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I. SUMMARY

On October 28, 1988, a request for a health hazard evaluation (HHE) was received from the Deputy Chief for Operations and Administration of the Hamilton, Ohio Fire Department who asked the National Institute for Occupational Safety and Health (NIOSH) for assistance to the fire department. Specifically, he requested that noise exposure levels emitted by the vehicles as well as time-weighted average noise levels in the fire stations be measured in conjunction with a hearing loss analysis of the Hamilton Fire Department (HFD).

Tape recordings of the department's front line and reserve fire apparatus were made in Hamilton, Ohio on May 25, 1989. The vehicles made Code 3 responses (lights and sirens) on an approximately one-third mile stretch of road on the outskirts of town away from major residential areas while recordings were being made in two riding positions on each of the vehicles. In addition, twenty-four hour noise dosimeter surveys were conducted for two consecutive days at the six HFD fire stations in June 1990. Audiometric testing was completed on 90 HFD fire fighters on March 13-15, 1990, by NIOSH hearing conservationists. Fifty-five of the 90 fire fighters had previously been tested by the department in late 1983 or early 1984. The hearing tests from the two time periods were compared in order to observe any changes that had occurred over this six-year span.

The noise surveys revealed that the 24-hour cumulative noise doses were generally less than the amount allowed under any of the environmental evaluation criteria used by NIOSH. However, portions of the analyses found noise levels that greatly exceeded the exposure limits for brief periods of time. These high exposures were usually associated with emergency response runs in the fire vehicles. The potential for high noise exposures from the vehicles was confirmed by the spectral data analyses which revealed noise levels in excess of 120 decibels (dB) at certain frequencies.

The audiometric data collected by NIOSH on the 90 HFD fire fighters showed a decline in hearing ability in the high frequency sound region, a pattern characteristic of noise-induced hearing loss. The statistical comparisons between the earlier tests and the hearing tests conducted during this evaluation found a significant decline in hearing at the 4000 Hertz (Hz) test tone. At the same time, a significant "improvement" in hearing at the low audiometric test frequencies, 500 Hz to 2000 Hz, was seen in the same group of 55 fire fighters. These data suggest that, in spite of the fire fighters' improved ability to take a hearing test, there was still a significant loss of hearing in the noise sensitive region.

Based on the results of the audiometric data analyses, as well as the potential for high level noise exposures in the HFD, the NIOSH investigator concludes that a health hazard exists for fire fighters in the department. A statistically significant loss of high frequency hearing was found in a comparison of two audiometric examinations administered to HFD personnel over a six-year period, the latter audiometric tests given in conjunction with this HHE and the initial tests given by the department in late 1983 or early 1984. Section IX of this health hazard evaluation report offers recommendations to the HFD to reduce the noise exposures to the fire fighters and help prevent further hearing losses.

KEYWORDS: SIC 9224 (Fire departments, including volunteer), noise exposure, noise dosimetry, fire apparatus noise, hearing loss, hearing conservation.

II. INTRODUCTION

On October 28, 1988, a request for a health hazard evaluation (HHE) was received from the Deputy Chief for Operations and Administration of the Hamilton, Ohio Fire Department who asked the National Institute for Occupational Safety and Health (NIOSH) for assistance in evaluating noise exposures during normal activities and the hearing loss among the Hamilton Fire Department (HFD) personnel. An opening conference was held on November 23, 1988, at the Hamilton City Building. In attendance at this meeting were members of the fire department's administration office, the city manager, a representative of union Local #20 of the International Association of Fire Fighters, and the NIOSH project officer. During the conference, it was determined that NIOSH would conduct audiometric examinations on fire department personnel, conduct noise dosimetry over 24-hour work shifts at each of the department's fire stations, and analyze the department's vehicles for the spectral content of the noise output from these vehicles. In addition, the results from audiometric tests given to HFD fire fighters in late 1983 or early 1984 would be provided to NIOSH for comparison to the hearing test results generated by this HHE.

The results of the spectral analysis of the department's vehicles along with preliminary recommendations to reduce vehicle noise were provided to management and union officials in an interim report dated July 1989. The results of the audiometric examination were briefly reviewed with each fire fighter by the Project Officer immediately following the test and were also provided in detail by letter on April 4, 1990. This final report presents a summary of the previously reported results and a more thorough analysis of the data than that provided in the earlier reports.

III. BACKGROUND

The HFD is a paid, municipal fire department that is responsible for providing fire protection, fire prevention, inspection, education, and emergency medical services (EMS) to a city of 61,000 people in southwestern Ohio. The city maintains six fire stations throughout the city, with six front-line pumpers, two ladder trucks, and two front-line EMS squads to serve the area. Approximately 100 fire fighters are employed by the HFD to man these stations 24 hours per day, seven days a week. Fire fighters are on a 24-hour shift schedule. In 1986 and 1987, the department responded to 4000 fire incidents and over 5000 EMS runs each of the two years.

IV. MATERIALS AND METHODS

A. Vehicle Spectrum Measurements

Tape recordings of the fire apparatus were made in Hamilton, Ohio on May 25, 1989. The vehicles made Code 3 responses (lights and sirens) on an approximately one-third mile stretch of road on the outskirts of town, away from major residential areas, while recordings were being made in two riding positions on each of the vehicles. The road coarse has a fairly steep incline which put a load on the engine to maximize the noise emissions from the engine and transmission. This scenario allowed a 30-60 second audio recording to be made for each vehicle tested at each of the two riding positions. For the department's engines and trucks, recordings were made in the center of the cab and in the passenger's side of the jumpseat. The department's EMS squads were measured at the passenger seat in the cab and in the patient compartment near the cot.

Audio recordings were made with a Panasonic Model SV-250 Digital Audio Tape (DAT) Recorder. A Sennheiser Model MKH 20P48U3 Omnidirectional Condenser Microphone, Neuman Model BS-48 Phantom Power Supply, and appropriate microphone cables were connected to the DAT recorder. Because of the potential for relatively high sound levels, the attenuators on the microphone and on the recorder were placed in the on position. However, the noise limiter on the recorder remained in the off position during the recordings. Prior to testing each vehicle, calibration tones were placed on the tape with a General Radio Model 1562-A Sound Level Calibrator with a 1" microphone coupler. The spectral analysis of these recordings were completed with a Wavetek Model 444A Mini-Ubiquitous FFT Computing Spectrum Analyzer. Either 24 second or 48 second time periods, depending on the length of time it took the vehicle to complete the road course, were integrated into the 1/3 octave band center frequencies from 25 Hertz (Hz) to 20000 Hz. These 1/3 octave band values were plotted with a personal computer system and associated software.

B. Dosimetry

Noise dosimeter surveys were conducted in June 1990 at each of the HFD fire stations. Each station was surveyed on two consecutive days for 24 hours each day. A NIOSH field investigator was at the surveyed station during the entire sampling period. Whenever a vehicle left the station, the NIOSH investigator rode in one of the extra jumpseat positions. A detailed time log was kept so that the time of the responses could be calculated and any noisy events could be noted.

Members of the crew assigned to a vehicle were asked to wear a noise dosimeter for their entire work shift. If they were required to put on their turnout gear for an emergency response, the fire fighters were reminded to place the microphone of the dosimeter outside of the turnout gear, exposing it to the noise environment. The noise dosimeters were Metrosonic Model dB301/26 Metrologgers, a small noise level recording device worn on the waist, with a 1/4-inch remote microphone placed on the shirt collar of the station uniform. This dosimeter measures noise in decibels, A-weighted levels (dB[A]) four times per second. The measurements are integrated according to the Occupational Safety and Health Administration (OSHA) noise regulation (see Evaluation Criteria section of this report) for an entire minute and stored separately in the Metrologger for data storage and later analysis. Generally, four or five fire fighters were given dosimeters at each of the surveyed station houses.

Each dosimeter was calibrated according to the manufacturer's instructions before being placed on a fire fighter. Memory constraints limit the time that these dosimeters are able to record and store noise data to eight hours. After the 8-hour period was completed, the dosimeter was removed from the fire fighter and placed in the standby mode of operation and another dosimeter put in its place. The data were transferred to a computer for storage and the dosimeter was calibrated to assure the accuracy of the device had not changed during the sampling period. The data from each Metrologger dosimeter were transferred to a Metrosonics Model dt-390 Metroreader/Data Collector following the noise sampling. The information was then transferred to a laptop computer with a Metrosonics' Metrosoft software package for permanent data storage and later analysis.

C. Audiometric Testing

The audiometric tests for the HHE were administered by a Council for Accreditation in Occupational Hearing Conservation (CAOHC) certified occupational hearing conservationist on March 13-15, 1990. Testing was conducted in the basement meeting room of Station #5, where an Acoustic Systems Model RE-60 Transportable Sound Booth was assembled to isolate the fire fighter during the testing procedure and keep the ambient noise levels to a minimum. Audiometric testing was done with a Tracor Model RA400 Microprocessor Audiometer, which also allowed for the electronic storage of the audiometric results. The audiometric data were downloaded daily to a laptop computer for permanent storage and later analysis.

The audiometric tests were administered over a three day period so that all three shifts of fire fighters would be on duty one of the test days. Engine and truck companies reported to the test site individually for audiometric testing. Informed consent was obtained from each fire fighter prior to testing. Additionally, a short, self-administered work history questionnaire (Appendix 1) was completed by the participants prior to taking the audiometric examination. Following a brief set of instructions about the hearing test procedure, pure-tone audiometric thresholds were obtained from the fire fighters at 500, 1000, 2000, 3000, 4000, 6000, and 8000 Hertz (Hz) separately for each ear, beginning with the left ear. Total test time was approximately 10 minutes per person. The audiometer was given an exhaustive calibration by a designated manufacturer's laboratory immediately prior to this HHE. Daily biological calibrations were made with a Tracor Oscar II electro-acoustic ear.

V. EVALUATION CRITERIA

A. Noise

Noise-induced loss of hearing is an irreversible, sensorineural condition that progresses with exposure. Although hearing ability declines with age (presbycusis) in all populations, exposure to noise produces hearing loss greater than that resulting from the natural aging process. This noise-induced loss is caused by damage to nerve cells of the inner ear (cochlea) and, unlike some conductive hearing disorders, cannot be treated medically.[1] While loss of hearing may result from a single exposure to a very brief impulse noise or explosion, such traumatic losses are rare. In most cases, noise-induced hearing loss is insidious. Typically, it begins to develop at 4000 or 6000 Hz (the hearing range is 20 Hz to 20000 Hz) and spreads to lower and higher frequencies. Often, material impairment has occurred before the condition is clearly recognized. Such impairment is usually severe enough to permanently affect a person's ability to hear and understand speech under everyday conditions. Although the primary frequencies of human speech range from 200 Hz to 2000 Hz, research has shown that the consonant sounds, which enable people to distinguish words such as "fish" from "fist," have still higher frequency components.[2]

The A-weighted decibel [dB(A)] is the preferred unit for measuring sound levels to assess worker noise exposures. The decibel unit is dimensionless, and represents the logarithmic relationship of the measured sound pressure level to an arbitrary reference sound pressure (20 micropascals, the normal threshold of human hearing at a frequency of 1000 Hz). Decibel units are used because of the very large range of sound pressure levels which are audible to the human ear. The dB(A) scale is weighted to approximate the sensory response of the human ear to sound frequencies. Because the dB(A) scale is logarithmic, increases of 3 dBA, 10 dBA, and 20 dBA represent a doubling, tenfold increase, and 100-fold increase of sound energy, respectively. It should be noted that noise exposures expressed in decibels cannot be averaged by taking the simple arithmetic mean.

The OSHA standard for occupational exposure to noise (29 CFR 1910.95)[3] specifies a maximum PEL of 90 dB(A)-slow response for a duration of eight hours per day. The regulation, in calculating the PEL, uses a 5 dB time/intensity trading relationship, or exchange rate. This means that in order for a person to be exposed to noise levels of 95 dB(A), the amount of time allowed at this exposure level must be cut in half in order to be within OSHA's PEL. Conversely, a person exposed to 85 dB(A) is allowed twice as much time at this level (16 hours) and is within his daily PEL. NIOSH, in its Criteria for a Recommended Standard,[4] proposes an exposure limit of 85 dB(A) for 8 hours, 5 dB less than the OSHA standard. The NIOSH criteria also use a 5 dB time/intensity trading relationship in calculating exposure limits. In 1994, the ACGIH changed its TLV to a more protective 85 dB(A) for an 8-hour exposure, with the stipulation that a 3 dB exchange rate be used to calculate time-varying noise exposures.[5] Thus, a worker can be exposed to 85 dB(A) for 8 hours, but to only 88 dB(A) for 4 hours or 91 dB(A) for 2 hours.

Time-weighted average (TWA) noise limits as a function of exposure duration are shown as follows:

Duration of Exposure (hrs/day)	Sound Level dB(A)		
	ACGIH	NIOSH	OSHA
16	82	80	85
8	85	85	90
4	88	90	95
2	91	95	100
1	94	100	105
1/2	97	105	110
1/4	100	110	115*
1/8	103	115*	---
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* No exposure to continuous or intermittent noise in excess of 115 dB(A).

** Exposure to impulsive or impact noise should not exceed 140 dB peak sound pressure level.

*** No exposure to continuous, intermittent, or impact noise in excess of a peak C-weighted level of 140 dB.

The duration and sound level intensities can be combined in order to calculate a worker's daily noise dose according to the formula:

$$\text{Dose} = 100 \text{ X } (C_1/T_1 + C_2/T_2 + ... + C_n/T_n),$$

where C_n indicates the total time of exposure at a specific noise level and T_n indicates the reference duration for that level as given in the above table. During any 24-hour period, a worker is allowed up to 100% of his daily noise dose. Doses greater than 100% are in excess of the OSHA PEL.

The OSHA regulation has an additional action level (AL) of 85 dB(A) which stipulates that an employer shall administer a continuing, effective hearing conservation program when the TWA value exceeds the AL. The program must include monitoring, employee notification, observation, an audiometric testing program, hearing protectors, training programs, and recordkeeping requirements. All of these stipulations are included in 29 CFR 1910.95, paragraphs (c) through (o).

The OSHA noise standard also states that when workers are exposed to noise levels in excess of the OSHA PEL of 90 dB(A), feasible engineering or administrative controls shall be implemented to reduce the workers' exposure levels. Also, a continuing, effective hearing conservation program shall be implemented.

B. Audiometry

Audiometric test results are combined according to different criteria in order to ascertain the hearing handicap for speech perception or for the determination of noise effects on hearing. A criterion proposed by NIOSH in its criteria document for occupational noise exposure[4] is intended to determine the amount of handicap in speech perception and communication abilities. It averages the hearing level in decibels (dB HL re ANSI S3.6-1969)[6] at the pure-tone frequencies of 1000, 2000, and 3000 Hz for both ears. The criterion incorporates a 25 dB "low fence" value. This means that the dB HL average value must exceed 25 dB before a hearing impairment is said to exist. The percentage of impairment is calculated by multiplying each decibel in excess of 25 dB HL by 1.5%. For example, an average dB HL of 40 for this metric would represent a 22.5% hearing impairment. A second criterion has been proposed by the American Academy of Otolaryngology - Head and Neck Surgery.[7] The criterion combines the pure-tone frequencies of 3000, 4000, and 6000 Hz. This combination will be most sensitive to the sensorineural effects on the ear from noise because of the propensity of these frequencies to deteriorate sooner when exposed to loud noises.[8] It also incorporates a 25 dB low fence in calculating the percentage of hearing handicap for these audiometric test frequencies.

Finally, a criterion proposed by Eagles, *et al.*[9] for single-frequency hearing impairment determination also uses a low fence of 25 dB HL. With this criterion, any person who had a hearing level of 26 dB HL or greater at any single frequency was classified as having some degree of hearing loss. The degree of loss could range from "mild" (26-40 dB HL) to "profound" (> 90 dB HL). This criterion differs from the other two criteria in that it looks at single test frequencies rather than average hearing levels across several frequencies. This single-frequency criterion was used to categorize the hearing losses for individual fire fighters in their audiometric test results letter.

VI. RESULTS

A. Vehicle Spectrum Measurements

All of the HFD front-line fire and EMS vehicles were tested on the road course for noise emissions. The vehicle descriptions and their warning devices are presented in Table 1. A total of 10 front-line vehicles, consisting of 6 engines, 2 ladder trucks, and 2 EMS squads, were brought to the road course for the noise analysis. As is shown in this table, the major warning device of the fire suppression vehicles is the Federal Signal "Q" Siren, usually located in the front of the vehicle above the bumper. All electronic siren speakers, with the exception of Squad #1, were located in light bars on the roof of the vehicle's cab. Squad #1 had front grille speakers for its electronic siren. Air horns were located on the roof area of the apparatus.

A review of the spectral plots of the vehicles (Figures 1-10) reveals several interesting findings. The noise from the diesel engine peaks at 125 Hz. This is seen most clearly in the spectral plots of the two Pirsch diesel engine pumpers (Companies #2 and #5). Because of the mid-chassis location of the engines on these vehicles, the levels in the jumpseats are generally 9-12 dB higher than the levels measured in the cabs. In two instances, the 1/3 octave band noise level exceeded 120 dB at the 125 Hz band. The engine sound levels from the Pirsch gasoline pumpers peak at a lower frequency than those from the diesel engines, with maximum sound levels generally seen at 63 Hz. The overall sound levels are also a little lower in the gasoline-powered vehicles, particularly in the jumpseat riding positions. The Pirsch ladder truck was found to be similar to the diesel powered Pirsch pumpers, both in terms of the overall sound levels and the spectral characteristics of the two types of vehicles. The newer Seagrave aerial ladder truck had lower overall sound intensity levels than the older Pirsch ladder truck.

The one engine with only an electronic siren in operation was the Ford E-One Pumper of Company #6. The spectral plots for this vehicle (Figure 5) reveal a different pattern than those observed for the other diesel-powered pumpers. This vehicle exhibits peak sound levels in the 800-1600 Hz range. These frequencies are from the siren, with the higher noise levels in the jumpseat the result of siren noise traveling over the top of the roof and down into the jumpseat. Additionally, in the cab there is a peak noise level for the 1/3 octave band at 630 Hz. This is the frequency of the air horns located on the roof of the cab. This same pattern of peak 1/3 octave bands measured in the 630-1600 Hz range from of the warning devices is seen in the EMS vehicles. The smaller engines on these vehicles produce less noise than those on the fire suppression apparatus. A comparison of the old EMS squad to the new 1988 vehicle show that improvements in noise reduction are possible. One major improvement seen in Squad #1 is the movement of the siren speakers from the roof light bar to the grille mounts. Additional improvements are the tighter seals around compartments in the patient area, resulting in fewer rattles when the vehicle is in motion.

Overall noise levels were calculated from the spectral data for each of the 10 vehicles tested, including both an unweighted calculation as well as a calculation of the A-weighted sound level of the vehicles. For the six engine companies, the value of the unweighted noise levels range from 106 dB for the Ford E-One pumper to 124 dB for a diesel-powered Pirsch pumper. The A-weighted noise levels for the same group ranged from 100 dB(A) for a gasoline-powered Pirsch pumper to 118 dB(A) for the Ford E-One. The two truck companies have noise levels that range from 108 to 119 dB on the unweighted scale and from 102 to 107 dB(A) for the weighted scale. In both instances, the newer Seagrave truck is the quieter of the two vehicles. The two EMS squads have unweighted noise levels of 91 to 94 dB, with the newer vehicle being the quieter one. A similar finding is seen for the A-weighted sound with levels ranging from 79 to 101 dB(A).

B. Dosimetry

A total of 40 full-shift noise dosimeter samples were collected in June 1990 on fire fighters at the six HFD stations. Each sample is the accumulation of the noise dose recorded from three consecutive eight-hour dosimeter periods, covering the 24-hour time period that the fire fighter was on duty. If any individual's three consecutive dosimeter readouts were unavailable due to equipment malfunction, the entire full-shift sample for that fire fighter was not included in the group data analysis. Dosimeter data were collected on two consecutive days at each fire station by a NIOSH field person who was at the station and responded along with HFD fire fighters.

The dosimeter results for the engine, truck, and squad companies are given in Table 2. The table gives the company number, the date of noise dosimeter testing, and the total number of times when the vehicle left the station house (responses) and how many of these responses were emergency in nature with sirens and/or air horns operating. The noise data are presented as a percentage of a daily noise dose according to OSHA regulations, which stipulates a maximum daily dose of 100%. If a fire fighter receives less than 100% of a dose during his or her work shift, the employee is within the OSHA exposure limit. If the dose exceeds 100%, then the fire fighter is over-exposed to noise on that particular day according to the OSHA noise standard. Finally, a column labeled "Maximum" is the greatest one minute average dB(A) level recorded for any of the fire fighters assigned to the vehicle on the sampling day. It represents a short-term exposure period indicative of siren noise, air horn noise, or equipment testing noise.

Only Company #2, which used a 1975 diesel-powered Pirsch pumper, exceeded a median noise dose of 50% on each of the days tested. This median value exceeds the NIOSH REL. There was one individual who also surpassed the OSHA noise PEL, with a dose of 118%. The median noise doses for the remaining engine companies, truck companies, and EMS squads were all below the NIOSH and OSHA limits. With only three exceptions, all of the tested companies had at least one emergency response where the vehicle used its warning devices for a period of time. All maximum one-minute noise levels captured with the dosimeters were greater than 90 dB(A). However, there was no instance where the maximum one-minute level exceeded 115 dB(A), which is the OSHA not-to-exceed limit for noise.

C. Audiometry

A total of 90 audiometric examinations and questionnaires were obtained from the approximately 100 HFD fire fighters employed at the time of the survey. Most of the fire fighters who were not tested were either on vacation or had some other scheduling problem which prevented them from reporting to the hearing test location on the audiometric testing days. Only one or two fire fighters declined to volunteer to have their hearing tested. In late 1983 or early 1984, unrelated to the NIOSH evaluation, the city had the hearing ability of the HFD personnel tested by the local health department. The results from the 84 hearing tests were provided to the NIOSH investigator for analysis. Fifty-five of the fire fighters tested in 1983-84 were also tested in March 1990 as part of this HHE. Retirements during the six-year period, along with new hires after early 1984, accounted for the differences in both the overall number and specific persons tested on the two occasions. The hearing tests given by the city varied in the audiometric frequencies that were recorded, with the city's test omitting 3000 Hz and 6000 Hz. The conditions under which the two sets of audiometric tests were performed were most likely comparable in all other respects.

The questionnaire data show that all but one HFD fire fighter is male, with a mean age of 37 years (range = 21 to 55 years of age). Their mean time in service is 12 years, ranging from 1 month to 30 years. For forty-eight percent of the department, fire fighting was the only career the people ever had. Fifty-six percent of the HFD personnel had military experience, most of them for four years. However, only 10 individuals reported having fired a weapon in the service more than 100 days. A review of the fire fighters' hobbies revealed that 31% are hunters and/or shooters, 22% have ridden motorcycles, 42% use a chain saw, 13% have done mechanized farming, 38% use power tools for woodworking, and 18% routinely listen to loud music. Thirty of the 90 respondents reported ear troubles that have been severe enough to visit a physician. Only 17% of the fire fighters reported tinnitus ("ringing in their ears").

The median audiometric test results from each ear of the 90 HFD fire fighters were graphed in order to observe any major differences between the two ears (Figure 11). The median difference is only 5 dB between the left and right ear, with the right ear being consistently the better of the two ears. Because of the small difference, the results from each fire fighter's two ears were averaged for the rest of the analyses.

The distributions of age and time in service were analyzed to organize the audiometric data in groups that were sufficiently large and also fairly equal in size. The resulting age groups are: thirty years of age or less (24 fire fighters), 31-35 years (17), 36-40 years (14), 41-45 years (16), and greater than 45 years of age (19). The groups of fire service time are: 4 years or less (20 fire fighters), 5-9 years (21), 10 -14 years (16), 15-19 years (13), and 20 or more years of service (20). The median hearing levels for the age categories are shown in Figure 12. The data are characterized by a sloping high-frequency loss of hearing from 2000 Hz to 6000 Hz, with a slight improvement at 8000 Hz. This pattern is indicative of noise-induced permanent threshold shifts. The oldest group of fire fighters exhibits the poorest hearing ability. However, in the younger groups, there is no clear relationship between age and degree of high frequency hearing loss. A steady, age-related increase in hearing loss is not apparent in these data. Similar findings are seen when the audiometric data are analyzed by length of fire service (Figure 13). A high-frequency loss of hearing is also seen in these data, with the fire fighters with the most service time exhibiting the greater losses. There is, however, a more consistent pattern of increasing hearing loss over time in service, at least for the two most senior groups, particularly at 3000 and 4000 Hz.

In order to see if the HFD fire fighters were exhibiting a change in hearing between 1984 and 1990, the data from the 55 fire fighters who were tested both times were evaluated. Each fire fighter's hearing levels at 500, 1000, and 2000 Hz were averaged in order to investigate changes in lower frequency hearing, which is less susceptible to change from noise exposures. A high-frequency indicator of noise insult was also analyzed, but the 1984 test's omission of 3000 and 6000 Hz made it impossible to use an average score. Therefore, the change in hearing between 1984 and 1990 at the 4000 Hz test frequency was compared. The mean hearing level for the lower frequency average was found to be 10.0 dB on the first test and 8.0 dB on the second test, an average improvement for the group of 2 dB. For the higher single-frequency comparison (4000 Hz), the mean hearing level was 21.0 dB on the first audiometric test and 24.0 dB on the second test. A *t*-test for two matched samples was used to see if the changes in the hearing levels from the first hearing test to the second hearing test were statistically significant. This analysis found significant changes for both the low-frequency average ($t = -3.896$, $p = 0.0003$) and for the 4000 Hz audiometric test frequency ($t = 2.965$, $p = 0.0045$). A third statistical analysis looked at each individual fire fighter's hearing change on the two tests at the low-frequency average and compared it to the amount of change for the high frequency, thus making each fire fighter his own control in the analysis. This latter difference was also found to be statistically significant ($t = 5.217$, $p = 0.0001$).

VII. DISCUSSION

The full-shift dosimeter survey of the HFD revealed that noise exposures were consistently less than 100% of the OSHA permissible limit. There was only one fire fighter assigned to Company #2 who had a dose greater than 100% for his 24-hour shift. Company #2 was also the only fire station surveyed that had a median dose greater than 50%, the NIOSH REL, for both days. The other nine engine, truck, and EMS companies and squads had noise dose values of less than 50%. Similar results have been found in other fire departments that have conducted noise dosimeter surveys.[10-12]

The rank ordering of engine company noise doses has the two Pirsch diesel-powered pumpers at the high end of the list. The spectral data from these vehicles also reveals very high sound energy at the 125 Hz third-octave band that comes from the engines. Indeed, the noise from the Pirsch diesel engine was so intense that there were several instances where the NIOSH investigator was unable to hear the siren while riding in the jumpseat. The next highest noise doses were seen on fire fighters assigned to the Ford E-One pumper, a result of the electronic siren speakers being mounted in a light bar on the roof of the vehicle. Siren noise could easily enter the cab and jumpseat because of this configuration. Because of these potential high exposures from the department's vehicles, the HFD began to issue ear muffs to fire fighters to wear whenever they rode the vehicles. This was done shortly before the NIOSH evaluation.

The audiometric data obtained during the NIOSH survey represent nearly 90% of the entire department. Additionally, over half of this same group had a previous hearing test that could be compared directly to the test performed as part of the NIOSH HHE. The NIOSH data seem to indicate that the fire fighters have been exposed to excessive noise levels during their lifetime. The data are characterized by a progressive loss of hearing at 3000, 4000, and 6000 Hz, as the time in service as a fire fighter increases. The statistical comparisons of the earlier hearing tests with the NIOSH data further indicate that this group of individuals has continued to lose hearing over the six-year period between the two tests. The finding that the group of 55 fire fighters had significant apparent improvement of low frequency hearing levels, which is most likely the result of learning to take this type of test and not a real improvement in hearing, while showing significant hearing loss at the noise sensitive 4000 Hz test frequency is strong evidence of an occupational noise loss. The mean differences between the hearing tests for the group are not great, being in the range of 3-5 dB. If one were to report such changes for an individual fire fighter, this difference would not cause alarm. However, the finding of significant losses for such a large percentage of the HFD is important. If this relationship of 5 dB of hearing loss for every six years of service were to continue, then a linear interpolation of the data would predict a 25 dB work-related hearing loss after a thirty-year career. Similar associations between hearing loss and time spent on the job as a fire fighter have been previously reported.[10-13]

VIII. CONCLUSION

The hearing data for approximately 90% of the department show a hearing pattern that is consistent with excessive exposures to noise. The additional finding of continued, significant hearing losses for high-frequency sounds over a relatively short six-year span for a large group of the fire fighters also adds evidence to this conclusion. The sound energy emitted by the vehicles was measured at levels high enough to be damaging to hearing. The dosimeter results revealed that the two companies with the loudest vehicles did have the potential to exceed existing evaluation criteria for noise, with the OSHA PEL being exceeded in one 24-hour period and the NIOSH REL equaled or exceeded in four instances. Thus, the environmental data, in conjunction with the audiometric data, suggest an occupational health hazard to the hearing of the HFD personnel.

IX. RECOMMENDATIONS

The results of the health hazard evaluation at the HFD reveal a risk for occupational hearing losses to fire fighters in the department. Although sensori-neural hearing loss is generally irreversible, additional loss of hearing from exposure to excessive noise can be prevented. The following recommendations are offered to help reduce the amount of noise to which the fire fighters are exposed and to set up surveillance programs to track the hearing ability of current and future fire fighters in order to implement changes to reduce the hearing losses associated with their jobs.

1. The HFD should implement a complete hearing conservation program for their department. The HFD has started some portion of a hearing conservation program with the issuance of ear muffs and the examination of fire fighters' hearing on one earlier occasion. However, a written program should be instituted with all aspects of it attended to on a periodic basis. At a minimum, the program should follow all of the requirements of the OSHA hearing conservation amendment, including noise monitoring, audiometric testing, hearing protection, training, and recordkeeping.[3] Additional guidelines for an effective hearing conservation program are contained in a NIOSH technical report.[14]

2. Some of the highest noise exposures experienced by the HFD fire fighters were observed during the use of their vehicles. The continued use of hearing protection

devices (HPDs) during this activity will greatly reduce fire fighters' noise exposures. A large number of alternative HPDs are available on the market. Ear plugs, as well as ear muffs, have been successfully used in fire departments. However, because of the time constraints associated with an emergency response run, it is more practical to use ear muffs because of their relative ease in fitting in a short time period. Communication systems with noise-blanking microphones and speakers placed in ear muffs have been developed to connect with fire department radio systems. The NIOSH investigator has seen these in use in several fire departments, including Sacramento, California, and Phoenix, Arizona, as well as in air ambulance services. Recently, an active noise-controlling ear muff that creates a destructive noise to reduce the wearer's exposure has been introduced in the U.S. and marketed as a way to lower noise in emergency medical service vehicles. This latter device is relatively new and expensive.

3. The audiometric data from the hearing conservation program should be analyzed by methods proposed by an American National Standards Institute (ANSI) working group concerned with audiometric database analyses.[15] The analysis techniques have been evaluated by hearing conservation investigators who have reported success in their use.[16-19] The techniques allow a hearing conservationist to identify groups of employees that may need further help in preventing hearing losses through the analysis of group audiometric data, rather than each individual's hearing tests, which are not as sensitive an indicator of a hearing conservation program problem. Small changes over a short period of time can be investigated in order to ascertain, for example, if different kinds of hearing protection are appropriate or if fire fighters assigned to a particular fire vehicle or fire station are exhibiting hearing losses that are changing more rapidly than other members of the department. The use of these techniques may allow for intervention into the problem quicker than if individual hearing tests are evaluated solely in a routine doctor/patient relationship and consultation.

4. The mechanical siren in use by the HFD generates the warning signal by rapidly turning a wheel inside of the siren's housing. The circular housing has several slots cut in the perimeter to allow the warning sound to escape. When this type of siren is placed on the left fender or left side of the front bumper of the fire vehicle, much of the sound energy is directed back to the driver's side window. A recently reported study by the Liberty Mutual Insurance Group describes an engineering control that incorporated a shroud installed on the siren to redirect the sound in a forward direction. The siren was also moved to the center of the front bumper. The report states that a 70% reduction in the sound pressure levels occurred as a result of the change.[20] The HFD should consider applying this type of engineering control to their mechanical sirens.

5. The spectral data for the Ford E-One pumper revealed high mid-frequency noise levels from the roof-mounted light bar and siren speaker. Alternate locations for the speakers on this vehicle, in the front grille or under the front bumper, should be investigated by the vehicle maintenance department. Locating the speakers under the front bumper has been observed by NIOSH investigators in Anaheim, California and Pittsburgh, Pennsylvania where the practice is used with some success.

6. Engine noise was a major source of exposure to the fire fighters during emergency response runs. It was especially evident in vehicles that were configured with the engine located behind the cab and between the jumpseat riding positions. The use of a metalicized blanket over the engine cowling has been observed by the NIOSH investigator at the Anaheim, California Fire Department to reduce the noise that is directed to fire fighters riding in the jumpseats. It also helps to reduce the heat generated by the engine, which was mentioned as a concern by fire fighters, during periods of hot weather. This kind of engineering control needs to be investigated with the manufacturers of the vehicles to make sure that heat build-up in the engine does not become a problem. Additional venting of the air around the engine, which will also redirect the noise output, can be pursued by the vehicle maintenance department.

7. The use of noise absorption materials on hard surfaces of the fire vehicles will reduce reverberant noise exposures to the personnel on the vehicles. The older vehicles still used by the HFD can have this kind of material added to the hard surfaces. Newer vehicles may already use this kind of noise control. In either case, a maintenance program that monitors the integrity of the sound absorption materials needs to be implemented. These materials will deteriorate over time in the harsh environments that the fire vehicles encounter. They need to be replaced when they become torn or brittle.

8. The engineering controls which have been contemplated by the HFD for the diesel-powered Pirsch vehicles should be pursued. Particular attention should be made to the installation of mufflers which are maximally effective in the 125 Hz range. The vehicle manufacturer or muffler manufacturers should be consulted in this endeavor. The technology of active noise control muffler systems is now becoming available in the marketplace and should be investigated by the department's maintenance personnel.

9. Noise controls that the vehicle manufacturer provides should be included in future vehicle purchases. The potential for the success of this recommendation is seen in the specifications for noise reduction that were included in the purchase of Squad

#1. The acoustical undercoating, grille-mounted siren speakers, and other noise reduction requirements written into the specifications for the EMS squad resulted in a quieter vehicle. Several makers of pumpers and trucks also advertise noise control as one of their features. Maximum noise levels for specific operations should be spelled out in the performance specifications for the purchase of all new vehicles and equipment. The NFPA guidelines for maximum noise levels are appropriate specifications to which the department can refer manufacturers.[21]

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XII. DISTRIBUTION AND AVAILABILITY

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Copies of this report have been sent to:

1. Fire Chief, Hamilton Fire Department
2. Local #20, International Association of Fire Fighters
3. City Manager, Hamilton, Ohio
4. Department of Health & Safety, International Association of Fire Fighters
5. OSHA, Region V

For the purpose of informing affected employees, copies of this report shall be posted by the employer in a prominent place accessible to the employees for a period of 30 calendar days.

Table 1

Vehicle Descriptions

Hamilton Fire Department
Hamilton, Ohio
HETA 89-026

COMPANY	MAKE	YEAR	ENGINE	WARNING DEVICES
Engine #1	Sutphen Pumper	1986	Diesel	Federal Signal Q: Center above bumper Federal Signal PA200: (not used) Roof Air Horn
Engine #2	Pirsch Pumper	1975	Diesel	Federal Signal Q: Center above bumper Dual Roof Air Horns
Engine #4	Pirsch Pumper	1966	Gasoline	Federal Signal Q: Left side bumper Roof Air Horn
Engine #5	Pirsch Pumper	1976	Diesel	Federal Signal Q: Center above bumper Roof Air Horn
Engine #6	E-One Pumper	1981	Diesel	Federal Signal Q: (not used) Federal Signal PA 200: Roof light bar speakers Dual Roof Air Horns
Engine #7	Pirsch Pumper	1970	Gasoline	Federal Signal Q: Left side bumper Roof Air Horn
Truck #9	Pirsch Ladder	1974	Diesel	Federal Signal Q: Center above bumper Dual Roof Air Horns
Truck #10	Seagrave Aerial	1986	Diesel	Federal Signal Q: Center above bumper Federal Signal PA200: Roof light bar speakers Dual Roof Air Horns
Squad #1	Ford	1988	Diesel	Federal Signal PA200: Recessed grille speakers
Squad #2	Ford	1985	Gasoline	Federal Signal PA 170: Roof light bar speakers

TABLE 2 (Page 1 of 2)

Number of Responses, Maximum Levels, and Median Noise Doses for the Surveyed Vehicles

Hamilton Fire Department
Hamilton, Ohio
HETA 89-0026
June, 1990

Company No.	Date	Responses	Maximum	24-HOUR DOSE (Range)
#1	6/19/90	3 (1)	99	18.7 %
#1	6/20/90	2 (1)	91	11.8 % (10.6 - 13.0 %)
#2	6/25/90	5 (2)	110	52.2 %
#2	6/26/90	13 (10)	113	64.4 % (55.6 - 118.4 %)
#4	6/19/90	1 (0)	98	23.2 % (21.7 - 24.5 %)
#4	6/20/90	5 (3)	103	22.8 % (16.8 - 22.9 %)
#5	6/25/90	6 (3)	107	30.4 % (26.4 - 50.2 %)
#5	6/26/90	7 (7)	105	40.9 % (37.7 - 43.6 %)
#6	6/28/90	5 (2)	111	36.8 % (30.9 - 40.5 %)
#6	6/29/90	6 (1)	98	38.4 % (36.3 - 40.4 %)

Note: Responses represents the number of occurrences where the vehicle left the station. Those which were emergency responses are enclosed in parentheses.

Maximum is the highest one minute average recorded for any one fire fighter assigned to a vehicle.

Dose is the percentage of a daily allowable noise exposure according to OSHA regulation. A dose of 100 % is the maximum allowed for a day. The range of Dose values is given in parentheses when more than one full-shift dosimeter sample was obtained.

TABLE 2 (Page 2 of 2)

Number of Responses, Maximum Levels, and Median Noise Doses for the Surveyed Vehicles

Hamilton Fire Department
Hamilton, Ohio
HETA 89-0026
June, 1990

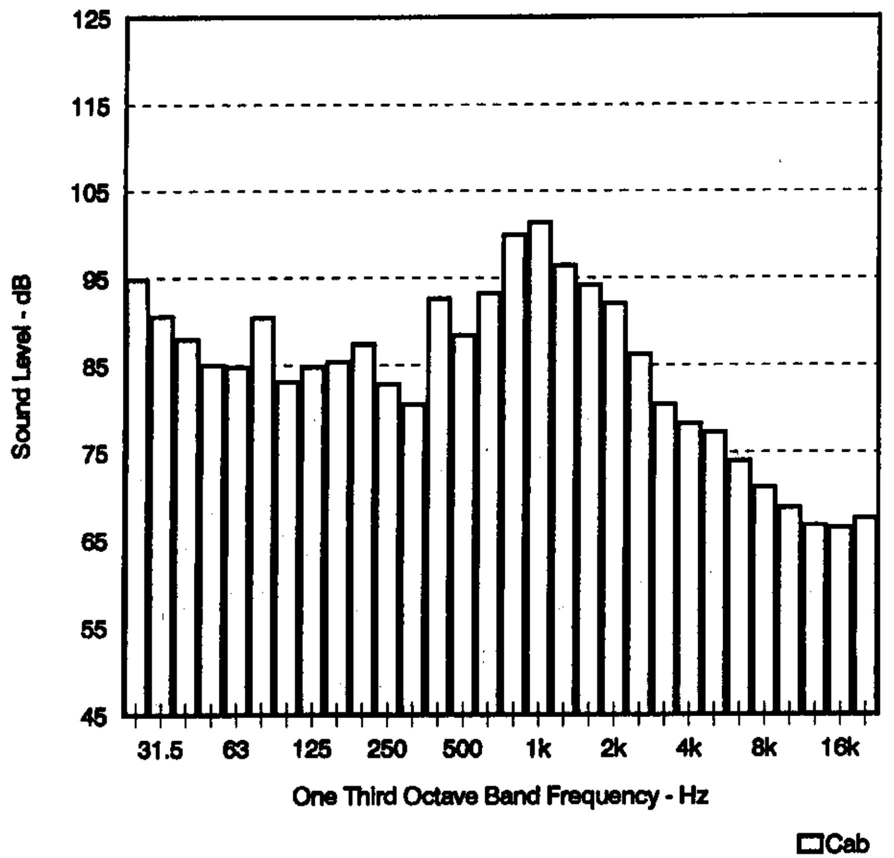
Company No.	Date	Responses	Maximum	24-HOUR DOSE (Range)
#7	6/28/90	1 (0)	101	14.4 % (13.7 - 19.6 %)
#7	6/29/90	4 (3)	109	31.4 % (31.3 - 38.7 %)
#9	6/28/90	1 (0)	89	23.0 %
#9	6/29/90	2 (1)	110	38.8 %
#10	6/26/90	5 (4)	103	49.3 %
Squad #1	6/25/90	11 (10)	91	23.9 % (21.8 - 26.0 %)
Squad #1	6/26/90	9 (9)	98	32.2 % (26.0 - 38.3 %)
Squad #2	6/19/90	8 (8)	98	35.8 % (24.5 - 42.2 %)
Squad #2	6/20/90	4 (4)	99	21.3 %

Note: Responses represents the number of occurrences where the vehicle left the station. Those which were emergency responses are enclosed in parentheses.

Maximum is the highest one minute average recorded for any one fire fighter assigned to a vehicle.

Dose is the percentage of a daily allowable noise exposure according to OSHA regulation. A dose of 100 % is the maximum allowed for a day. The range of Dose values is given in parentheses when more than one full-shift dosimeter sample was obtained.

Figure 1
One-Third Octave Band Sound Levels
1986 Sutphen Diesel Engine #1
HAMILTON FIRE DEPARTMENT
HETA 89-0026



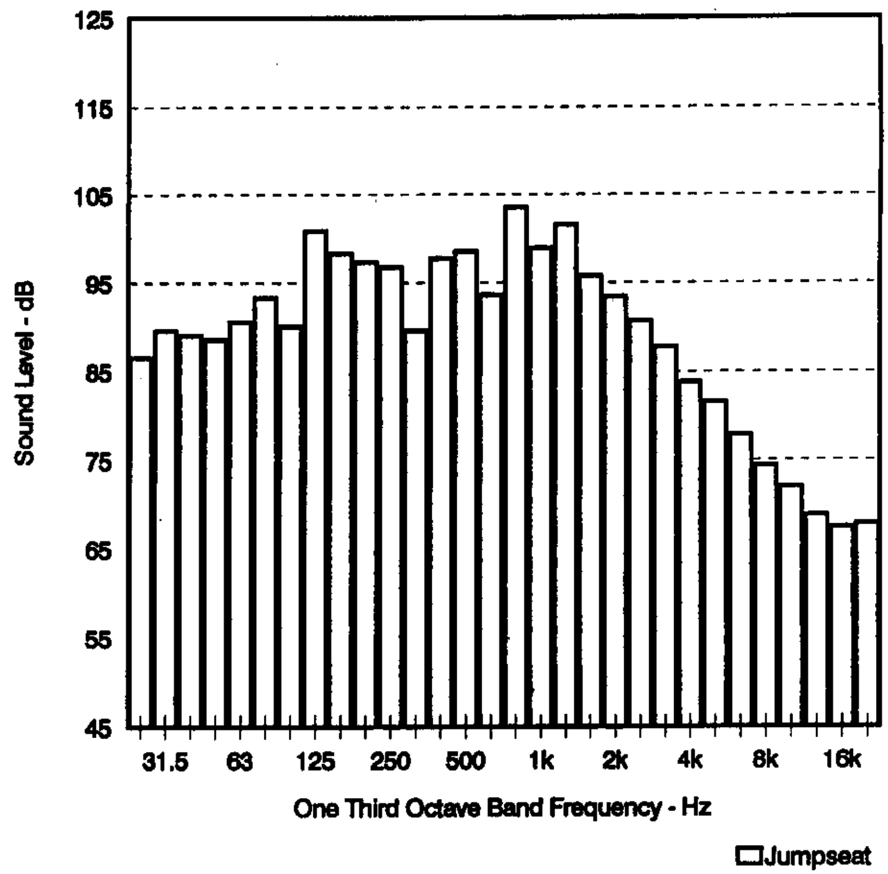


Figure 2
One-Third Octave Band Sound Levels
1975 Pirsch Diesel Engine #2
HAMILTON FIRE DEPARTMENT
HETA 89-0026

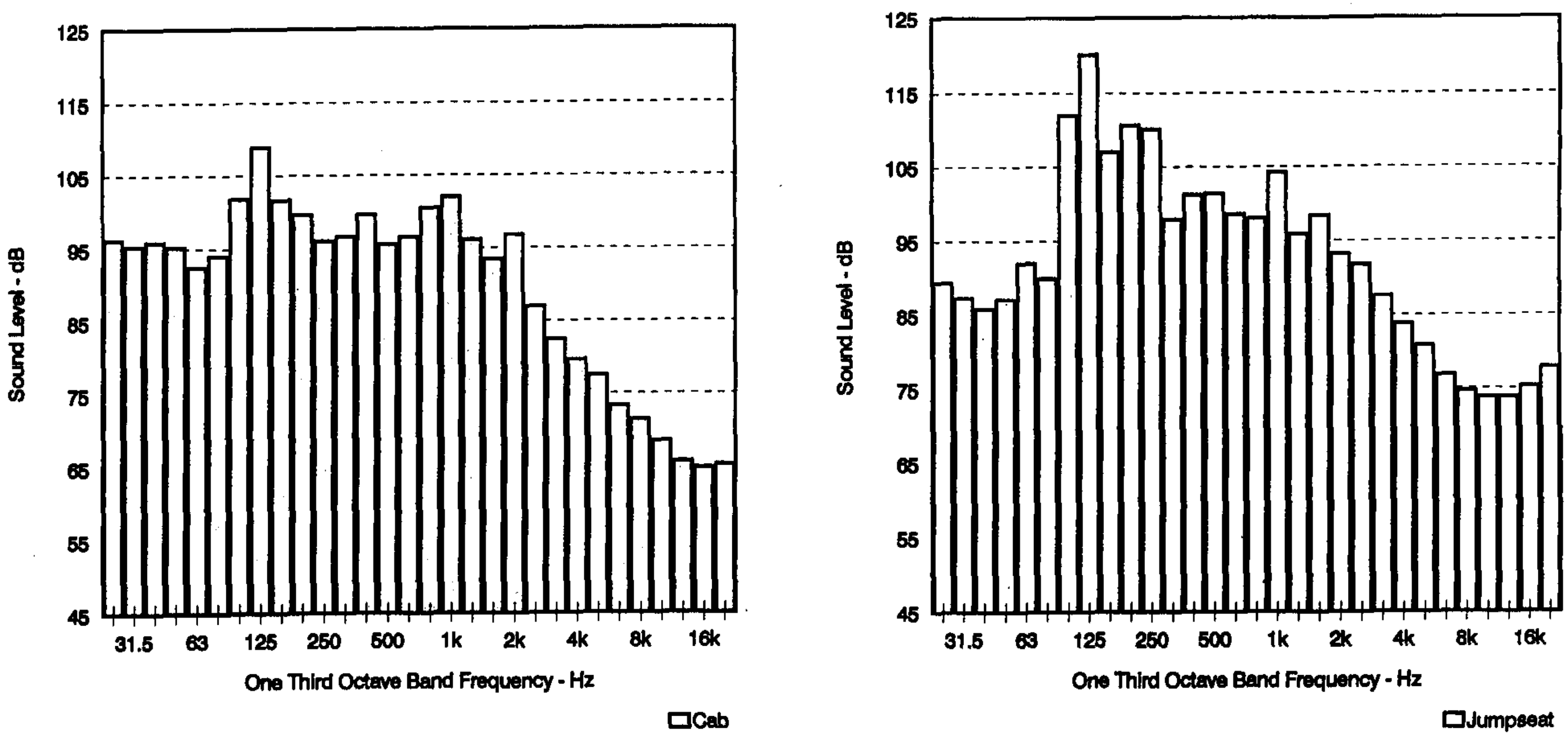
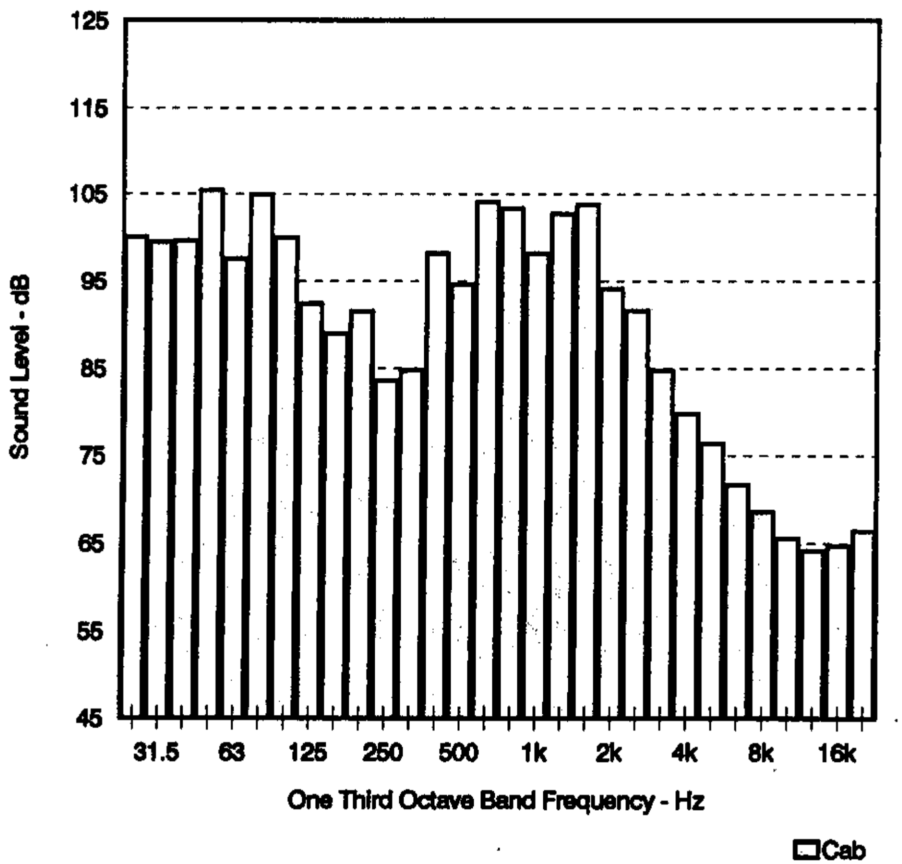


Figure 3
One-Third Octave Band Sound Levels
1966 Pirsch Gasoline Engine #4
HAMILTON FIRE DEPARTMENT
HETA 89-0026



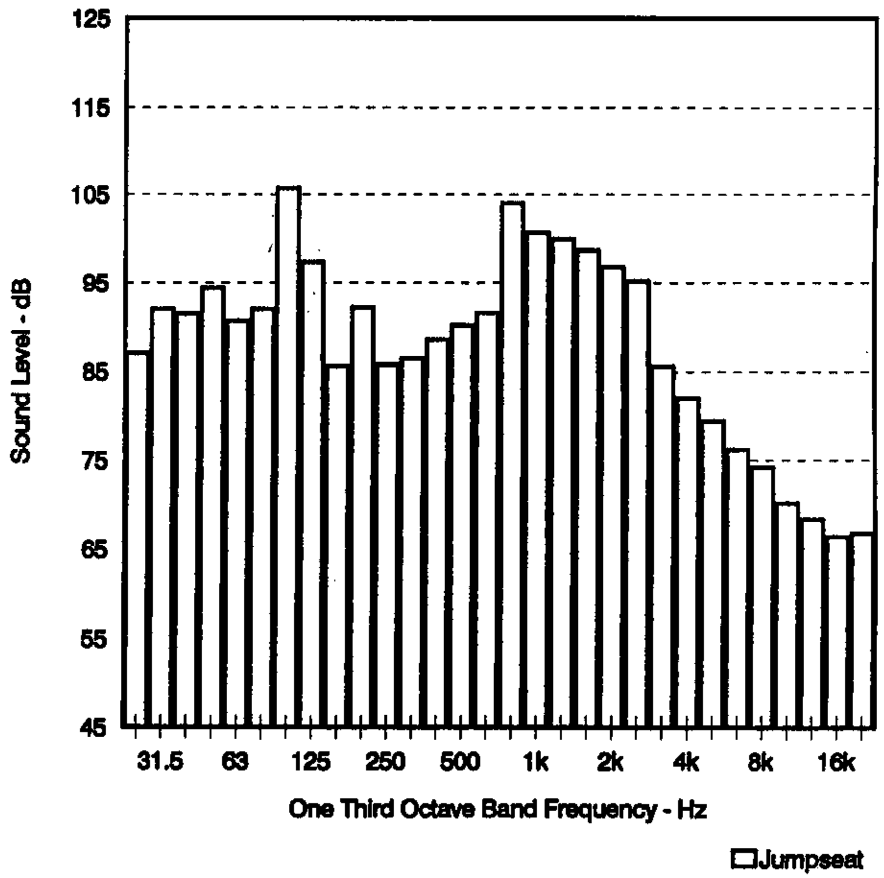
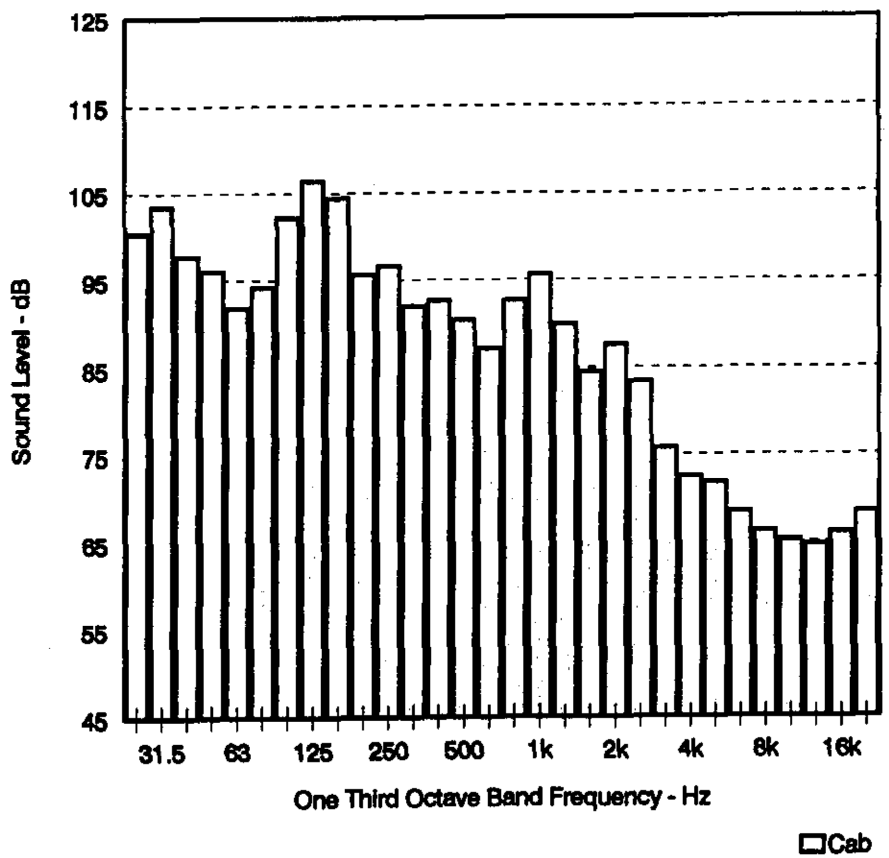


Figure 4
One-Third Octave Band Sound Levels
1976 Pirsch Diesel Engine #5
HAMILTON FIRE DEPARTMENT
HETA 89-0026



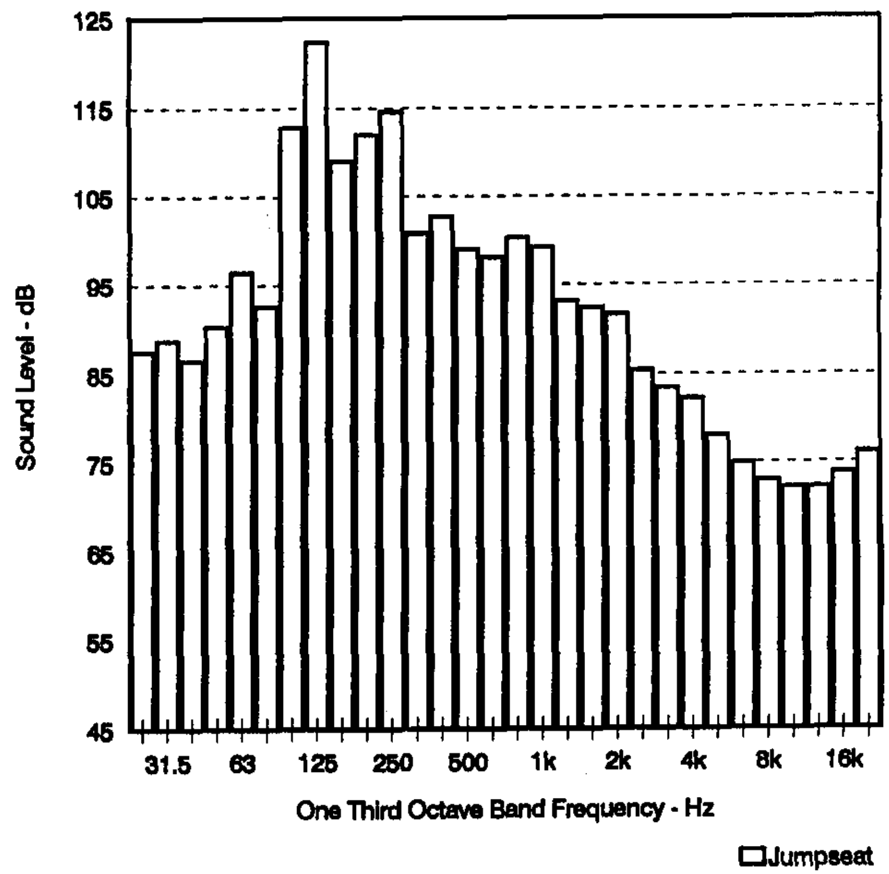
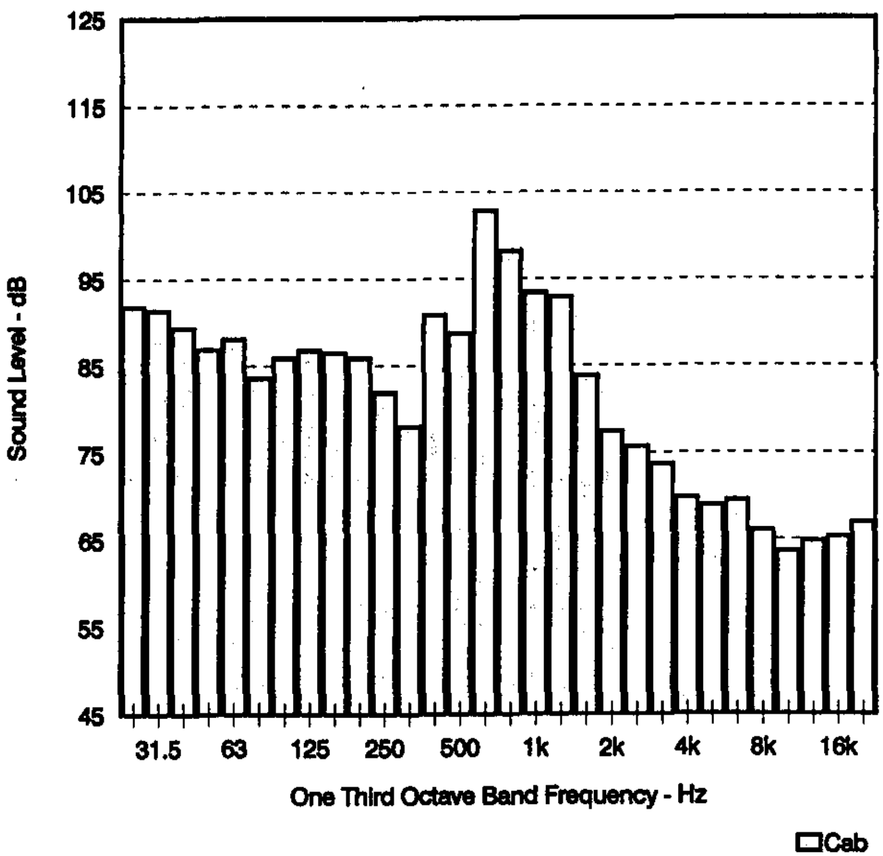


Figure 5
One-Third Octave Band Sound Levels
1981 Ford E-One Diesel Engine #6
HAMILTON FIRE DEPARTMENT
HETA 89-0026



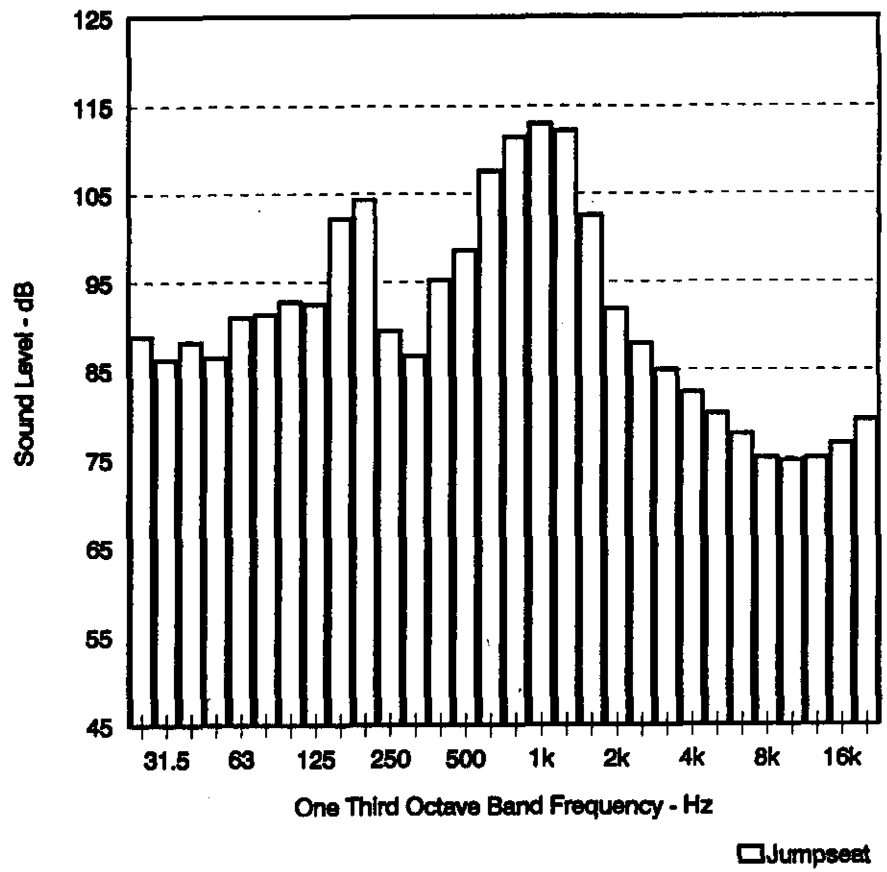
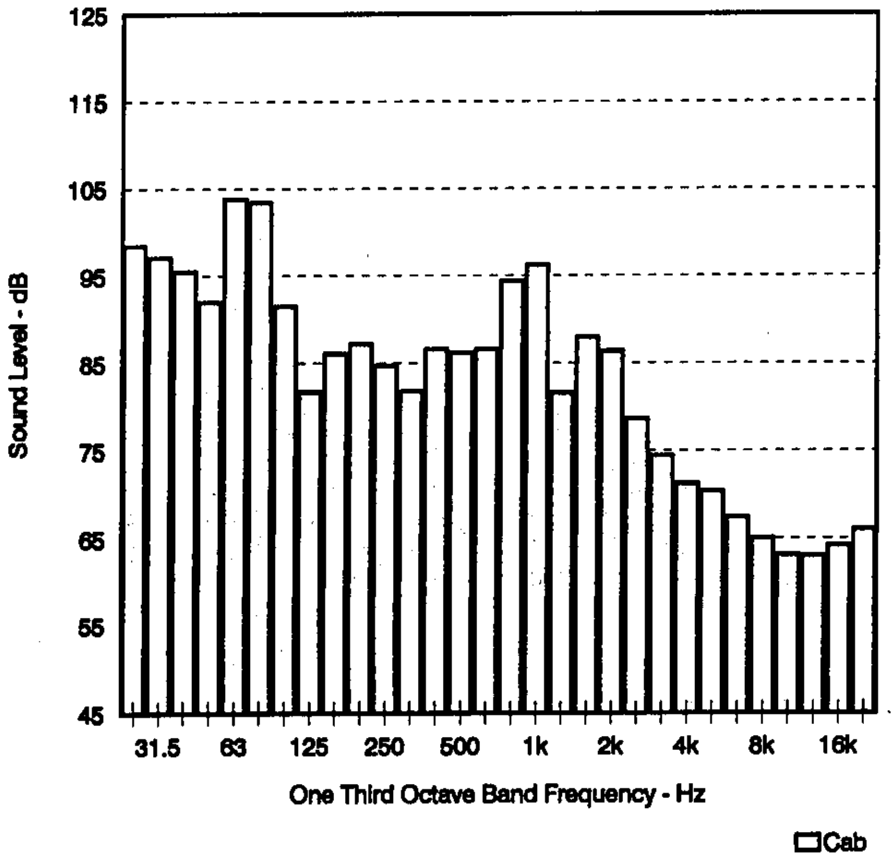


Figure 6
One-Third Octave Band Sound Levels
1970 Pirsch Gasoline Engine #7
HAMILTON FIRE DEPARTMENT
HETA 89-0026



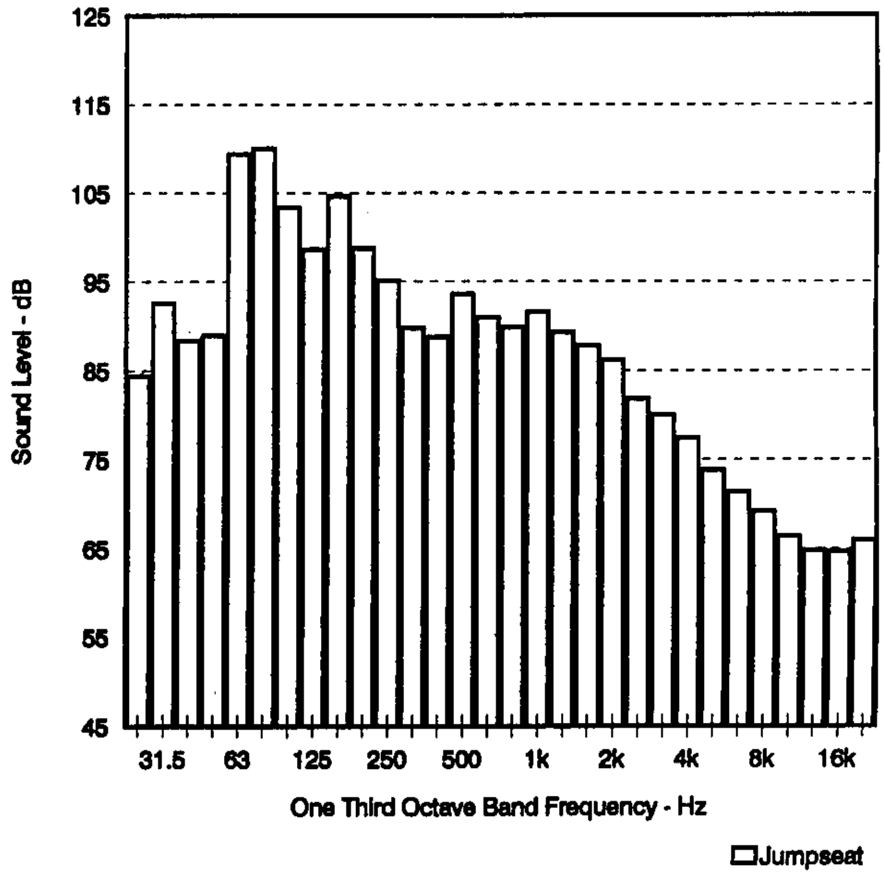
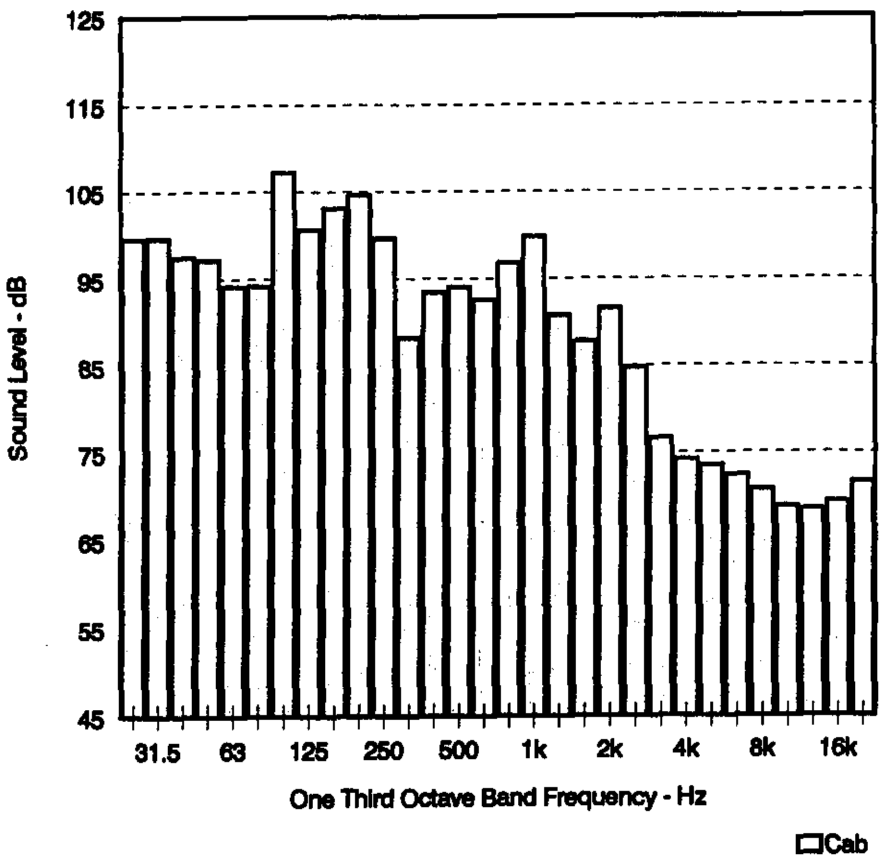


Figure 7
One-Third Octave Band Sound Levels
1974 Pirsch Diesel Engine Ladder Truck #9
HAMILTON FIRE DEPARTMENT
HETA 89-0026



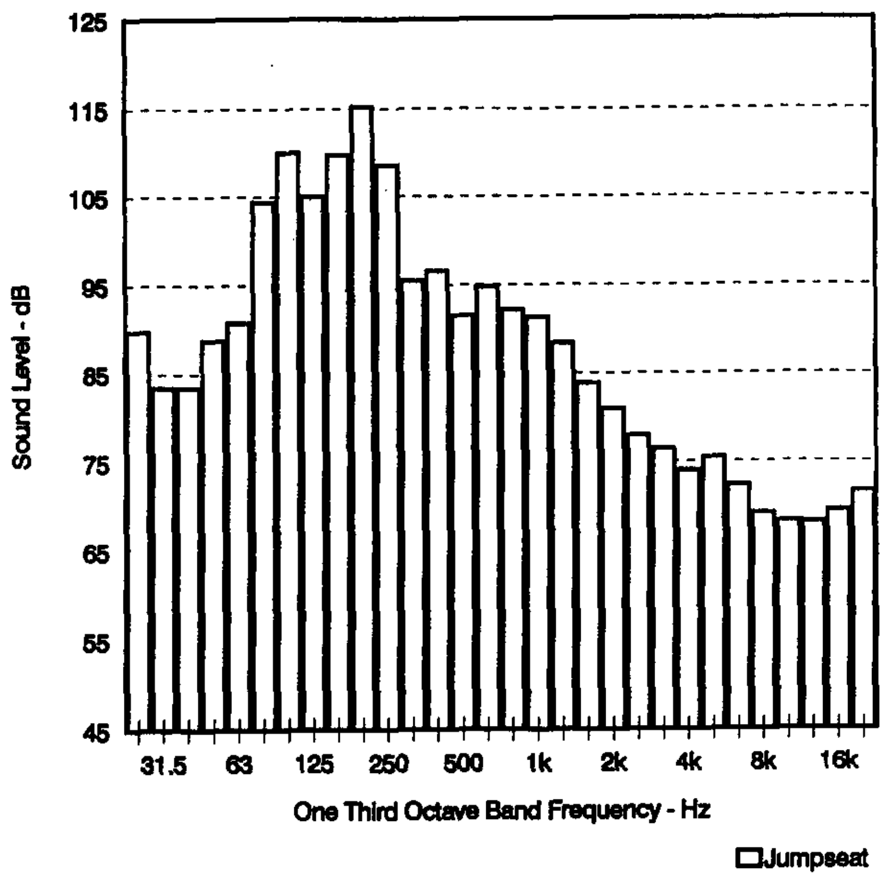
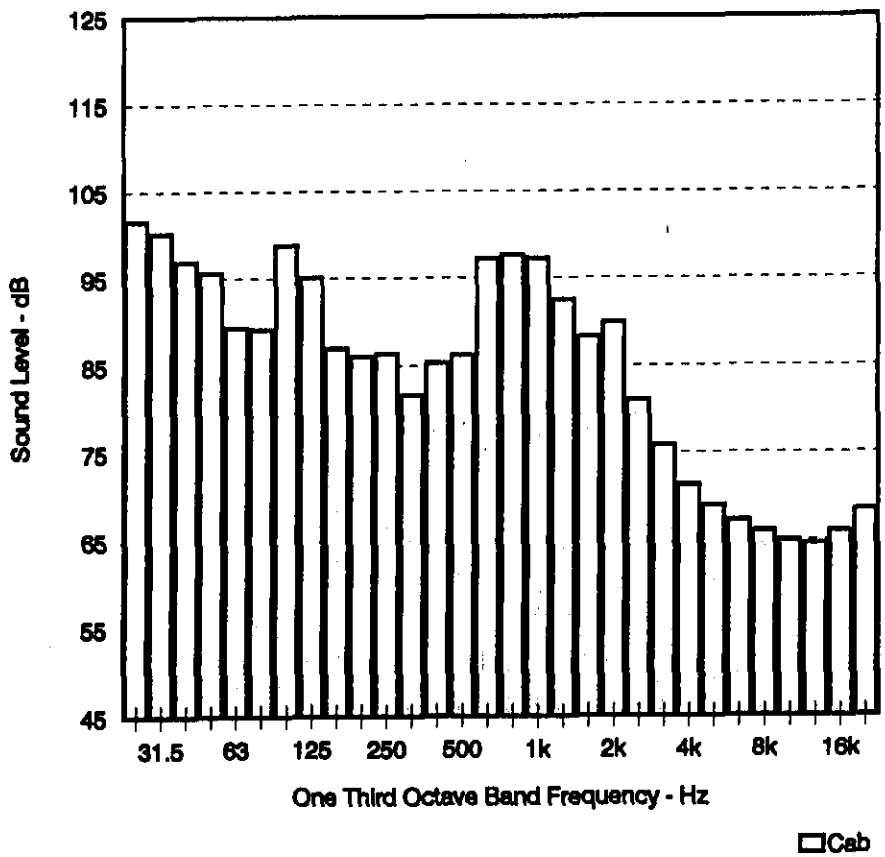


Figure 8
One-Third Octave Band Sound Levels
1986 Seagrave Diesel Engine Aerial TruckL#10
HAMILTON FIRE DEPARTMENT
HETA 89-0026



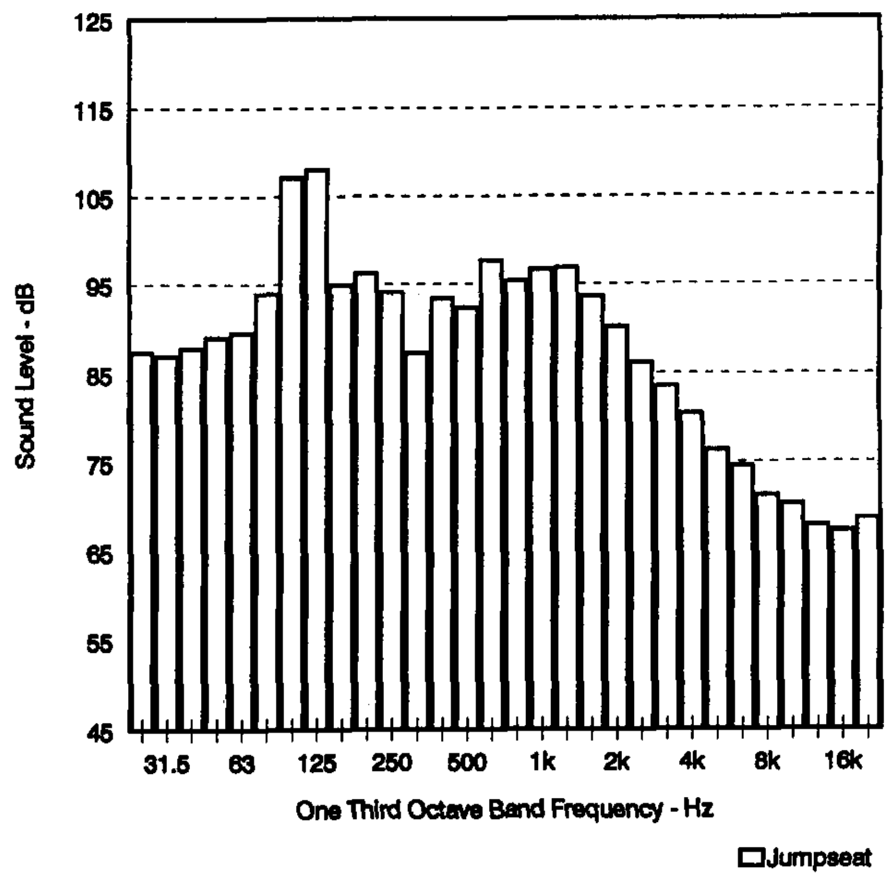


Figure 9
One-Third Octave Band Sound Levels
1988 Ford Diesel Engine Squad #1
HAMILTON FIRE DEPARTMENT
HETA 89-0026

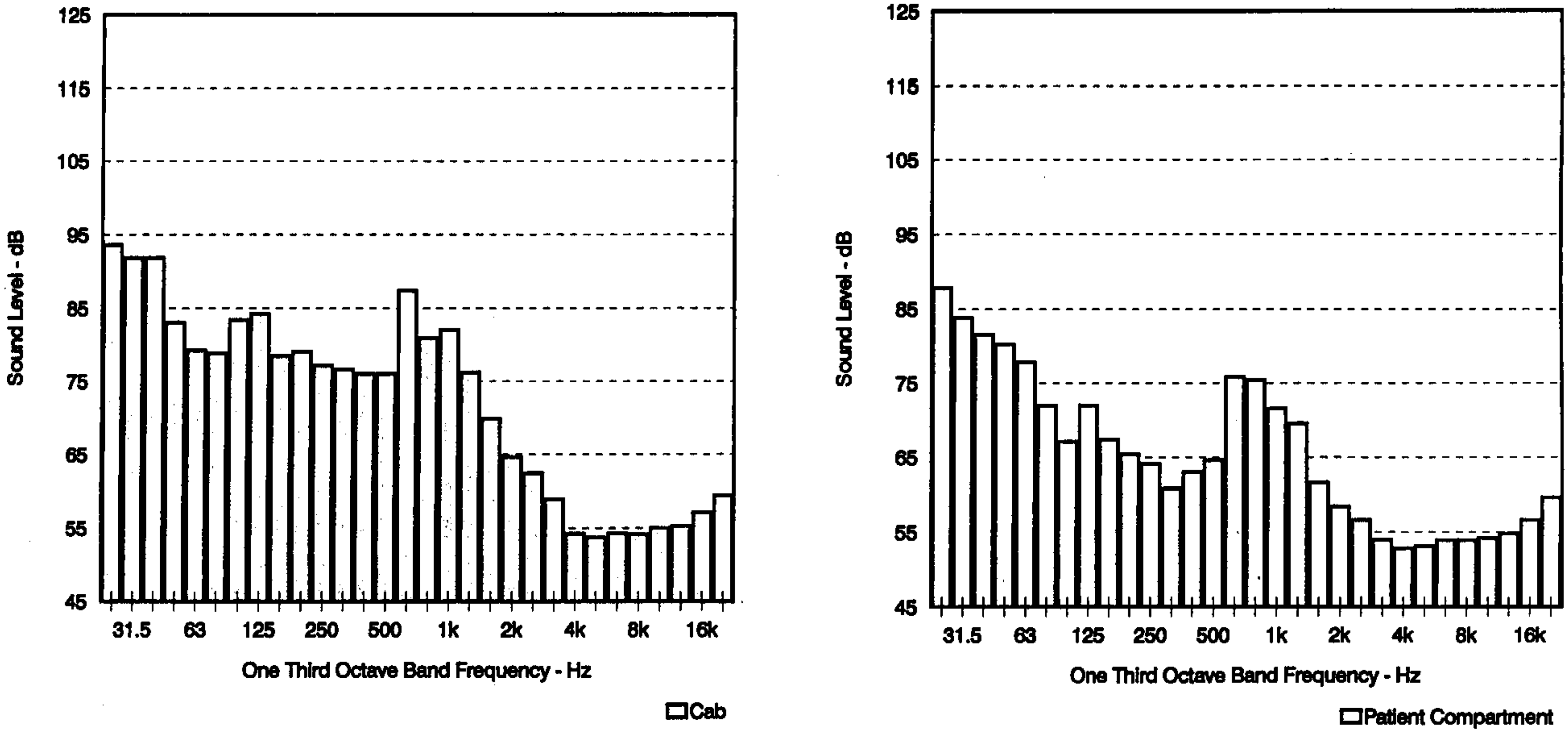
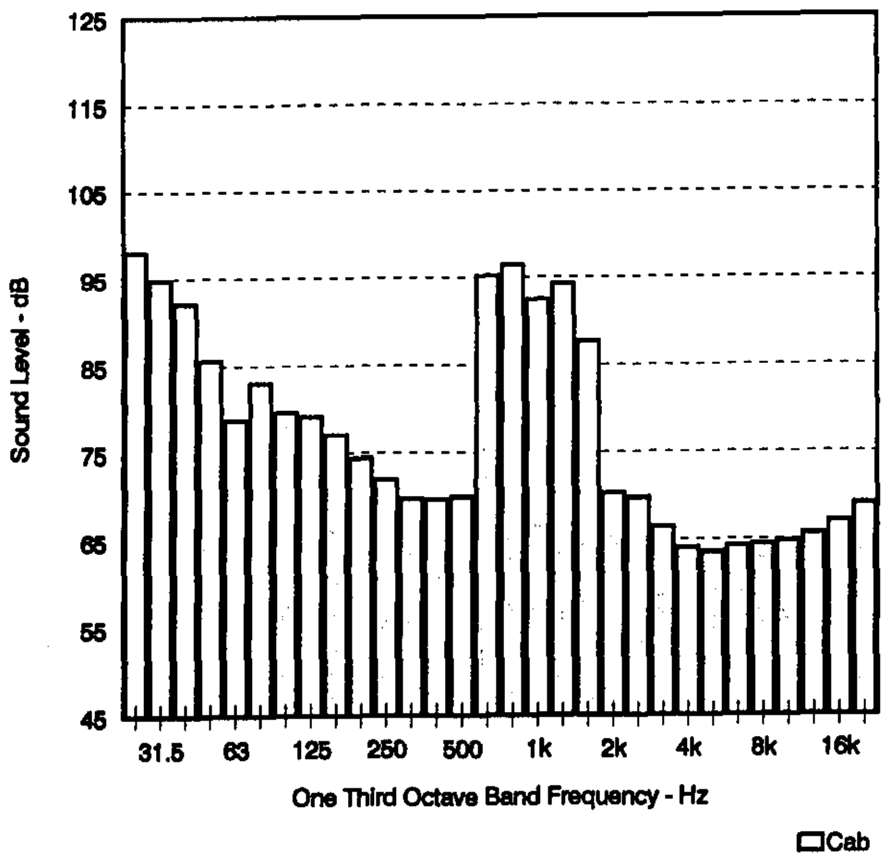


Figure 10
One-Third Octave Band Sound Levels
1985 Ford Gasoline Engine Squad #2
HAMILTON FIRE DEPARTMENT
HETA 89-0026



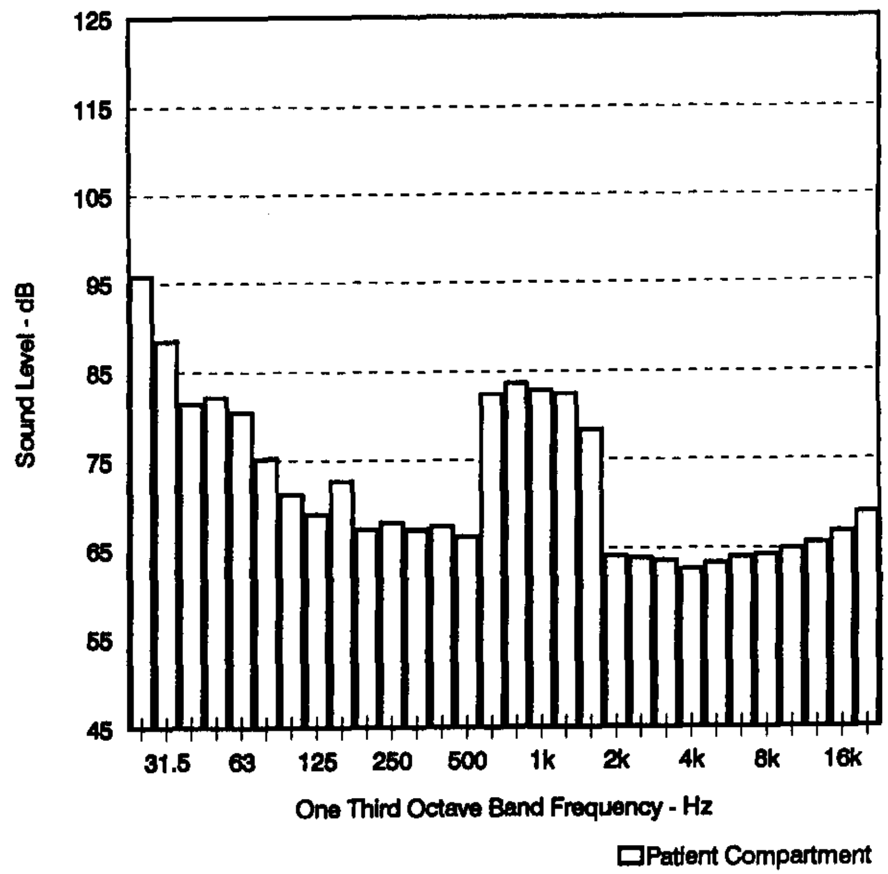


Figure 11
Median Hearing Levels by Test Ear
Hamilton Fire Department
HETA 89-0026

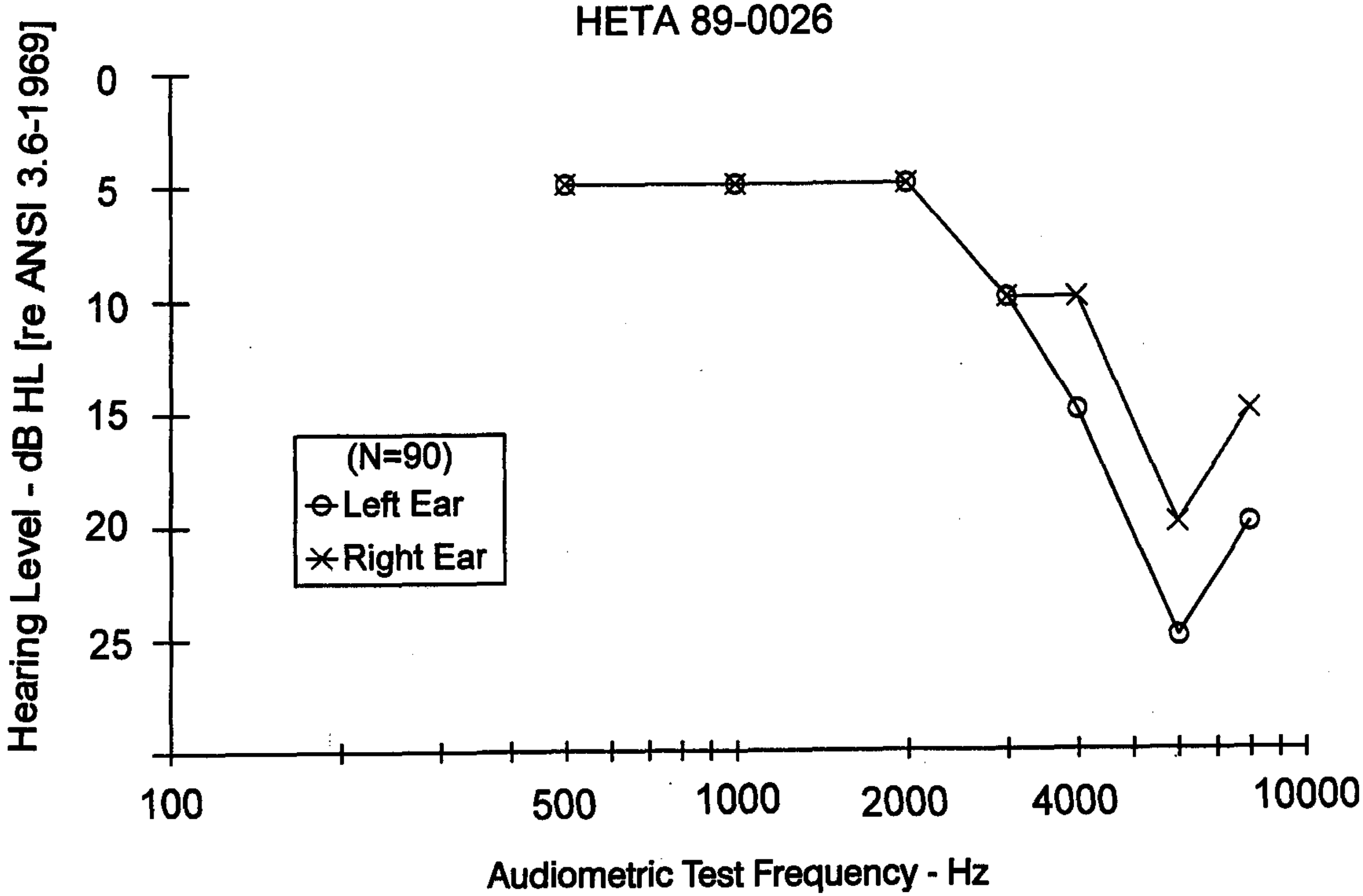


Figure 12
Median Hearing Levels by Age
Hamilton Fire Department
HETA 89-0026

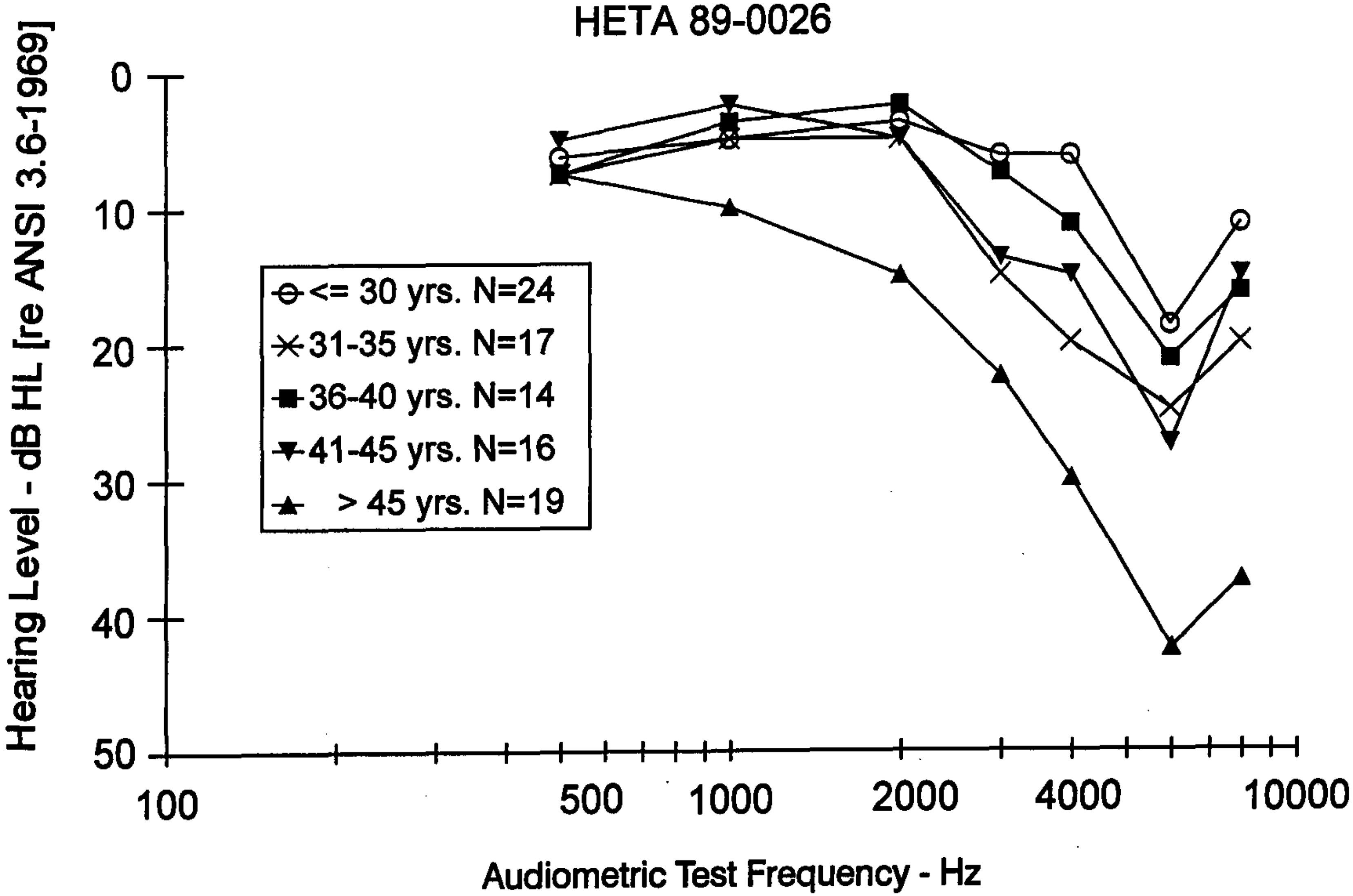
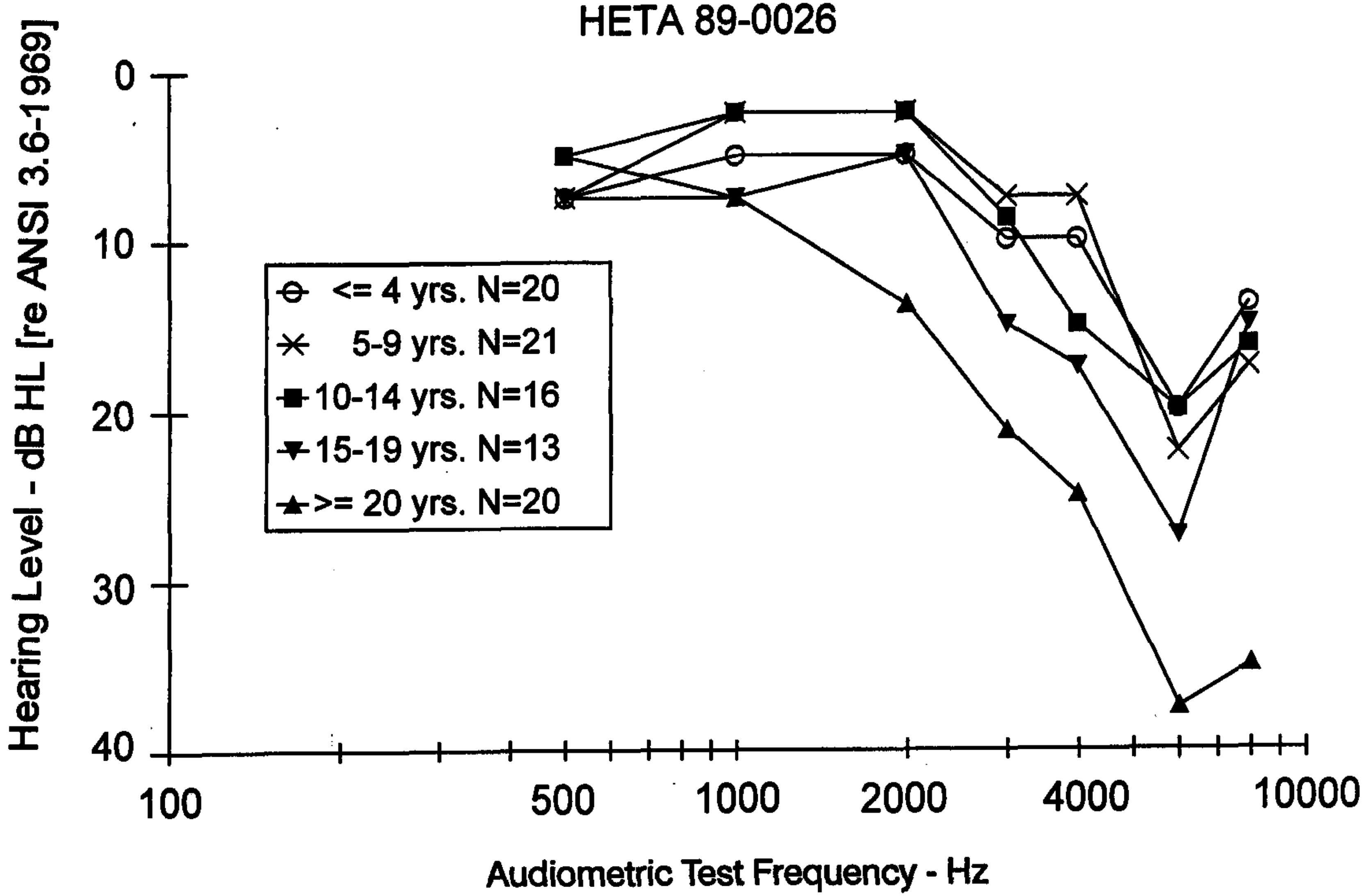


Figure 13
Median Hearing Levels by Years of Service
Hamilton Fire Department
HETA 89-0026



APPENDIX 1

Voluntary Consent Form and Job History Questionnaire

DEPARTMENT OF HEALTH AND HUMAN SERVICES
PUBLIC HEALTH SERVICE
CENTERS FOR DISEASE CONTROL AND PREVENTION
NATIONAL INSTITUTE FOR OCCUPATIONAL SAFETY AND HEALTH

CONSENT TO PARTICIPATE IN A MEDICAL STUDY

PROJECT TITLE:

HETA #:

PURPOSE:

I, ________________________________, agree to participate in this study.
(Please Print)
The procedures have been discussed with me, and I have been given a copy of this consent form. I understand that:

1. I will be asked questions about work history, noisy activities, and medical symptoms. I will also be given a hearing test which checks my ability to hear different sounding tones.

2. In the unlikely event of physical injury resulting from participation in this study, NIOSH will only be able to provide emergency treatment. Any compensation for medical care or lost wages will have to be obtained under the Federal Tort Claims Act (28 USC 1346 (b)).

3. Except as stated under provisions of the Privacy Act (PL 93-579), no information that I furnish for this study can be disclosed in a manner which will identify me unless I give written permission.

4. My participation is voluntary, and I may withdraw from the study at any time without prejudice to myself.

5. Any questions I have regarding this study should be directed to the project officer, Dr. Randy L. Tubbs, Hazard Evaluations and Technical Assistance Branch, Mail Stop R-11, 4676 Columbia Parkway, Cincinnati, Ohio 45226, telephone (513) 841-4374.

PARTICIPANT'S SIGNATURE ________________________DATE__________

MAILING ADDRESS: ____
(Please Print)

____

____

PROJECT OFFICER'S SIGNATURE ____________________DATE__________

HAMILTON FIRE DEPARTMENT
HETA 89-0026

FIRE FIGHTER'S SERVICE QUESTIONNAIRE

(leave blank) ID# ______________

1. NAME: ____

2. ADDRESS: ____
(Street)

________________ _____________ ____________
(City) (State) (Zip)

3. AGE: _______ (Years) DATE OF BIRTH: _____ _____ _____ (Mon) (Day) (Yr)

4. SEX: _______

5. HOW LONG HAVE YOU BEEN A FIRE FIGHTER?: ___________________

CURRENT ASSIGNMENT

6. STATION ASSIGNED: ___________ 7. HOW LONG: ___________

8. JOB CLASSIFICATION: _____________________________________

OTHER FIRE DEPARTMENT ASSIGNMENTS (HFD)

9. STATION ASSIGNED: ___________ 10. HOW LONG: __________

11. JOB CLASSIFICATION: _____________________________________

12. STATION ASSIGNED: ___________ 13. HOW LONG: __________

14. JOB CLASSIFICATION: _____________________________________

15. STATION ASSIGNED: ___________ 16. HOW LONG: __________

17. JOB CLASSIFICATION: _____________________________________

Note: If you have had additional assignments, please list on back of this page.

18. COMPANY NAME: ____________________ 19. HOW LONG: _____

20. JOB CLASSIFICATION: ____________________________________

21. WHEN DID YOU BEGIN THIS OCCUPATION: ______________________

22. HOURS PER (WEEK) (MONTH) (YEAR): _________________________

23. COMPANY NAME: ____________________ 24. HOW LONG: _____

25. JOB CLASSIFICATION: ____________________________________

26. WHEN DID YOU BEGIN THIS OCCUPATION: _____________________

27. HOURS PER (WEEK) (MONTH) (YEAR): _________________________

Note: If you have had additional jobs, please list on back of this page.

MILITARY EXPERIENCE

28. YEARS AND MONTHS OF ACTIVE DUTY: ________ _________
(Years) (Months)

29. BRANCH OF SERVICE: _____________ 30. TIME IN COMBAT: ______

31. MILITARY JOBS, ASSIGNMENTS, OR DUTIES:

A. ____
B. ____
C. ____

32. DID YOU FIRE WEAPONS? _____ _____
(YES) (NO)

33. DID YOU FIRE WEAPONS FOR MORE THAN 100 DAYS? _____ _____ (YES)
(NO)

HOBBIES AND ACTIVITIES

34. DO YOU ENGAGE IN ANY OF THE FOLLOWING?

	Activity	Yes	No	Times per... day	week	month	year
A.	Hunting	___	___	___	____	_____	____
B.	Shooting	___	___	___	____	_____	____
C.	Motorcycle	___	___	___	____	_____	____
D.	Drag Race	___	___	___	____	_____	____
E.	Chain Saw	___	___	___	____	_____	____
F.	Farm Tractor	___	___	___	____	_____	____
G.	Woodworking	___	___	___	____	_____	____
H.	Loud Music	___	___	___	____	_____	____
I.	Other:_________	___	___	___	____	_____	____

MEDICAL HISTORY

35. HAVE YOU EVER HAD TROUBLE WITH YOUR EARS? ____ (Yes) ____ (No)

IF YES, DESCRIBE:

____

____

36. HAVE YOU BEEN SEEN BY A PHYSICIAN ABOUT YOUR EARS? ____ (Yes) ____ (No)

37. HAVE YOU EVER NOTICED ANY CHANGES IN YOUR HEARING? ____ (Yes) ____ (No)

38. HAVE YOU EVER HAD ANY OF THE FOLLOWING:

		YES	NO	HEARING CHANGE?
a.	Mumps	___	___	_______
b.	Measles	___	___	_______
c.	Allergies	___	___	_______
d.	High Blood Pressure	___	___	_______
e.	Mycin Drugs (antibiotics)	___	___	_______
f.	Quinine	___	___	_______
g.	Severe Blow to Head	___	___	_______
h.	Tinnitus ("ringing in ears")	___	___	_______
i.	Excessive Ear Wax Buildup	___	___	_______