Analysis of Marine Emissions in the South Coast Air Basin

ARCADIS Final Report FR-99-100

ARCADIS
GERAGHTY & MILLI

6 May 1999

PREPARED FO

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UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION IX
75 Hawthorne Street
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May 27, 1999

Dear Interested Party:

Because you are a key interested stakeholder, we are providing you with a copy of the recently completed Arcadis Geraghty & Miller Final Report, "Analysis of Marine Emissions in the South Coast Air Basin." This US EPA contracted report describes expected emission reductions from international standards, potential national standards, and hypothetical speed reduction scenarios.

As you may recall, in 1997 EPA contracted Acurex Environmental to assist with analysis of the aforementioned emission reduction strategies. In December, 1997, a draft report was sent out to interested stakeholders for comment. In April, 1998, the California Air Resources Board announced the formation of a Technical Working Group to evaluate the onshore air quality impacts of the two operational controls under consideration for deep sea vessels. In May, 1998, EPA extended the contract with Acurex (now known as Arcadis Geraghty & Miller) so that the report could be completed.

It is important to note that during the course of the work unanticipated, new information become available which in some instances could not be incorporated into the final report. Because of budget constraints within EPA and the need to avoid further delays in completing the report, EPA decided to have Arcadis complete the work while recognizing that all of the comments received could not be addressed and the report could not take into account all of very recent information that might affect the analysis. Given that precaution, the final report does provide a very useful analysis of the reductions expected.

As the report was nearing completion, discussions within the Technical Working Group revealed that previously reported ship speeds used in the draft report were higher than actual ship speeds, possibly by as much as 15 to 20 percent. Therefore, the results presented in Chapter 5 of the final report must be tempered by recognition that the inventory and subsequent reductions may be slightly less than what is reflected in the report. Also, on December 11, 1998, EPA proposed new national emission standards for marine engines. Again because of funding and timing limitations, the final report does not take into account the proposed new standards, although the expected reductions by 2010 from the proposed new standards are not anticipated to be substantially different from the reductions described in Chapter 4.

With that said, the final report does provide the most thorough analysis to date of the expected reductions from the new international standards, expected national standards, and various reduced speed scenarios. Consistent with the State Implementation Plan and South Coast emission inventory, the reduction estimates provided in this report are based on emissions occurring within the overwater boundary. Additional analysis of the onshore air quality impacts of marine vessel emissions is currently under discussion within the Technical Working Group.

EPA would like to thank those who provided significant comments on the draft report, especially: James Corbett (Carnegie Mellon University); Robert Kanter (Port of Long Beach); Donald Rice/TL Garrett (Port of Los Angeles); Mike Osborne/Bill Remley (US Navy/John J. McMullen Associates, Inc); Zorik Pirveysian (South Coast Air Quality Management District); and Scott Johnson (Ventura County Air Pollution Control District). The revised report reflects many of the comments received. Unfortunately, all of the comments could not be addressed in the report. A brief summary of the comments which were not addressed is provided in the attachment.

If you have any questions or comments, please contact me at 415-744-1286 or ungvarsky.john@epa.gov. Thank you.

Sincerely,

John Ungvarsky
Air Division

Attachment

Attachment

A summary of key comments not addressed in the final report

Comment: EPA should address whether the estimated reductions meet the SIP target and the implications and intentions regarding this study and related ongoing studies. (POLB)

Response: This will be addressed during closure of the consultative process and upon completion of the pending report by the Technical Working Group.

Comment: EPA should investigate reductions from lower International Maritime Organization (IMO) Standards. (POLA)

Response: Estimating reductions from lower IMO is beyond the scope and budget for this contract. If and when the IMO considers revisiting the standards, EPA will consider estimating the potential benefits at that time.

Comment: EPA should conduct independent testing of marine vessels visiting United States ports. (POLA)

Response: Testing of marine vessels is significantly beyond the scope and budget for this contract.

Comment: Calculate the emission reductions from the current precautionary zone restrictions. (POLA)

Response: The emission reductions from the precautionary zone are incorporated into the speed reduction scenarios presented in the report. Do undertake a separate analysis of the precautionary zone restrictions would require that the baseline be recalculated, which is beyond the budget allocated to complete other portions of the report.

Comment: Calculate the emission reductions from the tankers already using a relocated shipping route. (POLA)

Response: The contractor has indicated to EPA that the distance traveled by the tankers did not significantly change because of the rerouting. The issue is best addressed within the ongoing efforts of the Technical Working Group.

Comment: Projected ship and age profiles should be verified. (SCAQMD)

Response: The report relies on previous information used in "Marine Vessel Emissions Inventory and Control Strategies" *Acurex Environmental, December, 1996). It is beyond the scope and budget for the contract to verify the ship and age profiles.

Comment: Potential controls for auxiliary/engines should be studied. (SCAQMD)

Response: It is beyond the scope and budget for the contract to address potential controls for auxiliary engines.

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1. INTRODUCTION AND SUMMARY

1.1 OZONE POLLUTION IN THE SOUTH COAST AIR BASIN

The South Coast Air Basin, located in Southern California, experiences higher levels of ozone pollution than any other area in the United States (Figure 1-1). Such high ambient concentrations of tropospheric ozone have been shown to be harmful to human pulmonary and respiratory systems and damaging to natural ecosystems and agricultural crops. The social costs of air pollution-related medical care, reduced worker productivity, reduced crop yields, and environmental damage are difficult to quantify, but are widely acknowledged to be high (see for example Hall et al.; Grantz et al.). In recognition of the seriousness of these problems, the U.S. Environmental Protection Agency (EPA) is authorized by the Clean Air Act to set national ambient air quality standards (NAAQS) for ozone and require regions which exceed these standards to develop plans and implement measures to bring the region into attainment of the NAAQS by a specified date. The South Coast is required to come into compliance with the NAAQS by the year 2010.

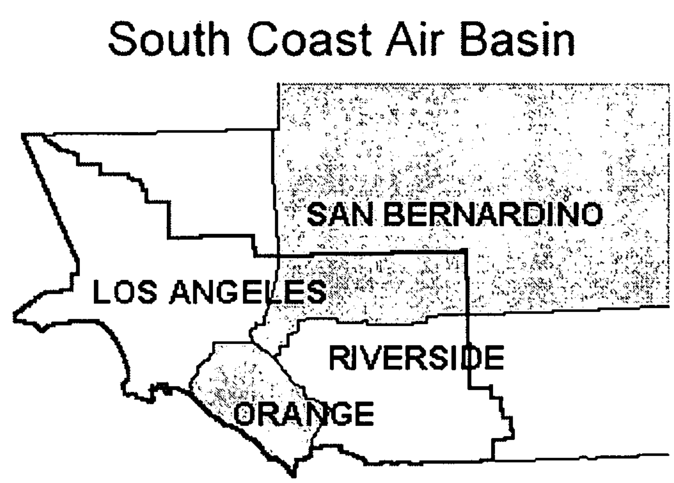

Figure 1-1. The South Coast Air Basin includes Los Angeles, Orange, Riverside, and San Bernardino Counties

1.2 CALIFORNIA'S 1994 OZONE PLAN AND THE CONSULTATIVE PROCESS

States containing regions which exceed the NAAQS must submit State Implementation Plans (SIP) describing how the nonattainment regions will come into compliance with the

NAAQS. More specifically, ozone SIPs describe how emissions of hydrocarbons and oxides of nitrogen (NO_x)[1] will be reduced to acceptable levels by the attainment year. The 1994 California SIP for ozone, which was approved by the U.S. EPA in September of 1996, commits to reduce emissions of NO_x from marine vessels in the South Coast Air Basin by 9 tons per day (tpd) in 2010, providing an important fraction of the total NO_x reductions needed to reach NAAQS attainment. The 1997 revision to the Air Quality Management Plan of the South Coast Air District, which is a component of the California SIP, increases this NO_x reduction commitment to 15 tpd. This revised estimate reflects an increased estimate of the inventory of NO_x emissions from marine vessels pursuant to a 1996 inventory study performed for the South Coast Air Quality Management District (Acurex Environmental). According to the District's 1997 plan revision, this 15 tpd is about 7 percent of the total NO_x reductions needed in 2010 for attainment and about 14 percent of the total NO_x reductions needed from offroad mobile sources. In other words, a very significant portion of the total NO_x reductions needed to protect public health and the environment from ozone pollution in the South Coast is expected to come from marine vessels.

Several of the emissions reduction measures included in the 1994 California SIP addressed such "national sources" as heavy-duty trucks, offroad heavy equipment, aircraft, and marine vessels by calling for new national or international emissions standards, which are not within the authority of local air districts or the California Air Resources Board (ARB) to implement. Thus, EPA was requested to implement measures critical to the success of the California air plan. To further explore emission reduction options for these sources and find appropriate balances between national and international emissions standards and measures that could be implemented locally in California, EPA proposed a "public consultative process" in March of 1996. The consultative process brought together representatives of industry, environmental groups, and State and local government agencies who, with EPA, worked to construct acceptable approaches to obtaining the emissions reductions committed to in the 1994 SIP. EPA's approval of the 1994 SIP included a mutual commitment of EPA and ARB to conduct the public consultative process and incorporate the results of the process (including any EPA commitments to rulemaking) into a revised plan for the South Coast Air Basin.

This report, which analyzes three strategies for reducing emissions from marine vessels in the South Coast, has been prepared to assist the discussions that are underway in the marine portion of the consultative process.

1.3 OPTIONS FOR REDUCING NO_x EMISSIONS FROM MARINE VESSELS IN THE SOUTH COAST

A number of options for reducing NO_x emissions from marine vessels are under discussion in the consultative process. These include:

- Implementing international emissions standards for engines used in marine vessels

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[1] NO_x and hydrocarbon emissions react in the presence of sunlight to form tropospheric ozone.

- Implementing national emissions standards for high speed marine engines used domestically

- Reducing ship cruising speeds in South Coast waters

- Moving the Santa Barbara shipping channel farther off the Coast

- Providing incentives to introduce various emission reducing technologies into the fleet — technologies may include lower-emitting engines, emission-reducing fuels, or add-on catalyst technology and would be applied as appropriate to marine propulsion engines of all sizes and marine auxiliary engines

- Reducing land-side emissions related to port activities — these emissions are generated by cargo handling equipment, trucks, and rail operations. These land-side sources were discussed as part of the consultative process because they are wholly or partly under the control of organizations involved in the process such as the Ports of Los Angeles and Long Beach, the tenants of the ports, and the shippers which use the ports.

This study investigates the first three options listed above, international and national emissions standards and speed reductions. In the marine vessel portion of the consultative process, NO_x emission reductions are the primary focus of the effort, therefore, this report investigates NO_x emissions only.

1.4 RESULTS AND CONCLUSIONS

Sections 2 through 5 of this report assess the NO_x reductions expected from the recently agreed upon IMO NO_x emission limits, the national emissions standards currently under consideration at EPA, and a reduction in ship cruising speeds in the South Coast. The results of these analyses are summarized in Table 1-1.

Table 1-1. NO_x reductions in the South Coast from control measures analyzed in this study

Measure	Affected Sector	Estimated NO_x Reductions in 2010 (tons per day)
IMO emission standards	Oceangoing vessels – main engines	0.2 to 0.8[a]
IMO emission standards	Oceangoing vessels – auxiliary engines	1.2
EPA + IMO emission standards	Harbor craft and fishing vessels	~0.8 (see Section 4)
Speed reduction	Oceangoing vessels calling on South Coast Ports	Possibly 1 to 4[b]
Combined measures (total)	All of the above	3.2 to 6.8

[a] Range represents results from two different methods of treating the available data. See Section 3 for discussion.

[b] Estimate based on analysis results of Section 5 discounted by 20 percent to approximate reduced benefit associated with actual cruise speeds lower than modeled. See Section 5 for discussion.

2. MARINE VESSEL OPERATIONS IN SOUTH COAST WATERS

2.1 BACKGROUND

In December of 1996, ARCADIS Geraghty & Miller (formerly Acurex Environmental) completed a study for the South Coast Air Quality Management District (District or SCAQMD) which examined emissions from marine vessels in the South Coast Air Basin. The final report, titled *Marine Vessel Emissions Inventory and Control Strategies,* updated the marine vessel emissions inventory in the South Coast for several pollutants, including NO_x, and covered all types of marine vessels except for pleasure craft. The results of this study (hereafter called the SCAQMD inventory study) were incorporated into the District's 1997 air plan revision.

We used the SCAQMD inventory study extensively as a resource for this evaluation of the effects of international and national standards and speed reductions in the South Coast Air Basin. It should be noted that this study is intended to evaluate reductions from the baseline inventory that would accrue due to emissions standards and speed reduction measures. It is not intended to update the baseline inventory presented in the SCAQMD study. Therefore, we attempted to maintain consistency with the inventory study and the data sources used in that study, even though in a few cases more recent or more detailed information was available.

Several aspects of the SCAQMD inventory study were used in this evaluation of potential control strategies, including the geographic area under consideration, ship characteristics, and various measures of activity levels. These are described in further detail in the remainder of this Section.

2.2 OVERWATER BOUNDARY

The SCAQMD inventory study was predicated on a defined overwater boundary within which emissions were "counted" toward the inventory. There is much controversy over the definition of this boundary and studies are underway to improve scientific understanding of the extent to which emissions offshore affect air quality in the South Coast Air Basin[2]. Resolving this controversy is well beyond the scope of this study. Here we continue to use the overwater

[2] Inventory analyses, which simply describe the mass of pollutants emitted in a certain timeframe (often reported as tons per day) are translated into ambient concentrations of pollutants using sophisticated airshed models which incorporate their own assumptions about where pollutants are emitted (using a grid overlay on the region being modeled) and how they travel and react in the atmosphere. As long as the overwater boundary is large enough to enclose the area within which emissions are thought to impact onshore air quality, it is the assumptions in the airshed model and not the inventory definition of the overwater boundary that will determine the effect of offshore emissions on onshore air quality.

boundary that was used in the SCAQMD inventory study. This boundary (shown in Figure 2-1, modified from a figure presented in a Booz-Allen & Hamilton report "Inventory of Air Pollutant Emissions from Marine Vessels") has been defined by the ARB[3]. The enclosed overwater area extends approximately 100 miles offshore.

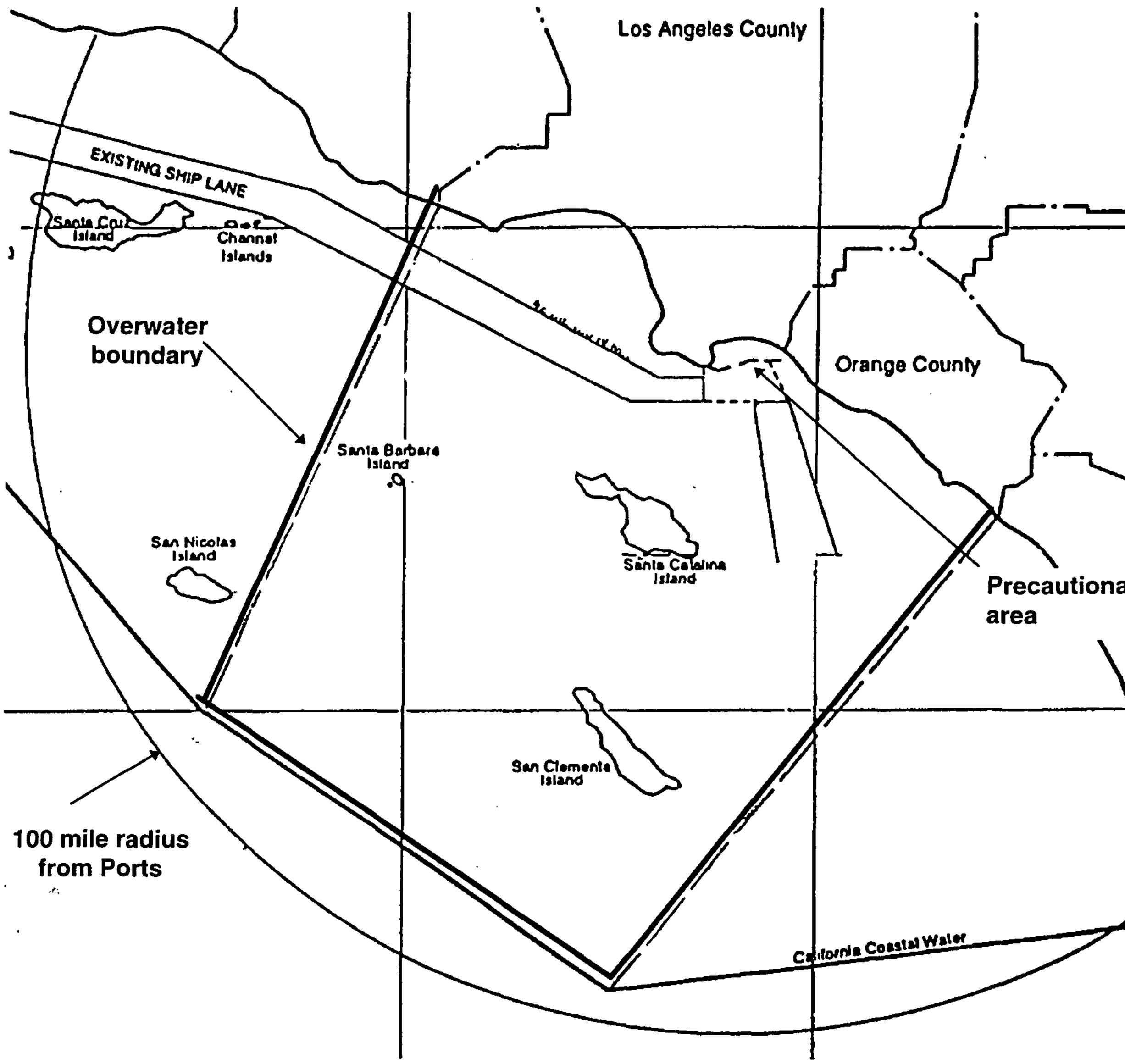

Figure 2-1. Overwater boundary used in the inventory study (modified from Booz-Allen Figure 2-1)

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[3] ARB has the responsibility to define air basin boundaries within California (26 CCR Section 39606).

2.3 MARINE VESSEL OPERATIONS IN SOUTH COAST WATERS

Marine vessels included in the SCAQMD inventory study were grouped into several categories. These were:

- Oceangoing vessels
  - Calling on the San Pedro Bay Ports (the Ports of Los Angeles and Long Beach)
  - Calling on the Chevron facility at El Segundo
  - Transiting through South Coast waters without calling on a port
- Tugboats and other harbor vessels (e.g., workboats, crewboats, passenger cruise boats)
- Fishing vessels
- U.S. Navy vessels
- U.S. Coast Guard vessels

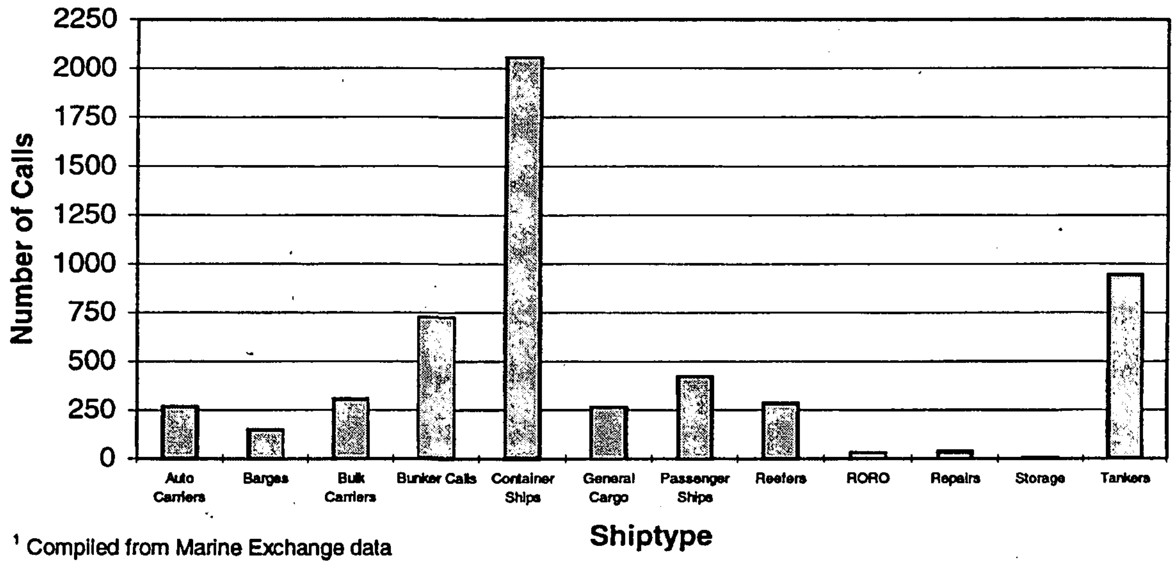
Separate analyses were performed for each of these categories to reflect their unique characteristics. The following sections describe vessel and operating characteristics for the three categories that would be affected by the control strategies investigated herein: oceangoing vessels that call on the San Pedro Bay, harbor craft, and fishing vessels. Information is taken directly from the SCAQMD inventory study.

2.3.1 Oceangoing Vessels That Use the San Pedro Bay Ports

The SCAQMD inventory study focused on 1993 as the baseline study year, consistent with the baseline year used in South Coast's 1997 air plan update. Therefore, the most detailed characterization of oceangoing vessel operation in South Coast waters is based on 1993 and, to some extent, 1994 data. Detailed data from the Marine Exchange of Los Angeles - Long Beach Harbor and from Lloyd's Maritime Information Services of Lloyd's Register was combined to evaluate vessel characteristics and activity for the 1993/1994 timeframe (see the SCAQMD study for an explanation of available data sources and how they were used). The inventory was also "backcast", based on Marine Exchange records of calls per shiptype, to 1990, which was the baseline year for the 1994 SIP. And, 2000 and 2010 inventories were forecasted, so characterizations for these years are also available, although they are more speculative, being largely extrapolated from the 1993/1994 data.

About 1530 vessels made 5498 calls on the San Pedro Bay Ports in 1993. In 1990, a similar number of vessels made 6672 calls on the Ports. These vessels included container ships, bulk carriers, tankers, passenger cruise ships, and a variety of other vessel types which came to the Ports for a number of purposes such as to load and offload cargo, be inspected or repaired, or to take on fuel. In 2010, growth to 7856 calls per year is projected, with the most dramatic trend being the increased number of calls by larger, faster, container ships (2010 projections in the inventory are based on growth projections for the Ports of Los Angeles and Long Beach contained in a report prepared by the Chambers Group for the U.S. Army Corps of Engineers and the Los Angeles Harbor Department.)

Many types of vessels call on the Ports of Los Angeles and Long Beach, but calls are dominated by container ships. Of the 5498 total ship arrivals recorded by the Marine Exchange for 1993, by far the majority were made by container ships (about 2050 calls) followed by tankers (about 950 calls) and passenger vessels (about 400 calls). Auto carriers, bulk carriers, general cargo ships, and reefers each accounted for about 300 calls per year and barges for about 150. RORO ships, and ships calling for repair and/or storage called fewer than 50 times each. About 700 arrivals were for the purpose of bunkering (Figure 2-2). Annual calls are fairly evenly distributed over the 12 months, with the most calls per month occurring in March, May, and October (between 480 and 500 calls per month), the next most occurring in December with about 465 calls, and the rest of the months seeing between about 432 and 455 calls per month (Figure A-1, Appendix A).



[1] Compiled from Marine Exchange data
[2] Barge calls are not recorded regularly.

Figure 2-2. 1993 ship calls by shiptype[1]

Foreign flag ships powered by diesel engines are most prevalent. Of the 1529 vessels identified as calling in 1993, 1438 were foreign flag and 91 (6 percent) were U.S. flag vessels. The U.S. flag ships were typically repeat visitors, however, and so U.S. flag vessels account for 21 percent of the total calls in 1994. Most of the vessels calling in 1993 were powered by direct-drive diesel engines while 169 had geared diesel engines and 70 were powered by geared-drive steam turbines. Data from the Marine Exchange for 1994 showed steamships making 744 calls, or 14 percent of the total calls. The SCAQMD inventory model projects steamship calls decline to 11 percent of the total calls in 2000 and 5 percent of the calls in 2010.

Because emissions tests show medium-speed engines to emit less NO_x than slow-speed engines (see Section 3), it is important to distinguish these two engine types. The percentage of main engines which are 4-stroke (mostly medium-speed) versus 2-stroke (slow-speed) varies from shiptype to shiptype. Bulk carriers, container ships, and tankers calling on the Ports in 1993 were dominated by 2-stroke engines; about 95 percent of these engines were 2-strokes. Approximately 90 percent of main engines powering ROROs were 2-stroke engines, while about 80 percent of motorship reefers and general cargo ships had 2-stroke engines. Finally, passenger ship engines were about half 2-stroke and half 4-stroke (Table A-1, Appendix A).

Figures 2-3 shows the number of calls in 1994 by the year the vessel was constructed. This figure illustrates that it is common for ships as old as 20 to 25 years to call on the Ports. Appendix A contains similar graphs for each shiptype (Figures A-5 through A-13).

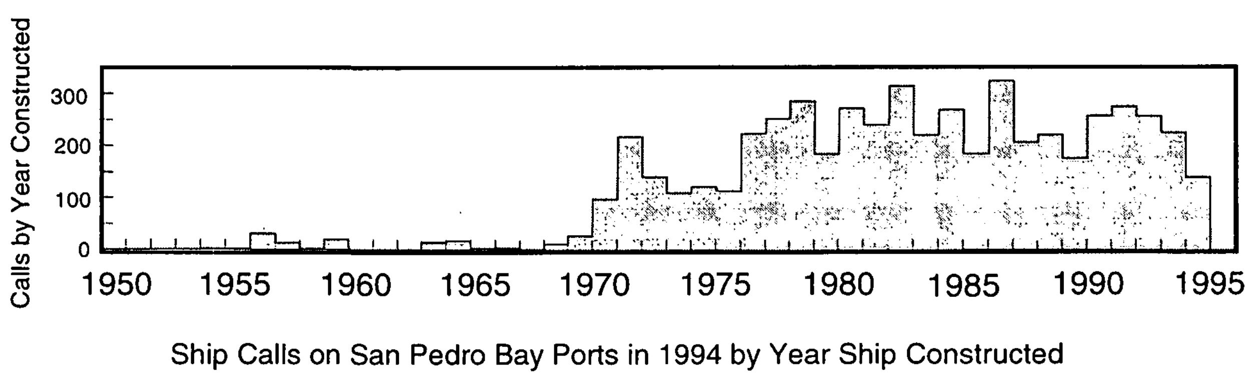


Figure 2-3. Calls in 1994 by year ship constructed — ALL SHIPTYPES

The size and speed of ships that use the San Pedro Bay Ports varies. Net and deadweight tonnage profiles which were constructed as part of the inventory study show a wide range of tonnages for most vessel types. The range of service speeds by shiptype is more narrow and for some shiptypes varies by only about 3 knots. Container ships and tankers calling on the Ports show the most variation with a more than 10 knot difference between the service speeds of the slowest and fastest ships. Figures A-2 through A-4 in Appendix A shows the profiles for container ships. Profiles for other shiptypes may be found in the SCAQMD inventory study[4].

Ship size and speed strongly affects the amount of work required to move a ship through water. The work required is directly correlated with ship emissions. Therefore, it is necessary to characterize calls in terms of ship size and speed as well as other critical parameters. The inventory study grouped vessels by shiptype (e.g., bulk carrier) and propulsion type (e.g., motorship or steamship) and by "design category" (e.g., 200-400, 400-600, etc.) . The design categories were based on ship deadweight tonnage and service speed such that ships in a single design category could be assumed to be well represented by a single average rated power

[4]Note that these profiles are based on the 1993 data which is per-ship data. The average ships speeds by shiptype, which were incorporated into the SCAQMD model and are shown in Table 5-2 of this report, are taken from the 1994 Marine Exchange data which provided data by call. Thus, unlike the speed profiles in Appendix A and the SCAQMD inventory study, the average speeds by shiptype used in the model are call-weighted.

associated with the category. Section 3.2.3 of the SCAQMD inventory study contains more discussion of the use of the design category and development of average rated power characterizations. Distribution of annual ship calls by shiptype, propulsion type, and design category, then, implied a certain distribution of annual calls by rated power. This power distribution combined with ship activity information gives total energy requirements for a year which can be multiplied by emission rates to calculate annual emissions inventories.

2.3.2 Oceangoing Vessel Activity

Ship activity information includes engine load in each operating mode and time spent in each operating mode while in South Coast waters. The SCAQMD inventory study distinguished four operational modes for ships using the San Pedro Bay Ports: full cruise, precautionary area cruise, maneuvering, and hotelling. Ship operations were characterized based primarily on Marine Exchange data.

In general, ships enter or exit the South Coast waters in cruise mode. Cruise mode in the SCAQMD study was assumed to be associated with ship service speed (usually about 15 to 23 knots) and an engine load of about 80 percent of maximum continuous rating (MCR)[5]. Four primary routes into and out of the Ports are used, designated in the inventory study as Northern, Southern, Western, and Catalina (Figure 2-4). The ships remain in cruise mode until they near the precautionary area within which ship speeds are regulated to be no more than 12 knots. The precautionary area begins approximately 5 miles outside the breakwater. About 1 mile from the breakwater, the ships slow to about 5 knots to take on a pilot and, typically assisted by tugboats, maneuver into the harbor at low speeds, slowing further as they approach the pier[6]. The inventory study estimates power requirements, separate for each shiptype, for operation within the precautionary area and for maneuvering.

While in Port, motorships operate auxiliary engines and boilers (and steamships operate their main boilers at low loads) to provide power for lights, ventilation, and other "hotelling" requirements, and steam for hot water and to keep fuel from solidifying. Auxiliary engines may also be used to offload cargo, especially to power pumps for offloading liquids such as crude oil. Loads on auxiliary engines can vary dramatically from ship to ship. The SCAQMD inventory study characterized auxiliary engine loads and auxiliary boiler use, specific by shiptype, based on a survey of about 60 ships made by the Environmental Management Division of the Los Angeles Harbor Department during 1994. Table 2-1 shows the average load assumed for auxiliary engines by mode for each shiptype.

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[5]The power required to cruise at the service speed varies with the extent to which the ship is loaded. (A more heavily-loaded ship sits lower in the water and requires more power for equal speed.) Data which would allow the loading of ships calling on the San Pedro Bay Ports to be characterized is not available. The assumption that service speed is associated with 80% MCR is consistent with most but not all ships being fully or near-fully loaded and is taken from a 1994 report prepared by the Ports of Los Angeles and Long Beach.

[6]Instead of docking at a pier, ships sometimes go to anchor. Anchorages are available both inside and outside the breakwater.

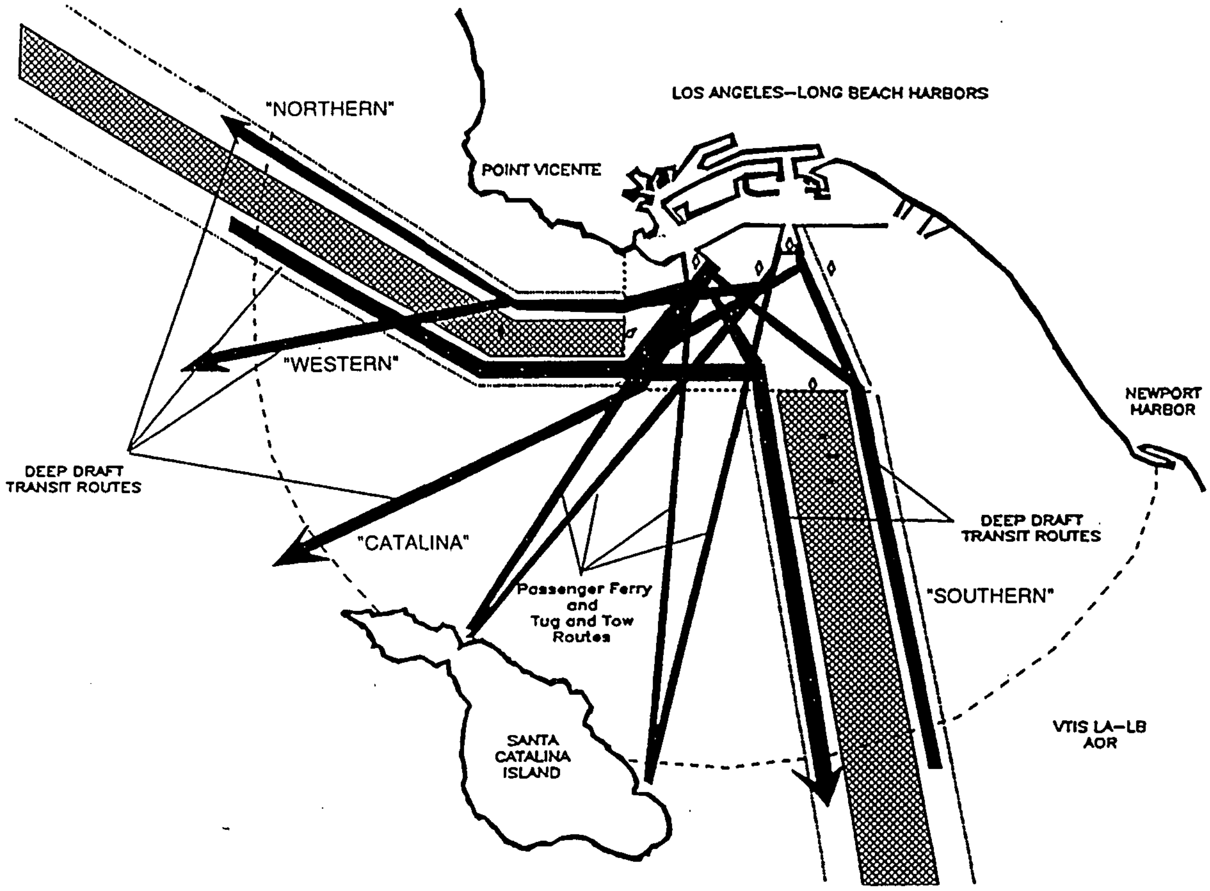

Figure 2-4. VTIS Los Angeles-Long Beach, standard transit routes (provided by the Marine Exchange)

Table 2-1. Auxiliary engine loads assumed in the SCAQMD inventory study

Shiptype	Cruise Load (kW)	Maneuvering Load (kW)	Hotelling Load (kW)
Passenger Vessels	5000	5000	5000
All other shiptypes	750	1250	1000

Vessels may "shift" while in port, moving from one berth to another or between berths and anchorages. Vessels may shift between the Port of Los Angeles and the Port of Long Beach, as well. The estimates of time spent hotelling and maneuvering in port per ship call made in the inventory study included this shifting, which is especially prevalent for tankers and bulk carriers.

Departure from the Ports is similar to arrival but tends to happen more quickly as outgoing ships have the right-of-way over incoming ships and as outgoing ships drop off the pilot at the breakwater rather than a mile or so outside the breakwater. And, of course, ships may depart on a different route than that over which they arrived.

The ports from which the most calls on the San Pedro Bay Ports originate are (based on 1994 Marine Exchange data and shown from highest number of calls to lowest):

- Yokohama
- Oakland
- Tokyo
- San Francisco
- Ensenada
- Kaohsiung
- Valdez
- Honolulu
- Hong Kong
- El Segundo
- Manzillo
- Vancouver, B.C.

Of a total of 5268 calls made on the San Pedro Bay Ports in 1994, 2620 of them originated in one of the 12 ports listed above. The most calls by far came from Yokohama (536) and Oakland (414).

Roughly half of the 1994 calls entered the breakwater by Queen Gate (Port of Long Beach) and the other half by Angel Gate (Port of Los Angeles).

2.3.3 Harbor Craft and Fishing Vessels

2.3.3.1 Harbor Craft

As used in this study, "harbor craft" includes tugboats, towboats, pushboats, workboats, crewboats, supplyboats, dredges, utility boats, and passenger/excursion vessels. Tugboats, towboats, and pushboats are treated as one category of vessels while passenger/excursion vessels are treated as another. All remaining harbor vessel types are grouped together and referred to in this study as workboats.

Tugboats operating in the South Coast include mooring tugs which are certified to put ships into berth at the San Pedro Bay Ports, "other" harbor tugboats or towboats or pushboats (called "non-mooring tugs" for the remainder of this report) operating in the area, and oceangoing tugs which tow barges into the harbor. Oceangoing tugs were estimated in the SCAQMD inventory study to contribute very little to the NO_x inventory (0.2 tpd in 1993 and 0.4 tpd in 2010 – less than 1 percent of the total marine NO_x inventory) and were not included in this study because reductions from this category would be negligibly small.

The SCAQMD inventory study used population and rated horsepower information on mooring tugs from the Los-Angeles/Long Beach Harbor Safety Committee, which publishes certified bollard pull test results for all certified mooring tugs serving the San Pedro Bay Ports. It also used information provided by Crowley Marine Services and Wilmington Transportation, two of the three operators of mooring tugs in San Pedro Bay. Information on non-mooring tugs operating in the South Coast was obtained from the U.S. Army Corps of Engineers[7]. Table 2-2 shows the population of mooring and non-mooring tugs operating in the San Pedro Bay based on these data.

Table 2-2. Population of mooring and non-mooring tugs by horsepower category operating in the South Coast

Tug Horsepower Category	# Mooring Tugs (1995 data)	# Non-Mooring Tugs (1993 data)
<300	0	0
300-599	0	5
600-749	0	1
750-999	0	1
1000-1499	2	2
1500-1999	2	1
2000-2499	5	0
2500-2999	1	0
3000-3499	2	0
3500-3999	5	0
4000-4499	0	0
4500-5499	4	0
5500-6499	0	0
6500-7499	1	0
Totals	22	10

[7]The U.S. Army Corps maintains information through the Waterborne Commerce Statistics Center in New Orleans, Louisiana on domestic vessels and operators of such vessels available for use on U.S. waterways, harbors, and channels. This organization has collected vessel information since the late 1960's. For the South Coast inventory study, we purchased data from the Army Corps for the entire United States, and then sorted out the vessels based in the South Coast. The data we purchased were updated as of March 1, 1993. The vessel data includes horsepower, vessels length, net tonnage, and vessel type. Although more recent data are now available from the Army Corps, this analysis uses the same data which was used in the South Coast inventory study.

Mooring tugs meet oceangoing ships near the breakwater and assist the ships to dock and depart. Typical travel times across the harbor may be from 20 minutes to over an hour depending on where the tug is based and to which gate it is traveling. The docking pilot decides whether or not to request a tug assist and it is fairly rare that tugs are not used. One or two tugs per ship is typical, and three tugs are required for tankers. The tugs are not necessarily maneuvering the ship at all times during a docking event. Sometimes the tugs will only stand by in case they are needed, sometimes they will accompany the ship for a distance before providing assistance. Under conditions of high winds, tugs may be required to hold ships for 4 hours or more. Tugs also provide assistance to ships that are shifting from berth to berth.

Because variability in tug operations made it difficult to construct a representative operating profile (in terms of time spent over the year at various engine loads), the SCAQMD study based tug emissions calculations on annual fuel consumption information provided by Crowley Marine Services and Wilmington Transportation Company. The fuel consumption data was used to calculate an average annual fuel consumption of 29.9 gallons per tug horsepower per year for 1993 operation. The fuel requirements were then projected, based on increases in ship calls, to be an estimated 42.7 gallons per tug horsepower per year in 2010.

In the absence of better information, the fuel consumption rates per horsepower developed for the mooring tugs were also used to characterize the operation of non-mooring tugs in the SCAQMD study. This approach was used because non-mooring tugs are relatively small contributors to the marine inventory and because developing additional operating information for these vessels would have been time-intensive and out of keeping with the scope of the inventory study

Passenger/excursion boats and workboats operating in the San Pedro Bay were characterized in the SCAQMD study based on data from the U.S. Army Corps of Engineers (which gave information on vessel population and horsepower) and on activity estimates for harbor vessels made by Booz Allen & Hamilton in an earlier marine inventory study. The SCAQMD study contains a discussion of this methodology. Table 2-3 shows the population of these vessels operating in the San Pedro Bay as estimated in the SCAQMD study.

2.3.3.2 Fishing Vessels

The SCAQMD inventory study characterized fishing vessel activity in the South Coast waters based on discussions with Department of Fish and Game representatives Mary Larson (commercial fishing) and Kevin Hill (sport fishing).

Commercial fishing vessel activity varies considerably depending on the type of fishing being done. Fishing vessels can be distinguished by gear type (e.g., set gill net) and by fishery (e.g., sea urchin), to indicate how they fish. This is important for the emissions inventory because the amount of time vessels spend cruising, idling, trawling, or drifting varies, both daily and seasonally, with the type of fishing being done. The major gear types used in the South Coast and typical activities are briefly described below based on discussions with Ms. Larson.

Table 2-3. Population of passenger vessels and workboats by horsepower category operating in the South Coast

Vessel Horsepower Category	# Passenger/Excursion (1993 data)	# Workboats (1993 data)
<500	11	12
500-999	2	3
1000-1499	3	4
1500-1999	5	2
2000-2499	3	3
2500-2999	0	0
3000-3499	2	2
3500-3999	1	1
4000-4499	1	0
4500-5499	0	0
5500-6499	0	0
6500-7499	0	1
- Totals	28	28

Drift Gill Net

Used for shark and swordfish. Typical operation is to travel to an offshore location, set a net, drift all night, and pull in the catch in the morning. Drift gill net fishing must be done a minimum of 6 miles offshore. Certain areas are restricted for certain dates. Drift gill nets cannot be used to take shark or swordfish from February 1 through April 30. From May 1 through August 14, they may not be used within 75 nautical miles of the California coast. From December 15 through January 31, they cannot be used within 25 miles of the California coast. During the May through August period, a drift gill net fishing vessel will typically go out for 10 to 14 days at a time, anchoring up at the nearest island during the daytime when not fishing. During other times in the year the vessels may go out and come in daily (when fishing close to shore) or may go out for multiple day trips.

Set Gill Net

Used for halibut, seabass, barracuda, and others. Typical operation is to travel 3 to 5 miles offshore, set the nets and go out every two or three days to pull in the catch. It takes approximately 10 hours at idle to pull in the nets. Set gill net fishing occurs all year round.

Purse Seine (round haul net)

Used for tuna, sardines, mackerel, anchovies, squid. Typical operation is to encircle schools with net and pull them in. Considerable time spent searching for schools at a higher rpm; once a school is located the boat idles for the 3 to 5 hours it takes to bring the catch on board. Generally fish at night when schools are close to the surface leaving in the late afternoon and returning between 8 pm and 11 am.

Trawling

Used for sea cucumbers, spot prawns, pink shrimp. Typically travel to their preferred location, put the trawl gear overboard and trawl at 2 to 3 knots and about 25 to 30 percent full power for 20 minutes to a few hours and then go into idle and pull in the catch. Locations are usually just outside the 3-mile limit. Pulling the catch onboard typically takes 30 minutes to one hour. These vessels go out daily, year-round. They usually leave after 7 pm and return with their catch around 10 in the morning.

Trapping

Used for spiney lobster (winter), spot prawn (spring, summer, fall). Typically out 12 to 16 hours per day, seven days per week, weather permitting. Travel to location, set strings in the evening and come back in the morning to pull strings (traps strung together — 25 or 30 are connected in a "string"), take in the catch, and re-bait the strings. About 11 hours per day might be spent at the strings, the rest traveling to, from, and between strings. Engine at idle or low rpm when pulling in and setting traps.

Rakes, airlifts

Used for sea urchins. Sea urchins may be harvested year-round, at times 7 days per week, but in the summertime only 2 to 4 days per week (depending on the month) are open. The vessels travel to a location which may be very close to the coast (urchins are found at depths of 10 to 60 feet) or may be near an offshore island such as San Clemente, and turn off the engines. Divers go down and use rakes to harvest the urchins and then airlift them up to the boat (using a small auxiliary gasoline engine to power the lift). There may be short trips between diving spots during the day and the boats working around the offshore islands typically make a short trip each evening to where they anchor at night.

Others (very few vessels)

- Abalone diving
- Harpoon (swordfish)
- Long lines
- Hook and line
- Kelp harvesting

This information was used in the SCAQMD study to characterize fishing vessel activity in terms of hours spent each day in four modes: 80 percent power (traveling at about 10 knots), 25 percent power (trawling or maneuvering within the harbor), idle, and drifting (no propulsion engines) based on typical operation on a summertime day. The study (which provides more detail) estimates a commercial fleet composition-weighted average of 3.0 hours per day per vessel at 80 percent power, 3.3 hours per day per vessel at idle, and 1.1 hour per day at 25 percent power for a summertime day.

Commercial Passenger Fishing Vessels (CPFV or sport fishing vessels) activity data were developed in the SCAQMD study based on data provided by the Kevin Hill of the CPFV unit of the Department of Fish and Game. The study estimates a CPFV fleet composition-weighted average of 0.8 hours per day per vessel at 80 percent power, 1.4 hours per day per vessel at idle, and 1.0 hour per day at 25 percent power for a typical day.

2.4 EMISSIONS INVENTORY SUMMARY

The SCAQMD inventory study estimated that marine vessels contributed about 41 tons per day of NO_x to the South Coast NO_x inventory in 1993 and would contribute about 53 tons per day of NO_x in 2010, in the absence of new regulations or programs (such as those evaluated in this study) to reduce emissions from the marine sector. Most of these emissions are from the oceangoing vessels that call on the San Pedro Bay Ports. Other categories of marine vessels that contribute substantially to the marine inventory include fishing vessels, tugboats, and oceangoing vessels that pass through South Coast waters without calling on the San Pedro Bay Ports ("transiting vessels"). Table 2-4 shows the NO_x results for each of these categories for the inventory study years, 1990, 1993, 2000, and 2010. Table 2-5 shows a further breakdown (for 2010) of the emissions of oceangoing vessels calling on the San Pedro Bay Ports.

Table 2-4. NO_x planning inventory for marine vessels in the South Coast (NO_x tpd)

Vessel Category	1990	1993	2000	2010
Oceangoing, San Pedro Bay Ports	28.1	24.0	26.8	34.7
El Segundo traffic	0.5	0.5	0.5	0.5
Transiting vessels	5.7	5.7	5.7	5.7
Tugboats (harbor)	1.7	1.4	1.5	1.9
Tugboats (oceangoing)	0.4	0.2	0.4	0.4
Harbor vessels	2.1	2.1	2.1	2.1
Fishing vessels	6.3	6.3	6.3	6.3
U.S. Navy	0.1	0.1	0.1	0.1
U.S. Coast Guard	0.8	0.8	0.8	0.8
Totals	45.7	41.1	44.2	52.5

Table 2-5. NO_x planning inventory for oceangoing vessels calling on the San Pedro Bay Ports — 2010

	Cruise	P-Area Cruise	Maneuvering	Hotelling	Totals
Main engine/boiler	15.8	1.2	1.5	0.5	19.0
Auxiliary engine	1.6		0.9	12.1	14.6
Auxiliary boiler	—	—	0.0	1.0	1.0
Totals	18.6		2.4	13.6	34.6

3. EMISSIONS REDUCTIONS EXPECTED FROM OCEANGOING VESSELS IN THE SOUTH COAST DUE TO INTERNATIONAL MARITIME ORGANIZATION (IMO) STANDARDS

3.1 INTRODUCTION

The first emission control strategy evaluated in this report is the new NO_x emission limits recently finalized at the International Maritime Organization (IMO). This Section uses the information presented in Section 2 and the SCAQMD inventory model together with the results of the Lloyd's Marine Exhaust Emissions Research Programme to estimate the impact of these new emission limits on the South Coast Air Basin.

3.2 IMO EMISSION LIMITS

On September 26, 1997, the IMO adopted a new Annex VI, Air Pollution, to the International Convention for the Prevention of Pollution from Ships (MARPOL 73/78). This Annex contains regulations addressing NO_x emissions from diesel engines, the sulfur content of fuel, CFCs and HFCs, and VOCs from tanker operations, and emissions from shipboard incineration. The NO_x requirements, contained in Regulation 13, will apply to any new diesel engine, propulsion or auxiliary, greater than 130 kW installed on a vessel constructed on or after January 1, 2000. While the provisions of the Annex are intended to cover ships operated anywhere in the world, a provision in Regulation 13 allows a country to set different emission limits for engines installed on vessels that operate domestically. Table 3-1 sets out the IMO NO_x emission limits.

Table 3-1. Proposed IMO standards for NO_x emissions from ship engines (for ships constructed on or after January 1, 2000)

Engine Speed, n	NO_x (g/kW-hr)	NO_x (g/bhp-hr)
n < 130	17	12.7
130 < n < 2000	$45*n^{-.2}$	12.7 to 7.3
n = 2000 +	9.8	7.3

In general, the provisions of Annex VI will not be enforceable until the Annex goes into effect, i.e., after a certain number of countries sign and ratify it. However, an interesting feature of Regulation 13 is that the date on which the program goes into effect is independent of the entry into force of the Annex. In other words, engines installed on vessels that are built on or after January 1, 2000 must comply regardless of whether the required number of countries have ratified the Annex by that date. Because of this feature, it is expected that engines on new ships will comply with the requirements. Consequently, this study assumes that all new ships built on or after January 1, 2000, are fitted with IMO-compliant engines.

The *Draft Technical Code on Emission of Nitrogen Oxides from Marine Diesel Engines* (NO_x Technical Code), which accompanies the proposed IMO standards, specifies that main engines shall verify compliance with the standards over either the E2 or E3 test cycle. The E2 cycle applies to constant speed propulsion engines and the E3 cycle applies to propeller law-operated propulsion engines. These cycles are 4-mode, steady state cycles. The modes for both cycles are 100, 75, 50, and 25 percent MCR. The emissions in each mode are weighted identically for both cycles, with the weighting shown in Table 3-2. The difference between the two cycles is the percent rated speed associated with the percent rated power in each mode.

Table 3-2. Test cycles E2 and E3 — engine load and weighting factor for each of four steady-state test modes

Power (% MCR)		100	75	50	25
Speed (% Rated)	E2	100	100	100	100
	E3	100	75	50	25
Weighting Factor		0.2	0.5	0.15	0.15

3.3 LLOYD'S MARINE EXHAUST EMISSIONS RESEARCH PROGRAM

To estimate the emissions benefits of the IMO NO_x emission limits, it is necessary to estimate ship emission levels that would occur absent IMO requirements. This study relies on research performed by Lloyd's Register of Shipping (Lloyd's) to evaluate emission rates of slow and medium speed marine propulsion engines.

Beginning in 1989, and largely in response to early IMO discussions of controlling air emissions from ships, Lloyd's conducted a Marine Exhaust Emissions Research Programme to evaluate the environmental impact of emissions from ships. Prior to the Lloyd's Research Programme, little information was available on emissions rates from ship engines and most of the data available was from test bed engine trials which might not have given an accurate picture of emission rates of ships at sea. The Lloyd's Research Programme was intended to provide needed data to inform the development of marine emissions control programs such as the IMO standards. (Lloyd's 1995). As part of the Programme, Lloyd's conducted emissions tests on a variety of ship engines under a range of load conditions.

More specifically, Lloyd's conducted steady state emissions trials on about 60 engines in 50 ships, and transient emissions trials on 8 engines in 8 ships. Steady state testing for particulate emissions was also conducted on 6 engines in 6 vessels. Engines tested included both medium speed (all but one 4-stroke) and slow-speed (2-stroke) technologies and, although most engines tested were main propulsion engines, a few generator-set engines were tested, as well. The smallest engine tested was a 364 kW (488 hp) engine in a dredger and the largest were two 21,634 kW (29,000 hp) engines in two container vessels. Table 3-3, taken from the 1995 Lloyd's report, lists the ships and engines tested in the steady-state test phase (data was published for 48 engines in 40 ships). Note that, although Lloyd's grouped the tug engines with all other medium-speed engines in their analysis, we did not include the tug emission trials in the data used to characterize the emissions of medium speed ocean-going vessels because tug emissions are evaluated separately from ocean-going vessels in the SCAQMD inventory study and in this study. A series of reports published by Lloyd's (Lloyd's 1990; 1993; 1995) provide a more detailed description of the Research Programme, and a discussion of sampling and analytical procedures.

Lloyd's published test parameters and results of the emissions trials (Lloyd's 1995; Lloyd's 1990). Exhibit 3-1 shows a sample of the data that was published for the emissions trials for one engine. In addition to this detailed information, Lloyd's also published line graphs of emissions rates (kg emissions / tonne fuel consumed) with each line representing one engine at a variety of speeds and loads, and average emission factors at 85 percent MCR operation for the slow speed and medium speed engines tested.

Based on the results of the emission tests, Lloyd's estimated average NO_x emission factors of 17 and 12 g/kWh (87 and 57 kg/tonne fuel) for slow speed and medium speed engines, respectively (Lloyd's 1995). These emission factors were used in the SCAQMD inventory study. However, evaluation of the benefits of the IMO NO_x emission limits required a somewhat more sophisticated use of the Lloyd's data. Section 3.4 explains how the Lloyd's data was used in this analysis.

3.4 METHODOLOGY FOR MAIN ENGINES

3.4.1 Developing NO_x Emissions Rates from Lloyd's Data

The first step in assessing ship emissions was to use the published data from Lloyd's Research Programme to calculate NO_x emission rates in g/kWh for each emissions trial[8]. Emissions calculations were performed in accordance with the NO_x Technical Code using a

[8]The Lloyd's reports contain detailed emissions trial data as were shown in Exhibit 3-1, average emission factors at 85% MCR, and line graphs of kg emissions per tonne fuel burned. The detailed data are "raw data" and do not show calculated emission rate results. Further, the line graphs did not identify the engine corresponding to each line. Emission rates in kg/kWh (or kg/tonne fuel) for each engine tested and at each test load condition were not published and were not readily available from Lloyd's Register as the materials associated with the test program had been archived and the key technical staff person who had performed the original calculations was no longer with the company. Therefore, it was necessary for us to calculate NO_x emission rates from the raw data so that the data could be used fully.

Table 3-3. Steady-state emission trials: vessels monitored

Vessel Code	Ship Type	Launch Date	Engine Type	Engine Duty	Max. MCR (kW)
B6	Bulk carrier	1987	SS	Main	14,123
CT1	Container	1980	SS	Main	21,634
CT2	Container	1977	SS	Main	21,634
R8	RORO ferry	1980	2 x SS	Main	6,510
R9	RORO ferry	1980	2 x SS	Main	6,606
TK6	Tanker	1970	SS	Main	5,296
TK7	Tanker	1974	SS	Main	6,914
TK8	Tanker	1971	SS	Main	18,389
TK9	Tanker	1977	SS	Main	20,081
B1	Bulk carrier	1979	MS	Main	1,346
B2	Bulk carrier	1983	MS	Main	886
B3	Bulk carrier	1975	MS	Main	736
B4	Bulk carrier	1986	MS	Main	4,355
B5	Bulk carrier	1986	MS	Main	4,355
CT1	Container	1980	MS	Generator	960
D1	Dredger	1975	MS	Main	3,531
D2	Dredger	1969	MS	Main	1,640
D3	Dredger	1963	MS	Main	364
D4	Dredger	1969	MS	Main	861
D5	Dredger	1974	MS	Main	1,725
D6	Dredger	1971	MS	Main	971
R1	RORO ferry	1974	2 x MS	Main	3,371
R2	RORO ferry	1987	2 x MS	Main	7,698
R3	RORO ferry	1978	2 x MS	Main	5,737
R4	RORO ferry	1978	MS	Main	4,193
R5	RORO ferry	1976	2 x MS	Main	3,371
R6	RORO ferry	1974	MS	Main	3,089
R7	RORO ferry	1987	MS	Generator	1,400
R7	RORO ferry	1987	2 x MS	Main	7,700
TK1	Tanker	1978	MS	Main	912
TK2	Tanker	1967	MS	Main	3,750
TK3	Tanker	1975	MS	Main	4,016
TK4	Tanker	1985	MS	Main	588
TK5	Tanker	1979	MS	Main	912
TG1	Tug	1968	MS	Main	1,350
TG2	Tug	1964	MS	Main	615
TG3	Tug	1969	MS	Main	1,260
TG4	Tug	1985	MS	Main	1,250
TG5	Tug	1965	MS	Main	1,350
TG6	Tug	1989	MS	Main	1,270
TG7	Tug	1969	MS	Main	1,260

MS = Medium speed SS = Slow speed

Ship number: B6	Principal particulars	Engine
	Ship type: bulk carrier	Engine: main
	L.B.P. (m): 277	Engine type: slow speed—2 stroke
	Ship size (dwt): 172810	Max. continuous rating (kW): 14323
	Launched: 1987	Number of cylinders: 6
	Propeller type: FPP	
		Fuel
	Ambient test conditions	Grade : heavy fuel oil
	Air temperature (deg C): 5.0	Density @ 15 deg C (kg/l): 0.974
	Air pressure (mbar): 1037	Viscosity @ 100 deg C (cSt): 19.2
	Humidity (g/kg): 4.2	Viscosity @ 50 deg C (cSt): 140
	Wind speed (knots): 5	Elemental composition (% m/m)
	Weather conditions (Beaufort): 2	Carbon: 88.32
		Hydrogen: 11.22
	Height of swell (m): 1.0	Nitrogen: 0.41
		Sulphur: 1.20

Trial data

Engine Output (kW)	486	1703	2997	3277	10012	11280	11324	12650
Engine Revs (rpm)	27	41	49.5	51	74	77	77.1	80
Fuel Consumption (l/min)	4.79	7.7	10.78	11.81	33.2	37.47	37.65	44.32
Ship Speed Grd. (knots)	4.8	5.8	8.0	7.2	12.0	—	13.4	13.0
NO (ppm)	250	670	910	950	1060	1150	1140	1240
SO_2 (ppm)	40	80	105	115	90	90	80	80
CO (ppm)	10	30	50	60	20	15	20	10
CO_2 (%)	0.3	2.1	3.05	3.3	3.0	3.1	3.1	3.3
O_2 (%)	19.3	16.7	15.1	15.1	15.1	15.4	17.4	17.7
Gaseous hydrocarbons (ppm.C)	54	48	60	66	27	36	24	39
Exhaust temperature at probe (deg C)	156	165	171	161	186	177	183	184

Exhibit 3-1. Lloyd's published data for each engine emission trial

carbon balance methodology[9]. Exhibits B-1 through B-3 in Appendix B show the formulas used and a sample calculation for one engine test. Our results compared very well with Lloyd's results. Specifically, we compared average emissions at 85 percent MCR (see Exhibits B-4 and B-5), the shape of the NO_x emissions (kg/tonne fuel consumed) vs. percent MCR curves, and the results for one engine at one test point for which Lloyd's provided us with a sample of their own analysis.

These calculations yielded NO_x emission rates in g/kWh for several engine loads for each engine tested. However, the test results did not directly indicate emissions in South Coast waters or whether or not the engine tested would meet or exceed the IMO NO_x limits. This was because the test engine loads varied from engine to engine and rarely coincided with the South Coast profile loads or with any of the four modes of the E2 test cycle. Furthermore, the test loads

[9]Data on the temperature of the intercooled air, needed for calculating the humidity correction factor, were not readily available from Lloyd's except for one engine at one test point, and for a few engine tests gaseous hydrocarbon exhaust data were not available. For the temperature of intercooled air, we simply used the temperature we had for the single test point of one engine in all calculations. Where gaseous hydrocarbon data was not available (only a few engines) we assumed gaseous HC emissions of 0, which seemed to give better results, especially at low loads, than the oxygen balance method. Neither of these assumptions had a very large effect on the results.

typically did not cover the entire load range (recall that the E2 cycle covers a range from 25 to 100 percent MCR). Some sort of curve-fitting was necessary in order to use the Lloyd's results to estimate future emissions in the South Coast Air Basin.

Two curve-fitting methods were used which ultimately provided a range of emission reduction estimates. In both cases medium-speed and slow-speed engines were analyzed separately. The first method combined all of the test data[10] into a single scatter plot and fit a linear curve. The second method considered the data on an engine-by-engine basis and interpolated between test data to fill in an estimated emission curve over the load range. These two methods, and their results, are discussed in more detail below.

3.4.2 Engine-Specific Methodology

Engine-Specific Methodology — Overview

This method considered the data on an engine-by-engine basis and interpolated between test data to fill in an estimated emission curve over the load range. The engine-specific method gives rise to a number of issues, which are discussed later in this section, but it has the advantage, compared to the combined data method described in Section 3.4.3, of retaining some of the valuable information developed by Lloyd's on ship-to-ship emissions variation over the load curve. Conceptually, this is important because, although the data for all ships combined yield average results very similar to IMO standards, the data also show that many engines tested would not individually comply with IMO standards. If the non-compliant engines were brought into compliance with the standards, and if the emissions characteristics of the engines already complying did not change, the average emissions would decrease significantly. Of course, there is no guarantee that engine models that might have tested below IMO limits in the past would not be modified to improve performance and thereby become higher emitting, just meeting the IMO requirements. Because of this and other uncertainties, described at the end of this section, the engine-specific methodology is assumed to provide an upper-bound estimate of the emissions reductions that might be achieved by the IMO standards. This overview section summarizes the engine-specific methodology. Subsequent sections provide additional detail.

First, average emission factors in grams of NO_x per kiloWatt hour (g NO_x / kWh) were developed for each of several engine load conditions that reflect vessel operations in the South Coast waters ("profile loads") based on test data from the Lloyd's Marine Exhaust Emissions Research Programme. Two sets of emission factors were developed from the data, one for uncontrolled engines and one for IMO-controlled engines. The IMO-controlled factors reflected

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[10] Based on engineering judgement, six of the emission rates at the test loads (out of 234 total) were not used in the analysis. These were rates which appeared very incongruous compared with the other test results for that engine and were also associated with some oddity in the reported test data. For example, the lowest-load result for the RORO R8, both port and starboard engines, appeared suspicious because they implied the very low NO_x emission rates of 3.4 and 4.6 g/ kWh, respectively. Examination of the data reported by Lloyd's showed that the fuel consumption rates reported for these two load points were extremely low for the engine output power. Because both the reported data and the calculated emission rates appeared questionable, these points were neglected.

the NO_x emission rates expected once IMO standards are fully implemented (that is, at some future time when even the oldest ships in operation were built after the IMO standards went into effect).

Next, to calculate the percentage NO_x reduction in any given calendar year from 2000 through 2010, IMO-controlled emission factors specific to the calendar year were needed. The calendar-year specific factors reflect the mix of ships in operation in the South Coast built before and after January 1, 2000, the date on and after which new ships are required to meet IMO emission limits. An age profile of the ships calling on the San Pedro Bay Ports from the SCAQMD inventory study (see Section 2) was used to estimate the percentage of ships built before and after this date in each calendar year evaluated. These percentages were then applied to the uncontrolled and IMO-controlled emission factors to calculate weighted-average IMO factors specific to the calendar year.

The slow speed and medium speed engine emission factors, both uncontrolled and calendar year IMO factors, still specific by profile load (e.g., 80 percent MCR), were averaged to calculate load-specific factors for the fleet (slow and medium speed combined) under the two scenarios: uncontrolled and calendar-year controlled operation. These load-specific factors were then weighted by the total energy spent by each ship speed type at each engine load to calculate energy-weighted average NO_x emission factors in g/kWh. Characterizations of vessel operations in the South Coast in terms of energy spent at various engine loads were taken from the SCAQMD inventory study. This provided average NO_x emission factors representing the main engine emissions of all ships using the San Pedro Bay Ports in each calendar year from 2000 through 2010 for two scenarios: with and without IMO control.

Energy-weighted average uncontrolled NO_x emission factors were then compared with IMO-controlled results for each calendar year to calculate a percentage NO_x reduction associated with the introduction of the IMO NO_x emission limit. This percentage reduction was then applied to the relevant portion[11] of the NO_x inventory, as estimated in the SCAQMD study, to give an estimated reduction in tons of NO_x per year.

Engine-Specific Methodology — Uncontrolled and IMO-Controlled NO_x Factors

In order to use the engine-specific test data available from Lloyd's to estimate emissions rates over the load range, we used the following methodology for each engine tested. Emission rates at loads in between tested loads were assumed to be best approximated by linearly interpolating between the two nearest test points[12]. For example, for the container ship CT1, the

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[11] The relevant portion of the NO_x inventory for this part of the analysis was total NO_x from oceangoing vessels, main engines (motorships only, not steamships), calling on the ports. Emissions reductions from transiting vessels and from auxiliary engines were evaluated separately (see Sections 3.4.4 and 3.5).

[12] Note that a series of 3 tests on a single engine performed over a 3 month period by Lloyd's in order to investigate the repeatability of test results gave a standard deviation of about 1 percent of the average (average in kg NO_x per tonne fuel) at 25 and 85 percent MCR and about 2 percent of the average at 50 percent MCR. This indicates that the NO_x test results on a particular engine would be expected to be very consistent from test to test over the load range.

emission rate at 75 percent MCR (one of the E2/E3 test loads) was estimated by interpolating between the emissions rates at 49 and 76 percent MCR, two loads tested by Lloyd's. To estimate emissions at loads higher or lower than tested loads, we assumed that the emission rate of the nearest load point was the best indicator. For CT1, for example, the NO_x rate at 100 percent MCR (the highest E2/E3 test point) was assumed to be equal to the NO_x rate at 76 percent MCR, the highest engine load tested for CT1. For two engines, CT1 and the port engine of the RORO, R9, the same load was tested twice with different results. In these cases we used the average of the two results to represent the emissions at that load in the calculations.

Figure 3-1 shows the results for the slow speed container ship, CT1. The diamond-shaped points represent actual test data, while the dashes represent interpolated (and extrapolated) emission rates. Similar graphs for each engine tested are contained in Appendix C.

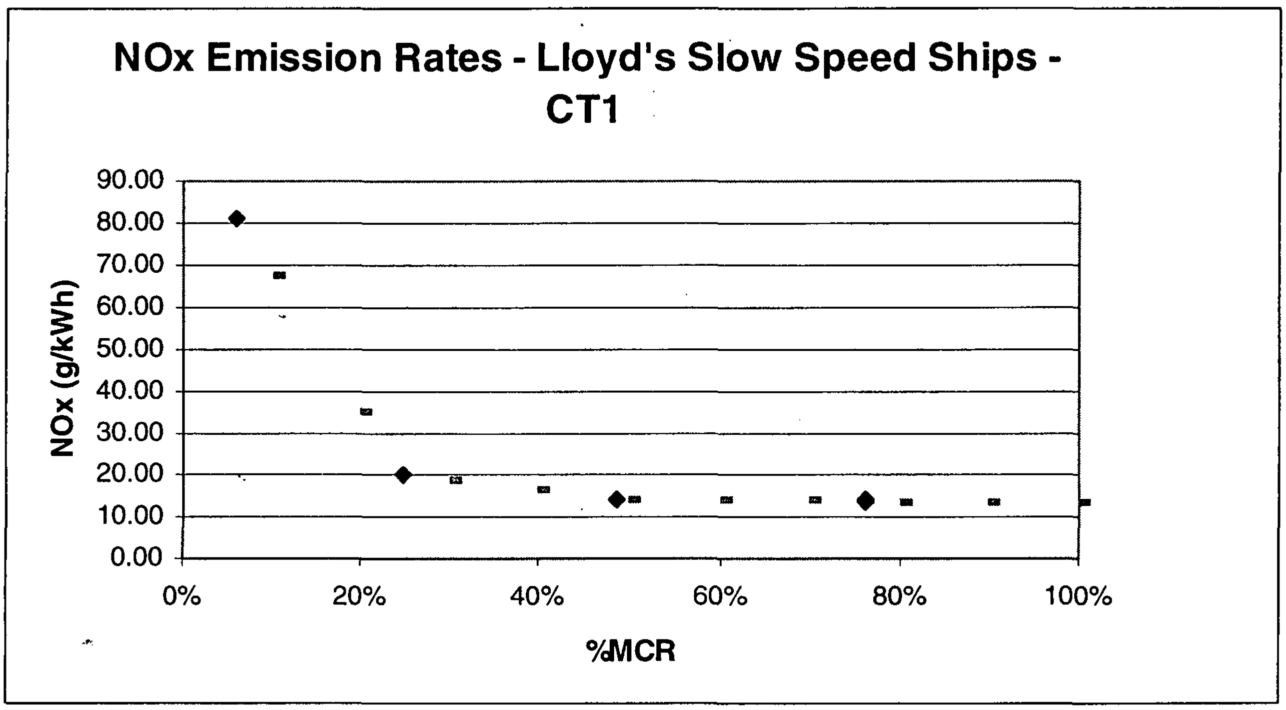

Figure 3-1. NO_x emission rates — Lloyd's slow speed ships — CT1

For each engine, we estimated the following using the methodology described above:

- NO_x g/kWh emission rates at 10, 20, 30, 40, 50, 60, 70, 80, 85, 90, and 100 percent MCR ("point estimates")
- NO_x g/kWh emission rates at each of the E2/E3 test procedure loads: 25, 50, 75, and 100 percent MCR (see Section 3.1)

- The E2/E3-weighted NO_x g/kWh emission rate (see Section 3.1) that determines whether or not an engine is in compliance with the IMO standard[13]

- NO_x g/kWh emission rates at South Coast "profile points": 80, 40, 35, 20, 15, and 10 percent MCR – these engine loads represent a set of engine loads consistent with operating modes assumed in the SCAQMD inventory study

To estimate IMO controlled emissions, the E2/E3-weighted NO_x g/kWh result was compared with the applicable IMO standard for each engine tested (the applicable IMO standard is a function of the rated speed of the engine). Where rated speeds were not available in the Lloyd's data, we estimated them based on the correlation between percent MCR and percent rated speed presented in test cycle E3. For engines that exceeded the IMO standard, we calculated a revised set of NO_x emission rates based on the interpolated curve minus the difference between the E2/E3-weighted rate and the IMO standard (the rationale for and shortcomings of this methodology are discussed later in this section). For example, for the 6,606 kW port main engine of RORO R8 tested by Lloyd's, the E2/E3-weighted NO_x rate was 18.6 g/kWh, exceeding the applicable IMO standard of 17 g/kWh by 1.6 g/kWh. Using a revised emissions curve equal to the original interpolated curve minus 1.6 g/kWh at every point, recalculated NO_x rates are such that the revised E2/E3-weighted NO_x rate equals 17 g/kWh, complying with the IMO standard.

For engines that were higher-emitting than the IMO standards would allow, this method was used to calculate a revised E2/E3-weighted NO_x rate (always equal to the applicable IMO standard) and a revised set of NO_x rates at the "profile points", the percent MCRs characterizing vessel operation in the South Coast waters. These revised points, combined with the unmodified[14] profile points results for compliant engines were used to represent IMO-controlled emissions rates.

The "profile points" (or "profile engine loads") were developed from the inventory model. There are three operating modes for main engines considered in the model: cruise, precautionary area cruise, and maneuvering. The fourth operating mode for oceangoing vessels, hotelling, is not relevant here because main engines are not used for hotelling power (see Section 3.6 for discussion of auxiliary engines). In the model all cruising (full cruise) was assumed to occur at 80 percent MCR. Power requirements for cruising in the precautionary area, where ship speeds are limited to 12 knots, were assumed to vary from shiptype to shiptype based on the ratio between 12 knots and the average speed at full cruise for the shiptype. Engine power required to propel the vessel was assumed to vary with ship speed cubed (a standard assumption which gives a very good first estimate). For example, an autocarrier, with an assumed average cruise speed of

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[13] The E2/E3-weighted emissions rate is calculated consistent with IMO requirements: E2/E3 NO_x = [(0.2 X 1.0 X NO_x@100% MCR) + (0.5 X 0.75 X NO_x@75%MCR) + (0.15 X 0.5 X NO_x@50%MCR) + (0.15 X 0.25 X NO_x@25%MCR)]/0.6875

[14] The interpolated curves and associated emissions rates for compliant engines were not modified, consistent with the assumption that the emissions of engines already cleaner than required by IMO would not increase.

18.3 knots at 80 percent MCR, would be assumed to operate at 22 percent MCR while traveling at 12 knots in the precautionary area. Power required during maneuvering was estimated for each shiptype based on shiptype average speed, typical maneuvering speeds (about 5 knots), and Lloyd's test data which included ship speed at various engine loads. Table 3-4 shows the engine loads (percent MCR) for each operating mode by shiptype as included in the inventory model. For simplicity, engine loads associated with precautionary area cruise in the inventory model were grouped and rounded to the nearest 5 percent MCR for use in this study of the effects of IMO standards. Table 3-5 summarizes the "South Coast profile points."

Table 3-4. Approximate engine loads by shiptype for each operating mode (South Coast, 2010)

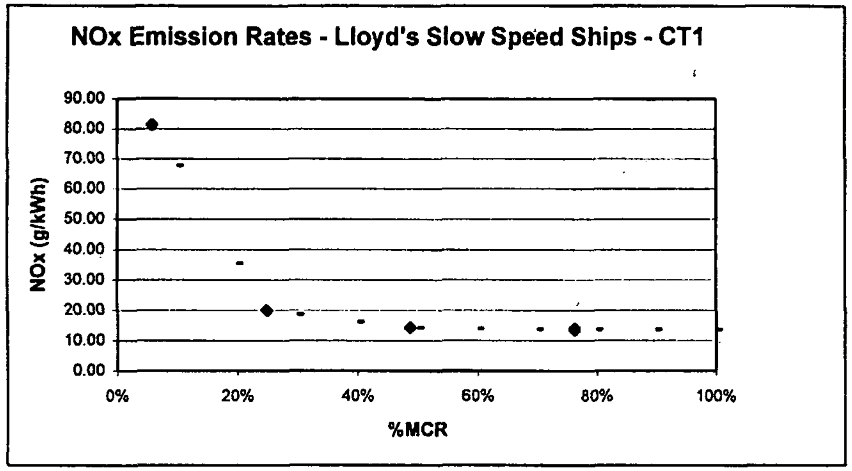
Shiptype	Cruise (%)	Precautionary Area Cruise (%)	Maneuvering (%)
Autocarrier	80	20	15
Bulk	80	40	20
Container	80	10	10
General Cargo	80	35	20
Passenger	80	20	15
Reefer	80	20	15
RORO	80	15	10
Tanker	80	40	20

Table 3-5. Profile points — unique engine loads representing vessels operations in the South Coast

Operating Mode	% MCR
Full Cruise	80
Lower Speed Modes (includes cruising in the precautionary area and maneuvering — % MCR varies by shiptype)	40 35 20 15 10

Appendix C shows all of these calculated emissions rates for each engine tested. Exhibits 3-2 and 3-3, taken from Appendix C, show examples of these calculations. Exhibit 3-2 (ship CT1) shows the calculations for an engine that already complies with IMO standards while Exhibit 3-3 (ship R8-P) shows the calculations for an engine that is higher-emitting that the IMO standard requires.

Exhibit 3-2. Analysis of Lloyd's Data for Ship CT1



Test Information:

	Test % MCR	Test NOx (g/kWh)
	6%	81.33
	25%	19.86
	49%	14.31
test =>	76%	13.96
test =>	76%	13.49
use avg.	76%	13.73

Vessel:	**CT1**	
Type:	Container	
Size:	27630	dwt (tonnes)
Launched:	1980	
Engine:	**main**	
MCR	21634	kW
Test %MCR	76%	
Test RPM	118	
Test % rated RPM	91%	
Propeller:	FPP	
Est. rated RPM	129	

Point Estimates

% MCR	NOx g/kWh
10%	67.71
20%	35.43
30%	18.66
40%	16.32
50%	14.28
60%	14.07
70%	13.86
80%	13.73
90%	13.73
100%	13.73

Profile Points

% MCR	**Uncon.** NOx g/kWh	**IMO** NOx g/kWh
85%	13.73	13.73
80%	13.73	13.73
40%	16.32	16.32
35%	17.49	17.49
20%	35.43	35.43
15%	51.57	51.57
10%	67.71	67.71

E2 Test Procedure

% MCR	NOx g/kWh	Revised NOx
25%	19.86	NA
50%	14.28	NA
75%	13.75	NA
100%	13.73	NA

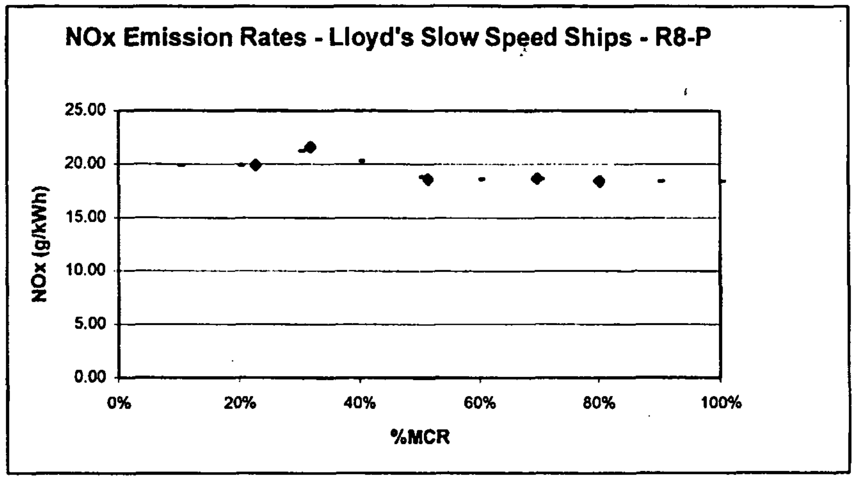
E2 Wghtd NOx g/kWh	Revised E2 NOx
14.13	NA

Applicable IMO std:

17.00	17.00

Comply with IMO?	Revised?
TRUE	NA

Exhibit 3-3. Analysis of Lloyd's Data for Ship R8-P



Point Estimates

% MCR	NOx g/kWh
10%	19.89
20%	19.89
30%	21.24
40%	20.33
50%	18.80
60%	18.61
70%	18.64
80%	18.42
90%	18.42
100%	18.42

Profile Points

	Uncon.	IMO
% MCR	NOx g/kWh	
85%	18.42	16.21
80%	18.42	16.21
40%	20.33	18.11
35%	21.09	18.88
20%	19.89	17.68
15%	19.89	17.68
10%	19.89	17.68

E2 Test Procedure

% MCR	NOx g/kWh	Revised NOx
25%	20.31	18.10
50%	18.80	16.59
75%	18.53	16.32
100%	18.42	16.21

E2 Wghtd NOx g/kWh	Revised E2 NOx
18.62	16.41

Applicable IMO std:

16.41	16.41

Comply with IMO?	Revised?
FALSE	TRUE

Test Information:

Test % MCR	Test NOx (g/kWh)
23%	19.89
32%	21.58
51%	18.58
70%	18.64
80%	18.42

Vessel:	**R8**	
Type:	RORO	
Size:	3855	dwt (tonnes)
Launched:	1980	
Engine:	**Port main**	
MCR	6606	kW
Test %MCR	all	
Test RPM	155	
Propeller:	CPP	
Est. rated RPM	155	

Exhibits B-6 through B-11 in Appendix B summarize the uncontrolled and the IMO-controlled (revised) emission rates at 85 percent MCR and at the profile points for each vessel tested by Lloyd's. The 85 percent uncontrolled rates, as noted in Section 3.4.1, matched the average NO_x results presented by Lloyd's (Lloyd's 1995) of 17 g/kWh and 12 g/kWh for slow speed and medium speed engines, respectively. Based on the methodology described in this section, the IMO-controlled NO_x rates are significantly lower than the average uncontrolled NO_x rates. For example, the average uncontrolled result for slow speed ships at 85 percent MCR of 17.0 g/kWh falls to 15.6 g/kWh with IMO control (see Appendix B). Reductions are obtained at other loads, as well, as reported in Table 3-6.

Table 3-6. NO_x rates (g/kWh) derived from Lloyd's data

South Coast Profile Engine Loads (% MCR)	Slow Speed		Medium Speed	
	Uncontrolled	IMO Controlled	Uncontrolled	IMO Controlled
80	17.06	15.28	12.77	11.56
40	18.26	16.38	13.53	12.33
35	18.14	16.64	13.87	12.67
20	20.94	19.26	16.93	15.73
15	23.94	22.28	20.42	19.22
10	28.89	27.21	25.27	24.06

The next two sections describe how these results were weighted to represent calendar year-specific emission factors at the profile loads and then energy-weighted to calculate final NO_x factors which could be used to estimate total emissions reductions.

Engine-Specific Methodology — Calendar Year NO_x Factors

To estimate the benefits of the IMO standards in each calendar year from 2000 through 2010, it was necessary to estimate how many IMO-compliant ships would be operating in each year. We used the ship age data, which was presented in Figure 2-3, to characterize the percentage of vessel calls in each calendar year that would be made by ships built before and after January 1, 2000 (assuming that ships built after this date would comply with IMO standards.) The age profile shown in Figure 2-3, which reflects actual data for all calls on the San Pedro Bay Ports in 1994, is assumed to apply in any calendar year through 2010. Exhibits B-12 and B-13 in Appendix B show how these percentages were combined with the average uncontrolled and IMO-controlled emission rates to calculate calendar year-specific emission rates for each of the profile engine loads. For example, in the year 2005, Figure 2-3 implies that about 23 percent of the calls will be made by IMO-controlled vessels. To estimate the 2005 NO_x rate at 80 percent MCR, then, 23 percent is multiplied by the IMO-controlled emission rate of 15.4 g/kWh (slow speed vessels) and the result is added to 77 percent times the uncontrolled rate of 17.1 g/kWh to calculate a 2005 rate of 16.7 g/kWh at 80 percent MCR.

Engine-Specific Methodology — Energy-Weighted NO_x Factors

Next, the SCAQMD model was used to calculate the total energy consumed (according to the model) in South Coast waters by oceangoing vessels calling on the Ports in 2010, specific to each engine load in the South Coast operating profile. Energy consumed by medium and slow speed ships (motorships only) was estimated separately (Appendix B, Exhibit B-14)[15]. Table 3-7 shows the energy consumption distribution.

Table 3-7. Annual energy consumption by profile engine load points (2010 inventory distribution)

Profile Loads (%MCR)	Energy MWh per year	% Medium Speed
80	494,592	10
40	13,289	11
35	1,487	11
20	15,152	11
15	7,729	11
10	28,856	11
Total energy, all modes	561,106	

Table 3-8 shows how the emission factor and energy output information is combined to calculate an energy-weighted, final NO_x factor (shown for the calendar year 2010). A NO_x emission factor, the weighted average of the slow speed and medium speed NO_x factors specific to the calendar year, is calculated for each engine load (NO_x g/kWh). The engine-load factors are then combined with the energy consumed in each mode to calculate an energy-weighted, final NO_x factor which represents all operating modes and all main engines in motorships calling on the Ports. This calculation was made using emission factors for each of the calendar years 2000 through 2010, and using uncontrolled and IMO-controlled (full IMO) emission factors[16].

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[15] This estimate was based on the assumed percentage of medium speed versus slow speed ships in each shiptype used in the SCAQMD model. The percentage by shiptype was derived from Lloyd's data for the set of ships that called on the San Pedro Bay Ports in 1993. Data on medium speed versus slow speed ships on a per-call basis was not available.

[16] To simplify calculations, the 2010 energy consumption distribution by engine load was used to represent operations in all calendar years from 2000 through 2010. Although the total energy consumed in the SCAQMD model in each of these calendar varies considerably, the relative distribution of the energy consumption by mode varies only slightly, not enough to affect the results significantly.

Table 3-8 Energy consumption and IMO-controlled NO_x by mode (motorship main engines) — 2010

Profile Loads (%MCR)	MWh per Year	SS NO_x g/kWh	MS NO_x g/kWh	% MS	SS/MS NO_x g/kWh
80	494,592	16.30	12.23	10	15.89
40	13,289	17.41	12.99	11	16.93
35	1,487	17.46	13.33	11	17.00
20	15,152	20.18	16.39	11	19.76
15	7,729	23.20	19.88	11	22.84
10	28,856	28.13	24.72	11	27.76
Total energy, all modes	561,106	MWh-weighted NO_x g/kWh			16.73

Energy-Specific Method — Results for Main Engines

Comparison of the uncontrolled and IMO-controlled, energy-weighted NO_x factors in each calendar year provided an estimated percentage reduction in NO_x that might be expected from IMO standards. For example, in 2010 the energy-weighted NO_x factor assuming IMO control was estimated to be 16.73 g/kWh, as was shown in Table 3-8. Compared to an uncontrolled factor of 17.47 (calculated similarly but using uncontrolled NO_x factors), this implied an expected reduction of the NO_x inventory in 2010 of 4.2 percent. The percentage reduction was then applied to the appropriate portion of the NO_x inventory,[17], taken from the SCAQMD model.

Results are shown in Table 3-9. NO_x reductions due to the IMO standards increase from 0 percent of the emissions from motorship main engines in 2000 to 4 percent of these emissions in 2010. Under full IMO implementation (after 2020), an ultimate reduction of 9 percent is projected. This translates to an estimated reduction in the South Coast Air Basin of 0.8 tpd NO_x in 2010 and an ultimate reduction of 1.7 tpd NO_x (when all ships in operation are IMO-controlled).

[17] The percentage reduction was applied to NO_x from main engines in motorships calling on the ports as estimated in the SCAQMD model. Emission reductions expected from auxiliary engines and from transiting vessels due to IMO standards were estimated separately.

Table 3-9. Summary of results for the engine-specific methodology — IMO NO_x reductions for motorship main engines by year

Calendar Year	Energy-weighted Uncontrolled NO_x (g/kWh)	Energy-weighted Controlled NO_x (g/kWh)	Controlled NO_x Divided by Uncontrolled NO_x	Percentage NO_x Reduction	Applies to SCAQMD NO_x Inventory (tpd)	Reduction from IMO NO_x tpd
2000	17.47	17.43	99.8%	0.2	13.7	0.0
2001	17.47	17.36	99.4%	0.6	14.2	0.1
2002	17.47	17.28	98.9%	1.1	14.6	0.2
2003	17.47	17.22	98.6%	1.4	15.1	0.2
2004	17.47	17.15	98.2%	1.8	15.5	0.3
2005	17.47	17.10	97.9%	2.1	16.0	0.3
2006	17.47	17.02	97.5%	2.5	16.4	0.4
2007	17.47	16.96	97.1%	2.9	16.9	0.5
2008	17.47	16.86	96.5%	3.5	17.3	0.6
2009	17.47	16.81	96.2%	3.8	17.8	0.7
2010	17.47	16.73	95.8%	4.2	18.2	0.8
Full Implementation	17.47	15.83	90.6%	9.4	18.2	1.7

Notes:
1. Uncontrolled and controlled NO_x values are based on the energy consumption by mode in 2010 from the SCAQMD inventory study.
2. Inventory NO_x for main motorship engines is taken from the SCAQMD inventory study for 2000 and 2010. The NO_x inventory in intervening years is filled in by linear interpolation.
3. Reduction under full implementation shown calculated from the 2010 uncontrolled baseline for illustration, even though IMO standards would not be fully rolled into the fleet until after 2020.

Issues With This Methodology

Although this method was designed to use the available emissions test data to the maximum extent reasonable, aspects of this method are non-ideal and require discussion.

First, this method assumes that the set of engines tested by Lloyd's adequately represents the fleet of vessels calling on the San Pedro Bay Ports (the combined data method makes this assumption, as well). In other words, in using all of the Lloyd's test data to develop an average emission rate (at a given operating mode) and using that rate to estimate the benefits of the IMO standard in the South Coast, we implicitly assume that if we had the same emissions data for all of the vessels calling on the San Pedro Bay Ports and calculated an average emission factor from all these data, the average would exactly match the average rate from the (relatively small) set of Lloyd's data. Of course, the averages would not match exactly. To the extent that this assumption is incorrect there will be an associated error in the NO_x reduction estimates. Unfortunately, there is no way to test this assumption.

Another weakness is evident in the graphs shown in Appendix C. Lloyd's data gives actual emissions results at different load points for each engine tested. However, estimates must be made to cover the load range from 10 to 100 percent to cover all of the engine loads of interest for the South Coast profile and the E2 test points. Often the tested load points are clustered, leaving emissions in large segments of the load range to be estimated by linear interpolation, or to be extrapolated as equal to the emissions at the nearest test point. Particularly as it is difficult to predict the shape of the emission versus engine load curves for each engine, based either on physical principles or on comparison with other engines tested (Appendix C shows a wide variety of implied curves), our chosen method of "filling in" the emissions curve may introduce errors. The combined data methodology, discussed in Section 3.4.3, presents an alternative way of using the data to develop emissions estimates over the load range. Other treatments of the data might be devised, as well. We believe the two methods used in this study provide a reasonable range of results.

Another difficulty is that it is not known how the requirement to comply with IMO standards will affect the emissions of marine engines over the load range. For example, a low rpm engine emitting 17 g/kWh across its entire load range would comply with the IMO standard, but so would an engine emitting 17.5 g/kWh at 100 percent MCR, 16 g/kWh at 75 percent MCR, 18 g/kWh at 50 percent MCR, and 18.5 g/kWh at 25 percent MCR. What the emission profile over the load range for an average or typical IMO-compliant engine will look like (or even if there will be a typical IMO-compliant engine) is unknown. So is any "compliance margin" manufacturers might incorporate into their IMO-compliant engine design. That is, engine manufacturers usually design their engines to test slightly under the standard to ensure that the engine will meet the standard and continue to meet the standard in service.

As was described, the engine-specific method addresses these unknowns by assuming (in the absence of better information) that emissions profiles over the load range for each engine tested by Lloyd's remain unchanged as to shape and that the compliance margin is zero (a conservative assumption in the sense that it probably overestimates emissions rates from IMO-compliant engines). If an engine tested by Lloyd's already complied with the IMO standard, its emissions profile was used "as is" to represent that engine under IMO control, including those engines in the Lloyd's data set that proved significantly lower-emitting than IMO would require. As noted above, this is a questionable assumption; it is possible that such engines would, in the future, be redesigned to improve performance and also have new emissions profiles, profiles which just meet IMO standards. If the engine was higher-emitting than the IMO standard would allow, then the amount by which that engine exceeded the IMO standard was subtracted from the entire profile. In other words, the curve was "moved down", its shape unchanged, until it would exactly meet the IMO standard. The revised set of Lloyd's data (where the emissions profiles of those engines exceeding the IMO standard were "moved down" until the engines were exactly in compliance and the emissions profiles of the already-compliant engines were left "as is") was used to represent the emissions of a hypothetical fleet 100 percent compliant with the IMO standards. Other assumptions might be made about how IMO control would affect emissions over the load range. Different assumptions would change the estimated reductions associated with the IMO standard in the South Coast.

3.4.3 Combined Data Methodology

Combined Data Methodology — Analysis

Although the Lloyd's data set is a large one compared to other available ship emissions test data, the set of ships and engines tested is very small compared to the worldwide fleet. The dataset is too small to provide meaningful results by subcategories such as shiptype, ship age, or categories of engine rated power. Another issue with the dataset is that the test loads (percent MCR) vary from test to test, sometimes with quite large gaps between test points. Because the data are limited, a reasonable use of the data is to combine all of the results for all of the engines tested (still treating medium speed and slow speed separately) into a single scatter plot and apply a linear fit to the data. Figures 3-2 through 3-7 show this approach.

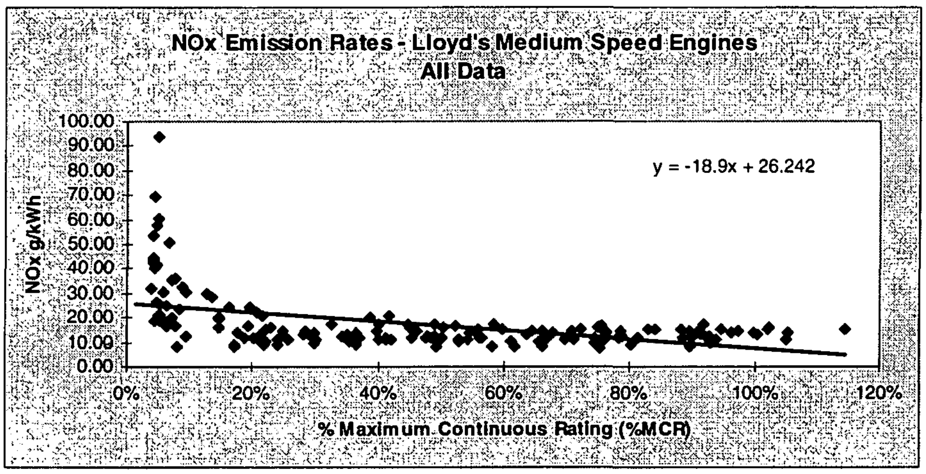

Figure 3-2. NO_x emission rates — Lloyd's medium speed engines — all data

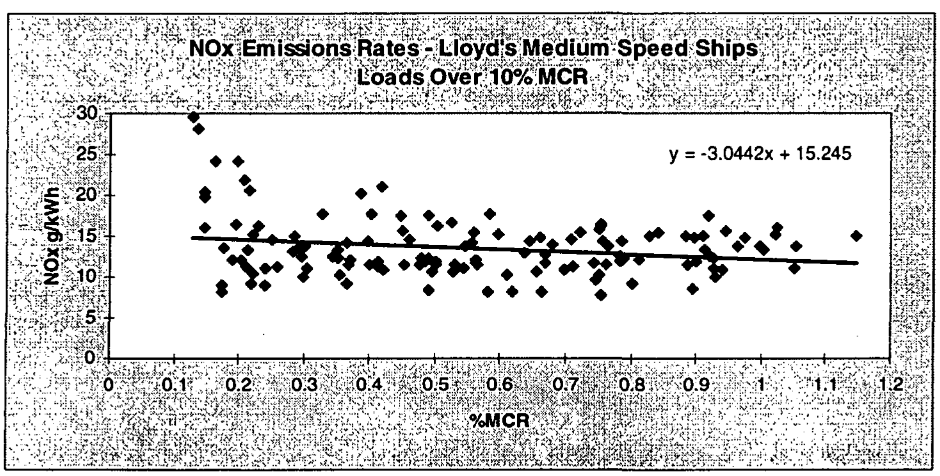

Figure 3-3. NO_x emission rates — Lloyd's medium speed ships loads over 10 percent MCR

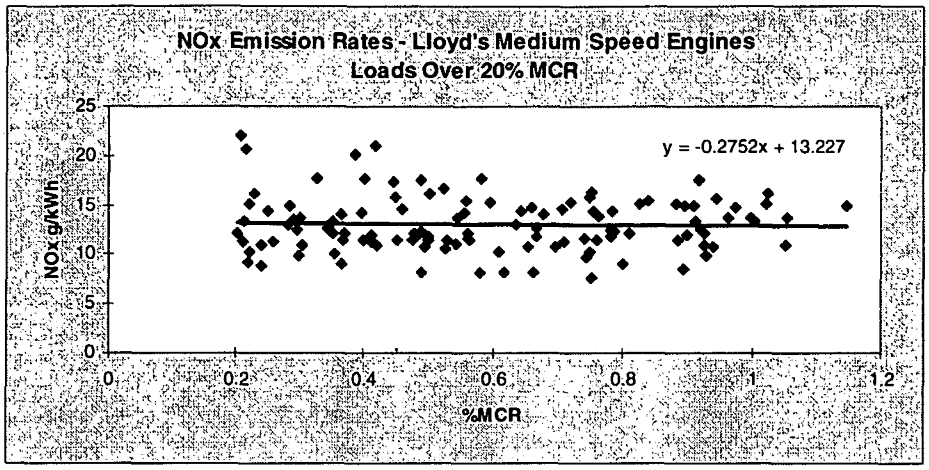

Figure 3-4 NO_x emission rates — Lloyd's medium speed engines loads over 20 percent MCR

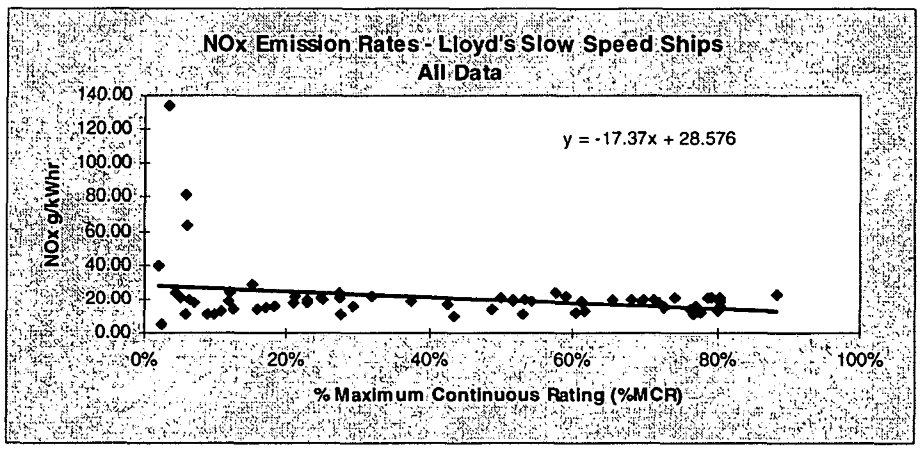

Figure 3-5. NO_x emission rates — Lloyd's slow speed ships — all data

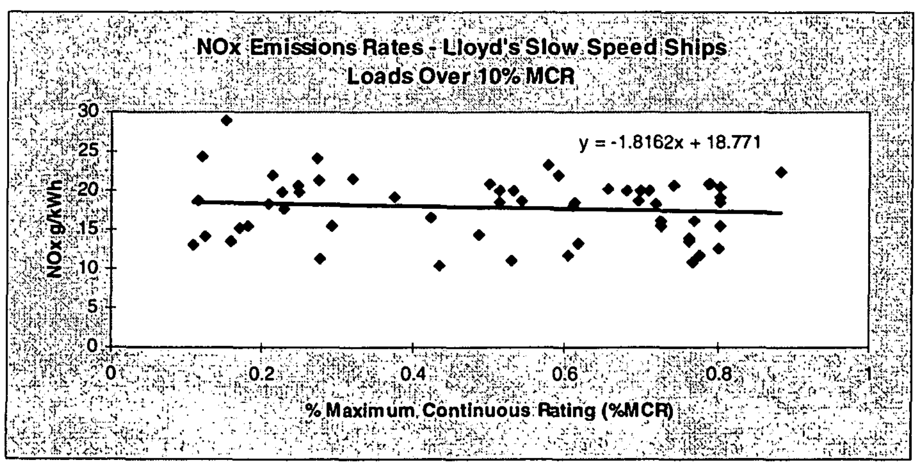

Figure 3-6. NO_x emission rates — Lloyd's slow speed ships loads over 10 percent MCR

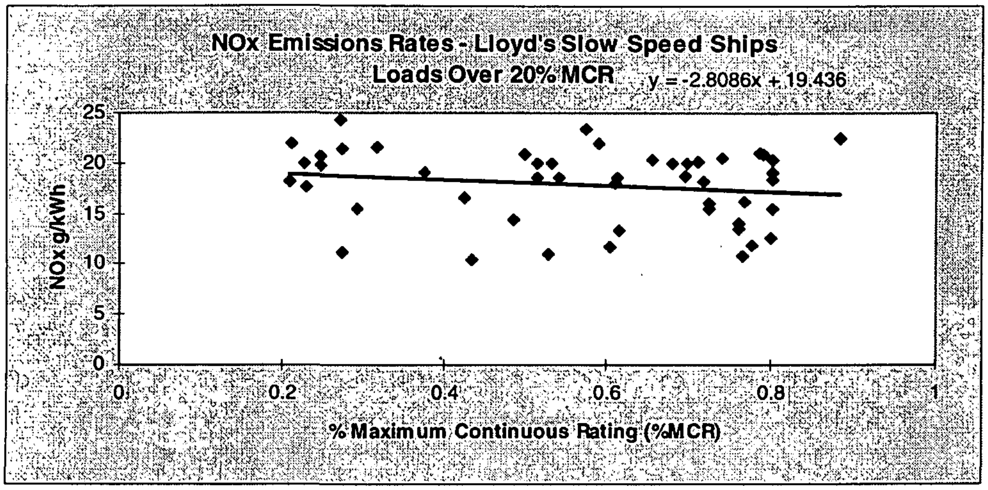

Figure 3-7. NO_x emission rates — Lloyd's slow speed ships loads over 20 percent MCR

Three sets of graphs are shown for each engine speed type. The graphs labeled "All" include all reported test data that appeared reasonable based on both the emission rate result and the raw data reported (see Section 3.4.2), that is, all but 6 points. This data is identical to the data used in the engine-specific methodology. The graphs labeled "10 percent MCR +" exclude all emissions test results under 10 percent MCR. This was done because a number of test results for operation under 10 percent MCR are dramatically higher than emissions rates for higher engine loads. Since relatively little energy is consumed by ships operating at such low loads and since the lowest load included in the E2/E3 test cycle is 25 percent MCR, a curve fit which excludes data at the lowest end of the load spectrum is a simple way of investigating the impact of very low load results and may be a better way of predicting how existing ships would fare on the E2/E3 cycle. Finally, for comparison, graphs are shown including only data for 20 percent MCR and higher for what might be an even better depiction of E2/E3 test cycle results. (Twenty percent MCR is used instead of 25 because for a few ships test results for 20 to just under 25 percent MCR are the best indication of how the ship is emitting at 25 percent MCR, the closest test results over 25 percent MCR being considerable higher.

Table 3-10 shows the E2/E3 results implied by each of the six graphs. The E2/E3 results are lowest for the graphs that include all of the data. This is because the high NO_x data at very low loads result in a steeper negative slope, giving lower NO_x estimates at typical cruise engine loads which are more heavily weighted by the E2/E3 cycle.

In this study, we chose to use the curves fit to the data for 10 percent MCR and higher to estimate emissions reductions. Note that excluding the data for loads below 10 percent MCR does not make results from this method incomparable to results from the engine-specific method. Because the engine-specific method interpolates between available data points, and because for most engines tested data was available at or near the 25 percent MCR load, especially high emission results at less than 10 percent MCR rarely[18] had significant influence on the NO_x estimates at 25 percent MCR, the lowest load included in the E2/E3 cycle.

Table 3-10. E2/E3 results for Figures 3-2 through 3-6

Slow Speed Engines	E2/E3 Results	IMO Standard
All data	15.2	17.0
10 percent + MCR data	17.4	17.0
20 percent + MCR data	17.3	17.0
Medium Speed Engines	**E2/E3 Results**	**IMO Standard**
All data	12.5	12.5
10 percent + MCR data	12.9	12.5
20 percent + MCR data	13.0	12.5

In order to estimate the effect of IMO standards, the "10 percent MCR +" curve fits were adjusted in the same way as the engine-specific curves. That is, the linear fit was "moved down" until the E2/E3 cycle results would equal the IMO standard. For slow speed engines, the 17 g/kWh standard was used. For medium speed engines, the IMO standards implied by the rpm of each engine were averaged and the result (12.5 g/kWh NO_x) was used as the representative IMO standard for the whole set of medium speed engine data. The resulting equations used to characterize emissions under the combined data methodology are shown below:

Uncontrolled:

Slow Speed: NO_x (g/kWh) = -1.8162 X (percent MCR) + 18.77

Medium Speed: NO_x (g/kWh) = -3.0442 X (percent MCR) + 15.245

Controlled (full IMO):

Slow Speed: NO_x (g/kWh) = -1.8162 X (percent MCR) + 18.77 **- 0.38**

Medium Speed: NO_x (g/kWh) = -3.0442 X (percent MCR) + 15.245 **- 0.42**

Emission factors at the South Coast profile loads were calculated using these equations. The uncontrolled and full-IMO controlled factors were then weighted to produce calendar year - specific factors as in the engine specific methodology. And, also as in the engine-specific methodology, the calendar year factors were weighted for medium speed versus slow speed operations and energy-weighted based on annual energy consumption in South Coast waters by approximate engine load. These calculations are shown in Appendix D.

[18] Dredger D1 and tanker TK3 are perhaps the only exceptions (see Appendix C).

Combined Data Methodology — Results

Table 3-11 is analogous to Table 3-9, above, but presents results based on the combined-data methodology rather than the engine-specific methodology.

Table 3-11. Summary of results for the combined data methodology — IMO NO_x reductions for motorship main engines by year

Calendar Year	Energy-weighted Uncontrolled NO_x (g/kWh)	Energy-weighted Controlled NO_x (g/kWh)	Controlled NO_x Divided by Uncontrolled NO_x	Percentage NO_x Reduction	Applies to SCAQMD NO_x Inventory (tpd)	Reduction from IMO NO_x tpd
2000	17.00	16.99	99.9%	0.1	13.7	0.0
2001	17.00	16.98	99.9%	0.1	14.2	0.0
2002	17.00	16.96	99.7%	0.3	14.6	0.0
2003	17.00	16.94	99.7%	0.3	15.1	0.1
2004	17.00	16.93	99.6%	0.4	15.5	0.1
2005	17.00	16.91	99.5%	0.5	16.0	0.1
2006	17.00	16.90	99.4%	0.6	16.4	0.1
2007	17.00	16.88	99.3%	0.7	16.9	0.1
2008	17.00	16.86	99.2%	0.8	17.3	0.1
2009	17.00	16.85	99.1%	0.9	17.8	0.2
2010	17.00	16.83	99.0%	1.0	18.2	0.2
Full IMO	17.00	16.62	97.7%	2.3	18.2	0.4

Figures 3-8 and 3-9 show how the results of the engine-specific and combined-data methodologies compare. The most obvious difference between the two methods is that the engine-specific method gives much higher NO_x emission factors at the low end of the load range. Results are about 60 percent higher for slow speed engines and about 70 percent higher for medium-speed engines at the 10 percent MCR load point. The other key difference is that the engine-specific methodology shows a slightly larger difference between uncontrolled and IMO-controlled NO_x factors than the combined-data method. This is largely due to the assumption in the engine-specific methodology that the engines tested by Lloyd's and shown to be significantly lower-emitting than would be required by the IMO limits are representative as-is. In other words, the method assumes (implicit in the treatment of the Lloyd's data) that some IMO-compliant engines manufactured after January 1, 2000 would emit significantly less than the IMO limits. Such an assumption is not required for the combined-data method which does not consider whether or not individual engines tested by Lloyd's would be IMO-compliant.

The most significant conclusion that can be drawn from Figures 3-8 and 3-9, however, is that over the load range from about 25 or 30 percent MCR to 80 percent MCR the two methods give very similar results. Because most of the energy consumed by marine vessels is associated with higher engine loads, this implies that emissions inventory results will be similar, regardless of which method is used to derive emission factors.

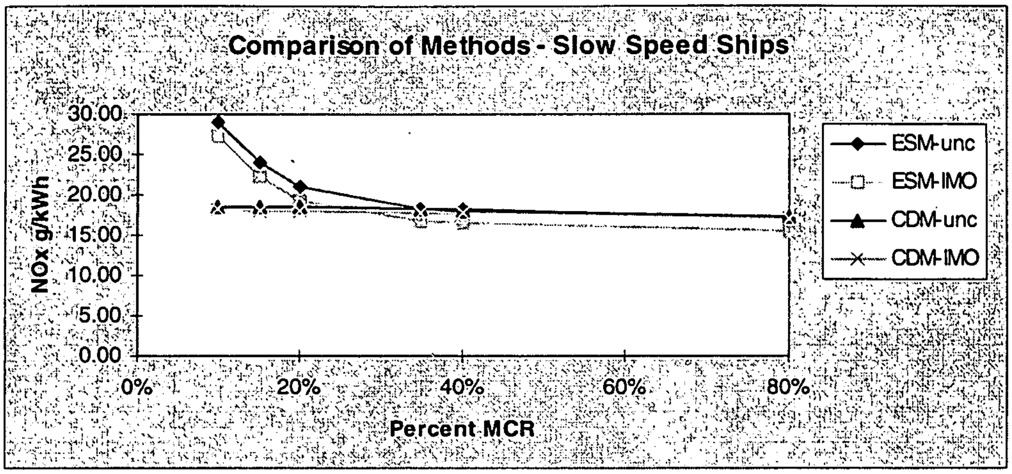

Figure 3-8. Comparison of methods — slow speed ships

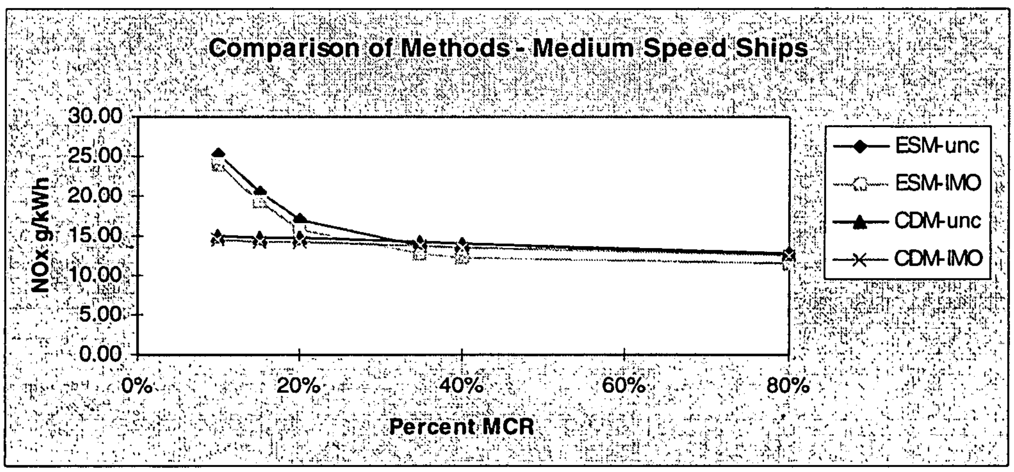

Figure 3-9. Comparison of methods — medium speed ships

3.4.4 Transiting Vessels

The IMO standards will also reduce emissions from oceangoing vessels that pass through South Coast waters without calling on the Ports ("transiting vessels"). As estimated in the SCAQMD study, these vessels contribute 5.7 tpd of NO_x in 2010 as they cruise (at an assumed engine load of 80 percent MCR) through South Coast waters[19]. Comparison of uncontrolled NO_x rates at 80 percent MCR and the 2010-controlled NO_x rates at 80 percent MCR (energy-weighted average of medium and slow speed factors) shows that, for the engine-specific method the controlled rate (15.9 g/kWh) is about 96 percent of the uncontrolled rate (16.6 g/kWh), indicating that a 4 percent NO_x reduction is expected from the main engines of transiting vessels. This

[19] This NO_x estimate includes main engine emissions only. The emissions of auxiliary engines during cruise mode for transiting vessels were neglected in the SCAQMD inventory study.

represents an additional reduction of 0.25 tpd NO_x in 2010. For the combined data method, the estimated reduction is similarly calculated to be 1 percent or about 0.06 tpd NO_x in 2010.

Therefore, the total reduction in NO_x from motorship main engines expected from the IMO standards in 2010 for the engine-specific method equals 0.8 tpd plus 0.3 tpd, for a total of 1.1 tpd NO_x reduced. The total for the combined data method equals 0.2 plus 0.1, a total of 0.3 tpd NO_x reduced. Additional reductions from the effect of IMO standards on the emissions from marine auxiliary engines are estimated in Section 3.5.

3.5 METHODOLOGY AND RESULTS FOR AUXILIARY ENGINES

The methodology used to estimate NO_x reductions from auxiliary engines due to the IMO standard is similar to that used for main engines. Uncontrolled emissions factors are developed from data presented in a 1989 report prepared by TRC Environmental Consultants. TRC reports results from emissions tests of 16 auxiliary engines tested in the San Pedro Bay in 1989. The report tabulates fuel consumption rates, power output, and NO_x emissions for each test. The arithmetic average of the emission rates (in g/kWh) for the engines tested is used to represent the uncontrolled emissions rates of all auxiliary engines operating in South Coast waters in a year. This is consistent with the SCAQMD inventory model which used this same source to characterize auxiliary engine emissions. Table E-1 in Appendix E shows the development of the uncontrolled emission rate.

To estimate average controlled emission factors, we assumed that all IMO-controlled engines would emit at their IMO standard which, for the typical auxiliary engine, is dependent on engine rated speed (see Table 3-1). Therefore, a profile of auxiliary engine rated speed was required. Data that could be used to characterize the rated speeds of auxiliary engines in ships that call on the San Pedro Bay Ports (or anywhere else) was not readily available. No electronic database appears to be available which contains this information. Manufacturer literature showed that marine auxiliary engines are available in a wide range of rated speeds and that rated speed cannot be well-correlated with engine rated power. To characterize auxiliary engine rated speeds, then, we contacted a number of shipping companies whose ships call on the Los Angeles and Long Beach Ports and requested rated speed and horsepower information for their own auxiliary engines. Table E-2 in Appendix E summarizes this information and shows how it was used to calculate a power-weighted, average, IMO-controlled NO_x emission rate. The data for the 268 auxiliary engines (excluding the data received for energy generators) was assumed to adequately represent the larger fleet.

A ship's auxiliary engines are typically rebuilt (to original specifications) over their lifetimes but are not replaced with new models (Reference 11). Thus it can be assumed that the age profile of auxiliary engines in ships calling on the San Pedro Bay Ports is the same as the age profile of the ships themselves. Table E-3 in Appendix E uses the same percentage of ships calling in a given calendar year that will have been built after January 1, 2000 as was used for propulsion engines in Exhibit B-11 and B-12 of Appendix B to calculate calendar year-specific NO_x emission rates for auxiliary engines. The calendar year-specific NO_x factors were then divided by the uncontrolled NO_x rate to calculate a percentage. The uncontrolled NO_x inventory from auxiliary engines for 2000 and 2010 was taken directly from the inventory model and the inventory for 2001 through 2009 was estimated with linear interpolation. The inventory values were multiplied by the percentage to give the IMO-controlled inventory for each calendar year. As Table E-3 in Appendix E shows, IMO standards were estimated to reduce auxiliary engine NO_x by 8 percent in 2010, which translates into a 1.2 tpd reduction.

3.6 SUMMARY OF NO_x REDUCTIONS FROM IMO STANDARDS

Tables 3-12 and 3-13 summarize the NO_x reductions projected due to IMO standards in the South Coast Air Basin. Reductions come from the main and auxiliary engines in ships calling on the San Pedro Bay Ports and from main and auxiliary engines in vessels transiting South Coast waters without calling on a local port. Table 3-12 reflects the engine-specific methodology while Table 3-13 is based on the combined data methodology.

Table 3-12. Summary of Results — NO_x reductions from IMO standards in the South Coast Air Basin - Engine Specific Methodology

Calendar Year	NO_x Reductions in the South Coast Air Basin (tpd)				
	Oceangoing Ships that Call on Ports		Transiting Oceangoing Ships		
	Main Engines	Auxiliary Engines	Main Engines	Auxiliary Engines	Total
2000	0.0	0.0	0.0	negligible	0.0
2001	0.1	0.1	0.0	negligible	0.2
2002	0.2	0.2	0.1	negligible	0.4
2003	0.2	0.3	0.1	negligible	0.6
2004	0.3	0.4	0.1	negligible	0.8
2005	0.4	0.5	0.1	negligible	1.0
2006	0.5	0.6	0.2	negligible	1.2
2007	0.5	0.7	0.2	negligible	1.4
2008	0.6	0.9	0.2	negligible	1.8
2009	0.7	1.0	0.2	negligible	2.0
2010	0.8	1.2	0.3	negligible	2.3

Table 3-13. Summary of Results — NO_x reductions from IMO standards in the South Coast Air Basin — Combined Data Methodology

Calendar Year	NO_x Reductions in the South Coast Air Basin (tpd)				
	Oceangoing Ships that Call on Ports		Transiting Oceangoing Ships		
	Main Engines	Auxiliary Engines	Main Engines	Auxiliary Engines	Total
2000	0.0	0.0	0.0	negligible	0.0
2001	0.0	0.1	0.0	negligible	0.1
2002	0.0	0.2	0.0	negligible	0.2
2003	0.1	0.3	0.0	negligible	0.4
2004	0.1	0.4	0.0	negligible	0.5
2005	0.1	0.5	0.0	negligible	0.6
2006	0.1	0.6	0.0	negligible	0.7
2007	0.1	0.7	0.0	negligible	0.8
2008	0.2	0.9	0.0	negligible	1.1
2009	0.2	1.0	0.0	negligible	1.2
2010	0.4	1.2	0.1	negligible	1.3

4. EMISSIONS REDUCTIONS EXPECTED FROM HARBOR CRAFT AND FISHING VESSELS IN THE SOUTH COAST DUE TO INTERNATIONAL MARITIME ORGANIZATION STANDARDS AND NATIONAL STANDARDS

> IMPORTANT NOTE TO READERS: On December 11, 1998, U.S. EPA proposed new national emission standards for new compression-ignition marine engines rated at or above 37 kilowatts (see 63 Federal Register 68508). Because of budget constraints within EPA, this section of the report has not been updated (from the September 30, 1997 draft) to reflect the recently proposed standards. Despite the differences, the estimated emission reductions are similar. A more accurate estimate of the reductions may be undertaken after EPA finalizes the standards applicable to marine diesel engines.

4.1 EMISSIONS STANDARDS APPLICABLE TO HARBOR CRAFT AND FISHING VESSELS

Section 3.1 discussed current International Maritime Organization (IMO) efforts to limit air pollution from ships. In addition to applying to oceangoing ships engaged in international voyages, the IMO requirements would apply to engines of less than 1600 rpm[20] powering harbor craft and fishing vessels. For engines of 1600 rpm and greater, national emissions standards, different from IMO standards, could be adopted by the EPA provided the engines are used in vessels which do not travel to ports outside of the United States. EPA is considering setting emission standards for these 1600+ rpm marine engines equivalent to the Tier 2 standards that EPA has proposed for engines used in nonroad equipment. This study estimates the NO_x reductions that would be created from harbor craft and fishing vessels assuming that EPA adopts the Tier 2 standards for 1600+ rpm engines and that IMO standards will apply to engines of less than 1600 rpm.

Table 4-1 shows the emissions standards which are assumed for this analysis. The standards proposed for nonroad engines are in terms of non-methane hydrocarbons (NMHC) plus NO_x. EPA staff provided assumptions for the expected NO_x emissions from marine engines meeting the proposed NMHC+NO_x standards. Note that engines in these smaller craft are rated at higher speeds than 130 rpm, so only the IMO NO_x standard for 130 rpm to 1599 rpm applies.

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[20] At the time the draft report was being completed (see Important Note to Readers, above) it was expected that engines under 1600 rpm would not be subject to EPA rulemaking. However, EPA's Notice of Proposed Rulemaking for compression-ignition engines, published in November of 1998, address all marine engines at or above 37 kW that are used domestically, regardless of engine speed.

Table 4-1. NO_x emissions standards which apply to harbor craft and fishing vessels in this analysis

Implementing Agency	Engine rpm	Engine hp	NMHC+NO_x Standard, g/bhp-hr	Implied NO_x, g/bhp-hr	First Year Standard Applies
IMO	130 to 1599	All over 174 hp	NA	$45*n^{-.2}$ g/kWh	2000
EPA	1600+	25-49	5.6	5.0	2004
		50-99	5.6	5.0	2004
		100-174	4.9	4.6	2003
		175-299	4.9	4.6	2003
		300-599	4.8	4.4	2001
		600-749	4.8	4.4	2002
		750+	4.8	4.4	2006

4.2 METHODOLOGY

4.2.1 Introduction

The basic elements of the methodologies used to calculate NO_x reductions from harbor craft and fishing vessels are

- Categorizing propulsion engines within each vessel type based on engine rated power and speed (rpm)
- Identifying the applicable NO_x standard (from Table 4-1) for each category
- Identifying the applicable baseline (uncontrolled) NO_x emission rate from the SCAQMD inventory study for each category
- Characterizing the age profile of the fleet in 2010 (to estimate the percentage of vessels built after emissions standards take effect)
- Combining uncontrolled and emissions standard NO_x rates along with age profiles (specific to the vessel type) to calculate average, controlled NO_x emission rates for each category in 2010
- Calculating annual energy (or fuel) consumption for each category based on the SCAQMD inventory study
- Combining energy (or fuel) consumption for each category with baseline uncontrolled NO_x rates for each category to calculate an energy-weighted average uncontrolled NO_x rate (g/kWh) in 2010

- Combining energy (or fuel) consumption for each category with 2010 controlled NO_x rates to calculate an energy-weighted average controlled NO_x rate in 2010

- Comparing the energy-weighted average controlled and uncontrolled NO_x rates to calculate the NO_x reductions expected in 2010 from IMO and national standards.

Each of these elements is discussed in this section. Appendix E contains the detailed calculations for harbor craft and fishing vessels.

4.2.2 Categorizing propulsion engines based on engine rated power and speed (rpm)

Information on vessel and engine populations by horsepower was obtained from the data sources used in the SCAQMD study and directly from operators of harbor craft in the San Pedro Bay. The principals of the data sources used in the SCAQMD study were the U.S. Army Corps of Engineers (which maintains a database of all domestic vessels by homeport), local tug operators, the Los Angeles/Long Beach Harbor Safety Committee, and the California Department of Fish and Game. More detail on these data sources can be found in the SCAQMD study.

In that study, vessels were categorized by total vessel horsepower as recorded in the various data sources used. The total vessel horsepower may be the total power of two main (propulsion) engines[21], or it may be the power of a single main engine. Auxiliary engine horsepower is usually not included in the vessel horsepower (Castagnola)[22]. For this study, it was necessary to categorize by engine horsepower rather than vessel horsepower. This was not entirely straightforward since the data sources used in the SCAQMD study only record vessel horsepower and do not note how many main engines produce this power. To categorize by engine power we made the following assumptions, based on conversations with and data provided by harbor craft operators (Castagnola, Bolen, McMahon, Rutter, Selga) and examination of the available data sources.

- Assume all tugs, passenger/excursion vessels, and workboats are twin-screw and the engines are of equal rated horsepower (that is, vessel horsepower = 2 times engine horsepower) except assume 1 main engine for:

  — Vessels of less than 600 hp built before 1976

[21] According to local operators, most of the harbor craft operating in the Los Angeles/Long Beach Harbor are twin-screw (2-engine) because of the greater maneuverability offered by twin screw vessels compared with single-engine vessels.

[22] Auxiliary engines in harbor craft and fishing vessels were neglected in the inventory study because they were unlikely to contribute substantially to the inventory and would have been time-intensive to investigate. The one exception is that auxiliary engines were implicitly included for mooring tugs where the emissions inventory was based on annual fuel use (main plus auxiliary diesel engines) per vessel. Auxiliary engines are treated similarly in this study, that is, neglected as not having a significant impact except for their inclusion in tug fuel consumption.

— Vessels for which the total horsepower is an odd number

— Vessels for which operator data shows only one main engine

- Assume all fishing vessels (most of which are under 500 hp) are powered by a single main engine

Average horsepower for each category was also calculated from the SCAQMD study data sources, using the assumptions listed above, and data provided by vessel operators.

Engine rated speeds were estimated for each category based on information from vessel operators in the San Pedro Bay and on manufacturer literature. Tables 4-2 through 4-5 show how engines were categorized by horsepower and the associated engine speed assumption for each vessel type.

Table 4-2. Horsepower and rated speed for tug engines operating in the South Coast

Horsepower Category	Engine Number			Average Rated Power (hp)		Assumed Rated Speed, rpm
	Mooring Tugs	Non-mooring	Total	Mooring Tugs	Non-mooring	
<300	0	4	4		225	1600+
300-599	0	9	9		405	1600+
600-749	5	0	5	620		1600+
749-999	2	2	4	925	825	1000
1000-1499	10	1	11	1130	1005	1000
1500-1999	16	0	16	1708		1000
2000-2499	1	0	1	2150		1000
2500-2999	8	0	8	2500		1000
3000-3499	0	0	0			1000
3500-3999	2	0	2	3500		1000
4000-4499	0	0	0			1000
4500-5499	0	0	0			1000
Totals	44	16	60			

Table 4-3. Horsepower and rated speed for passenger/excursion vessel engines operating in the South Coast

Horsepower Category	Engine Number	Average hp	rpm
0-49	0		1600+
50-99	0		1600+
100-174	3	143	1600+
175-299	3	235	1600+
300-599	22	442	1600+
600-749	0		1600+
750-999	4	850	1600+
1000-1499	6	1115	1600+
1500-1999	8	1683	1600+
2000-2499	2	2000	1600+
Totals	48		

Table 4-4. Horsepower and rated speed for work/crew/supply boat engines operating in the South Coast

Horsepower	Number	Average hp	rpm
<300	4	200	1600+
300-599	30	456	1600+
600-749	4	600	1600+
750-999	4	802	1000
1000-1499	2	1125	1000
1500-1999	2	1700	1000
2000-2499	0		1000
2500-2999	2	2870	1000
3000-3499	0		1000
Totals	48		

Table 4-5. Horsepower and rated speed for fishing boat engines operating in the South Coast

Horsepower Category	Number of Engines			Assumed rpm
	Commercial	CPFV	Total	
0-49	71	2	73	1600+
50-99	35	3	38	1600+
100-174	134	8	142	1600+
175-299	195	25	220	1600+
300-599	167	58	225	1600+
600-749	29	23	52	1600+
750+	14	25	39	1000
Totals	645	144	789	

4.2.3 Identifying the applicable NO_x standard and baseline NO_x rate for each category

The NO_x standards that apply to each engine were shown in Table 4-1. These standards are dependent on engine rated speed and, for 1600+ rpm engines, rated power. Engines built after (or installed in vessels built after, as in the IMO language) the date the standard goes into effect are assumed in this study to emit at NO_x rates equal to the standard[23].

As described in Section 4.1, the standards that would apply to the 1600+ rpm engines are given in terms of NMHC plus NO_x. EPA supplied the assumptions that marine engines that would certify to 5.6, 4.9, and 4.8 g/bhp-hr NMHC+NO_x standards would emit 5.0, 4.6, and 4.4 g/bhp-hr NO_x, respectively. These were the NO_x rates used for certified engines of 1600+ rpm (Table 4-1).

Baseline NO_x emission rates were taken from the SCAQMD study. For all of the harbor craft vessel types and for fishing vessels, the SCAQMD study assumed a baseline (uncontrolled) NO_x emission rate of 12 g/kWh which was the average emission rate for medium speed engines reported by Lloyd's (Lloyd's, 1995). This factor was converted to 419 pounds of NO_x per 1000 gallons of fuel consumed for use in the inventory study, consistent with an assumption of 160 g/hp-hr BSFC and a fuel density (for marine diesel) of 0.9 kg/l (7.5 lb/gal). In this study we use 12 g/kWh as the baseline rate for fishing vessels, workboats, and passenger/excursion vessels and characterize the activity of these vessels in terms of energy consumption (kWh or hp-hr).

[23] It is likely that engines will be designed to emit slightly less than the standard to give manufacturers a "compliance margin". For example, heavy truck engines required to meet a 5 g/bhp-hr NOx standard often emit at levels of 4.7 or 4.8 g/bhp-hr. However, in this study we will make the conservative assumption that certified engines emit at the standard.

Because tug operations were best characterized in terms of annual fuel consumption, we use the 419 lbs/1000 gal figure for tugs.

Average NO_x emission rates in 2010 were calculated as an average of baseline and emissions certified rates, weighted by the percentage of the 2010 fleet expected to have been built after the date the emissions standards take effect. Section 4.2.4 describes how the age profile of the 2010 fleet was characterized.

4.2.4 Fleet age profiles

Because the IMO and national emission standards would take effect between 2000 and 2006, it is critical, for estimating emissions reductions in 2010, to make assumptions about how many new vessels are introduced into operation in the South Coast between 2000 and 2010.

In general, harbor craft and fishing vessels are very long-lived. Engines are maintained and rebuilt and upgraded over the course of the vessel life, but it is very uncommon for an operator to replace an existing engine with a new engine. Therefore for this study the age of the vessel was used as a surrogate for the age of the engine in it. Figures 4-1 through 4-5 show vessel age distributions based on the U.S. Army Corps data (for 1993) and California Department of Fish and Game data.

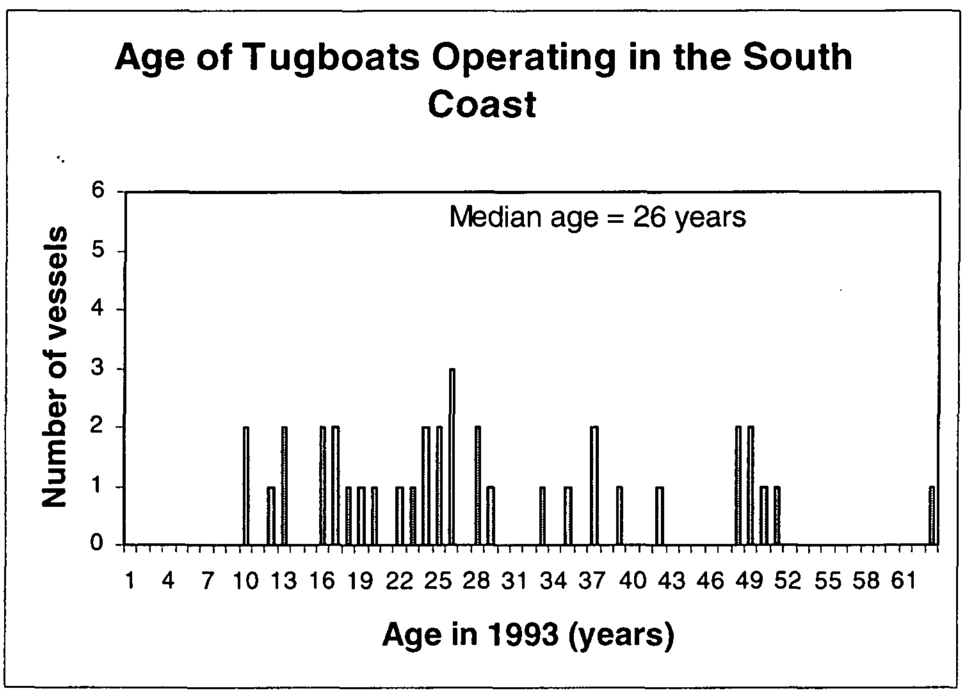

Figure 4-1. Age of tugboats operating in the South Coast

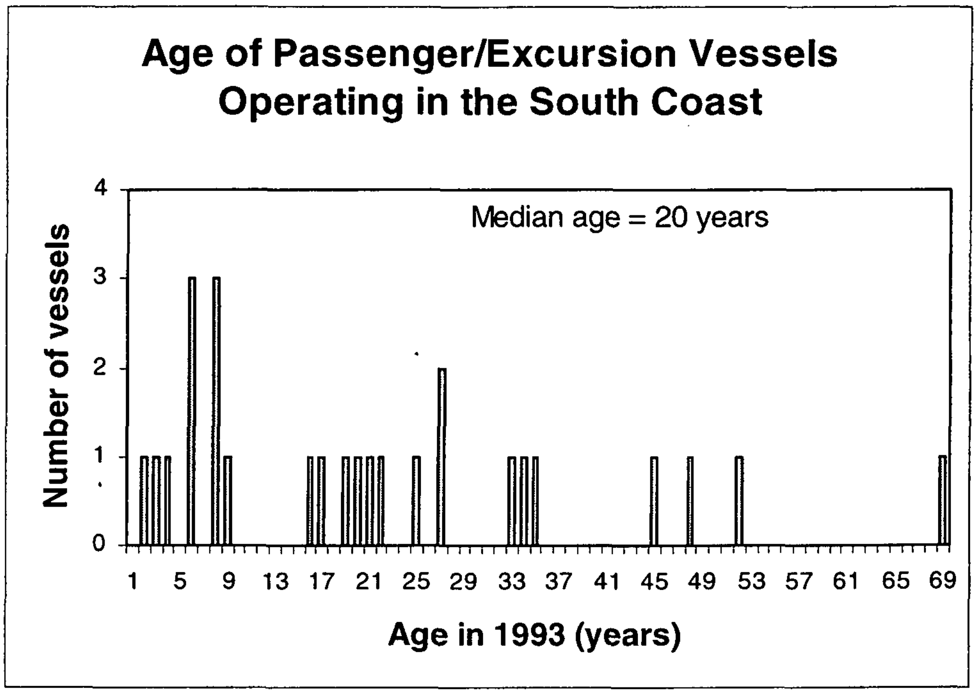

Figure 4-2. Age of passenger/excursion vessels operating in the South Coast

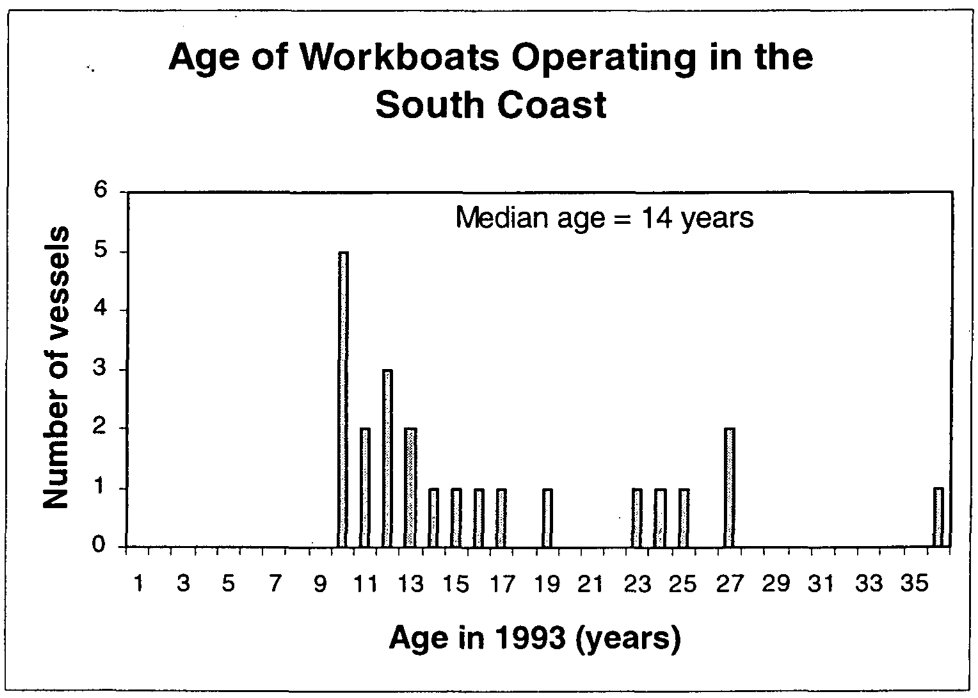

Figure 4-3. Age of workboats operating in the South Coast

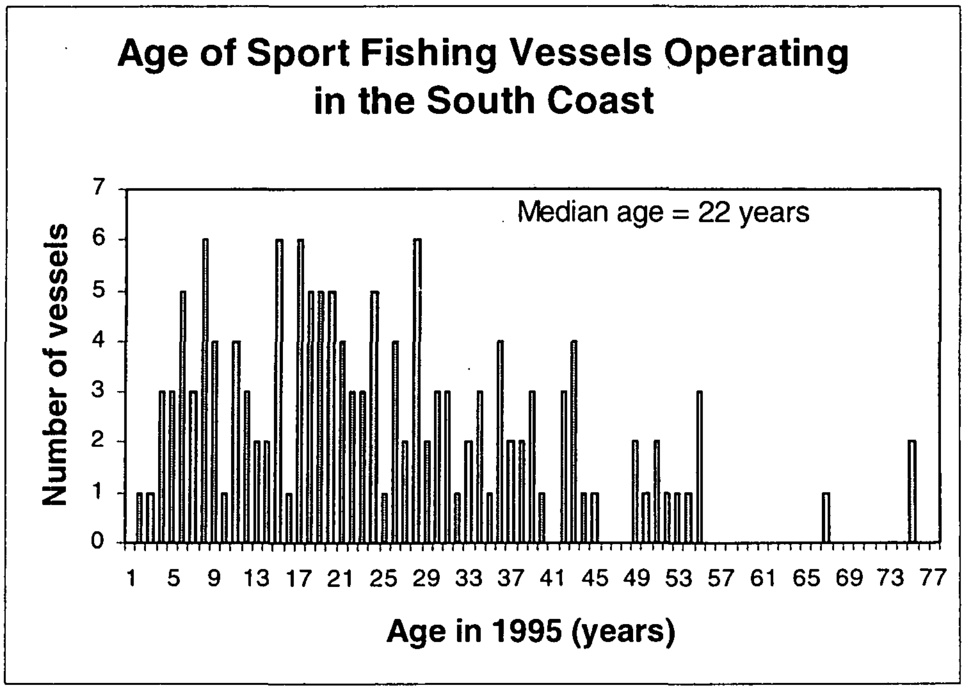

Figure 4-4. Age of sport fishing vessels operating in the South Coast

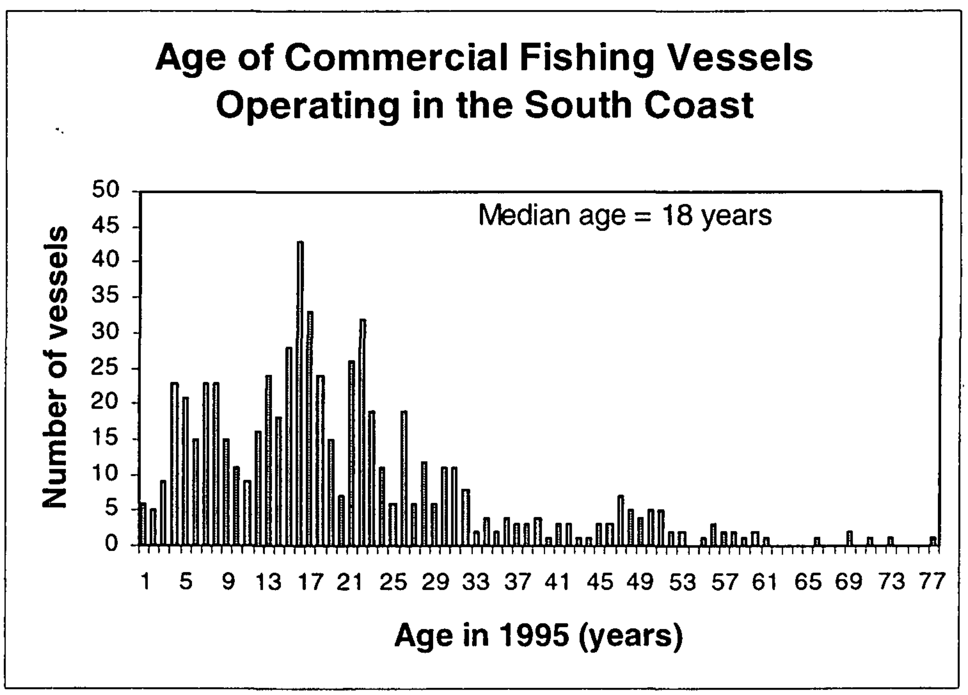

Figure 4-5. Age of commercial fishing vessels operating in the South Coast

Figures 4-1 through 4-5 show that it is difficult to use age data on the current fleet to characterize the age profile of the fleet in 2010. The graphs show no particular trend for vessel population as a function of vessel age, even for the relatively large commercial fishing fleet which comprises almost 700 vessels. As the graphs show, these vessels can be as much as 70+ years old and median ages range from 14 years for workboats to 26 years for tugs, with median age for sport fishing vessels at 22 years, median age for commercial fishing vessels at 18 years and median age for passenger/excursion vessels at 20 years.

Harbor craft operators (Castagnola, Bolen, McMahon, Selga) indicate that it is very difficult to predict how many new vessels might be introduced into operation in San Pedro Bay between 2000 and 2010. Various factors effect how many vessels of what power ratings will be needed and any need for additional (or different) vessels may be supplied by chartering or purchasing existing vessels rather than by ordering new ones. It is possible that as of 2010, no tugs, workboats, or passenger/excursion vessels built after emission standards take effect will be operating in the South Coast. It is also (perhaps equally) possible that many emissions-certified vessels will be operating in the South Coast in 2010. One operator described that some number of new boats were expected to be added through 2010 because the harbor craft fleet operating in San Pedro Bay is aging, and because it is hard to buy used boats right now[24] (Bolen).

Fishing vessels present another modeling difficulty in that much attention is currently being directed toward the depleted state of the world's fish resources from overfishing. Shrinking supplies of fish and government actions to protect fish species may result in few new fishing vessels being added to the South Coast fleet. In other words, the age profile of fishing vessels in 2010 may look much different than the 1995 age profile shown in Figures 4-4 and 4-5.

With these caveats about the inherent difficulties in modeling fleet turnover, we made assumptions based on Figures 4-1 through 4-5, and conversations with industry representatives. All types of harbor craft and fishing vessels were assumed to be adequately represented as having 40-year lifespans, with an equal number of vessels of every age through 40 (and no vessels older than 40 years)[25]. These assumptions make possible a scoping assessment of the benefits of IMO and national standards for harbor craft and fishing vessel emissions. Estimates can be refined as time passes and more information becomes available on the likely age composition of the 2010 fleet.

4.2.5 Annual energy consumption and calculation of NO_x reductions

Annual energy (or fuel) consumption for each vessel category was combined with baseline and certified NO_x emission rates to calculate the NO_x reductions expected in 2010 from the IMO and national standards for harbor craft and fishing vessels. For example (from Appendix E):

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[24] According to Mr. Bolen this is, in part, because increased oil field activity in the Gulf of Mexico has increased the demand for harbor craft in the Gulf.

[25] Note that Figure 4-3 indicates a lifespan of 30 years might be more appropriate for workboats. However, since none of the statements made by vessel operators implied that workboats would have different lifespans than other harbor craft, and since the data set used to create Figure 4-3 is relatively small, we chose to characterize workboats as having a 40-year lifespan, as well.

- 225 fishing vessels powered by 300 to 599 hp engines (assumed to be high speed, 1600+ rpm engines) are modeled to consume in total about 233,000 hp-hr per day of energy.

- For engines of this size a NO_x standard of 4.4 g/bhp-hr[26] applies beginning in 2001, which is much lower than the uncontrolled baseline NO_x rate of 9.0 g/bhp-hr.

- Assuming, as in Section 4.2.4, that the entire fishing fleet turns over in 40 years with vessel age distributed evenly over those years (that is, there are an equal number of vessels of each year of age up to 40 years and no vessels older than 40 years), 25% of the fishing vessels with engines of this size will be emissions-certified in 2010. In other words, 25% of this category of vessels will emit NO_x at 4.4 g/bhp-hr while the rest emit at 9.0 g/bhp-hr.

- This is represented by a composite 2010 NO_x emission rate of

$$(25\%)(4.4 \text{ g/bhp-hr}) + (75\%)(9.0 \text{ g/bhp-hr}) = 7.8 \text{ g/bhp-hr}$$

- Therefore the NO_x reduction from this category of fishing vessels in 2010 can be calculated as

$$(233{,}000 \text{ hp-hr/day})(9.0 \text{ g/bhp-hr} - 7.8 \text{ g/bhp-hr}) / 454 \text{ g/lb} = 616 \text{ lb/day } NO_x \text{ reduced}$$

This type of calculation was performed for all vessel types and horsepower categories. All annual energy or fuel consumption values were taken from the SCAQMD inventory study. For tugboats, annual fuel consumption based on data provided by two of the three operators of mooring tugs in the San Pedro Bay was used to calculate emissions (see Section 2.3.3.1) rather than energy consumption. For workboats and passenger/excursion vessels, the SCAQMD study took activity estimates in terms of time spent at various engine loads directly from an earlier study (Booz-Allen) without modification. From this engine load and time information we calculated, in this study, energy consumption (hp-hr per year) for each engine category for workboats and passenger/excursion vessels. Activity for fishing vessels in the SCAQMD study was based on typical summertime operations of fishing vessels of various gear types (see Section 2.3.3.2). This analysis yielded an estimated average time spent at specific engine loads (80% MCR, 25% MCR, idle, and drifting) which was used in this study to calculate energy consumption (hp-hr per year) for each engine category for fishing vessels. These assumptions and calculations are shown in detail in Appendix E.

[26] This is really an NMHC + NO_x standard of 4.8 g/bhp-hr.

4.3 RESULTS

Results are shown in Table 4-6. Note that reductions from tugs and workboats are projected to be negligible largely because most of these vessels are powered by medium speed engines (under 1600 rpm) which would not fall under national standards. Because IMO standards for these engines are not much lower than the assumed baseline NO_x rate, little reduction is expected.

Table 4-6. Estimated NO_x Reductions from Harbor Craft and Fishing Vessels (South Coast, 2010)

Vessel Type	NO_x Reductions in 2010	
	Percent Reduction	Tons per day
Tugs	98	0.05
Passenger/Excursion	93	0.10
Workboats	93	0.06
Fishing	90	0.57
Total		0.78

This 0.8 ton per day NO_x reduction is significant compared with the reductions projected (in Section 3) to come from oceangoing vessels.

5. SPEED REDUCTION

5.1 INTRODUCTION

Table 2-4, in Section 2, summarized the results of the SCAQMD inventory study. According to these results, oceangoing vessels calling on the San Pedro Bay Ports are the largest source of NO_x emissions generated by marine vessels in the South Coast (nearly 70 percent of the marine NO_x inventory in 2010 comes from these vessels). The inventory model estimates that about half of the emissions of the oceangoing vessels are from propulsion engines and boilers operating in full cruise mode. It is reasonable, therefore, to explore ways to reduce these cruising emissions. IMO emission limits (discussed in Section 3) will reduce cruise emissions to some extent. Additional reductions could be obtained by modifying how vessels are operated in South Coast waters.

Speed reduction is an operational modification that has the potential to provide significant emissions reductions from propulsion engines in vessels calling on the Ports[27]. Reducing ship cruising speeds has two effects. At lower speeds a ship requires more time to travel a given distance, tending to increase emissions over that distance. However, lower speeds also require less power from the engine to move the ship, tending to decrease emissions. The increase in emissions due to increased travel time is less significant (linear with ship speed) than the decreased power requirements (power is approximately proportional to the ship speed, cubed). The net result is that a ship traveling 20 miles[28] at a speed of 20 knots for 1 hour emits more NO_x than the same ship travelling 20 miles at 15 knots for 1.3 hours.

The costs of speed reductions are the costs of losing time while cruising at reduced speeds in South Coast waters. Typically, this lost time would translate into money outside of South Coast waters where the ship would presumably travel faster than its normally scheduled speed to make up for the lost time. The faster speed would mean greater fuel use and, therefore, added cost. (There would also be fuel savings in South Coast waters, because of the lower power requirements, but more fuel would potentially be used in making up for lost time than would be saved while cruising at reduced speed due to the variation of power with ship speed, cubed.)

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[27] In this study we assume that speed reductions could only practically be applied to vessels calling on the San Pedro Bay Ports. It is unlikely that a speed limit could be enforced on vessels passing by the coast without coming in to port.

[28] All references to "miles" refer to nautical miles unless otherwise noted.

This section investigates potential NO_x emissions that might result from reduction in ship cruising speeds in South Coast waters. Emissions reductions [29]are assessed based on a set of possible speed reduction scenarios, defined in this section, which provide a range of estimates. The section concludes with a brief discussion of potential cost impacts associated with such a strategy.

5.2 CURRENT SHIP SPEEDS (BASELINE OPERATION)

In the SCAQMD inventory study vessels were assumed to operate at full cruise, that is, at ship service speed, outside of the precautionary area. Within the precautionary area, ships were assumed to travel at the precautionary area speed limit of 12 knots. Figure 5-1 and Table 5-1, taken from the inventory study, show the routes used to enter and leave the Ports of Los Angeles and Long Beach and the distances traveled over each route. To simplify modeling, the SCAQMD study did not take into account the time and distance over which the ships slow or speed up (ships slow from cruise speed in order to enter the precautionary area at the 12 knot limit and

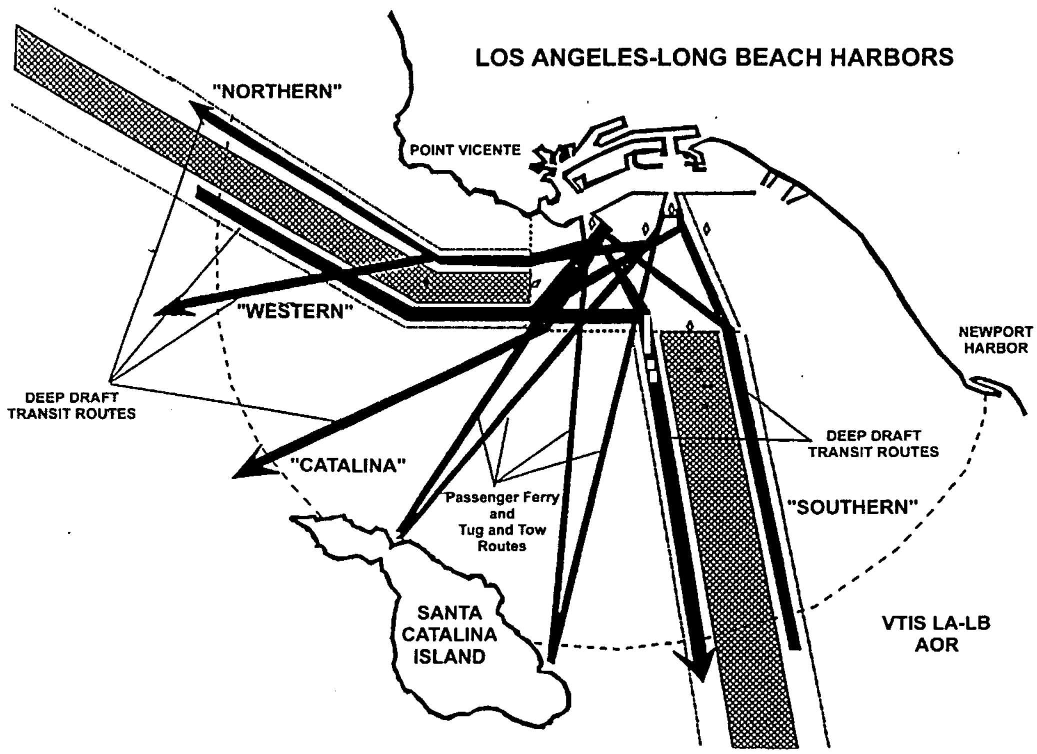

Figure 5-1. VTIS Los Angeles-Long Beach, standard transit routes (provided by the Marine Exchange)

[29] IMPORTANT NOTE TO READERS: Because of new gathered information on the actual speeds of ships, the emission reduction estimates in this report are overestimated, possibly by 15 to 20 percent. This new information came to light as this contract was nearing completion and could not be incorporated into the analysis contained in Section 5. See the discussion near the end of Section 5.2 for more detail.

Table 5-1. Distances (nautical miles) used to characterize cruising in South Coast waters

Inbound Route: South Coast border to Precautionary Area		
North	40	miles
South	34	miles
Western (most tanker)	43.5	miles
Catalina (Honolulu traffic)	66	miles
Inbound Route: Precautionary Area to POLA		
North	4.5	miles
South	7.5	miles
Western (most tanker)	4.5	miles
Catalina (Honolulu traffic)	5	miles
Inbound Route: Precautionary Area to POLB		
North	8	miles
South	6.5	miles
Western (most tanker)	8	miles
Catalina (Honolulu traffic)	8	miles
Outbound Route: South Coast border to Precautionary Area		
North	39	miles
South	38	miles
Western (most tanker)	43.5	miles
Catalina (Honolulu traffic)	66	miles
Outbound Route: Precautionary Area to POLA		
North	3.5	miles
South	6	miles
Western (most tanker)	3.5	miles
Catalina (Honolulu traffic)	5	miles
Outbound Route: Precautionary Area to POLB		
North	6	miles
South	6	miles
Western (most tanker)	6	miles
Catalina (Honolulu traffic)	8	miles

slow further as they approach the breakwater to take on the pilot.) To be consistent with the inventory assumptions, this study continues to use the simplified model that one set of ship speeds applies for the full distance in each speed zone, neglecting the distances over which ships accelerate and decelerate. According to Captain Dick McKenna of the Marine Exchange, ships typically require 1 to 2 miles or roughly 5 minutes to slow from full speed to the precautionary area speed of 12 knots and to slow from 12 knots to approximately 5 to 6 knots to pick up the pilot just outside the breakwater.

As part of the SCAQMD inventory study, data was obtained from Lloyd's Maritime Information Services (LMIS) for 1529 ships, the ships that called on the San Pedro Bay Ports in 1993. Ship service speeds from this data were graphed to show speed profiles for each shiptype (Figures F-1 through F-8 in Appendix F). These profiles show a modest range of speeds within each shiptype. Although the speeds of the slowest and fastest ships within a shiptype differ by as much as 12 knots, most of the ships within a shiptype fall within a narrow, 3 to 4 knot range of cruising speeds. Ship service speeds on a per-call basis were provided to us by the Marine Exchange for all calls on the Ports in 1994[30]. Averaging the ship speeds within each shiptype in the Marine Exchange database gave the following results (Table 5-2)[31]. The 1994 averages were used to characterize ship speeds in 1990, 1993 and, for all shiptypes but containers, 2010. The average speed of container vessels was assumed to increase by 2010 based on analysis by the U.S. Army Corps of Engineers (Chambers, 1992).

Table 5-2. Average ship cruise speeds (knots) by shiptype in 1990 and 2010

Shiptype	1990	2010
Auto Carrier	18.3	18.3
Bulk Carrier	15.1	15.1
Container Ship	21.5	23.4
General Cargo	15.7	15.7
Passenger Ship	19.9	19.9
Reefer	19.7	19.7
RORO	22.0	22.0
Tanker	15.4	15.4

[30] The Marine Exchange receives ship speed data from Lloyd's, so the LMIS and Marine Exchange databases are consistent.

[31] Because Table 5-2 was derived from Marine Exchange (per-call, 1994) data rather than the LMIS (per-ship, 1993) data, the tabulated average service speeds can not be directly compared with the speed profiles shown in Appendix F.

In the SCAQMD inventory study, these service speeds were assumed to be associated with operation at 80 percent of the maximum continuous power rating of the propulsion engines (80 percent MCR).

The draft report for this study assumed baseline average cruising speeds consistent with the SCAQMD inventory study. The service speed was associated with 80 percent MCR operation and with the "cruise" mode as in the SCAQMD inventory.

In November of 1998, however, new information was presented by the Marine Exchange of Los Angeles-Long Beach Harbor showing actual ship speeds for ships cruising in South Coast waters to be somewhat lower, on average, than the service speeds recorded for those ships in the LMIS database. In addition to its electronic database of ship calls which includes both ship activity in the ports and ship characteristics,[32] the Marine Exchange also maintains limited data through their Vessel Traffic Information Services (VTIS) system. The VTIS data includes actual ship speed at a distance of 25 miles from Point Fermin. In late 1998, the Marine Exchange compared actual ship speed data with service speed data from Lloyd's for several ships and concluded that many ships cruise at speeds somewhat below their service speeds in South Coast waters.[33] A more extensive data comparison over 60 days of calls indicated that, on average, ships appear to cruise at approximately 90 percent of service speeds in the South Coast, excepting passenger ships which cruise considerably slower, at about 66 percent of service speed.

Estimating the effect of this new information on the results of the speed reduction analysis is not entirely straightforward. Because ships appear, on average, to cruise below service speed, the baseline inventory can be assumed to overestimate power requirements and emissions. Revised estimates of the potential benefits of speed reduction can best be made in conjunction with a revision of the baseline inventory. Due to EPA budget constraints, it was not possible to perform the more extensive analyses needed to revise the speed reduction estimates in the light of this new information. However, for purposes of rough estimation, we will provisionally assume that the range of emissions reduction results in this section are high by 15 to 20 percent, based on comparing the lower power requirements of the lower actual speeds with the previous assumption that ships cruise at 80 percent MCR. Future revisions to the SCAQMD inventory will take the new actual speed information into consideration.

5.3 RELATIONSHIP BETWEEN SHIP SPEED AND REQUIRED POWER

As described previously, the power required to drive a ship varies approximately with the ship speed, cubed. In other words, if a ship traveling at 20 knots and 80 percent MCR slowed to 15 knots, the speed ratio, cubed, $(15/20)^3 = 0.4219$ also equals the ratio of power required so that the power required at 15 knots would be about 0.4219 X 80 percent MCR. As part of the SCAQMD inventory study, the inventory model was used to estimate emissions reductions under

[32] Because the Marine Exchange obtains their ship characteristic data from Lloyd's, these data are entirely consistent with the data from LMIS used in the SCAQMD inventory study.

[33] The Marine Exchange reports that ship speeds 25 miles out should adequately represent ship cruising speeds within South Coast boundaries.

a few speed reduction scenarios, using the approximation that power varies with ship speed, cubed.

Although the speed cubed (V^3) approximation is well-accepted, in this study we used speed-power curves provided by the Navy and their consultant, John J. McMullen (JJMA) (Osborne; Henderson). JJMA developed these curves from data for commercial ships. One set of curves was developed for tankers and bulk carriers and a separate set was developed for container ships, ROROs, and general cargo ships. Curves were for 100, 75, and 50 percent displacement[34]. These curves are shown in Figures 5-2 and 5-3. According to JJMA, these curves are representative above about 40 of the percent ship service speed (Remley).

Because the inventory study assumed ship service speed to be associated with 80 percent MCR, we adjusted the JJMA 75 percent displacement curve[35] (for which 100 percent service speed operation was associated with nearly 80 percent MCR) so that the 100 percent speed point would coincide with 80 percent power. These are the curves which were used to estimate reduced power (and, therefore, reduced NO_x emissions) at lower ship speeds. The JJMA curves are very similar to the V^3 curve (Figures 5-4 and 5-5).

5.4 SPEED REDUCTION SCENARIOS

Eight scenarios were defined for the purpose of estimating emissions reductions that might result from reduced cruising speeds compared with baseline operation (Table 5-3). The set of scenarios provides a range of potential reductions.

The scenarios were defined in terms of a "reduced speed zone" (RSZ) within which ship speeds would be limited. The reduced speed zone was assumed to begin at a certain distance from the boundary of the precautionary area. The distance was assumed to be the same regardless of the route the ship takes to or from the port, and regardless of whether the ship travels inbound or outbound. This assumption might or might not be consistent with real-life implementation, were a speed reduction program to be established in the San Pedro Bay, but it simplifies the analysis and avoids making more specific assumptions about implementation, which would be premature at this time.

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[34] A more heavily loaded ship (greater percent displacement) travels lower in the water and incurs higher drag forces, requiring more power to drive the ship at a certain speed.

[35] According to JJMA the 75 percent displacement curve was equal to the 50 percent displacement curve plus 2/3 times the difference between the 100 and 50 percent displacement curves. To adjust the 75 percent curve, we changed the 2/3 multiplier slightly (to 2.47/3 and 2.15/3 for tanker and container curves, respectively) so that 100 percent speed implied 80 percent power.

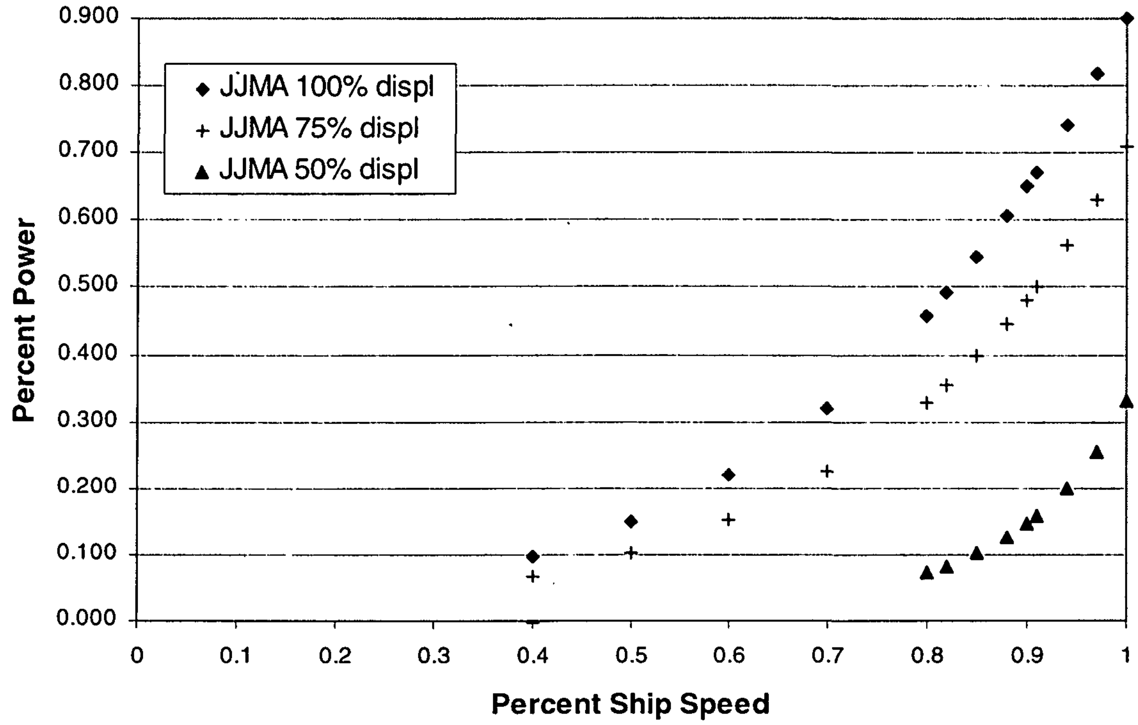

Figure 5-2. Speed-power relationship for tankers and bulk carriers — three displacements

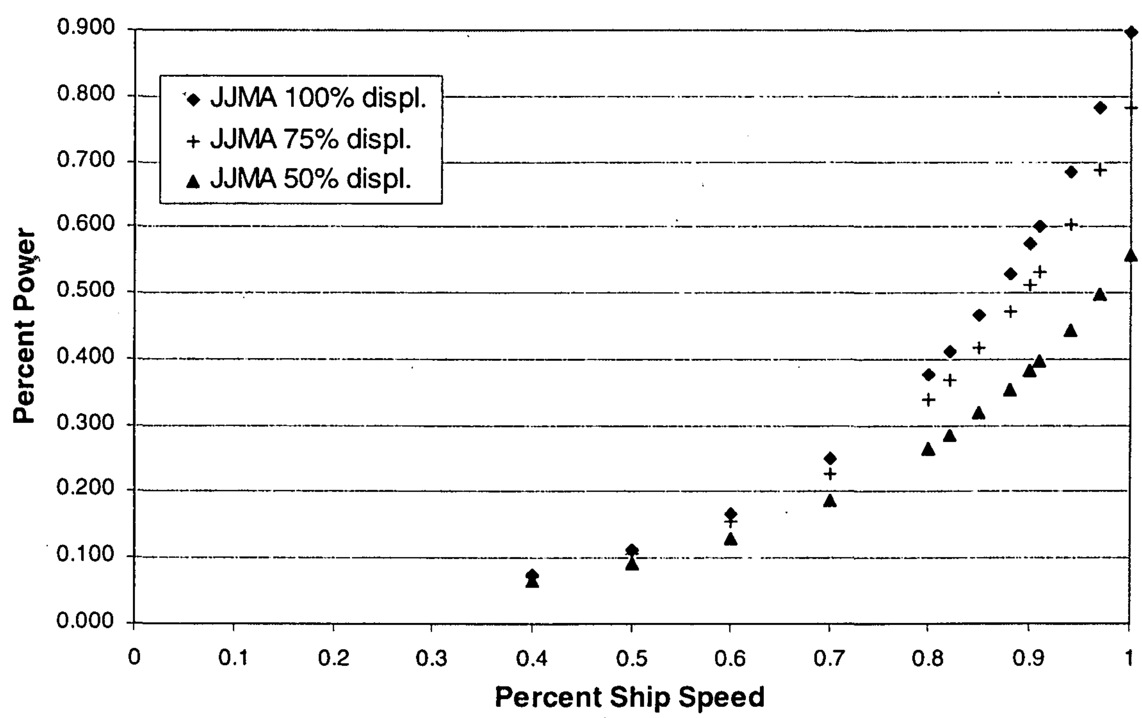

Figure 5-3. Speed power relationship for container, RORO, and general cargo ships — three displacements

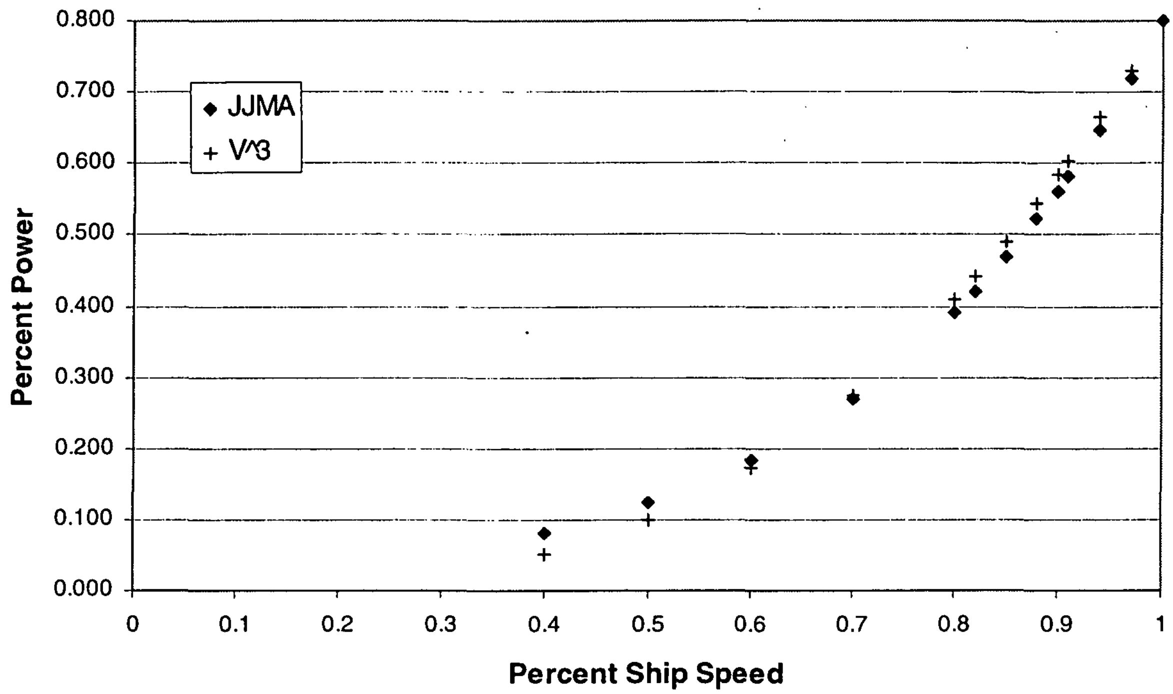

Figure 5-4. Speed-power relationship for tankers and bulk carriers — adjusted for 80 percent MCR at 100 percent speed

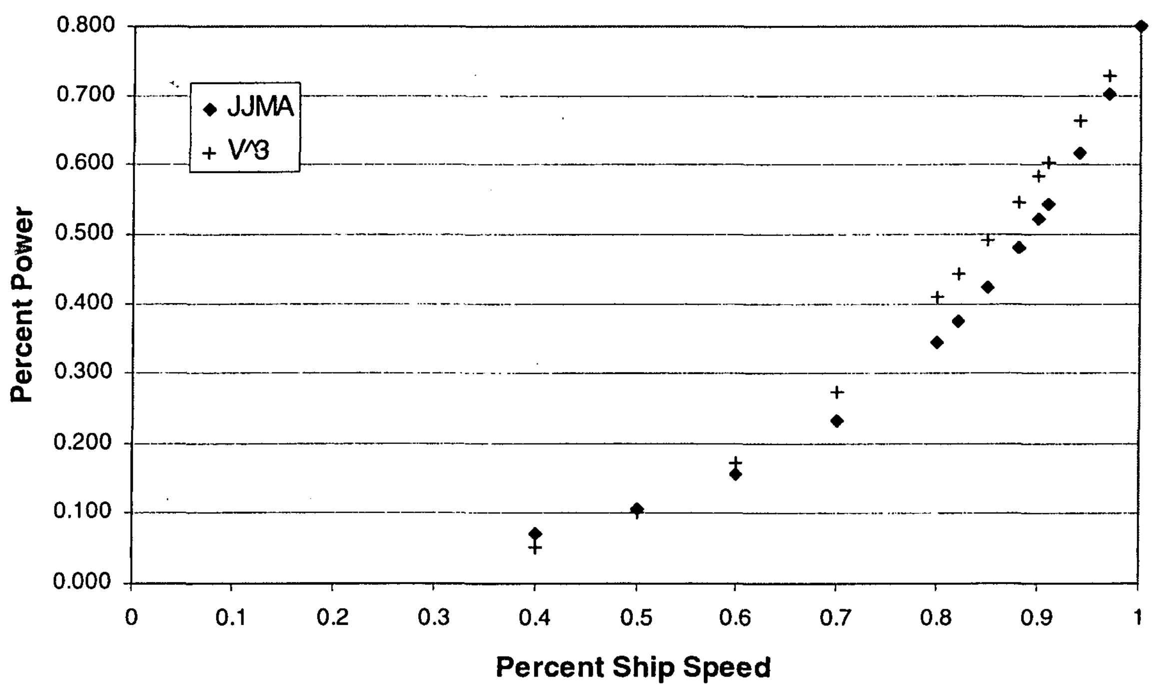

Figure 5-5. Speed-power relationship for container, RORO, and general cargo ships — adjusted for 80 percent MCR at 100 percent speed

Table 5-3. Speed reduction scenarios

		Maximum allowed ship speed (knots) in RSZ by shiptype							
Scenario No.	RSZ Distance[a]	Auto	Bulk	Container	General Cargo	Passenger	Reefer	RORO	Tanker
baseline	*NA*	*18.3*	*15.1*	*23.4*	*15.7*	*19.9*	*19.7*	*22.0*	*15.4*
1	all cruise[b]	15	12	15	15	15	15	15	12
2	all cruise[b]	15	15	18	15	15	15	18	12
3	30	15	12	15	15	15	15	15	12
4	30	15	15	18	15	15	15	18	12
5	20	15	12	15	15	15	15	15	12
6	20	15	15	18	15	15	15	18	12
7	15	15	12	15	15	15	15	15	12
8	15	15	15	18	15	15	15	18	12

[a] Distance from the start of the reduced speed zone (RSZ) to the precautionary area in nautical miles (one-way distance)

[b] "All cruise" denotes that the entire distance from the outer boundary used for the inventory to the precautionary area is considered to be the RSZ. For "all cruise" scenarios, distances from the inventory study are used which differ somewhat by shipping lane and inbound vs. outbound traffic. For all other scenarios, the distance between the start of the RSZ and the precautionary area in assumed to be one distance, independent of shipping lane or inbound vs. outbound.

Each scenario specifies the distance from the start of the RSZ to the precautionary area, the maximum allowed speed within the RSZ for each shiptype, and whether or not the speed limit is assumed to apply to all vessels. Note that only the effect of speed reductions on diesel motorships was analyzed. Steamships calling on the Ports were neglected in this analysis because in 2010 steamships were projected in the emissions inventory to produce only 0.2 tpd of NO_x in cruise mode out of total ship cruise emissions of about 16 tpd of NO_x.

5.5 METHODOLOGY

For each scenario, the following steps were taken (additional discussion of each step is provided below):

1. Recalculate distances by operational mode (full cruise and RSZ cruise — all other modes unaffected)

2. Use recalculated distances with scenario speeds to calculate revised hours by operating mode and shiptype

3. Use scenario speeds and the JJMA curves to estimate engine load (percent MCR) by operating mode and shiptype

4. Combine revised hours and engine loads to calculate energy consumption (MWh). Calculate total energy consumed in one year as well as distribution of energy by engine profile loads developed in Section 3 (e.g. 80 percent MCR, about 40 percent MCR, about 35 percent MCR, etc.)

5. Use the revised energy consumption with 2010, IMO-controlled NO_x emission rates (see Section 3 — NO_x factors based on the engine-specific methodology were used in this analysis[36]) to calculate normalized emissions in 2010, with IMO and speed reduction, compared with baseline operation (with and without IMO standards).

6. From revised hours by operating mode, calculate total increased time spent cruising compared with baseline operation and calculate the associated increased emissions from auxiliary engines.

7. Calculate net NO_x reductions attributable to speed reduction in 2010.

5.6 EXECUTION

As part of the SCAQMD inventory study, average distances traveled inbound and outbound were estimated for each shiptype, based on the distances shown in Table 5-1 and estimated distribution of traffic by route. For example, approximately half of the RORO traffic in 1994 was between Honolulu and San Pedro Bay. This traffic is associated with the "Catalina" route into the Ports which, as Table 5-1 shows, is significantly longer within South Coast waters than the Northern, Western, or Southern routes. Therefore, the average distance traveled at full cruise by ROROs is longer than for any other shiptype (50.8 miles inbound versus a range of 37.0 to 42.2 miles inbound for the other shiptypes). The speed reduction scenario defines the RSZ distance, that is the distance between the outer boundary of the RSZ and the boundary of the precautionary area. For each scenario, we subtracted the RSZ distance from the inventory full cruise distance. For example, if the scenario defined the RSZ distance as 20 miles, an inbound RORO would be assumed to travel in South Coast waters for 50.8 – 20 = 30.8 miles at full cruise and for 20 miles at reduced speed cruise.

The scenario also defines the RSZ speeds for each shiptype. The RSZ distance (inbound plus outbound) divided by the RSZ speed for a shiptype gives the time required to travel through the RSZ for that shiptype. The time spent at full cruise (outside of the RSZ) was calculated using the average ship speeds for 2010 from the SCAQMD inventory study which were shown in Table 5-2. Table 5-4 shows these calculations of distance and time for Scenario 3.

[36] The engine-specific methodology NO_x factors give more conservative results (that is, lower reductions) for the speed reduction analysis because this method resulted in a greater increase in NO_x emission rates at lower engine loads than the combined-data method.

Table 5-4. Average cruising distances, speeds, and times — Scenario 3

Shiptype	Distance[a], Boundary to Precautionary Area: Inbound	Distance[a], Boundary to Precautionary Area: Outbound	Distance[a], Boundary to Reduced Speed Zone: Inbound	Distance[a], Boundary to Reduced Speed Zone: Outbound	Cruise Speed (Knots)	Hours Cruise per call	Distance; Reduced Speed Zone to Precautionary Area: Inbound	Distance; Reduced Speed Zone to Precautionary Area: Outbound	RSZ Speed (Knots)	Hours RSZ per call
Auto Carrier	37.83	39.03	7.83	9.03	18.34	0.9	30	30	15	4.0
Bulk Carrier	37.24	38.61	7.24	8.61	15.06	1.1	30	30	12	5.0
Container Ship	38.82	41.43	8.82	11.43	23.36	0.9	30	30	15	4.0
General Cargo	37.00	38.50	7.00	8.50	15.73	1.0	30	30	15	4.0
Passenger	37.15	38.50	7.15	8.50	19.87	0.8	30	30	15	4.0
Reefer	37.00	38.50	7.00	8.50	19.65	0.8	30	30	15	4.0
RORO	50.80	51.32	20.80	21.32	22.01	1.9	30	30	15	4.0
Tanker	42.15	41.79	12.15	11.79	15.39	1.6	30	30	12	5.0

[a] One-way distance in nautical miles. "Boundary" is the boundary of South Coast waters (see Section 2).

Using the RSZ speed for each shiptype and the JJMA power curves, an engine load (percent MCR) associated with the RSZ speed was calculated for each shiptype. The JJMA tanker/bulk carrier curve was used for these shiptypes while the container/RORO/general cargo curve was used for all other shiptypes. The JJMA curves were also used to estimate engine load associated with cruising in the precautionary area. This is a slight modification to the SCAQMD inventory methodology where power requirements in the precautionary area were calculated using the V^3 relationship. Power requirements during maneuvering were left unchanged from the inventory study. Table 5-5 shows these calculations for Scenario 3.

Table 5-5. Impact of reduced ship speeds on engine output power — Scenario 3

Shiptype	Full Cruise Speed (knots)	RSZ Speed (knots)	RSZ/Cruise Speed Ratio	RSZ % MCR	PA[a]/Cruise Speed Ratio	PA % MCR
Auto Carrier	18.34	15	82	37	65%	19
Bulk Carrier	15.06	12	80	43	80%	43
Container Ship	23.36	15	64	18	51%	11
General Cargo	15.73	15	95	65	76%	30
Passenger	19.87	15	75	29	60%	16
Reefer	19.65	15	76	30	61%	16
RORO	22.01	15	68	22	55%	13
Tanker	15.39	12	78	40	78%	40

[a] Based on a "PA" (precautionary area) speed of 12 knots.

Appendix G contains the spreadsheet which calculates energy consumption by mode. This spreadsheet was modified from spreadsheet W1S5 in the SCAQMD inventory model. Table 5-6 shows a portion of the spreadsheet (auto carriers, non-bunker calls) for illustration. The inventory groups annual ship calls by shiptype, propulsion type, and design category[37]. For each design category, an average cruise power (horsepower at 80 percent MCR) was calculated from the LMIS database. The italicized percents at the top of the four power columns are the engine loads (percent MCR) associated with the indicated operating mode for the shiptype. For example, for the scenario shown (Scenario 3), RSZ cruising is associated with 37 percent MCR. Power requirements in horsepower for each mode were calculated from engine load and the 80 percent MCR horsepower for the design category. Power requirements were then multiplied by hours spent in each mode to calculate energy consumption per call and per year and converted to kiloWatt-hours.

Table 5-6. Example of calculation of energy consumption by mode — auto carrier, Scenario 3

				Power by mode (hp)				Time in Mode (hours/call)			
Shiptype	Propulsion Type	Design Categories	Non-Bunker Calls in 2010	Cruise	RSZ Cruise	PA Cruise	Maneu vering	Cruise	RSZ Cruise	PA Cruise	Maneu vering
Auto Carrier				*80%*	*37%*	*19%*	*15%*				
	Motorships	0-200	0	0		0	0	0.9	4.0	1.0	1.5
		200-400	331	11,784	5,470	2,847	2,210	0.9	4.0	1.0	1.5
		400-600	131	13,916	6,460	3,362	2,609	0.9	4.0	1.0	1.5
		>600	2	15,652	7,266	3,781	2,935	0.9	4.0	1.0	1.5

				Energy Consumed (kWh/call)				Energy Consumed (kWh/year)			
Shiptype	Propulsion Type	Design Categories	Non-Bunker Calls in 2010	Cruise	RSZ Cruise	PA Cruise	Maneu vering	Cruise	RSZ Cruise	PA Cruise	Maneu vering
Auto Carrier			NB calls								
	Motorships	0-200	0	0	0	0	0	0	0	0	0
		200-400	331	8081	16323	2044	2473	2674860	5403059	676722	818399
		400-600	131	9543	19276	2414	2920	1250093	2525114	316265	382478
		>600	2	10734	21681	2716	3284	21467	43362	5431	6568

[37] Design category, used in the SCAQMD inventory model, is equal to ship speed cubed times dead weight tonnage raised to the two-thirds power divided by 10,000. See the SCAQMD inventory study for a discussion of this parameter.

Using this spreadsheet, energy consumed was summed for each of the South Coast "profile engine loads" developed in Section 3 (see Exhibit 3-4 and the associated discussion). These were 80, 40, 35, 20, 15, and 10 percent MCR, chosen because, under baseline operation, the power required of each shiptype in each operating mode was easily classified under one of these engine loads. Energy consumed at these profile loads for all operating modes other than RSZ cruising is shown in Table 5-7 (for Scenario 3). For each scenario analyzed, the RSZ percent MCR for each shiptype (which varied substantially depending on the scenario) was associated with the nearest profile engine load[38] (Table 5-8). The distribution of energy consumed by engine load is important because the NO_x emission rates developed in Section 3 are different at different engine loads. And, of course, the total energy consumed is also important since it is directly related to the total NO_x produced. Table 5-9 shows the total energy consumption distribution (baseline modes plus the RSZ cruise mode) for Scenario 3.

With these scenario-specific estimates of annual energy consumption by profile load in hand, and using the NO_x emission factors developed in Section 3 as a function of engine load, it is possible to estimate an energy-weighted average NO_x emission factor for each speed reduction scenario. For each scenario, a spreadsheet was created (see Exhibit 5-1 for an example) which summarizes the scenario parameters, records the energy consumption distribution in 2010 under baseline operation (same for all scenarios) and under reduced speed operation and also records the percent of total energy estimated to be consumed by medium speed ships[39]. The scenario spreadsheet then calculates the energy-weighted average NO_x emission rate (g/kWh) for the reduced speed scenario from the 2010 IMO-controlled NO_x rates for each profile load.

Table 5-7. Energy consumed in full cruise, precautionary area cruise, and maneuvering — Scenario 3

Profile Engine Load (% MCR)	MWh per year	Energy, % of Total
80	120,870	65
40	13,289	7
35	1,487	1
20	15,152	8
15	7,729	4
10	28,856	15
Total	187,384	

[38] There is a rather large gap in the profile loads between 80 and 40 percent MCR. Any energy consumed at engine loads of greater than 60 percent was grouped with the 80 percent MCR energy and 60 percent and lower (down to 38 percent) was grouped with 40 percent. The NO_x emission rates do not vary much over this power range (see Section 3), so this broad grouping has little effect on the results.

[39] The medium speed energy consumption was based on the percentage of medium speed ships by shiptype which was derived from the LMIS data in the inventory study.

Table 5-8. Energy consumed in reduced speed zone cruise and associated percent MCR — Scenario 3

Shiptype	RSZ % MCR	Nearest Engine Profile % MCR	MWh per year
Auto Carrier	37	35	9,106
Bulk Carrier	43	40	31,525
Container	18	20	69,985
General Cargo	65	80	12,959
Passenger	29	35	12,692
Reefer	30	35	10,063
RORO	22	20	887
Tanker	40	40	33,274
TOTAL			180,491

Table 5-9. Total energy consumed by mode (all modes) — Scenario 3

Profile Engine Load (% MCR)	MWh per year	Energy, % of Total
80	133,829	36
40	78,088	21
35	33,348	9
20	86,024	23
15	7,729	2
10	28,856	8
Total	367,875	100[a]

[a] Numbers may not add due to rounding.

Scenario Description:

Reduced Speed Zone boundary distance from the Precautionary Area (nautical miles):	all cruise
Ship speed in Reduced Speed Zone (knots):	
Auto Carrier	15
Bulk Carrier	15
Container Ship	18
General Cargo	15
Passenger	15
Reefer	15
RORO	18
Tanker	12
Speed reduction assumed to apply to:	all ships

	2010 Baseline Operation			2010 Reduced Speed Operation		
Profile Loads (% MCR)	**MWh per year**	**% of total**	**Med. Speed %**	**MWh per year**	**% of total**	**Med. Speed %**
80	494,592	88	10	**79,749**	22	**10**
40	13,289	2	11	**59,835**	16	**11**
35	1,487	0	11	**173,806**	48	**11**
20	15,152	3	11	**15,152**	4	**11**
15	7,729	1	11	**7,729**	2	**11**
10	28,856	5	11	**28,856**	8	**11**
Total, all modes	561,106			**365,128**		

Exhibit 5-1. Speed reduction Scenario 3 — results

Energy use in 2010 and NO_x g/kWh by mode (motorship main engines)

2010 Baseline Operation — Uncontrolled NO_x Rates

Profile Loads (%MCR)	MWh / year	SS[a] g/kWh	MS[b] g/kWh	% MS	SS&MS g/kWh
80	494,592	17.06	12.77	10	16.63
40	13,289	18.26	13.53	11	17.74
35	1,487	18.14	13.87	11	17.67
20	15,152	20.94	16.93	11	20.50
15	7,729	23.96	20.42	11	23.57
10	28,856	28.89	25.27	11	28.49
Total energy/year	561,106		MWh-weighted NO_x g/kWh		17.47

2010 Reduced Speed Operation — 2010 NO_x Rates

Profile Loads (%MCR)	MWh / year	SS g/kWh	M g/kWh	% MS	SS&MS g/kWh
80	79,749	16.30	12.23	10	15.89
40	59,835	17.41	12.99	11	16.92
35	173,806	17.46	13.33	11	17.01
20	15,152	20.18	16.39	11	19.76
15	7,729	23.20	19.88	11	22.83
10	28,856	28.13	24.72	11	27.75
Total energy/year	365,128		MWh-weighted NO_x g/kWh		17.84

[a] "SS" = slow speed engines
[b] "MS" = medium speed engines

Increased Auxiliary Engine Emissions

Shiptype	Increased Hours/Call From Speed Reduction	Inventory Aux Engine NO_x lb/hr[a]	Motorship Calls per Year in 2010	Increased NO_x Aux Engines (tons per year)
Auto Carrier	**0.93**	22.05	523	5.4
Bulk Carrier	**0.02**	22.05	1260	0.3
Container Ship	**1.02**	22.05	2442	27.5
General Cargo	**0.23**	22.05	720	1.9
Passenger	**1.24**	147.00	584	53.1
Reefer	**1.19**	22.05	773	10.2
RORO	**1.03**	22.05	49	0.6
Tanker	**1.54**	22.05	1054	17.9
Totals (tpy)				116.7

[a] Taken from the SCAQMD inventory study.

Exhibit 5-1. Speed reduction scenario 3 — results (concluded)

Exhibit 5-1 (Scenario 3 — see Appendix G for the rest of the scenarios) shows the energy distribution and energy-weighted average NO_x rate in 2010 for two cases: (1) baseline operation (no RSZ) plus uncontrolled NO_x rates and (2) reduced speed operation plus IMO-controlled rates. The first case produces an energy-weighted NO_x factor consistent with operation in 2010 in the absence of IMO control or speed reductions ("baseline"). The second case reflects both IMO and speed control. Comparison of the energy-weighted NO_x factor multiplied by the total annual energy consumption for these two cases provides an estimate of the total NO_x reductions expected from the combination of IMO and speed control. Expected reductions from IMO alone, estimated in Section 3, can then be subtracted from this result to estimate reductions attributable solely to speed reductions (this is done in Section 5-7).

Note that the energy-weighted average NO_x rate for the reduced speed + IMO scenario is higher than the rate for the baseline + uncontrolled scenario (18.2 versus 17.4 g/kWh for Scenario 3), even though the 2010 IMO-controlled NO_x rate at any given profile load is lower than the uncontrolled rate for that profile load. This is because as the engine load becomes lower both the IMO and the uncontrolled NO_x rates become higher. In the reduced speed scenario, the energy consumption which under baseline operation was concentrated at the 80 percent MCR load, shifts largely into lower-power operating modes, weighting more heavily those higher NO_x rates. This increase in the energy-weighted average NO_x rate slightly offsets the benefit of reducing overall energy consumption.

Exhibit 5-1 also shows the calculation of increased auxiliary engine emissions. From the revised hours spent cruising in the reduced speed scenario compared with baseline operation, the total increased hours per call were calculated for each shiptype. The increased hours were multiplied by a NO_x emission rate in pounds per hour representing auxiliary engines at sea taken from the SCAQMD inventory study. This information, combined with the calls in 2010 per shiptype gave an estimate of the total annual increase in auxiliary engine emissions associated with reduced ship speeds.

Total energy consumed (MWh per year) multiplied by the energy-weighted NO_x emission rate (g/kWh) for baseline operation and speed reduction scenarios gives values for the NO_x emissions inventory. Because the methods used in this study were somewhat different than the methods used in the inventory study, giving somewhat different results, the tons of annual NO_x emissions calculated in this analysis were normalized to 2010 baseline, uncontrolled operation. Normalized NO_x results were then multiplied by the appropriate NO_x inventory in tons per day taken directly from the SCAQMD inventory study to estimate NO_x reductions associated with reduced cruising speeds, consistent with the inventory model. Increased emissions from auxiliary engines were added in to calculated net NO_x reductions. These calculations are detailed in the next section.

5.7 EMISSIONS RESULTS

Table 5-10 shows results for each speed reduction scenario analyzed. All results are for operation in 2010. The "baseline uncontrolled" NO_x, which is normalized to 1, was calculated from the baseline operation energy consumption distribution (total energy consumed per year of 561,106 MWh) and the uncontrolled NO_x factors which were weighted by the energy distribution to arrive at the weighted-average uncontrolled NO_x rate of 17.47 g/kWh. The "baseline IMO-2010" NO_x was calculated using the baseline energy consumption numbers in combination with the IMO-controlled, 2010 average NO_x factor of 16.73 g/kWh. Use of the IMO 2010 NO_x factor gave a normalized result of 0.96, a 4 percent NO_x reduction from baseline, uncontrolled operation.

Table 5-10. Speed reduction analysis: summary of results

For 2010, baseline operation (no speed reduction measures):	
Total energy consumed per year (MWh)	561,106
Uncontrolled energy-weighted average NO_x rate (g/kWh)	17.47
IMO-controlled (2010) energy-weighted average NO_x rate (g/kWh)	16.73

Results in 2010 — Motorships calling on the San Pedro Bay Ports											
Speed Reduction Scenario	Baseline Uncontrolled NO_x (normalized)	Baseline IMO-2010 NO_x (normalized)	Speed Reduction Scenario w/ IMO Energy MWh	Speed Reduction Scenario w/ IMO NO_x g/kWh	Speed Reduction + IMO NO_x (normalized)	Baseline Uncontrolled NO_x inventory (tpd)	IMO only NO_x Reduction (tpd)	Speed Reduction + IMO NO_x Reduction (tpd)	Speed Reduction Only NO_x Reduction (tpd)	New Auxiliary Engine NO_x (tpd)	Speed Reduction Net NO_x Reduction (tpd)
1	1	0.96	304654	19.08	0.59	15.6	0.7	6.3	5.7	0.44	5.2
2	1	0.96	365128	17.84	0.66	15.6	0.7	5.2	4.6	0.32	4.3
3	1	0.96	367875	18.21	0.68	15.6	0.7	4.9	4.3	0.33	3.9
4	1	0.96	414010	17.48	0.74	15.6	0.7	4.1	3.4	0.25	3.2
5	1	0.96	432285	17.56	0.77	15.6	0.7	3.5	2.9	0.22	2.6
6	1	0.96	463042	17.17	0.81	15.6	0.7	2.9	2.3	0.16	2.1
7	1	0.96	464490	17.31	0.82	15.6	0.7	2.8	2.1	0.03	2.1
8	1	0.96	487558	17.04	0.85	15.6	0.7	2.4	1.7	0.12	1.6

For each speed reduction scenario, Table 5-10 shows the total annual energy use and the weighted-average NO_x emission factors that were calculated in Exhibit 5-1 and Appendix G. These were combined to give the normalized NO_x emissions for each scenario. Note that the emission factors used for each scenario were the IMO, 2010 factors. The weighted average factors were different for each scenario because, as described in Section 5.4, the energy consumption distribution was different for each scenario.

All of the normalized NO_x results were then applied to the appropriate portion[40] of the NO_x inventory (15.6 tpd). For example, this baseline NO_x inventory of 15.6 multiplied by the normalized factor for IMO standards in 2010 of 0.96 gives 14.9 tons per day. This implies a reduction due to the IMO standard alone of 0.7 tpd from motorship main engines in cruise mode. The normalized NO_x factor for Scenario 3 including both IMO and speed reduction is 0.68, implying a reduced NO_x inventory of 15.6 X 0.68 = 10.7 and giving a reduction of 4.9 tpd. Subtracting the benefit of the IMO standard gives a speed reduction-only benefit of 4.9 – 0.7 = 4.2 tpd (4.3 tpd in Table 5-10 because the table is not using rounded numbers for the calculations). Finally, increased auxiliary engine emissions are added back in giving a net speed reduction benefit of 4.3 – 0.3 = 4.0 tpd (3.9 in Table 5-10) for Scenario 3.

The 2010 NO_x reductions from speed reduction alone for the scenarios analyzed range from 1.6 tpd for Scenario 8 (speed limits of 12, 15, and 18 knots depending on the shiptype beginning 15 miles from the precautionary area) to 5.2 tpd for Scenario 1 (a speed limit of 12 knots for bulk carriers and tankers and a speed limit of 15 knots for all other shiptypes, applied everywhere in South Coast waters outside of the precautionary area.)

5.8 COSTS OF SPEED REDUCTION

As described above, a speed reduction strategy may also lead to increased costs for shipping companies due to increased time spent in South Coast waters. In the most aggressive scenario (that is, Scenario 1, which provides the most NO_x reductions) the fastest shiptypes, containers and ROROs, lose about 2 hours per call due to the reduced cruise speed. Other shiptypes lose from 0.2 to 1.5 hours per call. And, of course, these estimates are based on average shiptype speeds. Individual ships within each shiptype may lose more or less time, depending on their own speeds.

This lost time affects different shipping companies in different ways. In early 1997, the Pacific Merchant Steamship Association and the Steamship Association of Southern California along with contractor, Seaworthy Systems, conducted a survey of shipping companies, outlining a few potential speed reduction scenarios and asking for information on how such scenarios would affect the companies' costs. Five companies responded and the responses were provided to assist with this study. We spoke with the five responders and with a few other shipping companies, as well. Of course, these were only a small portion of the number of shipping companies that use the San Pedro Bay Ports. The information gained does not represent the entire fleet calling on the San Pedro Bay Ports in any given year and cannot support a rigorous quantification of the costs associated with speed reduction. However, important insights emerged from the survey information and interviews which may be useful in considering speed reduction strategies. The following picture emerged from these discussions.

[40] The "appropriate portion" of the inventory is the NO_x tpd generated in modes of operation which would be affected by speed reduction. That is, emissions from main engines in cruise (outside of the precautionary area).

- Most ships would likely respond to reduced speeds in the South Coast by traveling faster outside of the South Coast to make up the time lost. Traveling faster would increase fuel consumption and therefore would increase cost. To the extent the ship could make up the lost time between Los Angeles or Long Beach and the next port of call, the only cost of the speed reduction would be the cost of increased fuel use[41].

- For some ships on some runs it would not be easy to make up the lost time. This is true for short runs, such as San Pedro Bay to Oakland, or for runs where the schedule is based on the ship running at maximum speed[42]. For longer runs (such as transpacific runs) and assuming the ship were not scheduled based on maximum speed, making up for as much as 2 hours lost in the South Coast would not be difficult.

- The extent to which schedules are arranged based on ships traveling at maximum speed varies by company. For example, Maersk Pacific schedules their container vessels based on maximum speed (Blichfeld) whereas APL, which also operates container vessels, does not (Sinclair).

- The costs associated with not being able to make up the lost time and arriving at a destination late can be large[43]. These costs can include the cost of the longshoremen gangs which may be waiting for the ship to arrive. A typical gang costs about $2000 per hour (Lemke)[44]. The hourly cost of the ship itself, which includes amortized capital cost, the cost of the crew, supplies, maintenance, insurance, as well as fuel,

[41] There might be maintenance cost implications of operating at lower speeds in South Coast waters and higher speeds elsewhere, but these would be harder to predict and are likely to be much smaller than increased fuel costs.

[42] According to Mr. Andy Sinclair of APL, the maximum speed is usually associated with 90 to 95 percent MCR and operating above that speed would be risky in terms of wear on the engine, especially for older engines. According to Mr. Sinclair, most engines are governed so that the ships could not travel faster than the maximum speed without an engineering modification.

[43] Note that not being able to make up lost time in transit doesn't necessarily mean the ship will arrive at its destination late. A ship may leave the port early and so arrive at the next port of call in time without traveling faster than planned (Watson-Jones).

[44] How any delay due to reduced speeds in the South Coast would produce increased labor costs at the destination port would be situation-specific. One situation-specific factor is that the number of gangs ordered varies depending on how much cargo needs to be transferred. (A typical container vessel might require 2 to 4 gangs (Lemke).) Also, the shipping company pays for the entire 8-hour shift regardless of the amount of time the longshoremen are needed (Campbell). This means that if a ship can be offloaded in, for example, 6 hours and the ship arrives one hour late, no additional costs are incurred because the shipping company pays for the 8-hour shift regardless. However, if a ship arrives late and can not be handled by a single shift, the shipping company would need to pay for another 8-hour shift, even if only one more hour of work was required. Night shifts are more costly than day shifts (Blichfeld).

can be more than $1000 per hour[45]. If the delay into Los Angeles/Long Beach or into the destination port cannot be made up before the next port of call, extra costs will be incurred at each destination until the ship is able to get back on schedule. Especially sensitive to delays are runs which take the ship through the Panama Canal. A limited number of ships are allowed through the Canal each day, and ships schedule their passage ahead of time. If a ship is late for its scheduled passage, it must wait until the next day to pass through the Canal. Clearly, the loss of a day is to be avoided.

- Schedule sensitivity varies with shiptype as well as company. Tankers carry crude oil and refined petroleum products between oil fields and refineries and bulk storage terminals. Because of the large on-site storage at typical tanker vessel destinations, it may not be considered essential for tankers to arrive at destinations on precise schedules (Kraatz). Furthermore, because oil spill prevention is so important for tankers, these ships are not scheduled as tightly as other vessels types, allowing the ship captain a great deal of discretion to slow the ship as needed to ensure ship safety (Kraatz).

- Bulk carriers, although more schedule-sensitive than tankers, would be less impacted by speed reduction than container vessels. Unlike container cargo, bulk commodities are not typically moved up and down the West Coast of the United States by ship. Most bulk carriers calling on the San Pedro Bay Ports would be coming from or going to a foreign port. The transpacific runs would allow plenty of distance for the ship to make up for time lost due to speed reduction in the South Coast.

Keeping these factors in mind, it is possible to make some case study-style estimates of the costs and cost-effectiveness of speed reductions. For these estimates, we assume the ship in question would be able to make up for lost time in South Coast waters and keep to its schedule. The costs calculated are the costs of increased fuel consumption. The parameters assumed in the base case are shown in Table 5-11. Again, while these parameters might be reasonable for a particular ship, this is merely an example based on certain assumptions and is not intended to be representative of all vessels calling on the San Pedro Bay Ports.

These assumptions yield the following results (results are per call; the ship was assumed to reduce speed in the RSZ each way, for a total RSZ distance per call of 60 miles):

- A savings of 5.2 tonnes of fuel in the South Coast and a cost of 15.1 tonnes of fuel outside of South Coast waters, for a net increase of 9.9 tonnes of fuel used

- A net cost of $1,490 for the increased fuel used

[45] Whether or not the hourly cost of the ship itself is relevant to the costs of reducing speeds in the South Coast depends on whether or not the lost time is eventually made up. Presumably, most ships would eventually be able to make up the lost time by increasing their cruising speed over some relatively long run.

Table 5-11. Base case assumptions for speed reduction cost example

Parameter	Assumed Value
Price of 1 tonne of heavy fuel oil ($)	150
One-way RSZ distance (nautical miles)	30
Baseline ship speed (knots)	23
RSZ ship speed (knots)	15
Baseline % MCR	80
MCR (horsepower)	30,000
Brake-specific fuel consumption (g/hp-hr)	130
Distance to next port (nautical miles)	3,500

- A total NO_x reduction of approximately 0.5 tons for the single call (a slow speed vessel was assumed and uncontrolled NO_x emission rates from Section 3 at 80 and 20 percent MCR were used)

- A cost effectiveness of approximately $3,100 per ton of NO_x reduced

These calculations are shown in Appendix G.

To investigate how different assumptions would affect the results, we varied some of the assumptions listed above while holding the other parameters constant. Table 5-12 shows the results.

Table 5-12. Estimated cost effectiveness of NO_x reductions for a variety of case assumptions

Parameter Varied	Effect of Parameter Increase on Cost Effectiveness	Parameter Range (See Table 5-11 for Units)	Associated Cost Effectiveness Range ($/ton NO_x)
One-way RSZ distance	Improves	20 - 40	3,000 – 3,100
Baseline ship speed	Worsens	16 - 24	190 – 4,800
RSZ speed	Improves	12 - 20	750 – 6,700
Engine power (MCR)	No effect	NA	NA
Brake-specific fuel consumption	Worsens	120 - 150	2,900 – 3,600
Distance to next port	Improves	500 - 5000	3,000 – 4,800

These are only a few cases presented for illustration. Actual costs would vary significantly from company to company, ship to ship, and call to call. These examples do indicate, however, that for some ships speed reduction might provide a relatively cost-effective way to reduce emissions.

It is important to remember that, in many cases, the costs of speed reduction may be prohibitively high. Some ships on some runs may not be able, practically, to make up for time lost in South Coast waters. As described above, ships making short, coastwise runs might not be able to increase speeds enough to make up for the time lost in the South Coast. Vessels leaving from Los Angeles/ Long Beach for the Panama Canal may not find it practical to risk missing their scheduled passage through the canal. Of course, schedules can be changed to be consistent with any speed limits in the South Coast. However, the speed with which vessels can carry cargo from one port to another and the amount of cargo transported in a year clearly affect the competitive position and revenue-generating potential of a ship. Analysis of these types of schedule-related cost issues are beyond the scope of this analysis, but in order to recognize that in some cases there might be schedule impacts associated with unacceptable costs, we examined how much of the traffic in and out of the Ports might experience schedule impacts were speed reductions required.

As described earlier, the runs most likely to experience schedule impacts are those to or from nearby ports or leaving for the Panama Canal. The data provided by the Marine Exchange for 1994 which was used in the inventory study identifies the previous port of call and the next port of call for each call on the San Pedro Bay Ports. We examined this data to determine how many calls in one year might be coming from or departing for nearby ports. In addition, the Marine Exchange identified for us the number of vessels which left the Ports in January of 1997 for the Panama Canal (the Canal is not identified as the next port, so this analysis required identifying those ports of call which would be reached from the South Coast through the Panama Canal.) Table 5-13 shows these runs for all shiptypes excepting tankers, which are assumed to be less schedule-sensitive than other shiptypes. January 1997 results for the Panama Canal for all shiptypes but tankers were multiplied by 12 to estimate total annual departures for the Canal.

This table shows that about one quarter of the arrivals and departures at the San Pedro Bay Ports in a given year might have difficulty reducing speeds in the South Coast without modifying their schedules in some way. Since the most schedule-sensitive ships are likely to be those operating at high speeds (higher NO_x emissions) on tight schedules, 24 percent of the runs would probably translate into more than 24 percent of the total NO_x reduction potential.

This 24 percent estimate is probably an upper bound on the percentage of arrivals and departures that might experience higher costs if required to reduce speeds in South Coast waters. Whether or not these runs really would incur serious cost impacts would require closer examination, probably by the shipping companies, themselves. For example, a ship arriving from Oakland and then departing for Hong Kong would probably be able to reduce speeds in the South Coast and still arrive in Hong Kong as scheduled. Even if the arrival time in San Pedro had to be delayed by a few hours, provided that longshoremen gangs could be scheduled appropriately, the only extra costs incurred would be the cost of increased fuel consumption on the San Pedro to Hong Kong run. By contrast, a ship dedicated to a route between Oakland and

Long Beach and scheduled based on maximum speed would not be able to make as many trips in one year if it was required to reduce speed in South Coast waters. The cost impact in such a case would likely be unacceptably large.

Table 5-13. Potentially schedule-sensitive runs in one year

Port	No. Departing For	No. Coming From	Total In + Out
Oakland	930	413	1,343
San Francisco	244	96	340
San Diego	76	52	128
Richmond	60	34	94
Port Hueneme	68	18	86
Stockton	3	9	12
Sacramento	2	3	5
Panama	588	NA	588
Totals	1,971	625	2,596
Approximate annual arrivals + departures in 1994 and 1997			11,000
Potentially schedule-sensitive percentage of arr. + dept.			24%

Another important "cost" to a speed reduction strategy would be incurred by other air basins. If ships sped up outside of South Coast waters to make up for time lost, neighboring areas such as Ventura, Santa Barbara, and San Diego counties might experience increased marine vessel emissions. This drawback to a speed reduction strategy in the South Coast would need to be evaluated as part of the consideration of control options.

Obtaining the greatest amount of NO_x reduction available at reasonable cost and implementing a speed reduction measure in a fair and safe manner would require careful program design. Input from the shipping industry would be needed to better evaluate what a variety of possible speed reduction scenarios would mean to individual companies in terms of cost, competitive position, and safety. Assistance from the Marine Exchange, the Ports, and the Coast Guard would be needed to ensure that any speed reduction program could be implemented and enforced uniformly. Program design features would need to be considered recognizing that different shipping companies would experience different cost impacts from speed reductions.

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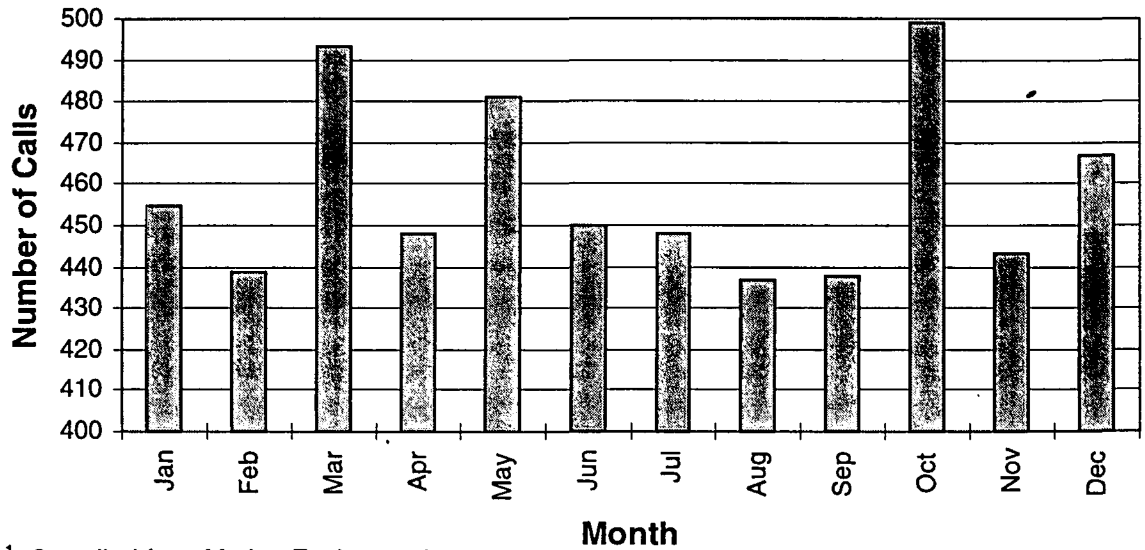
ANALYSIS OF MARINE EMISSIONS IN THE SOUTH COAST AIR BASIN

APPENDIX A



[1] Compiled from Marine Exchange data

Figure A-1. 1993 ship calls by month[1]

Table A-1. Main engines — % 4-stroke (medium speed)

Shiptype	% 4-Stroke
AutoCarrier	29
Bulk carrier	5
Container ship	4
General cargo	22
Passenger	52
Reefer	18
RORO	10
Tanker	10

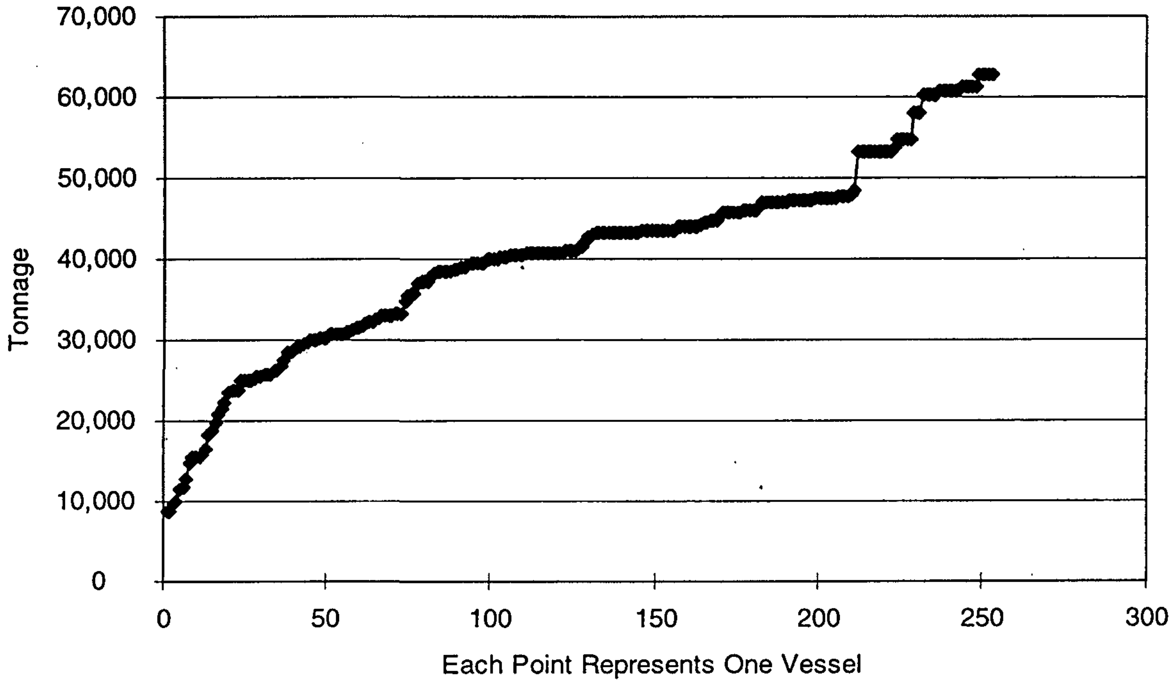


Figure A-2. Container ship net tonnage profile

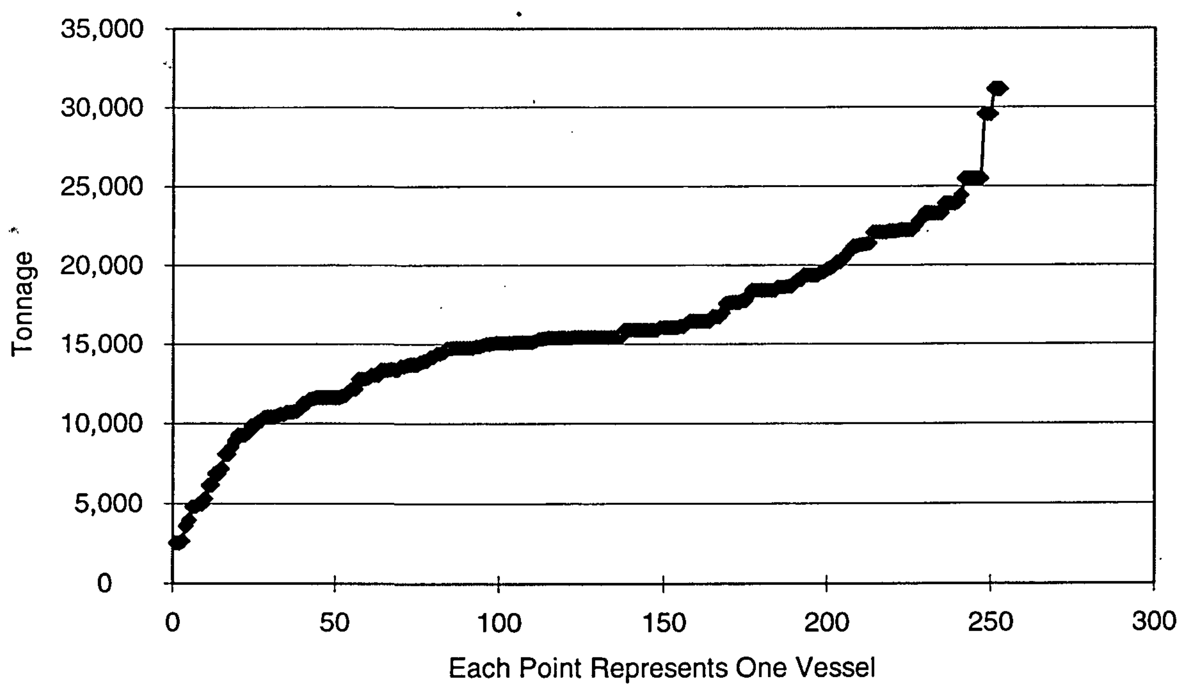


Figure A-3. Container ship deadweight tonnage profile

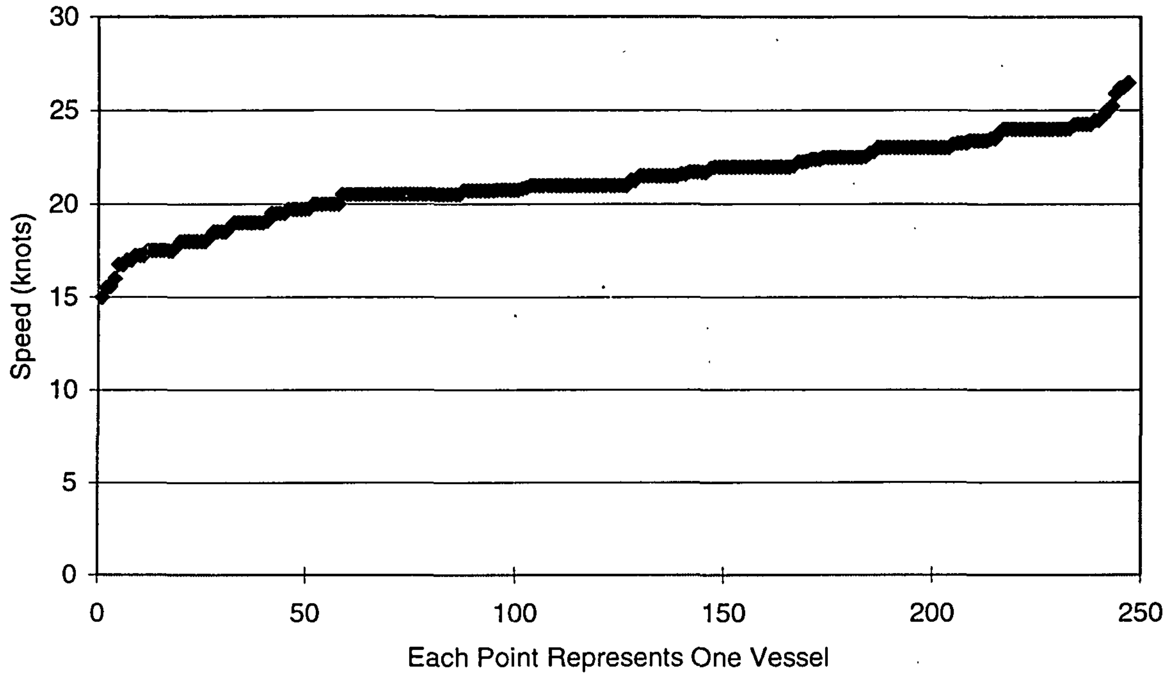


Figure A-4. Container ship service speed profile

Figure A-5. Calls in 1994 by year ship constructed — AUTOCARRIERS

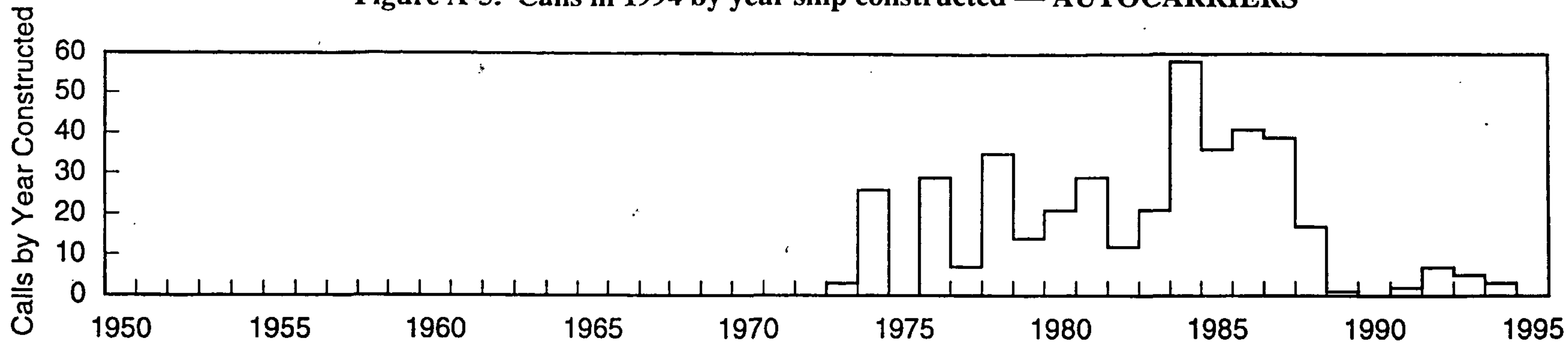


Figure A-6. Calls in 1994 by year ship constructed — BULK CARRIERS

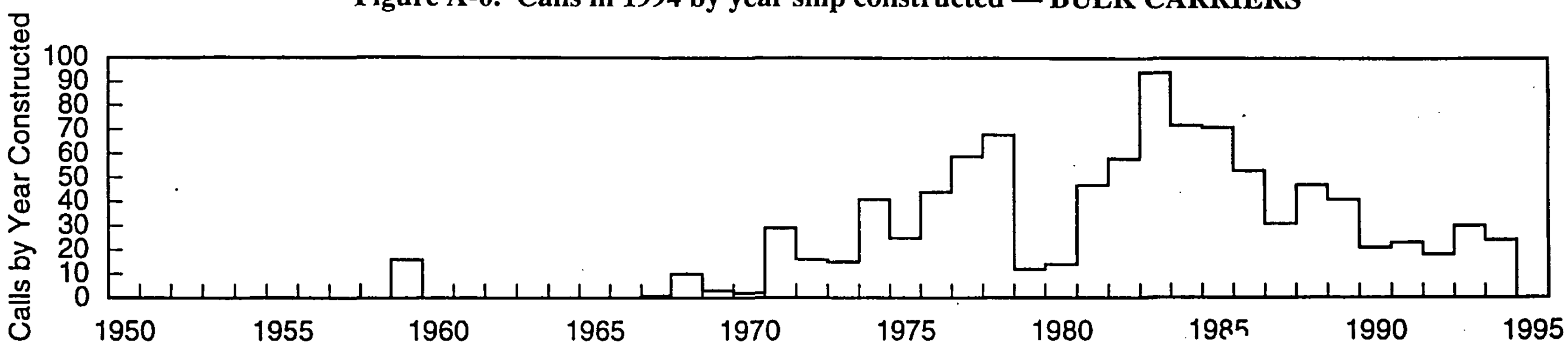


Figure A-7. Calls in 1994 by year ship constructed — CONTAINERS

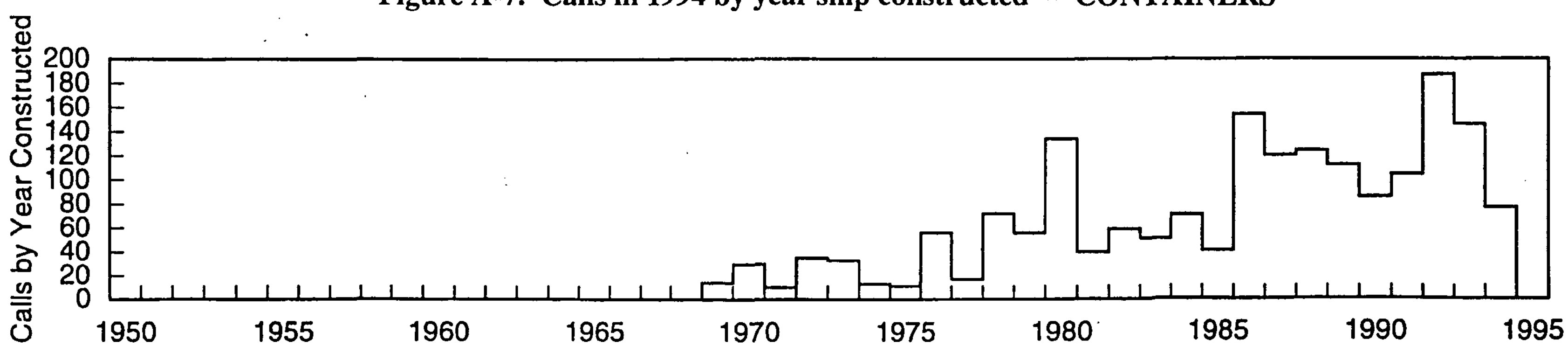


Figure A-8. Calls in 1994 by year ship constructed — GENERAL CARGO

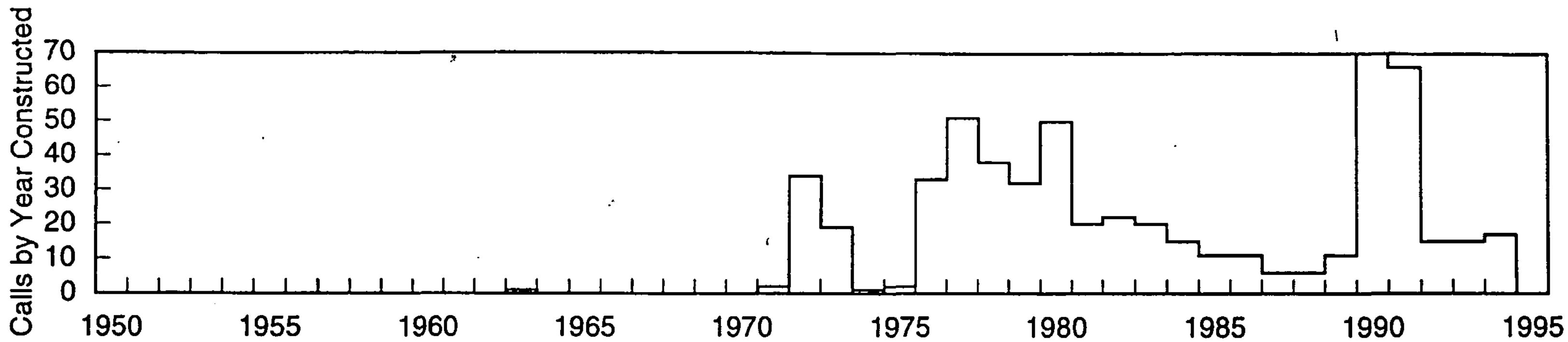


Figure A-9. Calls in 1994 by year ship constructed — PASSENGER

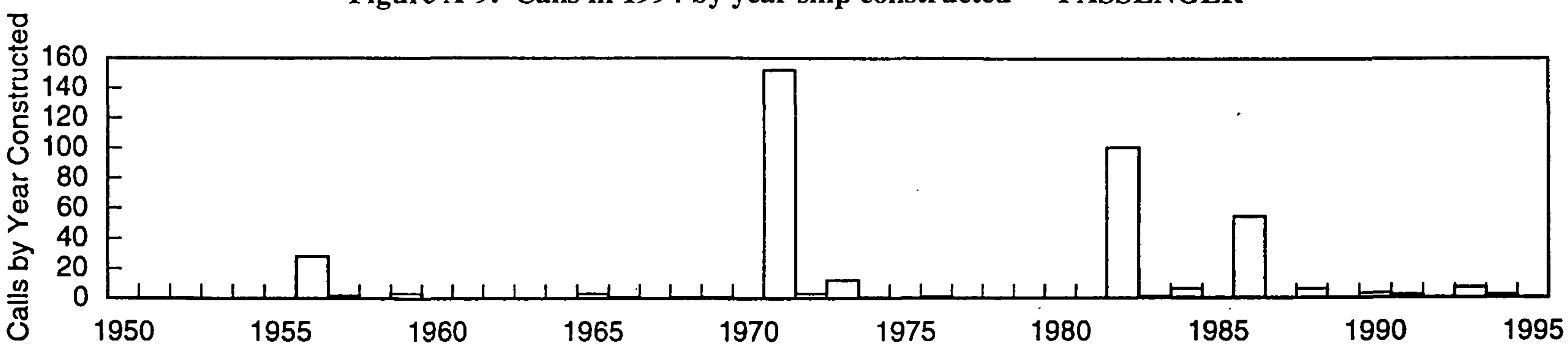


Figure A-10. Calls in 1994 by year ship constructed — REEFER

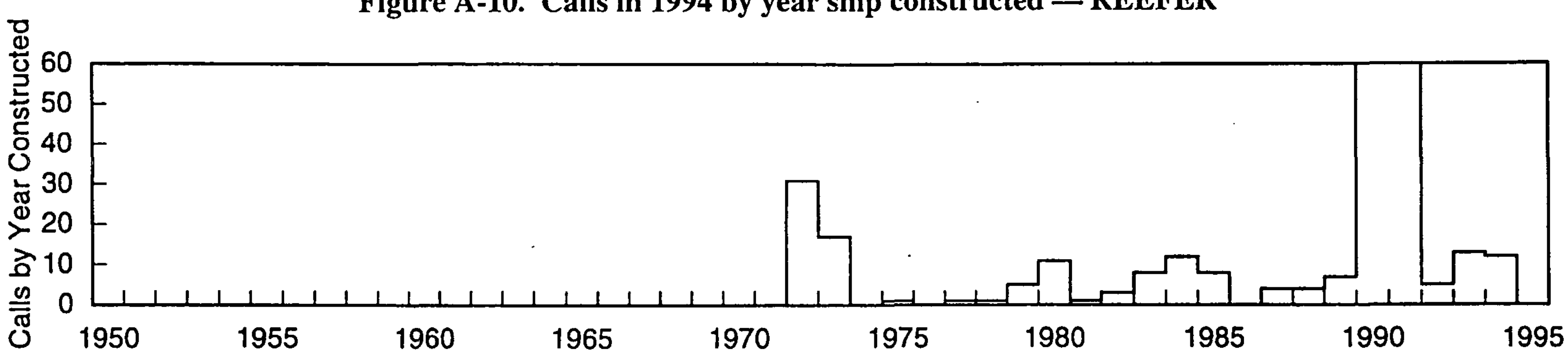


Figure A-11. Calls in 1994 by year ship constructed — RORO

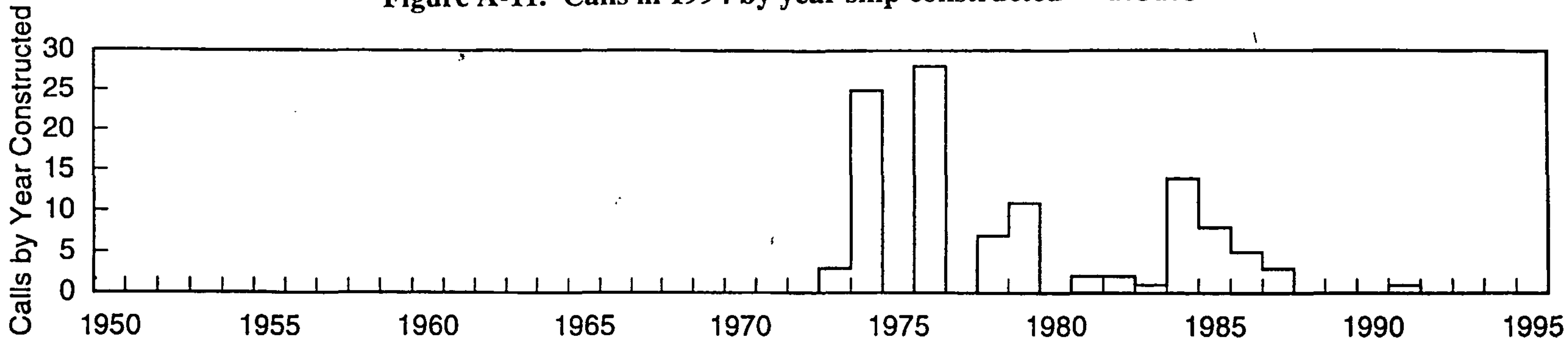


Figure A-12. Calls in 1994 by year ship constructed — TANKER

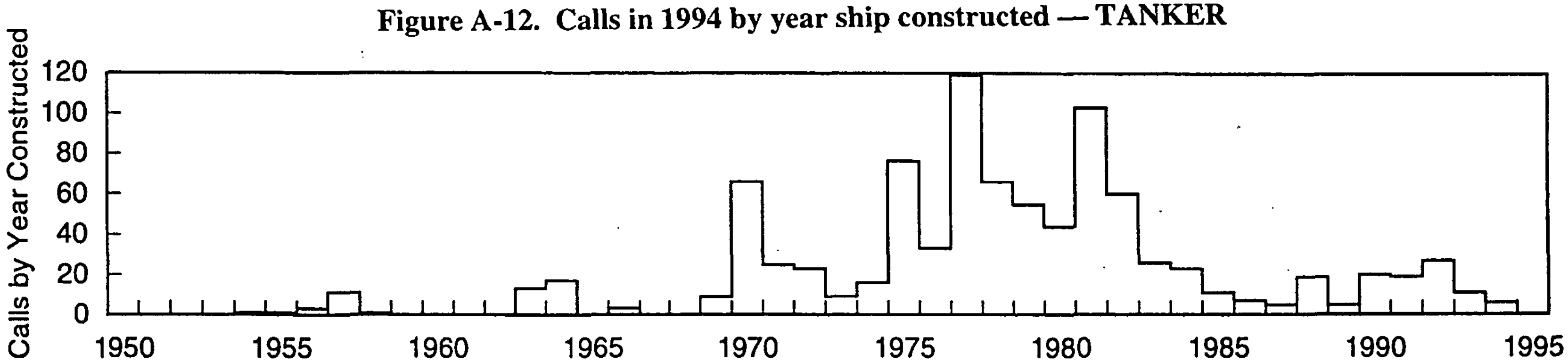
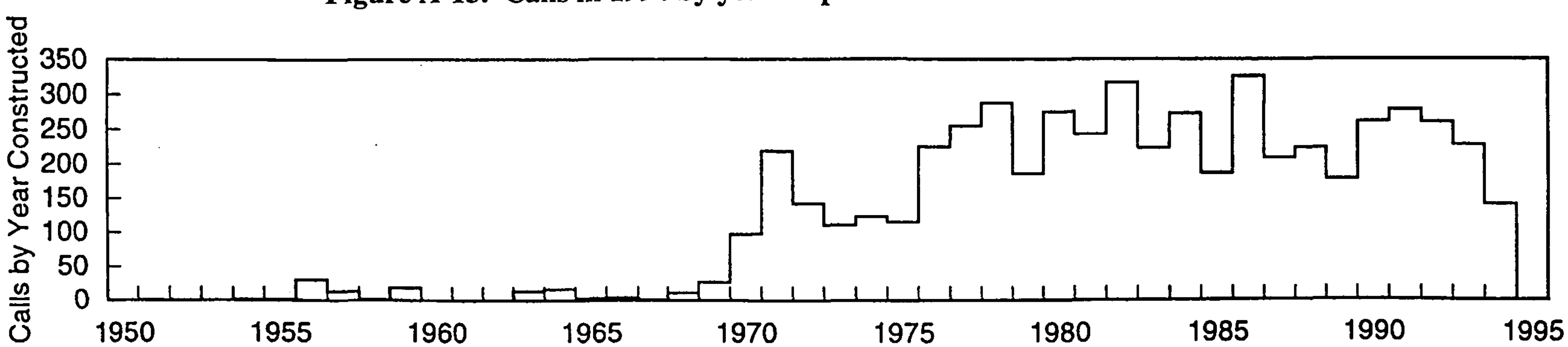


Figure A-13. Calls in 1994 by year ship constructed — ALL SHIPTYPES



ANALYSIS OF MARINE EMISSIONS IN
THE SOUTH COAST AIR BASIN

APPENDIX B

Emissions calculations from Lloyd's Data

Exhibit B-1 — Variables Used in Analysis

Exhibit B-2 — Equations Used in Analysis

Exhibit B-3 — Sample calculation for Ship B6 at 70% MCR

Demonstration that ARCADIS Geraghty & Miller, Results are Consistent with Lloyd's Results

Exhibit B-4 — Average NO_x Emission Rates at 85% MCR for Slow Speed Vessels

Exhibit B-5 — Average NO_x Emission Rates at 85% MCR for Medium Speed Vessels

Calculations of Average NO_x rates

Exhibit B-6 through B-13

Energy consumption calculations by medium speed versus slow speed ships

Exhibit B-14

Exhibit B-1. Variables Used in Analysis

Symbol	Description	Units	Remarks
ALF	H content of fuel	% m/m	
AWH	Atomic weight of H		
BET	C content of fuel	% m/m	
CO2D	Concentration of CO_2	% V/V	in dry exhaust
COD	Concentration of CO	ppm	in dry exhaust
DEL	N content of fuel	% m/m	
EAFCDO	Excess-air-factor based on complete combustion and the CO2-concentration	kg/kg	
EAFEXH	Excess-air-factor based on the exhaust gas concentration of carbon containing components	kg/kg	
EXHCPN	Exhaust gas ratio of components with carbon	V/V	
EXHDENS	Density of wet exhaust	kg/m^3	
FFH	Fuel specific factor used for calculation of wet concentration from dry concentration		dry basis
GAIRW	Intake air mass flowrate on wet basis	kg/h	
GAIRD	Intake air mass flowrate on dry basis	kg/h	
GAIRD	Combustion air mass flow	kg/h	dry combustion air
GAM	S content of fuel	% m/m	
GEXHW	Exhaust gas mass flowrate on wet basis	kg/h	
GEXHW	Exhaust mass flow	kg/h	wet exhaust
GFUEL	Fuel mass flow	kg/h	
H_a	Absolute humidity of the intake air	g/kg	
HCD	Hydrocarbons	ppm C1	in dry exhaust
HCW	Hydrocarbons	ppm C1	in wet exhaust
HTCRAT	Hydrogen-to-Carbon ratio of the fuel	mol/mol	
K_{HDIES}	Humidity correction factor for NO_x for intercooled diesel engines	—	
MVH2O	Molecular volume of H_2O	l/mol	individual gas
NOCONC	NO concentration	ppm	in wet exhaust
NO_x rate	NO_x emission rate	g/kWh	
STOIAR	Stoichiometric air demand for the combustion of 1 kg fuel	kg/kg	
T_a	Absolute temperature of intake air	K	
T_{SC}	Temperature of intercooled air	K	
T_{SCRef}	Intercooled air reference temperature	K	

Exhibit B-2. Equations Used in Analysis

Equation No.	Equation	NO_x Technical Equation Code No.
1	$STOIAR = \left(\frac{BET}{12.011} + \frac{ALF}{(4*1.00794)} + \frac{GAM}{32.060}\right) * \frac{31.9988}{23.15}$	(1-4)
2	$EAFCDO = \frac{\left[\frac{BET*10*22..262}{12.011*1000*\left(\frac{CO2D}{100}\right)} + \frac{STOIAR*0.2315}{1.42895} - \frac{BET*10*22.262}{(12.011*1000))} - \frac{GAM*10*21.891}{(32.060*1000)}\right]}{STOIAR*\left(\frac{0.7685}{1.2505} + \frac{0.2315}{1.42895}\right)}$	(1-5)
3	$HTCRAT = \frac{ALF*12.011}{(1.00794*BET)}$	(1-6)
4	$GAIRD = EAFCDO*GFUEL*STOIAR$	(1-15)
5	$FFH = \frac{(0.111127*ALF)}{\left[0.773329 + (0.0555583*ALF - 0.000109*BET - 0.000157*GAM)*\left(\frac{GFUEL}{GAIRD}\right)\right]}$	(1-12)
6	$HCD = \frac{HCW*EAFCDO*STOIAR}{(EAFCDO*STOIAR - FFH)}$	(1-18)
7	$EXHCPN = \left(\frac{CO2D}{100}\right) + \left(\frac{COD}{10^6}\right) + \left(\frac{HCD}{10^6}\right)$	(1-19)
8	$EAFEXH = \frac{\left[\frac{1}{EXHCPN} - \frac{COD}{10^6*2*EXHCPN} - \frac{HCD}{10^6*EXHCPN} + \frac{HTCRAT}{4}*\left(1 - \frac{HCD}{10^6*EXHCPN}\right) - \frac{0.75*HTCRAT}{\left(\frac{3.5*10^6*EXHCPN}{COD}\right) + \frac{1-3.5}{\left(1 - \frac{HCD}{10^6*EXHCPN}\right)}}\right]}{4.77*\left(1 + \frac{HTCRAT}{4}\right)}$	(1-20)
9	$GEXHW = GFUEL*(1 + EAFEXH*STOIAR)$	(1-24)
10	$K_{HDIES} = \frac{1}{1 - 0.012*(H_a - 10.71) - 0.00275*(T_a - 298) + 0.00285 + (T_{SC} - T_{SCRef})}$	(14)
11	$EXHDENS = \frac{FFH*200*AWH*\left(1*\frac{GFUEL}{GAIRW}\right)}{ALF*MVH2O}$	(2-61)
12	$u = \frac{0.002053}{EXHDENS}$	5.12.4.2
13	$NO_x Rate = u*GEXHW*NOCONC$	(15)

Exhibit B-3. Sample Calculation — B6 at 70% MCR

Symbol	Description	Value
Fuel		
ALF	H content of fuel %m/m	11.22
BET	C content of fuel, %m/m	88.32
GAM	S content of fuel, %m/m	1.20
DEL	N content of fuel, %m/m	0.41
	Fuel density kg/l	0.974
	Fuel flow rate, l/min	33.2
GFUEL	Calculated fuel mass flow rate, kg/hr	1940
Intake Air		
Ta	Ambient temperature, K	278.15
Ha	Absolute humidity of intake air, g/kg	4.2
Power Output		
	Power output at test point, kW	10012
	Rated power of engine, kW	14323
	Power output, %MCR	70%
Emissions Measurements		
NOCONC	NO ppm wet	1060
O2D	O_2 %V/V dry	15.10
CO2D	CO_2 %V/V dry	3.00
COD	CO ppm dry	20
HCW	HC ppmC1 wet	27
Calculations		
STOIAR	See Exhibit B-1	14.062
EAFCDO	See Exhibit B-1	5.055
HTCRAT	See Exhibit B-1	1.514
GAIRD	See Exhibit B-1	137912.817
FFH	See Exhibit B-1	1.595
HCD	See Exhibit B-1	27.620
EXHCPN	See Exhibit B-1	0.030
EAFEXH	See Exhibit B-1	5.119
GEXHW	See Exhibit B-1	141600
KHDIES	See Exhibit B-1	0.837
EXHDENS	See Exhibit B-1	1.293
u	See Exhibit B-1	0.001588
NO_x Rate	See Exhibit B-1	19.91

Exhibit B-4. Average NO_x Emission Rates at 85% MCR for Slow Speed Vessels

Ship/Engine	NO_x g/kWh at 85% MCR	Source
B6	21.8	ARCADIS Geraghty & Miller analysis of Lloyd's data
CT1	13.7	
CT2	11.8	
R8-P	18.4	
R8-S	19.2	
R9-P	15.5	
R9-S	20.4	
TK6	12.7	
TK7	18.6	
TK8	16.2	
TK9	22.1	
Average, SS	17.3	
Average reported by Lloyd's	17	Lloyd's
Match?	YES	

Exhibit B-5. Average NO_x Emission Rates at 85% MCR for Medium Speed Vessels

Ship/Engine	NO_x g/kWh at 85% MCR	Source
B1	16.2	
B2	8.8	
B3	11.6	
B4	16.4	
B5	15.5	
CT1gen	15.8	
D1	12.0	
D2	14.3	
D3	12.4	
D4	11.9	
D5	11.5	ARCADIS Geraghty &
D6	7.7	Miller analysis of
R1-C	9.7	Lloyd's data
R1-S	10.7	
R2-P	16.4	
R2-C	13.8	Note that for this
R3-P	14.6	comparison we
R3-S	13.7	include the tug data
R4	11.4	in the average, as
R5-C	14.4	Lloyd's did.
R5-S	12.1	We did not include
R6	14.9	the tug data,
R7-C	15.5	however, in the
R7-Sgen	10.1	IMO analysis for
R7-P	15.0	ocean-going vessels.
TK1	12.0	
TK2	10.8	
TK3	11.0	
TK4	8.1	
TK5	13.2	
T1	9.9	
T2	9.5	
T3	12.2	
T4	9.0	
T5	11.6	
T6	11.8	
T7	10.9	
Average, MS	12.3	
Average reported by Lloyd's	12	Lloyd's
Match?	YES	

Exhibit B-6. Average NO_x rates (g/kWh) at 85% MCR — slow speed ships

Ship/Engine	NO_x g/kWh at 85% MCR	Meets IMO?	NO_x g/kWh Meeting IMO	Revised NO_x	Revised Complying NO_x Rates
B6	21.85	FALSE		18.10	18.10
CT1	13.73	TRUE	13.73		13.73
CT2	11.82	TRUE	11.82		11.82
R8-P	18.42	FALSE		16.21	16.21
R8-S	19.15	FALSE		15.77	15.77
R9-P	15.51	TRUE	15.51		15.51
R9-S	20.41	FALSE		16.22	16.22
TK6	12.66	TRUE	12.66		12.66
TK7	18.57	FALSE		16.86	16.86
TK8	16.16	TRUE	16.16		16.16
TK9	22.11	FALSE		18.87	18.87
Average	**17.31**			**Revised Average**	**15.63**

Exhibit B-7. Average NO_x rates (g/kWh) at 85% MCR — medium speed ships

Ship/Engine	NO_x g/kWh at 85% MCR	Meets IMO?	NO_x g/kWh Meeting IMO	Revised NO_x	Revised Complying NO_x Rates
B1	16.2	FALSE		10.81	10.81
B2	8.8	TRUE	8.77		8.77
B3	11.6	TRUE	11.61		11.61
B4	16.4	FALSE		12.86	12.86
B5	15.5	FALSE		12.16	12.16
CT1gen	15.8	FALSE		11.36	11.36
D1	12.0	TRUE	12.04		12.04
D2	14.3	FALSE		11.56	11.56
D3	12.4	FALSE		11.23	11.23
D4	11.9	FALSE		11.08	11.08
D5	11.5	TRUE	11.46		11.46
D6	7.7	TRUE	7.69		7.69
R1-C	9.7	TRUE	9.68		9.68
R1-S	10.7	TRUE	10.70		10.70
R2-P	16.4	FALSE		14.77	14.77
R2-C	13.8	FALSE		13.40	13.40
R3-P	14.6	FALSE		12.30	12.30
R3-S	13.7	FALSE		11.94	11.94
R4	11.4	TRUE	11.39		11.39
R5-C	14.4	FALSE		13.39	13.39
R5-S	12.1	TRUE	12.09		12.09
R6	14.9	FALSE		13.36	13.36
R7-C	15.5	FALSE		13.64	13.64
R7-Sgen	10.1	TRUE	10.10		10.10
R7-P	15.0	FALSE		13.57	13.57
TK1	12.0	FALSE		10.81	10.81
TK2	10.8	TRUE	10.85		10.85
TK3	11.0	TRUE	10.99		10.99
TK4	8.1	TRUE	8.11		8.11
TK5	13.2	FALSE		11.71	11.71
Average, all ships	**12.7**				**11.51**

Exhibit B-8. Uncontrolled NO_x g/kWh at South Coast %MCRs — slow speed engines

Ship/Engine	80% MCR	40% MCR	35% MCR	20% MCR	15% MCR	10% MCR
B6	20.96	18.46	18.22	18.83	22.19	48.65
CT1	13.73	16.32	17.49	35.43	51.57	67.71
CT2	11.82	16.23	18.24	31.47	43.03	54.58
R8-P	18.42	20.33	21.09	19.89	19.89	19.89
R8-S	19.15	21.98	22.86	27.02	28.90	28.90
R9-P	15.51	20.33	16.19	15.60	15.53	15.53
R9-S	20.41	21.17	21.36	21.88	21.88	21.88
TK6	12.66	10.55	10.82	12.70	13.68	20.01
TK7	18.57	16.50	16.01	17.16	18.09	12.56
TK8	16.16	19.25	18.47	14.61	13.23	11.28
TK9	20.25	19.80	18.78	15.75	15.62	16.80
Average	**17.06**	**18.26**	**18.14**	**20.94**	**23.96**	**28.89**

Exhibit B-9. IMO-complying NO_x g/kWh at South Coast % MCRs — full IMO — slow speed engines

Ship/Engine	80% MCR	40% MCR	35% MCR	20% MCR	15% MCR	10% MCR
B6	17.22	14.71	14.47	15.08	18.44	44.90
CT1	13.73	16.32	17.49	35.43	51.57	67.71
CT2	11.82	16.23	18.24	31.47	43.03	54.58
R8-P	16.21	18.11	18.88	17.68	17.68	17.68
R8-S	15.77	18.60	19.47	23.64	25.52	25.52
R9-P	15.51	18.11	18.11	15.60	15.53	15.53
R9-S	16.22	16.98	17.17	17.69	17.69	17.69
TK6	12.66	10.55	10.82	12.70	13.68	20.01
TK7	16.86	14.79	14.30	15.46	16.38	10.85
TK8	16.16	19.25	18.47	14.61	13.23	11.28
TK9	17.02	16.56	15.55	12.51	12.39	13.57
Average	**15.38**	**16.38**	**16.64**	**19.26**	**22.28**	**27.21**

Exhibit B-10. Uncontrolled NO g/kWh at South Coast % MCRs — medium speed engines

Ship/Engine	80% MCR	40% MCR	35% MCR	20% MCR	15% MCR	10% MCR
B1	16.20	17.67	19.28	24.15	27.83	39.05
B2	9.11	16.95	16.45	17.67	23.85	30.03
B3	11.61	10.33	10.15	8.48	10.02	14.17
B4	16.39	14.32	14.02	12.14	22.04	31.61
B5	15.91	14.32	14.57	23.86	29.20	34.55
CT1gen	15.82	21.13	21.35	22.14	23.17	24.20
D1	12.31	12.13	13.33	22.13	25.06	28.00
D2	14.34	19.99	20.87	23.59	28.50	44.16
D3	12.42	15.73	16.65	19.39	20.35	25.63
D4	11.91	12.58	12.98	17.35	19.69	29.53
D5	11.42	11.21	11.03	10.69	12.93	15.18
D6	7.69	11.39	12.61	16.27	23.16	30.96
R1-C	9.68	11.99	12.53	12.59	12.59	12.59
R1-S	10.70	11.92	12.20	14.82	16.10	21.41
R2-P	15.57	10.94	10.77	9.68	8.87	8.87
R2-C	13.81	11.19	10.62	8.98	8.60	8.22
R3-P	14.88	18.21	18.86	22.33	27.91	33.48
R3-S	13.98	17.01	17.46	24.58	27.30	33.36
R4	11.67	11.10	11.66	13.36	13.62	13.62
R5-C	14.43	12.32	12.20	11.65	12.13	12.13
R5-S	11.99	11.35	11.17	15.11	17.12	19.13
R6	14.78	12.51	13.18	15.22	15.89	16.57
R7-C	15.29	12.64	12.15	14.05	16.51	18.97
R7-Sgen	10.20	12.89	13.42	16.05	17.61	19.17
R7-P	14.93	11.52	10.74	13.44	15.22	17.00
TK1	12.28	15.83	15.93	22.60	33.99	45.39
TK2	10.85	12.89	13.43	14.34	18.31	22.27
TK3	11.12	12.39	14.35	20.21	22.17	24.13
TK4	8.11	8.86	9.32	28.27	50.12	71.98
TK5	13.70	12.66	12.83	12.85	12.73	12.61
Average	**12.77**	**13.53**	**13.87**	**16.93**	**20.42**	**25.27**

Exhibit B-11. IMP-complying NO_x g/kWh at South Coast % MCRs — full IMO — medium speed engines

Ship/Engine	80% MCR	40% MCR	35% MCR	20% MCR	15% MCR	10% MCR
B1	10.81	12.28	13.89	18.76	22.44	33.66
B2	9.11	16.95	16.45	17.67	23.85	30.03
B3	11.61	10.33	10.15	8.48	10.02	14.17
B4	12.86	10.79	10.49	8.60	18.51	28.08
B5	12.61	11.02	11.27	20.56	25.91	31.25
CT1gen	11.36	16.67	16.89	17.68	18.71	19.74
D1	12.31	12.13	13.33	22.13	25.06	28.00
D2	11.56	17.21	18.09	20.80	25.71	41.38
D3	11.23	14.54	15.45	18.19	19.16	24.43
D4	11.08	11.75	12.16	16.52	18.86	28.70
D5	11.42	11.21	11.03	10.69	12.93	15.18
D6	7.69	11.39	12.61	16.27	23.16	30.96
R1-C	9.68	11.99	12.53	12.59	12.59	12.59
R1-S	10.70	11.92	12.20	14.82	16.10	21.41
R2-P	13.90	9.27	9.10	8.01	7.20	7.20
R2-C	13.44	10.82	10.25	8.61	8.23	7.85
R3-P	12.59	15.91	16.56	20.04	25.61	31.19
R3-S	12.25	15.28	15.73	22.85	25.57	31.63
R4	11.67	11.10	11.66	13.36	13.62	13.62
R5-C	13.39	11.28	11.16	10.61	11.09	11.09
R5-S	11.99	11.35	11.17	15.11	17.12	19.13
R6	13.21	10.93	11.61	13.64	14.32	15.00
R7-C	13.46	10.81	10.32	12.21	14.68	17.14
R7-Sgen	10.20	12.89	13.42	16.05	17.61	19.17
R7-P	13.50	10.09	9.31	12.01	13.79	15.57
TK1	11.04	14.59	14.69	21.36	32.75	44.15
TK2	10.85	12.89	13.43	14.34	18.31	22.27
TK3	11.12	12.39	14.35	20.21	22.17	24.13
TK4	8.11	8.86	9.32	28.27	50.12	71.98
TK5	12.22	11.19	11.35	11.37	11.25	11.13
Average	**11.56**	**12.33**	**12.67**	**15.73**	**19.22**	**24.06**

Exhibit B-12. Calendar year NO_x g/kWh at South Coast %MCRs — slow speed engines

	% MCR	80%	40%	35%	20%	15%	10%
	Uncontrolled NO_x	17.06	18.26	18.14	20.94	23.96	28.89
	IMO NO_x	15.38	16.38	16.64	19.26	22.28	27.21
Calendar Year	**%IMO**	**Calendar Year-Specific NO_x Rates (g/kWh)**					
2000	2%	17.0	18.2	18.1	20.9	23.9	28.8
2001	6%	16.9	18.1	18.0	20.8	23.9	28.8
2002	11%	16.9	18.1	18.0	20.7	23.8	28.7
2003	15%	16.8	18.0	17.9	20.7	23.7	28.6
2004	19%	16.7	17.9	17.8	20.6	23.6	28.6
2005	23%	16.7	17.8	17.8	20.6	23.6	28.5
2006	27%	16.6	17.8	17.7	20.5	23.5	28.4
2007	31%	16.5	17.7	17.7	20.4	23.4	28.4
2008	37%	16.4	17.6	17.6	20.3	23.3	28.3
2009	41%	16.4	17.5	17.5	20.3	23.3	28.2
2010	45%	16.3	17.4	17.5	20.2	23.2	28.1

Exhibit B-13. Calendar year NO g/kWh at South Coast % MCRs — medium speed engines

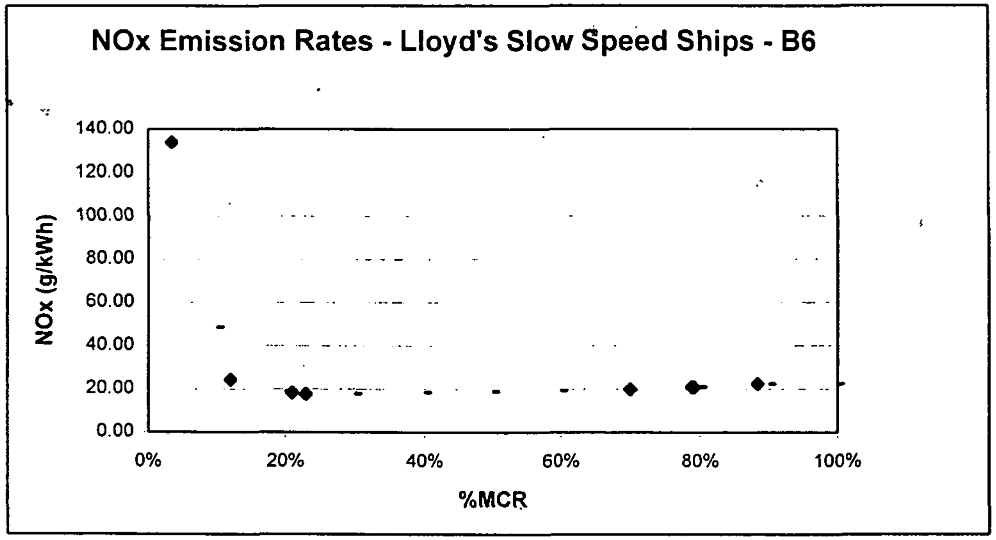
	% MCR	80%	40%	35%	20%	15%	10%
	Uncontrolled NO_x	12.77	13.53	13.87	16.93	20.42	25.27
	IMO NO_x	11.56	12.33	12.67	15.73	19.22	24.06
Calendar Year	**%IMO**	**Calendar Year-Specific NO_x Rates (g/kWh)**					
2000	2%	12.7	13.5	13.8	16.9	20.4	25.2
2001	6%	12.7	13.5	13.8	16.9	20.3	25.2
2002	11%	12.6	13.4	13.7	16.8	20.3	25.1
2003	15%	12.6	13.3	13.7	16.7	20.2	25.1
2004	19%	12.5	13.3	13.6	16.7	20.2	25.0
2005	23%	12.5	13.3	13.6	16.7	20.1	25.0
2006	27%	12.4	13.2	13.5	16.6	20.1	24.9
2007	31%	12.4	13.2	13.5	16.6	20.0	24.9
2008	37%	12.3	13.1	13.4	16.5	20.0	24.8
2009	41%	12.3	13.0	13.4	16.4	19.9	24.8
2010	45%	12.2	13.0	13.3	16.4	19.9	24.7

Exhibit B-14. Calculation of energy consumption from medium speed versus slow speed motorships

Shiptype	Total Cruise MWh/yr	% Total MWh/yr	% Ships MS	MS MWh/hr
Auto carrier	20,553	4	29	5,960,227
Bulk	58,993	12	5	2,949,671
Container	260,955	53	4	10,438,191
General cargo	19,026	4	22	4,185,814
Passenger	33,556	7	52	17,448,998
Reefer	25,955	5	18	4,671,961
RORO	3,826	1	10	382,588
Tanker	71,728	15	6	3,755,133
Total	494,592			49,792,583
Total cruise MWh/yr in MS engines				**10%**
	Precaut. Area and Maneuvering			
Shiptype	**MWh/yr**	**% Total MWh/hr**	**% Ships MS**	**MS MWh/yr**
Auto carrier	2,497	4	29	769,846
Bulk	11,258	17	5	539,327
Container	28,703	43	4	1,255,755
General cargo	3,045	5	22	738,802
Passenger	5,697	9	52	3,071,705
Reefer	3,461	5	18	633,296
RORO	268	0	10	27,163
Tanker	11,585	17	6	585,161
Total	66,514			7,621,053
Total low speed MWh/yr in MS engines				**11%**

ANALYSIS OF MARINE EMISSIONS IN THE SOUTH COAST AIR BASIN

APPENDIX C



Point Estimates

% MCR	NOx g/kWh
10%	48.65
20%	18.83
30%	17.98
40%	18.46
50%	18.95
60%	19.43
70%	19.91
80%	20.96
90%	22.43
100%	22.43

Profile Points

% MCR	Uncon. NOx g/kWh	IMO NOx g/kWh
85%	21.85	18.10
80%	20.96	17.22
40%	18.46	14.71
35%	18.22	14.47
20%	18.83	15.08
15%	22.19	18.44
10%	48.65	44.90

E2 Test Procedure

% MCR	NOx g/kWh	Revised NOx
25%	17.74	13.99
50%	18.95	15.20
75%	20.51	16.76
100%	22.43	18.68

E2 Wghtd NOx g/kWh	Revised E2 NOx
20.75	17.00

Applicable IMO std:	
17.00	17.00

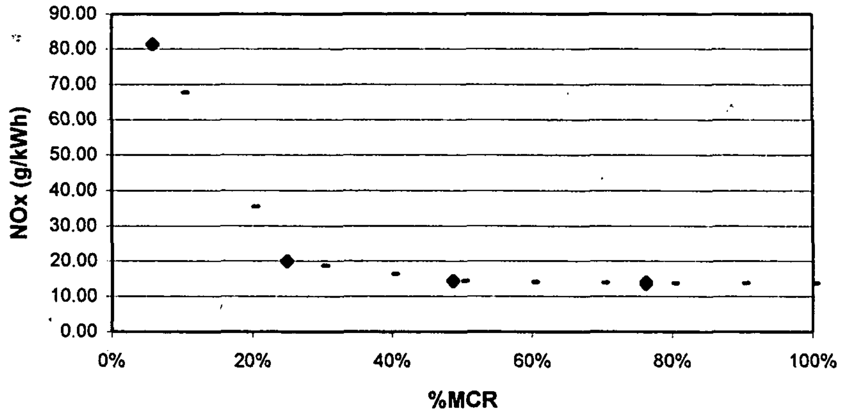
Comply with IMO?	Revised?
FALSE	TRUE

Test Information:

Test % MCR	Test NOx (g/kWh)
3%	133.83
12%	24.28
21%	18.21
23%	17.64
70%	19.91
79%	20.96
79%	20.80
88%	22.43

Vessel:	**B6**	
Type:	Bulk Carrier	
Size:	172810	dwt (tonnes)
Launched:	1987	
Engine:	**main**	
MCR	14323	kW
Test %MCR	79%	
Test RPM	77	
Test % rated RPM	93%	
Propeller:	FPP	
Est. rated RPM	83	

NOx Emission Rates - Lloyd's Slow Speed Ships - CT1



Point Estimates

% MCR	NOx g/kWh
10%	67.71
20%	35.43
30%	18.66
40%	16.32
50%	14.28
60%	14.07
70%	13.86
80%	13.73
90%	13.73
100%	13.73

Profile Points

% MCR	Uncon. NOx g/kWh	IMO NOx g/kWh
85%	13.73	13.73
80%	13.73	13.73
40%	16.32	16.32
35%	17.49	17.49
20%	35.43	35.43
15%	51.57	51.57
10%	67.71	67.71

E2 Test Procedure

% MCR	NOx g/kWh	Revised NOx
25%	19.86	NA
50%	14.28	NA
75%	13.75	NA
100%	13.73	NA

E2 Wghtd NOx g/kWh	Revised E2 NOx
14.13	NA

Applicable IMO std:

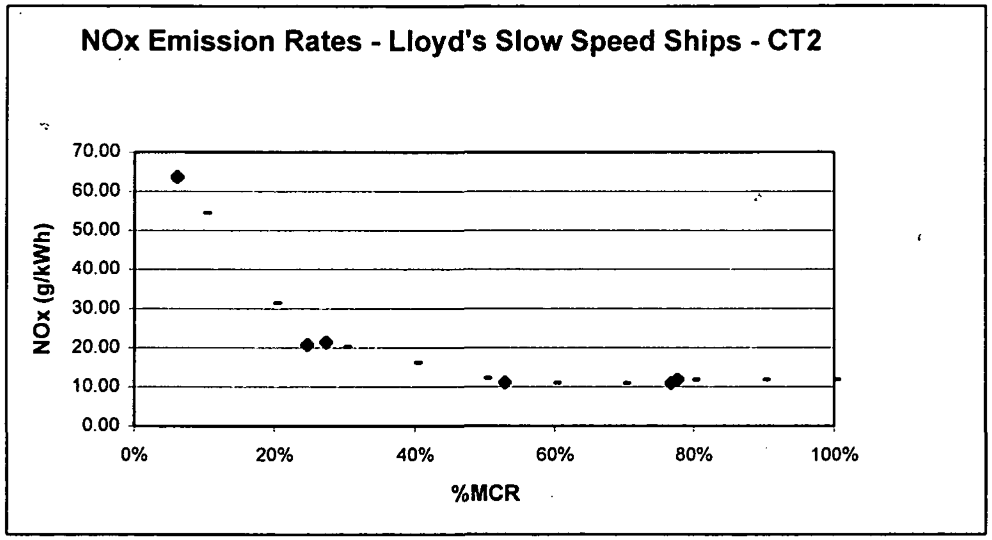
17.00	17.00

Comply with IMO?	Revised?
TRUE	NA

Test Information:

	Test % MCR	Test NOx (g/kWh)
	6%	81.33
	25%	19.86
	49%	14.31
test =>	76%	13.96
test =>	76%	13.49
use avg.	76%	13.73

Vessel:	**CT1**	
Type:	Container	
Size:	27630	dwt (tonnes)
Launched:	1980	
Engine:	**main**	
MCR	21634	kW
Test %MCR	76%	
Test RPM	118	
Test % rated RPM	91%	
Propeller:	FPP	
Est. rated RPM	129	



Point Estimates

% MCR	NOx g/kWh
10%	54.58
20%	31.47
30%	20.26
40%	16.23
50%	12.19
60%	10.98
70%	10.90
80%	11.82
90%	11.82
100%	11.82

Profile Points

	Uncon.	IMO
% MCR	NOx g/kWh	
85%	11.82	11.82
80%	11.82	11.82
40%	16.23	16.23
35%	18.24	18.24
20%	31.47	31.47
15%	43.03	43.03
10%	54.58	54.58

E2 Test Procedure

% MCR	NOx g/kWh	Revised NOx
25%	20.75	NA
50%	12.19	NA
75%	10.87	NA
100%	11.82	NA

E2 Wghtd NOx g/kWh	Revised E2 NOx
11.83	NA

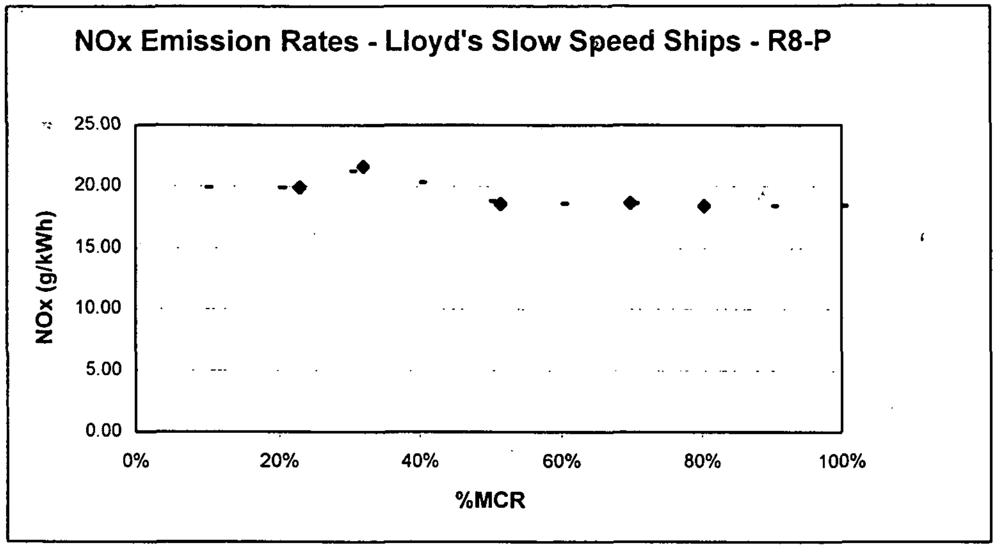
Applicable IMO std:	
17.00	17.00

Comply with IMO?	Revised?
TRUE	NA

Test Information:

Test % MCR	Test NOx (g/kWh)
6%	63.60
25%	20.75
27%	21.34
53%	11.03
77%	10.85
78%	11.82

Vessel:	**CT2**	
Type:	Container	
Size:	27893	dwt (tonnes)
Launched:	1977	
Engine:	**main**	
MCR	21634	kW
Test %MCR	78%	
Test RPM	113	
Test % rated RPM	92%	
Propeller:	FPP	
Est. rated RPM	122	



Point Estimates

% MCR	NOx g/kWh
10%	19.89
20%	19.89
30%	21.24
40%	20.33
50%	18.80
60%	18.61
70%	18.64
80%	18.42
90%	18.42
100%	18.42

Profile Points

	Uncon.	**IMO**
% MCR	NOx g/kWh	
85%	18.42	16.21
80%	18.42	16.21
40%	20.33	18.11
35%	21.09	18.88
20%	19.89	17.68
15%	19.89	17.68
10%	19.89	17.68

E2 Test Procedure

% MCR	NOx g/kWh	Revised NOx
25%	20.31	18.10
50%	18.80	16.59
75%	18.53	16.32
100%	18.42	16.21

E2 Wghtd NOx g/kWh	Revised E2 NOx
18.62	16.41

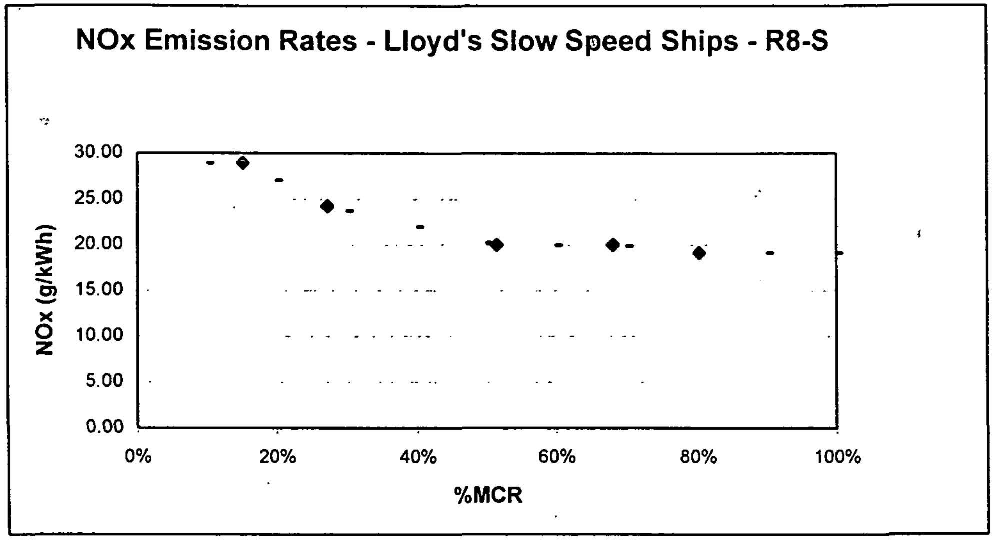
Applicable IMO std:	
16.41	16.41

Comply with IMO?	Revised?
FALSE	TRUE

Test Information:

Test % MCR	Test NOx (g/kWh)
23%	19.89
32%	21.58
51%	18.58
70%	18.64
80%	18.42

Vessel:	R8	
Type:	RORO	
Size:	3855	dwt (tonnes)
Launched:	1980	
Engine:	**Port main**	
MCR	6606	kW
Test %MCR	all	
Test RPM	155	
Propeller:	CPP	
Est. rated RPM	155	



Point Estimates

% MCR	NOx g/kWh
10%	28.90
20%	27.02
30%	23.73
40%	21.98
50%	20.23
60%	19.98
70%	19.87
80%	19.15
90%	19.15
100%	19.15

Profile Points

	Uncon.	**IMO**
% MCR	NOx g/kWh	
85%	19.15	15.77
80%	19.15	15.77
40%	21.98	18.60
35%	22.86	19.47
20%	27.02	23.64
15%	28.90	25.52
10%	28.90	25.52

E2 Test Procedure

% MCR	NOx g/kWh	Revised NOx
25%	25.08	21.70
50%	20.23	16.85
75%	19.52	16.14
100%	19.15	15.77

E2 Wghtd NOx g/kWh	Revised E2 NOx
19.79	16.41

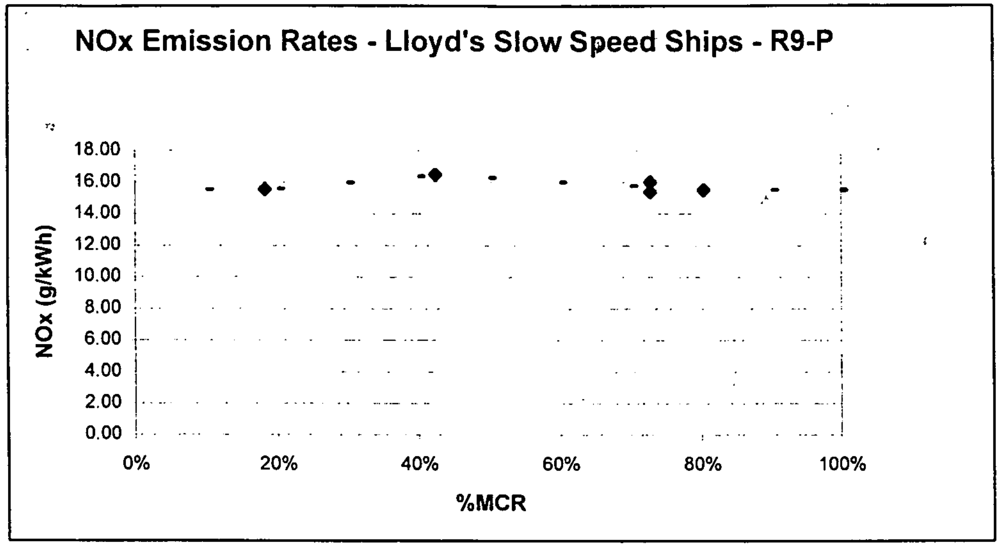
Applicable IMO std:	
16.41	16.41

Comply with IMO?	Revised?
FALSE	TRUE

Test Information:

Test % MCR	Test NOx (g/kWh)
15%	28.90
27%	24.21
51%	19.97
68%	20.00
80%	19.15

Vessel:	R8	
Type:	RORO	
Size:	3855	dwt (tonnes)
Launched:	1980	
Engine:	**starboard main**	
MCR	6606	kW
Test %MCR	all	
Test RPM	155	
Propeller:	CPP	
Est. rated RPM	155	



Point Estimates

% MCR	NOx g/kWh
10%	15.53
20%	15.60
30%	15.99
40%	16.38
50%	16.28
60%	16.03
70%	15.77
80%	15.51
90%	15.51
100%	15.51

Profile Points

% MCR	**Uncon.** NOx g/kWh	**IMO** NOx g/kWh
85%	15.51	15.51
80%	15.51	15.51
40%	16.38	16.38
35%	16.19	16.19
20%	15.60	15.60
15%	15.53	15.53
10%	15.53	15.53

E2 Test Procedure

% MCR	NOx g/kWh	Revised NOx
25%	15.80	NA
50%	16.28	NA.
75%	15.64	NA
100%	15.51	NA

E2 Wghtd NOx g/kWh	Revised E2 NOx
15.68	NA

Applicable IMO std:

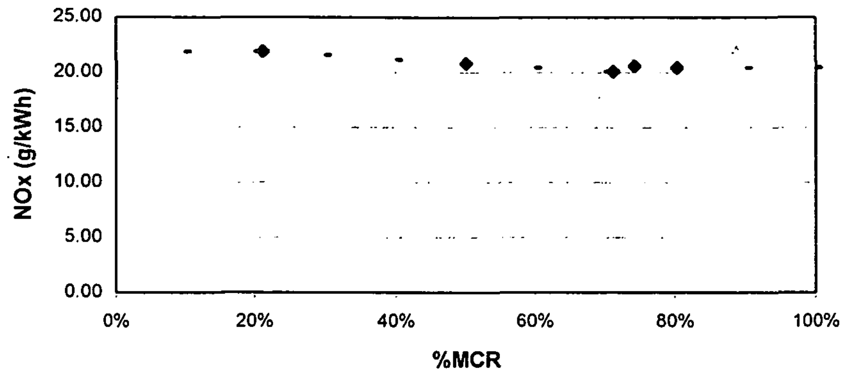
16.41	16.41

Comply with IMO?	Revised?
TRUE	NA

Test Information:

	Test % MCR	Test NOx (g/kWh)
	18%	15.53
	42%	16.48
use avg.	73%	15.69
test=>	73%	15.39
test=>	73%	16.00
	80%	15.51

Vessel:	R9	
Type:	RORO	
Size:	3060	dwt (tonnes)
Launched:	1980	
Engine:	**port main**	
MCR	6606	kW
Test %MCR	all	
Test RPM	155	
Propeller:	CPP	
Est. rated RPM	155	



Point Estimates

% MCR	NOx g/kWh
10%	21.88
20%	21.88
30%	21.55
40%	21.17
50%	20.79
60%	20.45
70%	20.10
80%	20.41
90%	20.41
100%	20.41

Profile Points

% MCR	Uncon. NOx g/kWh	IMO NOx g/kWh
85%	20.41	16.22
80%	20.41	16.22
40%	21.17	16.98
35%	21.36	17.17
20%	21.88	17.69
15%	21.88	17.69
10%	21.88	17.69

E2 Test Procedure

% MCR	NOx g/kWh	Revised NOx
25%	21.74	17.54
50%	20.79	16.60
75%	20.56	16.36
100%	20.41	16.22

E2 Wghtd NOx g/kWh	Revised E2 NOx
20.60	16.41

Applicable IMO std:

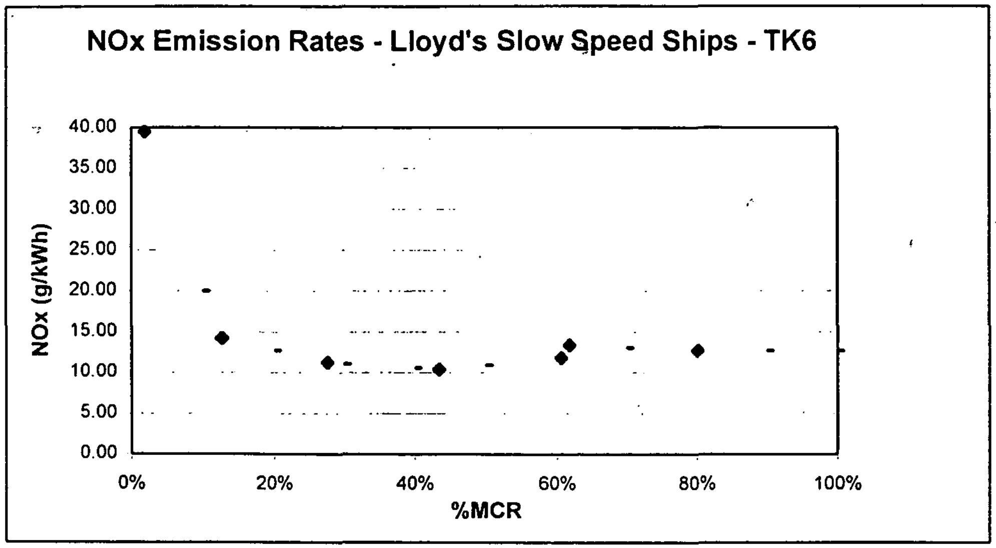
16.41	16.41

Comply with IMO?	Revised?
FALSE	TRUE

Test Information:

Test % MCR	Test NOx (g/kWh)
21%	21.88
50%	20.79
71%	20.06
74%	20.58
80%	20.41

Vessel:	R9	
Type:	RORO	
Size:	3060	dwt (tonnes)
Launched:	1980	
Engine:	**starboard main**	
MCR	6606	kW
Test %MCR	all	
Test RPM	155	
Propeller:	CPP	
Est. rated RPM	155	



Point Estimates

% MCR	NOx g/kWh
10%	20.01
20%	12.70
30%	11.09
40%	10.55
50%	10.91
60%	11.77
70%	13.04
80%	12.66
90%	12.66
100%	12.66

Profile Points

	Uncon.	**IMO**
% MCR	NOx g/kWh	
85%	12.66	12.66
80%	12.66	12.66
40%	10.55	10.55
35%	10.82	10.82
20%	12.70	12.70
15%	13.68	13.68
10%	20.01	20.01

E2 Test Procedure

% MCR	NOx g/kWh	Revised NOx
25%	11.72	NA
50%	10.91	NA
75%	12.85	NA
100%	12.66	NA

E2 Wghtd NOx g/kWh	Revised E2 NOx
12.52	NA

Applicable IMO std:

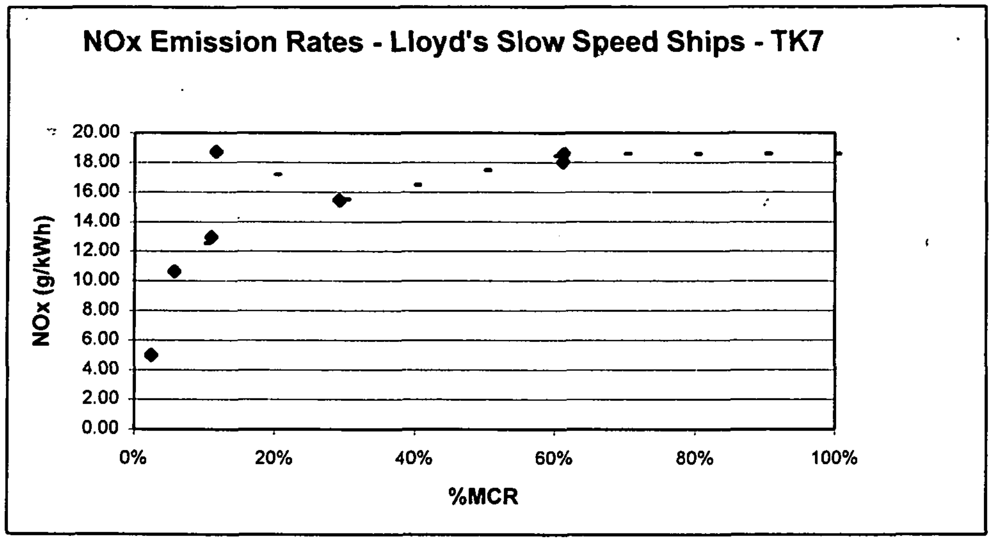
16.76 16.76

Comply with IMO?	Revised?
TRUE	NA

Test Information:

Test % MCR	Test NOx (g/kWh)
2%	39.43
12%	14.17
28%	11.23
43%	10.37
62%	13.36
60%	11.77
80%	12.66

Vessel:	**TK6**	
Type:	Tanker	
Size:	8317	dwt (tonnes)
Launched:	1970	
Engine:	**main**	
MCR	5371	kW
Test %MCR	80%	
Test RPM	130	
Test % rated RPM	93%	
Propeller:	FPP	
Est. rated RPM	140	



Point Estimates

% MCR	NOx g/kWh
10%	12.56
20%	17.16
30%	15.52
40%	16.50
50%	17.47
60%	18.45
70%	18.57
80%	18.57
90%	18.57
100%	18.57

Profile Points

	Uncon.	**IMO**
% MCR	NOx g/kWh	
85%	18.57	16.86
80%	18.57	16.86
40%	16.50	14.79
35%	16.01	14.30
20%	17.16	15.46
15%	18.09	16.38
10%	12.56	10.85

E2 Test Procedure

% MCR	NOx g/kWh	Revised NOx
25%	16.24	14.53
50%	17.47	15.76
75%	18.57	16.86
100%	18.57	16.86

E2 Wghtd NOx g/kWh	Revised E2 NOx
18.32	16.61

Applicable IMO std:

16.61	16.61

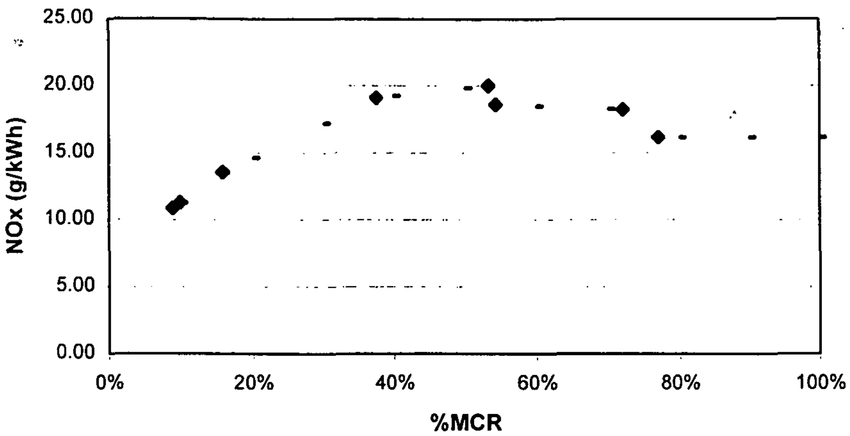
Comply with IMO?	Revised?
FALSE	TRUE

Test Information:

Test % MCR	Test NOx (g/kWh)
2%	4.98
6%	10.62
11%	12.97
12%	18.71
29%	15.45
61%	18.57

Vessel:	**TK7**	
Type:	Tanker	
Size:	20691	dwt (tonnes)
Launched:	1976	
Engine:	**port main**	
MCR	7012	kW
Test %MCR	61%	
Test RPM	124	
Test % rated RPM	85%	
Propeller:	FPP	
Est. rated RPM	146	

NOx Emission Rates - Lloyd's Slow Speed Ships - TK8



Test Information:

Test % MCR	Test NOx (g/kWh)
9%	10.85
10%	11.28
16%	13.52
37%	19.11
53%	20.00
54%	18.59
72%	18.20
77%	16.16

Vessel:	**TK8**	
Type:	Tanker	
Size:	131576	dwt (tonnes)
Launched:	1971	
Engine:	**main**	
MCR	18650	kW
Test %MCR	77%	
Test RPM	98	
Test % rated RPM	92%	
Propeller:	FPP	
Est. rated RPM	107	

Point Estimates

% MCR	NOx g/kWh
10%	11.28
20%	14.61
30%	17.18
40%	19.25
50%	19.82
60%	18.47
70%	18.25
80%	16.16
90%	16.16
100%	16.16

Profile Points

	Uncon.	**IMO**
% MCR	NOx g/kWh	
85%	16.16	16.16
80%	16.16	16.16
40%	19.25	19.25
35%	18.47	18.47
20%	14.61	14.61
15%	13.23	13.23
10%	11.28	11.28

E2 Test Procedure

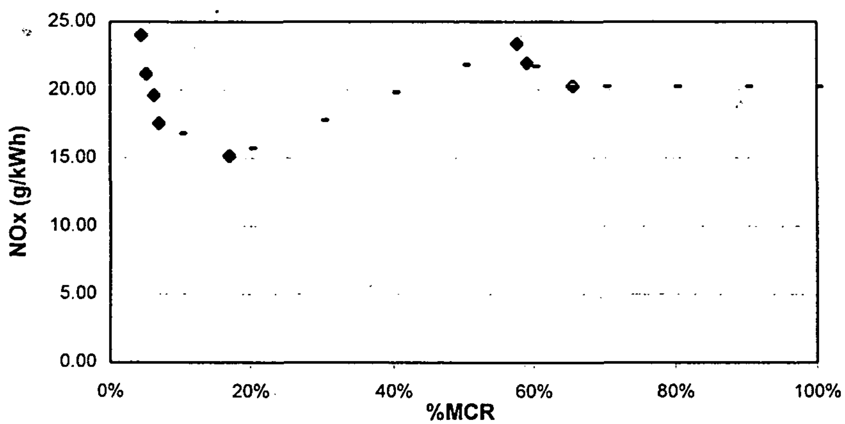
% MCR	NOx g/kWh	Revised NOx
25%	15.90	NA
50%	19.82	NA
75%	16.95	NA
100%	16.16	NA

E2 Wghtd NOx g/kWh	Revised E2 NOx
16.97	NA

Applicable IMO std:	
17.00	17.00

Comply with IMO?	Revised?
TRUE	NA

NOx Emission Rates - Lloyd's Slow Speed Ships - TK9



Point Estimates

% MCR	NOx g/kWh
10%	16.80
20%	15.75
30%	17.77
40%	19.80
50%	21.82
60%	21.70
70%	20.25
80%	20.25
90%	20.25
100%	20.25

Profile Points

	Uncon.	**IMO**
% MCR	NOx g/kWh	
85%	22.11	18.87
80%	20.25	17.02
40%	19.80	16.56
35%	18.78	15.55
20%	15.75	12.51
15%	15.62	12.39
10%	16.80	13.57

E2 Test Procedure

% MCR	NOx g/kWh	Revised NOx
25%	16.76	13.53
50%	21.82	18.59
75%	20.25	17.02
100%	20.25	17.02

E2 Wghtd NOx g/kWh	Revised E2 NOx
20.23	17.00

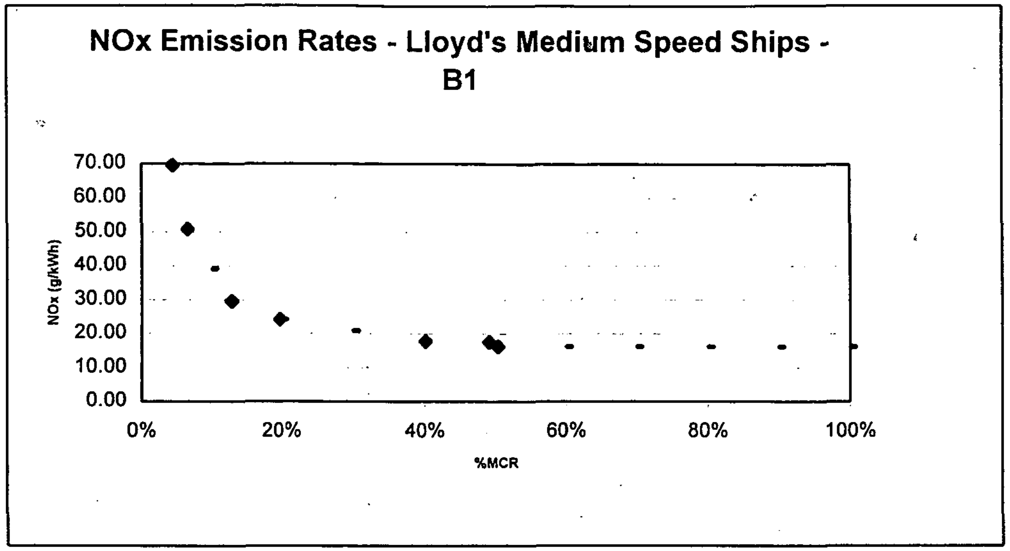
Applicable IMO std:	
17.00	17.00

Comply with IMO?	Revised?
FALSE	TRUE

Test Information:

Test % MCR	Test NOx (g/kWh)
4%	24.02
5%	21.17
6%	19.60
7%	17.54
17%	15.14
58%	23.36
59%	21.94
66%	20.25

Vessel:	**TK9**	
Type:	Tanker	
Size:	125457	dwt (tonnes)
Launched:	1977	
Engine:	**main**	
MCR	20299	kW
Test %MCR	66%	
Test RPM	110	
Test % rated RPM	87%	
Propeller:	FPP	
Est. rated RPM	126	



Point Estimates

% MCR	NOx g/kWh
10%	39.05
20%	24.15
30%	20.88
40%	17.67
50%	16.20
60%	16.20
70%	16.20
80%	16.20
90%	16.20
100%	16.20

Profile Points

	Uncon.	IMO
% MCR	NOx g/kWh	
85%	16.20	10.81
80%	16.20	10.81
40%	17.67	12.28
35%	19.28	13.89
20%	24.15	18.76
15%	27.83	22.44
10%	39.05	33.66

E2 Test Procedure

% MCR	NOx g/kWh	Revised NOx
25%	22.47	17.08
50%	16.20	10.81
75%	16.20	10.81
100%	16.20	10.81

E2 Wghtd NOx g/kWh	Revised E2 NOx
16.55	11.16

Applicable IMO std:

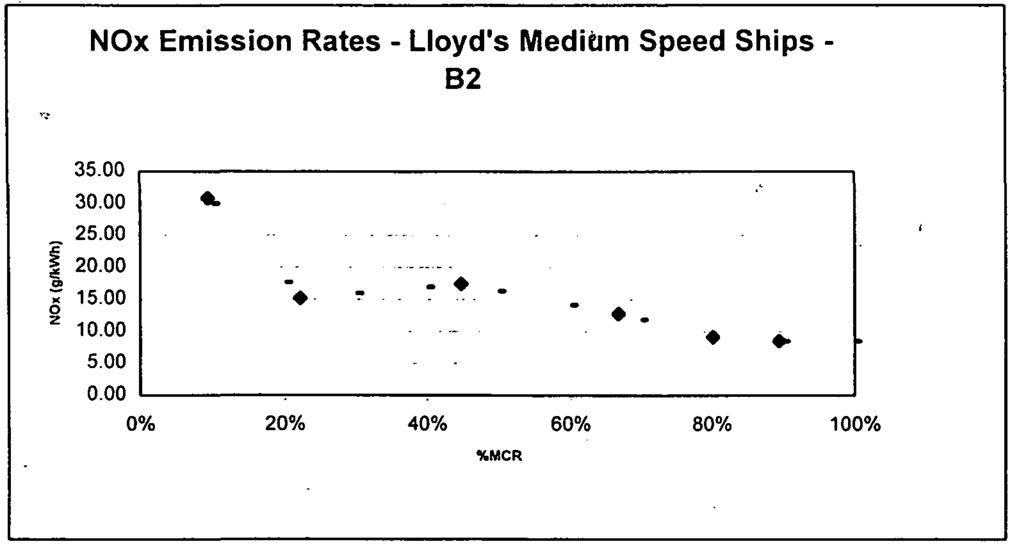
11.16	17.00

Comply with IMO?	Revised?
FALSE	TRUE

Test Information:

Test % MCR	Test NOx (g/kWh)
4%	69.54
7%	50.81
13%	29.54
20%	24.15
40%	17.67
49%	17.53
50%	16.20

Vessel:	**B1**	
Type:	Bulk carrier	
Size:	1720	dwt (tonnes)
Launched:	1979	
Engine:	**Main**	
MCR	1350	kW
Test %MCR	50%	
Test RPM	850	
Test % rated RPM	80%	
Propeller Type:	FPP	
Est. rated RPM	1068	



Point Estimates

% MCR	NOx g/kWh
10%	30.03
20%	17.67
30%	15.95
40%	16.95
50%	16.29
60%	14.16
70%	11.84
80%	9.11
90%	8.46
100%	8.46

Profile Points

	Uncon.	**IMO**
% MCR	NOx g/kWh	
85%	8.77	8.77
80%	9.11	9.11
40%	16.95	16.95
35%	16.45	16.45
20%	17.67	17.67
15%	23.85	23.85
10%	30.03	30.03

E2 Test Procedure

% MCR	NOx g/kWh	Revised NOx
25%	15.46	NA
50%	16.29	NA
75%	10.49	NA
100%	8.46	NA

E2 Wghtd NOx g/kWh	Revised E2 NOx
10.80	NA

Applicable IMO std:

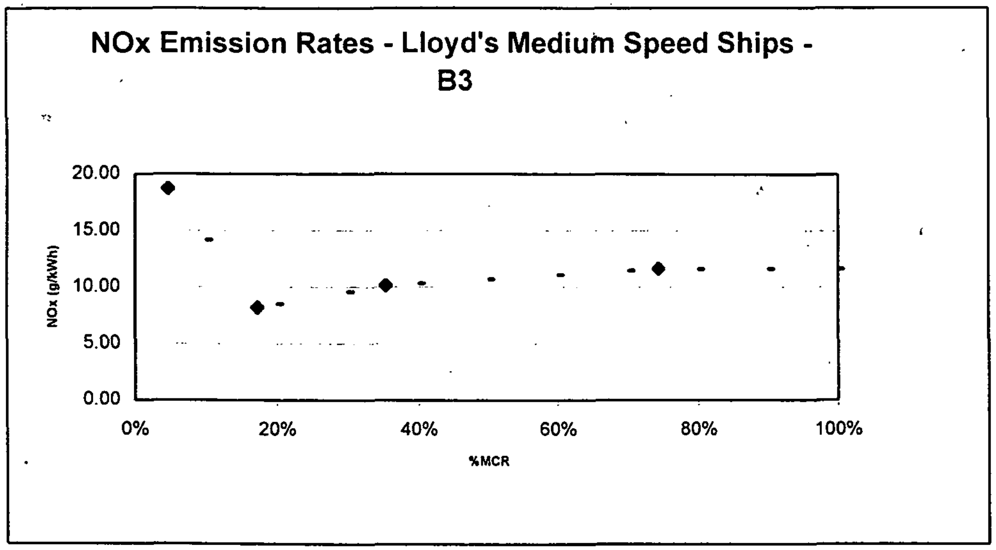
11.54	11.54

Comply with IMO?	Revised?
TRUE	NA

Test Information:

Test % MCR	Test NOx (g/kWh)
9%	30.84
22%	15.16
45%	17.42
67%	12.72
80%	9.11
89%	8.46

Vessel:	**B2**	
Type:	Bulk carrier	
Size:	2018	dwt (tonnes)
Launched:	1982	
Engine:	**Main**	
MCR	749	kW
Test %MCR	all	
Test RPM	900	
Test % rated RPM		
Propeller Type:	CPP	
Est. rated RPM	900	



Point Estimates

% MCR	NOx g/kWh
10%	14.17
20%	8.48
30%	9.57
40%	10.33
50%	10.70
60%	11.07
70%	11.45
80%	11.61
90%	11.61
100%	11.61

Profile Points

	Uncon.	**IMO**
% MCR	NOx g/kWh	
85%	11.61	11.61
80%	11.61	11.61
40%	10.33	10.33
35%	10.15	10.15
20%	8.48	8.48
15%	10.02	10.02
10%	14.17	14.17

E2 Test Procedure

% MCR	NOx g/kWh	Revised NOx
25%	9.03	NA
50%	10.70	NA
75%	11.61	NA
100%	11.61	NA

E2 Wghtd NOx g/kWh	Revised E2 NOx
11.37	NA

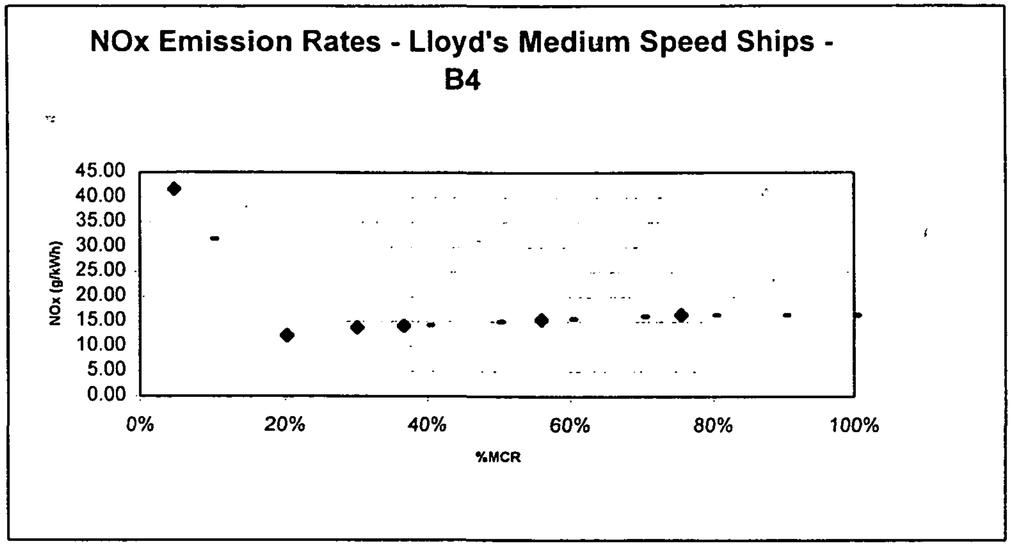
Applicable IMO std:	
13.92	13.92

Comply with IMO?	Revised?
TRUE	NA

Test Information:

Test % MCR	Test NOx (g/kWh)
5%	18.71
17%	8.18
35%	10.15
74%	11.61

Vessel:	**B3**	
Type:	Bulk carrier	
Size:	1593	dwt (tonnes)
Launched:	1975	
Engine:	**Main**	
MCR	552	kW
Test %MCR	74%	
Test RPM	320	
Test % rated RPM	91%	
Propeller Type:	FPP	
Est. rated RPM	353	



Point Estimates

% MCR	NOx g/kWh
10%	31.61
20%	12.14
30%	13.80
40%	14.32
50%	14.99
60%	15.60
70%	16.11
80%	16.39
90%	16.39
100%	16.39

Profile Points

	Uncon.	**IMO**
% MCR	NOx g/kWh	
85%	16.39	12.86
80%	16.39	12.86
40%	14.32	10.79
35%	14.02	10.49
20%	12.14	8.60
15%	22.04	18.51
10%	31.61	28.08

E2 Test Procedure

% MCR	NOx g/kWh	Revised NOx
25%	12.96	9.43
50%	14.99	11.46
75%	16.39	12.86
100%	16.39	12.86

E2 Wghtd NOx g/kWh	Revised E2 NOx
16.05	12.52

Applicable IMO std:

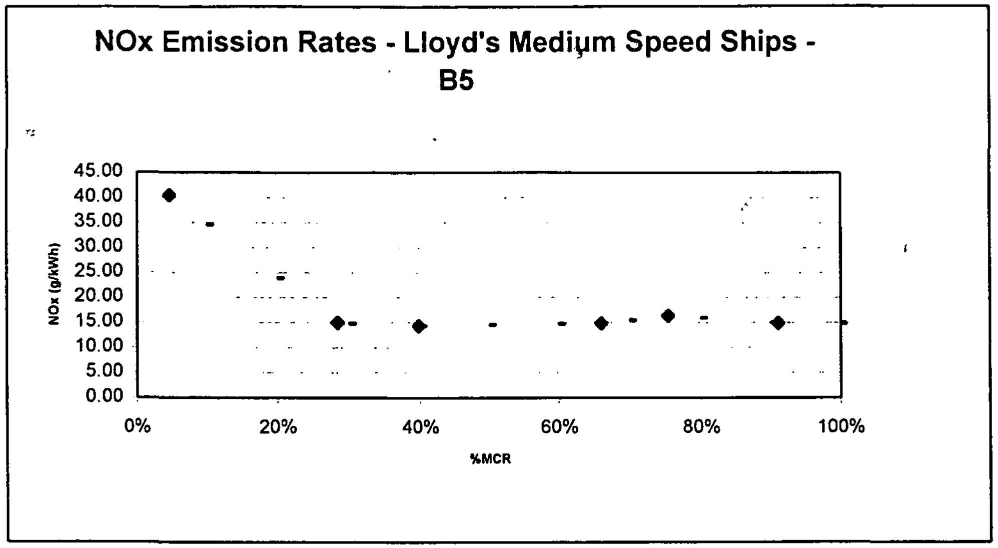
12.52	12.52

Comply with IMO?	Revised?
FALSE	TRUE

Test Information:

Test % MCR	Test NOx (g/kWh)
5%	41.57
20%	12.14
30%	13.80
37%	14.09
56%	15.39
75%	16.39

Vessel:	**B4**	
Type:	Bulk carrier	
Size:	14201	dwt (tonnes)
Launched:	1986	
Engine:	**Main**	
MCR	3965	kW
Test %MCR	all	
Test RPM	600	
Test % rated RPM		
Propeller Type:	CPP	
Est. rated RPM	600	



Point Estimates

% MCR	NOx g/kWh
10%	34.55
20%	23.86
30%	14.84
40%	14.32
50%	14.52
60%	14.72
70%	15.48
80%	15.91
90%	15.00
100%	14.91

Profile Points

	Uncon.	**IMO**
% MCR	NOx g/kWh	
85%	15.46	12.16
80%	15.91	12.61
40%	14.32	11.02
35%	14.57	11.27
20%	23.86	20.56
15%	29.20	25.91
10%	34.55	31.25

E2 Test Procedure

% MCR	NOx g/kWh	Revised NOx
25%	18.52	15.22
50%	14.52	11.22
75%	16.33	13.03
100%	14.91	11.61

E2 Wghtd NOx g/kWh	Revised E2 NOx
15.84	12.54

Applicable IMO std:

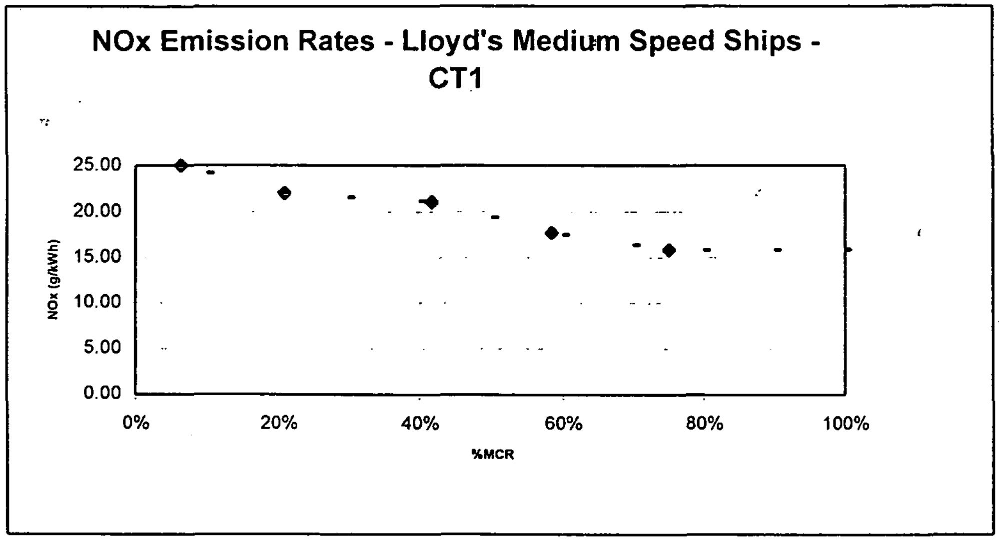
12.54	12.54

Comply with IMO?	Revised?
FALSE	TRUE

Test Information:

Test % MCR	Test NOx (g/kWh)
5%	40.38
28%	14.92
40%	14.32
66%	14.84
75%	16.33
91%	14.91

Vessel:	**B5**	
Type:	Bulk carrier	
Size:	14201	dwt (tonnes)
Launched:	1986	
Engine:	**Main**	
MCR	3963	kW
Test %MCR	all	
Test RPM	595	
Test % rated RPM		
Propeller Type:	CPP	
Est. rated RPM	595	



Point Estimates

% MCR	NOx g/kWh
10%	24.20
20%	22.14
30%	21.57
40%	21.13
50%	19.36
60%	17.48
70%	16.37
80%	15.82
90%	15.82
100%	15.82

Profile Points

	Uncon.	**IMO**
% MCR	NOx g/kWh	
85%	15.82	11.36
80%	15.82	11.36
40%	21.13	16.67
35%	21.35	16.89
20%	22.14	17.68
15%	23.17	18.71
10%	24.20	19.74

E2 Test Procedure

% MCR	NOx g/kWh	Revised NOx
25%	21.79	17.33
50%	19.36	14.90
75%	15.82	11.36
100%	15.82	11.36

E2 Wghtd NOx g/kWh	Revised E2 NOx
16.53	12.07

Applicable IMO std:

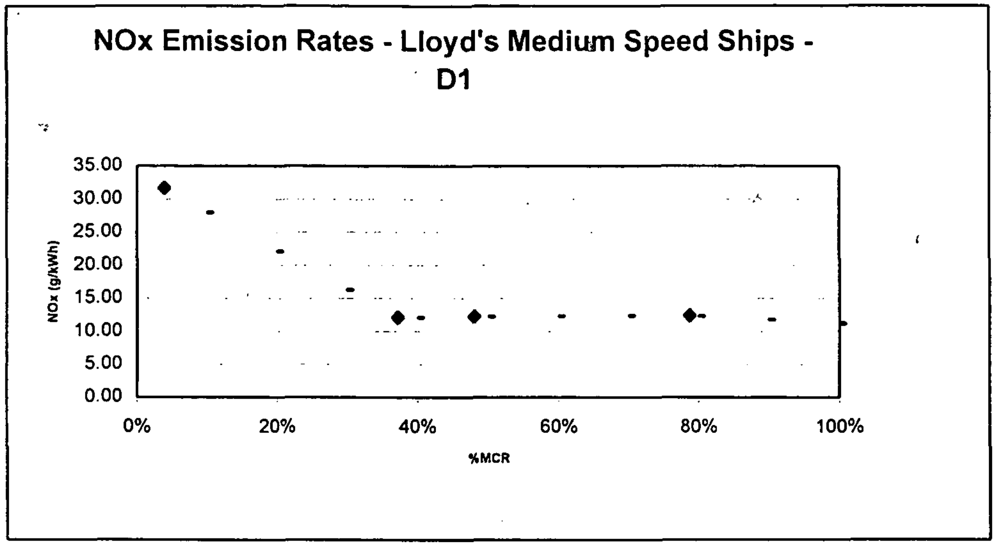
12.07	12.07

Comply with IMO?	Revised?
FALSE	TRUE

Test Information:

Test % MCR	Test NOx (g/kWh)
6%	24.97
21%	21.97
42%	21.06
58%	17.67
75%	15.82

Vessel:	**CT1**	
Type:	Container	
Size:	22858	dwt (tonnes)
Launched:	1980	
Engine:	**Gen Set**	
MCR	960	kW
Test %MCR	NA	
Test RPM	720	
Test % rated RPM		
Propeller Type:	NA	
Est. rated RPM	720	



Point Estimates

% MCR	NOx g/kWh
10%	28.00
20%	22.13
30%	16.26
40%	12.13
50%	12.25
60%	12.29
70%	12.34
80%	12.31
90%	11.78
100%	11.24

Profile Points

	Uncon.	IMO
% MCR	NOx g/kWh	
85%	12.04	12.04
80%	12.31	12.31
40%	12.13	12.13
35%	13.33	13.33
20%	22.13	22.13
15%	25.06	25.06
10%	28.00	28.00

E2 Test Procedure

% MCR	NOx g/kWh	Revised NOx
25%	19.20	NA
50%	12.25	NA.
75%	12.37	NA
100%	11.24	NA

E2 Wghtd NOx g/kWh	Revised E2 NOx
12.40	NA

Applicable IMO std:

12.52	12.52

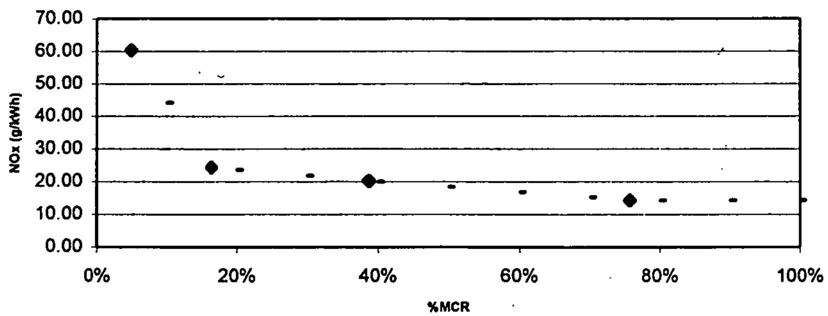
Comply with IMO?	Revised?
TRUE	NA

Test Information:

Test % MCR	Test NOx (g/kWh)
4%	31.65
37%	12.09
48%	12.24
79%	12.38
105%	10.96

Vessel:	**D1**	
Type:	Dredger	
Size:	5271	dwt (tonnes)
Launched:	1974	
Engine:	**main**	
MCR	3042	kW
Test %MCR	all	
Test RPM	600	
Test % rated RPM		
Propeller Type:	CPP	
Est. rated RPM	600	

NOx Emission Rates - Lloyd's Medium Speed Ships - D2



Point Estimates

% MCR	NOx g/kWh
10%	44.16
20%	23.59
30%	21.78
40%	19.99
50%	18.41
60%	16.82
70%	15.24
80%	14.34
90%	14.34
100%	14.34

Profile Points

	Uncon.	**IMO**
% MCR	NOx g/kWh	
85%	14.34	11.56
80%	14.34	11.56
40%	19.99	17.21
35%	20.87	18.09
20%	23.59	20.80
15%	28.50	25.71
10%	44.16	41.38

E2 Test Procedure

% MCR	NOx g/kWh	Revised NOx
25%	22.68	19.90
50%	18.41	15.63
75%	14.45	11.66
100%	14.34	11.56

E2 Wghtd NOx g/kWh	Revised E2 NOx
15.30	12.51

Applicable IMO std:

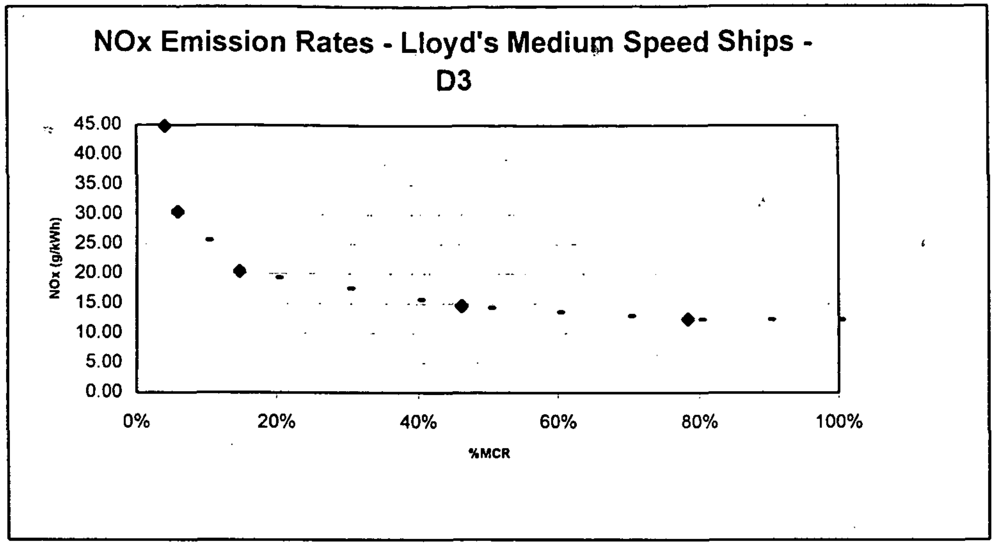
12.51	12.51

Comply with IMO?	Revised?
FALSE	TRUE

Test Information:

Test % MCR	Test NOx (g/kWh)
5%	60.28
16%	24.25
39%	20.20
76%	14.34

Vessel:	**D2**	
Type:	Dredger	
Size:	2636	dwt (tonnes)
Launched:	1969	
Engine:	**main**	
MCR	1504	kW
Test %MCR	76%	
Test RPM	550	
Test % rated RPM	91%	
Propeller Type:	FPP	
Est. rated RPM	601	



Point Estimates

% MCR	NOx g/kWh
10%	25.63
20%	19.39
30%	17.56
40%	15.73
50%	14.36
60%	13.67
70%	12.99
80%	12.42
90%	12.42
100%	12.42

Profile Points

	Uncon.	**IMO**
% MCR	NOx g/kWh	
85%	12.42	11.23
80%	12.42	11.23
40%	15.73	14.54
35%	16.65	15.45
20%	19.39	18.19
15%	20.35	19.16
10%	25.63	24.43

E2 Test Procedure

% MCR	NOx g/kWh	Revised NOx
25%	18.47	17.28
50%	14.36	13.16
75%	12.65	11.45
100%	12.42	11.23

E2 Wghtd NOx g/kWh	Revised E2 NOx
13.09	11.89

Applicable IMO std:

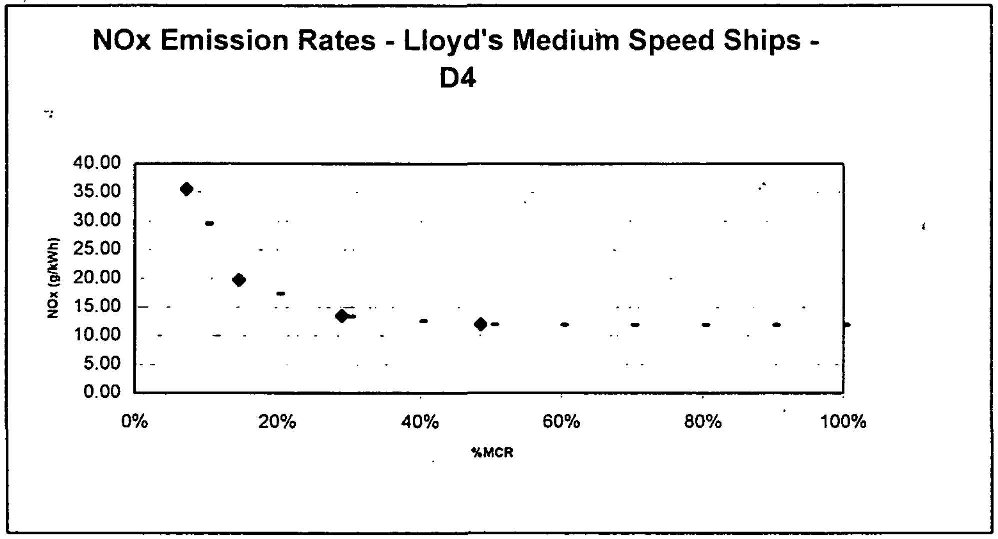
11.89	11.89

Comply with IMO?	Revised?
FALSE	TRUE

Test Information:

Test % MCR	Test NOx (g/kWh)
4%	44.76
6%	30.36
15%	20.35
46%	14.63
78%	12.42

Vessel:	D3	
Type:	Dredger	
Size:	2467	dwt (tonnes)
Launched:	1963	
Engine:	**main**	
MCR	369	kW
Test %MCR	78%	
Test RPM	716	
Test % rated RPM	92%	
Propeller Type:	FPP	
Est. rated RPM	776	



Point Estimates

% MCR	NOx g/kWh
10%	29.53
20%	17.35
30%	13.38
40%	12.58
50%	11.91
60%	11.91
70%	11.91
80%	11.91
90%	11.91
100%	11.91

Profile Points

	Uncon.	**IMO**
% MCR	NOx g/kWh	
85%	11.91	11.08
80%	11.91	11.08
40%	12.58	11.75
35%	12.98	12.16
20%	17.35	16.52
15%	19.69	18.86
10%	29.53	28.70

E2 Test Procedure

% MCR	NOx g/kWh	Revised NOx
25%	15.19	14.37
50%	11.91	11.08
75%	11.91	11.08
100%	11.91	11.08

E2 Wghtd NOx g/kWh	Revised E2 NOx
12.09	11.26

Applicable IMO std:

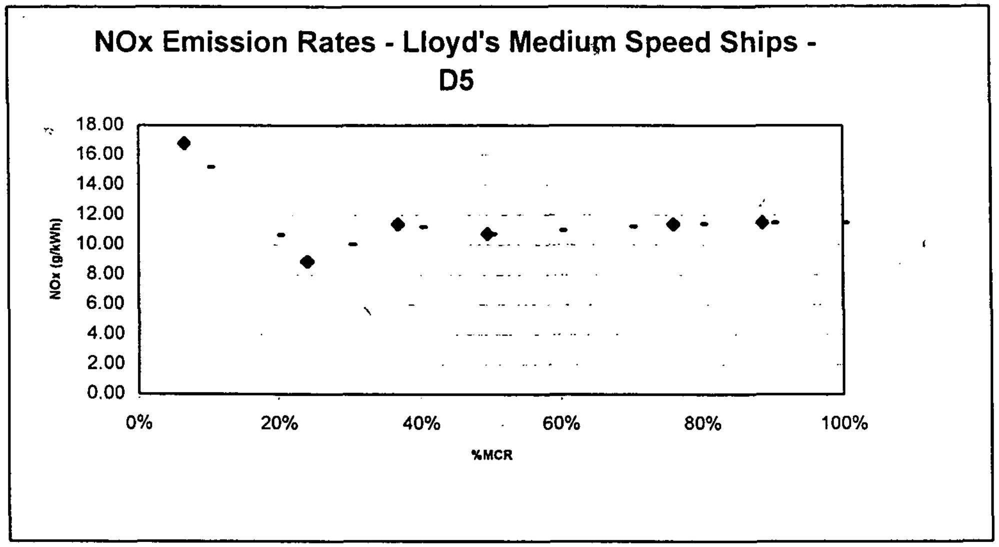
11.26	11.26

Comply with IMO?	Revised?
FALSE	TRUE

Test Information:

Test % MCR	Test NOx (g/kWh)
7%	35.51
15%	19.69
29%	13.46
48%	11.91

Vessel:	D4	
Type:	Dredger	
Size:	1944	dwt (tonnes)
Launched:	1969	
Engine:	**main**	
MCR	872	kW
Test %MCR	48%	
Test RPM	800	
Test % rated RPM	78%	
Propeller Type:	FPP	
Est. rated RPM	1019	



Point Estimates

% MCR	NOx g/kWh
10%	15.18
20%	10.69
30%	10.06
40%	11.21
50%	10.72
60%	10.98
70%	11.23
80%	11.42
90%	11.49
100%	11.49

Profile Points

	Uncon.	**IMO**
% MCR	NOx g/kWh	
85%	11.46	11.46
80%	11.42	11.42
40%	11.21	11.21
35%	11.03	11.03
20%	10.69	10.69
15%	12.93	12.93
10%	15.18	15.18

E2 Test Procedure

% MCR	NOx g/kWh	Revised NOx
25%	9.09	NA
50%	10.72	NA
75%	11.36	NA
100%	11.49	NA

E2 Wghtd NOx g/kWh	Revised E2 NOx
11.20	NA

Applicable IMO std:

11.75	11.75

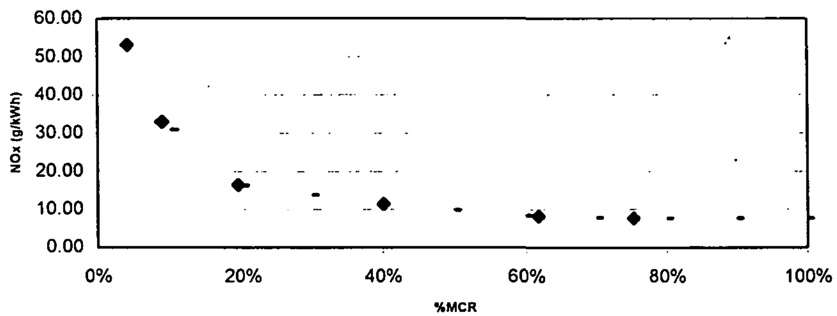
Comply with IMO?	Revised?
TRUE	NA

Test Information:

Test % MCR	Test NOx (g/kWh)
6%	16.75
24%	8.89
37%	11.38
50%	10.72
76%	11.38
89%	11.49

Vessel:	**D5**	
Type:	Dredger	
Size:	4734	dwt (tonnes)
Launched:	1974	
Engine:	**main**	
MCR	1725	kW
Test %MCR	all	
Test RPM	825	
Test % rated RPM		
Propeller Type:	CPP	
Est. rated RPM	825	

NOx Emission Rates - Lloyd's Medium Speed Ships - D6



Point Estimates

% MCR	NOx g/kWh
10%	30.96
20%	16.27
30%	13.83
40%	11.39
50%	9.89
60%	8.40
70%	7.86
80%	7.69
90%	7.69
100%	7.69

Profile Points

	Uncon.	IMO
% MCR	NOx g/kWh	
85%	7.69	7.69
80%	7.69	7.69
40%	11.39	11.39
35%	12.61	12.61
20%	16.27	16.27
15%	23.16	23.16
10%	30.96	30.96

E2 Test Procedure

% MCR	NOx g/kWh	Revised NOx
25%	15.05	NA
50%	9.89	NA
75%	7.69	NA
100%	7.69	NA

E2 Wghtd NOx g/kWh	Revised E2 NOx
8.33	NA

Applicable IMO std:

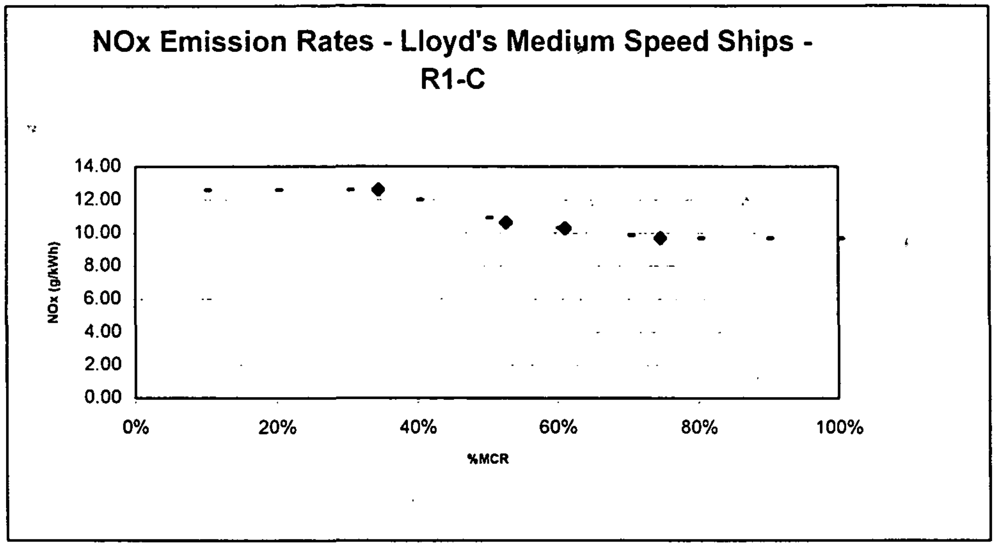
11.72	11.72

Comply with IMO?	Revised?
TRUE	NA

Test Information:

Test % MCR	Test NOx (g/kWh)
4%	53.13
9%	32.93
19%	16.43
40%	11.39
62%	8.14
75%	7.69

Vessel:	**D6**	
Type:	Dredger	
Size:	5209	dwt (tonnes)
Launched:	1971	
Engine:	**main**	
MCR	984	kW
Test %MCR	75%	
Test RPM	760	
Test % rated RPM	91%	
Propeller Type:	FPP	
Est. rated RPM	835	



Point Estimates

% MCR	NOx g/kWh
10%	12.59
20%	12.59
30%	12.59
40%	11.99
50%	10.93
60%	10.32
70%	9.88
80%	9.68
90%	9.68
100%	9.68

Profile Points

	Uncon.	IMO
% MCR	NOx g/kWh	
85%	9.68	9.68
80%	9.68	9.68
40%	11.99	11.99
35%	12.53	12.53
20%	12.59	12.59
15%	12.59	12.59
10%	12.59	12.59

E2 Test Procedure

% MCR	NOx g/kWh	Revised NOx
25%	12.59	NA
50%	10.93	NA
75%	9.68	NA
100%	9.68	NA

E2 Wghtd NOx g/kWh	Revised E2 NOx
9.97	NA

Applicable IMO std:

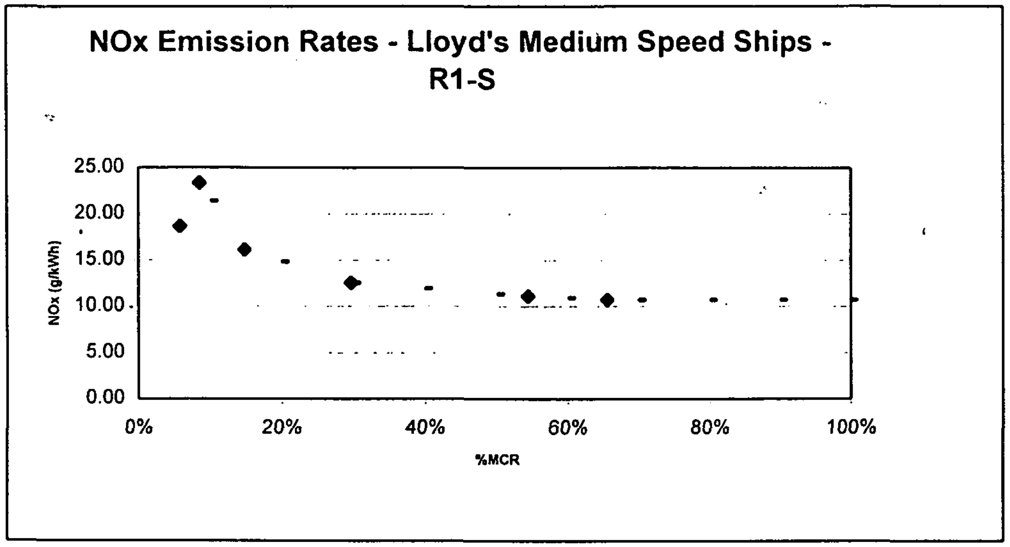
12.83 12.83

Comply with IMO?	Revised?
TRUE	NA

Test Information:

Test % MCR	Test NOx (g/kWh)
34%	12.59
53%	10.64
61%	10.28
75%	9.68

Vessel:	**R1**	
Type:	RORO	
Size:	2467	dwt (tonnes)
Launched:	1974	
Engine:	**centre main**	
MCR	3420	kW
Test %MCR	all	
Test RPM	530	
Test % rated RPM		
Propeller Type:	CPP	
Est. rated RPM	530	



Point Estimates

% MCR	NOx g/kWh
10%	21.41
20%	14.82
30%	12.51
40%	11.92
50%	11.34
60%	10.90
70%	10.70
80%	10.70
90%	10.70
100%	10.70

Profile Points

	Uncon.	**IMO**
% MCR	NOx g/kWh	
85%	10.70	10.70
80%	10.70	10.70
40%	11.92	11.92
35%	12.20	12.20
20%	14.82	14.82
15%	16.10	16.10
10%	21.41	21.41

E2 Test Procedure

% MCR	NOx g/kWh	Revised NOx
25%	13.62	NA
50%	11.34	NA
75%	10.70	NA
100%	10.70	NA

E2 Wghtd NOx g/kWh	Revised E2 NOx
10.93	NA

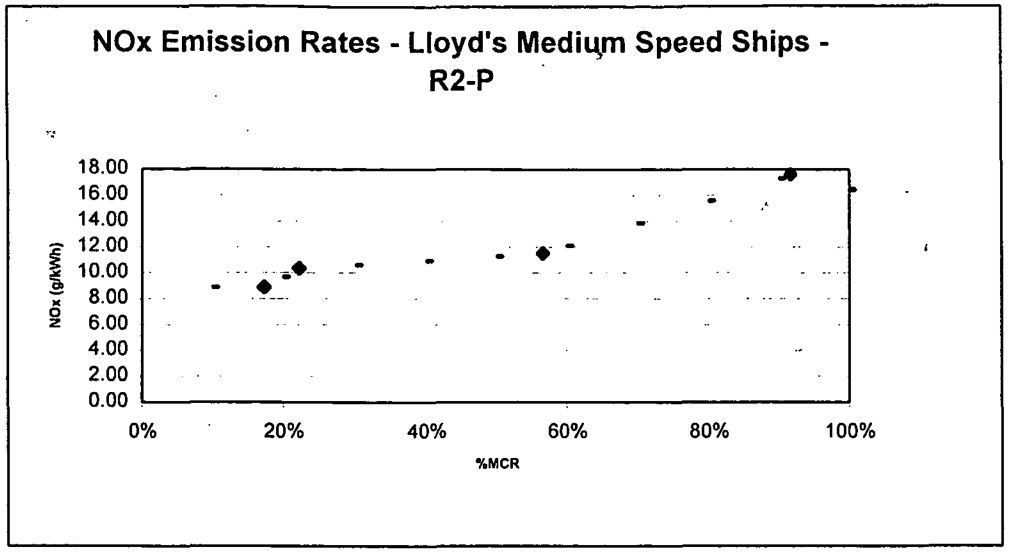
Applicable IMO std:	
12.98	12.98

Comply with IMO?	Revised?
TRUE	NA

Test Information:

Test % MCR	Test NOx (g/kWh)
6%	18.65
8%	23.31
15%	16.10
30%	12.51
54%	11.10
66%	10.70

Vessel:	**R1**	
Type:	RORO	
Size:	2467	dwt (tonnes)
Launched:	1974	
Engine:	**starboard main**	
MCR	3281	kW
Test %MCR	68%	
Test RPM	502	
Test % rated RPM		
Propeller Type:	CPP	
Est. rated RPM	500	



Point Estimates

% MCR	NOx g/kWh
10%	8.87
20%	9.68
30%	10.60
40%	10.94
50%	11.28
60%	12.11
70%	13.84
80%	15.57
90%	17.31
100%	16.44

Profile Points

	Uncon.	**IMO**
% MCR	NOx g/kWh	
85%	16.44	14.77
80%	15.57	13.90
40%	10.94	9.27
35%	10.77	9.10
20%	9.68	8.01
15%	8.87	7.20
10%	8.87	7.20

E2 Test Procedure

% MCR	NOx g/kWh	Revised NOx
25%	10.42	8.75
50%	11.28	9.61
75%	14.71	13.04
100%	16.44	14.77

E2 Wghtd NOx g/kWh	Revised E2 NOx
14.60	12.93

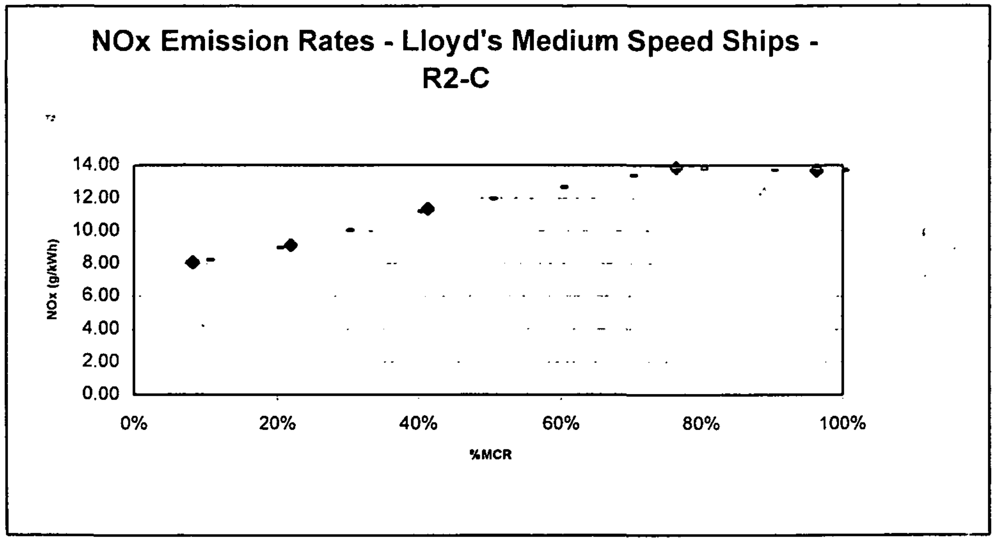
Applicable IMO std:	
12.93	12.93

Comply with IMO?	Revised?
FALSE	TRUE

Test Information:

Test % MCR	Test NOx (g/kWh)
17%	8.87
22%	10.33
57%	11.50
92%	17.60
102%	16.11
115%	14.99

Vessel:	**R2**	
Type:	RORO	
Size:	4621	dwt (tonnes)
Launched:	1987	
Engine:	**port main**	
MCR	6545	kW
Test %MCR	all	
Test RPM	510	
Test % rated RPM		
Propeller Type:	CPP	
Est. rated RPM	510	



Point Estimates

% MCR	NOx g/kWh
10%	8.22
20%	8.98
30%	10.05
40%	11.19
50%	11.96
60%	12.67
70%	13.38
80%	13.81
90%	13.72
100%	13.70

Profile Points

	Uncon.	**IMO**
% MCR	NOx g/kWh	
85%	13.77	13.40
80%	13.81	13.44
40%	11.19	10.82
35%	10.62	10.25
20%	8.98	8.61
15%	8.60	8.23
10%	8.22	7.85

E2 Test Procedure

% MCR	NOx g/kWh	Revised NOx
25%	9.48	9.11
50%	11.96	11.59
75%	13.74	13.37
100%	13.70	13.33

E2 Wghtd NOx g/kWh	Revised E2 NOx
13.30	12.93

Applicable IMO std:

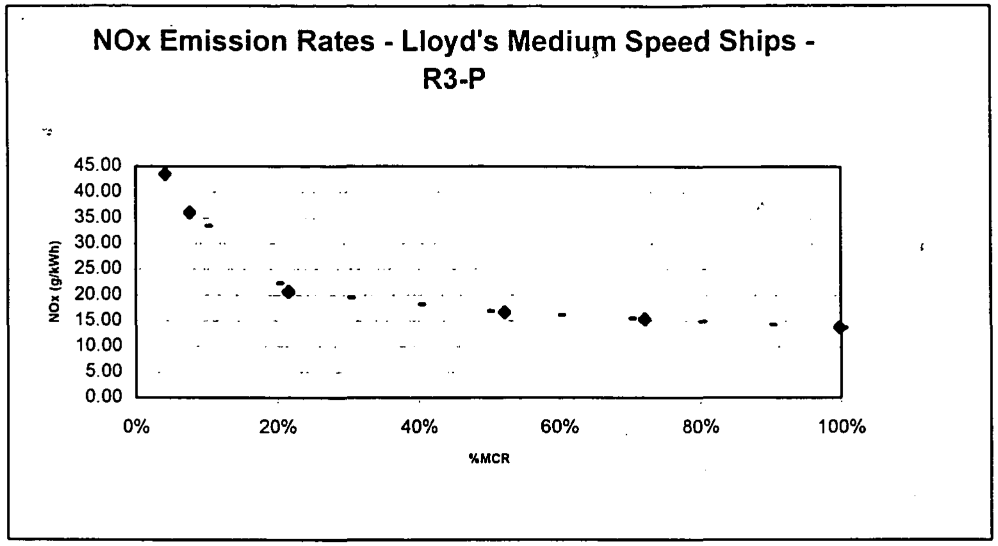
12.93	12.93

Comply with IMO?	Revised?
FALSE	TRUE

Test Information:

Test % MCR	Test NOx (g/kWh)
8%	8.06
22%	9.13
41%	11.33
76%	13.84
96%	13.67
105%	13.75

Vessel:	**R2**	
Type:	RORO	
Size:	4621	dwt (tonnes)
Launched:	1987	
Engine:	**centre main**	
MCR	6545	kW
Test %MCR	see data	
Test RPM	510	
Test % rated RPM		
Propeller Type:	CPP	
Est. rated RPM	510	



Point Estimates

% MCR	NOx g/kWh
10%	33.48
20%	22.33
30%	19.51
40%	18.21
50%	16.91
60%	16.11
70%	15.47
80%	14.88
90%	14.31
100%	13.75

Profile Points

	Uncon.	**IMO**
% MCR	NOx g/kWh	
85%	14.60	12.30
80%	14.88	12.59
40%	18.21	15.91
35%	18.86	16.56
20%	22.33	20.04
15%	27.91	25.61
10%	33.48	31.19

E2 Test Procedure

% MCR	NOx g/kWh	Revised NOx
25%	20.16	17.86
50%	16.91	14.61
75%	15.17	12.88
100%	13.75	11.45

E2 Wghtd NOx g/kWh	Revised E2 NOx
15.22	12.92

Applicable IMO std:

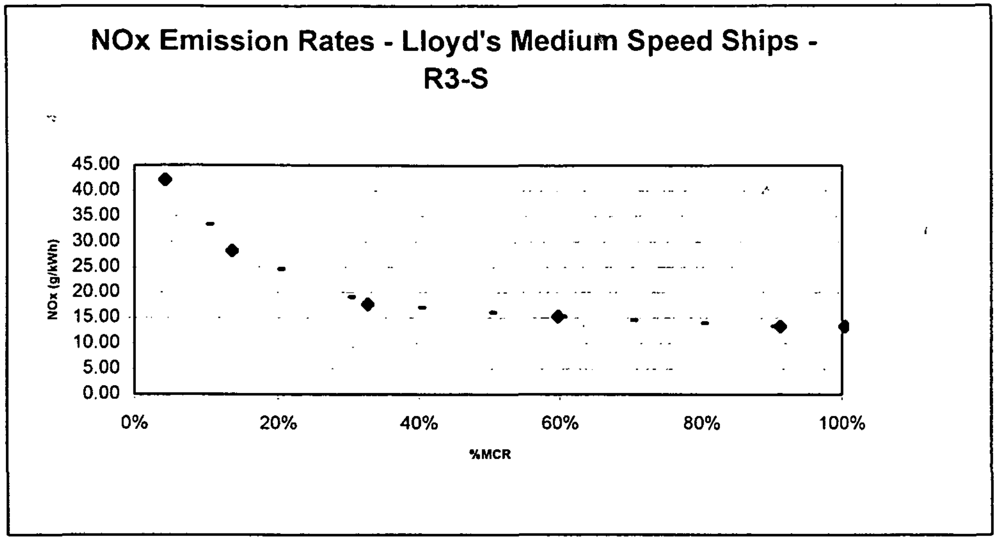
12.92	12.92

Comply with IMO?	Revised?
FALSE	TRUE

Test Information:

Test % MCR	Test NOx (g/kWh)
4%	43.47
8%	36.05
22%	20.60
52%	16.61
72%	15.34
100%	13.75

Vessel:	R3	
Type:	RORO	
Size:	8704	dwt (tonnes)
Launched:	1987	
Engine:	**port main**	
MCR	4780	kW
Test %MCR	all	
Test RPM	512	
Test % rated RPM		
Propeller Type:	CPP	
Est. rated RPM	512	



Point Estimates

% MCR	NOx g/kWh
10%	33.36
20%	24.58
30%	19.15
40%	17.01
50%	16.12
60%	15.25
70%	14.61
80%	13.98
90%	13.36
100%	13.29

Profile Points

	Uncon.	**IMO**
% MCR	NOx g/kWh	
85%	13.67	11.94
80%	13.98	12.25
40%	17.01	15.28
35%	17.46	15.73
20%	24.58	22.85
15%	27.30	25.57
10%	33.36	31.63

E2 Test Procedure

% MCR	NOx g/kWh	Revised NOx
25%	21.86	20.13
50%	16.12	14.39
75%	14.29	12.56
100%	13.29	11.56

E2 Wghtd NOx g/kWh	Revised E2 NOx
14.61	12.88

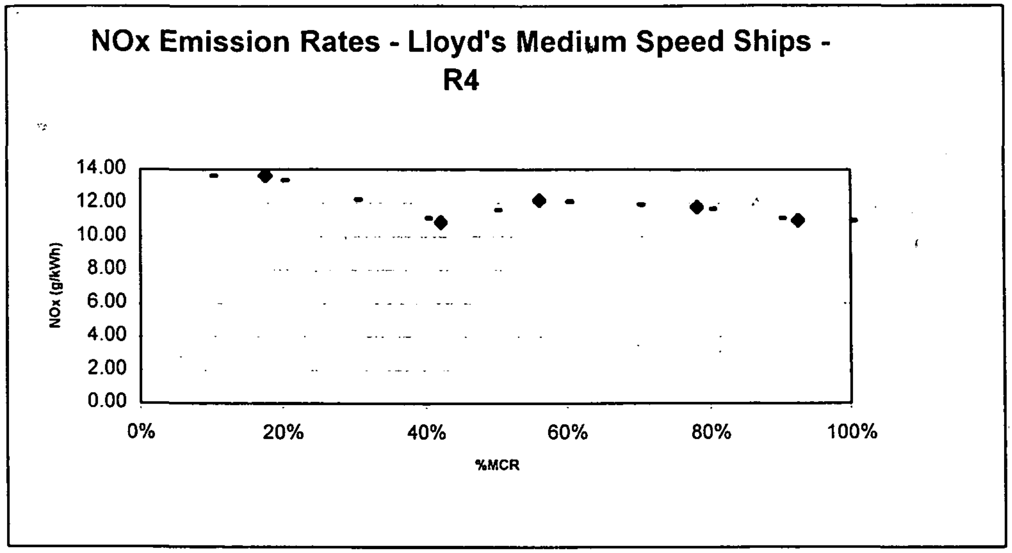
Applicable IMO std:	
12.88	12.88

Comply with IMO?	Revised?
FALSE	TRUE

Test Information:

Test % MCR	Test NOx (g/kWh)
4%	42.11
13%	28.13
33%	17.67
60%	15.25
91%	13.29
100%	13.29

Vessel:	R3	
Type:	RORO	
Size:	8704	dwt (tonnes)
Launched:	1987	
Engine:	**starboard main**	
MCR	4780	kW
Test %MCR	all	
Test RPM	520	
Test % rated RPM		
Propeller Type:	CPP	
Est. rated RPM	520	



Point Estimates

% MCR	NOx g/kWh
10%	13.62
20%	13.36
30%	12.23
40%	11.10
50%	11.59
60%	12.10
70%	11.92
80%	11.67
90%	11.11
100%	10.97

Profile Points

	Uncon.	**IMO**
% MCR	NOx g/kWh	
85%	11.39	11.39
80%	11.67	11.67
40%	11.10	11.10
35%	11.66	11.66
20%	13.36	13.36
15%	13.62	13.62
10%	13.62	13.62

E2 Test Procedure

% MCR	NOx g/kWh	Revised NOx
25%	12.79	NA
50%	11.59	NA
75%	11.83	NA
100%	10.97	NA

E2 Wghtd NOx g/kWh	Revised E2 NOx
11.61	NA

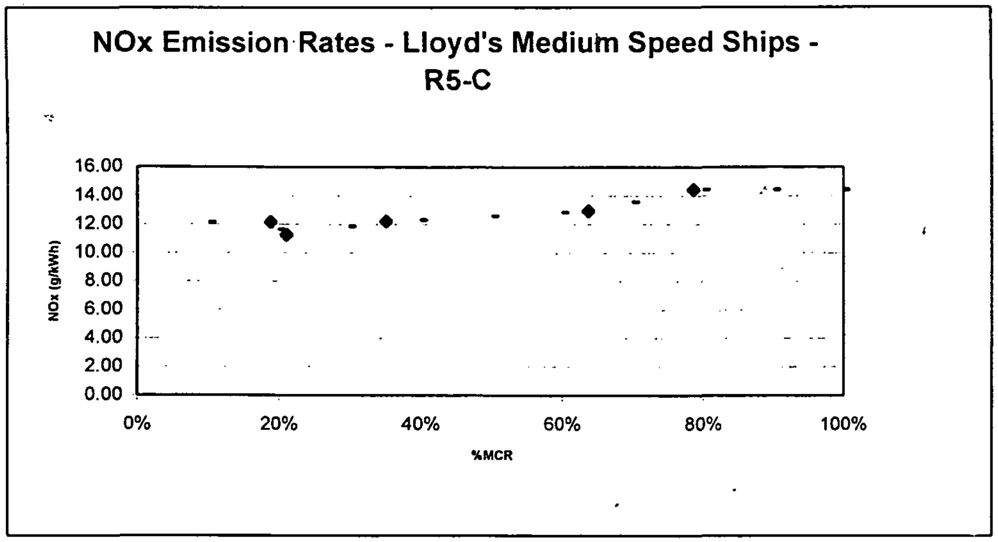
Applicable IMO std:	
12.65	12.65

Comply with IMO?	Revised?
TRUE	NA

Test Information:

Test % MCR	Test NOx (g/kWh)
18%	13.62
42%	10.86
56%	12.17
78%	11.77
93%	10.97

Vessel:	**R4**	
Type:	RORO	
Size:	3767	dwt (tonnes)
Launched:	1978	
Engine:	**port main**	
MCR	4246	kW
Test %MCR	all	
Test RPM	570	
Test % rated RPM		
Propeller Type:	CPP	
Est. rated RPM	570	



Point Estimates

% MCR	NOx g/kWh
10%	12.13
20%	11.65
30%	11.84
40%	12.32
50%	12.59
60%	12.85
70%	13.58
80%	14.43
90%	14.43
100%	14.43

Profile Points

	Uncon.	**IMO**
% MCR	NOx g/kWh	
85%	14.43	13.39
80%	14.43	13.39
40%	12.32	11.28
35%	12.20	11.16
20%	11.65	10.61
15%	12.13	11.09
10%	12.13	11.09

E2 Test Procedure

% MCR	NOx g/kWh	Revised NOx
25%	11.50	10.46
50%	12.59	11.55
75%	14.07	13.03
100%	14.43	13.39

E2 Wghtd NOx g/kWh	Revised E2 NOx
13.87	12.83

Applicable IMO std:

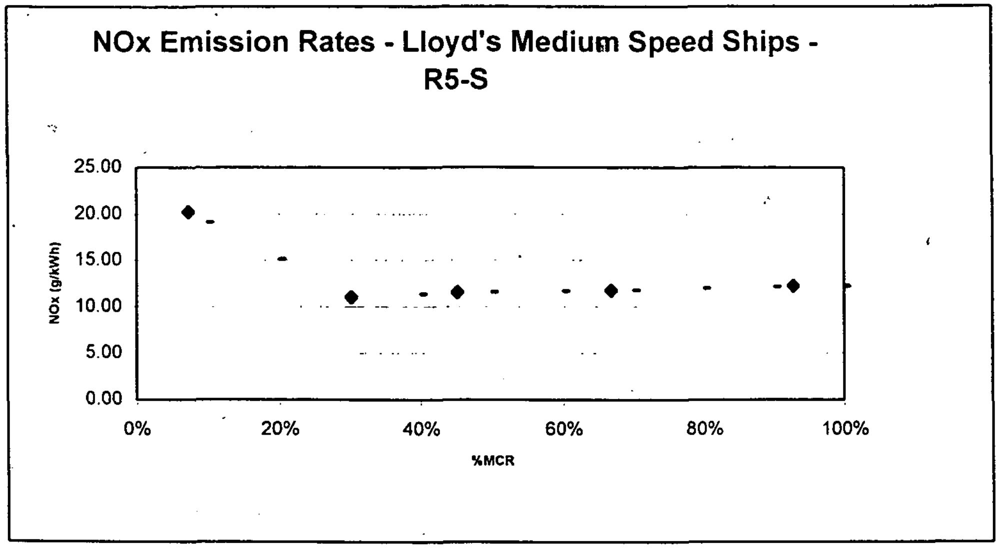
12.83	12.83

Comply with IMO?	Revised?
FALSE	TRUE

Test Information:

Test % MCR	Test NOx (g/kWh)
19%	12.13
21%	11.23
35%	12.20
64%	12.95
79%	14.43

Vessel:	**R5**	
Type:	RORO	
Size:	1616	dwt (tonnes)
Launched:	1976	
Engine:	**centre main**	
MCR	3952	kW
Test %MCR	all	
Test RPM	530	
Test % rated RPM		
Propeller Type:	CPP	
Est. rated RPM	530	



Point Estimates

% MCR	NOx g/kWh
10%	19.13
20%	15.11
30%	11.00
40%	11.35
50%	11.58
60%	11.67
70%	11.80
80%	11.99
90%	12.18
100%	12.23

Profile Points

% MCR	Uncon. NOx g/kWh	IMO NOx g/kWh
85%	12.09	12.09
80%	11.99	11.99
40%	11.35	11.35
35%	11.17	11.17
20%	15.11	15.11
15%	17.12	17.12
10%	19.13	19.13

E2 Test Procedure

% MCR	NOx g/kWh	Revised NOx
25%	13.10	NA
50%	11.58	NA
75%	11.89	NA
100%	12.23	NA

E2 Wghtd NOx g/kWh	Revised E2 NOx
12.02	NA

Applicable IMO std:

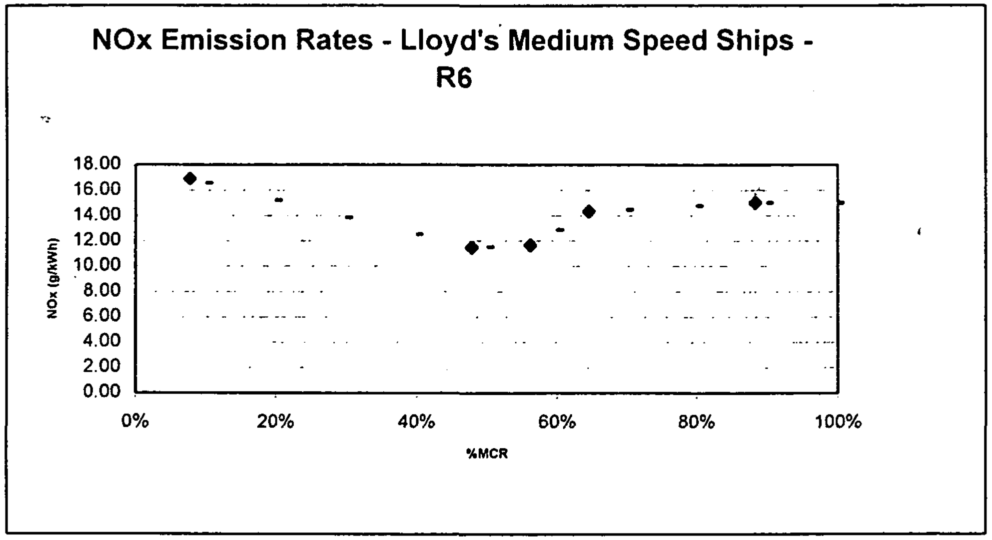
12.65	12.65

Comply with IMO?	Revised?
TRUE	NA

Test Information:

Test % MCR	Test NOx (g/kWh)
7%	20.21
30%	11.00
45%	11.54
67%	11.73
93%	12.23

Vessel:	**R5**	
Type:	RORO	
Size:	1616	dwt (tonnes)
Launched:	1976	
Engine:	**starboard main**	
MCR	3281	kW
Test %MCR	see data	
Test RPM	570	
Test % rated RPM		
Propeller Type:	CPP	
Est. rated RPM	570	



Point Estimates

% MCR	NOx g/kWh
10%	16.57
20%	15.22
30%	13.86
40%	12.51
50%	11.52
60%	12.90
70%	14.49
80%	14.78
90%	15.03
100%	15.03

Profile Points

	Uncon.	**IMO**
% MCR	NOx g/kWh	
85%	14.93	13.36
80%	14.78	13.21
40%	12.51	10.93
35%	13.18	11.61
20%	15.22	13.64
15%	15.89	14.32
10%	16.57	15.00

E2 Test Procedure

% MCR	NOx g/kWh	Revised NOx
25%	14.54	12.97
50%	11.52	9.95
75%	14.64	13.07
100%	15.03	13.46

E2 Wghtd NOx g/kWh	Revised E2 NOx
14.41	12.83

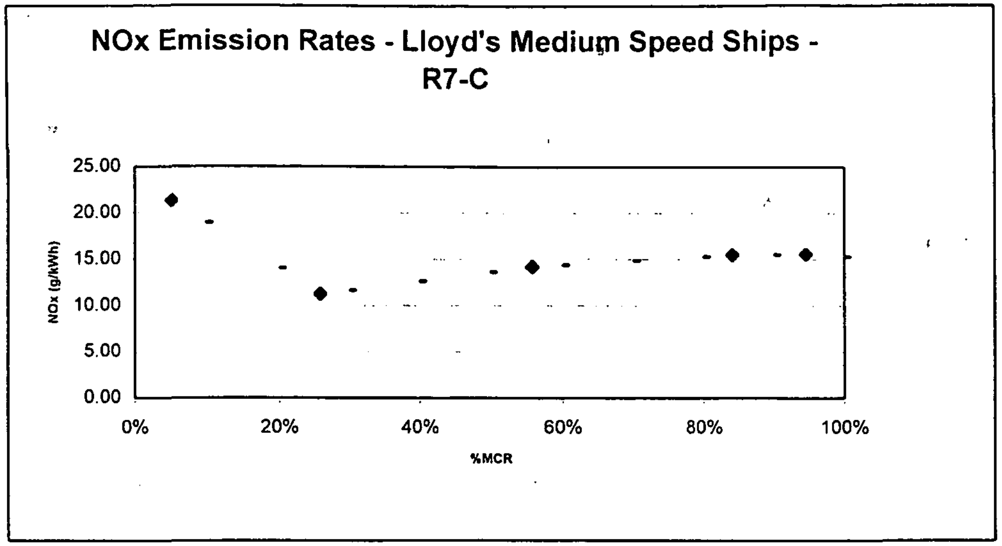
Applicable IMO std:	
12.83	12.83

Comply with IMO?	Revised?
FALSE	TRUE

Test Information:

Test % MCR	Test NOx (g/kWh)
8%	16.89
48%	11.47
56%	11.65
64%	14.33
88%	15.03

Vessel:	**R6**	
Type:	RORO	
Size:	1268	dwt (tonnes)
Launched:	1974	
Engine:	**centre main**	
MCR	3281	kW
Test %MCR	all	
Test RPM	530	
Test % rated RPM		
Propeller Type:	CPP	
Est. rated RPM	530	



Point Estimates

% MCR	NOx g/kWh
10%	18.97
20%	14.05
30%	11.65
40%	12.64
50%	13.63
60%	14.39
70%	14.84
80%	15.29
90%	15.51
100%	15.26

Profile Points

	Uncon.	IMO
% MCR	NOx g/kWh	
85%	15.48	13.64
80%	15.29	13.46
40%	12.64	10.81
35%	12.15	10.32
20%	14.05	12.21
15%	16.51	14.68
10%	18.97	17.14

E2 Test Procedure

% MCR	NOx g/kWh	Revised NOx
25%	11.58	9.75
50%	13.63	11.80
75%	15.06	13.23
100%	15.26	13.43

E2 Wghtd NOx g/kWh	Revised E2 NOx
14.78	12.94

Applicable IMO std:

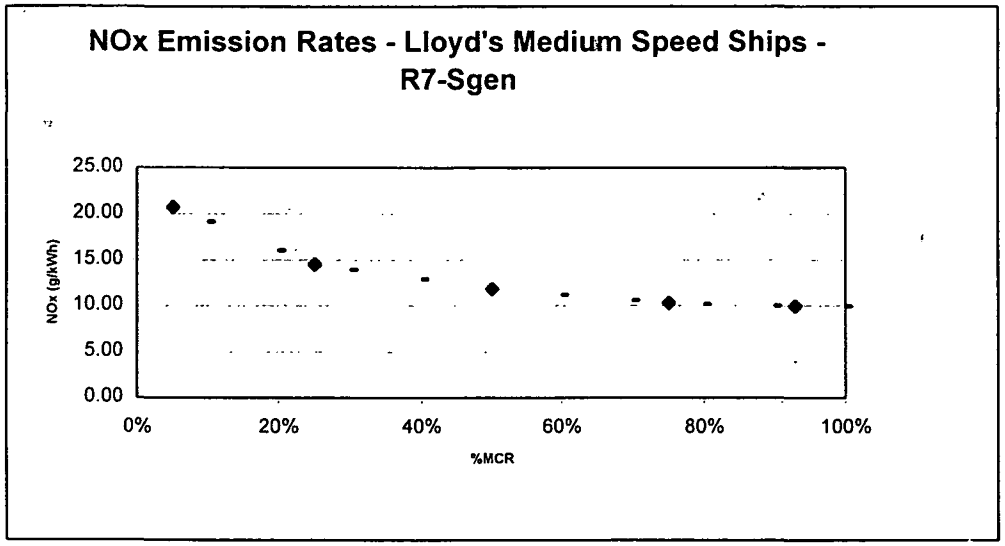
12.94	12.94

Comply with IMO?	Revised?
FALSE	TRUE

Test Information:

Test % MCR	Test NOx (g/kWh)
5%	21.34
26%	11.23
56%	14.20
84%	15.47
95%	15.54
102%	15.16

Vessel:	**R7**	
Type:	RORO	
Size:	4478	dwt (tonnes)
Launched:	1987	
Engine:	**centre main**	
MCR	7700	kW
Test %MCR	see data	
Test RPM	510	
Test % rated RPM		
Propeller Type:	CPP	
Est. rated RPM	508	



Point Estimates

% MCR	NOx g/kWh
10%	19.17
20%	16.05
30%	13.96
40%	12.89
50%	11.81
60%	11.21
70%	10.60
80%	10.20
90%	10.00
100%	9.94

Profile Points

	Uncon.	**IMO**
% MCR	NOx g/kWh	
85%	10.10	10.10
80%	10.20	10.20
40%	12.89	12.89
35%	13.42	13.42
20%	16.05	16.05
15%	17.61	17.61
10%	19.17	19.17

E2 Test Procedure

% MCR	NOx g/kWh	Revised NOx
25%	14.49	NA
50%	11.81	NA
75%	10.30	NA
100%	9.94	NA

E2 Wghtd NOx g/kWh	Revised E2 NOx
10.59	NA

Applicable IMO std:

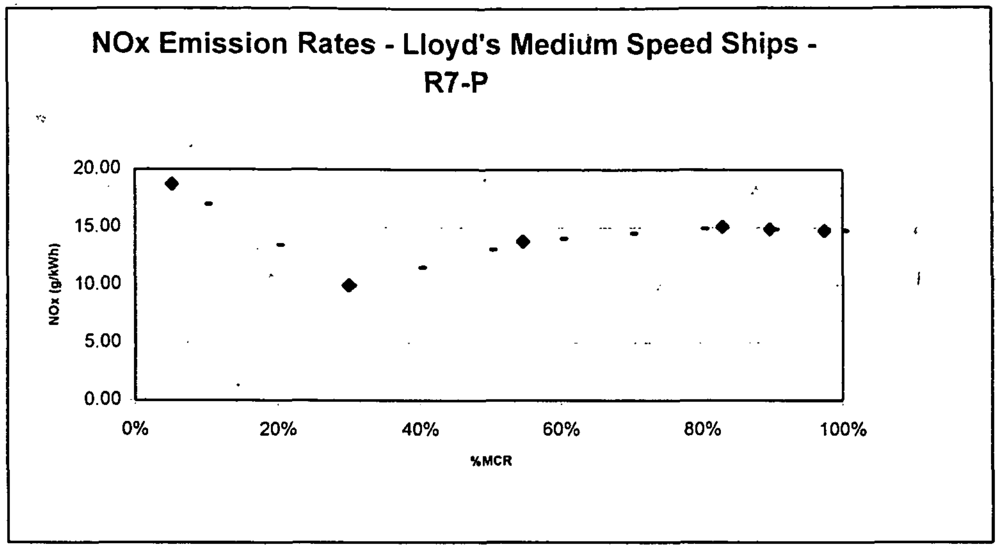
11.19	11.19

Comply with IMO?	Revised?
TRUE	NA

Test Information:

Test % MCR	Test NOx (g/kWh)
5%	20.72
25%	14.49
50%	11.81
75%	10.30
93%	9.94

Vessel:	**R7**	
Type:	RORO	
Size:	4478	dwt (tonnes)
Launched:	1987	
Engine:	**starboard generator**	
MCR	1400	kW
Test %MCR	NA	
Test RPM	1050	
Test % rated RPM		
Propeller Type:	NA	
Est. rated RPM	1050	



Point Estimates

% MCR	NOx g/kWh
10%	17.00
20%	13.44
30%	9.94
40%	11.52
50%	13.08
60%	14.04
70%	14.48
80%	14.93
90%	14.87
100%	14.71

Profile Points

	Uncon.	**IMO**
% MCR	NOx g/kWh	
85%	15.00	13.57
80%	14.93	13.50
40%	11.52	10.09
35%	10.74	9.31
20%	13.44	12.01
15%	15.22	13.79
10%	17.00	15.57

E2 Test Procedure

% MCR	NOx g/kWh	Revised NOx
25%	11.67	10.24
50%	13.08	11.65
75%	14.70	13.27
100%	14.71	13.28

E2 Wghtd NOx g/kWh	Revised E2 NOx
14.36	12.93

Applicable IMO std:	
12.93	12.93

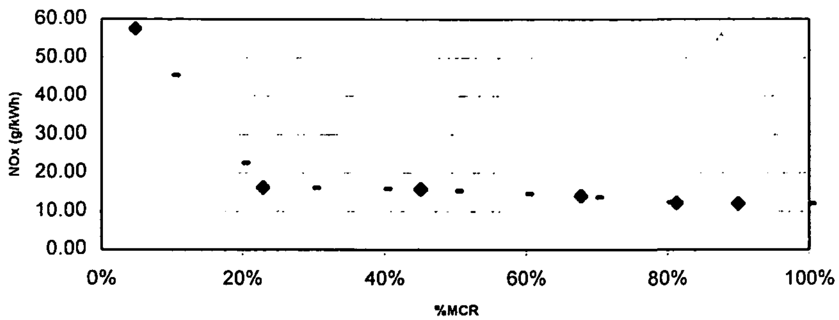
Comply with IMO?	Revised?
FALSE	TRUE

Test Information:

Test % MCR	Test NOx (g/kWh)
5%	18.71
30%	9.94
55%	13.79
83%	15.05
90%	14.87
97%	14.71

Vessel:	R7	
Type:	RORO	
Size:	4478	dwt (tonnes)
Launched:	1987	
Engine:	**port main**	
MCR	7700	kW
Test %MCR	all	
Test RPM	510	
Test % rated RPM		
Propeller Type:	CPP	
Est. rated RPM	510	

NOx Emission Rates - Lloyd's Medium Speed Ships - TK1



Point Estimates

% MCR	NOx g/kWh
10%	45.39
20%	22.60
30%	16.03
40%	15.83
50%	15.34
60%	14.58
70%	13.68
80%	12.28
90%	11.97
100%	11.97

Profile Points

	Uncon.	**IMO**
% MCR	NOx g/kWh	
85%	12.05	10.81
80%	12.28	11.04
40%	15.83	14.59
35%	15.93	14.69
20%	22.60	21.36
15%	33.99	32.75
10%	45.39	44.15

E2 Test Procedure

% MCR	NOx g/kWh	Revised NOx
25%	16.13	14.89
50%	15.34	14.10
75%	12.98	11.74
100%	11.97	10.73

E2 Wghtd NOx g/kWh	Revised E2 NOx
13.11	11.88

Applicable IMO std:

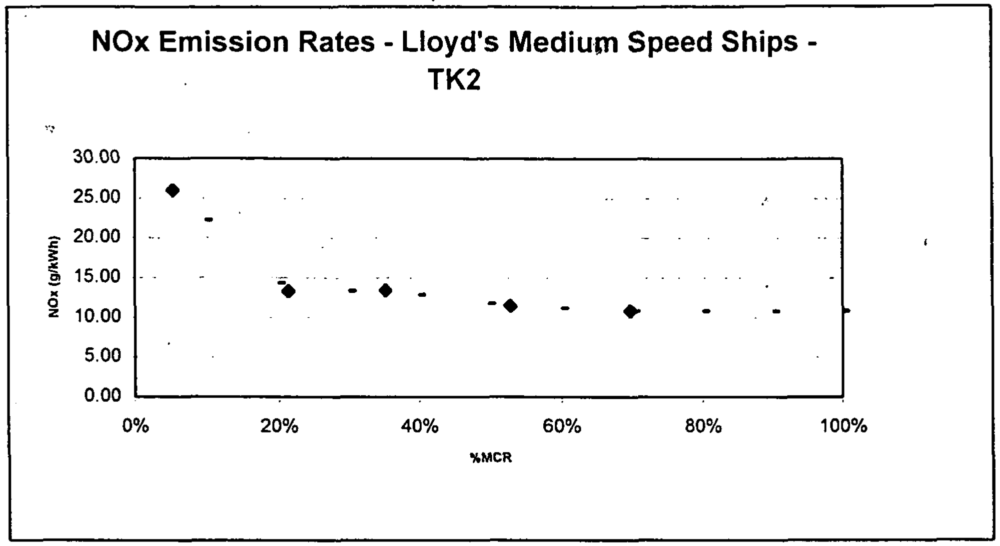
11.88	11.88

Comply with IMO?	Revised?
FALSE	TRUE

Test Information:

Test % MCR	Test NOx (g/kWh)
5%	57.47
23%	16.18
45%	15.73
68%	13.99
81%	12.11
90%	11.97

Vessel:	**TK1**	
Type:	Tanker	
Size:	844	dwt (tonnes)
Launched:	1978	
Engine:	**main**	
MCR	745	kW
Test %MCR	81%	
Test RPM	730	
Test % rated RPM	93%	
Propeller Type:	FPP	
Est. rated RPM	781	



Test Information:

Test % MCR	Test NOx (g/kWh)
5%	25.97
21%	13.29
35%	13.43
53%	11.45
70%	10.85

Vessel:	**TK2**	
Type:	Tanker	
Size:	18371	dwt (tonnes)
Launched:	1968	
Engine:	**centre main**	
MCR	3750	kW
Test %MCR	all	
Test RPM	440	
Test % rated RPM		
Propeller Type:	CPP	
Est. rated RPM	440	

Point Estimates

% MCR	NOx g/kWh
10%	22.27
20%	14.34
30%	13.37
40%	12.89
50%	11.77
60%	11.19
70%	10.85
80%	10.85
90%	10.85
100%	10.85

Profile Points

% MCR	**Uncon.** NOx g/kWh	**IMO** NOx g/kWh
85%	10.85	10.85
80%	10.85	10.85
40%	12.89	12.89
35%	13.43	13.43
20%	14.34	14.34
15%	18.31	18.31
10%	22.27	22.27

E2 Test Procedure

% MCR	NOx g/kWh	Revised NOx
25%	13.32	NA
50%	11.77	NA .
75%	10.85	NA
100%	10.85	NA

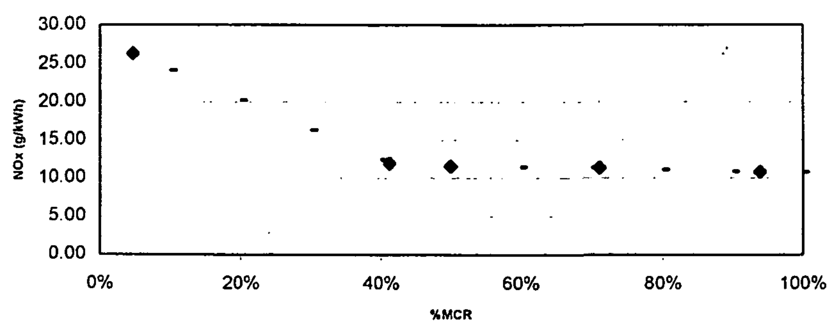
E2 Wghtd NOx g/kWh	Revised E2 NOx
11.08	NA

Applicable IMO std:

13.32 13.32

Comply with IMO?	Revised?
TRUE	NA

NOx Emission Rates - Lloyd's Medium Speed Ships - TK3



Point Estimates

% MCR	NOx g/kWh
10%	24.13
20%	20.21
30%	16.30
40%	12.39
50%	11.52
60%	11.43
70%	11.35
80%	11.12
90%	10.87
100%	10.77

Profile Points

	Uncon.	**IMO**
% MCR	NOx g/kWh	
85%	10.99	10.99
80%	11.12	11.12
40%	12.39	12.39
35%	14.35	14.35
20%	20.21	20.21
15%	22.17	22.17
10%	24.13	24.13

E2 Test Procedure

% MCR	NOx g/kWh	Revised NOx
25%	18.26	NA
50%	11.52	NA
75%	11.24	NA
100%	10.77	NA

E2 Wghtd NOx g/kWh	Revised E2 NOx
11.52	NA

Applicable IMO std:

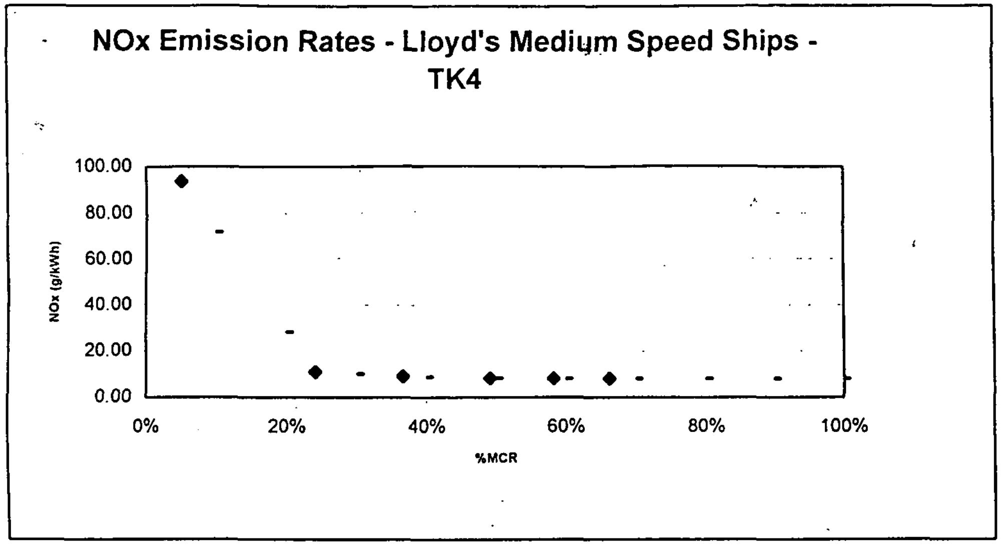
13.26	13.26

Comply with IMO?	Revised?
TRUE	NA

Test Information:

Test % MCR	Test NOx (g/kWh)
5%	26.24
41%	11.92
50%	11.52
71%	11.34
94%	10.77

Vessel:	**TK3**	
Type:	Tanker	
Size:	12317	dwt (tonnes)
Launched:	1978	
Engine:	**port main**	
MCR	3257	kW
Test %MCR	all	
Test RPM	450	
Test % rated RPM		
Propeller Type:	CPP	
Est. rated RPM	450	



Point Estimates

% MCR	NOx g/kWh
10%	71.98
20%	28.27
30%	10.08
40%	8.86
50%	8.22
60%	8.09
70%	8.11
80%	8.11
90%	8.11
100%	8.11

Profile Points

% MCR	Uncon. NOx g/kWh	IMO NOx g/kWh
85%	8.11	8.11
80%	8.11	8.11
40%	8.86	8.86
35%	9.32	9.32
20%	28.27	28.27
15%	50.12	50.12
10%	71.98	71.98

E2 Test Procedure

% MCR	NOx g/kWh	Revised NOx
25%	10.83	NA
50%	8.22	NA
75%	8.11	NA
100%	8.11	NA

E2 Wghtd NOx g/kWh	Revised E2 NOx
8.27	NA

Applicable IMO std:

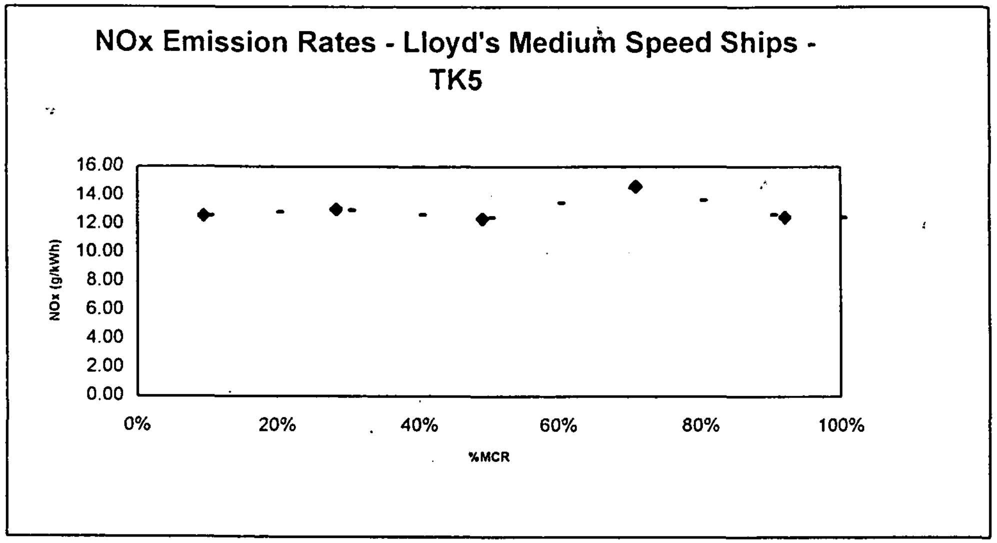
13.42	13.42

Comply with IMO?	Revised?
TRUE	NA

Test Information:

Test % MCR	Test NOx (g/kWh)
5%	93.73
24%	10.99
37%	9.09
49%	8.24
58%	8.08
66%	8.11

Vessel:	**TK4**	
Type:	Tanker	
Size:	1673	dwt (tonnes)
Launched:	1985	
Engine:	**main**	
MCR	597	kW
Test %MCR	66%	
Test RPM	370	
Test % rated RPM	87%	
Propeller Type:	FPP	
Est. rated RPM	424	



Test Information:

Test % MCR	Test NOx (g/kWh)
9%	12.60
28%	13.04
49%	12.38
71%	14.63
92%	12.48

Vessel:	**TK5**	
Type:	Tanker	
Size:	2566	dwt (tonnes)
Launched:	1979	
Engine:	**main**	
MCR	745	kW
Test %MCR	all	
Test RPM	750	
Test % rated RPM		
Propeller Type:	CPP	
Est. rated RPM	750	

Point Estimates

% MCR	NOx g/kWh
10%	12.61
20%	12.85
30%	12.99
40%	12.66
50%	12.48
60%	13.51
70%	14.54
80%	13.70
90%	12.68
100%	12.48

Profile Points

	Uncon.	**IMO**
% MCR	NOx g/kWh	
85%	13.19	11.71
80%	13.70	12.22
40%	12.66	11.19
35%	12.83	11.35
20%	12.85	11.37
15%	12.73	11.25
10%	12.61	11.13

E2 Test Procedure

% MCR	NOx g/kWh	Revised NOx
25%	12.97	11.49
50%	12.48	11.00
75%	14.21	12.73
100%	12.48	11.01

E2 Wghtd NOx g/kWh	Revised E2 NOx
13.45	11.97

Applicable IMO std:	
11.97	11.97

Comply with IMO?	Revised?
FALSE	TRUE

ANALYSIS OF MARINE EMISSIONS IN THE SOUTH COAST AIR BASIN

APPENDIX D

Table D-1. Characterization of emissions from uncontrolled auxiliary engines

Ship Name	Test kW	lb NO_x/1K gal	Gal/hr	Fuel API Specific Gravity deg API	Fuel Density kg/m^3	Fuel Density lb/gal	lb fuel/kWh	g NO_x/ kWh
Manhattan Bridge	330	570.9	24.3	11.7	988	8.23	0.606	19.09
President Adams	830	473.47	49.3	29.9	877	7.30	0.434	12.77
Spring Bride	400	732.19	18.8	15.2	965	8.03	0.377	15.62
Beltimber	213	355.31	15.9	12.0	986	8.21	0.613	12.04
National Dignity	66	143.26	18.3	18.5	943	7.86	2.178	18.03
Walter Jacobs	408	508.46	29.1	26	898	7.48	0.534	16.46
California Jupiter	485	405.58	37.2	12.8	981	8.17	0.626	14.12
Sealand Explorer	535	626.14	40.6	22.1	921	7.67	0.582	21.57
Aurora Ace	340	418.12	27.4	19.7	936	7.79	0.628	15.30
Dynachem	328	316.34	29.8	26.7	894	7.45	0.677	13.05
Star Esperanza	171	354.61	13.1	34.9	850	7.08	0.542	12.33
Madame Butterfly	560	591.77	34.6	11.4	990	8.25	0.509	16.60
Evergroup	515	284.83	33.2	19.5	937	7.80	0.503	8.34
President Washington	1315	280.75	90	13.8	974	8.11	0.555	8.72
Thorseggen	248	794.61	15.4	12.3	984	8.19	0.509	22.40
Hyundai Challenger	670	399.15	43.8	14.1	972	8.09	0.529	11.85
							Average	14.89

Table D-2. Characterization of IMO-controlled emissions for auxiliary engines

Shipping Line	Ship Class/Ship	# Ships	Application	# Engines per ship	Total Engines	hp per engine	Rated RPM	Total kW	IMO NO_x g/kWh	Weighted[1] NO_x g/hr
APL	C-10 "Adams"	5	Gen	3	15	3351	600	37500	12.5	469476
APL	C-9 "Lincoln"	3	Gen	3	9	3351	450	22500	13.3	298368
APL	Eisenhower	2	Gen	2	4	2145	600	6400	12.5	80124
Chevron	Carla Hills	6	Gen	2	12	805	720	7206	12.1	86989
Chevron	Samuel Ginn	2	Gen	2	4	1307	900	3900	11.5	45023
Chevron	Kenneth Hill	2	Gen	2	4	939	720	2802	12.1	33823
Chevron	Atlantic	1	Gen	2	2	1200	720	1790	12.1	21612
Evergreen	R	10	Gen	4	40	2000	720	59680	12.1	720402
Evergreen	G	20	Gen	3	60	1100	720	49236	12.1	594332
Evergreen	GX	11	Gen	3	33	1200	720	29542	12.1	356599
Evergreen	L	6	Gen	3	18	1100	720	14771	12.1	178299
Evergreen	B	3	Gen	3	9	385	720	2585	12.1	31202
Maersk	Mayview	1	Gen	3	3	2574	720	5760	12.1	69529
Matson	Mahi Mahi	3	Gen	3	9	3500	450	23499	13.3	311616
Matson	Chief Gadao	3	Gen	1	3	2793	900	6251	11.5	72160
Matson	R.J. Pfeiffer	1	Gen	3	3	2681	720	6000	12.1	72426
Matson	Maui	2	Gen	1	2	3500	1200	5222	10.9	56913
Zim	Unknown Class 2	8	Gen	2	16	1800	720	21485	12.1	259345
Zim	Unknown Class 1	7	Gen	2	14	1780	720	18592	12.1	224425
Chevron	Louisville	4	GT Gen	2	8	2950	1800	17606	10.0	176933
APL	C-10 "Adams"	5	Emer Gen?	1	5	525	1800	1960	10.0	19698
APL	C-9 "Lincoln"	3	Emer Gen?	1	3	670	1800	1500	10.0	15075
APL	Eisenhower	2	Emer Gen?	1	2	268	1800	400	10.0	4020
Matson	Matsonia	2	Emer Gen	1	2	469	1800	700	10.0	7035
Evergreen	R	10	Emer Gen	1	10	167	1800	1246	10.0	12520
Evergreen	GX	11	Emer Gen	1	11	150	1800	1231	10.0	12370
Matson	Mahi Mahi	3	Emer Gen	1	3	670	1800	1500	10.0	15075
Matson	Chief Gadao	3	Emer Gen	1	3	335	1200	750	10.9	8174
Matson	Maui	2	Emer Gen	1	2	375	1800	560	10.0	5623
Matson	R.J. Pfeiffer	1	Emer Gen	1	1	670	1800	500	10.0	5025
TOTALS		**142**			**310**			**352672**		**4264211** g/hr
TOTALS Less Emergency Gens		**100**			**268**			**342326**		**4159597** g/hr
Total less emergency gens g/hr divided by total kW										**12.2** g/kWh

Notes:

[1]Weighted NO_x g/hr is weighted by total power output at each NO_x emissions rate to calculate an appropriate weighted average NO_x rate

Table D-3. Results — IMO NO_x reductions from auxiliary engines by year

Uncontrolled NOx		14.9	g/kWh			
IMO NOx		12.3	g/kWh			
Calendar Year	**%IMO**	**Calendar Year-Specific NO_x Rates (g/kWh)**	**As Percent of Uncontrolled Rate**	**Uncontrolled NO_x Inventory (tpd) Auxiliary Engines**	**IMO-Controlled NO_x Inventory (tpd) Auxiliary Engines**	**NO_x Reduction from IMO (tpd)**
2000	2.44%	14.8	99.6%	10.9	10.9	0.0
2001	6.48%	14.7	98.9%	11.27	11.1	0.1
2002	11.27%	14.6	98.0%	11.64	11.4	0.2
2003	15.37%	14.5	97.3%	12.01	11.7	0.3
2004	19.49%	14.4	96.6%	12.38	12.0	0.4
2005	22.74%	14.3	96.0%	12.75	12.2	0.5
2006	27.23%	14.2	95.2%	13.12	12.5	0.6
2007	31.03%	14.1	94.5%	13.49	12.8	0.7
2008	37.09%	13.9	93.4%	13.86	13.0	0.9
2009	40.57%	13.8	92.8%	14.23	13.2	1.0
2010	45.19%	13.7	92.0%	14.6	13.4	1.2

ANALYSIS OF MARINE EMISSIONS IN THE SOUTH COAST AIR BASIN

APPENDIX E

Harbor Craft and Fishing Vessels - Analysis of Effects of National and International Standards

Introductory notes:

1. Distribution of engines by hp categories and calculation of average hp for each category were made based on original data sets used for the SCAQMD study plus information from operators. See text for more detail.

2. RPM assumptions based on manufacturer literature, information provided by operators of harbor craft operating in San Pedro Bay, and discussion with EPA staff.

3. Standards applicable to high-speed engines (1600+ rpm) are assumed to be those set forth for nonroad engines in the Statement of Principles. These are NMHC+NOx standards of 5.6, 4.9, and 4.8 g/bhp-hr. For this study, it is assumed that NMHC emissions from SOP-certified marine engines will be 0.6, 0.3, and 0.4 g/bhp-hr, respectively.

4. For engines under 1600 rpm, the IMO standard is applied.

5. Fleet turnover is expressed in terms of years to 100% turnover of the fleet. The fleet is assumed to be distributed evenly over all years up to the "turnover age"

6. For tugs where the activity is modeled in terms of annual fuel consumption, NOx emission rates in g/bhp-hr are converted to g/1000 gal fuel with the assumptions of BSFC = 160 g fuel/bhp-hr (Reference 3) and a fuel density of 7.5 lbs per gallon (0.9 kg/l).

7. For passenger vessels and workboats, load factors and activity were taken from the SCAQMD study (which took them from an earlier study (Booz-Allen).

TUG/TOW/PUSH BOATS

Assumed years to 100% fleet turnover: 40

Horsepower Category	Number 1995 Mooring Tugs	Number 1993 Non-mooring	Number total	Assumed rated speed rpm	NOx std. g/bhp-hr	Year of effect	% cert in 2010	Unc. NOx g/bhp-hr	Unc. NOx lbs/1000gal	2010 NOx g/bhp-hr	2010 NOx lbs/1000gal
<300	0	4	4	1600+	4.6	2003	20%	9.0	420	8.1	379
300-599	0	9	9	1600+	4.4	2001	25%	9.0	420	7.8	366
600-749	5	0	5	1600+	4.4	2002	23%	9.0	420	7.9	372
749-999	2	2	4	1000	8.4	2000	28%	9.0	420	8.8	413
1000-1499	10	1	11	1000	8.4	2000	28%	9.0	420	8.8	413
1500-1999	16	0	16	1000	8.4	2000	28%	9.0	420	8.8	413
2000-2499	1	0	1	1000	8.4	2000	28%	9.0	420	8.8	413
2500-2999	8	0	8	1000	8.4	2000	28%	9.0	420	8.8	413
3000-3499	0	0	0	1000	8.4	2000	28%	9.0	420	8.8	413
3500-3999	2	0	2	1000	8.4	2000	28%	9.0	420	8.8	413
4000-4499	0	0	0	1000	8.4	2000	28%	9.0	420	8.8	413
4500-5499	0	0	0	1000	8.4	2000	28%	9.0	420	8.8	413
Totals	44	16	60								

TUG/TOW/PUSH BOATS

Horsepower Category	Average Rated Power (hp) Mooring Tugs	Average Rated Power (hp) Non-mooring	2010 fuel use (gal/hp/year)	Fuel used (gal/category/year) Mooring Tugs	Fuel used (gal/category/year) Non-mooring	Unc. NOx lbs/1000gal	Unc. NOx tpy	2010 NOx lbs/1000gal	2010 NOx tpy	controlled/ uncontrolled NOx
<300		225	42.7	0	38430	0	0	0	0	NA
300-599		405	42.7	0	155642	420	33	366	29	87%
600-749	620		42.7	132370	0	420	28	372	25	89%
749-999	925	825	42.7	78995	70455	420	31	413	31	98%
1000-1499	1130	1005	42.7	482510	42914	420	110	413	108	98%
1500-1999	1708		42.7	1166906	0	420	245	413	241	98%
2000-2499	2150		42.7	91805	0	420	19	413	19	98%
2500-2999	2500		42.7	854000	0	420	179	413	176	98%
3000-3499			42.7	0	0	420	0	413	0	NA
3500-3999	3500		42.7	298900	0	420	63	413	62	98%
4000-4499			42.7	0	0	420	0	413	0	NA
4500-5499			42.7	0	0	420	0	413	0	NA
Totals				3105486	307440		708		690	**98%**

PASSENGER/EXCURSION

assumed average load factor= 47%
assumed years to 100% fleet turnover = 40

Horsepower Category	Engine Number	Avg hp	Hours/yr per boat	hp-hr/yr per category	rpm	NOx std. g/bhp-hr	Year of effect	% cert in 2010	Unc. NOx g/bhp-hr	2010 NOx g/bhp-hr
0-49	0		1760	0	1600+				9.0	
50-99	0		1760	0	1600+	5.0	2004	18%	9.0	8.3
100-174	3	143	1760	354869	1600+	4.6	2003	20%	9.0	8.1
175-299	3	235	1760	583176	1600+	4.6	2003	20%	9.0	8.1
300-599	22	442	1760	8043693	1600+	4.4	2001	25%	9.0	7.8
600-749	0		1760	0	1600+	4.4	2002	23%	9.0	7.9
750-999	4	850	1760	2812480	1600+	4.4	2006	13%	9.0	8.4
1000-1499	6	1115	3900	12262770	1600+	4.4	2006	13%	9.0	8.4
1500-1999	8	1656	3500	21792960	1600+	4.4	2006	13%	9.0	8.4
2000-2499	2	2000	3500	6580000	1600+	4.4	2006	13%	9.0	8.4
Totals	48			52429948						

PASSENGER/EXCURSION

Horsepower Category	Number	hp-hr/yr per category	Unc. NOx g/bhp-hr	2010 NOx g/bhp-hr	Unc. NOx tpy	2010 NOx tpy	2010/ Uncontrolled
0-49	0	0					
50-99	0	0	9.0	8.3	0	0	NA
100-174	3	354869	9.0	8.1	3	3	90%
175-299	3	583176	9.0	8.1	6	5	90%
300-599	22	8043693	9.0	7.8	79	69	87%
600-749	0	0	9.0	7.9	0	0	NA
750-999	4	2812480	9.0	8.4	28	26	94%
1000-1499	6	12262770	9.0	8.4	121	113	94%
1500-1999	8	21792960	9.0	8.4	215	201	94%
2000-2499	2	6580000	9.0	8.4	65	61	NA
Totals	48	52429948			517	479	**93%**

WORK/SUPPLY/CREW/UTILITY

Assumed years to 100% fleet turnover: 40

Horsepower	Number	Avg hp	Hours/yr per boat	hp-hr/yr per category	rpm	NOx std. g/bhp-hr	Year of effect	% cert in 2010	Unc. NOx g/bhp-hr	2010 NOx g/bhp-hr
<300	4	200	880	704000	1600+	4.6	2003	20%	9.0	8.1
300-599	30	456	880	12038400	1600+	4.4	2001	25%	9.0	7.8
600-749	4	600	1320	3168000	1600+	4.4	2002	23%	9.0	7.9
750-999	4	802	1320	4234560	1000	8.4	2000	28%	9.0	8.8
1000-1499	2	1125	880	1980000	1000	8.4	2000	28%	9.0	8.8
1500-1999	2	1700	880	2992000	1000	8.4	2000	28%	9.0	8.8
2000-2499	0		880	0	1000	8.4	2000	28%	9.0	8.8
2500-2999	2	2870	880	5051200	1000	8.4	2000	28%	9.0	8.8
3000-3499	0		880	0	1000	8.4	2000	28%	9.0	8.8
Totals	48			30168160						

WORK/SUPPLY/CREW/UTILITY

Horsepower	Number	hp-hr/yr per category	Unc. NOx g/bhp-hr	2010 NOx g/bhp-hr	Unc. NOx tpy	2010 NOx tpy	2010/ Uncontrolled
<300	4	704000	9.0	8.1	6.9	6.3	90%
300-599	30	12038400	9.0	7.8	118.7	103.6	87%
600-749	4	3168000	9.0	7.9	31.2	27.7	89%
750-999	4	4234560	9.0	8.8	41.7	41.1	98%
1000-1499	2	1980000	9.0	8.8	19.5	19.2	98%
1500-1999	2	2992000	9.0	8.8	29.5	29.0	98%
2000-2499	0	0	9.0	8.8	0.0	0.0	NA
2500-2999	2	5051200	9.0	8.8	49.8	49.0	NA
3000-3499	0	0	9.0	8.8	0.0	0.0	NA
Totals	48	30168160			297.4	275.8	**93%**

FISHING VESSELS

Assumed years to 100% fleet turnover: 40

Horsepower Category	Number of Vessels Commercial	CPFV	TOTAL	assumed rpm (both)	NOx std. g/bhp-hr	Year of effect	% cert in 2010	Unc. NOx g/bhp-hr	2010 NOx g/bhp-hr
0-49	71	2	73	1600+	5.0	2004	18%	9.0	8.3
50-99	35	3	38	1600+	5.0	2004	18%	9.0	8.3
100-174	134	8	142	1600+	4.6	2003	20%	9.0	8.1
175-299	195	25	220	1600+	4.6	2003	20%	9.0	8.1
300-599	167	58	225	1600+	4.4	2001	25%	9.0	7.8
600-749	29	23	52	1600+	4.4	2002	23%	9.0	7.9
750+	14	25	39	1000	8.4	2000	28%	9.0	8.8
Totals	645	144	789						

Notes:
1. 0-49 hp category includes 51 vessels at "0" hp, 4 vessels under 25 hp, and 13 vessels 25-49 hp. We assume all of these vessels to be 25 to 49 hp.
Note that vessels with "0" hp are about 20 to 60+ ft long and are of all ages and are from commercial landings file so seems clear 0 does not mean boat has no engine
2. The data file from the Department of Fish and Game was modified to remove duplicate records. Duplicate records were assumed to be those for which the vessel name, owner name, and vessel horsepower were all identical.

FISHING VESSELS

Horsepower Category	Number of Vessels Commercial	CPFV	Assumed avg hp	Commercial %MCR * hrs/ day / boat	CPFV %MCR * hrs/ day / boat	hp-hr per day/category	Unc. NOx g/bhp-hr	uncontrolled NOx tpd	2010 NOx g/bhp-hr	2010 NOx tpd	2010/ uncontrolled NOx
0-49	71	2	25	2.77	0.93	4970	9	0.05	8.3	0.05	92%
50-99	35	3	75	2.77	0.93	7491	9	0.07	8.3	0.07	92%
100-174	134	8	137	2.77	0.93	51947	9	0.51	8.1	0.46	90%
175-299	195	25	237	2.77	0.93	133723	9	1.32	8.1	1.19	90%
300-599	167	58	450	2.77	0.93	232791	9	2.30	7.8	2.00	87%
600-749	29	23	675	2.77	0.93	68770	9	0.68	7.9	0.60	89%
750+	14	25	1383	2.77	0.93	85934	9	0.85	8.8	0.83	98%
Totals	645	144				585627		5.8		5.2	**90%**

TOTAL NOx REDUCTIONS FROM HARBOR CRAFT AND FISHING VESSELS IN 2010

Vessel Type	NOx Reduction in 2010	
	Percent	tpd
Tugs	98%	0.05
Passsenger	93%	0.10
Workboats	93%	0.06
Fishing	90%	0.57
Total		0.78

ANALYSIS OF MARINE EMISSIONS IN THE SOUTH COAST AIR BASIN

APPENDIX F

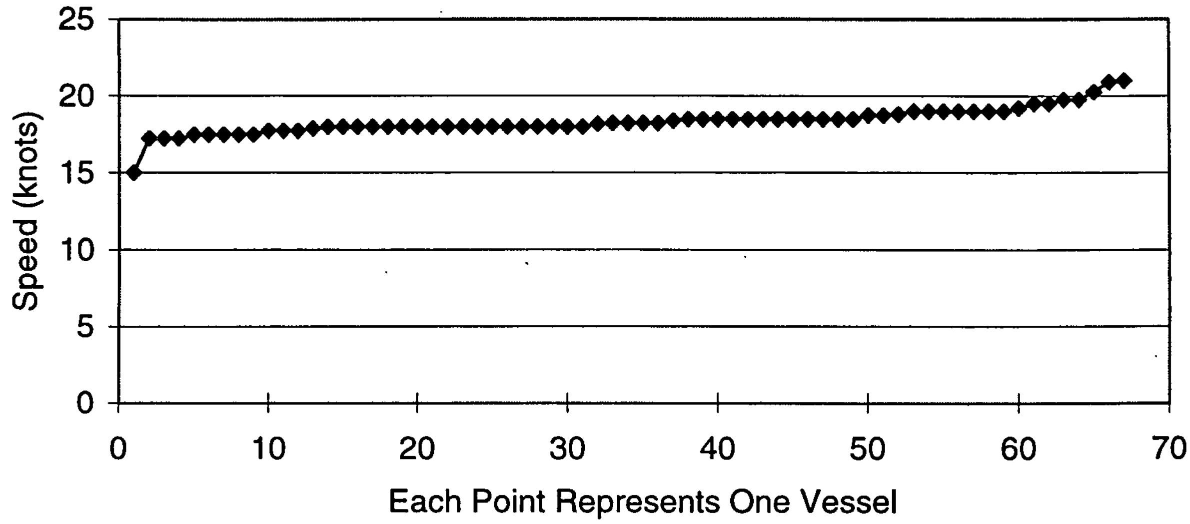


Figure F-1. Auto carrier service speed profile

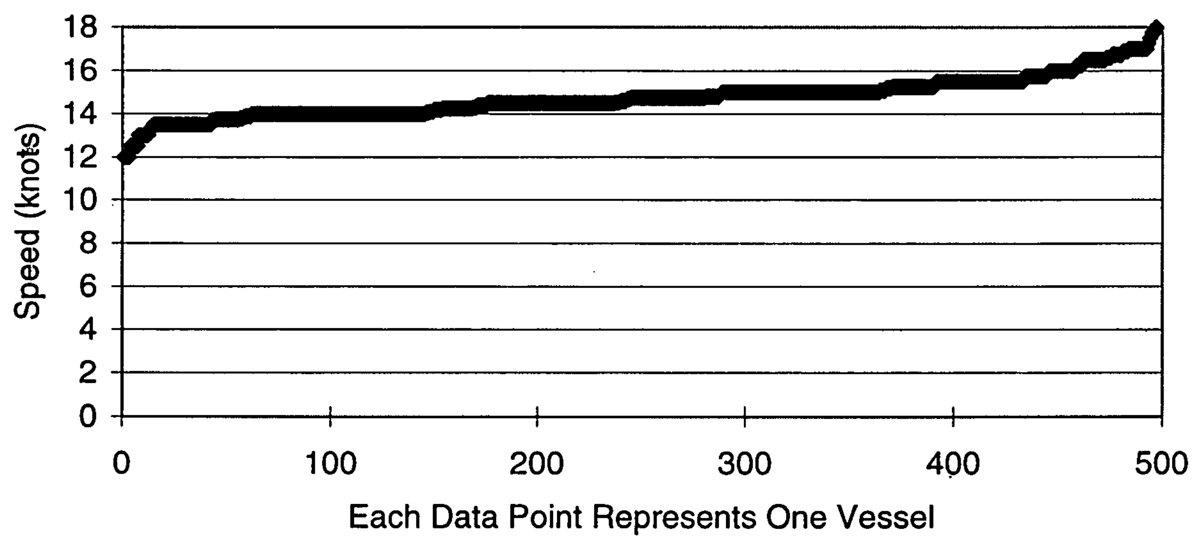


Figure F-2. Bulk carrier service speed profile

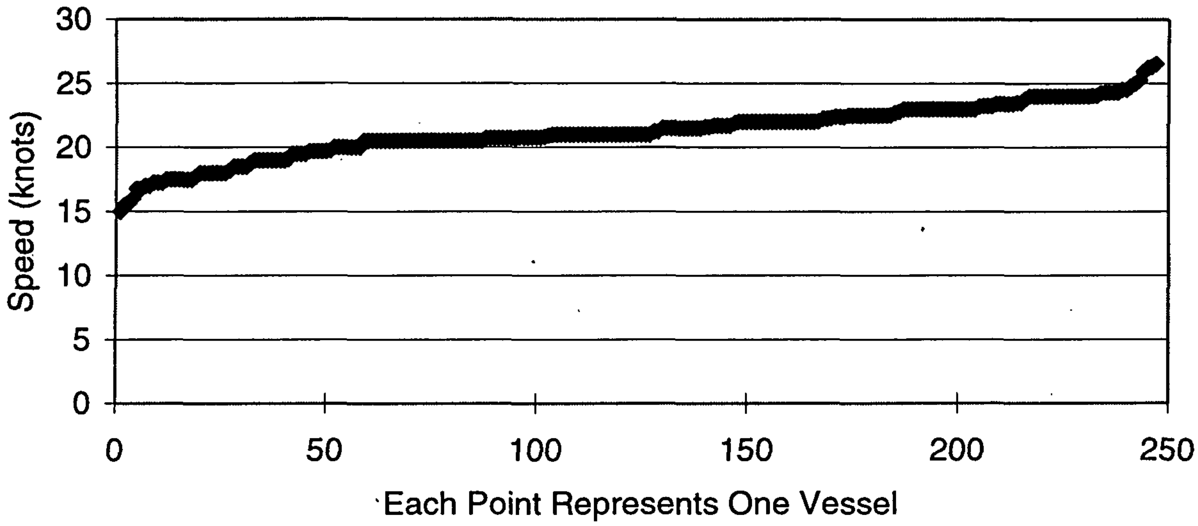


Figure F-3. Container ship service speed profile

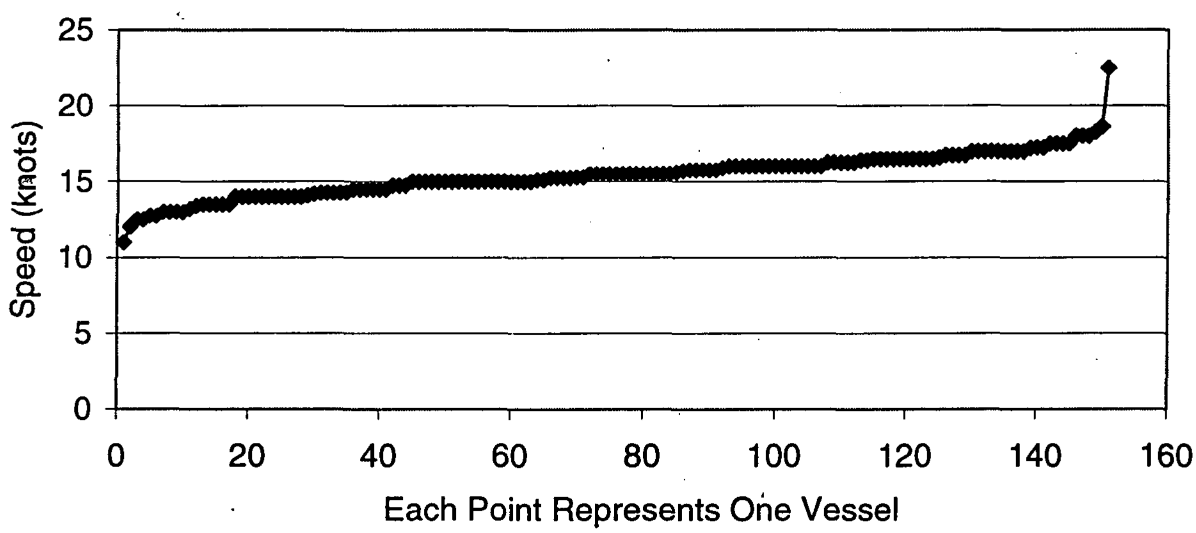


Figure F-4. General cargo service speed profile

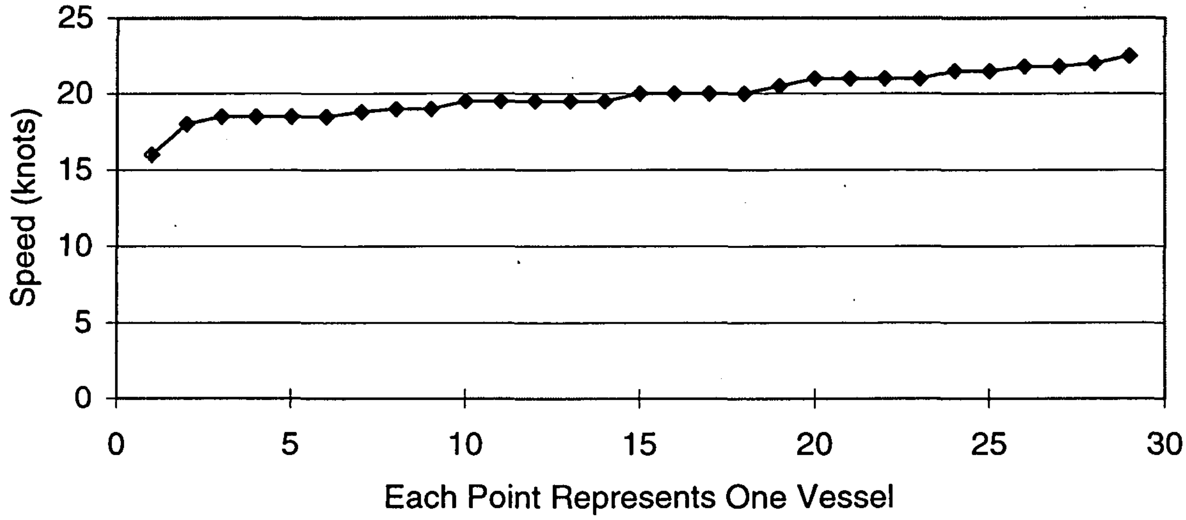


Figure F-5. Passenger vessel service speed profile

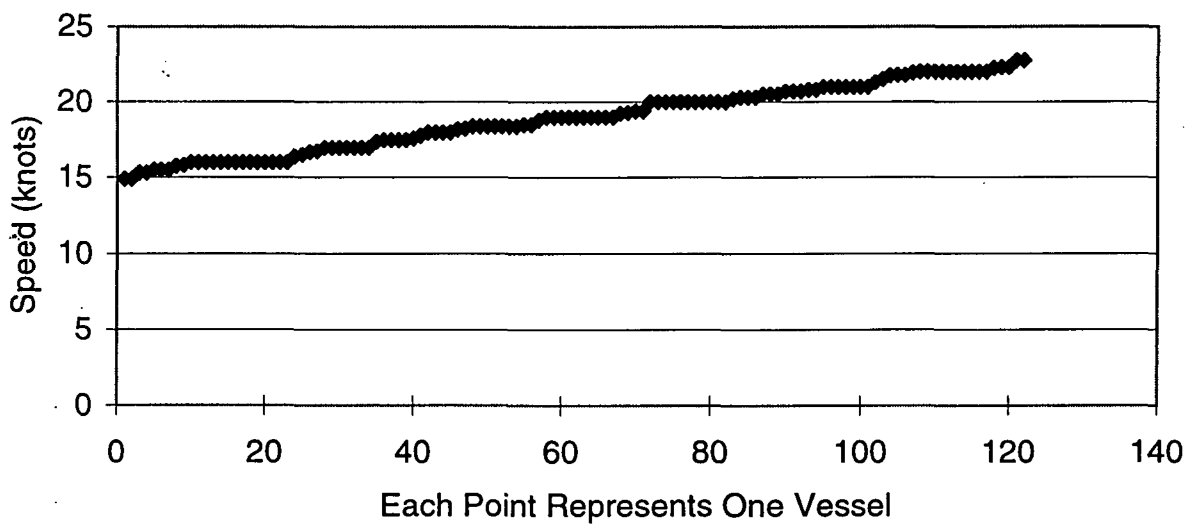


Figure F-6. Reefer cargo service speed profile

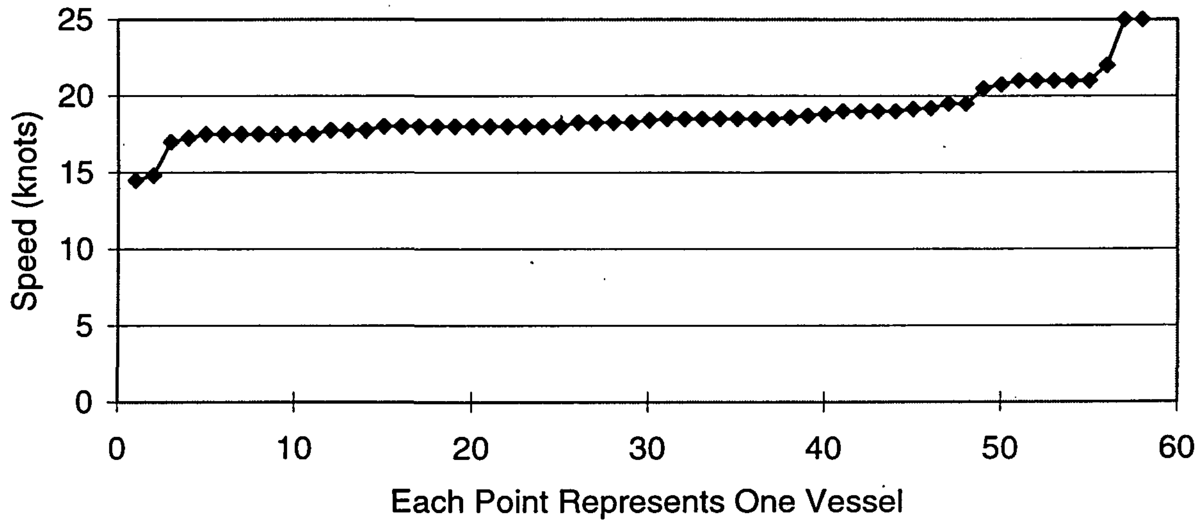


Figure F-7. RORO service speed profile

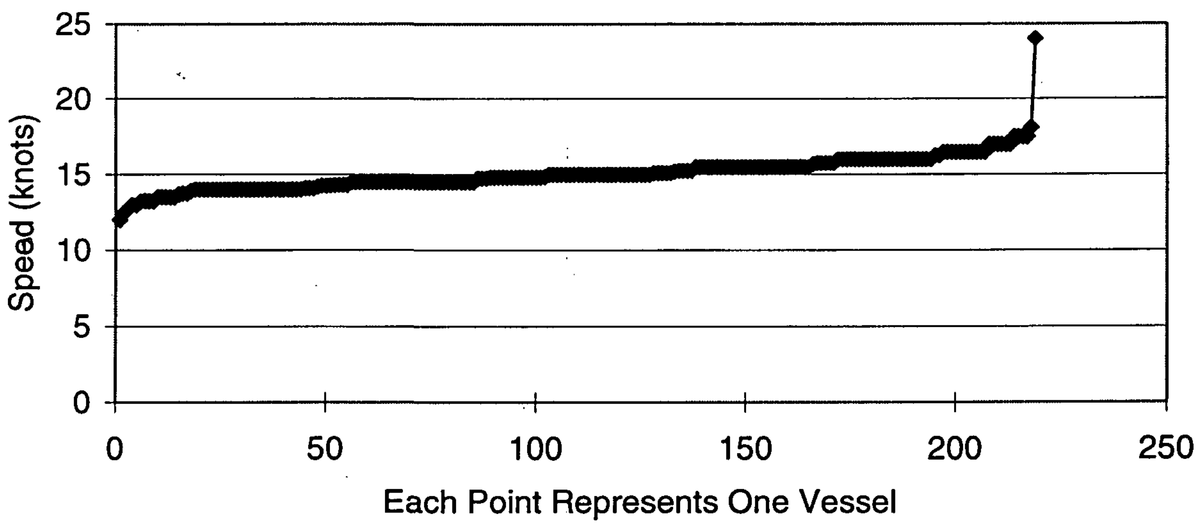


Figure F-8. Tanker service speed profile

ANALYSIS OF MARINE EMISSIONS IN THE SOUTH COAST AIR BASIN

APPENDIX G

FROM MARINE EMISSIONS INVENTORY - Distances, Speeds, Times, and Engine Loads
Ocean-going Vessels calling on SPBP: Average Distance and Time period of Cruising within South Coast Waters by Ship type and Propulsion type
Source: Marine Exchange of Los Angeles - Long Beach Harbor

Inbound Route: South Coast border to Precautionary Area

North	40 miles
South	34 miles
Western (most tanker)	43.5 miles
Catalina (Honolulu traffic)	66 miles

Inbound Route: Precautionary Area to POLA

North	4.5 miles
South	7.5 miles
Western (most tanker)	4.5 miles
Catalina (Honolulu traffic)	5 miles

Inbound Route: Precautionary Area to POLB

North	8 miles
South	6.5 miles
Western (most tanker)	8 miles
Catalina (Honolulu traffic)	8 miles

Outbound Route: South Coast border to Precautionary Area

North	39 miles
South	38 miles
Western (most tanker)	43.5 miles
Catalina (Honolulu traffic)	66 miles

Outbound Route: Precautionary Area to POLA

North	3.5 miles
South	6 miles
Western (most tanker)	3.5 miles
Catalina (Honolulu traffic)	5 miles

Outbound Route: Precautionary Area to POLB

North	6 miles
South	6 miles
Western (most tanker)	6 miles
Catalina (Honolulu traffic)	8 miles

Assumed Distribution of Traffic over Sea-lane Routes for Non-Honolulu Traffic:

	Inbound from ...			Outbound to ...		
SHIPTYPE	North	South	West	North	South	West
Auto Carrier	50%	50%	0%	50%	50%	0%
Bulk Carrier	50%	50%	0%	50%	50%	0%
Container Ship	50%	50%	0%	50%	50%	0%
General Cargo	50%	50%	0%	50%	50%	0%
Passenger	50%	50%	0%	50%	50%	0%
Reefer	50%	50%	0%	50%	50%	0%
RORO	50%	50%	0%	50%	50%	0%
Tanker	30%	10%	60%	30%	10%	60%

Source: Estimate from inspection of Marine Exchange 1994 data

Distribution of Honolulu Traffic:

	% 1994 Calls by Port		% Calls Honolulu - POLA		% Calls Honolulu - POLB		% Total Honolulu Calls	
SHIPTYPE	POLA	POLB	Inbound	Outbound	Inbound	Outbound	Inbound	Outbound
Auto Carrier	67%	33%	3%	2%	0%	0%	3%	2%
Bulk Carrier	24%	76%	1%	0%	0%	0%	1%	0%
Container Ship	50%	50%	6%	6%	0%	5%	6%	11%
General Cargo	46%	54%	0%	0%	0%	0%	0%	0%
Passenger	100%	0%	1%	0%	0%	0%	1%	0%
Reefer	65%	35%	0%	0%	0%	0%	0%	0%
RORO	94%	6%	48%	47%	0%	0%	48%	47%
Tanker	35%	65%	1%	1%	1%	0%	3%	1%

Scenario Description:

Reduced Speed Zone boundary distance from the Precautionary Area (nautical miles)	30
Ship speed in Reduced Speed Zone (knots):	
Auto Carrier	15
Bulk Carrier	12
Container Ship	15
General Cargo	15
assenger	15
Reefer	15
RORO	15
Tanker	12
Speed reduction assumed to apply to:	all

Average Cruising Distances (nautical miles), Speeds (knots), and Times (hours):

SHIPTYPE	Boundary to Precautionary Area Inbound	Boundary to Precautionary Area Outbound	Boundary to Reduced Speed Zone Inbound	Boundary to Reduced Speed Zone Outbound	2010 Full Cruise Speed (Knots)	Hours Cruise per call	Reduced Speed Zone to Precautionary Area Inbound	Reduced Speed Zone to Precautionary Area Outbound	RSZ Speed (Knots)	Hours RSZ per call
Auto Carrier	37.83	39.03	7.83	9.03	18.34	0.9	30	30	15	4.0
Bulk Carrier	37.24	38.61	7.24	8.61	15.06	1.1	30	30	12	5.0
Container Ship	38.82	41.43	8.82	11.43	**23.36**	0.9	30	30	15	4.0
General Cargo	37.00	38.50	7.00	8.50	15.73	1.0	30	30	15	4.0
Passenger	37.15	38.50	7.15	8.50	19.87	0.8	30	30	15	4.0
Reefer	37.00	38.50	7.00	8.50	19.65	0.8	30	30	15	4.0
RORO	50.80	51.32	20.80	21.32	22.01	1.9	30	30	15	4.0
Tanker	42.15	41.79	12.15	11.79	15.39	1.6	30	30	12	5.0

Precautionary Area Distances (nautical miles), Speeds (knots), and Times (hours):

SHIPTYPE	Precautionary Area to Breakwater Inbound	Precautionary Area to Breakwater Outbound	PArea Speed (knots)	PArea Hours per Call
Auto Carrier	6.38	5.17	12	1.0
Bulk Carrier	6.94	5.70	12	1.1
Container Ship	6.57	5.49	12	1.0
General Cargo	6.68	5.43	12	1.0
Passenger	5.99	4.75	12	0.9
Reefer	6.44	5.19	12	1.0
RORO	5.60	4.95	12	0.9
Tanker	6.78	5.22	12	1.0

Impact of Reduced Speeds on Engine Output Power:

SHIPTYPE	Full Cruise Speed (knts)	RSZ/Cruise Speed Ratio	100% displ % MCR	50% displ % MCR	RSZ %MCR	PA/Cruise peed Rat	100% disp % MCR	50% displ % MCR	PA %MCR
Auto Carrier	18.34	82%	41%	28%	37%	65%	21%	16%	19%
Bulk Carrier	15.06	80%	45%	33%	43%	80%	45%	33%	43%
Container Ship	23.36	64%	20%	15%	18%	51%	12%	10%	11%
General Cargo	15.73	95%	73%	47%	65%	76%	32%	23%	30%
Passenger	19.87	75%	31%	23%	29%	60%	17%	13%	16%
Reefer	19.65	76%	32%	23%	30%	61%	17%	14%	16%
RORO	22.01	68%	23%	17%	22%	55%	13%	11%	13%
Tanker	15.39	78%	43%	31%	40%	78%	43%	31%	40%

Notes:
Full cruise speed is assumed to be at 80 percent MCR
Percent MCR required is taken from equations developed by JJMA (for commercial vessels) under contract to the Navy. See text.
One set of equations was used to characterize tankers and bulkers. A different set of equations was used for all other shiptypes.

Increased Time Cruising Outside the Precautionary Area (for calculating increased emissions from auxiliary engines)

SHIPTYPE	Naut. Miles -Boundary to Precautionary Area Inbound	Naut. Miles -Boundary to Precautionary Area Outbound	Full Cruise Speed (knts)	Baseline Operation Cruise hrs	With Speed Reduction Cruise hours	With Speed Reduction RSZ hours	With Speed Reduction Total hours	S.R. minus baseline hours
Auto Carrier	37.83	39.03	18.34	4.19	0.92	4.0	4.92	**0.73**
Bulk Carrier	37.24	38.61	15.06	5.04	1.05	5.0	6.05	**1.02**
Container Ship	38.82	41.43	23.36	3.44	0.87	4.0	4.87	**1.43**
General Cargo	37.00	38.50	15.73	4.80	0.99	4.0	4.99	**0.19**
Passenger	37.15	38.50	19.87	3.81	0.79	4.0	4.79	**0.98**
Reefer	37.00	38.50	19.65	3.84	0.79	4.0	4.79	**0.95**
RORO	50.80	51.32	22.01	4.64	1.91	4.0	5.91	**1.27**
Tanker	42.15	41.79	15.39	5.45	1.56	5.0	6.56	**1.10**

MARINE EMISSIONS INVENTORY

Ocean-going VesselsCalling on SPBP: Main Engine Fuel Consumption Calculations and Time in Operating Mode

Shiptype	Propulsion Type	Design Catego-ries	NB / B Calls in 2010	Power by mode (hp) Cruise	RSZ Cruise	PA Cruise	Maneu-vering	Time in Mode (hours/call) Cruise	RSZ Cruise	PA Cruise	Maneu-vering	Energy Consumed (kWh/call) Cruise	RSZ Cruise	PA Cruise	Maneu-vering	Energy Consumed (kWh/year) Cruise	RSZ Cruise	PA Cruise	Maneu-vering
Auto Carrier	*(% MCR)*		**NB calls**	*80%*	*37%*	*19%*	*15%*												
	Motorships	0-200	0	0		0	0	0.9	4.0	1.0	1.5	0	0	0	0	0	0	0	0
		200-400	331	11,784	5,470	2,847	2,210	0.9	4.0	1.0	1.5	8081	16323	2044	2473	2674860	5403059	676722	818399
		400-600	131	13,916	6,460	3,362	2,609	0.9	4.0	1.0	1.5	9543	19276	2414	2920	1250093	2525114	316265	382478
		>600	2	15,652	7,266	3,781	2,935	0.9	4.0	1.0	1.5	10734	21681	2716	3284	21467	43362	5431	6568
Auto Carrier	*(% MCR)*		**B calls**	*80%*	*37%*	*19%*	*15%*												
	Motorships	0-200	0	0	-	-	-	0.9	4.0	1.0	1.3	0	0	0	0	0	0	0	0
		200-400	58	11,784	5,470	2,847	2,210	0.9	4.0	1.0	1.3	8081	16323	2044	2143	468707	946760	118580	124285
		400-600	3	13,916	6,460	3,362	2,609	0.9	4.0	1.0	1.3	9543	19276	2414	2530	28628	57827	7243	7591
		>600	6	15,652	7,266	3,781	2,935	0.9	4.0	1.0	1.3	10734	21681	2716	2846	64401	130086	16293	17077
Bulk Carrier	*(% MCR)*		**NB calls**	*80%*	*43%*	*43%*	*20%*												
	Motorships	0-200	8	7,081	3,811	3,811	1,770	1.1	5.0	1.1	2.5	5559	14217	2993	3301	44472	113733	23943	26412
		200-400	145	8,785	4,729	4,729	2,196	1.1	5.0	1.1	2.5	6897	17639	3713	4096	1000063	2557583	538413	593936
		400-600	151	10,877	5,855	5,855	2,719	1.1	5.0	1.1	2.5	8539	21837	4597	5071	1289359	3297434	694164	765748
		600-800	169	13,588	7,314	7,314	3,397	1.1	5.0	1.1	2.5	10667	27281	5743	6335	1802784	4610477	970581	1070670
		800-1000	2	20,663	11,123	11,123	5,166	1.1	5.0	1.1	2.5	16222	41487	8734	9634	32444	82974	17467	19269
		>1000	2	27,130	14,604	14,604	6,783	1.1	5.0	1.1	2.5	21299	54471	11467	12650	42598	108942	22934	25299
	Steamships	600-800	0					1.1	5.0	1.1	2.5	0	0	0	0	0	0	0	0
		800-1000	0					1.1	5.0	1.1	2.5	0	0	0	0	0	0	0	0
		1000-120	0					1.1	5.0	1.1	2.5	0	0	0	0	0	0	0	0
Bulk Carrier	*(% MCR)*		**B calls**	*80%*	*43%*	*43%*	*20%*												
	Motorships	0-200	11	7,081	3,811	3,811	1,770	1.1	5.0	1.1	1.1	5559	14217	2993	1453	61149	156383	32921	15979
		200-400	186	8,785	4,729	4,729	2,196	1.1	5.0	1.1	1.1	6897	17639	3713	1802	1282840	3280761	690654	335225
		400-600	202	10,877	5,855	5,855	2,719	1.1	5.0	1.1	1.1	8539	21837	4597	2231	1724839	4411137	928617	450726
		600-800	266	13,588	7,314	7,314	3,397	1.1	5.0	1.1	1.1	10667	27281	5743	2788	2837518	7256727	1527660	741486
		800-1000	60	20,663	11,123	11,123	5,166	1.1	5.0	1.1	1.1	16222	41487	8734	4239	973334	2489223	524022	254347
		>1000	58	27,130	14,604	14,604	6,783	1.1	5.0	1.1	1.1	21299	54471	11467	5566	1235355	3159322	665089	322817

Shiptype	Propulsion Type	Design Categories	Calls in 2010	Power by mode (hp)				Time in Mode (hours/call)				Energy Consumed (kWh/call)				Energy Consumed (kWh/year)			
				Cruise	RSZ Cruise	PA Cruise	Maneu-vering	Cruise	RSZ Cruise	PA Cruise	Maneu-vering	Cruise	RSZ Cruise	PA Cruise	Maneu-vering	Cruise	RSZ Cruise	PA Cruise	Maneu-vering
Container Ship	(% MCR)		NB calls	80%	18%	11%	10%												
	Motorships	0-200	10	6,957	1,602	972	870	0.9	4.0	1.0	1.9	4497	4781	729	1233	44969	47808	7286	12325
		200-400	41	13,082	3,013	1,828	1,635	0.9	4.0	1.0	1.9	8456	8990	1370	2318	346710	368601	56177	95028
		400-600	45	13,360	3,077	1,867	1,670	0.9	4.0	1.0	1.9	8636	9182	1399	2367	388630	413168	62969	106518
		600-800	20	16,725	3,852	2,337	2,091	0.9	4.0	1.0	1.9	10812	11494	1752	2963	216231	229884	35036	59266
		800-1000	60	22,173	5,107	3,098	2,772	0.9	4.0	1.0	1.9	14333	15238	2322	3929	859990	914290	139343	235711
		1000-120	86	22,710	5,230	3,174	2,839	0.9	4.0	1.0	1.9	14681	15607	2379	4024	1262527	1342244	204566	346040
		1200-140	441	26,188	6,031	3,660	3,273	0.9	4.0	1.0	1.9	16928	17997	2743	4640	7465432	7936800	1209614	2046164
		1400-160	88	33,686	7,758	4,707	4,211	0.9	4.0	1.0	1.9	21775	23150	3528	5968	1916241	2037233	310486	525213
		1600-180	121	36,985	8,518	5,168	4,623	0.9	4.0	1.0	1.9	23908	25418	3874	6553	2892880	3075537	468730	792896
		1800-200	399	41,436	9,543	5,790	5,179	0.9	4.0	1.0	1.9	26785	28476	4340	7341	10687202	11361993	1731633	2929203
		2000-220	366	46,267	10,656	6,465	5,783	0.9	4.0	1.0	1.9	29908	31796	4846	8197	10946340	11637493	1773621	3000229
		2200-240	761	58,330	13,434	8,151	7,291	0.9	4.0	1.0	1.9	37706	40087	6109	10335	28694377	30506143	4649311	7864703
Container Ship	(% MCR)		B calls	80%	18%	11%	10%												
	Motorships	0-200	0	6,957	1,602	972	870	0.9	4.0	1.0	1.5	4497	4781	729	973	0	0	0	0
		200-400	0	13,082	3,013	1828	1635	0.9	4.0	1.0	1.5	8456	8990	1370	1830	0	0	0	0
		400-600	0	13,360	3,077	1867	1670	0.9	4.0	1.0	1.5	8636	9182	1399	1869	0	0	0	0
		600-800	0	16,725	3,852	2337	2091	0.9	4.0	1.0	1.5	10812	11494	1752	2339	0	0	0	0
		800-1000	0	22,173	5,107	3098	2772	0.9	4.0	1.0	1.5	14333	15238	2322	3101	0	0	0	0
		1000-120	0	22,710	5,230	3174	2839	0.9	4.0	1.0	1.5	14681	15607	2379	3177	0	0	0	0
		1200-140	0	26,188	6,031	3660	3273	0.9	4.0	1.0	1.5	16928	17997	2743	3663	0	0	0	0
		1400-160	0	33,686	7,758	4707	4211	0.9	4.0	1.0	1.5	21775	23150	3528	4712	0	0	0	0
		1600-180	0	36,985	8,518	5168	4623	0.9	4.0	1.0	1.5	23908	25418	3874	5173	0	0	0	0
		1800-200	4	41,436	9,543	5790	5179	0.9	4.0	1.0	1.5	26785	28476	4340	5796	107140	113905	17360	23183
		2000-220	0	46,267	10,656	6465	5783	0.9	4.0	1.0	1.5	29908	31796	4846	6472	0	0	0	0
		2200-240	0	58,330	13,434	8151	7291	0.9	4.0	1.0	1.5	37706	40087	6109	8159	0	0	0	0

Shiptype	Propulsion Type	Design Categories	Calls in 2010	Power Cruise	Power RSZ Cruise	Power PA Cruise	Power Maneu-vering	Time Cruise	Time RSZ Cruise	Time PA Cruise	Time Maneu-vering	kWh/call Cruise	kWh/call RSZ Cruise	kWh/call PA Cruise	kWh/call Maneu-vering	kWh/year Cruise	kWh/year RSZ Cruise	kWh/year PA Cruise	kWh/year Maneu-vering
General Cargo	(% MCR)		NB calls	80%	65%	30%	20%												
	Motorships	0-200	172	2,259	1,846	840	565	1.0	4.0	1.0	1.8	1661	5509	632	758	286142	949301	108918	130675
		200-400	342	8,851	7,234	3,290	2,213	1.0	4.0	1.0	1.8	6507	21586	2477	2971	2222700	7373990	846053	1015057
		400-600	47	11,294	9,230	4,198	2,823	1.0	4.0	1.0	1.8	8302	27543	3160	3791	390440	1295318	148618	178305
		600-800	0	14,670	11,989	5,453	3,667	1.0	4.0	1.0	1.8	10783	35775	4105	4925	0	0	0	0
		800-1000	0	30,442	24,879	11,315	7,610	1.0	4.0	1.0	1.8	22377	74239	8518	10219	0	0	0	0
		>1000	7	22,609	18,477	8,404	5,652	1.0	4.0	1.0	1.8	16619	55136	6326	7590	117240	388954	44627	53541
General Cargo	(% MCR)		B calls	80%	65%	30%	20%												
	Motorships	0-200	22	2,259	1,846	840	565	1.0	4.0	1.0	0.8	1661	5509	632	337	36535	121207	13907	7415
		200-400	126	8,851	7,234	3290	2213	1.0	4.0	1.0	0.8	6507	21586	2477	1321	819822	2719828	312059	166397
		400-600	4	11,294	9,230	4198	2823	1.0	4.0	1.0	0.8	8302	27543	3160	1685	33208	110171	12640	6740
		600-800	0	14,670	11,989	5453	3667	1.0	4.0	1.0	0.8	10783	35775	4105	2189	0	0	0	0
		800-1000	0	30,442	24,879	11315	7610	1.0	4.0	1.0	0.8	22377	74239	8518	4542	0	0	0	0
		>1000	0	22,609	18,477	8404	5652	1.0	4.0	1.0	0.8	16619	55136	6326	3373	0	0	0	0

Shiptype	Propulsion Type	Design Categories	NB / B Calls in 2010	Power by mode (hp) Cruise	RSZ Cruise	PA Cruise	Maneuvering	Time in Mode (hours/call) Cruise	RSZ Cruise	PA Cruise	Maneuvering	Energy Consumed (kWh/call) Cruise	RSZ Cruise	PA Cruise	Maneuvering	Energy Consumed (kWh/year) Cruise	RSZ Cruise	PA Cruise	Maneuvering
Passenger Ship	*(% MCR)*		**NB calls**	*80%*	*29%*	*16%*	*15%*												
	Motorships	0-100	3	12,124	4,365	2,405	2,273	0.8	4.0	0.9	2.5	7123	13025	1606	4240	21370	39075	4819	12719
		100-200	348	17,864	6,431	3,543	3,350	0.8	4.0	0.9	2.5	10496	19191	2367	6247	3652555	6678526	823638	2173935
		200-300	139	22,698	8,172	4,502	4,256	0.8	4.0	0.9	2.5	13336	24384	3007	7937	1853693	3389391	418001	1103284
		300-400	89	25,095	9,034	4,977	4,705	0.8	4.0	0.9	2.5	14744	26959	3325	8775	1312211	2399317	295899	781005
		400-500	3	29,418	10,591	5,835	5,516	0.8	4.0	0.9	2.5	17284	31603	3898	10287	51852	94810	11693	30862
		500-600	0	-	-	-	-	0.8	4.0	0.9	2.5	-	-	-	-	-	-	-	-
		600-700	0	-	-	-	-	0.8	4.0	0.9	2.5	-	-	-	-	-	-	-	-
		700-800	2	42,389	15,260	8,407	7,948	0.8	4.0	0.9	2.5	24905	45537	5616	14823	49809	91074	11232	29646
Passenger Ship	*(% MCR)*		**B calls**	*80%*	*29%*	*16%*	*15%*												
	Motorships	0-100	0	12,124	4,365	2405	2273	0.8	4.0	0.9	0	7123	13025	1606	0	0	0	0	0
		100-200	0	17,864	6,431	3543	3350	0.8	4.0	0.9	0	10496	19191	2367	0	0	0	0	0
		200-300	0	22,698	8,172	4502	4256	0.8	4.0	0.9	0	13336	24384	3007	0	0	0	0	0
		300-400	0	25,095	9,034	4977	4705	0.8	4.0	0.9	0	14744	26959	3325	0	0	0	0	0
		400-500	0	29,418	10,591	5835	5516	0.8	4.0	0.9	0	17284	31603	3898	0	0	0	0	0
		500-600	0	-	-	-	-	0.8	4.0	0.9	0	-	-	-	-	-	-	-	-
		600-700	0	-	-	-	-	0.8	4.0	0.9	0	-	-	-	-	-	-	-	-
		700-800	0	42,389	15,260	8407	7948	0.8	4.0	0.9	0	24905	45537	5616	0	0	0	0	0
Reefer	*(% MCR)*		**NB calls**	*80%*	*30%*	*16%*	*15%*												
	Motorships	0-100	0	4,464	1,663	909	837	0.8	4.0	1.0	1.8	2627	4961	658	1124	0	0	0	0
		100-200	114	5,678	2,115	1,156	1,065	0.8	4.0	1.0	1.8	3341	6310	837	1430	380915	719365	95364	162979
		200-300	21	7,817	2,911	1,592	1,466	0.8	4.0	1.0	1.8	4600	8686	1152	1968	96592	182416	24182	41328
		300-400	63	11,170	4,160	2,275	2,094	0.8	4.0	1.0	1.8	6573	12414	1646	2812	414113	782060	103676	177183
		400-500	227	10,770	4,011	2,193	2,019	0.8	4.0	1.0	1.8	6337	11968	1587	2712	1438573	2716773	360155	615512
		500-600	105	14,443	5,379	2,941	2,708	0.8	4.0	1.0	1.8	8499	16050	2128	3636	892366	1685250	223409	381810
		600-700	87	18,084	6,735	3,683	3,391	0.8	4.0	1.0	1.8	10642	20097	2664	4553	925827	1748443	231786	396127
		700-800	42	20,174	7,513	4,108	3,783	0.8	4.0	1.0	1.8	11871	22419	2972	5079	498594	941605	124826	213330
		>800	3	22,174	8,258	4,516	4,158	0.8	4.0	1.0	1.8	13048	24642	3267	5583	39145	73925	9800	16749
Reefer	*(% MCR)*		**B calls**	*80%*	*30%*	*16%*	*15%*												
	Motorships	0-100	0	4,464	1,663	909	837	0.8	4.0	1.0	0.8	2627	4961	658	500	0	0	0	0
		100-200	36	5,678	2,115	1156	1065	0.8	4.0	1.0	0.8	3341	6310	837	635	120289	227168	30115	22874
		200-300	24	7,817	2,911	1592	1466	0.8	4.0	1.0	0.8	4600	8686	1152	875	110391	208475	27637	20992
		300-400	20	11,170	4,160	2275	2094	0.8	4.0	1.0	0.8	6573	12414	1646	1250	131464	248273	32913	24999
		400-500	12	10,770	4,011	2193	2019	0.8	4.0	1.0	0.8	6337	11968	1587	1205	76048	143618	19039	14461
		500-600	4	14,443	5,379	2941	2708	0.8	4.0	1.0	0.8	8499	16050	2128	1616	33995	64200	8511	6465
		600-700	16	18,084	6,735	3683	3391	0.8	4.0	1.0	0.8	10642	20097	2664	2024	170267	321553	42627	32378
		700-800	0	20,174	7,513	4108	3783	0.8	4.0	1.0	0.8	11871	22419	2972	2257	0	0	0	0
		>800	0	22,174	8,258	4516	4158	0.8	4.0	1.0	0.8	13048	24642	3267	2481	0	0	0	0

Shiptype	Propulsion Type	Design Categories	NB / B Calls in 2010	Power by mode (hp) Cruise	RSZ Cruise	PA Cruise	Maneuvering	Time in Mode (hours/call) Cruise	RSZ Cruise	PA Cruise	Maneuvering	Energy Consumed (kWh/call) Cruise	RSZ Cruise	PA Cruise	Maneuvering	Energy Consumed (kWh/year) Cruise	RSZ Cruise	PA Cruise	Maneuvering
RORO	*(% MCR)*		NB calls	*80%*	*22%*	*13%*	*10%*												
	Motorships	0-200	1	0	0	0	0	1.9	4.0	0.9	1.5	0	0	0	0	0	0	0	0
		200-400	7	14,507	3,901	2,290	1,813	1.9	4.0	0.9	1.5	20706	11641	1502	2029	144942	81486	10513	14204
		400-600	5	16,596	4,463	2,620	2,074	1.9	4.0	0.9	1.5	23687	13317	1718	2321	118436	66585	8591	11607
		600-800	4	24,261	6,524	3,830	3,033	1.9	4.0	0.9	1.5	34628	19468	2512	3393	138512	77871	10047	13574
		800-1000	17	26,217	7,050	4,139	3,277	1.9	4.0	0.9	1.5	37421	21038	2714	3667	636150	357642	46143	62342
		1000-120	11	30,423	8,181	4,803	3,803	1.9	4.0	0.9	1.5	43424	24413	3150	4255	477664	268542	34647	46810
RORO	*(% MCR)*		B calls	*80%*	*22%*	*13%*	*10%*												
	Motorships	0-200	0	0	0	0	0	1.9	4.0	0.9	1.3	0	0	0	0	0	0	0	0
		200-400	3	14,507	3,901	2290	1813	1.9	4.0	0.9	1.3	20706	11641	1502	1759	62118	34923	4506	5276
		400-600	0	16,596	4,463	2620	2074	1.9	4.0	0.9	1.3	23687	13317	1718	2012	0	0	0	0
		600-800	0	24,261	6,524	3830	3033	1.9	4.0	0.9	1.3	34628	19468	2512	2941	0	0	0	0
		800-1000	0	26,217	7,050	4139	3277	1.9	4.0	0.9	1.3	37421	21038	2714	3178	0	0	0	0
		1000-120	0	30,423	8,181	4803	3803	1.9	4.0	0.9	1.3	43424	24413	3150	3688	0	0	0	0
Tanker	*(% MCR)*		NB calls	*80%*	*40%*	*40%*	*20%*												
	Motorships	0-200	21	5,125	2,593	2,593	1,281	1.6	5.0	1.0	1.5	5946	9673	1934	1434	124859	203132	40614	30109
		200-400	112	10,296	5,209	5,209	2,574	1.6	5.0	1.0	1.5	11944	19431	3885	2880	1337702	2176304	435122	322583
		400-600	287	13,263	6,711	6,711	3,316	1.6	5.0	1.0	1.5	15386	25031	5005	3710	4415686	7183872	1436317	1064832
		600-800	188	14,131	7,150	7,150	3,533	1.6	5.0	1.0	1.5	16393	26670	5332	3953	3081963	5014041	1002489	743208
		800-1000	120	16,635	8,417	8,417	4,159	1.6	5.0	1.0	1.5	19298	31395	6277	4654	2315718	3767438	753248	558430
		1000-120	27	21,501	10,879	10,879	5,375	1.6	5.0	1.0	1.5	24943	40579	8113	6015	673453	1095639	219058	162401
		1200-140	0	19,730	9,983	9,983	4,933	1.6	5.0	1.0	1.5	22889	37238	7445	5520	0	0	0	0
		>1400	167	30,435	15,400	15,400	7,609	1.6	5.0	1.0	1.5	35307	57440	11484	8514	5896225	9592558	1917901	1421860
Tanker	*(% MCR)*		B calls	*80%*	*40%*	*40%*	*20%*												
	Motorships	0-200	0	5,125	2,593	2593	1281	1.6	5.0	1.0	1.5	5946	9673	1934	1434	0	0	0	0
		200-400	11	10,296	5,209	5209	2574	1.6	5.0	1.0	1.5	11944	19431	3885	2880	131381	213744	42735	31682
		400-600	35	13,263	6,711	6711	3316	1.6	5.0	1.0	1.5	15386	25031	5005	3710	538498	876082	175161	129858
		600-800	30	14,131	7,150	7150	3533	1.6	5.0	1.0	1.5	16393	26670	5332	3953	491803	800113	159972	118597
		800-1000	30	16,635	8,417	8417	4159	1.6	5.0	1.0	1.5	19298	31395	6277	4654	578930	941860	188312	139607
		1000-120	5	21,501	10,879	10879	5375	1.6	5.0	1.0	1.5	24943	40579	8113	6015	124713	202896	40566	30074
		1200-140	0	19,730	9,983	9983	4933	1.6	5.0	1.0	1.5	22889	37238	7445	5520	0	0	0	0
		>1400	21	30,435	15,400	15400	7609	1.6	5.0	1.0	1.5	35307	57440	11484	8514	741441	1206250	241173	178797

TOTAL ENERGY CONSUMPTION BY MODE/SHIPTYPE

Energy Consumed by Mode (Full Cruise, PA Cruise, and Maneuvering):

	MWh/yr	% of total
At 80% MCR	120,870	65%
At 40% MCR	13,289	7%
At 35% MCR	1,487	1%
At 20% MCR	15,152	8%
At 15% MCR	7,729	4%
At 10% MCR	28,856	15%
Total	187,384	

Energy Consumed by Mode (RSZ Cruise):

	% MCR	Nearest %MCR bin	MWh/yr
Autocarrier	37%	35%	9106
Bulk	43%	40%	31525
Container	18%	20%	69985
General Carg	65%	80%	12959
Passenger	29%	35%	12692
Reefer	30%	35%	10063
RORO	22%	20%	887
Tanker	40%	40%	33274

Energy Consumed by Mode (All modes):

	MWh/yr	% of total
At 80% MCR	133,829	36%
At 40% MCR	78,088	21%
At 35% MCR	33,348	9%
At 20% MCR	86,024	23%
At 15% MCR	7,729	2%
At 10% MCR	28,856	8%
Total	367,875	

Cruise energy by shiptype:	MWh/yr	% total	%MS	MS MWh/yr	
Autocarrier	4508	4%	29%	1307	
Bulk	12327	10%	5%	616	
Container	65829	54%	4%	2633	
General Carg	3906	3%	22%	859	
Passenger	6941	6%	52%	3610	
Reefer	5329	4%	18%	959	
RORO	1578	1%	10%	158	
Tanker	20452	17%	6%	1227	
Total	120870			11370	9%

	PA	MNV	sum	%MS	MS MWh/yr	
Autocarrier	1140534	1356397	2496931	29%	724110	
Bulk	6636467	4621914	11258381	5%	562919	
Container	10666131	18036479	28702610	4%	1148104	
General Carg	1486822	1558131	3044952	22%	669890	
Passenger	1565282	4131450	5696732	52%	2962301	
Reefer	1334041	2127189	3461230	18%	623021	
RORO	114447	153812	268260	10%	26826	
Tanker	6652669	4932038	11584707	6%	695082	
Total	29596393	36917410	66513803		7412253	11%

Speed Reduction Scenario - Results

Scenario Description:

Reduced Speed Zone boundary distance from the Precautionary Area (nautical miles) all cruise

Ship speed in Reduced Speed Zone (knots):

uto Carrier	15
Bulk Carrier	12
Container Ship	15
General Cargo	15
Passenger	15
Reefer	15
RORO	15
Tanker	12

Speed reduction assumed to apply to: all ships

	2010 Baseline Operation			2010 Reduced Speed Operation		
Profile Loads (% MCR)	MWh per year	% of total	Med. Speed %	MWh per year	% of total	Med. Speed %
80%	494,592	88%	10%	**16,306**	5%	**10%**
40%	13,289	2%	11%	**99,687**	33%	**11%**
35%	1,487	0%	11%	**41,817**	14%	**11%**
20%	15,152	3%	11%	**110,257**	36%	**11%**
15%	7,729	1%	11%	**7,729**	3%	**11%**
10%	28,856	5%	11%	**28,856**	9%	**11%**
Total, all modes	561,106			**304,654**		

Speed Reduction Scenario - Results
Page 2

Energy Use (in 2010) and NOx g/kWh by Mode (Motorship main engines)

2010 Baseline Operation - Uncontrolled NOx Rates					SS&MS
Profile Loads (%MCR)	MWh / year	SS g/kWh	MS g/kWh	% MS	g/kWh
80%	494,592	17.06	12.77	10%	16.63
40%	13,289	18.26	13.53	11%	17.74
35%	1,487	18.14	13.87	11%	17.67
20%	15,152	20.94	16.93	11%	20.50
15%	7,729	23.96	20.42	11%	23.57
10%	28,856	28.89	25.27	11%	28.49
Total energy/year	561,106		MWh-weighted NOx g/kWh		17.47

2010 Reduced Speed Operation - 2010 NOx Rates					SS&MS
Profile Loads (%MCR)	MWh / year	SS g/kWh	MS g/kWh	% MS	g/kWh
80%	16,306	16.30	12.23	10%	15.89
40%	99,687	17.41	12.99	11%	16.92
35%	41,817	17.46	13.33	11%	17.01
20%	110,257	20.18	16.39	11%	19.76
15%	7,729	23.20	19.88	11%	22.83
10%	28,856	28.13	24.72	11%	27.75
Total energy/year	304,654		MWh-weighted NOx g/kWh		19.08

Increased Auxiliary Engine Emissions

SHIPTYPE	S.R. minus baseline hours/call	Inventory Aux Engine NOx lb/hr	Motorship Calls per year in 2010	Increased NOx Aux Engines (tons per year)
Auto Carrier	**0.93**	22.05	523	5.4
Bulk Carrier	**1.28**	22.05	1260	17.8
Container Ship	**1.91**	22.05	2442	51.5
General Cargo	**0.23**	22.05	720	1.9
Passenger	**1.24**	147.00	584	53.1
Reefer	**1.19**	22.05	773	10.2
RORO	**2.17**	22.05	49	1.2
Tanker	**1.54**	22.05	1054	17.9
Totals (tpy)				158.9

Scenario 2

Speed Reduction Scenario - Results

Scenario Description:

Reduced Speed Zone boundary distance from the Precautionary Area (nautical miles) all cruise

Ship speed in Reduced Speed Zone (knots):

uto Carrier	15
Bulk Carrier	15
Container Ship	18
General Cargo	15
Passenger	15
Reefer	15
RORO	18
Tanker	12

Speed reduction assumed to apply to: all ships

	2010 Baseline Operation			2010 Reduced Speed Operation		
Profile Loads (% MCR)	MWh per year	% of total	Med. Speed %	MWh per year	% of total	Med. Speed %
80%	494,592	88%	10%	**79,749**	22%	**10%**
40%	13,289	2%	11%	**59,835**	16%	**11%**
35%	1,487	0%	11%	**173,806**	48%	**11%**
20%	15,152	3%	11%	**15,152**	4%	**11%**
15%	7,729	1%	11%	**7,729**	2%	**11%**
10%	28,856	5%	11%	**28,856**	8%	**11%**
Total, all modes	561,106			**365,128**		

Speed Reduction Scenario - Results
Page 2

Energy Use (in 2010) and NOx g/kWh by Mode (Motorship main engines)

2010 Baseline Operation - Uncontrolled NOx Rates					SS&MS
Profile Loads (%MCR)	MWh / year	SS g/kWh	MS g/kWh	% MS	g/kWh
80%	494,592	17.06	12.77	10%	16.63
40%	13,289	18.26	13.53	11%	17.74
35%	1,487	18.14	13.87	11%	17.67
20%	15,152	20.94	16.93	11%	20.50
15%	7,729	23.96	20.42	11%	23.57
10%	28,856	28.89	25.27	11%	28.49
Total energy/year	561,106		MWh-weighted NOx g/kWh		17.47

2010 Reduced Speed Operation - 2010 NOx Rates					SS&MS
Profile Loads (%MCR)	MWh / year	SS g/kWh	MS g/kWh	% MS	g/kWh
80%	79,749	16.30	12.23	10%	15.89
40%	59,835	17.41	12.99	11%	16.92
35%	173,806	17.46	13.33	11%	17.01
20%	15,152	20.18	16.39	11%	19.76
15%	7,729	23.20	19.88	11%	22.83
10%	28,856	28.13	24.72	11%	27.75
Total energy/year	365,128		MWh-weighted NOx g/kWh		17.84

Increased Auxiliary Engine Emissions

SHIPTYPE	S.R. minus baseline hours/call	Inventory Aux Engine NOx lb/hr	Motorship Calls per year in 2010	Increased NOx Aux Engines (tons per year)
Auto Carrier	**0.93**	22.05	523	5.4
Bulk Carrier	**0.02**	22.05	1260	0.3
Container Ship	**1.02**	22.05	2442	27.5
General Cargo	**0.23**	22.05	720	1.9
Passenger	**1.24**	147.00	584	53.1
Reefer	**1.19**	22.05	773	10.2
RORO	**1.03**	22.05	49	0.6
Tanker	**1.54**	22.05	1054	17.9
Totals (tpy)				116.7

Scenario 3

Speed Reduction Scenario - Results

Scenario Description:

Reduced Speed Zone boundary distance from the Precautionary Area (nautical miles) 30

Ship speed in Reduced Speed Zone (knots):

uto Carrier	15
Bulk Carrier	12
Container Ship	15
General Cargo	15
Passenger	15
Reefer	15
RORO	15
Tanker	12

Speed reduction assumed to apply to: all ships

	2010 Baseline Operation			2010 Reduced Speed Operation		
Profile Loads (% MCR)	MWh per year	% of total	Med. Speed %	MWh per year	% of total	Med. Speed %
80%	494,592	88%	10%	**133,829**	36%	**9%**
40%	13,289	2%	11%	**78,088**	21%	**11%**
35%	1,487	0%	11%	**33,348**	9%	**11%**
20%	15,152	3%	11%	**86,024**	23%	**11%**
15%	7,729	1%	11%	**7,729**	2%	**11%**
10%	28,856	5%	11%	**28,856**	8%	**11%**
Total, all modes	561,106			**367,875**		

Speed Reduction Scenario - Results
Page 2

Energy Use (in 2010) and NOx g/kWh by Mode (Motorship main engines)

2010 Baseline Operation - Uncontrolled NOx Rates					SS&MS
Profile Loads (%MCR)	MWh / year	SS g/kWh	MS g/kWh	% MS	g/kWh
80%	494,592	17.06	12.77	10%	16.63
40%	13,289	18.26	13.53	11%	17.74
35%	1,487	18.14	13.87	11%	17.67
20%	15,152	20.94	16.93	11%	20.50
15%	7,729	23.96	20.42	11%	23.57
10%	28,856	28.89	25.27	11%	28.49
Total energy/year	561,106		MWh-weighted NOx g/kWh		17.47

2010 Reduced Speed Operation - 2010 NOx Rates					SS&MS
Profile Loads (%MCR)	MWh / year	SS g/kWh	MS g/kWh	% MS	g/kWh
80%	133,829	16.30	12.23	9%	15.93
40%	78,088	17.41	12.99	11%	16.92
35%	33,348	17.46	13.33	11%	17.01
20%	86,024	20.18	16.39	11%	19.76
15%	7,729	23.20	19.88	11%	22.83
10%	28,856	28.13	24.72	11%	27.75
Total energy/year	367,875		MWh-weighted NOx g/kWh		18.21

Increased Auxiliary Engine Emissions

SHIPTYPE	S.R. minus baseline hours/call	Inventory Aux Engine NOx lb/hr	Motorship Calls per year in 2010	Increased NOx Aux Engines (tons per year)
Auto Carrier	**0.73**	22.05	523	4.2
Bulk Carrier	**1.02**	22.05	1260	14.1
Container Ship	**1.43**	22.05	2442	38.5
General Cargo	**0.19**	22.05	720	1.5
Passenger	**0.98**	147.00	584	42.1
Reefer	**0.95**	22.05	773	8.1
RORO	**1.27**	22.05	49	0.7
Tanker	**1.10**	22.05	1054	12.8
Totals (tpy)				122.0

Scenario 4

Speed Reduction Scenario - Results

Scenario Description:

Reduced Speed Zone boundary distance from the Precautionary Area (nautical miles) 30

Ship speed in Reduced Speed Zone (knots):

uto Carrier	15
Bulk Carrier	15
Container Ship	18
General Cargo	15
Passenger	15
Reefer	15
RORO	18
Tanker	12

Speed reduction assumed to apply to: all ships

	2010 Baseline Operation			2010 Reduced Speed Operation		
Profile Loads (% MCR)	MWh per year	% of total	Med. Speed %	MWh per year	% of total	Med. Speed %
80%	494,592	88%	10%	**184,015**	44%	**9%**
40%	13,289	2%	11%	**46,563**	11%	**11%**
35%	1,487	0%	11%	**131,694**	32%	**11%**
20%	15,152	3%	11%	**15,152**	4%	**11%**
15%	7,729	1%	11%	**7,729**	2%	**11%**
10%	28,856	5%	11%	**28,856**	7%	**11%**
Total, all modes	561,106			**414,010**		

Speed Reduction Scenario - Results
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Energy Use (in 2010) and NOx g/kWh by Mode (Motorship main engines)

2010 Baseline Operation - Uncontrolled NOx Rates					SS&MS
Profile Loads (%MCR)	MWh / year	SS g/kWh	MS g/kWh	% MS	g/kWh
80%	494,592	17.06	12.77	10%	16.63
40%	13,289	18.26	13.53	11%	17.74
35%	1,487	18.14	13.87	11%	17.67
20%	15,152	20.94	16.93	11%	20.50
15%	7,729	23.96	20.42	11%	23.57
10%	28,856	28.89	25.27	11%	28.49
Total energy/year	561,106		MWh-weighted NOx g/kWh		17.47

2010 Reduced Speed Operation - 2010 NOx Rates					SS&MS
Profile Loads (%MCR)	MWh / year	SS g/kWh	MS g/kWh	% MS	g/kWh
80%	184,015	16.30	12.23	9%	15.93
40%	46,563	17.41	12.99	11%	16.92
35%	131,694	17.46	13.33	11%	17.01
20%	15,152	20.18	16.39	11%	19.76
15%	7,729	23.20	19.88	11%	22.83
10%	28,856	28.13	24.72	11%	27.75
Total energy/year	414,010		MWh-weighted NOx g/kWh		17.48

Increased Auxiliary Engine Emissions

SHIPTYPE	S.R. minus baseline hours/call	Inventory Aux Engine NOx lb/hr	Motorship Calls per year in 2010	Increased NOx Aux Engines (tons per year)
Auto Carrier	**0.73**	22.05	523	4.2
Bulk Carrier	**0.02**	22.05	1260	0.2
Container Ship	**0.76**	22.05	2442	20.6
General Cargo	**0.19**	22.05	720	1.5
Passenger	**0.98**	147.00	584	42.1
Reefer	**0.95**	22.05	773	8.1
RORO	**0.61**	22.05	49	0.3
Tanker	**1.10**	22.05	1054	12.8
Totals (tpy)				89.8

Scenario 5

Speed Reduction Scenario - Results

Scenario Description:

Reduced Speed Zone boundary distance from the Precautionary Area (nautical miles) 20

Ship speed in Reduced Speed Zone (knots):

uto Carrier	15
Bulk Carrier	12
Container Ship	15
General Cargo	15
Passenger	15
Reefer	15
RORO	15
Tanker	12

Speed reduction assumed to apply to: all ships

	2010 Baseline Operation			2010 Reduced Speed Operation		
Profile Loads (% MCR)	MWh per year	% of total	Med. Speed %	MWh per year	% of total	Med. Speed %
80%	494,592	88%	10%	**254,083**	59%	**10%**
40%	13,289	2%	11%	**56,488**	13%	**11%**
35%	1,487	0%	11%	**22,728**	5%	**11%**
20%	15,152	3%	11%	**62,400**	14%	**11%**
15%	7,729	1%	11%	**7,729**	2%	**11%**
10%	28,856	5%	11%	**28,856**	7%	**11%**
Total, all modes	561,106			**432,285**		

Speed Reduction Scenario - Results
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Energy Use (in 2010) and NOx g/kWh by Mode (Motorship main engines)

2010 Baseline Operation - Uncontrolled NOx Rates					SS&MS
Profile Loads (%MCR)	MWh / year	SS g/kWh	MS g/kWh	% MS	g/kWh
80%	494,592	17.06	12.77	10%	16.63
40%	13,289	18.26	13.53	11%	17.74
35%	1,487	18.14	13.87	11%	17.67
20%	15,152	20.94	16.93	11%	20.50
15%	7,729	23.96	20.42	11%	23.57
10%	28,856	28.89	25.27	11%	28.49
Total energy/year	561,106		MWh-weighted NOx g/kWh		17.47

2010 Reduced Speed Operation - 2010 NOx Rates					SS&MS
Profile Loads (%MCR)	MWh / year	SS g/kWh	MS g/kWh	% MS	g/kWh
80%	254,083	16.30	12.23	10%	15.89
40%	56,488	17.41	12.99	11%	16.92
35%	22,728	17.46	13.33	11%	17.01
20%	62,400	20.18	16.39	11%	19.76
15%	7,729	23.20	19.88	11%	22.83
10%	28,856	28.13	24.72	11%	27.75
Total energy/year	432,285		MWh-weighted NOx g/kWh		17.56

Increased Auxiliary Engine Emissions

SHIPTYPE	S.R. minus baseline hours/call	Inventory Aux Engine NOx lb/hr	Motorship Calls per year in 2010	Increased NOx Aux Engines (tons per year)
Auto Carrier	**0.49**	22.05	523	2.8
Bulk Carrier	**0.68**	22.05	1260	9.4
Container Ship	**0.95**	22.05	2442	25.7
General Cargo	**0.12**	22.05	720	1.0
Passenger	**0.65**	147.00	584	28.1
Reefer	**0.63**	22.05	773	5.4
RORO	**0.85**	22.05	49	0.5
Tanker	**0.73**	22.05	1054	8.5
Totals (tpy)				81.3

Scenario 6

Speed Reduction Scenario - Results

Scenario Description:

Reduced Speed Zone boundary distance from the Precautionary Area (nautical miles) 20

Ship speed in Reduced Speed Zone (knots):

uto Carrier	15
Bulk Carrier	15
Container Ship	18
General Cargo	15
Passenger	15
Reefer	15
RORO	18
Tanker	12

Speed reduction assumed to apply to: all ships

	2010 Baseline Operation			2010 Reduced Speed Operation		
Profile Loads (% MCR)	MWh per year	% of total	Med. Speed %	MWh per year	% of total	Med. Speed %
80%	494,592	88%	10%	**287,540**	62%	**10%**
40%	13,289	2%	11%	**35,472**	8%	**11%**
35%	1,487	0%	11%	**88,292**	19%	**11%**
20%	15,152	3%	11%	**15,152**	3%	**11%**
15%	7,729	1%	11%	**7,729**	2%	**11%**
10%	28,856	5%	11%	**28,856**	6%	**11%**
Total, all modes	561,106			**463,042**		

Speed Reduction Scenario - Results
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Energy Use (in 2010) and NOx g/kWh by Mode (Motorship main engines)

2010 Baseline Operation - Uncontrolled NOx Rates					SS&MS
Profile Loads (%MCR)	MWh / year	SS g/kWh	MS g/kWh	% MS	g/kWh
80%	494,592	17.06	12.77	10%	16.63
40%	13,289	18.26	13.53	11%	17.74
35%	1,487	18.14	13.87	11%	17.67
20%	15,152	20.94	16.93	11%	20.50
15%	7,729	23.96	20.42	11%	23.57
10%	28,856	28.89	25.27	11%	28.49
Total energy/year	561,106		MWh-weighted NOx g/kWh		17.47

2010 Reduced Speed Operation - 2010 NOx Rates					SS&MS
Profile Loads (%MCR)	MWh / year	SS g/kWh	MS g/kWh	% MS	g/kWh
80%	287,540	16.30	12.23	10%	15.89
40%	35,472	17.41	12.99	11%	16.92
35%	88,292	17.46	13.33	11%	17.01
20%	15,152	20.18	16.39	11%	19.76
15%	7,729	23.20	19.88	11%	22.83
10%	28,856	28.13	24.72	11%	27.75
Total energy/year	463,042		MWh-weighted NOx g/kWh		17.17

Increased Auxiliary Engine Emissions

SHIPTYPE	S.R. minus baseline hours/call	Inventory Aux Engine NOx lb/hr	Motorship Calls per year in 2010	Increased NOx Aux Engines (tons per year)
Auto Carrier	**0.49**	22.05	523	2.8
Bulk Carrier	**0.01**	22.05	1260	0.1
Container Ship	**0.51**	22.05	2442	13.7
General Cargo	**0.12**	22.05	720	1.0
Passenger	**0.65**	147.00	584	28.1
Reefer	**0.63**	22.05	773	5.4
RORO	**0.40**	22.05	49	0.2
Tanker	**0.73**	22.05	1054	8.5
Totals (tpy)				59.8

Scenario 7

Speed Reduction Scenario - Results

Scenario Description:

Reduced Speed Zone boundary distance from the Precautionary Area (nautical miles) 15

Ship speed in Reduced Speed Zone (knots):

uto Carrier	15
Bulk Carrier	12
Container Ship	15
General Cargo	15
Passenger	15
Reefer	15
RORO	15
Tanker	12

Speed reduction assumed to apply to: all ships

	2010 Baseline Operation			2010 Reduced Speed Operation		
Profile Loads (% MCR)	MWh per year	% of total	Med. Speed %	MWh per year	% of total	Med. Speed %
80%	494,592	88%	10%	**314,210**	68%	**10%**
40%	13,289	2%	11%	**45,688**	10%	**11%**
35%	1,487	0%	11%	**17,418**	4%	**11%**
20%	15,152	3%	11%	**50,588**	11%	**11%**
15%	7,729	1%	11%	**7,729**	2%	**11%**
10%	28,856	5%	11%	**28,856**	6%	**11%**
Total, all modes	561,106			**464,490**		

Speed Reduction Scenario - Results
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Energy Use (in 2010) and NOx g/kWh by Mode (Motorship main engines)

2010 Baseline Operation - Uncontrolled NOx Rates					SS&MS
Profile Loads (%MCR)	MWh / year	SS g/kWh	MS g/kWh	% MS	g/kWh
80%	494,592	17.06	12.77	10%	16.63
40%	13,289	18.26	13.53	11%	17.74
35%	1,487	18.14	13.87	11%	17.67
20%	15,152	20.94	16.93	11%	20.50
15%	7,729	23.96	20.42	11%	23.57
10%	28,856	28.89	25.27	11%	28.49
Total energy/year	561,106		MWh-weighted NOx g/kWh		17.47

2010 Reduced Speed Operation - 2010 NOx Rates					SS&MS
Profile Loads (%MCR)	MWh / year	SS g/kWh	MS g/kWh	% MS	g/kWh
80%	314,210	16.30	12.23	10%	15.89
40%	45,688	17.41	12.99	11%	16.92
35%	17,418	17.46	13.33	11%	17.01
20%	50,588	20.18	16.39	11%	19.76
15%	7,729	23.20	19.88	11%	22.83
10%	28,856	28.13	24.72	11%	27.75
Total energy/year	464,490		MWh-weighted NOx g/kWh		17.31

Increased Auxiliary Engine Emissions

SHIPTYPE	S.R. minus baseline hours/call	Inventory Aux Engine NOx lb/hr	Motorship Calls per year in 2010	Increased NOx Aux Engines (tons per year)
Auto Carrier	**0.36**	22.05	523	2.1
Bulk Carrier	**0.51**	22.05	1260	7.1
Container Ship	**0.72**	22.05	2442	19.3
General Cargo	**0.09**	22.05	720	0.7
Passenger	**0.49**	147.00	584	21.0
Reefer	**0.47**	22.05	773	4.0
RORO	**0.64**	22.05	49	0.3
Tanker	**0.55**	22.05	1054	6.4
Totals (tpy)				61.0

Scenario 8

Speed Reduction Scenario - Results

Scenario Description:

Reduced Speed Zone boundary distance from the Precautionary Area (nautical miles) 15

Ship speed in Reduced Speed Zone (knots):

uto Carrier	15
Bulk Carrier	15
Container Ship	18
General Cargo	15
Passenger	15
Reefer	15
RORO	18
Tanker	12

Speed reduction assumed to apply to: all ships

	2010 Baseline Operation			2010 Reduced Speed Operation		
Profile Loads (% MCR)	MWh per year	% of total	Med. Speed %	MWh per year	% of total	Med. Speed %
80%	494,592	88%	10%	**339,303**	70%	**10%**
40%	13,289	2%	11%	**29,926**	6%	**11%**
35%	1,487	0%	11%	**66,590**	14%	**11%**
20%	15,152	3%	11%	**15,152**	3%	**11%**
15%	7,729	1%	11%	**7,729**	2%	**11%**
10%	28,856	5%	11%	**28,856**	6%	**11%**
Total, all modes	561,106			**487,558**		

Speed Reduction Scenario - Results
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Energy Use (in 2010) and NOx g/kWh by Mode (Motorship main engines)

2010 Baseline Operation - Uncontrolled NOx Rates					SS&MS
Profile Loads (%MCR)	MWh / year	SS g/kWh	MS g/kWh	% MS	g/kWh
80%	494,592	17.06	12.77	10%	16.63
40%	13,289	18.26	13.53	11%	17.74
35%	1,487	18.14	13.87	11%	17.67
20%	15,152	20.94	16.93	11%	20.50
15%	7,729	23.96	20.42	11%	23.57
10%	28,856	28.89	25.27	11%	28.49
Total energy/year	561,106		MWh-weighted NOx g/kWh		17.47

2010 Reduced Speed Operation - 2010 NOx Rates					SS&MS
Profile Loads (%MCR)	MWh / year	SS g/kWh	MS g/kWh	% MS	g/kWh
80%	339,303	16.30	12.23	10%	15.89
40%	29,926	17.41	12.99	11%	16.92
35%	66,590	17.46	13.33	11%	17.01
20%	15,152	20.18	16.39	11%	19.76
15%	7,729	23.20	19.88	11%	22.83
10%	28,856	28.13	24.72	11%	27.75
Total energy/year	487,558		MWh-weighted NOx g/kWh		17.04

Increased Auxiliary Engine Emissions

SHIPTYPE	S.R. minus baseline hours/call	Inventory Aux Engine NOx lb/hr	Motorship Calls per year in 2010	Increased NOx Aux Engines (tons per year)
Auto Carrier	**0.36**	22.05	523	2.1
Bulk Carrier	**0.01**	22.05	1260	0.1
Container Ship	**0.38**	22.05	2442	10.3
General Cargo	**0.09**	22.05	720	0.7
Passenger	**0.49**	147.00	584	21.0
Reefer	**0.47**	22.05	773	4.0
RORO	**0.64**	22.05	49	0.3
Tanker	**0.55**	22.05	1054	6.4
Totals (tpy)				45.1