Risks of a Lifetime in Construction. Part II: Chronic Occupational Diseases

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Background *We developed working-life estimates of risk for dust-related occupational lung disease, COPD, and hearing loss based on the experience of the Building Trades National Medical Screening Program in order to (1) demonstrate the value of estimates of lifetime risk, and (2) make lifetime risk estimates for common conditions among construction workers.*

Methods *Estimates of lifetime risk were performed based on 12,742 radiographic evaluations, 12,679 spirometry tests, and 11,793 audiograms.*

Results *Over a 45-year working life, 16% of construction workers developed COPD, 11% developed parenchymal radiological abnormality, and 73.8% developed hearing loss. The risk for occupationally related disease over a lifetime in a construction trade was 2–6 times greater than the risk in non-construction workers.*

Conclusions *When compared with estimates from annualized cross-sectional data, lifetime risk estimates are highly useful for risk expression, and should help to inform stakeholders in the construction industry as well as policy-makers about magnitudes of risk.* Am. J. Ind. Med. *© 2014 Wiley Periodicals, Inc.*

KEY WORDS: diseases; occupation; lifetime risk; construction industry; lung disease; COPD; hearing loss; surveillance; radiographic; audiometry; spirometry

INTRODUCTION

Lifetime estimates of risk have been used with great effectiveness to influence individuals' perceptions of risk and policy priorities in other fields of public health [Arndt et al., 2004], but this has not been done in occupational safety and health. Instead, the magnitude of occupational risk has generally been described as odds ratios, population attributable risks or relative risk based on cross-sectional data or short time periods [Fosbroke et al., 1997]. While such studies are useful, they tend to understate risks [Robinson et al., 1995]. Longitudinal cohort studies can improve on these deficiencies [Schubauer-Berigan et al., 2009; Neitzel et al., 2011], but such studies are difficult to maintain due to reasons such as investigators losing interest/funding or participants leaving the cohort. Consequently, there have been very few longitudinal studies of occupational risks [Arndt et al., 2005]. This study is based on results from a medical surveillance program with 16 years of experience to assess risk of chronic obstructive pulmonary disease (COPD), occupational lung disease, and hearing loss over a working lifetime.

Construction workers are at an elevated risk for several chronic medical conditions, including COPD, pneumoconiosis consisting primarily of asbestosis and silicosis, and noise-induced hearing loss [Dement et al., 2003, 2005, 2009, 2010]. Occupational exposure to the general category of "vapors, gases, dusts, and fumes" (VGDF) has been associated with increased COPD risk [Becklake, 1989; National Institute for Occupational Safety and Health, 2002;

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Trupin et al., 2003; American Thoracic Society, 2005; Balmes, 2005; Blanc et al., 2009a,b; Global Initiative for Chronic Obstructive Lung Disease, 2013]. As components of the broad category of VGDF, construction workers have significant exposures to known occupational risks for COPD: organic dusts, wood dusts, cadmium, lead, silica, welding fumes, cement dust, and isocyanates. Glencross et al. [1997] found that sheet metal workers followed over a 10-year period sustained significant accelerated loss of forced expiratory volume (FEV1) if they were exposed to asbestos and had smoked. Using spirometry data from the National Health and Nutrition Examination Survey (NHANES) III for 1988–1994, workers in construction trades were found to be at an increased risk of COPD [Hnizdo et al., 2002], and Bergdahl et al. [2004] found an increased risk of COPD-related mortality among construction workers. Hnizdo et al. [2002] estimated a population attributable risk (PAR) for work-related COPD of 19% overall and 31% among those who never smoked. Blanc et al. [2009a] suggested that the occupational PAR for COPD might be higher due to joint effects of smoking and occupational factors. Dement et al. [2009] reported that compared to the general US population construction workers had a COPD odds ratio between 1.6 and 2.9 by trade after adjusting for age, race, sex, smoking, and years worked.

Although asbestos use has been discontinued for over 30 years, construction workers still face significant risks for asbestos-related lung diseases [Dement et al., 2003; Cullen et al., 2005; Welch et al., 2007]. Nationally, the age-adjusted mortality rate from asbestosis increased from 2.04/million in 1980 to 5.04/million in 1990, and again to 6.58/million in 2002; among these deaths, when occupation was coded on the death certificate, construction occupations made up seven of the top 10 occupations. Exposures for some construction workers regularly exceeded 20–40 fibers per cubic centimeter (f/cm^3), levels that are 400 times the current Occupational Safety and Health Administration (OSHA) standard of 0.1 f/cm^3 [Paik et al., 1973]. Exposures to asbestos were first regulated in the 1970s, but due to the long latency for pneumoconiosis, many of the cases of asbestos-related diseases found today are occurring among workers who were first exposed in 1970 or earlier.

Excess noise exposures among construction workers and high rates of noise-induced hearing loss among these workers are well documented for more than 40 years [Workers' Compensation Board of British Columbia, 2000; Kerr et al., 2002; Suter, 2002]. More recent studies in Washington State found that excessive noise exposures are still common in the construction trades [Seixas et al., 2001; Neitzel et al., 2011]. The rate of hearing loss claims in the construction industry in Washington State is approximately five times higher than the average rate for all industries combined [Daniell et al., 2002]. Dement et al. [2005] reported that in a medical surveillance program among construction workers, 60.3% of workers examined were found to have material impairment of hearing by the NIOSH criteria; the prevalence ranged from 47% among insulators to 78% among plumbers and steamfitters.

Taken together, the prior research expresses the risks of occupational disease as odds ratios, relative risks, and population attributable risks. Those measures are useful for identifying high-risk populations and for setting priorities for public health action, but not that useful when communicating risk to an individual person with the relevant occupational exposures. In order to accomplish this, working lifetime estimates are a more suitable measure.

The objectives of this study are to develop working-life estimates of risk for parenchymal radiological abnormality, COPD, and hearing loss based on the experience of the Building Trades National Medical Screening Program in order to (1) demonstrate the value of estimates of lifetime risk, and (2) make lifetime risk estimates for common conditions among construction workers.

METHODS

Building Trades National Medical Screening Program (BTMed)

For the estimates of lifetime risk for COPD, parenchymal radiological abnormality, and noise-induced hearing loss, data from the Building Trades National Medical Screening Program (BTMed) were used. In 1993, Congress added Section 3162 to the Defense Authorization Act, calling for the Department of Energy (DOE) to determine whether workers within the nuclear weapons facilities were at "significant risk" for work-related illnesses and if so, to provide them with medical surveillance. In 1996 and 1997, the DOE established surveillance programs for construction workers at the Hanford Nuclear Reservation in Richland, Washington; the Oak Ridge Reservation in Oak Ridge, Tennessee; and the Savannah River Site (SRS) in Aiken, South Carolina; and in 1999 the Amchitka Atomic Test Site in Alaska was added. The number of DOE sites included was expanded in 2004 to include Portsmouth and Paducah, and in 2005 and 2006 an additional 16 facilities were added and consolidated to form BTMed. BTMed now covers 26 sites including Idaho National Laboratory, Rocky Flats, Fernald, Kansas City Plant and Brookhaven National Laboratory. BTMed is conducted by a consortium which includes The Center for Construction Research and Training; University of Cincinnati; Duke University; and Zenith Administrators. BTMed is the largest medical monitoring program ever undertaken for a broad spectrum of US construction trades and has reported on topics such as the prevalence of respiratory diseases, hearing loss, beryllium sensitivity, COPD, and mortality patterns [Dement et al., 2003, 2005, 2009, 2010; Welch et al., 2004, 2013].

BTMed provides a comprehensive medical screening examination tailored to the exposures reported by workers during an in-depth occupational history interview. The respiratory examination includes a respiratory history and symptom questionnaire; a posterior anterior (P–A) chest radiograph, classified by a B-reader according to International Labor Organization (ILO) Classification of Radiographs of Pneumoconiosis [International Labour Office, 1980, 2011]; and spirometry. All participating clinical facilities agree to obtain spirometry according to American Thoracic Society (ATS) standards [American Thoracic Society, 1995, 2005]. Audiometric tests are conducted according to procedures recommended by the National Institute for Occupational Safety and Health (NIOSH) at frequencies of 500–8,000 Hz [National Institute for Occupational Safety and Health, 1998].

Approximately 14,400 participants who had completed a medical screening exam between 1997 and 2010 were included in this study. Over 88% of participants are white and fewer than 6% are female. Because participants can chose to accept or reject any given screening test, or they may not be eligible for a particular screening test due to past medical history or other considerations, the number of participants included in the analyses varied by condition: COPD (n = 12,679), parenchymal radiological abnormality (n = 12,742), and hearing loss (n = 11,739).

COPD, Parenchymal Radiological Abnormality, and Noise-Induced Hearing Loss Case Definitions

Estimates of age-specific prevalence for COPD, parenchymal radiological abnormality, and noise-induced hearing loss were derived from the BTMed data through December 2010. All analyses were restricted to males as the small number of females did not allow for stable estimates by trade; all races were combined in the analyses. The current analyses are based on initial exams only. We used the following case definitions:

COPD was defined as an FEV1/FVC ratio below the lower limit of normal (LLN) using the prediction equations of Hankinson et al. [1999] [American Thoracic Society, 2005; Hnizdo et al., 2006; Hansen et al., 2007; Enright et al., 2008; Swanney et al., 2008],

Parenchymal radiological abnormality was defined as a radiographic chest film change with any dust-related parenchymal abnormality with a profusion score of 1/0 or greater bilaterally for any shape or size of small opacity as reported by a B-reader certified by the National Institute for Occupational Safety and Health (NIOSH) using the International Labour Office (ILO) classification system [ILO, 2011],

Hearing loss was defined using NIOSH criteria for 'material hearing impairment' [National Institute for Occupational Safety and Health, 1998]. Material hearing impairment was defined as an average hearing threshold for both ears that exceeds 25 dB at 1,000; 2,000; 3,000; and 4,000 Hz [National Institute for Occupational Safety and Health, 1998]. Hearing sensitivity declines gradually and progressively with age; therefore, meaningful assessments of noise-induced hearing loss risks among construction trades requires age-specific prevalence data for a comparison population of workers without elevated work-related noise exposures. NIOSH provided hearing loss data from the American National Standard Institute (ANSI) S12.13 Working Group, which consisted of 22 diverse companies within the US and Canada [Adera and Gaydos, 1997; Adera et al., 2000]. A comparison population of industrial workers from companies identified by Adera et al. [2000] as having been exposed to <80 dBA was selected as the comparison population for this study. Our quality control procedures for audiometry are described in more detail in another report [Dement et al., 2005]. All providers were required to follow the protocol established by NIOSH [National Institute for Occupational Safety and Health, 1998], and each exam was reviewed by a program nurse.

Quality Assurance

BTMed contracts with a large number of medical providers across the US to perform exams (approximately 170 providers, of which a core of 12 providers conduct over 80 percent of exams). These providers are contractually obligated to follow detailed procedures for each examination. BTMed staff review tracings for spirometry test results for technical errors causing unacceptable curves and non-repeatable tests when results are submitted to the database, and the BTMed medical director provides feedback to clinical providers annually. In addition, the worker is offered the opportunity to return to the clinic for repeat testing whenever the spirometry is unacceptable. Two credentialed B-readers perform reviews of X-rays, including review of the quality of the film (or digital image). Tests that do not meet any of the quality requirements specified may be repeated.

Lifetime Risk Estimation

We defined working life as starting at age 20 years and extending 45 years to age 65 years, unless a participant died earlier than that. The probabilities of dying at, say, age 40 years therefore reflects the risks of a 20-year working life in construction.

Estimates of the age conditional probability of developing COPD and parenchymal radiological abnormality were developed using methods adopted from procedures used to estimate age-conditional probabilities of developing cancer [Fay et al., 2003; Fay, 2004]. The DevCan software

developed by the National Cancer Institute (NCI) was employed for these estimates [National Cancer Institute, 2011].

DevCan uses cross-sectional incidence and mortality rates in a life table context to develop age-conditional probabilities of developing a disease while taking into account competing risks. Required inputs to the DevCan model for developing a disease include age-specific incidence of the disease, age-specific mortality rates for the disease under study, and age-specific all-causes mortality rates for the theoretical study population. For the current study estimates, DevCan age-specific all-cause mortality rates for the U.S. male population (all races combined) for 2005–2007 were used.

Age-specific incidence rates for COPD and occupational lung disease were estimated using BTMed cross-sectional prevalence data employing methods developed by Leske et al. [1981]. Using the Leske method, incidence was estimated from BTMed prevalence data assuming: (1) the duration of a disease is lifelong after diagnosis; (2) the mortality risk for those with and without a disease is approximately the same; and (3) the disease incidence is reasonably stable over time. Under these assumptions, the probability of developing COPD or parenchymal radiological abnormality during a given 5-year age interval was estimated by subtracting consecutive age-specific prevalence proportions. These probabilities of developing a disease by 5-year age categories were then converted to incidence rates using life table methods [Bender et al., 1992]. In order to smooth prevalence estimates across age categories, logit models for disease prevalence were fitted to the BTMed data for each disease with age and trade groups as independent variables. Predicted prevalence by age group for each disease was then used to estimate age-specific incidence for input into the DevCan model as described above.

The DevCan program also requires age-specific death rates for the conditions in question. NIOSH Life Table Analysis System (LTAS.NET Version 3.03) death rates for COPD and pneumoconiosis for 2005–2009 were used in the DevCan program [National Institute for Occupational Safety and Health, 2010]. Data for all races were combined for these estimates.

Estimates for lifetime risk of noise-induced hearing loss employed a different procedure in order to account for rising age-specific risk among individuals without elevated work-related noise exposures. In order to refine prevalence estimates across age categories, log-binomial models for prevalence of material hearing impairment were fitted to the BTMed data and comparison population data for each disease with age and trade groups as independent variables. For hearing impairment, a log-binomial model was chosen over a logit model due to the high prevalence, thus suggesting that an odds ratio might not be a good approximation of the prevalence ratio [Spiegelman and Hertzmark, 2005]. Model fit was assessed, and adding age raised to the second power produced a superior fit to the observed data for both construction workers and the comparison population. Predicted prevalence by construction trade and age group was compared to data for the external low-noise exposed population for purposes of risk estimation. The estimates of lifetime risk for hearing loss was cut off at age 65 since there is little evidence that noise-induced hearing loss is a long latency condition, and also since loss of hearing is ubiquitous in the older age groups [Cruickshanks et al., 1998].

In addition, the medical screening program included Administrative/Scientific/Security workers who were employed by construction employers, but not engaged in construction activities. Therefore, these workers were used as an internal low exposure comparison group. The trades, Construction Worker NEC (not elsewhere classified), Pile Driver, Building Maintenance NEC, Elevator Constructor, and Welders, had fewer than 100 workers and were subsequently combined into one group named "All other construction trades," which excluded Administrative/Scientific/Security workers.

Human Subjects Protection

BTMed is conducted under the oversight of two Institutional Review Boards (IRBs): The Department of Energy Central IRB is the IRB of record and the CPWR: The Center for Construction Research and Training provides secondary review.

RESULTS

Table I shows the distribution of BTMed participants by construction trade for each condition studied. The number of participants included in the analysis for each condition were: lung disease (n = 12,742), COPD (n = 12,679), and hearing loss (n = 11,739). The trades with the largest number of participants were plumbers and fitters, electricians, and laborers. The number of participants included in the internal control group were: COPD (n = 360; 2.8% of all examined), parenchymal radiological abnormality (n = 356; 2.8%), and hearing loss (n = 345; 2.9%).

Lifetime Probability of COPD

Table II shows working lifetime probability of COPD based on spirometry. For all construction trades combined, the lifetime probability was 15.9% compared to 7.9% in the Administrative/Scientific/Security subgroup. There was considerable variation in risk between trades, from 12.3% for boilermakers to over 33.3% for roofers.

TABLE I. Summary of Building Trades National Medical Screening program (BTMED) Participants by Trade Group Included in Lifetime Risk Analyses

	Number of workers included in analyses[a]		
Trade group	**Spirometry**	**Radiography**	**Audiometry**
Asbestos worker/insulator	356	361	348
Boilermaker	262	261	241
Carpenter	922	928	820
Cement mason/brick mason/plasterer	219	224	208
Electrician	2,421	2,427	2,283
Ironworker	767	766	685
Laborer	1,731	1,753	1,601
Machinist and mechanical trade	191	194	184
Millwright	228	230	191
Operating engineer	822	841	772
Painter	340	338	316
Plumber, steamfitter, pipefitter	2,566	2,548	2,343
Roofer	109	110	108
Sheetmetal worker	741	755	697
Teamster	476	482	444
All other construction trades	168	168	153
Administrative/scientific/security[b]	360	356	345
All construction workers combined	12,679	12,742	11,739

[a]All analyses of trade-specific risks were restricted to initial exams for male construction trade workers.
[b]These are non-construction trade workers included for comparison purposes.

TABLE II. Age-Conditional Probability of Developing Chronic Obstructive Pulmonary Disease (COPD) for Construction Workers Entering Trades at Age 20 years

	Cumulative probability of developing COPD (%) for workers entering trade at age 20												
Attained age (years)	**25**	**30**	**35**	**40**	**45**	**50**	**55**	**60**	**65**	**70**	**75**	**80**	**85**
Trade group													
Asbestos worker/insulator	0.8%	1.8%	3.0%	4.2%	5.6%	7.1%	8.7%	10.5%	12.3%	14.1%	15.9%	17.4%	18.7%
Boilermaker	0.5%	1.2%	1.9%	2.7%	3.6%	4.6%	5.7%	6.8%	8.0%	9.2%	10.4%	11.5%	12.3%
Carpenter	0.9%	1.9%	3.1%	4.4%	5.9%	7.4%	9.1%	10.9%	12.8%	14.7%	16.5%	18.2%	19.4%
Cement mason/brick mason/plasterer	1.0%	2.3%	3.6%	5.2%	6.8%	8.6%	10.6%	12.7%	14.8%	17.0%	19.1%	20.9%	22.4%
Electrician	0.6%	1.4%	2.2%	3.1%	4.2%	5.3%	6.5%	7.8%	9.2%	10.6%	12.0%	13.2%	14.2%
Ironworker	0.6%	1.4%	2.3%	3.3%	4.4%	5.6%	6.8%	8.2%	9.6%	11.1%	12.5%	13.8%	14.8%
Laborer	0.8%	1.8%	2.9%	4.1%	5.4%	6.8%	8.4%	10.1%	11.8%	13.6%	15.3%	16.8%	18.0%
Machinist and mechanical trade	0.7%	1.6%	2.6%	3.8%	5.0%	6.3%	7.8%	9.3%	10.9%	12.6%	14.2%	15.6%	16.7%
Millwright	0.6%	1.3%	2.1%	2.9%	3.9%	5.0%	6.1%	7.3%	8.6%	9.9%	11.2%	12.4%	13.3%
Operating engineer	0.7%	1.6%	2.6%	3.7%	4.9%	6.2%	7.6%	9.1%	10.7%	12.3%	13.8%	15.2%	16.3%
Painter	1.0%	2.3%	3.7%	5.2%	6.9%	8.7%	10.7%	12.8%	15.0%	17.2%	19.3%	21.2%	22.6%
Plumber, steamfitter, pipefitter	0.7%	1.5%	2.5%	3.5%	4.7%	6.0%	7.3%	8.8%	10.3%	11.9%	13.4%	14.7%	15.8%
Roofer	1.6%	3.5%	5.7%	8.1%	10.6%	13.4%	16.3%	19.4%	22.5%	25.7%	28.7%	31.3%	33.3%
Sheetmetal worker	0.7%	1.5%	2.5%	3.5%	4.7%	5.9%	7.3%	8.7%	10.2%	11.8%	13.3%	14.6%	15.7%
Teamster	0.8%	1.8%	2.9%	4.1%	5.5%	6.9%	8.5%	10.2%	12.0%	13.8%	15.5%	17.0%	18.3%
All other construction trades	0.5%	1.2%	1.9%	2.8%	3.7%	4.7%	5.8%	6.9%	8.2%	9.4%	10.6%	11.7%	12.6%
Administrative/scientific/security	0.3%	0.7%	1.2%	1.7%	2.3%	2.9%	3.6%	4.3%	5.1%	5.9%	6.7%	7.4%	7.9%
All construction workers combined	0.7%	1.6%	2.5%	3.6%	4.8%	6.1%	7.5%	8.9%	10.5%	12.0%	13.5%	14.9%	15.9%

Lifetime Probability of Parenchymal Radiological Abnormality

Table III shows working lifetime probability of parenchymal radiological abnormality defined as a chest X-ray profusion >1/0. For all construction trades combined, the lifetime probability was 11% compared to 3.7% in the Administrative/Scientific/Security subgroup. There was considerable variation in risk between trades, from 5.4% for operating engineers to over 22% for asbestos workers.

Lifetime Probability of Hearing Loss

Table IV shows working lifetime probability of hearing loss based on audiometry. For all construction trades combined, the lifetime probability was 73.8% compared to 43.5% in the internal comparison group of Administrative/Scientific/Security workers, and 53.1% in the external control group of low noise industrial workers. There was considerable variation in risk between trades, although it was somewhat less than for COPD or parenchymal radiological abnormality.

Table V shows the relative risk of hearing loss, comparing construction workers to the internal comparison group as well as the external comparison group. The relative risk compared to the internal comparison was elevated for all construction trades, although the lower confidence limit (LCL) was slightly below 1.0 for roofers. Compared to the external group of industrial workers, the relative risk was somewhat lower than for the internal comparison group.

DISCUSSION

Our analysis found that over a 45-year working life employed in construction, 15.9% of construction workers developed COPD, 11% developed parenchymal radiological abnormality, and 73.8% developed material hearing loss. These risks reflect an accumulation of all exposures our participants have faced, both occupational and non-occupational. For instance, although the smoking rate varies a great deal between construction trades, construction workers have typically been much more likely to smoke and less likely to quit than white collar workers [Ringen et al., 2002; Lee et al., 2007].

People's perceptions of the innumerable risks they face in daily living vary greatly and are influenced by a number of sources of conflicting information. Over 30 years ago, Slovic [1987] showed that an individual's ranking of perceived risks may have little relationship to the scientific evidence about

TABLE III. Age-Conditional Probability of Developing Parenchymal Radiological Disorder (Chest X-Ray ILO Profusion Score of ≥1/0[a]) for Construction Workers Entering Trades at Age 20 Years

	Cumulative probability of developing ILO profusion score ≥ 1/0 (%) for workers entering trade at age 20												
Attained age (years)	**25**	**30**	**35**	**40**	**45**	**50**	**55**	**60**	**65**	**70**	**75**	**80**	**85**
Trade group													
Asbestos worker/insulator	0.2%	0.4%	0.7%	1.2%	1.9%	2.9%	4.2%	6.0%	8.3%	11.3%	14.9%	18.8%	22.4%
Boilermaker	0.1%	0.3%	0.5%	0.8%	1.2%	1.9%	2.7%	3.9%	5.4%	7.4%	9.9%	12.6%	15.1%
Carpenter	0.1%	0.2%	0.3%	0.5%	0.8%	1.3%	1.9%	2.7%	3.7%	5.1%	6.8%	8.8%	10.6%
Cement mason/brick mason/plasterer	0.1%	0.2%	0.3%	0.5%	0.8%	1.2%	1.8%	2.6%	3.6%	5.0%	6.6%	8.5%	10.3%
Electrician	0.1%	0.2%	0.3%	0.6%	0.9%	1.3%	1.9%	2.8%	3.9%	5.3%	7.1%	9.0%	10.9%
Ironworker	0.1%	0.2%	0.4%	0.7%	1.0%	1.5%	2.2%	3.2%	4.5%	6.2%	8.2%	10.5%	12.7%
Laborer	0.1%	0.2%	0.4%	0.6%	0.9%	1.4%	2.0%	2.9%	4.0%	5.5%	7.3%	9.4%	11.4%
Machinist and mechanical trade	0.0%	0.1%	0.2%	0.3%	0.5%	0.7%	1.0%	1.5%	2.1%	2.9%	3.9%	5.0%	6.1%
Millwright	0.1%	0.2%	0.3%	0.6%	0.9%	1.3%	1.9%	2.8%	3.9%	5.3%	7.1%	9.0%	10.9%
Operating engineer	0.0%	0.1%	0.2%	0.3%	0.4%	0.6%	0.9%	1.3%	1.9%	2.6%	3.4%	4.4%	5.4%
Painter	0.1%	0.2%	0.3%	0.5%	0.8%	1.2%	1.7%	2.4%	3.4%	4.7%	6.2%	8.0%	9.7%
Plumber, steamfitter, pipefitter	0.1%	0.2%	0.3%	0.6%	0.9%	1.3%	1.9%	2.8%	3.9%	5.4%	7.1%	9.2%	11.1%
Roofer	0.1%	0.2%	0.4%	0.6%	1.0%	1.5%	2.2%	3.1%	4.4%	6.0%	8.0%	10.3%	12.4%
Sheetmetal worker	0.1%	0.3%	0.5%	0.8%	1.2%	1.9%	2.7%	3.9%	5.4%	7.4%	9.8%	12.5%	15.1%
Teamster	0.1%	0.2%	0.3%	0.5%	0.7%	1.1%	1.6%	2.3%	3.3%	4.5%	6.0%	7.7%	9.4%
All other construction trades	0.1%	0.2%	0.5%	0.8%	1.2%	1.8%	2.6%	3.7%	5.2%	7.1%	9.4%	12.0%	14.5%
Administrative/scientific/security	0.0%	0.1%	0.1%	0.2%	0.3%	0.4%	0.6%	0.9%	1.3%	1.7%	2.3%	3.0%	3.7%
All construction trades combined	0.1%	0.2%	0.3%	0.6%	0.9%	1.3%	2.0%	2.8%	3.9%	5.3%	7.1%	9.1%	11.0%

[a]ILO, 2011. International Labor Organization.

TABLE IV. Age-Specific Prevalence of Material Hearing Impairment for Construction Workers and Comparison Population

	Age category (years)								
Trade group	**20–24**	**25–29**	**30–34**	**35–39**	**40–44**	**45–49**	**50–54**	**55–59**	**60–64**
Asbestos worker/insulator	2.4%	4.6%	8.1%	13.5%	20.9%	30.4%	41.3%	52.6%	62.7%
Boilermaker	3.3%	6.2%	10.9%	18.1%	28.0%	40.7%	55.4%	70.5%	84.1%
Carpenter	3.4%	6.4%	11.4%	18.9%	29.3%	42.5%	57.9%	73.7%	87.8%
Cement mason/brick mason/plasterer	2.6%	4.9%	8.7%	14.5%	22.4%	32.6%	44.3%	56.4%	67.3%
Electrician	2.4%	4.5%	8.0%	13.2%	20.5%	29.7%	40.4%	51.5%	61.4%
Ironworker	3.4%	6.4%	11.2%	18.6%	28.9%	42.0%	57.1%	72.7%	86.7%
Laborer	2.7%	5.1%	9.0%	14.9%	23.0%	33.5%	45.5%	58.0%	69.1%
Machinist and mechanical trade	2.5%	4.7%	8.3%	13.8%	21.3%	31.0%	42.2%	53.7%	64.0%
Millwright	3.1%	5.9%	10.4%	17.2%	26.6%	38.7%	52.6%	66.9%	79.8%
Operating engineer	3.1%	5.9%	10.5%	17.4%	27.0%	39.2%	53.3%	67.9%	81.0%
Painter	2.8%	5.3%	9.3%	15.5%	24.0%	34.8%	47.4%	60.3%	71.9%
Plumber, steamfitter, pipefitter	2.8%	5.4%	9.5%	15.7%	24.4%	35.4%	48.2%	61.4%	73.2%
Roofer	2.2%	4.1%	7.3%	12.1%	18.8%	27.4%	37.2%	47.4%	56.5%
Sheetmetal worker	3.0%	5.7%	10.1%	16.8%	26.1%	37.9%	51.5%	65.6%	78.2%
Teamster	2.8%	5.3%	9.5%	15.7%	24.3%	35.3%	48.0%	61.2%	72.9%
All other construction trades	3.3%	6.2%	11.0%	18.2%	28.2%	40.9%	55.6%	70.9%	84.5%
Administrative/scientific/security	1.7%	3.2%	5.6%	9.4%	14.5%	21.1%	28.7%	36.5%	43.5%
All construction workers combined	3.1%	5.6%	9.7%	15.8%	24.2%	34.9%	47.6%	61.0%	73.8%
Low noise industrial controls	2.1%	3.9%	6.9%	11.4%	17.7%	25.7%	35.0%	44.6%	53.1%

either the magnitude or severity of risks; this was especially true for chronic disease risks. Conflicting views of risks among ordinary people and experts about what is "perceived" and what is "real" have had a polarizing effect that has not benefited risk communication or regulation of risks [Finkel, 2008].

Lifetime risk has been presented in a few areas of public health that have garnered substantial policy emphasis, such as

TABLE V. Relative Risk of Material Hearing Impairment for Construction Workers by Trade, Including Lower (LCL) and Upper (UCL) Confidence Limits

	External comparison[a]			Internal comparison[b]		
Trade group	**Relative risk**	**LCL**	**UCL**	**Relative risk**	**LCL**	**UCL**
Asbestos worker/insulator	0.98	0.83	1.16	1.44	1.14	1.82
Boilermaker	1.31	1.14	1.51	1.93	1.56	2.40
Carpenter	1.37	1.22	1.54	2.02	1.65	2.47
Cement mason/brick mason/plasterer	1.05	0.86	1.28	1.55	1.19	2.01
Electrician	0.96	0.85	1.08	1.41	1.15	1.73
Ironworker	1.36	1.21	1.52	1.99	1.63	2.44
Laborer	1.08	0.96	1.22	1.59	1.30	1.95
Machinist and mechanical trade	1.00	0.82	1.23	1.47	1.13	1.91
Millwright	1.25	1.04	1.49	1.84	1.44	2.34
Operating engineer	1.27	1.12	1.43	1.86	1.52	2.29
Painter	1.12	0.96	1.31	1.65	1.32	2.08
Plumber, steamfitter, pipefitter	1.14	1.02	1.28	1.68	1.38	2.06
Roofer	0.88	0.67	1.16	1.30	0.94	1.79
Sheetmetal worker	1.22	1.08	1.38	1.80	1.46	2.21
Teamster	1.14	0.99	1.32	1.68	1.35	2.09
All other construction trades	1.32	1.12	1.56	1.94	1.54	2.46

[a]NIOSH low-noise exposed industrial population.
[b]Department of Energy (DOE) Administrative/Scientific/Security workers.

breast cancer [Phillips et al., 1999], hypertension [Vasan et al., 2002], dementia [Seshadri et al., 1997], and total cardiovascular disease [Wilkins et al., 2012]. Although diabetes is one of the main public health problems of our era, it was not until the Centers for Disease Control and Prevention (CDC) published its estimates of lifetime risks for diabetes in 2003 that the full magnitude of this epidemic began to be realized. Up until that point, risk for diabetes had been expressed as an annual cross-sectional prevalence. In 2000, the CDC estimated that 4% of the population had diabetes, and this was projected to increase to 11% by 2050 [Boyle et al., 2001]. The new lifetime estimate found that over 30% of males and almost 40% of females born in 2000 were likely to develop diabetes in their lifetime [Narayan et al., 2003], and this presentation had a great impact on perceptions of diabetes risk and on public health policy [Narayan et al., 2011]. It was, in many ways, a "game changer." In policy proceedings, such as legislative hearings, a simple expression of risk is very powerful [Kleinkauf, 1981; Eddy et al., 1982].

In spite of this demonstrated effect on policy, lifetime risk estimates have not been adopted to characterize occupational safety and health risks, even as this field has struggled to maintain its policy relevance and funding for occupational safety health regulation and research has remained stagnant for the last two decades [AFL-CIO, 2013]. The data presented on hearing loss point to the importance of using a measure of lifetime risk to communicate likelihood of an occupational disease. A risk expressed as a 25% increase in hearing loss above that of industrial workers, or even the five-fold risk reported from Washington State by Daniell et al. [2002], does not communicate the finding that just about all construction workers develop material hearing loss over a lifetime. In addition, the lifetime risk expression for hearing loss shows that within only a few years in construction, material hearing loss is already starting to develop. On average, 3% of construction workers in the early 20 years of age have already developed material hearing loss. This key finding would be missed if risk were expressed as an average for all workers.

For chronic diseases, in particular, it is very important to measure cumulative risk through end of life since a large proportion of diagnosed disease will not be expressed until after retirement. According to our analysis, at retirement age of 65 years, there is a very large prevalence of latent occupational lung disease and COPD. For instance, for all construction trades combined, the cumulative prevalence of parenchymal radiological abnormality at age 65 years is 3.9%, which is slightly less than one-third of the cumulative prevalence of 11.0% achieved at age 85 (see Table II). While the relative risk (RR) for all construction trades combined compared to the population of Administrative/Scientific/Security personnel is about the same at age 65 and age 85 years (3.9% vs. 1.3% is a RR of 3 at age 65; 11.0% vs. 3.7% in a RR of 3.7 at age 85 years), the absolute risk is easier to understand when it is expressed as 11%.

Our data have limitations. The clinical examinations were performed by many different physicians across the country, and although BTMed specified the quality criteria to be used for the clinical examinations, and conducted a nurse review of each examination report, and additional periodic quality reviews with both record review and site visits, we cannot be sure that all testing was conducted according to specifications. The workers examined were volunteers from a much larger cohort of workers ever employed at these Department of Energy facilities, and we cannot be sure they are fully representative of the population from which they come.

Different working definitions of COPD exist. One area of contention is whether bronchodilation should be required. Some clinical guidelines, such as those developed by the Global Initiative for Chronic Obstructive Lung Disease [GOLD, 2013], recommend use of post bronchodilator spirometry, but population based studies generally do not apply those clinical criteria [Swanney et al., 2008]. We relied on results from pulmonary function tests administered without bronchodilation. Our approach is consistent with the procedures developed by the American Thoracic Society (ATS) and the European Respiratory Society (ERS) for an obstructive defect; which does not require use of broncho-dilators.[Miller et al., 2005] Nearly all large population-based epidemiology studies of obstructive lung disease/COPD use spirometry without bronchodilators, including the NHANES survey, the basis for much of our understanding of the relationship between work and COPD in the US [Hnizdo et al., 2002, 2006; Hansen et al., 2007]. In addition to NHANES, large population based surveys in the Netherlands and the UK also did not administer bronchodilators [Swanney et al., 2007]. Our methods replicate those used in analysis of these population-based studies of spirometry.

We defined COPD as FEV1/FVC ratio below the lower limit of normal (LLN), an approach is consistent with a recent expert group's findings [Bakke et al., 2011] which concluded that the "fixed ratio" definition leads to overstatement of prevalence; this is consistent with findings of other investigators that use of a fixed FEV_1/FVC ratio to define airway obstruction may result in disease misclassification based on studies that show that the FEV_1/FVC declines with normal aging, resulting in underreporting of COPD in young workers and false positive COPD classification for workers older than age 55 years [Hansen et al., 2007; Enright et al., 2008; Swanney et al., 2008].

We recognize that other ways of defining COPD using fixed FEV_1/FVC ratios have been adopted by the British Thoracic Society [BTS, 1998] and the Global Initiative for Chronic Obstructive Lung Disease [GOLD, 2008]. In a previous study of COPD in this population [Dement et al., 2010] we compared results using the GOLD definition

and the ATS definition adopted in this study, and we found prevalence according to GOLD to be somewhat greater. Based on these findings the definition used in this study is less likely to overstate prevalence.

We estimated incidence of COPD and occupational lung disease based on age-specific prevalence data using methods developed by Leske et al. [1981]. These estimates are based on a number of assumptions including similar all causes age specific mortality rates among those with and without the diseases in question. To the extent that the mortality of workers with COPD or occupational lung disease may exceed mortality in the general population, our model will underestimate the incidence of these diseases, resulting in underestimates of lifetime risks. The degree of underestimation, however, is likely small given that the all causes mortality risk for DOE workers used for the incidence estimates was not significantly elevated compared to the US population (SMR = 0.93, 95% CI 0.86–1.01) [Dement et al., 2009].

One weakness of the approach is that it uses past experience to predict future risk, even though it is clear that safety and health protections, including exposures to disease risks, have changed over time. There are ways to model such changes to adjust future risk to current and projected exposure levels that can mitigate this limitation [Sasieni and Adams, 1999]. However, it is more important to communicate the likelihood that the unadjusted risk projections based on past exposures represent an upper limit, which is appropriate in the setting of protecting public health.

Despite the limitations, this study of estimated lifetime risks can aid in communicating the risk of developing work-related chronic diseases to workers. Even though this technique has been underused in the field of occupational safety and health and with regard to communicating occupational disease risks, it is a powerful way to communicate risk, especially to young construction workers and to policy-makers.

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