Appendix 10:
Clarification Note
Blasting Methodology and Mitigation

Aberdeen Harbour Expansion Project

Clarification Note: Blasting methodology and mitigation

Scottish Natural Heritage (SNH) has raised concerns that the estimated sound level of 262 dB from a single buried charge is capable of causing auditory damage to cetaceans at a distance of approximately 820 m.

As reported in ES Appendix 13-B, modelling the propagation of sound from explosive blasts in open water is well developed: by comparison, that from confined detonations is rudimentary and there is very little published data available that allows for an estimation of peak levels underwater following detonations from confined explosions.

The results of the underwater noise modelling (ES Appendix 13-B) indicate that for a 20 kg charge, the peak pressure in the blast hole at a distance of 1 m from the point of detonation is 263 dB re 1 uPa, falling to 170 dB re 1 uPa at a distance of 830 m from the source. It should be noted that the peak level in the water is expected to be significantly less, as the blast loses a considerable amount of energy within the blast hole. The underwater noise modelling was based on a 20 kg charge placed at a depth of 2.5 m below the surface of the rock; however, a number of the charges will be placed at greater depths (to achieve the required dredge depth of 9 m or 10.5 m below Chart Datum), which will increase the amount of energy that is that is absorbed within the blast hole.

SNH has raised concerns about the possibility that multiple waveforms from multiple charges will result in constructive and destructive interactions, which may affect the amplitude of the blast wave. No data is available in the literature to quantify the effects of multiple blasts. However, the initial rise of pressure from a single detonation is of the order of microseconds, whilst the detonations will occur at intervals of the order of 25 milliseconds. This means that the initial rise in pressure will have decayed before the next rise comes along. The effect of constructive interference from successive blasts is, therefore, considered to be small.

As there would be no more than 2 blasts per day and 25-100 holes drilled per day, the total number of charges detonated in a single sequence will be in the region of 50. The duration of the dredging to remove the rock in between blasting operations will vary depending on the contractor's methodology: one contractor is proposing alternate days of blasting and dredging, whereas others have proposed up to 7 days of blasting followed by 1-2 days of dredging.

Mitigation for blasting

It is possible that some of the blasting activities in the north of the bay will be carried out behind a partially constructed breakwater where there is no 'direct line of sight' to open water. Where this is the case, the same rationale applies as to marine impact piling activities (see Aberdeen Harbour Board's Clarification Note: Underwater Noise, February 2016), i.e. the presence of the breakwater will largely impede the propagation of sound outside of Nigg Bay. In any location where blasting will be carried out in 'open water', a bubble curtain will be deployed around the blast location to reduce the propagation of underwater noise.

A bubble curtain consists of walls of bubbles rising from a nozzle or porous pipe that is secured to the seabed and connected to an air compressor. This technique has been applied as an effective noise mitigation technique in several experimental and practical setups (e.g., CALTRANS[1]; Grießmann *et al*.[2]; Betke & Matuschek[3]). Bubble curtains have been used with success in shallow, protected waters to attenuate the blast pressure of detonations (Regalbuto *et al*.[4]).

The presence of air bubbles in water effectively lowers the sound velocity through reflection, refraction, and absorption (Mallock[5]). Bubble curtains work by providing a break in the path by which sound travels from one point to another. The presence of air in the propagation path results in a change of impedance (given by ρ c where ρ is the density of the medium and c is its sound speed) and sound is thus reflected at the impedance contrast.

Croci *et al*.[6] carried out a series of tank-based experiments where well-defined amounts of air were used to generate a curtain of bubbles. An impulsive waveform, representative of what might be achieved from an explosive blast, was transmitted into the water using a projector hydrophone. Measurements taken before and after the generation of the bubble curtain indicate a reduction in peak level of approximately 48 dB. It should be noted that the experiments took place in a controlled environment where the bubble curtains did not disperse other than when the air supply was reduced or switched off. In open-sea conditions the longevity of the bubble clouds is more variable.

Rude and Lee undertook a series of at-sea noise measurements at Roach cove underwater demolition site in Canada[7]. They reported an attenuation in peak shock wave of approximately 60% and an attenuation in energy density of 40%. Based on the Department of Fisheries and Oceans' limit of 100 kPa[8], the safety distance for detonations were reduced to a quarter of what they would have been had the bubble curtain not been in place.

Both the tank-based experiments and the Roach Cove measurements involved sound waves generated within the water column - the so-called 'free-water' case. By contrast, the effectiveness of bubble curtains in reducing the peak sound levels from buried explosives is less well understood. Rickman[9] attempted to address this by setting up a bubble curtain around an array of charge holes drilled into the river bed in water depths of approximately 9 m; however very little usable data ensued

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[1] CALTRANS - CALIFORNIA DEPARTMENT OF TRANSPORTATION (2003), Underwater sound pressures associated with the restrike of the pile installation de-monstration project piles. Report prepared by Illingworth & Rodkin, Inc. for State of California, Department of Transportation.

[2] Grießmann, T. (2009), Forschungsplattform FINO 3 - Einsatz des großen Blasenschleiers. Presentation at BSH "Meeresumweltsymposium" 2009.

[3] Betke, K. & Matuschek, R. (2010), Messungen von Unterwasserschall beim Bau der Windenergieanla-gen im Offshore-Testfeld „alpha ventus". Abschlussbericht des ITAP zum Monitoring nach StUK 3 in der Bauphase an die Stiftung Offshore-Windenergie, Varel.

[4] Regalbuto, J.A., A.A. Allen, K.R. Critchlow, and C.I. Malme, eds. (1977), Underwater blast propagation and effects, George F. Ferris (drilling rig), Kachemak Bay, Alaska. Paper presented at the 9th Annual Offshore Technology Conference, OTC 3035, Houston, Texas, May 2–5.

[5] Mallock, A. (1910), 'The damping of sound by frothy liquids'. Proc. R. Soc. London A 84(572), 391–395.

[6] Croci K., Arrigoni M., Boyce P., Gabillet C., Grandjean H., (2014), Mitigation of underwater explosion effects by bubble curtains: experiments and modelling. 23rd MABS (Military Aspects of Blast and Shock), Oxford, UK, 7-12 September 2014, United Kingdom. 14 p.

[7] Rude, G.; Lee, J., (2007), Performance Evaluation of the Roach Cove Bubble Curtain Apparatus, Defence R&D Canada Report Number: DRDC-SUFFIELD-TM-2007-046; Technical Memorandum.

[8] The Department of fisheries and Oceans, Canada stipulate a threshold limit of 100 kPa on fish exposed to explosive blast. See Wright, D.G., and G.E. Hopky. 1998. Guidelines for the use of explosives in or near Canadian fisheries waters. Can. Tech. Rep. *Fish. Aquat. Sci*. 2107: iv + 34p.

[9] Rickman, D. R., (2000), Analysis of water shock data and bubble curtain effectiveness on the blast effect mitigation test series, Wilmington Harbor, North Carolina. Prepared for U.S. Army Engineer District, Wilmington. 100 p. Downloaded from http://www3.epa.gov/region1/superfund/sites/newbedford/550569.pdf

due to instrumentation problems, movement of the test rigs due to river current; and the river bed topography shielding the hydrophones and creating shadow zones within which little or no acoustic energy propagated.

The Woodrow Wilson Bridge project required foundation piles being driven in the river bed[10]. A bubble curtain was set up and measurement of peak sound level were recorded downstream. The results indicated that the presence of the curtain was very effective with peak levels being reduced by 80-90%.

Modelling the effectiveness of a bubble curtain

In order to illustrate the effective reduction in blast levels likely due to the presence of a bubble curtain, a simple model is constructed whereby a bubble curtain is placed at a distance of 50 m from the charge detonation site. It is assumed that the bubble curtain extends from the seabed to the sea-surface and has a width of 10 m. The confined-blast model gives sound pressure levels at increasing range in the water. Various levels of attenuation, given by data from the literature search, are applied to the sound pressure levels from a distance on 60 m onwards.

Figure 1 shows the blast level from a confined detonation both with and without a bubble curtain in place. The amount of attenuation applied to the 'no bubble curtain' baseline is, variously, 48 dB, 60% reduction and 90% reduction in peak levels.

If the 170 dB threshold is used as a metric, it can be seen in Figure 1 that the noise level falls to 170 dB at a distance of 830 m when there is no curtain in place. With a curtain in place and producing an attenuation of 60%, the 170 dB threshold is attained at a distance of approximately 420 m, while the distance falls to 200 m if the curtain has a 90% attenuation. If a 48 dB reduction in blast levels is applied, the critical threshold is attained at a distance of 58 m.

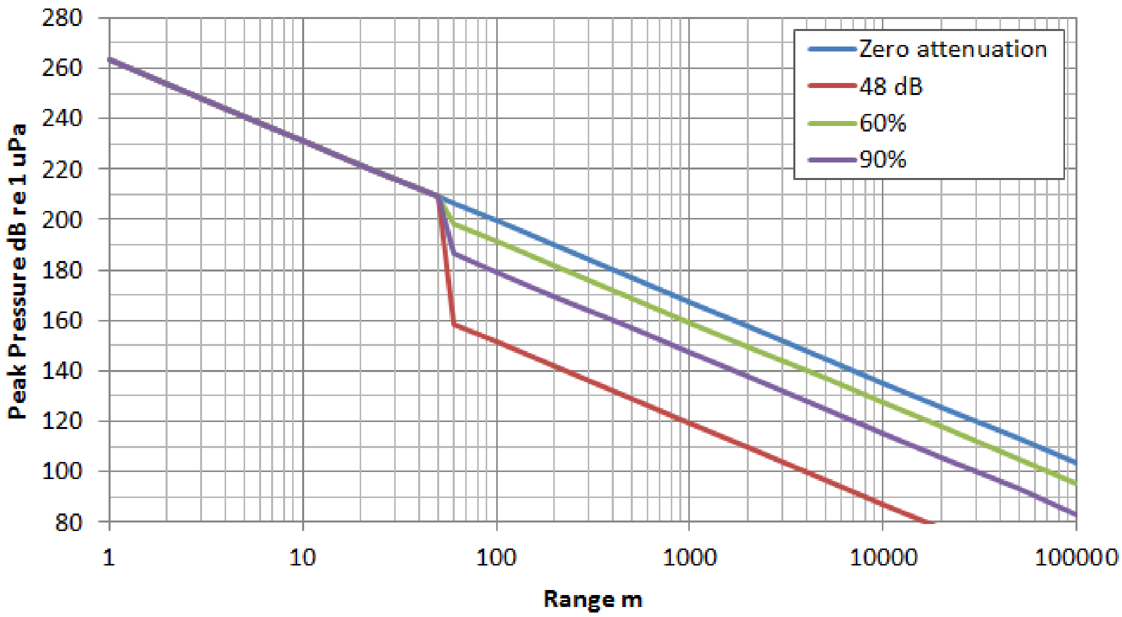

Figure 1: Underwater blast levels from a confined detonation with varying degrees of bubble curtain attenuation in place

[10] Woodrow Wilson Bridge Project: Shortnose Sturgeon Biological Assessment Supplement, January 2003. Downloaded from www.wwblessonslearned.com.

Use of bubble curtains in Nigg Bay

There are many examples of bubble curtains being used to reduce the propagation of underwater noise in the marine environment (e.g. Federal Agency for Nature Conservation[11]), often in environments that are considerably deeper and more exposed than Nigg Bay. As the areas to be blasted are in shallow water and adjacent to the land, it should be possible to fully encapsulate the blast site using a bubble curtain. At least one of the contractors tendering for the project have proposed to use a bubble curtain during blasting activities, so the practicality of their use at this site is deemed to be viable.

The detailed methodology for drilling, blasting and dredging of rock will be set out in the Construction Environmental Management Plan (CEMP). Each of the five potential contractors has expressed their intention to work with SNH at an early stage after contract award to develop the CEMP, to ensure that the proposed methodology is acceptable to SNH. During the development of the CEMP, the successful contractor will also be investigating alternative options to reduce the propagation of underwater noise and, if these are found to be more effective than the bubble curtain, the contractor will discuss the benefits and suitability of these options with SNH; however, the use of a bubble curtain is the intended measure and any deviation from this will require agreement with SNH through the CEMP process.

Concluding remarks

This purpose of this technical note is to illustrate the effectiveness of a bubble curtain in attenuating sound levels on the downstream side of an explosive blast. Based on a review of the available literature, peak sound levels may be reduced by 48 dB or else by 60-90% depending on the measurement metrics used. The effectiveness of a bubble curtain is modelled where the levels of attenuation are based on the data given by the literature search. With a bubble curtain in place, the distance at which the 170 dB threshold is reached falls from 830 m to as low as 58 m.

The mitigation measures proposed in Chapter 15 of the ES, i.e. to utilise Marine Mammal Observers and Passive Acoustic Monitoring with a mitigation zone of 1 km, and to adhere to the JNCC blasting guidance, will prevent injury to marine mammals by ensuring that blasting does not take place when marine mammals are in the vicinity. The predicted reduction in propagation distances when a bubble curtain is deployed will greatly reduce the distances over which injury to marine mammals could occur.

Due to the intermittent nature of the activity (one or two blasts per day over 3-7 months, with breaks in blasting activity for dredging), and with mitigation measures in place to reduce the distance over which the sound from a blast will propagate (as described in this note) the effects of disturbance are considered to be limited.

The information presented above is considered to support the conclusion in the Habitats Regulations Appraisal (Volume 4 of the ES) that underwater noise generated by blasting activities will have no adverse effect on site integrity for the Moray Firth Special Area of Conservation.

March 2016

[11] Federal Agency for Nature Conservation (2013) Development of Noise Mitigation Measures in Offshore Wind Farm Construction. https://www.bfn.de/fileadmin/MDB/documents/themen/meeresundkuestenschutz/downloads/Berichte-und-Positionspapiere/Mitigation-Measures-Underwater-Noise_2013-08-27_final.pdf

Aberdeen Harbour Expansion Project

Response to Marine Scotland Science

Clarification of underwater noise issues

This note addresses additional questions raised by Marine Scotland Science (MSS) on 11 April 2016, relating to the potential effects of the Aberdeen Harbour Expansion Project (AHEP) on marine mammals.

1. Marine impact piling

Thank you for confirming that the proposed mitigation measures are acceptable and that no further action is required.

2. Blasting

a. You have requested information on the likely range at which a Sound Pressure Level (SPL) of 200 dB re 1µPa (the SPL threshold for injury in harbour porpoise, since this is the lowest threshold of the species likely to be present) might be detected. If an injury threshold of 200 dB re 1 uPa is used instead of the 170 dB threshold, then the zone of impact decreases from a radius of 820 m to **95 m**. This calculation is based on a semi-empirical approach that determines the blast level from a confined detonation, using Wright & Hopky (1998)[1]. This paper is referenced in the Environmental Statement (ES) Appendix 13-B (Underwater noise modelling study).

b. You have asked us to consider alternative mitigation strategies for blasting, including whether bedrock could be broken using alternative or refined methods, whether the noise levels produced can be mitigated and whether there are techniques that could be used to ensure that marine mammals are not in the Permanent Threshold Shift (PTS) zone. Due to the strength of the bedrock, our design team are not aware of any other viable solution and can see no alternative method that would allow the bedrock to be dredged. As described in the Clarification Note on Blasting Methodology and Mitigation (March 2016), the combined use of Marine Mammal Observers (MMOs) and Passive Acoustic Monitoring (PAM), the deployment of bubble curtains, the limited number of blasts per day (maximum of two) and night-time restriction on blasting are considered to be the best mitigation strategy available.

c. We note that there will be a requirement for works to be carried out under a European Protected Species (EPS) licence. Our appointed contractor will be responsible for obtaining all necessary EPS licences.

d. You have requested further information on whether the stated source level is the level expected from such charges in bedrock of this type, or whether the values are taken from examples elsewhere in the literature. As reported in the Clarification Note on Blasting Methodology and Mitigation (March 2016), modelling the propagation of sound from explosive blasts in open water is well developed; however, by comparison, that from confined detonations is rudimentary and there is very little published data available that allows for an estimation of peak levels underwater following detonations from confined explosions. We are confident that the modelling study uses the best available data from the literature; however, as noted in ES Appendix 13-B, the modelling presents a worst-case scenario as most of the data available relates to open water blasting, and the sound

[1] Wright D.G., Hopky G.E., (1998) "Guidelines for the Use of Explosives In or Near Canadian Fisheries Waters", Canadian Technical Report of Fisheries and Aquatic Sciences 2107, Department of Fisheries and Oceans, Canada.

pressure created by confined borehole blasting is considerably less, as explained in ES Appendix 13-B.

e. You have requested information on how multiple explosions at almost the same time will interact in terms of noise propagation. As stated in the Clarification Note on Blasting Methodology and Mitigation (March 2016), no data is available in the literature to quantify the effects of multiple blasts. However, the initial rise of pressure from a single detonation is of the order of microseconds, whilst the detonations will occur at intervals of the order of 25 milliseconds. This means that the initial rise in pressure will have decayed before the next rise comes along. The effect of constructive interference from successive blasts is, therefore, considered to be small.

3. Bubble curtains

a. Thank you for confirming that you consider it likely that the use of bubble curtains as proposed will reduce sound levels to the extent that injury can be sufficiently mitigated using standard methods (MMOs and PAM). You have requested further information regarding the integrity of a bubble curtain under differing weather conditions, i.e. whether the action of large waves or tidal currents would compromise the effectiveness of this method. Due to the relatively limited tidal exchange that is experienced in Nigg Bay (as presented in Chapter 6 of the ES), tidal currents are unlikely to interfere with the effectiveness of bubble curtains. Limited information is available in the literature on the effects of large waves on bubble curtains; however, the three contractors in the tendering process all have experience with using bubble curtains and they do not foresee any issues with deployment or effectiveness at this site.

b. You have recommended that we produce a comprehensive plan for mitigation of the effects of blasting noise, as part of our construction documentation. This will include a more detailed investigation into the integrity of bubble curtains at this location (see above). This will form part of the Construction Environmental Management Plan, as detailed in Chapter 26 of the ES.

4. Habitats Regulations Assessment (HRA)

You have advised that the Appropriate Assessment should consider the cumulative effects of the Moray Firth and Forth and Tay wind farm developments. Section 6.3.2.1 of the HRA states that the offshore wind farm and port construction projects in the Moray Firth and Forth and Tay are over 100 km away from Aberdeen, so noise impacts will not spatially overlap. The additional mitigation measures proposed in the Clarification Notes on Underwater Noise (February 2016) and Blasting Methodology and Mitigation (March 2016) further reduce the propagation of underwater noise to an extent whereby in-combination effects between the AHEP and these distant offshore wind farm projects are not predicted. It should also be noted that there is uncertainty around the status and likely construction programme for these wind farms, and it is unlikely that there will be substantial overlap in the construction periods between the AHEP and the Neart Na Gaoithe, Inch Cape Offshore, Seagreen Alpha, Seagreen Bravo and Moray Firth Eastern/Western wind farm projects.

14 April 2016