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Regional Class Research Vessel (RCRV): UNDERWATER NOISE ANALYSIS

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TABLE OF CONTENTS

0.0 EXECUTIVE SUMMARY

Noise Control Engineering (NCE) has performed a prediction of the underwater (radiated) sound pressure levels of the newly designed Regional Class Research Vessel (RCRV). The purpose of the evaluation is to confirm whether the underwater noise limits specified in the RCRV specification, Section 073 will be achieved. These limits are from the International Council for the Exploration of the Seas (ICES), Cooperative Research Report No. 209 (CRR-209). The RCRV specification requires that the ICES underwater noise limit be achieved at 6 knots and states that it would be desirable for the vessel to achieve the limit at 8 knots.

The underwater noise predictions were carried out for three different ship speeds; 6, 8 and 10 knots. For each speed, the noise prediction included contribution from the propellers, propulsion motors, diesel generators, air conditioning chillers, air compressors and sixteen other types of auxiliary equipment. All equipment, except the propeller and propulsion motors had the same number of units operating and same input vibration for all three speeds. This includes the diesel generators, of which two units were assumed for all three speeds. The Bow Thrusters were not assumed to be operating for any of the speeds.

The noise predictions were performed using *Designer-NOISE*™ a commercial shipboard noise prediction program developed by NCE. NCE used the element vibration output along with proprietary hull vibration-to-underwater noise transfer function to compute underwater noise of the RCRV. In using *Designer-NOISE*™, the results are computed in octave bands. NCE compared these results to the octave band form of the ICES criteria even thought the limit must be achieved in one-third octave bands. Predicted levels over the octave band limit would also then be in excess of the one-third octave band limit. However, results below the octave band limit may not necessarily be below the one-third octave band limit. Any predicted noise value below the octave band limit, but above the one-third octave band limit are potentially above the one-third octave band limit.

The baseline noise prediction included the following three noise treatments: (1) double stage isolated diesel generators, (2) single stage isolated propulsion motors and auxiliary equipment and (3) machinery space high transmission loss (HTL) insulation. At 6 knots, the underwater noise is 0.5 decibels below the ICES octave band limit in the 63 Hertz band. All other frequencies are below the ICES one-third octave band limit. At 8 knots, the underwater noise is 2 decibels over the ICES octave band limit in the 63 Hertz band. All other frequencies are just slightly above the one-third octave band ICES limit. At 10 knots, the underwater noise is 1-6 dB over the ICES octave band noise limit.

Two noise treatment cases were evaluated; one called “Local Damping” and one called “Global Damping”. For the “Local Damping” approach, certain machinery would have higher stiffness foundations and have damping applied to the foundation. The machineries this would apply to are: Diesel Generators, Air Compressors, Fuel Oil Purifier, Marine Sanitation Device (MDS), Air Conditioning Chillers and the Propulsion Motors. For the “Global Damping” approach, damping would be applied to tank top, hull, longitudinal and transverse bulkheads. Damping cannot be used inside fuel, potable water or ballast tanks for various reasons. The damping can be used in either tile or spray-on forms.

The "Local Damping" approach reduces the underwater noise at the 63 Hertz octave band such that it is below the ICES one-third octave band limit. The "Global Damping" does not provide enough reduction at the lower 63 Hertz band, but reduces higher frequencies more effectively. At 8 knots, the "Local Damping" approach will reduce the noise below the ICES octave band limit. However, predicted sound levels remain just slightly above the ICE one-third octave band limit. No treatment approaches were evaluated for the 10 knot case as the noise is solely controlled by propellers for which there are not treatment approaches.

NCE concludes that this evaluation shows that existing design should achieve the ICES noise limit at 6 knots. NCE recommends that the "Local Damping" approach be used as risk reduction measure given the predicted noise is so close to the limit. The evaluation further shows that the ICES limit is very close to being achieved at 8 knots. Additional, study, treatment and modification to the propeller would be required to meet the requirement at 8 knots.

1.0 INTRODUCTION

Noise Control Engineering was retained by The Glosten Associates and Nichols Brothers Boat Builders to provide acoustical engineering evaluations of the Regional Class Research Vessel (RCRV) being designed for the National Science Foundation (NSF). This report evaluates the underwater (radiated) noise of the vessel as specified in section 073 of the RCRV Statement of Requirements, reference [1]. Table 1 lists the ships general particulars as known of the date of this report.

TABLE 1: RCRV Particulars

Length, Overall	155 feet
Beam, Overall	38 feet
Draft at Design Waterline	12 feet
Frame Spacing	
Displacement at Design Load Waterline	1,028 LT @ 12ft Draft
Maximum Service Speed	11 ½ knots
Propulsion Motors	(2) Siemens HT-Direct (AC) Motors, Model 1FW4 - 453 - 1HA, Grade B**,** Rated at 331kW, 200rpm*
Diesel Generators	(3) Caterpillar C18 587 BHP @ 1800 RPM with Siemens DSG 62M Alternator*
Propellers	(2) Custom Design, 5-Bladed
Bow Thruster	Elliott White Gill T3S QR Model 32 (quiet version)
Hull Material	Steel
Superstructure Material	Steel

**Vibration Isolation to be Determined*

2.0 UNDERWATER NOISE LIMITS

One of the important design features of RCRV is that it shall meet the underwater noise limits given in the ICES Report CRR-209, reference [2]. According to the RCRV specification, reference [1], it is required to meet the ICES limit at 6 knots and desired to meet the limit at 8 knots. The criteria shown in the RCRV specification (Figure 073-1) are the narrowband form of the ICES limit. This limit is duplicated in Figure 1.

However, the National Science Foundation (NSF) changed the requirement from the narrowband format to the one-third octave band format in reference [2]. Figure 2 shows the one-third octave band form of the limit. Further, it is required that the radiated noise levels be achieved with all main propulsion and auxiliary machinery (except bow thruster) operating, all normally operating hotel services such as refrigeration and HVAC systems, and all navigational and scientific instrumentation systems in operation.

3.0 NOISE PREDICTION METHODS

The underwater noise predictions were carried out by NCE using a software program called *Designer NOISE* ™. This software requires the construction of an acoustic model which is created from large elements approximately the size of compartment decks and bulkheads. The program will compute the individual sound contribution from Airborne (AB), First Structureborne (FSB) and Secondary Structureborne (SSB) noise paths as shown in Figure 3.

This software was developed by NCE under a SBIR grant from the U.S. Navy and its intended use is for prediction of compartment (airborne) noise[1].

Designer NOISE ™ uses Statistical Energy Analysis (SEA) based algorithms and as such it computes the vibration on each of the elements within the model. To determine underwater noise, NCE uses the *Designer NOISE* ™ calculated element vibration for only the water loaded elements (i.e. the hull) and then applies a hull vibration-to-underwater noise transfer function to compute underwater radiated noise at 1 meter. The hull vibration-to-underwater noise transfer function was developed by NCE.

The acoustic model for the RCRV was created from the General Arrangement drawing, reference [6] as part of the compartment (airborne) noise evaluation. For the airborne model, only Propulsion Motors, Ship Service Diesel Generators, Propellers and Air Conditioning Chillers were included. For the underwater noise evaluation many additional pieces of machinery were included in the acoustic model as listed in Table 2. The 3-D acoustic model is shown in Figures 4-6.

TABLE 2: Machinery Evaluated for Underwater Noise and Quantity Operating for three speeds.

MEL Item #	Machinery Name	**Total Qty on Ship**	**Qty Operating for Each Speed**			**Evaluated Separately**
			6 knots	**8 knots**	**10 knots**	
8	Main Switchboard	1	1	1	1	No
11	Drive Motor Power Converter	2	2	2	2	No
12	Harmonic Filters Ship Service Power	2	2	2	2	No
13	Ship Service Diesel Generator	3	2	2	2	Yes
18	Air Compressors	2	1	1	1	Yes
20	Fuel Oil Purifiers	1	1	1	1	Yes
26	Sewage/Graywater Pumps	1	1	1	1	No
28	Vacuum Collection Unit	1	1	1	1	No
30	Marine Sanitation Device (MSD)	1	1	1	1	Yes
37	Sea Water Service Pumps	2	1	1	1	No
43	Fresh Water Cooling Pumps	2	1	1	1	No
44	Chill Water Pumps	1	1	1	1	No
45	Air Conditioning Chillers	2	1	1	1	No
46	Potable Water Supply Pumps	2	1	1	1	No
48	Waste Heat Recovery Pumps	2	1	1	1	No
51	Propulsion Motors	2	2	2	2	Yes
53	Propulsion Motor Transformer	2	2	2	2	No
54	Steering Gear HPU	2	2	2	2	No
57	Engine Room Supply Fan	1	1	1	1	Yes
58	Prop Motor Room Supply & Return Fans	2	2	2	2	No

[1] NCE has found the results to be compatible or better than previously used prediction methods from the SNAME Design Guide for Airborne Noise, reference [4]. Reference [5] gave a report on the verification by Hyundai on the accuracy of *Designer-NOISE*™.

4.0 BASELINE NOISE PREDICTION

The baseline noise predictions were carried out for three different speed conditions; 6, 8 and 10 knots. The quantity of equipment for each speed is listed in Table 2. Surprising, the quantities do not change for increased speed, even the number of diesel generators. The only machinery source that changes input with speed is the propulsion motor. Its vibration increases by 4.4 dB from 6 to 8 knots and by 2.5 dB from 8 to 10 knots. All other machinery vibration source levels remain the same for all three conditions.

The propeller noise was determined by NCE using methods based on tip vortex cavitation as given in reference [7]. The propeller noise was based on generalized propeller parameters take from references [8] & [9]. This includes: blade rate, rpm, tip clearance, and 'acoustic' cavitation inception speed.

The baseline underwater noise prediction assumed the following: (1) double stage vibration isolation of the Diesel Generators, (2) single stage vibration isolation of all other rotating machinery in Table 2 and (3) high transmission loss (HTL) material on the engine room perimeter, side shell, hull and forward and aft bulkheads and overhead. The HTL was found to be required to meet the airborne noise requirements as reported in reference [10]. The baseline vibration isolation requirements were based on previous experience with the NOAA Fisheries Research Vessels (FRV's) and the University of Delaware, *R/V HUGH R. SHARP*.

Figures 7 & 8 shows the results of the 6 knot baseline evaluation for port and starboard aspects, respectively. Figures 9 & 10 shows the results of the 8 knot baseline evaluation for port and starboard aspects, respectively. Figures 11 & 12 shows the results of the 10 knot baseline evaluation for port and starboard aspects, respectively. Each graphs shows the total machinery[2] contribution and total propeller contribution.

Figures 13 through 15 shows a comparison of port and starboard aspect for 6, 8 and 10 knots, respectively. At 6 knots, there is very little aspect dependence in the underwater noise levels. At 8 and 10 knots, the sound pressure levels are almost the same port to starboard. Figure 16 compares the total underwater noise for all three speeds.

Figures 17 & 18 shows the separated results for selected machinery at the critical 63 Hertz octave band for 6 and 8 knots, respectively. The detailed results for the 6, 8 and 10 knot conditions are given in Appendix B.

NCE concludes from the baseline data the following:

1. At 6 knots, RCRV will be just under (0.5 dB) the ICES limit. The critical frequency is in the 63 Hertz octave band which has a sound pressure level (L_p) just under the limit, but controlled by no single piece of equipment.

[2] The machinery contribution includes all three paths airborne (AB), first structureborne (FSB) and secondary structureborne (SSB).

2. At 8 knots, RCRV will be just over (1.7 dB, starboard/1.0 dB, port) the ICES limit. The excess occurs at only the 63 Hertz band which has a sound pressure level just over the limit. The excess is controlled by no single piece of equipment.
3. At 10 knots, RCRV will be significantly over (6 dB) the ICES limit. The excess occurs throughout the entire frequency range and due to the propeller.
4. There are differences in radiated noise between the port and starboard aspects. For individual pieces of equipment the difference is a high as 8 dB. However, for total noise the difference between aspects is only 1 dB.
5. The differences in radiated noise between 6, 8 and 10 knots are attributable to changes in propeller noise. Machinery noise stays mostly the same during the three speeds.

5.0 TREATMENT OPTIONS

Technically, the results show that underwater noise at 6 knots is below the ICES limit, again by 0.5 dB. First, the prediction accuracy is not as good as 0.5 dB so the computation could result in actual noise excesses, especially at 63 Hertz. Second, NCE computed underwater noise in octave bands, but the limits must be achieved in one-third octave bands.

All the results, Figures 7 through 18 show both octave and 1/3 octave band forms of the ICES underwater noise limit. Any octave band predicted sound pressure level that was over the octave band noise limit would be over the limit when evaluated on a 1/3 octave band basis, but any octave band predicted sound pressure level that was below the octave band limit could still be over on the 1/3 octave band basis. Thus, predicted sound pressure levels below the octave band limit, but above the 1/3 octave band limit are in potential excess situation. Such is the case for the 6 knot condition at 63 Hertz and 8 knot condition at most frequencies.

Treatment options exist as long as the controlling noise is due to the machinery. For the 6 knot condition, see Figure 6, the machinery noise is well above the propeller noise. For the 8 knot condition, only the 63 Hertz octave band is controlled by machinery noise by 5 decibels. With redesign of the propeller, the only options for making the ship quieter is noise mitigation of the machinery induced noise.

Options for lowering machinery induced underwater noise are hull damping, foundation damping, vibration isolation, engine room acoustic insulation and/or quieter equipment. The baseline noise prediction already assumed single stage vibration isolation for all equipment evaluated except for the diesel generators which were assumed to be double stage isolated. Acoustic insulation was assumed on the Engine Room and Propulsion Motor Room bulkheads as requirement for airborne noise.

NCE did not evaluate double stage mounting for the remaining auxiliary equipment and does not recommend such as a viable option. First, Figure 17 shows that no single piece of equipment controls the 63 Hertz octave band sound pressure level. The highest noise generators are the Fuel Oil Purifier, Propulsion Motors, Air Compressor and the Marine Sanitation Device. In order to get reduction from improved vibration isolation all four of these machines would require double stage isolation. The propulsion motor could not be double stage vibration isolated due shafting interface requirements. The other devices could be double stage isolated, but such treatment requires added space, added weight of at least half the weight of the machine and the design of the double stage frame and mounting. NCE believes all this to be more expensive than two proposed damping treatment options as discussed below.

The two potential treatment options evaluated were "local damping" and "global damping". The local damping approach is to analyze the machinery foundations for the critical equipment and make sure they are dynamically stiff and to add damping to the any plating that is larger than eight by eight inches (8x8"). Damping should be EAR Specialty Composites CN-38 or CN-62 (see Appendix C for data sheet). The damping tile must be at least same thickness as the plating. The critical equipment this applies to is given in Table 3. The foundation high dynamic stiffness requirement can be achieved through further engineering analysis during detail design and construction.

TABLE 3: Machinery Requiring Stiffened & Damped Foundations.

MEL Item #	Machinery	Qty on Ship
13	Diesel Generator	3
18	Air Compressor	2
20	Fuel Oil Purifier	1
30	Marine Sanitation Device (MDS)	1
45	Air Conditioning Chiller	2
51	Propulsion Motor	2

The other treatment option evaluated is global damping. In this case, the treatment approach is to put damping tiles or spray-on damping[3] on large portions of ship structure between the machinery and the hull. This includes the Engine Room and Propulsion Motor Room deck/tank top, longitudinal bulkheads, transverse bulkheads and hull as applicable. Neither the damping tile nor spray on material can be located inside fuel or potable water tanks. It would be possible to install damping in ballast water tanks, but this is not likely to be safe location.

The two treatment options, local damping and global damping were evaluated using features of *Designer NOISE* ™. The local damping was evaluated by turning off a resonance correction factor which is built into the *Designer NOISE* ™ prediction algorithm. The resonance correction accounts for typical foundation resonances inherent in shipboard machinery foundations.

The global damping was evaluated by adding damping to following bulkheads as part of surface treatment input (Coverings/Treatments for Elements) in *Designer NOISE* ™. The damping was located from Frame 18 to 28 on the tank top of the centerline and outboard void areas. It was also added to the transverse bulkhead at Frame 28 and longitudinal frames in the area that were not the interior of tanks. Figures 19 & 20 show the results of the two treatments for 6 and 8 knots, respectively.

[3] Mascoat Delta-DB, see Appendix C for data sheet.

Both treatments are much more effective at 6 knots than 8 knots due to fact that higher frequencies are controlled by propeller noise and the damping has no affect in this situation. However, at 6 knots, with propeller noise much lower, both damping treatments were found to be very effective. The local damping is very effective at the peak frequency of 63 Hertz. However, the global damping is more effective in the mid and high frequencies. At 8 knots, the local damping is just effective enough to reduce the sound level to below the octave band limit. The global damping does not reduce the sound level to below the limit.

6.0 RECOMMENDATIONS & SUMMARY

Based on the above evaluation, NCE believes that the RCRV will achieve the ICES noise requirement at 6 knots. As matter of risk reduction, NCE recommends that the critical machinery have high stiffness foundations with damping (i.e. the local damping). NCE does not recommend use of global damping due to fact that it does not provide enough reduction at the required frequencies, is costly and impacts other ship systems.

NCE believes that the RCRV may be able to achieve the ICES limit at 8 knots. Additional study and detail design will be required to insure this goal is achieved. This would require further study of the propeller design and/or more tank testing. Additional treatments would include the local damping approach described above and possibly some global damping.

REFERENCES

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8. .Brocket, Terry E., Design Summary II, Propeller Cavitation Model Geometry for the Glosten RCRV Twin-Screw Vessel, report number MBRD-2008-002-LR, dated July 10, 2008.
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FIGURE 1: Narrowband form of the ICES Underwater Radiated Noise Requirement from reference [2], CRR-209. Blue and red lines are the full frequency range as specified in CRR-209. The red line is the frequency limit as used by most organizations, such as the National Oceanic and Atmospheric Administration (NOAA).

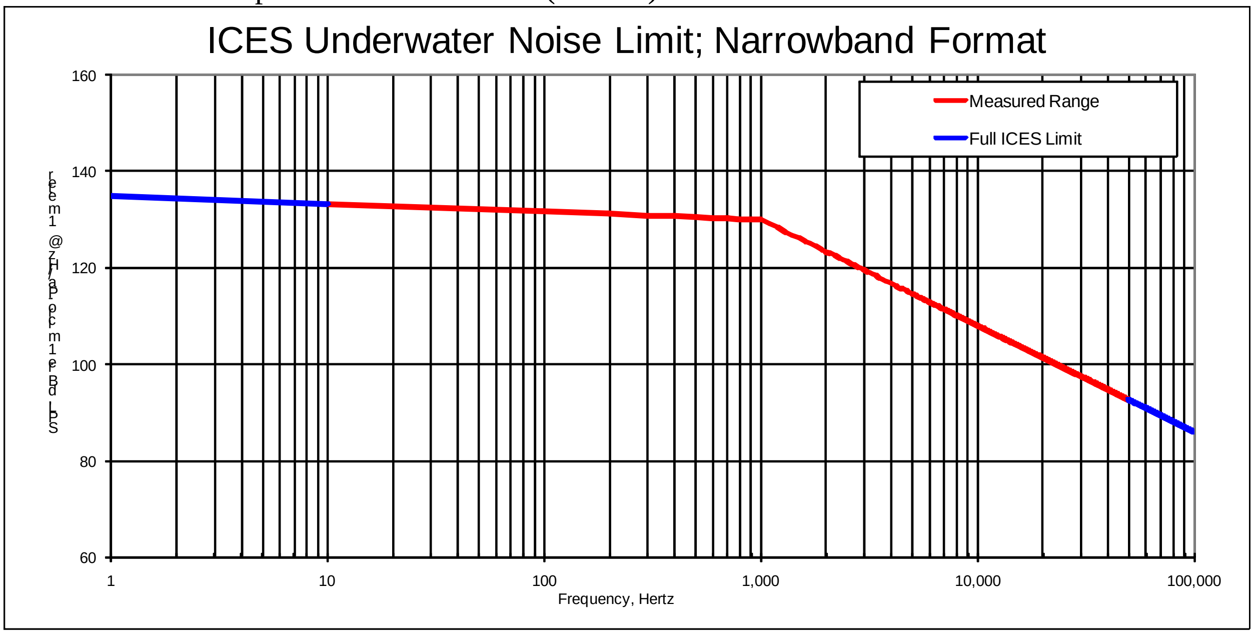

FIGURE 2: One-third octave band form of the ICES Underwater Radiated Noise Requirement from reference [2], CRR-209. This is the requirement that RCRV must achieve.

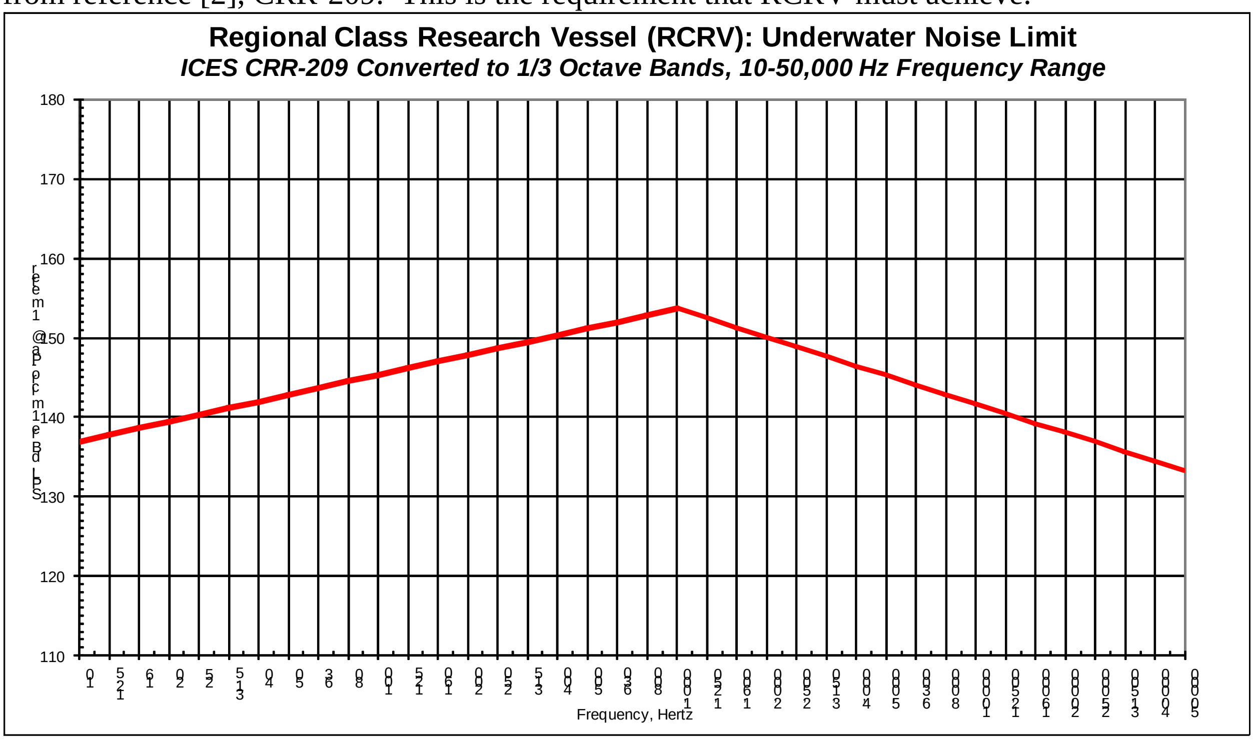

FIGURE 19: RCRV Underwater Noise Prediction for 6 knots with noise control treatments.

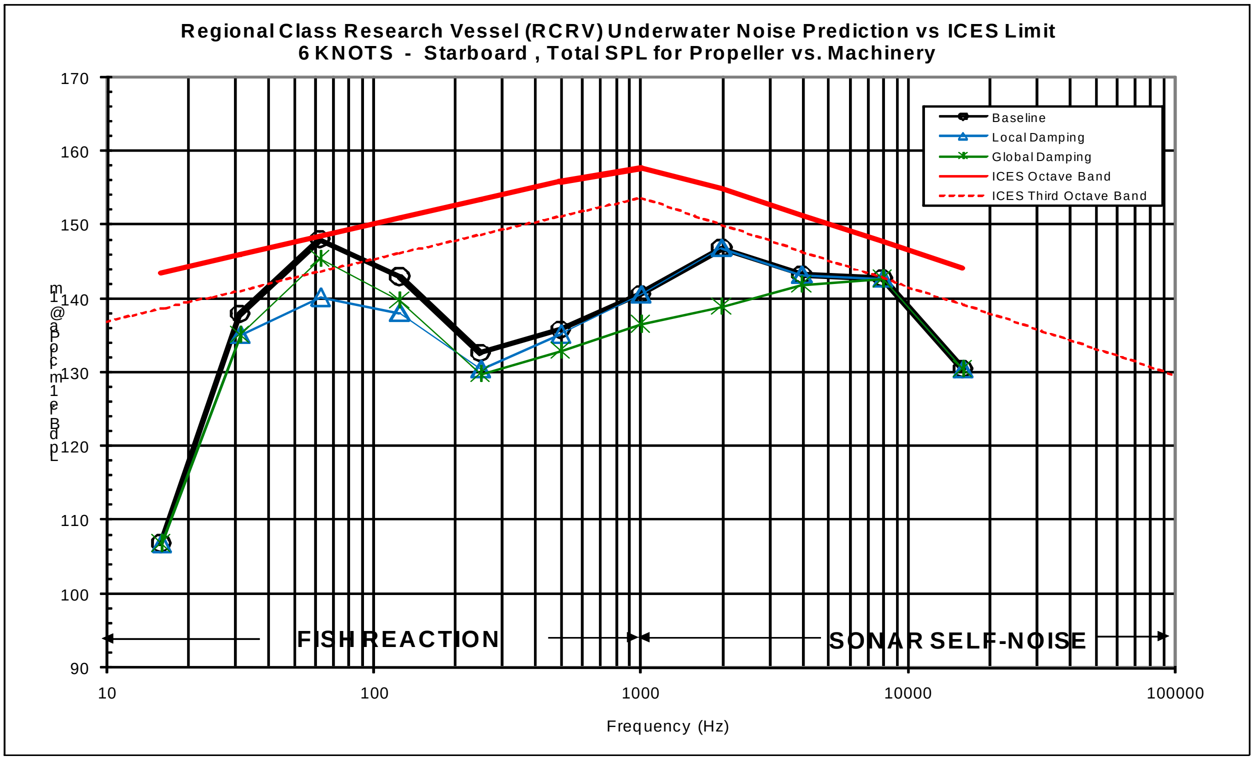

FIGURE 20: RCRV Underwater Noise Prediction for 8 knots with noise control treatments.