



Final Performance Report

Department of Health and Human Services,
Center for Disease Control and Prevention

Research Grant No. 5 K01 OH00156-03,

Hazmat Firefighters: Medical and Incident Surveillance

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Submitted: 29 July 1999

a. List of Publications

1. Kales SN, Polyhronopoulos GN, Castro MJ, Goldman RH, Christiani DC. Injuries due to hazardous materials accidents. *Ann Emerg Med* 1997; 30:598-603.
2. Kales SN, Polyhronopoulos GN, Castro MJ, Goldman RH, Christiani DC. Mechanisms of and facility types involved in hazardous materials accidents. *Environmental Health Perspectives* 1997;105:998-1001.
3. Kales SN, Aldrich JM, Polyhronopoulos GN, Artzerounian D, Gassert T, Hu H, Kelsey K, Sweet C, Christiani DC. Fitness for duty evaluations in hazardous materials firefighters. *J Occup and Environ Med* 1998; 40:925-931.
4. Kales SN, Polyhronopoulos GN, Aldrich JM, Dimitriadis EA, Christiani DC. Interlaboratory comparisons of red blood cell cholinesterase activity. *J Environ Med* 1999; 1: 19-26.
5. Kales SN, Aldrich JM, Polyhronopoulos GN, Dimitriadis EA, Christiani DC. Influence of age on RBC Cholinesterase in men. International Society for Environmental Epidemiology/International Society of Exposure Analysis joint conference 1998. *Epidemiology* 1998; 9 (suppl):524
6. Kales SN, Polyhronopoulos GN, Aldrich JM, Leitao EO, Christiani DC. Correlates of body mass index in hazardous materials firefighters. *J Occup and Environ Med* 1999; 41:589-595.
7. Kales SN, Aldrich JM, Polyhronopoulos GN, Leitao EO, Artzerounian D, Gassert T, Hu H, Kelsey KT, Sweet C, Christiani DC. Correlates of fitness for duty in hazardous materials firefighters. *American Journal of Industrial Medicine* (in press).
8. Kales SN, Pinzon de Botero A, Polyhronopoulos GN, Aldrich JM, Dimitriadis EA, Christiani DC. Sources of interindividual variation in red blood cell cholinesterase activity. Submitted to *J Environ Med*.
9. Kales SN, Pinzon de Botero A, Polyhronopoulos GN, Aldrich JM, Dimitriadis EA, Christiani DC. Liver dysfunction is associated with lower erythrocyte cholinesterase. International Society for Environmental Epidemiology/ International Society of Exposure Analysis joint conference 1999. *Epidemiology* (in press).
10. Risk factors for hearing loss among hazardous materials firefighters. (in preparation)
11. Firefighters' hearing loss: a comparison with the general population. (in preparation)

12. Medical surveillance of hazardous materials response fire fighters: a longitudinal study of end-organ effect markers. (in preparation)
13. Medical surveillance of hazardous materials response fire fighters: a longitudinal study of pulmonary function. (in preparation)

b. Significant Findings

1) Injuries due to hazardous materials accidents. *Ann Emerg Med* 1997; 30:598-603.

The purpose of this study was to investigate hazardous materials incidents to determine the chemicals involved, their association with producing accident victims, and these victims' exposures, symptoms or injuries and requirements for hospital transport. We analyzed 165 hazardous materials incident responses by Massachusetts' six district hazmat teams from their inception through May 1996. Information from incident reports was extracted onto standard coding sheets. The 47 incidents with victims were then further analyzed for additional information.

The chemicals most frequently involved were various hydrocarbons and corrosive materials. Chlorine derivatives were involved in 18% of all incidents and associated with victims in 38% of these. Chlorine derivatives were involved in 23% of all incidents resulting in victims.

Most incidents produced no reported victims: 115 of 162 (71%). Civilians were victims in 40 of 162 (25%); public service personnel (regular firefighters, police and/or ambulance personnel) in 12 of 162 (7%); and hazmat team members in 1 of 162 (1%).

For the 47 incidents with victims, respiratory exposures were the most frequent type of exposure, produced the largest absolute number of victims requiring hospital transport, and the highest number of victims per incident. Overall, 24 of 26 (92%) incidents with chemical exposures resulted in symptomatic victims and 33 of 35 (94%) resulted in victims requiring hospital transport. (There was insufficient information on symptoms and hospital transports for some incidents which accounts for different totals). Inhalation exposures resulted in the highest absolute number of victims requiring hospital transport followed by dermal exposures. The mean number of hospital transports was also greater for inhalation exposures than dermal exposures: 7.4 victims/incident (155/21) versus 2.7 victims/incidents (24/9).

Respiratory symptoms (respiratory irritation and shortness of breath) were the most common both in terms of the number of incidents where they occurred and the absolute number of victims. Although physical trauma was common, it produced only 1.4 victims per incident.

2) Mechanisms of and facility types involved in hazardous materials accidents. *Environmental Health Perspectives* 1997;105:998-1001.

The purpose of this study was to investigate hazardous materials releases, and to determine the causes of these accidents, and the industries/activities and chemicals involved. We analyzed 165 hazardous materials incident responses by Massachusetts' six district hazmat

teams from their inception through May 1996. Information from incident reports was extracted onto standard coding sheets.

For 3 (2%) of the accidents, information on causes was unavailable, and for 8 (5%) information on the facility or activity involved was missing. One hundred twenty three of 162 (76%) hazardous materials incidents were caused by spills, leaks or escapes of hazardous materials and 80% occurred at fixed facilities (126 of 157). Transportation related accidents accounted for the remaining 20% of incidents. Eleven percent of hazardous materials incidents were at schools or healthcare facilities.

The proportions of incidents resulting in injury was highest for explosions (43%), but similar across other causes of accidents (fires, spills, and motor vehicle accidents) (26-33%), whether there was a single cause or a combination of non-explosion causes.

Several facility/activity types were strongly and mutually associated with certain classes of hazardous materials. These include electroplating operations and cyanide, gas stations and gasoline, and petroleum-derived fuels and transportation accidents. On the other hand, Chlorine derivatives were involved in 18% of all accidents but associated with a wide variety of facility types and activities.

3) **Fitness for duty evaluations in hazardous materials firefighters.** *J Occup and Environ Med* 1998; 40:925-931.

In this study, we analyzed various physical and laboratory examination results from the medical examinations of our hazardous materials cohort of 340 firefighters. We studied the clinical yields of different tests and their role in fitness for duty determinations by attending physicians. We then applied various objective criteria including guidelines from the proposed National Fire Protection Association (NFPA) revision of standard 1582 and consensus criteria from a Medical Workshop to our population as determinants of fitness for duty. This allowed us to compare our physicians' clinical determinations against these objective criteria. Finally, we examined the practical implications of applying various uniform objective criteria to our cohort.

Ten percent had elevated blood pressures, 13% had far visual acuity worse than 20/30 in one or both eyes, and 38% had abnormal audiometry. The strictest standards for resting blood pressure and corrected visual acuity (NFPA) would have failed 2% and 1% of the cohort, respectively. For audiometry, 0-5% of the cohort would have failed depending on the hearing requirements set. The strictest hearing standard (NFPA) did not allow for corrective devices so that few failures would be reversible.

Spirometry produced a small, but not insignificant number (6%) of abnormals (either a percent predicted FVC or FEV1 less than 80%). Very few had spirometry worse than any selected study criteria, and none were worse than 65% of predicted.

Attending physicians disqualified some individuals from duty even though others had equally poor or worse testing results. Attending physicians also failed only a minority of those individuals who would have failed any of the NFPA or Medical Workshop criteria. This was probably due to a lack of objective criteria that were agreed upon beforehand and uniformly applied.

4) **Interlaboratory comparisons of red blood cell cholinesterase activity.** *J Environ Med* 1999; 1: 19-26.

Each hazardous materials team responds to incidents throughout their assigned regions. Due to potential exposure to cholinesterase inhibitors during chemical accidents or terrorist scenarios, the medical surveillance examinations include a baseline determination of red blood cell cholinesterase (AChE). The nearest hospital post-exposure is likely to be different than the hospital where their medical surveillance is performed. Therefore, the post-exposure AChE is likely to be sent to a different reference laboratory. Given the possible need to directly compare AChE values from multiple reference laboratories, we undertook this study to systematically evaluate different methods of interlaboratory comparison and derive simple conversion formulas for practicing clinicians.

Eleven subjects gave triplicate samples for analysis by three commercial laboratories (labs). Comparisons were done by dividing values by the mid-point of each lab's reference range, and by transformation to Ellman Assay activity in U/ml using published/derived conversion factors. To observe each lab's reliability, four subjects submitted two additional duplicate samples to each lab.

The mean intraspecimen variabilities were 3%, range 1-8% ; 4%, range 0-9%; and 13%, range 2-24% for labs 1-3, respectively. The mean mid-range percent for lab 3 was substantially lower than the means for labs 1 and 2. Therefore, lab 3 values were adjusted based on the means for labs 1 and 2 and the mid-point suggested by lab 3's assay kit. The mean AChE relative to these mid-points were 109%, 107%, and 107% for labs 1-3, respectively. Ellman activities were 19.0, 19.9 and 20.8 U/ml for labs 1-3, respectively.

Intrasubject differences for both comparison methods showed agreement that approximated intraspecimen variabilities for each lab. For intrasubject comparisons using the mid-range percent between lab1/lab2, the mean difference was 5+/-4%, range 0-13%.

Comparisons involving lab 3 showed the poorest agreement which was consistent with lab 3's poor intraspecimen reliability.

5) **Influence of age on rbc cholinesterase activity in men.** *Epidemiology* 1998; 9 (suppl):524.

Because of the potential for exposure to cholinesterase inhibitors during chemical accidents or terrorist scenarios, our firefighters' medical surveillance examinations include a baseline determination of red blood cell cholinesterase activity (AChE). Little physiologic variation exists in AChE in healthy individuals over periods of weeks to months. It is unknown, however, how AChE varies over longer periods of time. Therefore, we evaluated the relationship between increasing age and AChE.

Baseline AChE was measured in 306 hazardous materials firefighters (21-55 years old). All subjects' values were transformed to Ellman Assay activity in U/ml using published/derived conversion factors.

The mean values in U/ml for each age group are summarized below:

<30 years old:	21.4+/-3.6;
30-39 years old:	23.1+/-4.1;
40-49 years old:	23.0+/-3.7;
50-55 years old:	23.2+/-3.8.

AChE in the 30-39 years old group was 8% higher than for those <30 years old, and basically stable thereafter.

6) **Correlates of body mass index among hazardous materials firefighters.** *J Occup Env Med* 1999; 41: 589-595.

Excess body weight is an increasing health problem in the United States. Using the new National Institutes of Health standard for healthy weights, BMI < 25, it is estimated that 97 million or 55% of adult Americans will be considered overweight. Obesity, or a BMI \geq 30, is also epidemic with a prevalence of 22.5% in the United States, according to the third National Health and Nutrition Examination Survey (NHANES) conducted from 1988-1994.

We analyzed results from the medical examinations of 340 hazardous materials (HAZMAT) firefighters and observed the relationships between selected parameters and body mass index (BMI). Heights and weights were available for 98% of the subjects (333/340). The mean BMI was 28.9 +/- 4.1 kg/m². Eighty seven percent (290/333) of subjects were overweight (BMI \geq 25) and 34% (113/333) were obese (BMI \geq 30). Two percent (7/333) were morbidly obese (BMI \geq 39). For comparison purposes, we divided subjects into LOW (BMI < 27), MEDIUM (BMI 27 to < 30), and HIGH (BMI \geq 30) BMI groups. The results demonstrated adverse associations between increasing BMI and resting blood pressures, forced vital capacity (FVC), alanine aminotransferase (ALT), aspartate aminotransferase (AST), serum cholesterol, and overall morbidity scores.

Selected results are summarized below.

Table I: Correlates of Body Mass Index: Males and Females*

VARIABLE	LOW BMI	MEDIUM BMI	HIGH BMI	ANOVA P
AGE	38 +/- 6 n = 100	40 +/- 7 n = 108	40 +/- 7 n = 107	<0.05
SBP	119 +/- 13 n = 106	123 +/- 13 n = 114	125 +/- 13 n = 113	<0.005
DBP	77 +/- 9 n = 106	79 +/- 9 n = 114	80 +/- 9 n = 113	<0.05
FVC %	105 +/- 13 n = 104	104 +/- 13 n = 112	100 +/- 13 n = 111	<0.05
FEV ₁ %	103 +/- 14 n = 104	104 +/- 14 n = 112	102 +/- 14 n = 111	n.s.
ALPKPHOS	82 +/- 22 n = 103	81 +/- 22 n = 113	85 +/- 22 n = 113	n.s.
CHOL	219 +/- 39 n = 57	224 +/- 39 n = 69	242 +/- 39 n = 62	<0.005
BUN	15 +/- 4 n = 105	16 +/- 4 n = 114	16 +/- 4 n = 113	n.s.
CR	1.08 +/- 0.16 n = 105	1.13 +/- 0.16 n = 114	1.13 +/- 0.16 n = 113	<0.05
AST	24 +/- 10 n = 104	24 +/- 10 n = 114	27 +/- 10 n = 112	<0.05
ALT	31 +/- 20 n = 104	35 +/- 20 n = 114	43 +/- 20 n = 112	<0.001
FITRANK	3.2 +/- 1.3 n = 106	3.7 +/- 1.3 n = 114	4.2 +/- 1.3 n = 113	<0.001

* Unadjusted Data

7) **Correlates of fitness for duty in hazardous materials firefighters.** *American Journal of Industrial Medicine* (in press).

From a statewide medical examination program, we identified firefighters who were deemed unfit for duty by attending physicians (ATTENDING FAIL, n=9) and those who would have been disqualified by the application of selected numerical criteria from the 1997 NFPA guidelines (NFPA FAIL, n=27) and criteria from a Medical Workshop (WORK FAIL, n=16). The subjects who were unfit for duty or failed numerical criteria were compared with those who were fit for duty and passed all objective criteria (FIT group, n=302). All subjects were also given an overall morbidity rating by a board-certified internist.

No gold standard exists for determining fitness for duty. In order to evaluate the ability of various methods to select firefighters who might be considered "unfit" for duty, two surrogate measures of fitness, predicted VO_2 max and predicted coronary heart disease risk (CHD), were developed.

We found a significant tendency towards worse results (e.g. higher blood pressure or lower spirometric function) among the three FAIL groups compared with the FIT group. The FAIL groups shared only a small overlap, however, with the firefighters with the highest morbidity ratings, lowest predicted VO_2 max, and highest coronary heart disease risks.

Increasing morbidity was associated with higher age, lower spirometric function and predicted VO_2 max; and increasing cholesterol, BMI, and predicted 10-year coronary heart disease risk.

When the age-based NFPA guidelines for stress testing were compared with the use of a multivariate CHD risk prediction formula, the NFPA age-based guidelines were a sensitive selection tool for identifying firefighters above certain thresholds of CHD risk, but had the disadvantage of selecting a large proportion of firefighters for stress testing who did not have high CHD risks.

Selected results are summarized below.

Table I shows the relationship between age and CHD risk for the firefighters' cohort and how the firefighters' CHD risks compare to the Framingham population.

Table I: Predicted Coronary Heart Disease Risk of Firefighter Age Groups (Males Only)

Age Group	N	Mean Predicted 10 Year CHD Risk	Average 10 Yr CHD Risk (Framingham Study)
< 30	6	3.0 +/- 0.9 %	NA
30-34	35	4.3 +/- 1.5 %	3 %
35-39	36	5.1 +/- 2.4 %	5 %
40-44	36	7.1 +/- 2.9 %	7 %
45-49	30	10.8 +/- 3.5 %	11 %
50-54	10	14.4 +/- 5.4 %	14 %
55-59	1	13.0	16 %
Total	154	7.1 +/- 4.2 %	NA

ANOVA: Between age groups (Combined); Sum of Squares: 1487.30; df: 6; Mean Square: 247.895; F: 31.116; p=0.000

Table II : Surrogate measures of fitness for Fit versus Various Fail Groups

VARIABLE	FIT BY ALL N=302	NFPA FAIL N=27	WORKSHOP FAIL N=16	UNFIT PER MD N=9
PREDICTED 10- YEAR CHD RISK	6.8 +/- 4.1% N= 138	9.3 +/- 4.6% N =15; p =0.063	8.0 +/- 3.1% N=6; p=0.393	Insufficient Data
PREDICTED VO ₂ MAX	33 +/- 7 N=281	31 +/- 7 N= 24; P=0.217	28 +/- 6 N= 14; P=0.017	30 +/- 5 N=8; P=0.118

Table III: Surrogate measures of fitness by morbidity ratings

VARIABLE	Low Morbidity N=173	Moderate Morbidity N= 158	High Morbidity N= 9
PREDICTED 10-YEAR CHD RISK	5.3 +/- 2.6 % N=81	8.1 +/- 3.9 % N= 67; p = 0.000	16.3 +/- 6.2 % N=7; p = 0.003
PREDICTED VO ₂ MAX	35 +/- 6 N= 160	31 +/- 7 N= 147; p=0.000	25 +/- 6 N= 9; p=0.001

Table IV: Five-year CHD risk by morbidity ratings

<i>5-Year Coronary Heart Disease Risk</i>	<i>< 3% N (% of row total)</i>	<i>3 to <5% N (% of row total)</i>	<i>≥ 5% N (% of row total)</i>
Low Morbidity Group N=81	56 (69%)	15 (18%)	10 (12%)
Moderate Morbidity Group N=67	25 (37%)	16 (24%)	26 (39%)
High Morbidity Group N=7	0 (0%)	1 (14%)	6 (86%)

8) **Sources of interindividual variation in red blood cell cholinesterase activity.** Submitted to *Journal of Environmental Medicine*.

In this study, we performed a cross-sectional study of erythrocyte acetylcholinesterase (AChE) activity and various physiologic and clinical variables in a cohort of 306 male hazardous materials firefighters to investigate possible sources of interindividual variation in AChE. Simple correlations between AChE activity and various parameters were performed to look for associations. Significant associations ($p < 0.05$) were then further explored with multivariate regression.

Simple correlation analysis demonstrated negative associations with alanine aminotransferase (ALT) ($r = -0.224$, $p < 0.001$) and alkaline phosphatase activity ($r = -0.128$, $p < 0.05$) and a positive association with serum creatinine ($r = 0.216$, $p < 0.001$). Using multivariate regression, we found significant associations remained for serum creatinine and ALT, both $p < 0.005$. The most consistent association was for ALT. In addition to the significant negative relationships with AChE in univariate and multivariate models, those subjects with the highest 10% and lowest 10% of AChE levels had significantly different ALT activities (30 ± 16 versus 53 ± 32 , $p < 0.005$). Finally, the 9 subjects with the absolute lowest ALT values had significantly higher AChE, (24.6 ± 3.1) than the 8 subjects with the highest ALT values (20.2 ± 2.7) ($p < 0.01$).

9) **Risk factors for hearing loss among hazardous materials firefighters.** (in preparation)

Firefighters are known to be at high risk for hearing loss. We are currently studying hearing loss and its correlates by analyzing the results from the year 01 medical examinations of the 340 hazardous materials firefighters.

The actual audiograms for all firefighters judged abnormal by the attending physician were obtained for systematic review. Each abnormal was compared to various numerical standards for minimum hearing requirements including those of the National Fire Protection Association (NFPA) and the Department of Transportation (DOT). These subgroups with abnormal hearing are being compared with those with normal audiograms. Comparisons involve the prevalence of potential risk factors and results of various laboratory parameters. Selected preliminary results are shown below.

The prevalence of abnormal audiometry was high 125/331 (38%). Another 18/331 (5%) had "borderline" abnormal audiometry, while 188/331 (57%) were judged normal. Five percent of the total cohort failed the NFPA criteria for hearing, including 2% with more severe hearing loss who also failed a less stringent consensus standard. None failed the DOT standard. Firefighters with abnormal hearing were significantly older on average than normals: 42.8 ± 6.1 vs. 36.8 ± 6.5 years ($p < 0.001$). Those failing NFPA and workshop criteria were even older: 45.7 ± 6.6 ($p < 0.001$ vs. normals) and 47.1 ± 6.4 ($p < 0.01$ vs.

normals), respectively. Firefighters with abnormal hearing were significantly more likely than normals to be current or former smokers: 43% vs. 26% ($p < 0.01$). Those failing NFPA and workshop criteria were also more likely to be current or former smokers than normals: 53% vs. 26% ($p < 0.05$), 38% vs. 26% (NS), respectively. Subgroups with abnormal hearing also had higher mean cholesterols and body mass indices than normals, but the differences did not reach statistical significance.

Further analyses will study the patterns of hearing loss in decibels across different frequencies in an attempt to determine the relative roles of noise, aging and other factors.

10) Firefighters' hearing loss: a comparison with the general population. (in preparation)

Firefighters are known to be at high risk for hearing loss. We are currently studying hearing loss from the 1996 medical examinations of the 340 hazardous materials firefighters in comparison with the distribution of hearing loss in the general population.

The actual audiograms for all firefighters judged abnormal by the attending physician were obtained, and hearing thresholds at each frequency for each ear were entered into a database. The 20th, 50th and 80th percentiles (99th percentile being the worst) for hearing loss at each frequency were determined for the group of 124 subjects with abnormal hearing. These percentiles for the subset of 124 abnormals correspond to the 69th, 81st and 92nd percentiles for the entire cohort of 323 male firefighters who had audiometry performed.

Using Database A from the ANSI standard ISO 1999, for each of the 340 firefighters we determined hearing thresholds at each frequency for a male "control" subject of the same age at each of the following percentiles: the 69th, 81st and 92nd percentiles. Database A was developed from the hearing thresholds of a large "highly screened", otologically normal population. Therefore, Database A allows the estimation of excess hearing loss due to noise exposure.

Selected preliminary results are shown below.

The average age of the 323 firefighters and the "control" subjects was 39.4 years. At the 69th percentile, the firefighters' hearing was similar to controls from Database A, and slightly better at 2000 and 3000 Hz. At the 81st percentile, firefighters' hearing was similar from 500-3000 Hz, but over 10 dB worse at 4000 and 6000 Hz. At the 92nd percentile, the firefighters had worse hearing at 500 and 1000 Hz, but thresholds similar to the controls at 2000 Hz. At 3000, 4000 and 6000 Hz the firefighters' hearing became progressively worse than the controls.

These data are shown graphically in Figures 1 and 2.

Figure 1

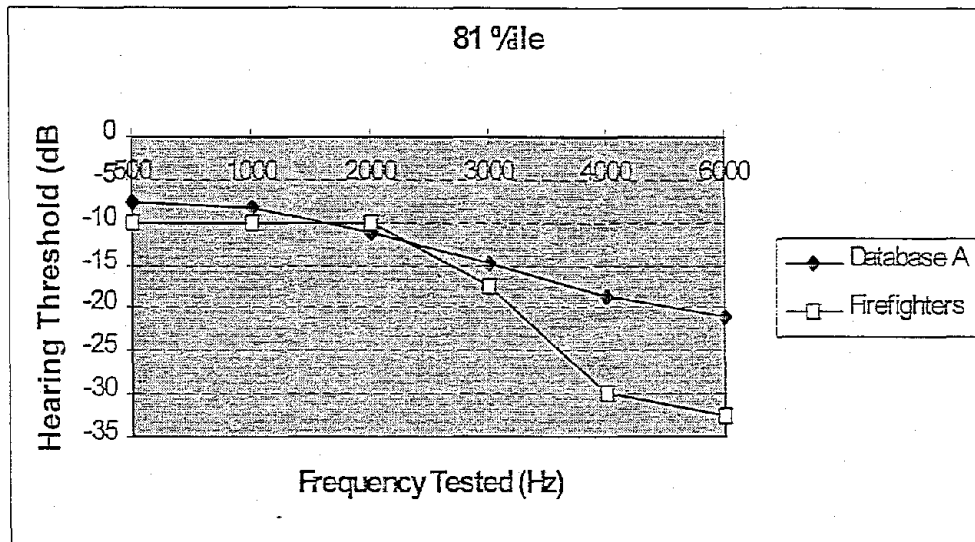
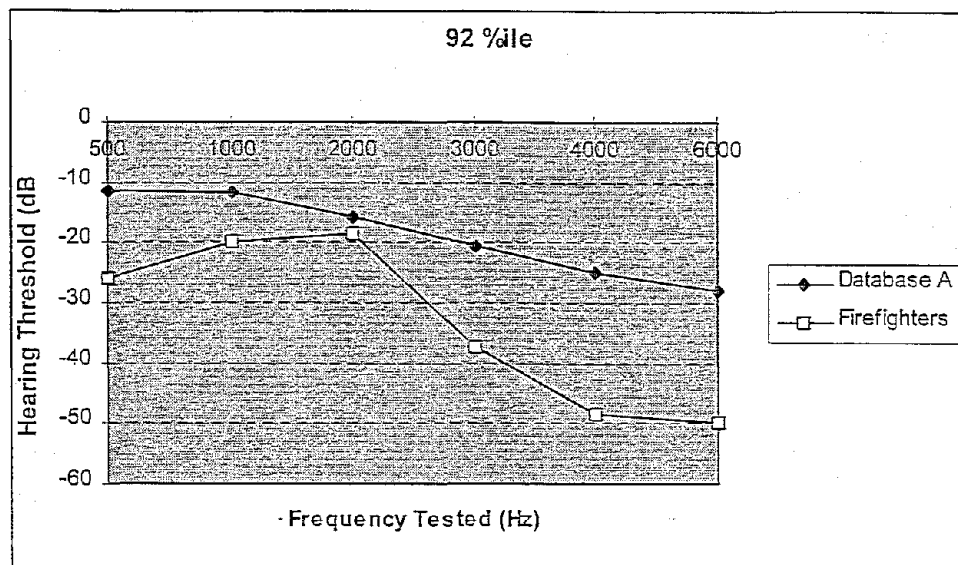


Figure 2



The proportion of firefighters whose hearing loss exceeded an average of 30 dB over the high frequency range of 3000, 4000 and 6000 Hz was 14% versus 3% of the control group (RR 4.67). Likewise, the proportion of firefighters whose hearing loss exceeded an average of 20 dB over a broad frequency range of 500, 1000, 2000, and 4000 Hz was 14% versus 3% of the control group (RR 4.67).

11) Medical surveillance of hazardous materials response fire fighters: a longitudinal study of end-organ effect markers. (in preparation)

The purpose of this study is to prospectively evaluate possible clinical and subclinical health effects of hazardous materials firefighting duty and to examine the utility of end-organ effect markers as medical surveillance tools.

SUBJECTS

The subjects were 340 members of six regional hazardous materials (hazmat) response teams of the Commonwealth of Massachusetts who underwent state mandated medical surveillance/fitness for duty examinations. They were also all members of municipal fire departments in addition to their hazmat duty with the state teams. The cohort included 268 (79%) hazardous materials technicians and 72 (21%) support members. The majority of the technicians were already incumbent members of the hazardous materials teams prior to the start of the study. Three hundred sixteen firefighters {249 (79%) hazardous materials technicians and 67 (21%) support members} were examined in 1996 or 1997 (year 01) and remained active with the team through the 1998 (year 03) examination.

HAZARDOUS MATERIALS EXPOSURE STATUS

Technicians are involved with the actual assessment and mitigation of hazardous materials accidents within the "hot" or contaminated zone of the accident. Most situations are responded to on a "level A" basis which entails the use of vapor type clothing and a positive pressure self-contained breathing apparatus (SCBA). Field decontamination is routinely performed after all accidents unless the hazard poses a threat only by pulmonary absorption (eg, carbon monoxide).

Support members are presumed to have a very limited potential for exposure compared with technicians, since they do not enter the "hot" or contaminated zone of an accident and their role is ancillary. Both technicians and support members perform regular fire duty in their non-state jobs. Since support members are non-exposed in their hazmat team duties, but do serve as municipal firefighters, they are an ideal control group for the investigation of potential health effects arising solely from duty within the contaminated zone of hazmat accidents.

INITIAL AND FOLLOW-UP MEDICAL EXAMINATIONS

Medical surveillance examinations for the firefighters were performed at one of three Hospitals in 1996 or 1997 in year 01 of a statewide surveillance program. A smaller number (N=214) were examined during the year 02 examinations in 1997. This was due to an administrative decision by the Commonwealth of Massachusetts in 1997 to have all teams' subsequent examinations conducted within a two-month time period in the fall of each year. Due to the fact that year 01 examinations were conducted throughout 1996, and 16 months is the maximum time period allowed between examinations, some firefighters were not reexamined until the fall of 1998.

A sub-group of 40 technicians from "Metrofire," the major Boston-area HAZMAT team, had initial examinations conducted at Massachusetts Respiratory Hospital, one of the three hospitals mentioned above, between November 1992 and August 1993. Thirty-seven firefighters from this sub-group had follow-up examinations performed in April and May of 1995. In addition, 37 of the original "Metrofire" firefighters participated in the year 01 examinations (1996-1997) conducted in the statewide program, and 35 remained active through the year 03 (1998) examination.

All examinations were conducted in a similar fashion. Examinations included a detailed medical, smoking and environmental/occupational history tailored to emergency responders; physical examination; visual and audiometric testing; routine laboratory tests (complete blood count, blood urea nitrogen, creatinine, alkaline phosphatase, AST and ALT, and urinalysis); and spirometry.

MEDICAL RECORDS REPOSITORY

Summary results of each firefighter's examination were transferred to the Massachusetts Respiratory Hospital where they were entered into a statewide computerized medical record repository.

The repository facilitates tracking any incident-related injuries and exposures requiring transport to a hospital. In such cases, the local treating facility would request medical information from the repository and each request would then be dated and logged with the name of the firefighter and the facility requesting the records. This enables the investigators to obtain additional medical information from the local treating facility.

STATISTICAL ANALYSES

Differences in mean values for paired comparisons (e.g. year 01 vs. year 03) were compared using paired *t* tests. Differences between technicians and support controls were examined using independent *t* tests and separate variances. For the Metrofire technician subcohort, ANOVA's were used to look for differences as a factor of time among the means for the 5 years studied. If a significant difference among the 5 years was found, then a paired t-Test was performed for 1993 vs 1998 data.

RESULTS

No record requests were reported to the repository during the study period. Also, there were no known significant exposures or injuries during the course of hazardous materials work.

Selected results for end-organ marker surveillance are shown below. Although several statistically significant differences were found, no clinically significant differences were found with the exception of ALT values, which increased in 1998. Both of the above observations were true for comparisons between the "exposed" technicians versus the "nonexposed" support members, as well as for paired and other longitudinal comparisons within subjects over time. The increase in mean ALT values in 1998 appeared to be due to the use of a new laboratory with a higher reference range at one of the hospitals in 1998 (see table 4).

Platelet values showed significant differences both within and between groups in a pattern not explained by exposure status. Again these differences were not clinically significant.

Creatinine values tended to decrease over time perhaps due to loss of muscle mass associated with aging.

Table 1: Independent Samples t-tests, Hazmat technician vs. support membersLiver Function Tests

Variable	Year	Technicians	Support	P-value
Alk Phos	Year 1	82 +/- 21 N=266	84 +/- 22 N=70	0.499
	Year 3	82 +/- 20 N=251	84 +/- 20 N=69	0.643
AST	Year 1	25 +/- 10 N=266	24 +/- 9 N=71	0.383
	Year 3	25 +/- 10 N=251	24 +/- 9 N=69	0.748
ALT	Year 1	37 +/- 20 N=266	35 +/- 21 N=71	0.675
	Year 3	44 +/- 17 N=251	43 +/- 19 N=69	0.900

Renal Function Tests

Variable	Year	Technicians	Support	P-value
BUN	Year 1	16 +/- 4 N=268	16 +/- 4 N=71	0.948
	Year 3	16 +/- 4 N=251	16 +/- 4 N=69	0.441
Creatinine	Year 1	1.1 +/- 0.2 N=268	1.1 +/- 0.2 N=71	0.228
	Year 3	1.0 +/- 0.1 N=251	1.0 +/- 0.2 N=69	0.877

Table 1 (cont.)

Hematologic Tests

Variable	Year	Technicians	Support	P-value
WBC	Year 1	6.6 +/- 2.2 N=266	6.6 +/- 1.4 N=71	0.849
	Year 3	6.7 +/- 1.8 N=251	6.6 +/- 1.5 N=69	0.634
HCT	Year 1	45.2 +/- 3.1 N=266	45.3 +/- 3.0 N=71	0.850
	Year 3	45.6 +/- 3.0 N=251	45.8 +/- 3.1 N=69	0.524
PLT	Year 1	239 +/- 51 N=268	252 +/- 57 N=70	0.085
	Year 3	229 +/- 58 N=251	245 +/- 53 N=69	0.036

Table 2: Paired Samples t-test (Year 01 vs. Year 03) for Hazmat Technicians and Support

Liver Function Tests

Variable	Year 1 (1996-97)	Year 3 (1998)	P Value (2-tailed)
Alk Phos			
Technicians (n=248)	83 +/- 21	83 +/- 20	0.760
Support (n=65)	84 +/- 23	83 +/- 20	0.509
AST			
Technicians (n=247)	25 +/- 10	25 +/- 10	1.000
Support (n=66)	24 +/- 9	25 +/- 9	0.473
ALT			
Technicians (n=247)	36 +/- 20	44 +/- 17	0.000
Support (n=66)	35 +/- 22	44 +/- 19	0.002

Renal Function Tests

Variable	Year 1 (1996-97)	Year 3 (1998)	P Value (2-tailed)
BUN			
Technicians (n=249)	16 +/- 4	15 +/- 4	0.082
Support (n=66)	16 +/- 4	16 +/- 4	0.758
Creatinine			
Technicians (n=249)	1.1 +/- 0.2	1.0 +/- 0.1	0.000
Support (n=66)	1.1 +/- 0.2	1.0 +/- 0.2	0.000

Hematologic Tests

Variable	Year 1 (1996-97)	Year 3 (1998)	P Value (2-tailed)
WBC			
Technicians (n=247)	6.7 +/- 2.3	6.7 +/- 1.8	0.954
Support (n=66)	6.6 +/- 1.4	6.6 +/- 1.5	0.933
HCT			
Technicians (247)	45.4 +/- 3.2	45.6 +/- 3.0	0.283
Support (n=66)	45.3 +/- 2.9	45.8 +/- 3.1	0.146
PLT			
Technicians (249)	240 +/- 52	229 +/- 58	0.000
Support (n=65)	254 +/- 57	245 +/- 54	0.021

Table 3: Five Year Follow-up for Metrofire Technician Cohort

Liver Function Tests

Variable	1993	1995	1996	1997	1998	ANOVA p-value
Alk Phos	74 +/- 16 (n=35)	78 +/-16 (n=34)	77 +/-18 (n=34)	78 +/-17 (n=34)	78 +/- 19 (n=35)	0.770
AST	26 +/- 11 (n=35)	25 +/-13 (n=34)	29 +/-13 (n=34)	24 +/-7 (n=34)	27 +/- 16 (n=35)	0.560
ALT	24 +/- 8 (n=35)	26 +/- 8 (n=34)	28 +/-17 (n=34)	27 +/-14 (n=34)	48 +/- 14 (n=35)	0.000

Renal Function Tests

Variable	1993	1995	1996	1997	1998	ANOVA p-value
BUN	17 +/- 3 (n=35)	16 +/- 4 (n=34)	17 +/- 4 (n=34)	16 +/- 4 (n=34)	17 +/- 5 (n=35)	0.886
Creatinine	1.3 +/- 0.1 (n=35)	1.3 +/- 0.1 (n=34)	1.2 +/- 0.1 (n=34)	1.2 +/- 0.2 (n=34)	1.1 +/- 0.1 (n=35)	0.000

Hematologic Parameters

Variable	1993	1995	1996	1997	1998	ANOVA p-value
WBC	7.1 +/- 1.6 (n=35)	6.3 +/- 1.6 (n=34)	6.7 +/- 1.6 (n=34)	6.8 +/- 1.5 (n=34)	6.5 +/- 1.4 (n=35)	0.237
HCT	45.4 +/- 2.1 (n=35)	44.8 +/- 2.6 (n=34)	44.7 +/- 2.2 (n=34)	45.4 +/- 2.5 (n=34)	44.1 +/- 2.4 (n=35)	0.164
PLT	237 +/- 42 (n=35)	247 +/- 54 (n=33)	242 +/- 48 (n=34)	220 +/- 44 (n=34)	210 +/- 40 (n=35)	0.004

Table 4. Further analysis of ALT data by hospital and year of testing

Year	Holyoke Hospital	Massachusetts Respiratory Hospital *	Marlborough Hospital
1996	30 +/- 15 (n=99)	27 +/- 14 (n=118)	50 +/- 22 (n=120)
1997	31 +/- 12 (n=89)	29 +/- 14 (n=102)	60 +/- 45 (n=21)
1998	32 +/- 17 (n=105)	49 +/- 16 (n=111)	48 +/- 15 (n=115)

Table 4a.) Analysis of ALT data for the "Metrofire" subgroup

Year	1993	1995	1996	1997	1998
ALT	24 +/- 8 (n=35)	26 +/- 8 (n=34)	28 +/- 17 (n=34)	27 +/- 14 (n=34)	48 +/- 14 (n=35)
Hospital	MRH	MRH	MRH	MRH	MRH
Laboratory Used	Quest [@] Diagnostics	Quest Diagnostics	Quest Diagnostics	Quest Diagnostics	Gateway
Reference range	0-45	0-45	0-45	0-45	20-65

* Laboratory used in 1996 and 1997 was Quest[@], and in 1998 it was Gateway.

[@] Formerly Corning Bioran

12) Medical surveillance of hazardous materials response fire fighters: a longitudinal study of pulmonary function. (in preparation)

The purpose of this investigation is to longitudinally study the pulmonary function of firefighters to determine if they lose pulmonary function at a more exaggerated rate than reference groups. We are also studying whether risk factors that may be associated with hyperreactive airways predict accelerated declines in lung function.

SUBJECTS

The subjects were 340 members of six regional hazardous materials (hazmat) response teams of the Commonwealth of Massachusetts who underwent state mandated medical surveillance/fitness for duty examinations. They were also all members of municipal fire departments in addition to their hazmat duty with the state teams. Three hundred sixteen firefighters were examined in 1996 or 1997 (year 01) and remained active with the team through the 1998 (year 03) examination.

INITIAL AND FOLLOW-UP MEDICAL EXAMINATIONS

Medical surveillance examinations for the firefighters were performed at one of three Hospitals in 1996 or 1997 in year 01 of a statewide surveillance program. A smaller number (N=214) were examined during the year 02 examinations in 1997. This was due to an administrative decision by the Commonwealth of Massachusetts in 1997 to have all teams' subsequent examinations conducted within a two-month time period in the fall of each year. Due to the fact that year 01 examinations were conducted throughout 1996, and 16 months is the maximum time period allowed between examinations, some firefighters were not reexamined until the fall of 1998.

A sub-group of 40 technicians from "Metrofire," the major Boston-area HAZMAT team, had initial examinations conducted at Massachusetts Respiratory Hospital, one of the three hospitals mentioned above, between November 1992 and August 1993. Thirty-seven firefighters from this sub-group had follow-up examinations performed in April and May of 1995. In addition, 37 of the original "Metrofire" firefighters participated in the year 01 examinations (1996-1997) conducted in the statewide program, and 35 remained active through the year 03 (1998) examination.

All examinations were conducted in a similar fashion. Examinations included a detailed medical, smoking and environmental/occupational history tailored to emergency responders; physical examination; visual and audiometric testing; routine laboratory tests (complete blood count, blood urea nitrogen, creatinine, alkaline phosphatase, AST and ALT, and urinalysis); and spirometry.

CLASSIFICATION BY RISK FACTORS FOR HYPERREACTIVE AIRWAYS OR ACCELERATED LOSS OF PULMONARY FUNCTION

Initial, year 01 examinations (1996-1997) were reviewed for the presence of the following risk factors: asthma, atopy, current smoking, physician diagnosis of obstructive airways, % predicted FEV1 <80%, % predicted FVC <80%, or FEV1/FVC <0.7. Firefighters were then classified into the following groups: no known risk factors for hyperreactive airways and any risk factor for hyperreactive airways. The latter group was classified by the presence of one or more of the following: asthma, atopy, current smoking, physician diagnosis of obstructive airways, or low pulmonary function (% predicted FEV1 <80%, % predicted FVC <80%, or FEV1/FVC <0.7).

STATISTICAL ANALYSES

Differences in mean values for paired comparisons (e.g. year 01 vs. year 03) were compared using paired *t* tests. For the Metrofire technician subcohort, ANOVA's were used to look for differences as a factor of time among the means for the 5 years studied. If a significant difference among the 5 years was found, then a paired *t*-test was performed for 1993 vs 1998 data.

RESULTS

Selected results are shown below in Tables 1-5.

Comparison of year 01 and year 03 spirometric values for the entire cohort showed a trend towards a lower FVC % predicted and a significantly lower FEV1 % predicted in year 03, although the difference appears clinically unimportant (Table 1). The five-year follow-up data for the Metrofire subcohort showed no significant differences among the mean FVC and FEV1 % predicted values as a function of time (Table 2).

Table 3 compares spirometric values between firefighters with one or more risk factors for hyperreactive airways or accelerated loss of pulmonary function and firefighters without risk factors. As expected, the firefighters with any of the risk factors (all risk factor groups combined) had lower pulmonary function than the no risk factors group at both year 01 and 03. For the various subgroups of risk factors, several points are worth mentioning. First, as expected, firefighters selected on the basis of low FVC and/or FEV1 % predicted had lower values for both FVC and FEV1 % predicted. Second, atopics, smokers and those with a FEV1/FVC <0.7 all had significantly lower FEV1 % predicted at both time points. Differences for the asthma, MD obstruction and sinusitis groups were not significant, but these groups had small sample sizes.

Table 4 compares paired longitudinal trends in spirometry for firefighters with and without risk factors for hyperreactive airways or accelerated loss of pulmonary function. As with the total cohort, firefighters with and without risk factors showed small, but significant

declines in the FEV1 % predicted. The rate of change was similar for both groups of firefighters.

Table 5 shows five year follow-up data for the Metrofire subcohort by risk factor status. While spirometric values were consistently lower for firefighters with risk factors, neither group showed significant differences in predicted values for FVC or FEV1 as a factor of time. In other words, we did not observe an accelerated decline in spirometric values for either group.

Table 1) Spirometric Values at Baseline and Follow-Up for Total Cohort

Variable	Year 1 (1996-97)	Year 3 (1998)	P Value (2-tailed) [@]
FVC (n=310)	5.2 +/- 0.8	5.1 +/- 0.8	0.003
FVC (% predicted) (n=310)	104 +/- 13	103 +/- 12	0.095
FEV1 (N=310)	4.2 +/- 0.6	4.1 +/- 0.7	0.000
FEV1 (% predicted) (n=310)	103 +/- 14	101 +/- 14	0.000

[@]All comparisons are paired year 1 versus year 3.

Table 2) Spirometric Values at Baseline and Follow-Up Examination for Metrofire subgroup

Variable	1993	1995	1996	1997	1998	ANOVA p- value
FVC (% predicted)	105 +/- 12 (n=35)	106 +/- 12 (n=34)	106 +/- 11 (n=34)	106 +/- 13 (n=32)	103 +/- 10 (n=35)	0.891
FEV1 (% predicted)	107 +/- 13 (n=35)	105 +/- 13 (n=34)	109 +/- 13 (n=34)	106 +/- 13 (n=32)	104 +/- 11 (n=35)	0.617

Table 3) Independent samples t-test, Comparison of Risk Factor Groups vs. No Risk Factors Group[@]

Pulmonary Function Test	No Risk Factors	All Risk Factor Groups Combined	Atopy	Smokers	FVC% or FEV1% pred <80% or FEV1/FVC < 0.7	FVC% or FEV1% pred <80%	FEV1/FVC < 0.7	Asthma	MD obstruction	Sinusitis
FVC% predicted (YEAR 1)	105 ± 12 (n=209)	101 ± 14 (n=125) p=0.008	102 ± 11 (n=70) p=0.137	104 ± 13 (n=33) p=0.781	94 ± 18 (n=33) p=0.003	80 ± 6 (n=19) p=0.000	107 ± 16 (n=17) p=0.558	105 ± 12 (n=12) p=0.879	102 ± 20 (n=6) p=0.809	100 ± 12 (n=3) p=0.615
FVC% predicted (YEAR 3)	104 ± 12 (n=203)	101 ± 13 (n=111) p=0.031	102 ± 11 (n=61) p=0.306	102 ± 12 (n=31) p=0.514	96 ± 17 (n=29) p=0.020	85 ± 8 (n=16) p=0.000	106 ± 16 (n=15) p=0.648	103 ± 14 (n=11) p=0.853	104 ± 19 (n=6) p=0.968	103 (n=1)
FEV1% predicted (YEAR 1)	106 ± 12 (n=209)	98 ± 14 (n=125) p=0.000	102 ± 12 (n=70) p=0.027	98 ± 13 (n=33) p=0.001	83 ± 11 (n=33) p=0.000	77 ± 6 (n=19) p=0.000	88 ± 13 (n=17) p=0.000	100 ± 15 (n=12) p=0.218	93 ± 17 (n=6) p=0.119	85 ± 12 (n=3) p=0.096
FEV1% predicted (YEAR 3)	104 ± 13 (n=203)	96 ± 14 (n=111) p=0.000	100 ± 11 (n=61) p=0.025	96 ± 13 (n=31) p=0.004	85 ± 14 (n=29) p=0.000	78 ± 9 (n=16) p=0.000	89 ± 16 (n=15) p=0.003	97 ± 18 (n=11) p=0.228	94 ± 14 (n=6) p=0.144	94 (n=1)

[@]All comparisons are independent t-tests versus the No Risk Factors Group

Table 4) Paired Samples t-test, Comparison within groups between years 01 and year 03.

Group	FVC% predicted (YEAR 1)	FVC% predicted (YEAR 3)	P-value (2 tailed) paired difference [@]	FEV1% predicted (YEAR 1)	FEV1% predicted (YEAR 3)	P-value (2 tailed) paired difference [@]
No Risk Factors (n=200)	105 ± 12	104 ± 12	0.212	106 ± 12	104 ± 13	0.001
All Risk Factor Groups Combined (n=110)	102 ± 14	101 ± 13	0.237	98 ± 14	96 ± 14	0.002
Atopy (n=60)	104 ± 11	102 ± 11	0.217	103 ± 12	100 ± 11	0.000
Smokers (n=31)	104 ± 13	102 ± 12	0.182	98 ± 12	96 ± 13	0.123
FVC% or FEV1% pred <80% or FEV1/FVC < 0.7 (n=29)	95 ± 19	96 ± 17	0.546	84 ± 12	85 ± 14	0.451
FVC% or FEV1% pred <80% (n=16)	80 ± 6	85 ± 8	0.046	76 ± 6	78 ± 9	0.243
FEV1/FVC < 0.7 (n=15)	109 ± 16	106 ± 16	0.160	89 ± 14	89 ± 16	0.906
Asthma (n=11)	105 ± 12	103 ± 14	0.118	100 ± 16	97 ± 18	0.200
MD obstruction (n=6)	102 ± 20	104 ± 19	0.595	93 ± 17	94 ± 14	0.614
Sinusitis (n=1)	112	103	.	98	94	.

[@]All comparisons are paired year 1 versus year 3.

Table 5) Baseline and Follow up Spirometric Values for Metrofire Subcohort Pulmonary Function Risk Factor Groups

Variable	Pulmonary Function Risk Factor Group	1993	1995	1996	1997	1998	ANOVA w/in each group as a factor of time P-value
FVC % predicted	No Risk Factors	107 ± 12 (n=22)	108 ± 11 (n=21)	108 ± 10 (n=22)	109 ± 13 (n=21)	105 ± 10 (n=22)	0.810
	Risk Factors Group	101 ± 11 (n=11)	101 ± 12 (n=12)	102 ± 13 (n=12)	100 ± 13 (n=11)	100 ± 12 (n=12)	0.994
FEV1 % predicted	No Risk Factors	109 ± 14 (n=22)	107 ± 13 (n=21)	110 ± 13 (n=22)	110 ± 13 (n=21)	106 ± 12 (n=22)	0.805
	Risk Factors Group	104 ± 11 (n=12)	102 ± 13 (n=12)	105 ± 12 (n=12)	100 ± 11 (n=11)	101 ± 10 (n=12)	0.819

c) Usefulness of findings, and relation to the specific aims of the project.

Specific Aims:

- 1) To prospectively evaluate possible clinical and subclinical health effects of hazardous materials firefighting duty.
- 2) To evaluate the clinical utility and cost effectiveness of various components of the baseline and periodic screening medical examinations among firefighters. Utility will be examined in the context of serial determinations of fitness for duty and in medical monitoring.
- 3) To longitudinally study the pulmonary function of hazardous materials firefighters and determine if they lose pulmonary function at a more exaggerated rate than reference groups.
- 4) To investigate the acute effects of various hazardous materials incidents on spirometry and to prospectively study whether these acute effects predict any long-term changes in pulmonary function.
- 5) To further characterize the number and type of incidents that Hazardous Materials teams will respond to, and determine the number of hazmat and non-hazmat, emergency responders (i.e. police and regular duty firefighters) sustaining injury or requiring acute treatment due to hazmat incidents, and the type and severity of their complaints.

- 1) Injuries due to hazardous materials accidents. *Ann Emerg Med* 1997; 30:598-603.
(Specifically relates to aim #5)

This study further characterized the number and type of incidents that Hazardous Materials teams respond to, and determined the number of hazmat and non-hazmat, emergency responders (i.e. police and regular duty firefighters) sustaining injury or requiring acute treatment due to hazmat incidents, and the type and severity of their complaints.

Our data suggest that single hazmat incidents which result in the transport of multiple victims to emergency departments are most likely to result from an inhalation exposure to a respiratory irritant. In most situations, these exposures and injuries should be successfully managed by excellent supportive and/or trauma care. Less frequent exposures, however, may require advanced toxicologic knowledge, specific decontamination procedures, treatment and/or antidotes.

Regular duty firefighters and other first responders continue to have a higher rate of injury due to hazardous materials accidents than designated hazardous materials

technician firefighters. In the first six years of hazardous materials duty for the six Massachusetts regional teams, no significant chemical exposures were reported and minor musculoskeletal injuries were reported in only a single incident.

This information should allow fire departments, ambulance services, emergency medicine practitioners and poison centers to better prepare for and manage public service and civilian victims of hazardous materials accidents. Preventive efforts may also be concentrated on the types of accidents most likely to produce multiple victims and to protect the public service personnel most likely to be injured (regular duty firefighters).

2) **Mechanisms of and facility types involved in hazardous materials accidents.**

Environmental Health Perspectives 1997;105:998-1001.

(Specifically relates to aim #5)

This study further characterized the number and type of incidents that Hazardous Materials teams respond to according to the mechanism of hazardous materials release and the types of industries and facilities involved in accidents.

Certain industries, natural disasters, waste-sights, transportation routes and other unique factors may predominate in different geographic areas and thus, predispose those areas to certain types of incidents and exposures. Such data suggest ample ideas for accident prevention and mitigation. This regional data should be useful to hazardous materials teams in preparing for the most likely accident scenarios and to Local Emergency Planning Committees in determining their prevention and accident contingency plans. Such information may also be useful to toxic use reduction programs in identifying target hazards for various types of industry and commerce.

3) **Fitness for duty evaluations in hazardous materials firefighters.** *J Occup and Environ Med* 1998; 40:925-931. (Specifically relates to aim #2)

This study evaluated the clinical utility and clinical yield of various components of firefighters' medical examinations in the context of determinations of fitness for duty.

Visual and audiometric testing and measurement of resting blood pressure all had significant clinical yields in the present study. Visual and acoustic acuity testing are also essential components of fitness for duty determinations that can detect potential safety problems. In the case of vision, the vast majority of deficits will be correctable and the NFPA standard for corrected binocular far acuity seems reasonable.

In the case of hearing, 5% of our cohort had hearing impairment severe enough to disqualify them by the proposed NFPA standard. Preliminary analysis of follow-up examinations suggest that more firefighters would fail this standard every year as cumulative hearing losses produce greater deficits. The application of this standard could

have had serious implications for manpower and could have produced legal challenges to its implementation.

The results of this study support changes made in the final 1997 NFPA 1582 that changed hearing requirements from Category A to Category B conditions. The final 1997 NFPA 1582 also specifies that in order to be disqualified, a firefighter, in addition to failing the minimum numerical hearing requirements, is also unable to pass a job-specific functional hearing task or a "Hearing In Noise Test" to be disqualified. The final NFPA standard, however, does not allow for correction by hearing aids and has not been objectively validated. Therefore, studies of simulated firefighting are needed to establish minimum hearing requirements and whether corrective devices can be worn safely during duty.

Assessment of resting blood pressure seems prudent to identify persons with possible hypertension and to temporarily disqualify those with pressures persistently $\geq 180/100$ (greater than the NFPA standard) until corrected.

This study suggested that spirometry plays little role in determining fitness for duty. Spirometry may be useful, however, in identifying individuals who are at potential risk for subsequent losses of pulmonary function, as well as in looking for longitudinal group trends.

The adoption and uniform application of objective criteria will determine fitness for duty in a more consistent manner. Temporary disqualifications from fitness for duty should provide an impetus for the correction of reversible abnormalities in many cases.

4) **Interlaboratory comparisons of red blood cell cholinesterase activity.** *J Environ Med* 1999; 1: 19-26. (Specifically relates to aim #1)

In order to monitor possible health effects of hazardous materials duty, baseline assessment of AChE is recommended for hazardous materials firefighters. Subsequent post-exposure testing, however, may be done on an urgent basis at the nearest hospital and therefore, may be performed by a different laboratory than the one used for baseline determination. Because multiple assays are in use and different laboratories may use different units and/or reference ranges, methods for interlaboratory comparisons are desirable.

AChE from different labs can be compared by both methods evaluated in this study, but all comparisons are limited by the precision and reliability of the labs involved. Transformation of a subject's AChEs to percent mid-ranges (percentage of the mid-point of the reference range) gives clinicians a fast and simple way to compare values from different labs. For labs with good intraspecimen reliability (Labs 1 and 2), intrasubject differences did not exceed 13%. Such a method is acceptable given that experts believe duplicate AChE samples from the same laboratory should not differ by more than 15%.

A protocol for further evaluation is outlined in the full article. This protocol has potential utility for the evaluation of hazardous materials firefighters, hazardous waste workers, agricultural workers, and military personnel who have had a baseline AChE, but may have subsequent measurements of AChE elsewhere.

The study results for intralaboratory reliability within split specimens suggest another important point. In this small study, non-physiologic variation alone sometimes exceeded 20%. Although worker safety must be protected by initially assuming that depressions of 20-25% in the AChE are significant, they are not conclusive proof of exposure to cholinesterase-inhibiting agents even when data from only one laboratory is considered. Therefore, serial follow-up testing of both plasma and AChE should always be done.

- 5) **Influence of age on RBC Cholinesterase activity in men.** *Epidemiology* 1998; 9 (suppl):524. (Specifically relates to aims #1,2)

In order to monitor possible health effects of hazardous materials duty, baseline assessment of AChE is recommended for hazardous materials firefighters. In the absence of known exposure, the appropriate frequency for periodic testing is unknown. The assessment of age-related changes could assist in determining the appropriate frequency for retesting.

In this population, AChE increased about 8% with age from the third to fourth decades of life with little change thereafter. The lack of data on individuals older than 55 leaves unclear the effect of age on AChE in older subjects. Sidell and Kaminskis found that AChE increased 10% in men from <30 to 50-59 years old. Therefore, it appears that aging may affect AChE, and this potential for variation should be recognized in interpreting clinical and research results.

Experts in the field of cholinesterase assessment and monitoring feel that duplicate AChE samples from the same laboratory should not differ by more than 15%. Depressions of 20-25% in the AChE are considered to be clinically significant. Age-related changes in AChE do not appear to exceed 8-10% over periods of 10-30 years. Therefore, in situations where no known exposure to cholinesterase-inhibitors has occurred, it is probably unnecessary to reassess the baseline AChE more frequently than every 5-10 years.

- 5) **Correlates of body mass index among hazardous materials firefighters.** *J Occup Env Med* 1999;41: 589-595. (Specifically relates to aim #2)

This study examined the relation of obesity to various health indicators in an active firefighting population and the potential effect of obesity on fitness for duty. The prevalence of both overweight and obesity among our HAZMAT firefighters was strikingly high and greater than those of the US adult population. Thus, our cohort would

appear to be at a heightened risk for morbidity and mortality when compared to the general U.S. population.

Epidemiologic studies suggest increased cardiac mortality rates for firefighters. In addition, fatality statistics have consistently shown that myocardial infarctions account for about 45% of firefighter deaths in the line of duty. They also demonstrate that most of these persons have a prior history of heart and/or other vascular disease. Others have shown obesity to be associated with insulin resistance, Type II diabetes, and cardiovascular disease, itself.

Numerous studies have examined the association between obesity and other problems that affect fitness for duty such as decreased muscular endurance and diminished aerobic and anaerobic capacity. Others report a strong association, especially in men, between obesity and sleep apnea, sleep disturbances, and increased daytime sleepiness even in the absence of apnea. The possible presence of an obesity-related sleep disorder that could impair a firefighter's abilities and heighten the risks to personal and public safety should be addressed in fitness for duty examinations.

Therefore, the high prevalence of obesity in our cohort and its adverse associations with heart disease, decreased aerobic capacity and sleep apnea provide strong arguments for increased attention to obesity-related disorders during fitness for duty examinations. The findings also underline the need for the development of effective fitness and health promotion programs for firefighters.

7) Correlates of fitness for duty in hazardous materials firefighters.

American Journal of Industrial Medicine (in press). (Specifically relates to aim #2)

This study evaluated the clinical utility of various components of firefighters' medical examinations in the context of determinations of fitness for duty, and the cost effectiveness of different strategies for selecting firefighters for exercise stress testing.

Fitness for duty guidelines traditionally review at what point or in the presence of which manifestations, single, specific conditions or diseases become incompatible with the safe performance of firefighting. Although such criteria are needed to guide physicians when the presence of a single, advanced, or poorly controlled condition may render a firefighter unfit for the safe performance of his/her essential job functions, poor fitness may be the result of a combination of several problems or risk factors. Based on examination of the data from our firefighter cohort, many of the least healthy or highest risk firefighters do not display extreme results on any single variable usually considered in fitness examinations.

Our investigation also demonstrated that the group clinically rated as being in the lowest 3%ile of health status (the high morbidity group) was a sub-group with high CHD risk, decreased pulmonary function, and low predicted aerobic capacity. The results suggest that firefighters clinically assessed to be in relatively poor health should undergo

additional testing to further delineate their CHD risks and exercise tolerances. Although the presence of a single serious or poorly controlled condition may render an individual unfit for safe performance as a firefighter, examination of our cohort suggests that multiple risk factor models or overall clinical assessments are superior means of identifying firefighters with poor health status and increased CHD risk.

The use of a multivariate CHD risk prediction formula appears to be the most accurate, cost-effective, evidence-based, and least arbitrary means of selecting firefighters for exercise stress testing. The NFPA suggested age-based guideline is a sensitive selection tool, but has the disadvantage of selecting for stress testing a large proportion of firefighters who do not have a high CHD risk. It is still unclear, however, above what threshold of CHD risk exercise stress testing should be recommended. Such a threshold needs to be determined and validated in prospective studies of firefighter cohorts.

Because cardiac events are the leading cause of deaths in firefighters, the findings in this initial cross-sectional study of surrogate outcome measures raise fundamental questions about traditional fitness for duty examinations. We believe that these issues can be answered in part by our prospective studies of this cohort that are now in progress.

8) Sources of interindividual variation in red blood cell cholinesterase activity.

Submitted to *Journal of Environmental Medicine*. (Specifically relates to aim #1)

In order to monitor possible health effects of hazardous materials duty, baseline assessment of AChE is recommended for hazardous materials firefighters. In the interpretation of follow-up testing, it is important to recognize what non-exposure related factors may affect AChE activity.

This study and that of Kakimoto et al (1995) found that liver dysfunction as measured by ALT is associated with decreased AChE. These findings should be of relevance to physicians who conduct medical surveillance of persons exposed or potentially exposed to cholinesterase-inhibitors such as hazardous materials firefighters and hazardous waste workers and others who evaluate toxicity using AChE as a biomarker. Further studies will be needed to investigate whether liver dysfunction renders one more susceptible to the effects of cholinesterase-inhibitors. Longitudinal studies are needed to address whether AChE fluctuates with improvements and/or decrements in liver function.

9) Risk factors for hearing loss among hazardous materials firefighters.

(in preparation) (Specifically relates to aim #1)

This study examines the risk factors for hearing loss, a known risk of firefighting. The high prevalence of abnormal audiometry and its severity in some cases again highlight the need for comprehensive hearing conservation programs for firefighters. Such programs should include hearing protection and engineering controls to reduce noise exposures. As expected, aging appears to be associated with worse hearing. The associations between higher rates of smoking, higher mean cholesterol and body mass

index among those with abnormal hearing are also in agreement with literature suggesting that risk factors for vascular disease are associated with increased susceptibility to noise-induced hearing loss. The control of these risk factors may prove to be useful adjuncts to comprehensive hearing conservation programs.

10) Firefighters' hearing loss: a comparison with the general population.

(in preparation) (Specifically relates to aims #1,#2)

Firefighters' significant noise exposure and risk of hearing loss is well documented. This study attempts to quantify the average excess hearing losses in firefighters due to noise exposure as compared with an otologically normal population. In addition, the degree of hearing deficit that begins to impair firefighter job performance and safety (fitness for duty) is not yet clear.

In this study, we are comparing firefighters classified as abnormal in 1996 with standardized population databases (Database A from ISO 1999) from the American National Standards Institute. Initial results indicate that our cohort's hearing levels are worse than those of an otologically normal population, especially in the higher frequencies. The relative risk of hearing loss in excess of that which is associated with the onset of functional impairment appears to be about 4.5 for our firefighters compared to the general population.

We had already determined which firefighters failed NFPA and other recommended minimum hearing guidelines based on their 1996 examinations. These criteria are based primarily on lower frequency thresholds, and are not validated.

Further prospective study of our cohort should assist us in determining the threshold of hearing loss that begins to impair safety. Our baseline ratings based on comparisons with recommended criteria and thresholds for a standardized population will allow us to objectively compare the hearing profiles of firefighters who have experienced adverse outcomes versus those who have not.

11) Medical surveillance of hazardous materials response fire fighters: a longitudinal study of end-organ effect markers. (in preparation)

(Specifically relates to aims #1,#2)

This study is a prospective evaluation of the possible clinical and subclinical health effects of hazardous materials firefighting duty and an examination of the utility of end-organ effect markers as medical surveillance tools.

No clinical health effects were reported during the study period. This is consistent with our previous studies of hazardous materials incidents responded to by the same six Massachusetts regional teams. In the first six years of hazardous materials duty for these teams, no significant chemical exposures were reported and minor musculoskeletal injuries were reported in only a single incident.

To study the subclinical health effects of firefighting, we studied liver and renal function tests and hematologic indices as markers of end-organ effect. Such testing has been recommended as standard or optional components of hazardous materials and firefighter medical surveillance. We compared markers of end-organ effects within hazardous materials technicians over time and also compared their initial and follow-up results to those of a control group of support members. Support members are presumed to have a very limited potential for exposure during hazardous materials duty, since they do not enter the "hot" or contaminated zone of an accident and their role is ancillary.

We found no clinically significant differences in any of the effect markers studied across exposure status: hazardous materials technicians versus support controls. Likewise, no clinically significant changes were observed within subjects over time with the exception of ALT values in 1998. A change of the same magnitude was also observed in the support controls in 1988 suggesting that a factor other than exposure accounted for the increase. The use of a new laboratory with a higher reference range by one of the hospitals in 1998 was identified as the cause by reexamining the data according to the hospital and laboratory used. Data by hospital and laboratory for the entire cohort and the subcohort with five years of follow-up both showed that the increase was isolated to those tested at a different laboratory in 1998.

Although hazardous materials duty obviously has the potential for serious exposures and injuries due to explosions, fires and other releases of dangerous substances, this study and our previous studies suggest that clinical health effects are infrequent among hazardous materials technicians. In addition, we could detect no consistent subclinical effects of hazardous materials duty on liver and renal function or hematologic indices. Therefore, current protective equipment and procedures including decontamination appear to be effective in protecting these organ systems. Alternatively, the effect markers used are insufficiently sensitive to detect subclinical effects. Nonetheless, the five year study of the Metrofire subcohort is reassuring.

Although the determination of these end-organ effect markers as a baseline assessment for comparison after significant exposures is still prudent, the results of this study suggest that annual routine testing of these indices is not required and their clinical utility in identifying subclinical health effects is limited. Because certain laboratory values may vary as a function of age, it may be desirable to retest at some interval. The results of the subcohort followed over five years suggest that in the absence of a clinical indication, it is unnecessary to reassess the indices studied more frequently than every five years.

12) Medical surveillance of hazardous materials response fire fighters: a longitudinal study of pulmonary function. (in preparation)
(Specifically relates to aim #3,#4)

The purpose of this investigation is to longitudinally study the pulmonary function of firefighters to determine if they lose pulmonary function at a more exaggerated rate than reference groups. We are also studying whether risk factors that may be associated with

hyperreactive airways predict accelerated declines in lung function to determine whether conditions associated with acute pulmonary effects predict longitudinal changes in pulmonary function.

The preliminary results showed three basic findings. First, although we observed a significant decline in the % predicted FEV1 for the entire cohort from year 01 to year 03 of the study, this difference was clinically insignificant. Second, the magnitude of decline was similar irrespective of the presence or absence of risk factors for hyperreactive airways or accelerated loss of pulmonary function.

Third, when we examined the five year follow-up data for the Metrofire subcohort, there was no evidence for any change in the % predicted FVC or FEV1 over the five years of observation. This was also true when we stratified the firefighters by the presence or absence of pulmonary risk factors.

The preliminary results suggest the following. First, firefighters do not appear to lose pulmonary function at a more exaggerated rate than predicted. Second, although firefighters with various pulmonary risk factors had consistently lower spirometric values, they did not experience more exaggerated declines in pulmonary function during the study period. Therefore, the preliminary results do not support fitness for duty criteria which would exclude firefighters with pulmonary problems or risk factors who are currently capable of doing their job on the basis of a perceived risk of future impairment.

Nevertheless, the follow-up period may have been too short and/or the sample size was too small to detect more significant changes. In addition, paired comparisons at two time points may be too sensitive to small changes in measurement techniques that could result in statistically significant differences that do not persist over longer periods of observation. In a previous study of the Metrofire subcohort over two years (1992/1993-1995), we had observed a trend towards a lower % predicted FEV1 similar to what we observed for the full cohort from 1996-1998 (year 01-03) in the current study. Yet, five year follow up showed no decline as a function of time in % predicted FEV1 or FVC. Therefore, continued longitudinal study of firefighters with and without risk factors is warranted.

