hydrophone sensitivity is to have a maximum uncertainty within ± 2.5 dB within the frequency range of the measurements.

4.2.4 The instrumentation used to record and analyze the data is to have a dynamic range of 90 dB or higher.

4.2.5 The hydrophone vertical array line is to be linked to a free-floating surface buoy which is uncoupled from the sea surface. Additional mooring features (e.g. hardware swell compensation device) are also to be considered when appropriate. (Ref. Fig. 5.3.2 (a))

4.2.6 The hydrophone line should be bottom mounted. A free-floating line is acceptable when water depth prevents the deployment of bottom mounted lines. (Ref. Fig. 5.3.2 (b))

4.2.7 The vertical arrangement of hydrophones is to be defined to ensure measuring the beam aspect of the tested vessel.

4.3 Distance Measurement

4.3.1 The distance is to be measured to determine the distance between the ship to be tested and the hydrophone.

4.3.2 The ship reference point is taken at the centre line, at the middle between propeller and engine(s) arrangement and vertically at the nominal source depth defined at 0.7 times of the ship's draft.

4.3.3 The distance measurement accuracy is to be within ±10 m. The use of DGPS is recommended.

4.3.4 Tilt angle measurements of the hydrophone array line are recommended to optimize the accuracy.

4.3.5 The constantly changing distance between the reference acoustic centre of the tested vessel and each of the hydrophones is to be recorded. Distance measurement is to be continuously recorded in 2 second cycles for each complete voyage.

4.4 Speed Measurement

4.4.1 The ship's speed for each measurement voyage is to be recorded. In general, the speed measurement equipment fitted on a ship can be used.

4.5 Celerity Profile Measurement

4.5.1 To be able to calculate the propagation loss via numerical modelling, the celerity profile of the water column needs to be ascertained.

4.5.2 In order to calculate the transmission loss more accurately, either a CTD (Conductivity, Temperature, Depth) measurement device or a direct sound speed sensor can be used.

4.5.3 ISO 17208-2, provides further guidance on the most appropriate and acceptable process to follow for deep water measurements.

4.5.4 The following non-exclusive numerical modelling methods for characterizing propagation losses may be used:

- Parabolic waves equations (see Note 1)
- Scooter/Fields model (wave integration model) for low frequencies (below 1000Hz) (see Note 2)
- Bounce or Bellhop model (ray trace-based model) for higher frequencies (see Note 3).

Note 1: Collins, M. D. (1994). Generalization of the Split-Step; Pade. J. Acoust. Soc. Am., 96, 382-385. Collins, M. D., Cederberg, R. J., & King, D. B. (1996). Comparison of Algorithms for Solving Parabolic Wave Equations. J. Acoust. Soc. Am., 100, 178-182.

Note 2: P.C. Etter, Underwater Acoustic modeling and simulation, 4th Edition (CRC Press, 2013).

Note 3: F. B. Jensen, W. A. Kuperman, M. B. Porter, H. Schmidt, Computational Ocean Acoustics, 2nd Edition (Springer, 2011).

4.5.5 To consider that the vessel is a moving noise source, the modelling propagation loss is to be range-average smoothed or is to be calculated for each individual data window

4.5.6 Onsite direct sound speed measurements covering the whole range of frequencies for the test is an acceptable alternative to modelling.

4.5.7 In addition, seabed characteristics are to be considered in the modelling, especially in case of shallow water depths.

4.6 Calibration

4.6.1 Calibration of underwater acoustic measurement equipment is to be carried out using IEC 60565.

4.6.2 The calibration of hydrophones is to be undertaken every 24 months at maximum and as recommended by the hydrophone manufacturer, by an external recognized lab (preferably NABL accredited).

4.6.3 In addition, an in-situ check of the whole system using a dedicated calibrator (e.g. pistonphone) is to be performed prior and after the measurements. This calibrator is to be calibrated every 12 months at maximum.

4.6.4 The data acquisition system is to be laboratory checked every 24 months at maximum.

4.6.5 The measuring celerity profile device is to be calibrated every 24 months at maximum.

Section 5

Underwater Radiated Noise Measurements

5.1 General

5.1.1 URN measurement procedures rely on the deployment of in-water measuring equipment and so, manned operations at sea are to be undertaken safely and securely. Further, the quality and robustness of data collected during URN measurement is often influenced by external factors that can affect the consistency of sound measurements, including meteorological and weather conditions, marine traffic, and overall site topology.

5.1.2 Location of the measurement test site is to be determined by the ship owner, shipyard and agreed by IRS before any measurement is carried out. Important factors to consider when selecting a suitable test site are the geographical location and weather when carrying out the URN measurements. Other factors include, but are not limited to, salinity, water temperature, water depth, sea conditions, weather conditions, a safe zone (for the safety and ability of the vessel under test to manoeuver considering the sea traffic in the vicinity; distance from shore (prevent unwanted reflections), and low background noise (considering the surrounding shipping activities in vicinity of the proposed test site).

5.1.3 The URN measurements are to be carried out once the vessel is complete in all respects, under a representative loading condition. The vessel is to maintain a straight path on a pre-determined course at a constant speed, without excessive rudder actions. The operating conditions of the vessel are to remain unchanged from the beginning to the end of the measurement period.

5.2 Test Site and Environmental Conditions

5.2.1 Sea Bottom Profile

5.2.1.1 The nature (characteristics and bathymetric topology) of the sea bottom is to be recorded. Where possible the sea bottom should be flat and lack significant features.

5.2.2 Weather Conditions

5.2.2.1 Weather conditions are not to exceed:

Wind: Beaufort wind force 4
Sea state: 3

5.2.2.2 Rainy conditions are to be avoided view generation of background noise.

5.2.2.3 The following additional information is to be reported:

- effective wind speed and direction
- effective sea state
- ship heading during the test

5.2.3 Tides and Current

5.2.3.1 Measurements are not to be carried out where the current speed exceeds 2 [m/s].

5.2.3.2 The following information regarding current is to be reported:

- speed and direction
- tide related data

5.2.4 Water Depth

5.2.4.1 The minimum water depth is to be the greater of 60 [m] or 0.3 v^2.

Where, v = vessel speed over the bottom in [m/s].

5.2.4.2 Measurement in water of depths between 60 and 40 [m] may be carried out provided due account is made for the frequency limitation (cut-off frequency):

Table 5.2.4.2: Cut-off frequency relative to water depth assuming a constant sound speed in water of 1490 [m/s] and a sandy seabed sound speed of 1790 [m/s]
(Source: NPL Good Practise Guide N°133 – Underwater noise Measurements)

Water depth (m)	10	20	30	40	50	60	70	77	80	90	100	200	300
Cut-off frequency (Hz)	77.1	38.5	25.7	19.3	15.4	12.8	11.0	10.0	9.6	8.6	7.7	3.9	2.6

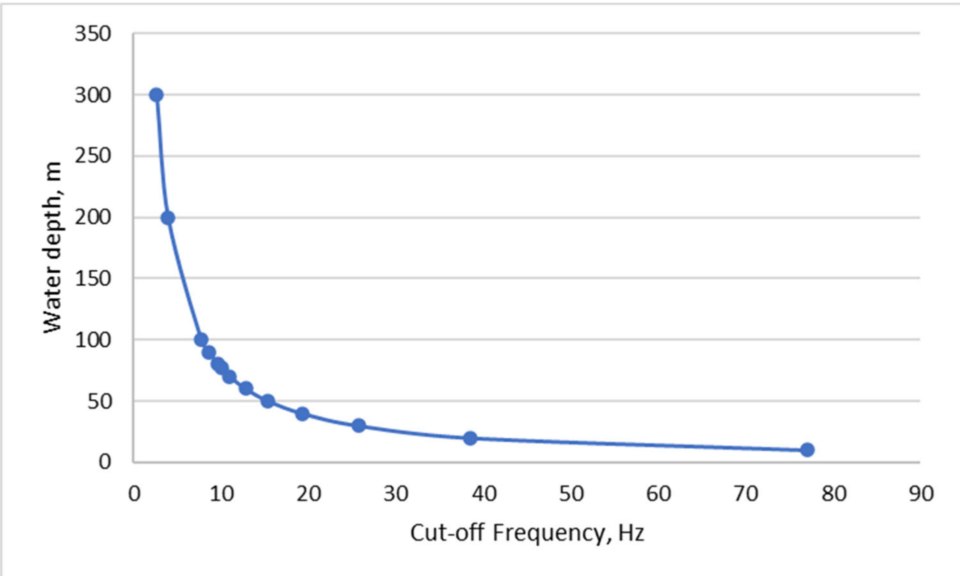

Figure 5.2.4.2: Cut-off frequency relative to water depth assuming a constant sound speed in water of 1490 [m/s] and a sandy seabed sound speed of 1790 [m/s]
(Source: NPL Good Practice Guide No. 133 – Underwater noise Measurements)

5.2.4.3 Measurements are not to be carried out in water with a depth of less than 40 [m]. In cases, where the depths are less than 40 [m], shallow water corrections will be specially considered in consultation with IRS.

5.2.5 Background Noise

5.2.5.1 Background noise is to be eliminated to the extent possible. The test site is to be as far as possible from vessel traffic lanes, port in/out lanes, marine works such as dredging, pile driving, fishing or diving zones, seismic exploration, mine clearing activities or coastal civil engineering works.

5.2.5.2 The background noise is to be recorded before and after the trials. The vessel under test is to be totally disconnected or located far from the hydrophones (at least 2000m or 1.08 nautical miles).

5.2.5.3 Background noise is to be recorded at least for two minutes. Real time signal stability is to be checked during the recording to ensure the reliability of the measurement.

5.3 Data Acquisition and Recording

5.3.1 General

5.3.1.1 The instrumentation set-up is to ensure, during the various test legs, synchronous acquisition, recording and processing of the following:

- sound pressure measurements from hydrophones
- distance between tested vessel and hydrophones
- tested vessel speed over ground

5.3.1.2 Other measurements (calibration checks, celerity profile, etc.) are to be recorded.

5.3.1.3 For measurements taken in a water depth of less than 60 [m] a propagation model enhanced with actual field characteristics measurements is to be carried out. It is to demonstrate that less than 3dB uncertainty is achieved.

5.3.2 Measurement line deployment

5.3.2.1 A minimum of three hydrophones on a single line array is to be used. It is recommended that the deployment method incorporates a line from a buoy decoupled from the sea surface. A swell compensation device is recommended for this purpose.

5.3.2.2 The hydrophone array should not be directly coupled to the support vessel to limit not only the noise disturbances caused by the vessel behaviour but also prevent masking from occurring.

5.3.2.3 For deep water measurements the array is to be arranged as required by ISO 17208-1, see Figure 5.3.2 (a).

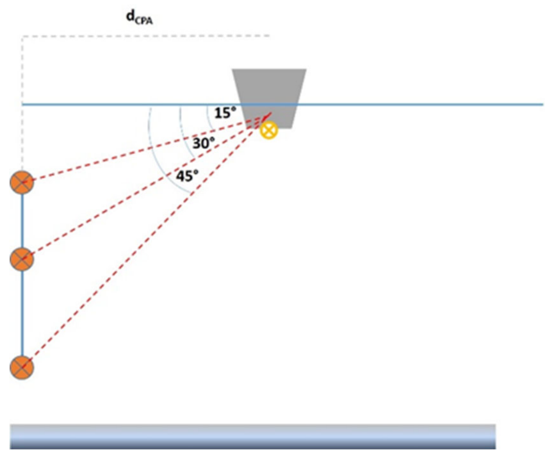

Fig. 5.3.2 (a) Recommended array deployment for deep water (Ref. ISO 17208-1)

5.3.2.4 For shallow waters bottom mounted deployment are recommended as likely to be easier to deploy and potentially interesting for long duration measurements, see figure 5.3.2 (b).

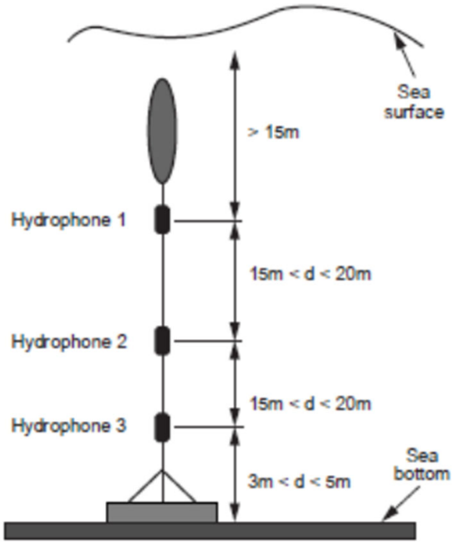

Fig. 5.3.2 (b) Recommended array deployment for shallow water

5.3.3 Testing segments and closest point of approach (CPA)

5.3.3.1 Distance at CPA (d_{CPA})

.1 The minimum distance at closest point of approach is to be the greater of 200 m or one ship length.

.2 For ships with length less than 200 m, a minimum distance of 100 m can be accepted.

5.3.3.2 Vessel transects

.1 A minimum of 4 measurement runs are to be carried out, 2 for starboard side and 2 of port side.

.2 Vessel speed, engine power and engine speed are to be recorded and thus, the tested propulsion configuration reported. Steady state forward motion is to be achieved by the time the ship enters COMEX and is to be maintained until FINEX. This includes no rudder adjustments, no engine load/ speed changes, no pitch changes for CPPs), no genset change etc.

.3 Reciprocal runs should be performed to compensate for the consequences of tidal, swell and/or current effects and the averaged propulsive power reported. The variation in tidal, swell and/ or current effects should be as minimum as possible in case only 2 runs are performed (see 5.3.3.2.4).

.4 Accounting that, for large ships, the course and speed stabilization to performs 4 runs takes a significant time, the number of vessel runs may be reduced to 2 for ships over 10,000 GT. A compensation (degradation of accuracy) should be reported when two runs of measurements are taken for ships over 10,000 GT.

.5 If two lines of three hydrophones are used to measure port and starboard simultaneously, the number of runs may be reduced to 2.

.6 The vessel under test is to transit a straight-line course to achieve the required distance at CPA for the run-in progress. Recording of data is to be performed from:

- a minimum of 800m or 4 minutes before the fore end of the vessel reaches the CPA; this defines the COMEX, to
- a minimum of 800m or 4 minutes after the aft end of the vessel has passed the CPA; this defines the FINEX.

.7 Before the vessel crosses the starting point of the record, the required machinery operating conditions must be achieved and in steady state.

.8 The distance between the measurement line and the vessel under test is to be recorded during all the segments (from COMEX to FINEX).

.9 Operating condition of the vessel should be recorded during the measurements. Operating condition should correspond to the normal operations of the vessel, i.e. all major equipment including main engine, auxiliary engine(s), AC plant(s), refrigeration plant and sea water pumps, should be functional during the measurements. Measurements to include as a minimum, vessel speed, equipment power in normal operating condition (percentage of full load).

5.3.4 Recording of Measurements

5.3.4.1 An indicative format/ template for recording of URN measurements data is provided in Appendix 1.

Section 6

Post-processing of Measurement Data

6.1 Global post-processing scheme

6.1.1 The data is to be post processed following the ordering/scheme of Figure 6.1.1 below where:

r_k represent the k-th run;
w_j the j-th data window; and
h_i the i-th hydrophone.

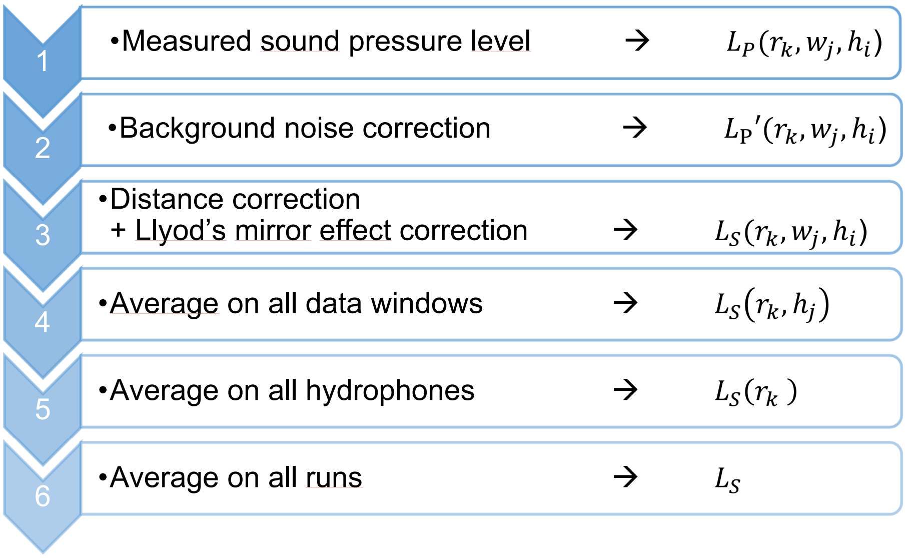

Fig. 6.1.1 Data post-processing scheme for the hydrophone h_i, data window w_i during run r_k

6.2 Data Windows

6.2.1 Raw time series measurements are to be recorded in order to be permit more detailed analysis including data correction, narrow band analysis as deemed necessary.

6.2.2 The hydrophone data should be recorded while the ship's reference point lies within the data window and analysed by dividing it into 10 sub data windows as shown in Figure 6.2.2 below. Each of the sub data window should be sized as evenly as possible.

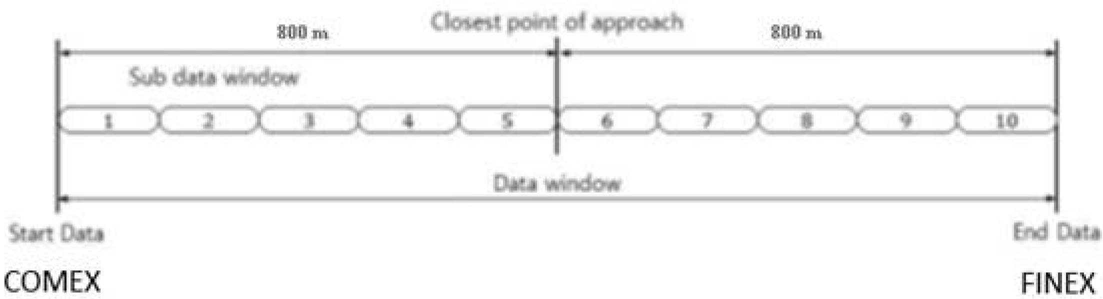

Fig. 6.2.2 Illustration of Data window subdivision

6.2.3 The middle instant of a data window is reached when the reference acoustic centre of the vessel is superimposed with the centre of this window.

6.2.4 For each data window, p_{rms} for each hydrophone is to be recorded in decidecade band spectrum

6.3 Background Noise Correction

6.3.1 Each p_{rms} in decidecade band spectrum is to be corrected for background noise L_{BN} according to the following procedure for each hydrophone following the global scheme of Figure 6.3.1 below.

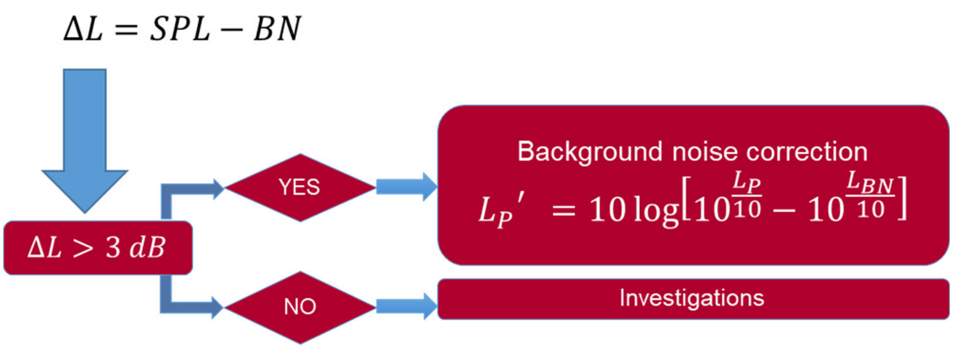

Fig. 6.3.1 Background Noise Correction Scheme

Where,

SPL : Sound Pressure Level (L_p)
BN : Background Noise Level (L_{BN})
Lp' : Background Noise Correction

6.3.2 The background noise correction process is as follows:

- Calculate the arithmetic mean (linear average) of the sound pressure level measured for the hydrophone h_i prior to and after ship test trial. This is the background noise $L_{BN}(h_i)$.

- Calculate the variation of background noise between the start and end of runs

- Calculate, for each run r_k, data window w_j and hydrophone h_i the signal plus noise :
$$\Delta L(r_k, w_j, h_i) = L_p(r_k, w_j, h_i) - L_{BN}(h_i)$$

- If $\Delta L(r_k, w_j, h_i)$≥3dB the measurement can be considered acceptable with regards to the background noise. The following correction is to be applied:
$$L_p'(r_k, w_j, h_i) = 10log\left[10^{\frac{L_p(r_k,w_j,h_i)}{10}} - 10^{\frac{L_{BN}(h_i)}{10}}\right]$$

- If $\Delta L(r_k, w_j, h_i)$<3dB the measurement is to be rejected. A case-by-case investigation should be conducted.

6.4 Distance and LME correction

6.4.1 Vessel source levels, including distance correction and Lloyd's mirror effect correction, are to be calculated and reported.

6.4.2 The propagation loss $N_{PL}(r_k, w_j, h_i)$ is recommended to be calculated through modelling enriched with onsite actual water column properties using CDT probes, for each run *r*, data window *w* and hydrophone *h*.

6.4.3 As a result and with reference to Figure 6.1.1:

$$L_S(r_k, w_j, h_i) = L'_p(r_k, w_j, h_i) + PL(r_k, w_j, h_i)$$

The distance correction and Lloyd's mirror effect correction is to be corrected in accordance with ISO 17208-1and ISO 17208-2.

Shallow water corrections will be specially considered.

6.5 Final Averaging and Calculation of URN

6.5.1 Measurements are to be averaged considering the following:

- linear average of source level on all data windows
- linear average of source level for three hydrophones
- linear average of source level for all runs

6.5.2 The resulting source levels L_S is the URN signature of the vessel and the metrics to be compared to required URN limits.

Section 7

Surveys

7.1 Initial Survey

7.1.1 The underwater noise measurement and data collection are to be carried out by an approved service supplier for URN measurements and witnessed by the Surveyor.

7.1.2 The hydrophones and measuring instruments used in the data acquisition system are to be calibrated prior to the underwater noise measurements. The relevant instrumentation calibration certificates, together with the results of the field setup and calibration check are to be provided to the Surveyor.

7.1.3 The main propulsion and auxiliary machinery conditions are to be initialised in accordance with the conditions specified in the approved URN measurement plan. The same is to be verified by the Surveyor.

7.1.4 The test personnel are to fill-in requisite details in the URN Measurements Observation Sheet (see Appendix 1 for template) at the time of the Survey.

7.1.5 The Surveyor is to verify that the URN measurement is carried out according to the approved measurement plan, and endorse the URN Measurements Observation Sheet, as relevant and applicable.

7.1.6 Survey may be suspended in case the requisite preparations are not made, qualified test personnel are not present, or the Surveyor considers that it is not safe to carry out the URN measurements.

7.2 Periodical Surveys

7.2.1 Annual Surveys

7.2.1.1 At each Annual Survey, the IRS Surveyor is to verify that no modifications (such as changes to the hull form, the main machinery, including propulsion and large auxiliary equipment, and propellers) have been carried out that alter the vessel’s underwater noise performance.

If such modifications have been carried out, confirmatory URN measurements may be required as per revised test plan approved by IRS.

7.2.2 Special Surveys

7.2.2.1 Requirements for Special Surveys are same as that of Annual Surveys in 7.2.1.1.

7.2.3 Occasional Surveys

7.2.3.1 Occasional Surveys are to be carried out in the following cases:

- Where modifications affecting the vessel’s URN levels have been carried out.
- On Owner’s application for such surveys.

7.3 Validity of URN Certification

7.3.1 The duration of validity of URN Certification will be in accordance with the certificate of Classification.

7.4 Suspension/ Withdrawal of URN Certification

7.4.1 The URN Certification is liable to be suspended/ withdrawn in case the Owner does not inform IRS about modifications in advance (also see Section 3.6) and offer for Surveys. The suspension/ withdrawal would be in accordance with the procedures of IRS.

References:

- ANSI S1.11-2004, R2009: American National Standard Specification for Octave-band and Fractional-octave-band Analog and Digital Filters.
- ANSI/ASA S12.64/Part 1 2009: American National Standard Quantities and Procedures for Description and Measurement of Underwater Sound from Ships Part 1: General Requirements.
- ISO 18405:2017: Underwater acoustics – Terminology.
- IEC 60565 Ed. 2.0 b:2006: Underwater acoustics - hydrophones - Calibration in the frequency range 0.01 Hz - 1 MHz.
- IEC 61260-1:2014: Electroacoustics - Octave-band and fractional-octave-band filters - Part 1: Specifications.
- ISO 17208-1:2016: 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 17208-2:2019: Underwater acoustics - Quantities and procedures for description and measurement of underwater sound from ships - Part 2: Determination of source levels from deep water measurements.
- MEPC.1/ Circ. 833 - Guidelines for the reduction of underwater noise from commercial shipping to address adverse impacts on marine life
- Good Practice Guide No. 133 – Underwater Noise Measurements, NPL, 2014 edition.
- Underwater Noise of Research Vessels, CRR Report No. 209: ISSN 1017 6195, May 1995 (ICES)

Appendix 1

Template for URN Measurements Observation Sheet

General Information			
Ship's Name		Vessel GT	
IMO Number		LBP [m]	
Maximum Draft [m]		Moulded Breadth [m]	
Test Location		Test Agency (AOSS Certificate Number & Validity)	
Test Date		Test Protocol	

Item	Test Run No.1	Test Run No.2	Test Run No.3	Test Run No.4
Environmental Conditions				
Effective Sea State				
Wind Speed				
Wind Direction				
Water Depth				
Weather				
Current Speed				
Tidal Conditions				
Vessel Traffic				
Vessel Condition				
Loading Condition				
Vessel Draft				
Engine rpm				
Vessel Speed				
Date of last cleaning of underwater hull and propeller				
Echo-sounder off (Yes/ No)				
Known issues or concerns that may affect URN levels:				
URN Measurement Equipment (See Note 1)				
Type of hydrophone				
Sensitivity of hydrophone				
Data recording equipment (including sampling frequency)				
Preamplifier (if used)				
Distance measurement equipment				
Speed measurement equipment				
Data processing equipment				

Other Test Records				
Item	**Test Run No.1**	**Test Run No.2**	**Test Run No.3**	**Test Run No.4**
Hydrophone 1 Depth				
Hydrophone 2 Depth				
Hydrophone 3 Depth				
Distance at CPA, d_{CPA}				

Item			
Propulsion Machinery		**Auxiliary Machinery**	
Type		Type	
Quantity		Quantity	
Number of Cylinders		Number of Cylinders	
Max. rated power (kW)		Max. rated power (kW)	
Max. rated speed (rpm)		Max. rated speed (rpm)	
Type of Mounting		Type of Mounting	
Propellers			
Type		Number of blades per propeller	
Number of propellers		Nominal pitch	
Design speed (rpm)		Diameter	
Thrusters			
Type		Number of blades per propeller	
Qtty. Of Thrusters		Nominal pitch	
Design speed (rpm)		Diameter	

Characteristics of Other Sources (Eg.: AC Plant(s), Ref Plant(s), Sea water pump(s), etc)		
Type of Source	Location	Further Information (rpm, etc.)

Participants Involved			
	Name	Signature	Date
Owner’s Rep			
Yard Rep			
Person in charge of test			
IRS Surveyor			

Note 1: Annex 1 to include Certificates of calibration of measurement equipment.

End of Guidelines