THE SOCIETY OF NAVAL ARCHITECTS AND MARINE ENGINEERS
One World Trade Center, Suite 1369, New York, N.Y. 10048
Paper to be presented at the Ship Vibration Symposium
Arlington, Va., October 16-17, 1978

Approaches to Noise Exposure

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ABSTRACT

This paper deals with the assessment of noise exposure and of the need for noise exposure control. Noise exposure is dealt with in terms of hearing damage risk as defined by criteria such as CHABA (1) and in terms of the damaging effects of noise in a broader sense as generally defined in the Environmental Protection Agency's "Levels Document" (2). Also discussed are noise exposure measurement techniques, various methodologies of assessing noise exposure, and the correlation of exposure measurements to simpler measures. The paper does not discuss engineering noise controls for specific applications. It does discuss the need for engineering controls and their applications, and other controls such as personal hearing protection and administrative controls.

UNIQUE MARINE NOISE EXPOSURE PROBLEMS

Merchant Marine noise has many problems in common with other industries but has unique problems in several areas.

1. The exposure periods are generally longer. The shift of the worker or the watch is normally two 4 hour periods (or one 8 hour period) per day, 7 days per week, and overtime is normal. Work weeks exceeding 60 hours are common.

2. The noise is not as intermittent as is industrial noise in general. That is, there are less breaks from the noise exposure for periods of effective quiet.

3. The work place is also the living place. The employee's total environment while on board ship is controlled by the employer, and the employee has little or no control over his noise exposure in his off time.

THE LANGUAGE OF NOISE EXPOSURE AND HEARING DAMAGE

Longer, steady noise exposure causes increased hearing damage due to several interrelated problems. The hearing damage is related to noise level and duration. Then, related to these two parameters, the danger of hearing damage is also dependent upon the cycle of exposure and whether the noise level is intermittent and what the noise level fluctuation is.

A decibel (dB) is a logarithm of the ratio of the measured sound pressure to the reference sound pressure (2×10^{-5}Pa). Therefore, each 3 dB increase represents a doubling of the measured sound pressure. The relationship of exposure duration to exposure noise level is that a three to five dB increase in noise level for the same duration doubles the exposure (See OSHA and EPA curves in Fig. 1). Or, conversely, doubling the time at the same noise level doubles the exposure. The question of whether the relationship is three or five dB or some value in-between for doubling of exposure with equal duration is dependent upon the intermittency or the variations in the way the exposure is received. The relationship stated above is based on studies of temporary threshold shift (TTS), which is defined as the recoverable change in hearing acuity which results from exposure to high intensity noise. If one looks at the relationship over the short term, a three dB increase in level doubles the exposure. That is, the amount of TTS suffered at a level 3 dB higher would indicate the need to have the duration of exposure reduced by half. However, since rest periods of effective quiet at frequent intervals greatly affect the degree of permanent hearing damage received from given exposures, over the long term for intermittent noise, a five dB exchange rate between duration and level has been shown to be appropriate for many industrial applications.

The above factors affect the way in which the noise levels are to be measured, combined, and evaluated and the types of instrumentation that will be used. Steady state noise levels (measured with a standard sound level meter) are often not important. Rather what is of concern is the equivalent continuous noise level (L_{eq} for a 3 dB exchange rate or $L_{eq}*$ for a 5 dB) which would present the same risk of hearing damage over the same duration.

L_{eq} is the integrated noise level taking into account all of the levels from high to low and the duration at each level. L_{eq} may be obtained with an audio noise dosimeter or an integrating sound level meter, the latter of which has recently become available providing a single number, combined noise level reading.

The most respected criteria for damage risk in the United States have been the CHABA recommendations endorsing the 5 dB exchange rate. The CHABA criteria, derived from the study of numerous audiometric test programs and hearing conservation studies, relate TTS to permanent threshold shifts (permanent hearing damage). The CHABA criteria generally do apply to the industrial noise environment. The marine noise environment has not been broadly classified and the relationship between noise levels and durations of exposure that create a hearing damage risk have not been defined because the interdependent parameters of exposure cycle, intermittency, and fluctuation in level have not been determined.

Other organizations and industries have applied the CHABA criteria in various methods which are examined in the following paragraphs and illustrated in Fig. 1. Some 3 dB exchange rate criteria are also shown in this Figure.

OSHA

The Occupational Safety and Health Administration (OSHA) regulations (3) are some of the most widespread and comprehensive requirements for noise exposure control. The regulations were preceded by the Walsh-Healey Public Contracts Act which required employers on public contracts not to expose their workers to more than 90 dB A-weighted for 8 hours on the job. (A-weighting is defined in ANSI S1.4, "Specifications for Sound Level Meters" and is a frequency weighting which approximates human hearing and the effects of noise on hearing.) For each 5 dB increase in noise level the allowable exposure is cut in half, thus an exchange rate of 5 dB. These requirements were based on eight hour exposures per day for 40 hours per week with the typical

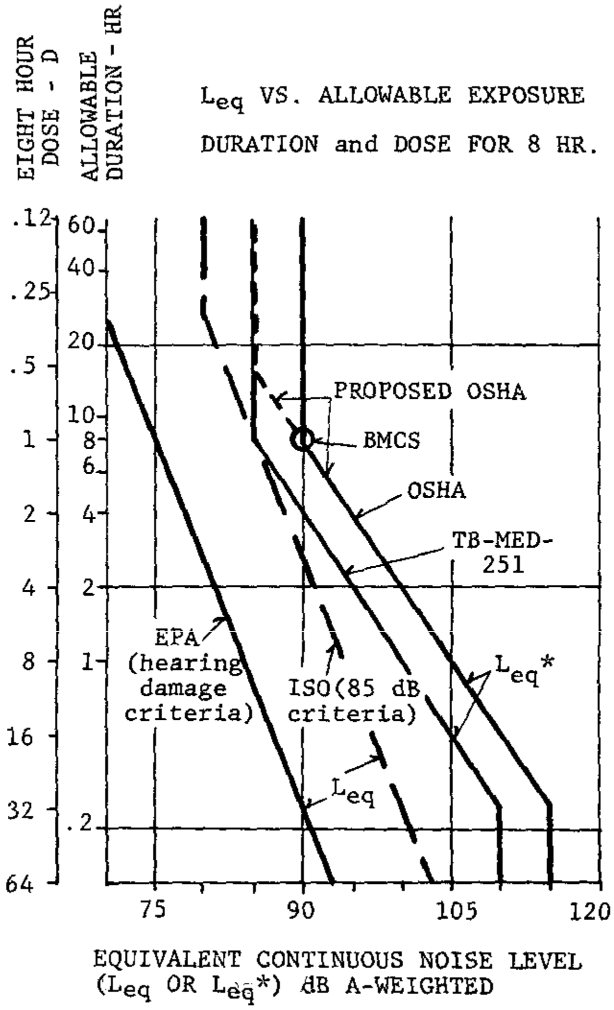

Fig. 1 Allowable noise exposure duration and corresponding 8 hour noise dose for six criteria in equivalent continuous noise level

industrial exposure pattern. The regulations promulgated under OSHA extended the same criteria to industry in general.

Since the promulgation of the basic noise exposure regulations under OSHA, the National Institute of Occupational Safety and Health (NIOSH) has further studied the industrial noise exposure problem and concluded that the regulations should be changed to allow no more than 85 dB A-weighted exposure for 8 hours. OSHA has tempered this proposal somewhat to propose that exposure not exceed 85 dB A-weighted for a period of 16 hours. This proposal has resulted in one of the longest and most extensive rulemaking processes in the United States. As of 1 January 1978 the rulemaking was still not finalized after over 3 years of receiving and responding to public comments including more than one month's public hearings. The effect of the proposed rule is, basically, to leave the standard the same as it is now but to change the measurement methodology. That is, allow only 90 dB A-weighted per 8 hours exposure; however, it was no longer assumed that levels below 90 dB A-weighted are effective quiet. With the proposed regulations, measurements would have to be taken down to 85 dB A-weighted even though the employee is only exposed for 8 hours. Thus, even though the 8 hour level is the same, this change makes some noise environments unacceptable which were previously acceptable. The effects of various types of exposures and various methods of evaluating these exposures are addressed later.

Basically the OSHA regulations require that the employer not expose the employee beyond the limits described above. There are three methods by which this can be accomplished. Engineering controls are the first priority and are required whether or not complete compliance with the regulations is achieved by this method. Administrative controls are to be taken as an interim measure until engineering controls can be instituted or in addition to engineering controls when they are not totally adequate. Personal protective equipment is only to be used as a last resort and only as an interim measure until engineering and administrative controls can be affected.

The proposed regulation changes have another important feature which requires that audiometric testing and a hearing conservation program be instituted when employees are exposed to levels above 85 dB A-weighted. This measure is very important because it is the best indicator of whether the noise control measures being taken are achieving the desired effect. This extra measure is so important because the methods of determining compliance are somewhat cumbersome.

To determine compliance or to enforce the regulation one must measure the noise levels to which the employee is exposed and the time of exposure to each of these levels. As an alternative, an audio noise dosimeter may be used to determine the employee's noise dose, the dose simply being the cumulative or combined index of the employee's exposure. These methods can be effective but are somewhat complicated to implement and require a certain degree of expertise. A number of OSHA citations have been overturned due to inadequate measurements. While the techniques of determining compliance can be cumbersome, in some industries they are rather effective.

The industries in which this methodology has worked well are those having stationary equipment, steady noise levels, and fixed employee locations or relatively few working stations. For these industries, the measurements are straightforward, the determination of engineering control feasibility is not too complicated, and methods of instituting them are well established. However, with certain manufacturers and the construction industry it has caused problems.

The operations with problems are ones which have mobile sources of noise, mobile employees, and operations and noise environments which are not very regimented. As an example, in order for the employer to meet the regulations, he generally wants to buy equipment that complies. However, when he requests equipment that complies with OSHA, the questions of where it will be used, how long it will be operated, what the installation will be, and the like have to be answered. Answering these questions becomes rather involved and complicated. Even if the equipment to be purchased is always less than 90 dB A-weighted, the installation, mounting, location, and surrounding equipment may result in levels which exceed the regulations.

SAE and OSHA

One of the industries which is hardest hit by these regulations is construction. Construction machinery manufacturers would like to supply machinery with noise levels that are always lower than those required by the regulation. However, the noise levels of construction machinery are so high that it was initially beyond the state-of-the-art to provide machines at such low noise levels. There was no reasonable way to estimate how the machine would be used, and the maximum levels the machines could produce were generally considered to be much higher than the exposure an operator might reasonably be expected to receive from the machine. The Society of Automotive Engineers (SAE) has developed several generations of standards to measure operator noise on those machines. The objective of the first standards was to give engineers an effective tool for designing quieter machines. To accomplish the objective, standards were designed to give very repeatable noise levels and explore the worst case noise levels. These goals for construction machinery noise standards were typical of the thinking of many groups developing such standards because of repeatability and reproducibility. It was felt that if the maximum noise could be reduced the other levels produced by the machines would be reduced accordingly. The philosophy of the SAE and similar groups was so deeply committed to developing standards of this nature that, when it was discovered that machines produced higher noise levels when travelling in reverse rather than forward at high speed, changing the test mode to reverse was seriously considered. However, these types of test conditions were getting further away from what was required for determining compliance with noise exposure criteria (4).

To combat the problem of establishing reasonable measurement methodologies for estimating noise exposure compliance, users of the equipment and the equipment manufacturers have gotten together within SAE and developed work cycle tests for noise measurement (5). The work cycle is designed to measure the noise of the vehicle averaged over an entire sequence of high production work. The resultant noise measurement is a single noise level which can be used to compare with regulation requirements and determine compliance. The individual user can compare the results from the duty cycle and noise exposure tests on his particular operations to determine if an adjustment is required in his specifications for equipment noise level. This adjustment would compensate for the severity of use in his particular operation.

The basic need in the noise exposure control process is for noise test methodologies which are repeatable, easy to perform, and cost conscious. The OSHA noise regulations fit these criteria for relatively steady state noise in certain industries. In other industries such as construction, as mentioned above, this is not the case.

BUREAU OF MOTOR CARRIERS SAFETY

An example of a noise measurement methodology which is tailored to a specific application is the operator noise requirement for heavy trucks and buses of the Bureau of Motor Carriers Safety. The regulations require that the noise level in the cab should not exceed 90 dB A-weighted when the truck is operated at high idle (maximum governed engine speed, no load). Substantial surveys were carried out demonstrating that this one test method, which is very easy, repeatable, and does not require elaborate instrumentation, relates well with exposures received in the trucking industry (6).

This regulation was implemented rather quickly and made use of the available technology to afford slightly more protection to operators of these vehicles than OSHA gives to general industry. However, the degree of protection offered to the operator still needs continued evaluation because there is no audiometric testing, and the level of 90 dB A-weighted may still be too high. In this particular case the duration of the exposure is not addressed, but generally the operator exposure durations are fairly well controlled due to other driving regulations and operational circumstances.

U. S. ARMY HEARING CONSERVATION PROGRAM

The Army Surgeon General has a program of noise exposure control outlined in TB-MED-251 "Noise and Conservation of Hearing". The Army Surgeon General's noise exposure criteria apply within the Army as the OSHA criteria apply to general industry. However, the Army Surgeon General's approach is quite different from OSHA's. Any noise levels in excess of 85 dB A-weighted require use of personal protective equipment. There are also equivalent requirements for impulse noise and a hearing conservation program which requires audiometric testing of all personnel regardless of the noise level to which they are exposed. The 85 dB A-weighted criterion means that if the person is exposed to 85 dB A-weighted for 1 minute, 1 hour, or 8 hours, personal hearing protective equipment is required. This applies, of course, only during the period of the exposure. This program does not overlook the need for engineering control of excessive noise. In cases where systems or equipment noise levels cannot be reduced to below 85 dB A-weighted under all conditions, the criteria of 85 dB A-weighted over an 8 hour exposure period with the five dB exchange rate for higher levels is used (L_{eq}*). If the system or the equipment is then known to produce maxima above 85 dB A-weighted, but it is also known that the total exposure is below the 85 dB A-weighted criterion, the operator may not be required to wear hearing protection. These judgements of compliance for this criterion are handled on a case by case basis depending on the given system or equipment.

The Army's hearing conservation program meets many of the requirements for an effective program. The criteria are relatively easy to enforce because complicated instrumentation and a great deal of expertise are not required. Since the Army has a continuing audiometric test program it is known whether the employee is being adequately protected. And, finally, the use of hearing protection is carried out by issuance of hearing protection to all personnel, and by regulations requiring its use. The degree of protection for the personnel is adequate provided the hearing protection is worn. The extent to which the hearing protection is worn varies, but a high degree of wear can be achieved if adequate attention is given to training and indoctrination.

IMCO

The member nations of the Inter-governmental Maritime Consultative Organization (IMCO) have recognized the need for noise control on bridges of ships since their 1960 Safety Conference (7). More recently they have started discussions of noise control in machinery spaces and other areas of vessels. No agreed upon position has yet been developed. The work has started by requesting each member nation to submit its national standard for comparison and study. The position of the U. S. is that more time is required for study before an IMCO assembly resolution or interrelated treaty requirement can be established. Table I shows the Swedish Research Foundation's summary of some national standards as of 1976 (8). Since 1976, the British have proposed standards which are very similar to the recommendations shown for Norway. Also, Israel established Noise Rating Curves (NR) recommendations rather than dB A-weighted. No changes have been submitted to the levels listed in the table.

WHAT DEGREE OF PROTECTION IS REQUIRED?

Various foreign countries and the International Standards Organization have endorsed noise control programs which vary from those described above, and there are other noise exposure regulations and programs within other agencies of the United States government. The passage of the Noise Control Act of 1972 required that the Environmental Protection Agency coordinate all noise activities in the United States and identify noise levels which are adequate to protect the public health and welfare with a margin of safety. After considerable study by a very distinguished panel convened by EPA, the "Levels Document" was published. This document identifies noise level goals which will protect the public health and welfare with an adequate margin of safety. The document identifies several levels for different circumstances, but the A-weighted noise

TABLE I

NOISE CRITERIA

dB(A) Suggested, recommended or required	Sweden Recommendations (1973)	W Germany Guidelines	USSR Regulations (1962)	(1976)	Norway Recommendations (1973)	Canada Proposal (1971)	Denmark Proposal (1975)
Engine room	100[1]	110	95	90	110		110
Manned engine room	85[1]	90	85	80	90		90
Control room	70		70	65	75		75
Workshop	75	90	85	65	85		85
Bridge, wheel house	70/65	60	60[2]-50	55	70/65		65
Radio room	55	60	60[2]-50	-	65		65
Cabins	55	60	60[2]-50	50	60	70	60
Offices	55		60[2]-50	50	65		65
Mess and dayrooms	65	65	60[2]-50	50	65	74	65
Deck, cargo holds	65				70		
Listening posts							70
Galley							70

1. A higher dB(A) sound level permitted when octave band frequency analysis carried out.

2. Space in vicinity of engine room and below main deck aft.

level of 70 dB averaged over an entire 24 hour period ($L_{eq(24)}$) is the goal if hearing loss is to be avoided. An outdoor activity interference and annoyance level of 55 dB A-weighted is also identified. This level is referred to as 55 L_{dn} (L_{dn} being the equivalent continuous day-night noise level.) The nighttime levels in the averaging process have 10 dB added to them, thus requiring lower nighttime levels to comply with the criterion. This L_{dn} level (like L_{eq}) is measured with a 3dB exchange rate between noise level and time. An indoor activity interference and annoyance level of 45 L_{dn} is also identified.

If one were to comply with the 70 $L_{eq(24)}$ criterion, it is clear that the 8 hour work day L_{eq} could not exceed 75 dB A-weighted if the remainder of the day had no other significant noise exposure. Seventy-five dB A-weighted is considerably lower than the controversial 85 dB A-weighted (for 16 hours) proposed change to the OSHA regulations for general industry.

The 70 $L_{eq(24)}$ is probably a suitable conservative goal, but it was never intended to be implemented without regard to technological feasibility and evaluation of costs and benefits. There is clearly room for compromise between the EPA "Levels Document" and the other regulations discussed earlier as EPA only recommended that at present OSHA lower its standards to 85 dB A-weighted over 8 hours. However, any evaluation of marine noise exposure should be based upon comparison with the "Levels Document" criteria if it is to be valid for any length of time.

ELEMENTS OF A NOISE EXPOSURE CONTROL PROGRAM

Noise Measurements

First, measurements should be made of the merchant marine seaman's total daily or weekly exposure. This should include measurements down to 45 dB A-weighted in the ship's quieter spaces and about 10 dB below the L_{eq} in noisier spaces. In other words, if the noise level is near 90 dB A-weighted in a machinery space, a noise dosimeter which has a cut off or threshold of 90 or 85 dB A-weighted should not be used. An instrument with a threshold of 80 or 75 dB A-weighted should be used. For machinery spaces, if nothing is known about the noise a priori, instrumentation with a 75 dB A-weighted threshold and 40 dB dynamic range should be used. As an alternative, some measurements with a standard sound level meter may be used as a guide to select the proper instrument settings. Measurements should be made with the instrument on the person, giving close attention to proper instruction of the wearer and observation of him.

As background to the above recommendations, part of a hypothetical noise exposure is shown in Figure 2. As the engineer performs his duties on watch he passes through many relatively steady state noise levels associated with the various equipment he tends. If the noise levels at his ear were recorded for the entire watch and then played back through a statistical distribution analyzer, we might get the histogram shown in Figure 3. This figure shows the total duration of noise levels within the ranges shown for the time spent on watch. With the data in this form, one can use the formula in the OSHA regulations to calculate the percent of permissible exposure or noise dose. Going back to Figure 1, the equivalent continuous noise level can be obtained according to any of the various criteria shown.

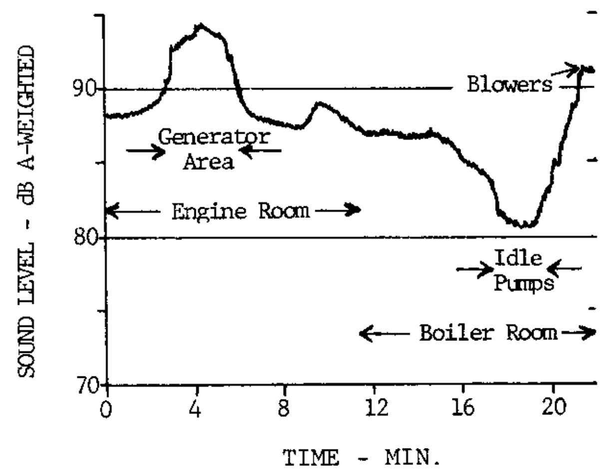

Fig. 2 Hypothetical noise level at engineer's ear during segment of rounds on watch.

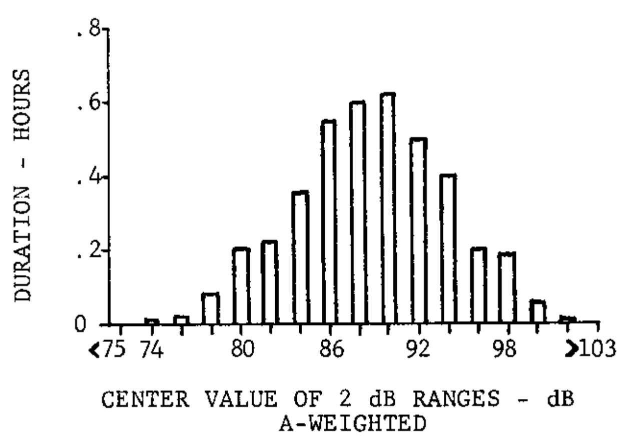

Fig. 3 Histogram of noise exposure received during engineer's 4 hour watch

However, it should be noted at this point that the resultant dose from Figure 3 will depend on how much data we include below the criterion level (defined here as the allowable exposure level for an 8 hour shift) or what threshold is selected. Table II shows the resultant dose and equivalent noise levels for the Figure 3 data using various thresholds. It can be seen from the table that the first 5 dB below the criterion level makes a significant impact on the resultant L_{eq} but more than 10 dB below the criterion is negligible. Also illustrated by the table is the difference the exchange rate of 5 vs. 3 dB makes for this data. The difference due to exchange rate would be more pronounced as the distribution of noise exposure is spread out over a wider range and less pronounced, the more concentrated the data.

Why go through all these calculations? The main point is to develop some usable measures to which one can relate. The L_{eq}* seems to do that. Having established the L_{eq}* for the engineer's watch and knowing the duration (C) of the watch, the total daily exposure can be calculated if L_{eq}* and C are known for the rest of the engineer's daily activities. Likewise for the weekly, monthly, and perhaps annual exposure. Table III shows more calculations of weekly exposure. With the dosimeter used to obtain the L_{eq}* of the various activities, this calculation becomes fairly straightforward. The recalculation of the exposure with hearing protection worn part-time shows that the L_{eq}* measure can be used as a tool to develop solutions to exposure poblems.

Looking at exposure on a weekly basis is endorsed by International Standards Organization (ISO) Recommendation 1999, but the assessment of noise exposure on a monthly and yearly basis has not been widely studied, if at all. Since merchant marine personnel work such different schedules it may be important to review their exposure over longer intervals.

In the Table III example, for nighttime levels (resting) or similar quiet times, steady state noise levels may be adequate, but this assumption should not be made without first verifying it by equivalent continuous noise level measurements.

TABLE II

Resultant Noise Exposure Calculations from Hypothetical Noise Histogram Shown in Figure 3

Criterion Level (C.L.) dB A-weighted	Threshold Level (T.L.) dB A-weighted	Exchange Rate of 5: Dose (D*)	Exchange Rate of 5: Noise Level (L_{eq}*)[1] dB A-weighted	Exchange Rate of 3: Dose (D)	Exchange Rate of 3: Noise Level (L_{eq})[2] dB A-weighted
90	90	0.82	88.6	1.19	90.8
90	85	1.01	90.1	1.33	91.2
90	80	1.08	90.6	1.36	91.3
90	75	1.08	90.6	1.36	91.3
85	85	2.02	90.1	4.22	91.2
85	80	2.16	90.6	4.31	91.3
85	75	2.16	90.6	4.31	91.3
80	80	4.32	90.6	13.69	91.3
80	75	4.32	90.6	13.69	91.3
75	75	8.64	90.6	43.44	91.3

1. $L_{eq}* = C.L. + 16.61 \, Log_{10} D*$

2. $L_{eq} = C.L. + 9.97 \, Log_{10} D$

TABLE III

Engineer's Noise Exposure

i	Activity, Operation	$L_{eq}{}^*i$ Exposure Level dB A-wt	Duration per day Hr	Days per week Dy	C_i Duration per week Hr	$L_{eq}{}^*i$ With Hearing Protection dB A-wt
1	Watch, full ahead	90.5	8	2.5	20	75.5
2	Overtime, full ahead	95	4	4	16	80
3	Watch, at anchor (or loading)	83	8	3	24	
4	Watch, off loading	81	8	1.5	12	
5	Off duty, ship idle	62	12(4)[2]	4.5	56(18)	
6	Off duty (sleep period L_{dn}), ship idle	72[1]	(8)	(4.5)	(36)	
7	Off duty (recreation), ship idle	65	4	3	12	
8	Off duty, full ahead	70	12(4)	2.5	30(10)	
9	Off duty (sleep L_{dn}), full ahead	80[1]	(8)	(2.5)	(20)	
Total					168	

Calculation of total week's noise exposure with 10 dB nighttime penalty.

$$L_{dn}{}^*(wk) = 16.61 \log_{10} \left[\sum_{i=1}^{9} \frac{C_i}{168}\, {}^{(0.2\ L_{eq}{}^*i)} \right]$$

$$L_{dn}{}^*(wk) = 84.2$$

Weekly noise exposure without penalty (less i = 6 & 9).

$$L_{eq}{}^*(wk) = 83.6$$

Weekly noise exposure if hearing protection were worn during activites 1 & 2 and with nighttime penalty.

$$L_{dn}{}^*(wk) = 77.2$$

1. Actual level increased 10 dB for EPA L_{dn} nighttime penalty.
2. Numbers in parentheses are values used when allowing for nighttime penalty.

As in Table III when personnel are exposed to a range of noise levels, $L_{eq}{}^*$ values should be established for the various activities such as the watch, overtime jobs, maintenance, recreation, etc. For these activities the $L_{eq}{}^*$ is the result of a sampling of all the various noises contributing to the exposure. There are a number of ways to arrive at it, especially after something is known about the acoustical environment. Identifying repeated mechanical cycles as does the SAE work cycle test method, may help.

In the absence of machine or equipment cycles, personnel cycles may be studied to reduce the number of complete shift noise exposure measurements and to simplify the reduction of data. Any measure which can simplify the evaluation process should be given attention.

It may be found that by measuring steady state noise levels at the proper places in the vessel and weighing properly, reasonable estimates of L_{eq}* can be reached. If these cycles can be identified during initial surveys the level of effort could be reduced in follow-up surveys, after noise controls have been applied, or after operating procedures are changed.

For the evaluation of noise exposure, speech interference, and annoyance, only A-weighted measurements are required. Various groups have recommended octave band measurements and requirements for NR (noise rating), NC (noise criterion) curves, and PSIL-4 (Preferred Speech Interference Level). To insure an adequate personnel environment, all of these concerns can be handled by A-weighted noise measurements without the complications of octave band frequency analysis. However, for noise control purposes, more detailed frequency analysis than octave band would be desirable.

When the industries mentioned earlier initiated noise exposure programs, they had to invent the instruments and techniques to analyze the problems. Fortunately, the marine industry should have all the instruments and methods necessary to attack its problems.

Audiological Testing

Audiometric tests should be included in any noise exposure control program. Statistically valid samples must be taken and something must be known about the seaman's hearing prior to his marine exposure. Also of concern is his port time and off time noise exposure. This is no small order. Often the necessary background data is going to be sketchy, which makes the need to get some base line audiograms even more urgent.

There will be a tendency to want to put off audiometric tests until the last resort because of the possible damaging results which will be indicated. Experience has shown that these tests will become necessary eventually and it is better to get a base line now so that follow-up tests can be used to get on with the task of implementing an effective program.

Hearing Protection and Noise Control

If noise levels are found which are greater than those proposed in the revised OSHA regulations, hearing protection should be provided and instruction given in the proper use and need to wear the devices. Then it must be decided whether engineering and administrative controls would provide adequate protection and if they are economically feasible.

Administrative Controls

Administrative Controls are simply measures taken to limit the duration of the employee's noise exposure. In some situations, employees with similar skills and capabilities can be moved from a noisy environment to a quiet environment and vice versa in order to lessen one employee's noise exposure and distribute it evenly among all available employees. However, in order to break up an employee's exposure, job assignments with the same required skills and with different noise levels are often not available. Then the only administrative control available is to shorten the employee's working hours, which then requires more people to do the same job.

Engineering Controls

Engineering controls are the most desirable way to control excessive noise levels. Engineering controls deal with the initial design or redesign of the ship and its systems to reduce hazardous noise levels. It should be standard practice to perform engineering studies of a ship's projected noise characteristics before construction begins. Basically, there are only three ways to reduce noise:

(1) Modify the noise output of the source,

(2) Intercept the noise along its path from the source to the receiver, or

(3) Change the receiver's sensitivity (wearing of hearing protection as mentioned above).

Engineering controls involve the two areas of modification at the source and along the path of the noise. At the source, engineering control means finding smoother, quieter, and more efficient methods of supplying power and doing the work which must be done. Engineering control along the path involves three different areas of consideration. They are; airborne noise, structureborne noise, and fluidborne noise. In dealing with airborne noise, basically, the noise can be abated by absorption or by blocking the noise with barrier materials. Structureborne noise treatments involve vibration isolation and damping at the vibration source, along the path, or at the "speaker." Fluidborne noise reductions must be accomplished by absorption or damping of fluid vibrations or reduction of fluid flow ripple. Engineering controls at the source can be expensive, but on the other hand they can often provide more efficient and longer lasting systems with lower maintenance costs. Some of the lower maintenance costs are the result of changed employee attitudes brought about by the lower noise environment.

Equipment Noise and Vibration Standards

A complete noise exposure control program should include the development of equipment standards and specifications which will eventually bring the vessel into compliance with noise exposure requirements by virtue of engineering controls. Since these specifications and standards must address each group of equipment individually, their development must necessarily be slower and more complex. However, to ignore the development of the standards is not appropriate because the use of hearing protection can never be as foolproof as engineering controls. Also, equipment noise level requirements will always be more easily enforced and place the vessel owner/operator in less jeopardy.

Regulations for Noise Exposure Control

Regulations for noise exposure control should be fair and enforceable. They should be fair in the sense that they should provide an adequate degree of protection for those exposed to excessive noise levels, and they should be fair from the standpoint that the vessel owner/operator should be able to determine compliance with a reasonable degree of confidence that any enforcing agency will not come up with different results when evaluating the noise environment. The noise exposure measurements therefore, should be repeatable and reproducible. Relatively simple and straightforward measures should be used to determine compliance.

In accordance with these objectives it is the author's opinion that: 1) A-weighted equivalent continuous noise level criteria should be used. To use any other measure would needlessly confuse the important issues at hand. 2) Audiometric testing of exposed personnel should be performed at least annually. 3) The use of hearing protection should not only be allowed but encouraged for some reasonable period of time (perhaps 3 years) until sufficient other controls are developed. This recommendation is to recognize that (a) hearing protection is an effective tool when properly implemented and (b) any other efficient and effective programs will need at least this time to be implemented. 4) In the absence of noise exposure measures, maximum steady state noise level standards should be used as criteria for use of hearing protection. 5) Priority should be given to machinery spaces for prevention of hearing damage and to ship's bridges for good communication. However, the criteria for machinery spaces should be developed with cognizance of the impact of the rest of the ship's noise environment on the seaman.

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