Science Advisory Panel
for
Alaska Department of Environmental Conservation
Commercial Passenger Vessel Environmental Compliance Program

Review and Comment Regarding Whole Effluent Toxicity Test Results for Five Commercial Passenger Vessels in Alaska

July 2002

Summary

Bioassays conducted in July 2002 by the Alaska Department of Environmental Conservation (ADEC) on a variety of commercial passenger vessel effluents indicate that acute or chronic toxic effects on marine organisms are not expected at the high dilutions that occur when vessels are underway.

The highest toxicities observed were from a graywater sample taken from a small cruise ship. The no observed effect concentration (NOEC) of 0.05% graywater effluent (a dilution factor of 2000) from this small cruise ship could be a concern if the effluent was discharged when moored, drifting or at anchor because dilution benefits are greatly reduced at such times.

The lowest toxicities were from (1) a sample of blackwater from a large cruise ship with reverse osmosis treatment and (2) an untreated blackwater sample from a small cruise ship. In fact these samples gave no toxic response even at the greatest concentration tested.

The Panel concludes that excess chlorine is the mostly likely cause of the observed toxicities.

These test results suggest tradeoffs between disinfection and chlorine toxicity and the difficulty of optimizing the amount of chlorine usage. The vessels sampled with advanced treatment technology (ultrafiltration and reverse osmosis) had very low marine organism toxicity and can safely discharge even when moored, drifting or at anchor.

Methodology

Six different effluent samples from five different cruise ships operating in Alaska waters were taken and analyzed for whole effluent toxicity (WET) in July 2002. The sampling events were arranged and scheduled in advance. The effluents covered a range of sources and treatments and came from both large and small cruise ships. The sampling, transporting, and testing followed standard EPA methods, met all test acceptability

criteria, and fulfilled the requirements of the quality assurance (QA) plan. The laboratory conducting the testing was certified by the Washington Department of Ecology for conducting WET tests. Observations of conventional water quality parameters were made upon receipt at the lab. The tests were run on a dilution series of six different concentrations of effluent. Because of the high initial dilution rates associated with moving cruise ships, the dilution series started at 50% effluent and increased by a factor of 10 in each step such that the percent effluent tested progressively decreased and included concentrations of 50%, 5%, 0.5%, 0.05%, 0.005% and 0.0005% effluent. The dilution series represented concentrations that are attained in receiving waters with dilution factors of 2, 20, 200, 2,000, 20,000 and 200,000. For comparison, a typical large cruise ship discharging 200 cubic meters per hour while traveling at 6 knots (11 km/hour) would have a dilution factor of about 50,000.[1]

The test species were selected because they were the marine species most likely to be sensitive to the effluents and have well established testing protocols. Each effluent was tested using two different species for acute tests (where lethality was the effect measured) and using two different species for chronic tests (where sub-lethal effects were measured).

Validity of the test

The Science Advisory Panel has reviewed the Whole Effluent Toxicity study results[2] (hereafter called the Study) and a separate laboratory analysis of the conventional and priority pollutant concentrations of each sample[3]. The Panel concluded that the Study is a valid and useful characterization.

What do the test results say?

Table 6 from the Study summarizes the results of all the bioassay tests. It is repeated here with some changes in vessel order and column headings. For the purposes of our comments and conclusions and for ease of understanding, we focused on comparisons of no observable effects concentrations (NOEC).

Numbers represent the highest effluent concentration at which the tests exhibited no observable acute or chronic effects. Values in parentheses show dilution ratios associated with the no observed effect concentrations (NOEC).

[1] The Panel has developed a formula for predicting dilution/dispersion in the wake of large cruise ships.
Dilution factor = 4 x (ship width x ship draft x ship speed)/(volume discharge rate)

[2] AMEC Earth & Environmental Northwest Bioassay Laboratory. 2002. *Results of Toxicity Evaluation of Cruise Ship Wastewater Whole Effluent - Southeast Alaska.* Prepared for Alaska Department of Environmental Conservation, Juneau, AK. Project no. 31-1-11132-003

[3] Analytica Environmental Laboratories, Juneau

Whole Effluent Toxicity Test Results
No Observed Effect Concentration (NOEC) in % Effluent

Vessel	Treatment System	Mysid Acute NOEC	Topsmelt Acute NOEC	Bivalve Larvae NOEC	Echinoderm Fertilization NOEC
Dawn Princess Graywater	Chlorine added to collection tanks	5 (1:20)	5 (1:20)	0.5 (1:200)	0.5 (1:200)
Mercury Mixed Effluent	Reverse Osmosis	50 (1:2)	50 (1:2)	50 (>1:2)	50 (1:2)
Volendam Mixed Effluent	Aerated Membrane (Ultrafiltration)	50 (1:2)	5 (1:20)	5 (1:20)	5 (1:20)
Kennicott Mixed Effluent	Macerator/ Chlorinator	5 (1:20)	5 (1:20)	5 (1:20)	0.5 (1:200)
Yorktown Clipper Graywater	Chlorine injection	0.5 (1:200)	0.5 (1:200)	0.5 (1:200)	0.05 (1:2000)
Yorktown Clipper Blackwater	Macerator/ Chlorinator	50 (>1:2)	50 (1:2)	50 (1:2)	50 (1:2)

What do the test results mean?

Whole Effluent Toxicity (WET) testing is an alternative to directly analyzing environmental samples for individual constituents. WET testing addresses the effect that simultaneous exposure to a mixture of pollutants has on an organism. A full description of the WET process is provided as an appendix to these comments.

In summary, samples from the Mercury and of the Yorktown blackwater did not demonstrate any toxicity at any concentration. The Volendam sample demonstrated an effect at 50% (one part seawater to one part wastewater) for the Topsmelt acute and both chronic test species. The Dawn Princess and the Kennicott demonstrated some effect at 50% concentration in the acute test and some effect at 5% wastewater concentration in the chronic tests. The Yorktown graywater sample exhibited the most observable toxicity effect of all vessels tested.

If the wastewater effluents were all from large cruise ships that were discharging underway, the observed WET values would not be of concern because of the high dilution rates[1]. Because the greatest chronic toxicity measurement was observed from a small ship which discharges continuously (Yorktown Clipper graywater), attaining the necessary dilution might be a concern.

The chronic toxicity of the Yorktown Clipper graywater and the Kennicott mixed effluent may be explained by the excessive chlorination of the effluent. Alaska's water quality standard for total residual chlorine is 2 ppb for salmonids and 10 ppb for other organisms. The total residual chlorine in the Yorktown Clipper graywater and Kennicott mix was 16,200 ppb and 30,300 ppb, respectively. These chlorine concentrations support the NOEC measured for these two vessels, where effects were observed at lower

concentrations than those of other vessels and effluents. The observed toxicity of the Dawn Princess graywater is not readily explained. There was no residual chlorine in the sample, but nevertheless, the toxicity of the Dawn Princess graywater would not be significant at the dilutions estimated for cruise ships discharging underway.

An interesting observation from the above data set is the lack of toxicity of the Yorktown Clipper blackwater sample. When the sample was drawn, it was evident that the treatment system was not functioning properly. The bacteria concentration of 2,400 MPN/100 ml indicates that the effluent must have been chlorinated, but not with enough chlorine to have any residual chlorine left at the time of the test. For all four tests, the sample exhibited no acute or chronic toxicity at the highest concentration (50%).

Conclusions of the Science Advisory Panel

1. The bioassay (WET test) conducted by AMEC Earth & Environmental on behalf of the Alaska Department of Environmental Conservation is valid and useful to the Panel's study of the potential for impacts or effects of commercial passenger vessel wastewater discharges.
2. The various effluents tested and analyzed would be expected to impart no acute or chronic toxic effects to marine organisms at the high dilutions that occur when vessels are underway.
3. The highest toxicities were observed from a graywater sample taken from a small cruise ship. The highly chlorinated graywater effluent from this small cruise ship could be a concern if the effluent was discharged when moored, drifting or at anchor because dilution benefits are greatly reduced at such times.
4. The effluents from the vessel employing reverse osmosis advanced treatment technology (Mercury) would not be expected to impart observable effects on marine organisms if discharged in port.
5. The effluents from the vessel employing ultrafiltration advanced treatment technology (Volendam) would not be expected to impart observable effects on marine organisms if discharged in port, provided the effluent is diluted by a factor 20. The Panel believes this mixing rate is easily achieved for large cruise ships, given the discharge velocity required to overcome the static head pressure at the depth of the discharge port[4].
6. This study highlights the trade-offs created when chlorine is used for disinfection.

[4] We made the following assumptions regarding the dilution achieved when a vessel is at rest. One is that the effluent is being pumped. One can also assume that the discharge pipe diameter would be no larger than 8 inches. The EPA approved dilution-modeling CORMIX model shows that at a discharge rate of $50m^3$/hr yields a dilution factor of 36 at a distance about 4.5m from the ship, and a dilution factor of 50 at 7m from the ship after 43 seconds.

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Appendix

Whole Effluent Toxicity (WET) Testing
Theory, Procedures, and Process

Whole Effluent Toxicity (WET) testing is an alternative to directly analyzing environmental samples for individual constituents. In WET testing, impact of a discharge stream on the environment can be evaluated in terms of its short (acute) or long-term (chronic) lethal or reproductive effects on indigenous animal species. Test organisms are exposed to various dilutions. Conditions of exposure can be varied based on the desired type of response. In a static non-renewal test, the test organisms are exposed to a single portion of the test solution for the duration of the test. In a static renewal test, the test organisms are exposed to fresh changes of the test water every day for the duration of the test. In a flow through test, the test organisms are continuously exposed to fresh batches, or mixes of test solution. Both the acute and the chronic tests were static. Effect of the exposure is measured in terms of a no observable effect concentration (NOEC) and a lowest observable effect concentration (LOEC) based on whether there is a statistical difference between controls and test samples. Additionally, a lethal concentration (LC) or a dose response curve can be calculated from the test results. LC is the concentration of the test material that kills a specified percentage of the test organisms over the observation time. An example of how the LC is expressed would be a "48-hr LC_{50}." This is the concentration of the test sample that resulted in death of 50% of the organisms after a 48-hour exposure. A dose response expresses the response of the organism to a toxicant based upon body weight or dilution. The curve plots percent response verses log dose.[5] Sub-lethal effect concentrations (EC) can be similarly described.

This WET testing investigation examined the toxicity of six effluent samples from five commercial cruise ships using marine organisms. Mysid shrimp (*Mysidopsis bahia)* and Topsmelt (*Atherinops affinis)* were selected as the test organisms for the acute testing. Survival was evaluated after a 48-hour exposure period to the Mysid shrimp and a 96-hour exposure period to the Topsmelt. The bivalve *Mytilus galloprovincialis* and the echinoderm *Strongylocentrotus purpuratus* were used as the test organisms for the chronic tests. Test concentrations examined were 50%, 5%, 0.5%, 0.05%, 0.005%, and 0.0005% of the effluent.
EPA has a method for calculating a concentration from an LC_{50} that represents "virtually no mortality." However, the reported acute NOECs are sufficient for our evaluation. The acute NOECs varied from 50% to 0.5% effluent. The lowest acute NOEC of 0.5% was for a heavily chlorinated effluent. Note that a 0.5% effluent concentration is attained after a dilution factor of only 200. Discharges from moving cruise ships attain much greater dilutions and acute whole effluent toxicity is not a concern for discharges when moving.

The chronic bioassay results have NOECs varying from 50% to 0.05% effluent. Alaska has a water quality standard of 1 chronic toxic unit (TU_c). The chronic toxic units for a

[5] Smith, Roy-Keith, Handbook of Environmental Analysis, Fourth Edition, Genium Publishing Corporation, 1999.

discharge may be determined by dividing 100 by the NOEC. Consequently, the chronic toxic units observed in the above effluents varied from 2 to 2,000. Following Alaska and EPA's approach, dilution is considered in determining where the 1 TU_c standard is to be applied. The chronic toxic units actually are the same as the amount of dilution needed to meet the 1 TU_c standard.

For large cruise ships traveling at a speed of at least 6 knots, a dilution factor of 50,000 is considered reasonable and conservative. For small cruise ships also traveling at 6 knots it may be around 37,500. It is clear that as soon as effluent is entrained in turbulence behind the stern of a ship moving at 6 knots or greater, within a minute or so a dilution factor substantially greater than 2000 will have been achieved for either small or large vessels. In terms of the NOEC, this means that the concentration of the effluent in seawater will be substantially less than 0.05% at that same location. It is also evident that small cruise ships will require better methods to ensure highly chlorinated discharges are not released while the vessels are stationary, or (preferably) traveling at less than 6 knots.