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Noise Exposure Reduction Aboard an Oceangoing Hopper Dredge*

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Reported industrial hygiene surveys aboard seagoing vessels are few, despite the presence of many potentially hazardous chemical and physical agents aboard ships. This investigation focused on crew noise exposure aboard an oceangoing hopper dredge. Noise exposure criteria were adopted based on the 24-hr equivalent continuous sound level ($L_{eq(24)}$) because of the absence of standards for U.S. shipboard noise exposure. Personal noise dosimeters were used to measure the noise exposure of watchstanders, whose duties were predictable and repetitive. Watchstanders with high noise doses were asked to estimate their duration of exposure in specific areas of the vessel to enable calculation of noise dose per space. Noise sources within spaces associated with high noise dose were identified by sound pressure and surface vibration analysis in octave bands. Almost all accommodation spaces (cabins, recreation rooms, dining rooms, and hospital) were sufficiently quiet (sound pressure levels [SPLs] < 65 dBA) to permit hearing threshold recovery. Machinery space SPLs ranged from 85 to 108 dBA, and engineering personnel noise exposure exceeded the selected criterion of $L_{eq(24)}$ = 80 dBA. Selective noise abatement and use of an enclosed operating station in the engine room were recommended to control engineering personnel noise exposure. This approach to noise exposure assessment and reduction should be applicable to other oceangoing ships where personnel may be exposed to noise 24 hr per day for weeks at a time.

Reported industrial hygiene surveys aboard seagoing vessels are few, despite the presence of many potentially hazardous chemical and physical agents aboard ships. During 1988, 14 500 civilian seamen were employed aboard 403 U.S. oceangoing ships over 1000 gross tons.[1] This investigation focused on crew noise exposure aboard an oceangoing hopper dredge. Our purposes were to evaluate crew noise exposure and to identify options for noise hazard abatement.

The 30-year-old dredge was 107 m (352 ft) long and 18 m (60 ft) wide. The inboard profile of the dredge is shown in Figure 1. The galley, mess rooms and berthing areas for the engine and steward departments were located aft near the engine rooms. Deck department berthing areas were located forward near the pump room. Major machinery was located in several spaces. The ship was propelled by two 2240-kW (3000-hp) electric motors located in the lower motor room, each turning a single propeller. Service speed was 16 knots (18 miles/hr). The output from each of two 3000-kW (4000-hp) steam turbine engines was geared down and drove three in-line generators: one for a propulsion motor, one for a dredge pump motor, and one for the ship's service electric power. The turbines and reduction gears were located on the engine room operating flat. The generators were located on the motor room generator flat. Steam for the turbines was produced by two oil-fired boilers located in the boiler room.

The dredging process involved removal of sediment (spoil) from the riverbed through two trailing drag arms. Spoil was pumped through the drag arms by two 2240-kW (3000-hp) dredge pumps (located in the pump room) that discharged into hoppers. The spoil is either transported to a dumping area and released through doors in the bottom of the hoppers, or the dredge is tied up to a pipeline terminal, and the spoil pumped to a disposal area ashore. During this study, spoil was pumped ashore.

The crew of 70 included 29 in the deck department who were involved in various phases of vessel navigation or dredging, 27 in the engine department who maintained auxiliary and propulsion machinery, and 12 in the steward department who prepared meals and maintained living spaces. About half the crew (dayworkers) worked conventional 8-hr days with lunch and rest breaks; the rest stood watches (watchstanders), which usually consisted of two 4-hr watches, separated by 8 hr off, per day. Occasionally, watchstanders stood two 6-hr shifts per day. The

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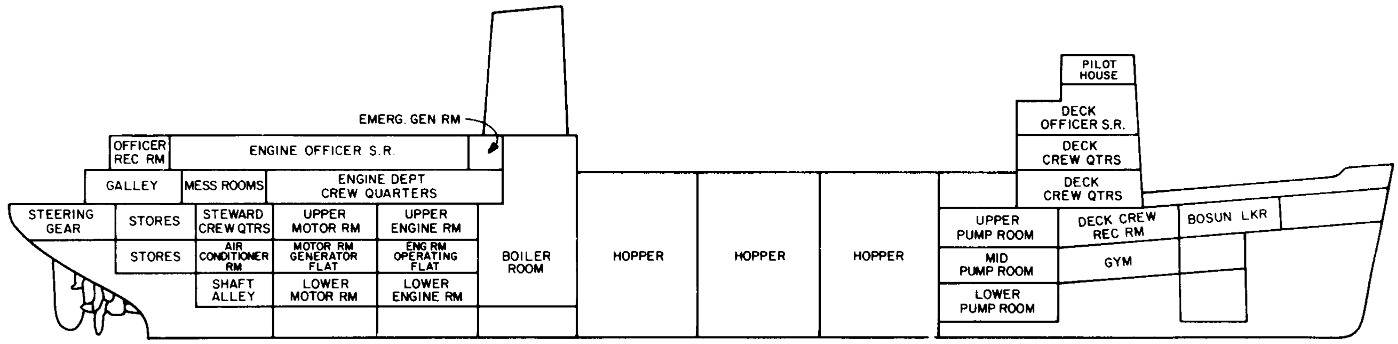

Figure 1—Inboard profile of dredge showing work and accommodation spaces including staterooms (SR) and crew quarters (QTRS).

crew lived aboard the dredge for 10 days followed by 4 days off. The crew had received pre-employment physical exams, including audiometric exams, but periodic exam or hearing conservation programs were not in effect. The authors did not conduct audiometric examinations as part of this investigation, or otherwise attempt to measure crew hearing loss.

Although the U.S. Coast Guard had statutory authority for promulgation and enforcement of safety and health standards aboard vessels subject to their inspection and certification,(2) they had not promulgated occupational noise regulations. Instead, the Coast Guard issued a Navigation and Vessel Inspection Circular,(3) which outlined its recommendations to ship owners for safe occupational noise levels on ships.

METHODS

Shipboard Noise Exposure Criteria

Because occupational noise exposure aboard the dredge occurred on- and off-duty for 10-day periods, it was decided that application of the threshold limit values (TLVs®) for noise(4) would not be sufficiently protective for two reasons: the unusual work schedule and the possibility of continuous noise exposure aboard ship. For this investigation, the noise exposure recommendations of the International Maritime Organization (IMO)(5) were adopted, which were similar to those of Gales(6) and are more conservative than the recommendations of the U.S. Coast Guard in its Navigation and Vessel Inspection Circular.(3) For noise exposure aboard existing ships, the IMO recommended a maximum 24-hr equivalent continuous sound level ($L_{eq(24)}$) of 80 decibels, A-weighted (dBA), which permits continuous 8-hr exposure to sound pressure levels (SPLs) of 85 dBA if the balance of each workday was spent in quiet areas. The IMO also recommended that SPLs in accommodation spaces be no greater than 60 dBA in sleep cabins and hospital or 65 dBA in offices, mess, and recreation rooms. While the 8-hr limit of 85 dBA is similar to the TLV,(4) the use of $L_{eq(24)}$ is more protective because it incorporates a 3 dB exchange rate (i.e., for each 3 dB increase in noise level, permissible exposure time is halved). The documentation of the TLV for noise(7) states that the recommended 5 dB exchange rate of the TLV . . . "may be overly permissive in some plant conditions for continuous exposure." Table I summarizes the permissible exposure duration as a function of SPL in accordance with the exposure criteria adopted in this study.

Exposure Assessment: Dayworkers

The work routines of dayworkers (e.g., captain, chief engineer, cooks, clerks, electricians, and wipers) were variable and unpredictable. Their noise exposure was not characterized by dosimetry; this would have required an extensive effort. Reduction of hazardous noise exposure by this group could be ensured by their use of personal hearing protection in noise hazardous spaces (posted when SPL are 85 dBA or greater) and their inclusion in a hearing conservation program.

Exposure Assessment: Watchstanders

Watchstanders (e.g., watch engineer, watch officer, quartermaster, bintender, oiler, and fireman) had generally predictable work routines. The noise exposures of at least half the watchstanders in each job category, chosen randomly, were measured using personal noise dosimeters (Genrad 1945-9710, Concord, Mass.), which conformed to standard noise dosimeter specifications.(8) The dosimeters were adjusted to integrate with a 3-dB exchange rate and to measure noise levels above 60 dBA. Dosimeters were field calibrated with a Genrad 1954 monitor/calibrator. Microphones were fitted with windscreens and attached to the right lapel of sampled workers. The noise exposure of each sampled watchstander was monitored for one dredging cycle, rather than a full watch period, because noise levels and personnel duties were generally related to the dredging cycle. The dredging cycle lasted about 3 hr (most of a 4-hr watch) and included dredging, transport of spoil to the pipeline, pumpout,

TABLE I
Permissible Exposure Duration as a Function of Sound Pressure Level

Duration per Day (hr)	Sound Pressure Level (dBA)
16	82
8	85
4	88
2	91
1	94
1/2	97
1/4	100
1/8	103

and steaming back to the dredging site. Replicate dosimetry was not performed; hence, cycle-to-cycle noise dose variability could not be evaluated.

Measurement of Ambient Noise Levels

The SPLs in accommodation and work spaces were measured during the noisiest operating conditions, if obvious by listening, otherwise with the vessel fully laden under full power, while dredging, and during pumpout. Noise levels were measured in accordance with standard methods[9] using a precision sound level meter (Genrad 1933) that was field calibrated with an acoustic calibrator (Genrad 1562A).

Noise Exposure Analysis

Watchstanders, whose 8-hr equivalent noise exposure, $L_{eq(8)}$, exceeded 83 dBA on the basis of dosimetry, were asked after their exposure period to describe their work activities on the basis of time spent in identifiable areas of the ship (e.g., 20 min on the motor room generator flat per 4-hr watch). The criterion of $L_{eq(8)} > 83$ dBA was selected to accommodate noise dosimeter response accuracy,[8] which was assumed to be within ±2 dB for most noise spectra on this ship. Noise dose per area (*attributable dose*) was estimated based on exposure duration per area (from interview) and measured SPL per area. Attributable dose was defined as:

$$\text{Attributable dose} = \frac{\text{(exposure duration per area)}}{\text{(permissible exposure duration per area)}}$$

where permissible exposure duration per area was taken from Table I. By this dose estimation, it was possible to identify ship areas that contributed substantially to work noise exposure and others which were of less importance.

Identification of Noise Sources

Major noise sources in work spaces were identified by first analyzing the SPL in octave bands with a precision sound level meter (Genrad model 1933). Next, A-weighting correction[10] was applied to octave band SPLs. Any corrected levels greater than 80 dB were considered problem bands because the addition of several 80 dB SPLs could exceed the criterion level. Sound power sources in a particular problem band usually became apparent by plotting SPL contours for the problem band in the noisy space. Noise source vibration was measured to isolate specific noise-producing components. For this analysis, a type 4332 accelerometer and model ZR 0020 vibration integrator (Bruel and Kjaer, Marlborough, Mass.) were used with the precision sound level meter and were calibrated with a Genrad model 1557A vibration calibrator.

RESULTS

All measurements were made with the ship operating in the Delaware River. The captain observed that operating conditions were typical, although noise levels were occasionally greater than measured when the ship dredged rocky areas. Table II presents a summary of noise levels measured in hearing threshold recovery areas (with quiet occupants). Table III lists the range of noise levels and conditions for spaces where noise levels exceeded 85 dBA.

The range of equivalent 8-hr noise exposures ($L_{eq(8)}$) measured for watchstanders is listed in Table IV. The bintender, fireman, watch engineer, and oiler had noise exposures greater than $L_{eq(8)} = 83$ dBA. Their noise exposure patterns are presented in Table V.

TABLE II
Sound Pressure Levels in Accommodation Spaces with Quiet Occupants Expressed as Range of Measured Values, Number of Rooms of Each Type, and Permissible Sound Pressure Level Criteria for Each Space

Location	No. of Rooms	Sound Pressure Level (dBA)	SPL Limit (dBA)
Deck officer stateroom	8	52–65	60
Engine officer stateroom	7	50–58	60
Deck crew quarters	15	45–65	60
Engine crew quarters	10	54–64	60
Steward crew quarters	8	52–60	60
Officer recreation room	1	47	65
Crew recreation room (fwd)	1	64	65
Crew recreation room (aft)	1	64	65
Gym	1	63	65
Officers' mess (dining)	1	57	65
Crew mess	1	64	65

TABLE III
Operating Conditions and Sound Pressure Levels in Noise Hazardous Work Spaces Aboard the Dredge

Location	Condition	Sound Pressure Level Range (dBA)
Electric shop	emergency generator running	104
Emergency generator rm.	emergency generator running	103–112
Standby generator rm.	standby generator running	103–108
Air cond. compressor rm.	air cond. compressor running	85–94
Shaft alley	sewage plant blower running	93–94
Upper pump room	dredging and pumpout only	82–98
Mid pump room	all conditions	80–98
Lower pump room	all conditions	81–98
Upper engine room	all conditions	87–89
Main deck engine room	all conditions	85–95
Eng. rm. operating flat	all conditions	98–100
Lower engine room	all conditions	90–98
Upper motor room	all conditions	77–90
Motor rm. generator flat	all conditions	85–93
Lower motor room	all conditions	85–97

TABLE IV
Watchstander Noise Exposure Expressed as 8-hr Equivalent Noise Level ($L_{eq(8)}$)

Watchstander Group	Group Size	Sample Size	$L_{eq(8)}$ Range (dBA)
Watch officer	4	2	81
Quartermaster	5	3	79–83
Bintender	12	6	85–96
Watch engineer	4	2	93–96
Oiler	6	3	95–96
Fireman	5	3	89–90

DISCUSSION

Noise dose estimates ranged from 0 to 7 dBA lower, in terms of $L_{eq(8)}$, than measured noise dose (Tables IV and V)—an observation that underscores the value of personal versus area sampling. The discrepancy between measured and estimated noise dose was probably associated with the uncertainty of exposure duration estimates, rather than with SPL or noise dosimetry instrument accuracy.

Noise Exposure Sources

In controlling the flow of spoil into the hoppers, the bintender spent much of his watch on the hopper deck where noise levels were about 93 dBA while dredging. The principal noise source was cascading spoil from the distribution piping into the partially filled hoppers. The fireman, who operated the boilers, spent most of his watch in the boiler room where noise levels were generally below 85 dBA. When the fireman went into the lower engine room to check the feed pumps or pump bilges, he was exposed to 94 dBA noise levels. The main noise sources in the lower engine room included the feed pumps, turbine reduction gear casings, and lubricating oil piping. The watch engineer (who was

TABLE V
Watchstander Noise Exposure Patterns and $L_{eq(8)}$ Based on Attributable Dose

Location	Avg. Exposure Duration (min)	SPL (dBA)	Permissible Exposure Duration (min)	Attributable Dose	$L_{eq(8)}$ (dBA)
Bintender					
Hopper deck, dredging	53	93	60	0.88	
Hopper deck, pumpout	213	75	>960	0	
Pilothouse	151	75	>960	0	
Fwd. mooring station	30	75	>960	0	
Aft mooring station	30	89	180	0.17	
Bintender total	480			1.05	85
Fireman					
Lower boiler room	455	84	600	0.75	
Lower engine room	25	94	60	0.42	
Fireman total	480			1.17	86
Watch engineer					
Engine rm. operating flat	240	93	60	4.0	
Lower engine room	30	94	60	0.5	
Lower boiler room	60	84	480	0.13	
Motor rm. generator flat	30	89	240	0.13	
Lower motor room	30	89	240	0.13	
Shaft alley, sewage plant	10	93	60	0.17	
Undefined	80				
Watch engineer total	480			5.06	92
Oiler					
Air cond. compressor rm.	10	88	240	0.04	
Upper engine room	10	88	240	0.04	
Engine rm. operating flat	300	93	60	5.00	
Lower engine room	30	94	60	0.5	
Motor rm. generator flat	20	89	180	0.11	
Lower motor room	20	89	180	0.11	
Shaft alley, sewage plant	15	93	60	0.25	
Lower pump room	40	94	60	0.67	
Steering engine room	10	78	>960	0	
Fwd. sewage plant	10	84	480	0.02	
Undefined	15				
Oiler total	480			6.74	93

responsible for auxiliary and propulsion machinery operation) received the greatest noise dose on the engine room operating flat and a substantial noise dose in the lower engine room. The oiler (who assisted the engineer) also received his greatest noise dose on the engine room operating flat, with other substantial sources including the lower engine room and lower pump room. Major noise sources on the engine room operating flat included the turbine reduction gear casing, turbine lubricating oil pumps and piping, main condenser and distilling unit air ejectors, and steam pressure reducing stations. While dredging or pumping out, the flow of spoil through the dredge pumps and piping caused noise levels up to 94 dBA in the pump room. With the dredge pumps off, noise levels in the pump room were 80–90 dBA, and the major noise sources were the hydraulic pumps and piping.

Noise Exposure Reduction Options

A hearing conservation program and use of personal hearing protection in noisy spaces by personnel is an option for noise exposure control. Engineering options for noise exposure control were also considered. Alteration of the spoil distribution piping to reduce the cascade of spoil would reduce bintender noise exposure. Noise reduction on the lower engine room to 85 dBA should be possible by replacing the feed pump motors and by acoustic enclosure of reduction gear lower casings and lubricating oil piping. This would reduce the noise dose of the fireman, watch engineer, and oiler. Installation of an acoustically isolated enclosed operating station (EOS) on the operating flat would substantially reduce the watch engineer and oiler noise dose if the EOS was properly designed to accommodate routine machinery monitoring instruments and gauges. If 75% of the time presently spent on the operating flat were instead spent within an EOS (with internal noise levels below 80 dBA), the oiler noise dose could be reduced from 5.7 to 2.7 and the watch engineer noise dose could be reduced from 4.3 to 1.9 by this measure alone. Noise reduction on the engine room operating flat would involve acoustic enclosure and lagging of reduction gear casings, lubricating oil piping, and pressure reducing station, and installation of silencers on the air ejector vents or replacement of the air ejectors with vacuum pumps. Noise reduction in the lower pump room during dredging was considered unlikely, but lagging the hydraulic piping should reduce noise levels in the lower pump room below 85 dBA with the dredge pumps off. The engineering consequences of acoustic lagging on machinery performance was not investigated, but would probably be small.

Noise levels in mess rooms and recreation rooms were, in general, sufficiently low to permit hearing threshold recovery off-duty. The SPLs in the officers' staterooms were below 60 dBA except for the normally unoccupied visiting officers' stateroom where the SPL was 65 dBA while dredging. Most of the deck crew quarters had SPLs below 60 dBA, although pump room noise resulted in SPLs of 65 and 66 dBA in two rooms occupied by two launch operators and two deckhands, respectively. These rooms shared a common steel bulkhead (partition) with the pump room. Noise reduction to 60 dBA in these spaces was considered likely by simple acoustical treatment of the steel bulkhead. The engine department crew quarters had SPLs less than 60 dBA, except for the first electrician quarters, which measured 64 dBA. Noise from cascading spoil entered this space through a poorly sealed window. Identical rooms with windows in good repair had SPLs below 60 dBA, reinforcing the efficacy of window repair.

SUMMARY AND CONCLUSION

Worker noise exposure aboard the dredge consisted of work period and off-duty exposure. With a few correctable exceptions, noise levels in accommodation spaces were low enough to allow hearing threshold recovery off duty for noise-exposed personnel. Work period noise evaluation was approached by dividing the dredge crew into either of two groups based on job duties—dayworkers and watchstanders.

No attempt was made to measure the noise exposure of dayworkers (who were characterized by unpredictable work routines). Dayworker noise exposure control was assumed if no exposure during an 8-hr workday exceeded 85 dBA. Because most machinery spaces had noise levels between 85 and 108 dBA and noise reduction to 85 dBA in all spaces was deemed unlikely, the use of personal hearing protection by dayworkers in noisy spaces was recommended.

The noise exposure of a random sample of the watchstanders was measured during a typical dredging cycle with personal noise dosimeters. The measured noise dose of the bintender, fireman, watch engineer, and oiler exceeded the selected criteria. To identify those areas of the vessel associated with high noise exposure, and to clarify the causes and extent of overexposure, the workers with high noise exposure were interviewed to determine work routine and work site for a typical work period.

In addition to programs of hearing conservation and the use of personal hearing protection, engineering options for noise reduction were identified. Noise sources responsible for worker overexposure included spoil flow in piping, reduction gear casings, hydraulic and lubricating oil piping, air ejector vents, and steam pressure reducing stations. Installation of an enclosed operating station in the engine room was identified as one means to substantially reduce the noise dose of the watch engineer and oiler.

The approach to shipboard noise exposure evaluation and control employed for this investigation was straightforward. In the absence of noise exposure standards for U.S. ships, relatively conservative noise exposure criteria were used. The approach used here identified those areas of the ship associated with high noise dose, not merely high noise level, and enabled the authors to target noise reduction efforts on the machinery that was responsible for excessive noise exposure.

While the dredging mission and machinery were unique to this class of ships, the propulsion machinery and other noise sources were similar to those found aboard other commercial steamships. Like the crews of other ships, the dredge crewmen were confined to their vessel where noise exposure was practically unavoidable 24 hr a day for weeks at a time. Assessment and control of the exposure of such a population to noise, or other environmental agents, requires recognition of the potential for on-duty and off-duty exposure in selection of exposure criteria and measurement procedures.

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